# An Experimental Approach Towards Characterizing the Transient Response of Drain Water Heat Recovery Systems

by

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# Author's Declaration

I hereby declare that I am the sole author of this thesis. This is a true copy of the thesis, including any required final revisions, as accepted by my examiners.

I understand that my thesis may be made electronically available to the public.

# Abstract

Drain Water Heat Recovery (DWHR) systems recover thermal energy from the gray water and use it to pre-heat incoming mains water. So far, the research conducted in this field has focused on the steady-state (SS) operation of DWHR systems. It has now become important to characterize the transient behaviour of DWHR systems, so that it could be included in energy simulation models. The ultimate focus of this thesis was to study the transient response of various DWHR systems, and in particular, to estimate the time it would take to reach quasi-steady-state operating conditions.

The analysis was approached using two experimental methods. The first approach dealt with estimating the time dependent rate of heat recovery, based solely on the fluid inlet and outlet temperatures and flowrates. Correlations were used to estimate 63.2% and 86.5% steady-state time responses. The correlations were validated by performing random experiments. The predicted and experimental time responses were in good agreement. The second approach used infrared thermography to estimate fluid temperatures through the DWHR systems, along with estimating the time responses. This approach provided an estimation of energy storage in the DWHR during transient operation. The time responses derived by both methods were compared.

It was found that both the 63.2% and 86.5% time responses increased with increasing DWHR system length and decreasing flowrate. The time responses estimated using infrared thermography were always a few seconds longer than the first approach.

Recommendations were made to suggest ways to improve and build on the current work. One of the major recommendations was modification of the Heat Exchanger Test Platform (HXTP), to better facilitate transient experiments.

## Acknowledgements

First of all, I would like to thank my supervisor, Professor Michael Collins, for providing me with the opportunity to work on this research project. I am really grateful for the technical skills and knowledge that I have learned from him in the last couple of years. It has been a pleasure to be a part of his research team.

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The support provided by RenewABILITY Energy Inc. is greatly acknowledged. They provided all the DWHR systems that were tested for the experiments conducted in this thesis.

A special thanks goes to Professor Kyle Daun, who trusted me with his thermal camera. It is because of the thermal camera that this research project has been completed successfully.

I am really thankful to my parents Manjinder Singh Dhillon and Rupinderjeet Dhillon, who have always supported me at every step of my life.

# Dedications

This thesis is dedicated to my brother "***Jasjeet Singh Dhillon***" who always stood firmly beside me during my high'-s and low'-s.

I can't wait to see you graduate from Waterloo Mechanical Engineering in the summer of 2020.

You will be a way better Mechanical Engineer than I am.

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# List of Abbreviations

| | |
|---|---|
| ASTM | American Society for Testing and Materials |
| CSA | Canadian Standards Association |
| CSV | Comma Separated Value |
| DAQ | Data Acquisition |
| DWHR | Drain Water Heat Recovery |
| FM | Flow Meter |
| HX | Heat Exchanger |
| HXTP | Heat Exchanger Test Platform |
| ID | Internal Diameter |
| IR | Infrared |
| LabVIEW | Laboratory Virtual Instrument Engineering Workbench |
| L/hr | Litres per Hour |
| LPM | Litres per Minute |
| OD | Outer Diameter |
| RTD | Resistance Temperature Device |
| SS | Steady-State |
| STRL | Solar Thermal Research Laboratory |
| UW | University of Waterloo |

# Nomenclature

| | |
|---|---|
| $A_c$ | Cross-sectional area ($m^2$) |
| $Bi_{lam}$ | Laminar Biot number (Dimensionless) |
| $Bi_{turb}$ | Turbulent Biot number (Dimensionless) |
| $c_{p,c}$ | Specific heat capacity of cold mains-side water (kJ/kgK) |
| $d_h$ | Hydraulic diameter (m) |
| $dT/dt$ | Change in coil set temperature at different time instants (K/s) |
| $D$ | Coil mean diameter (m) |
| $De$ | Dean's number (Dimensionless) |
| $h$ | Convective heat transfer coefficient ($W/m^2K$) |
| $h_{lam}$ | Laminar convective heat transfer coefficient ($W/m^2K$) |
| $h_{turb}$ | Turbulent convective heat transfer coefficient ($W/m^2K$) |
| $k_{solid}$ | Thermal conductivity of copper (W/mK) |
| $k_{water}$ | Thermal conductivity of water (W/mK) |
| $L$ | Litres |
| $L_c$ | Characteristic length (m) |
| $L_{DS}$ | Drain-side length (inches) |
| $\dot{m}$ | Mass flowrate (kg/s) |
| $Pr$ | Prandtl number (Dimensionless) |
| $q_c$ | Cold mains-side heat transfer rate (kW) |
| $q_{c,SS}$ | Steady-state cold mains-side heat transfer rate (kW) |
| $q_{conv}$ | Convective heat transfer rate (kW) |
| $q_{flow}$ | Mains-side flow energy transfer rate (kW) |
| $Q_{flow}$ | Mains-side flow heat gain (kJ) |
| $q_{flow,SS}$ | Steady-state mains-side flow energy transfer rate (kW) |
| $q_{flow,63.2\%}$ | 63.2% of steady-state mains-side flow energy transfer rate (kW) |
| $q_{flow,86.5\%}$ | 86.5% of steady-state mains-side flow energy transfer rate (kW) |
| $q_{storage}$ | Storage heat transfer rate (kW) |
| $Re_d$ | Reynolds number (Dimensionless) |
| $t_{63.2\%}$ | 63.2% steady-state time response (s) |
| $t_{86.5\%}$ | 86.5% steady-state time response (s) |
| $t_{99\%}$ | 99% steady-state time response (s) |
| $T_{ambient}$ | Ambient room temperature ($^0C$) |
| $T_{ci}$ | Cold mains-side inlet temperature ($^0C$) |
| $T_{co}$ | Cold mains-side outlet temperature ($^0C$) |
| $T_{hi}$ | Hot drain-side inlet temperature ($^0C$) |
| $T_{ho}$ | Hot drain-side outlet temperature ($^0C$) |
| $u_c$ | Instrumental uncertainty (m) |
| $u_d$ | Design stage uncertainty (m) |
| $u_0$ | Random error (m) |
| $V$ | Fluid velocity (m/s) |
| $\dot{V}$ | Volumetric flowrate ($m^3/s$) |
| $\dot{V}_{CSA}$ | CSA flowrate (LPM) |
| $\forall$ | Coil set internal volume ($m^3$) |

# Greek Symbols

| | |
|---|---|
| $\varepsilon_c$ | Steady-state effectiveness of the DWHR system (Dimensionless) |
| $\varepsilon$ | Emissivity of copper (Dimensionless) |
| $\alpha$ | Absorptivity of copper (Dimensionless) |
| $\tau$ | Transmissivity of copper (Dimensionless) |
| $\tau_{flow}$ | Time constant for flow energy transfer rate (s) |
| $\tau_c$ | Time constant for mains-side heat transfer rate (s) |
| $\rho$ | Reflectivity of copper (Dimensionless) |
| $\rho_c$ | Density of mains-side water ($kg/m^3$) |
| $\mu$ | Dynamic viscosity of water ($Ns/m^2$) |

# Chapter 1 Introduction

## 1.1 Background

Energy consumption and conservation are issues that have been of deep interest in recent years. A lot of research has dealt with the conservation of energy, where the focus is not only to reduce energy usage, but also to recycle some of the energy which would otherwise be wasted. An example would be the extraction of energy in the form of heat from warm drain water to use in the preheating of incoming potable water.

In North America, hot water consumption represents a large share of total building energy usage. In the USA and the European Union, domestic hot water production accounts for approximately 18% and 14% of total energy consumption in the residential sector [1]. Americans on average spent about $34 billion on residential water heating in the year 2010 [2]. Hence, it is clear that water heating is one of the leading sources of energy consumption.

The idea of preheating incoming potable water with thermal energy from drain water has a lot of potential for re-using energy that would otherwise be wasted. In practical applications, the preheated mains water could be used for any household purposes like showers, dishwashing, etc. A device that is capable of reclaiming energy from the waste drain water is Drain Water Heat Recovery (DWHR) system.

DWHR systems are counter-flow heat exchangers (HX). The majority of commercial products consist of a copper mains pipe that is tightly coiled around the drain stack. A typical DWHR system is shown in Figure 1-1.

**Figure 1-1: Typical DWHR system**

The larger diameter (drain-side) pipe is where warm gray water flows by forming a falling film on the inside surface of the drain-side pipe. This film rapidly imparts its heat to the pipe wall [3]. This smaller diameter pipe, which is coiled around the drain pipe, represents the cold mains-side of DWHR systems. As the incoming potable water flows through the coils, it extracts heat from the gray water and leaves at a higher temperature. Both of the fluid streams remain unmixed, and there is no possibility of any mains water contamination. Figure 1-2 shows the water flow configuration through a DWHR system.

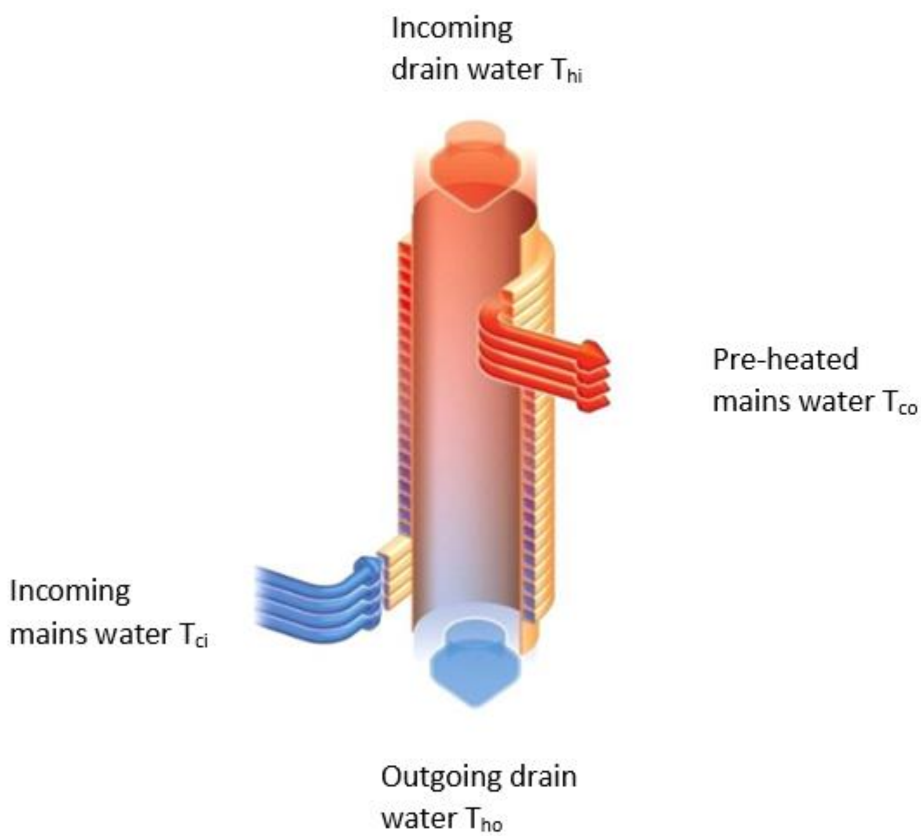


**Figure 1-2: DWHR water flow configuration [3]**

## 1.2 Review of Literature related to DWHR Systems

DWHR systems are the centre of attention of this thesis. Hence, the research work related specifically to DWHR systems will be reviewed first. Steady-state aspects of DWHR systems have been investigated in several recent studies conducted at the University of Waterloo (UW) [4] [5] and elsewhere [6] [7]. This section starts with a study to demonstrate the potential DWHR systems have when it comes to energy recovery. The next two studies summarizes some of the other research work conducted on DWHR systems. The last few studies deals with some in-situ studies related to DWHR systems.

### 1.2.1 Study # 1

Title: Analysis of Profitability of using a Heat Recovery System from Grey Water Discharged from the Shower [8]

The purpose of this study was to demonstrate the benefits of heat recovery, by installing a DWHR system below the shower on a single family dwelling. Two different DWHR system configurations were considered and modelled as shown in Figure 1-3. Method 1 used supplemental heating sources in multiple locations with the DWHR system only preheating shower water. Method 2 used the DWHR system to preheat all water going to the hot water boiler, and more closely resembled the way in which DWHR systems are predominantly installed.

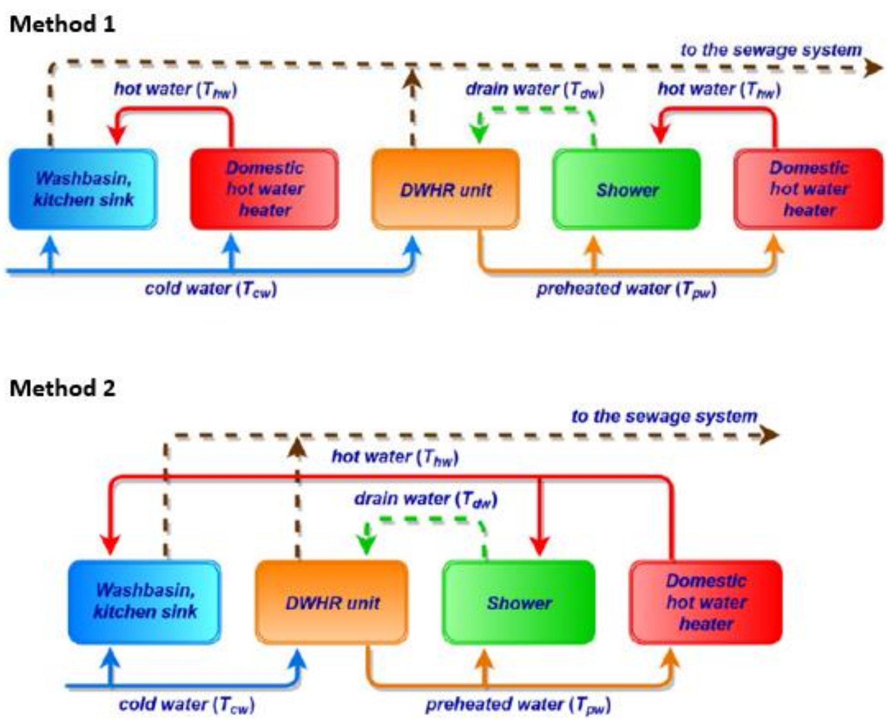


**Figure 1-3: Different heating methods with single and double water heaters [8]**

The main assumptions made in order to simplify the analysis were equal-flowrates for both fluid streams, and negligible heat loss from the DWHR system. The study was further simplified by assuming that each occupant was using the shower only once per day, and that the water drawing habits did not change for any occupant.

The results indicated that the DWHR systems performed better for Method 1. In that case, at a flowrate of 6 litres per minute (LPM), the heat recovery rate was 7.4kW. With increasing flowrates, the heat recovery rates also increased and the final energy demand was still lower when compared to Method 2. This study provided a good indication about the energy recovery potential of DWHR systems and why more research was required in this field.

### 1.2.2 Study # 2

Title: Characteristic Effectiveness Curves for Falling-Film Drain Water Heat Recovery Systems [9]

This experimental study, conducted at the University of Waterloo (UW), focused on examining the performance of DWHR systems at various equal-flow conditions. More specifically, the effectiveness of DWHR systems with parallel and counter-flow configurations was examined as a function of volumetric flowrate. The theoretical effectiveness curve of DWHR system performance is shown in Figure 1-4.

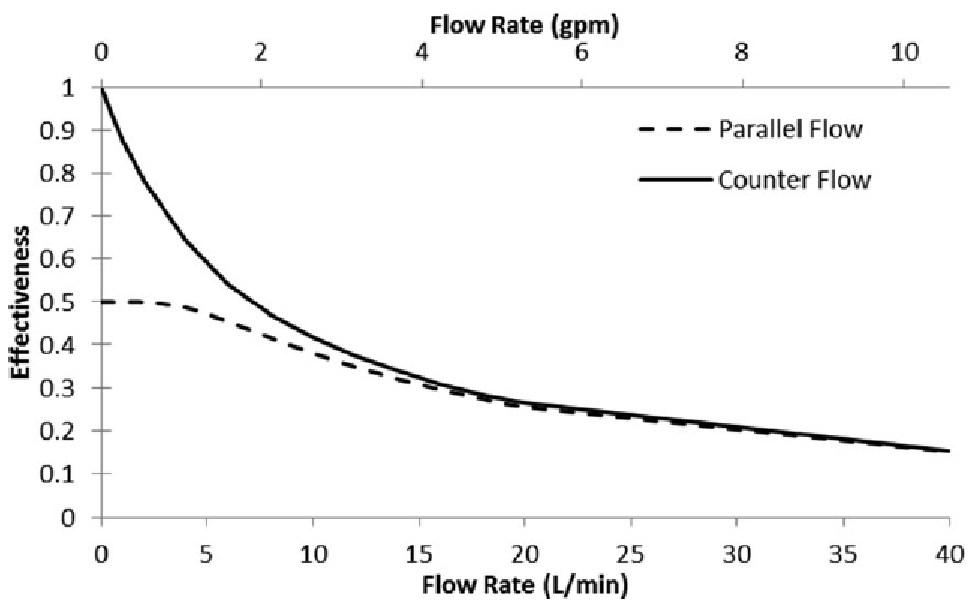


**Figure 1-4: Theoretical effectiveness vs volumetric flowrate of a DWHR system [9]**

All of the test cases produced curves similar to the one shown in Figure 1-4, with the exception of the inflection point at lower flowrates. The authors concluded that the inflection point was not likely due to transition to turbulence on the mains-side of DWHR systems, since it is predicted to occur at higher flowrates than what the DWHR systems would typically experience. Hence, the inflection point was most likely due to the transition to turbulence on the drain-side. More research and investigations on DWHR system behaviour were recommended. This study provided a very brief insight about the nature of fluid flow inside the DWHR system.

### 1.2.3 Study # 3

Thesis Title: Predicting Steady-State Performance of Falling-Film Drain Water Heat Recovery Systems from Rating Data [10]

This experimental investigation on DWHR systems, followed from study # 2, and focused on characterizing the performance of DWHR systems under steady-state conditions. The work focused on the performance of DWHR systems under varying inlet temperatures, and equal and unequal-flow conditions. Semi-empirical models were developed, and used to compare the predicted and measured heat transfer rates and effectiveness. It was concluded that the percent difference between the measured and predicted heat transfer rates was within 4%. The flowrates investigated ranged from 5.5 to 14LPM. Correction factors were also developed to allow for extrapolation of the results for this model to higher flowrates. The author also showed that the inflection point mentioned in the previous study was due to break-down of the drain-side film.

Figure 1-5 shows the Heat Exchanger Test Platform (HXTP) that was constructed in Solar Thermal Research Lab (STRL) at UW for studying DWHR systems.

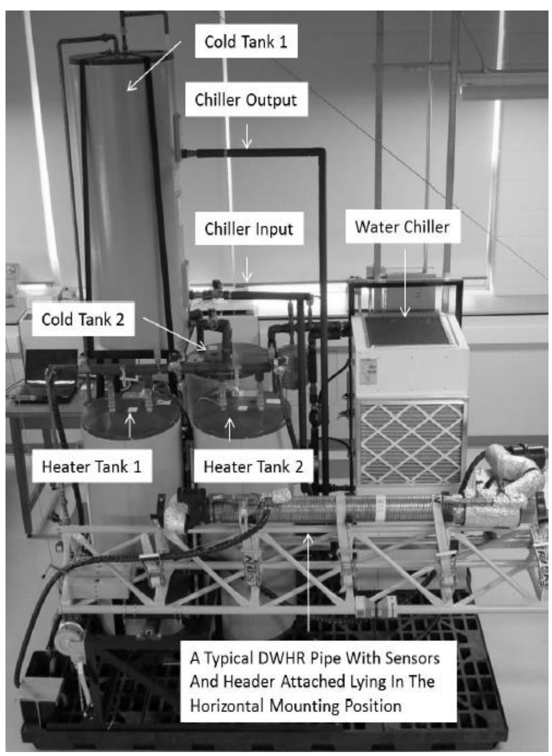


**Figure 1-5: HXTP set-up in STRL [10]**

The model that was developed did not take transient effects into account. The study of transient behaviour of DWHR systems was stressed in the recommendations and is the motivation for the current studies being performed.

#### 1.2.4 Study # 4

Title: In-Situ studies related to DWHR systems [11] [12] [13] [14] [15]

Several studies looked at the in-situ energy performance of DWHR systems [11] [12] [13] [14] [15].These works are not directly related to the current research, but will be briefly discussed.

The first study was performed by Zaloum et al. [11], at the Canadian Centre of Housing Technology, with the scope of determining the heat recovery benefits of DWHR systems, using standard operating conditions. Five different DWHR systems from 3 different manufacturers were installed in a basement and tested under different flow configurations. It was concluded that DWHR systems reduced natural gas consumption for water heating by 9 to 27%

The next study was performed by Bartkowiak et al. [12] in Ann Arbor Michigan, in order to investigate the energy improvements that can be achieved by using DWHR systems. Cold water was supplied by the residential water main at approximately 7 $^0$C. At the same time, hot water was generated using a 300 litres natural gas hot water tank maintained at 49$^0$C. Monte-Carlo simulations were performed to characterize the variation in annual savings of a typical US household. It was concluded that over a range of tested showering conditions, the energy savings ranged from $74 to $160/year, depending on the type of water heating.

A third study was performed by Tanha et al. [13] in Vaughan Ontario, to understand the performance of DWHR systems along with two solar domestic water heaters. The DWHR systems were installed in identical houses, labelled as house A and house B. Identical DWHR systems were installed in both the houses, with the difference of the solar collectors and types of water heaters. It was concluded that DWHR systems were capable of an annual heat recovery of 789 kWh.

Another study conducted by Wong et al. [14] in Hong Kong investigated the potential of heat recovery from shower water from bathrooms equipped with instantaneous water heaters. For this study, a simple single-pass counter-flow heat exchanger was installed beneath the shower drain. Shower usage patterns and durations were sampled from an interview survey conducted on 1300 households of 14 typical high-rise buildings. The results indicated that 4-15% of shower water heat could be recovered through a 1.5m long single-pass counter-flow heat exchanger for the drainage pipe of 50mm.

The last study conducted by Oak Ridge National Laboratory [15] focused on evaluating the performance of a 60" long DWHR system in the basement of a single family home in Knoxville, Tennessee. The set-up allowed the authors to investigate the performance of DWHR system at both equal and unequal flow conditions. The results showed that the DWHR system was able to induce energy savings between 30-50%.

The main purpose of presenting the in-situ studies was to demonstrate the energy and cost saving potential of DWHR systems.

## 1.3 Review of Literature related to Transient Response of Heat Exchangers

All of the studies examined in Section 1.2 either dealt with the steady-state aspects of DWHR systems, or with overall system performance. Unfortunately, almost no research exists about the transient operation of DWHR systems. The transient behaviour, is important when the system undergoes time-varying input conditions, which may result from external load variations such as a shower start-up, a tap opening or flushing of a toilet etc. In all those cases, the system will be acting in transient. Currently, this cannot be captured by modelling. So, for example, if a hot water tap is turned on, models will show instantaneous energy recovery even for that case. In reality, the hot water may never have reached the taps, and no energy may have been exchanged. Load fluctuations can cause disturbances in inlet fluid temperatures and flowrates [16] which must be accounted for in the energy models.

In case of DWHR systems, transient aspects becomes important when the system is run after a long period of time, and the water in the mains coils have reached ambient conditions. Investigating the transient response of DWHR systems is also important so that these effects can be implemented in building simulation models.

Several works were reviewed that considered transient response of heat exchangers in general. This section summarizes those works.

### 1.3.1 Study # 5

Title: Analytic Model for Transient Heat Exchanger Response [17]

This study conducted at the Rensselaer Polytechnic Institute, aimed to investigate the transient behaviour of HX, in which one fluid was single phase and the other had a constant temperature, using an analytical approach. Two different cases were considered: (1) when the constant temperature fluid undergoes a step change in temperature, and (2) when a single phase fluid undergoes a flowrate step change. The analysis provided the time varying fluid and tube wall temperatures over the whole length of the HX. For both cases, explicit analytical solutions were developed and validated by comparison against the numerical solution results over a wide range of operating conditions. Figure 1-6 shows one case of the validation of an analytical model. Both the numerical and analytical models were in good agreement.

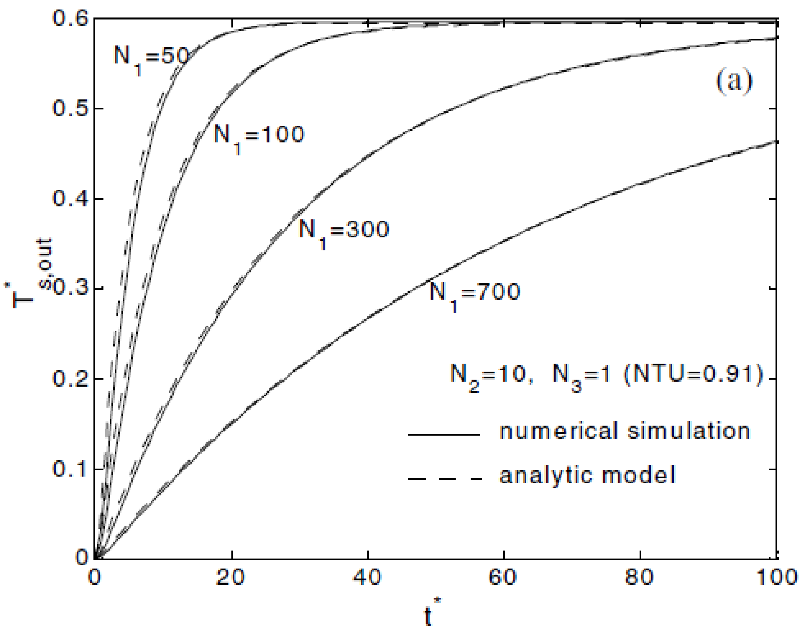


**Figure 1-6: Sample validation of analytical model with numerical results [17]**

Step change input conditions for temperature and flowrates were used with one of the fluid temperatures kept constant. This is not the case for an ideal transient HX response, where all the inlet and outlet temperatures change until they settle at some final steady-state conditions. No experimental validation was performed on the model itself. The work provided some insight on the expected shape of the transient temperature versus time behaviour of HXs.

### 1.3.2 Study # 6

Title: Cross Flow Heat Exchanger Modeling of Transient Temperature Input Conditions [18]

This cross flow HX modelling conducted by Gao et al., focused on predicting the cross flow HX dynamics under arbitrary input temperature conditions. Step, ramp and exponential inlet boundary conditions were studied, and the outlet temperature response times were evaluated.

The model presented relied on the numerical solution of the model equations. The numerical solution provided performance relationships, whereas a polynomial regression helped to determine simplified relationships for predicting response time of the HX. It was found that different initial input conditions (idle or steady-state) of the HX did not affect the transient response time.

Second order polynomial equations were developed to estimate the time responses for different type of input conditions. The model used air as one of the working fluids for a cross flow HX, since the focus of this study was to predict the transient behaviour of HX used in data center cooling equipment. It was found that the initial and final values of inlet temperature variation function did not influence the transient behaviour of the fluid outlet temperature. This study provided an understanding about using time constants as a metric for transient response of the HX outlet temperature.

### 1.3.3 Study # 7

Title: Transient Analysis in Heat Exchangers [16]

A survey of new developments on the transient analysis of HX was presented in this heat exchanger textbook. Applications of a transient HX model were introduced. Based on the model, general mathematical descriptions of the dynamic response of HX were provided, and the effect of the dispersion coefficient on the transient behaviour was analyzed. The authors provided a brief review of the previous work done in the field. They concluded that previous models assumed plug flow, which meant that the flow in the HX was uniform everywhere. The actual flow, however, is very complicated and various forms of flow mal-distributions occur. This deviation from the ideal plug flow pattern has great influence on the dynamic response of HX. The authors concluded that an axial dispersion model is most suitable for dynamic simulations of processes.

For the axial dispersion model, emphasis was placed only on the mathematical models. Analytical solutions for transient response of heat exchangers were developed using Laplace transforms, Fast Fourier transforms and partial differential methods. The Peclet number (Pe), which is the ratio of heat transfer by fluid motion to the heat transfer by thermal conduction was used to describe the effects of mal-distribution on transient behaviour.

For an ideal plug flow, $Pe = \infty$. The final part of the transient chapter in this HX textbook demonstrated an example of using this model. In the example, initially a uniform temperature distribution throughout the HX was achieved, before it was subjected to a sudden change in inlet shell side temperature. The quantitative description revealed that the effect of mal-distribution was stronger if $Pe < 25$. For $Pe > 55$, the dispersion model was identical to the plug flow model.

### 1.3.4 Study # 8

Title: Experimental Study on Transient Behaviour of Embedded Spiral Coil HX [19]

This experimental study, conducted at Prince Mohammad Bin Fahd University, focused on the transient flow behaviour in spiral shaped circular cross-sectional tubes where the coil was embedded in a rectangular conducting slab. Results were shown for the derived heat transfer based on factors like tube diameter, coil curvature, coil orientation, coil pitch, shell and tube side flow, number of loops and Reynolds number. Once the test started, the data was collected for 2 hours so that the whole process could reach steady-state. In this study, a dimensionless temperature, which was a combination of coil and fluid inlet and outlet temperatures, was plotted against time. Figure 1-7 shows the impact that the number of loops had while approaching steady-state.

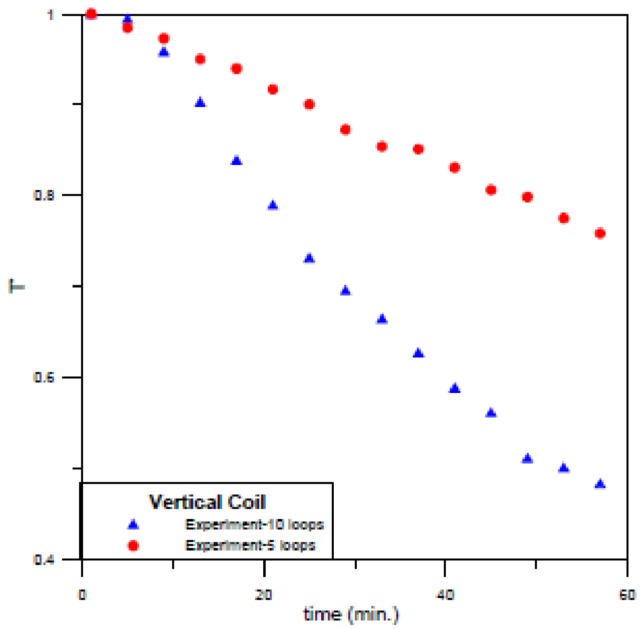

**Figure 1-7: Impact of number of coils on reaching steady-state [19]**

The comparison of the normalized temperature shows that increasing the number of loops would increase the rate of heat transfer despite the identical length of 2 different coils. The author briefly discussed the theory behind the heat transfer coefficient in helical coils, thereby providing insight on the application of heat transfer coefficients on helical coils.

## 1.4 Review of Literature related to Infrared Thermography of Heat Exchangers

Both the steady-state and transient studies in Section 1.2 and 1.3 mostly focused on the fluid temperatures at the inlet and outlet of the DWHR systems or HXs. The investigation of mains-side water temperature throughout the DWHR system length could help in examining the transient response more accurately.

One way to estimate the fluid temperatures across the entire HX is with the help of thermal imaging. Hence, studies related to the use of infrared thermography on HX were reviewed. Only a limited number of studies were found, and were reviewed to understand the methodology that has been used.

### 1.4.1 Study # 9

Title: Investigations of a Heat Exchanger using Infrared Thermography and Artificial Neural Networks [20]

In this experimental study, an investigation of a heat exchanger was performed at steady-state, using infrared thermography. More specifically, a single panel radiator was used. The main purpose of this research paper was to propose a new algorithm for the inverse heat transfer problem of calculating the power consumption of the heat exchanger being investigated. The algorithm developed was based on a supervised artificial neural network, which was trained using the data obtained from the infrared thermography measurements. The temperature fields or thermograms were obtained for the frontal surface of the radiator under investigation. Figure 1-8 shows the schematic of the algorithm used to calculate heat power consumption using neural networks, where $f^1$ and $f^2$ were the transfer functions for the neurons in the hidden and output layer respectively.

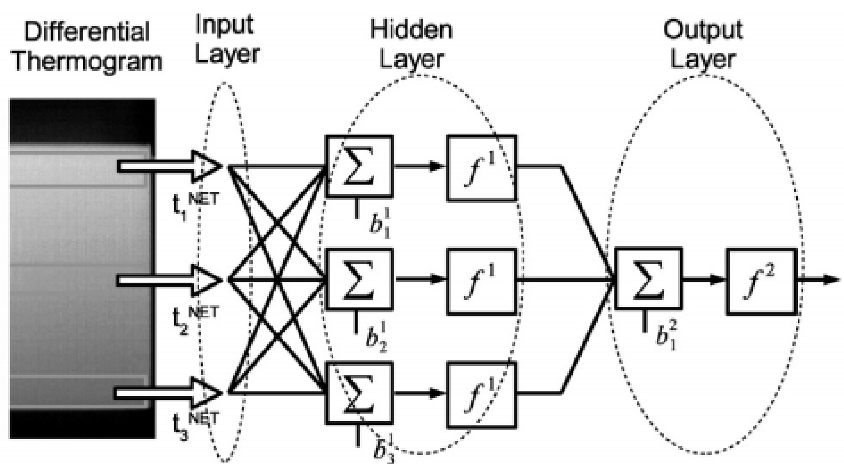


**Figure 1-8: Schematic of algorithm used for heat power consumption calculation [20]**

The heat power consumption was measured using 2 methods. In the first method, a standard HX operating curve determined in a closed chamber, based on the European EN 442-2 [21] standard was used. The second method was based on the difference between the inlet and outlet enthalpy of the supplied water. The thermograms for the frontal surface temperature measurements of the radiator were recorded with the frame rate of 1 frame per second, and were used in the development of the algorithm.

It was concluded that by using the neural network, the steady-state power consumption could be estimated with a limiting error of about 2%. In this study, the major focus was on the development and performance of the neural networks. No information was derived about the fluid properties inside the HX. This study provided insight into how infrared thermography could be used to study DWHR systems.

### 1.4.2 Study # 10

Title: Local Heat Transfer Measurements of Plate Finned-Tube Heat Exchangers by Infrared Thermography [22]

The focus of this experimental study was to monitor the temperature distribution over a plate-fin surface inside the plate finned-tube heat exchangers. The local convective heat transfer coefficients over the fin were determined by a control volume based finite difference formulation, after the temperature values were established on the surface of the plate-finned heat exchanger.

The experimental set-up consisted of a wind tunnel, in which the tubes were installed either in staggered or in-line configurations. Eight type K thermocouples were mounted evenly on the inlet and outlet section of the test model. The thermal camera used, had the ability to capture thermograms up to the rate of 60 frames per second.

Thermographic measurements for the frontal surface temperature of the tubes were taken once the air flow had reached steady-state conditions in the air duct. After the frontal thermograms were recorded, a control volume based energy balance was applied to the sections of interest. Figure 1-9 shows the energy balance schematic for the estimation of convective heat transfer coefficients.

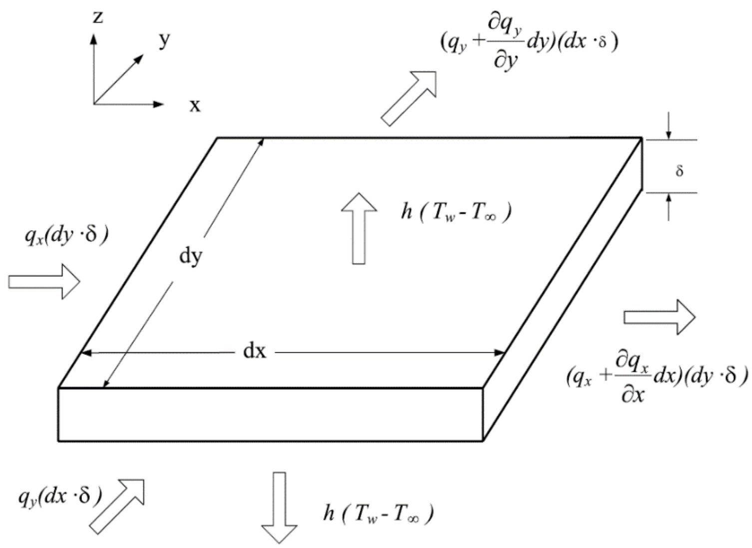


**Figure 1-9: Energy balance applied to estimate convective heat transfer coefficient [22]**

It was determined that if the Reynolds number was lower than 2172 for the in-line array of heat exchangers, the span-averaged convective coefficient profile on the fin would be similar to that of pipe flow. For Reynolds number greater than 3258, a lot of roughness was observed in the local convective coefficient curves. It was also demonstrated that the averaged heat transfer coefficients of a staggered configuration was 14-32% higher than that of the in-lined configuration. This study was conducted under steady-state conditions using air as the working fluid. This study showed a possible application of thermocouples, thermal camera and energy balance while performing experimental analysis on any kind of heat exchangers.

## 1.5 Research Question

The review of the literature has shown that experimental studies of DWHR systems have focused solely on steady-state behaviour. Further, studies of transient HX behaviour have been done, but not on the conditions experienced in DWHR systems, and only on an analytical basis. The current work aims to bridge this gap.

The overall objective of this thesis is to experimentally investigate different transient aspects of DWHR systems. To do this work, two experimental approaches will be employed. The first approach will rely only on the flowrate along with inlet and outlet temperatures of DWHR systems. The second approach will include the use of infrared thermography on DWHR systems.

For both test methods, inlet and outlet temperature profile development, nature of heat recovery curve, and the time responses of DWHR systems will be investigated. At the end, time responses derived from both experimental approaches will be compared.

The nature of mains-side water temperature change across the entire length of DWHR system, along with the temperature change across different sections of DWHR systems will be investigated using the infrared thermography approach.

## 1.6 Thesis Breakdown

The topics covered and chapter descriptions in this thesis are as follows:

- **Chapter 2** – Is an introduction to energy balance and heat transfer rates, and a description of test method 1 and the HXTP. An estimation of equipment uncertainty is also included.
- **Chapter 3** – Included the data analysis, results and discussions related to test method 1. Repeatability of the experimental measurements is established. An estimation of flow energy transfer rates ($q_{flow}$) and time responses is made.
- **Chapter 4** – Is an introduction to infrared thermography and test method 2. Equipment preparation and set-up related to test method 2 is described.
- **Chapter 5** – Is the data analysis, results and discussions related to test method 2. A study of temperature profiles throughout the DWHR system is performed, and estimation of system energy storage ($q_{storage}$), mains-side heat transfer rates ($q_c$) and time responses is performed.
- **Chapter 6** – Contains the conclusions and recommendations resulting from this work.
- **Appendix A to C** – Contains plots and tables associated with test method 1.
- **Appendix D to P** – Contains plots and tables associated with test method 2.

# Chapter 2 Test Method 1

## 2.1 Introduction to DWHR Heat Transfer Rate

Assuming no energy generation, the overall energy rate balance applied over the entire DWHR system could be written as:

$$E_{in} - E_{out} + Q_{in} = E_{stored} \tag{2.1}$$

The 3 components in Equation 2.1 are heat transfer rate by inlet and outlet flow of mains-side water, mains-side heat transfer rate and storage effects.

Figure 2-1 shows the schematic of the overall energy balance applied to the entire DWHR system.

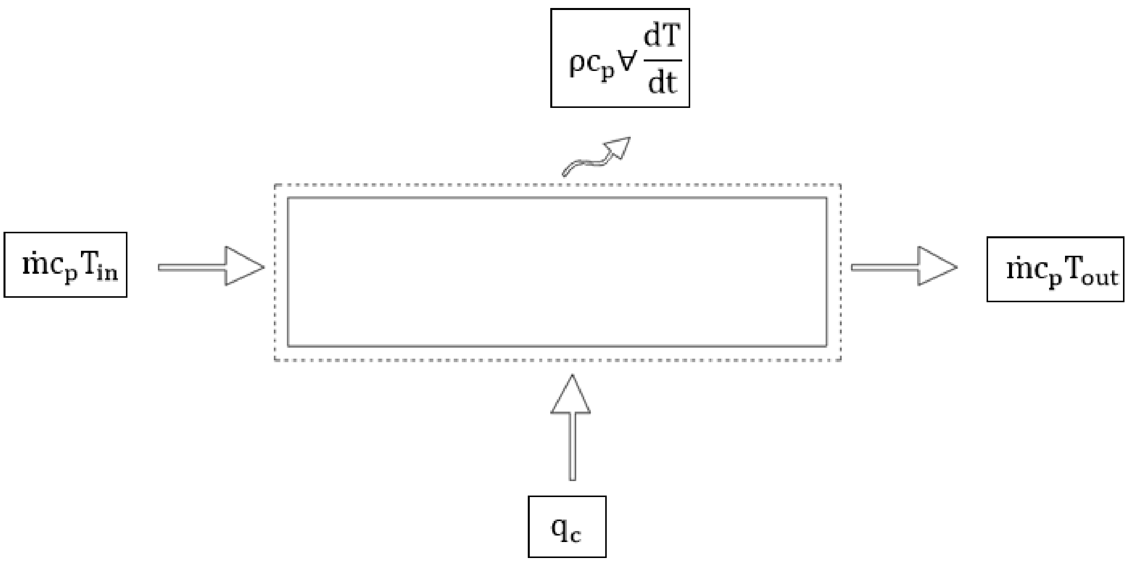


**Figure 2-1: Schematic of energy balance on DWHR system**

Substituting the energy balance variables from Figure 2-1 into Equation 2.1 yields Equation 2.2.

$$\dot{m}c_p T_{in} - \dot{m}c_p T_{out} + q_c = \rho c_p \forall \frac{dT}{dt} \tag{2.2}$$

Further simplification of Equation 2.2 leads to the derivation of the cold mains-side heat transfer rate ($q_c$), which is the same as heat recovered from the wastewater and is shown in Equation 2.3.

$$q_c = \dot{m}c_p (T_{out} - T_{in}) + \rho c_p \forall \frac{dT}{dt} \tag{2.3}$$

Equation 2.3 could be further broken down into two different components shown in Equation 2.4 and Equation 2.5.

$$q_{flow} = \dot{m}c_p (T_{out} - T_{in}) \tag{2.4}$$

$$q_{storage} = \rho c_p \forall \frac{dT}{dt} \quad (2.5)$$

In Equation 2.4, $q_{flow}$ is the mains-side flow energy transfer rate in $kW$, $\dot{m}$ represents the mass flowrate of mains-side water in $kg/s$, $c_p$ is the specific heat capacity of mains-side water in $kJ/kgK$ and $(T_{out} - T_{in})$ is the difference between mains-side outlet ($T_{co}$) and inlet water temperature ($T_{ci}$) in $K$.

Similarly in Equation 2.5, $q_{storage}$ is the energy storage rate in kW. $\rho$, $\forall$ and $\frac{dT}{dt}$ represent the density of mains-side water in kg/m$^3$, volume of water in DWHR coils in m$^3$ and the change in mains-water temperature for the entire DWHR system throughout the duration of the test in K/s. Storage effects play a crucial role during the beginning phases of a test due to the changing $dT/dt$ term.

Unfortunately, the previous test approaches were for steady-state analysis, and didn't account for energy storage effects in the DWHR systems. As such, they relied only on mains-water inlet and outlet temperatures. The work described here consisted of two experimental approaches. Both approaches relied on an existing DWHR experimental test platform located in the STRL at UW. For the first test method, time responses will be calculated using the current generalized approach, solely based on $q_{flow}$. In the second approach, due to the introduction of infrared thermography, time responses will be calculated, but $q_c$ and $q_{storage}$ will be estimated.

## 2.2 HXTP Set-Up and Experimental Procedures

### 2.2.1 HXTP Set-Up

The HXTP was constructed by the STRL at UW for the purpose of performing research on DWHR systems. A secondary goal of the test platform was to perform steady-state testing and Canadian Standards Association (CSA) certification of the DWHR systems [10]. CSA develops standards in testing, inspection and certification for a broad array of industries. Figure 1-5 and Figure 2-2 show a photo and schematic of the HXTP used for the current experiments. A detailed description of the HXTP is provided in the MASc thesis of Manouchehri [10]. A brief overview of how the HXTP operates, and the modifications made to accommodate the current research, are described here. The greyed flow paths in Figure 2-2 were used in other studies or during system set-up, and are not relevant to the present study.

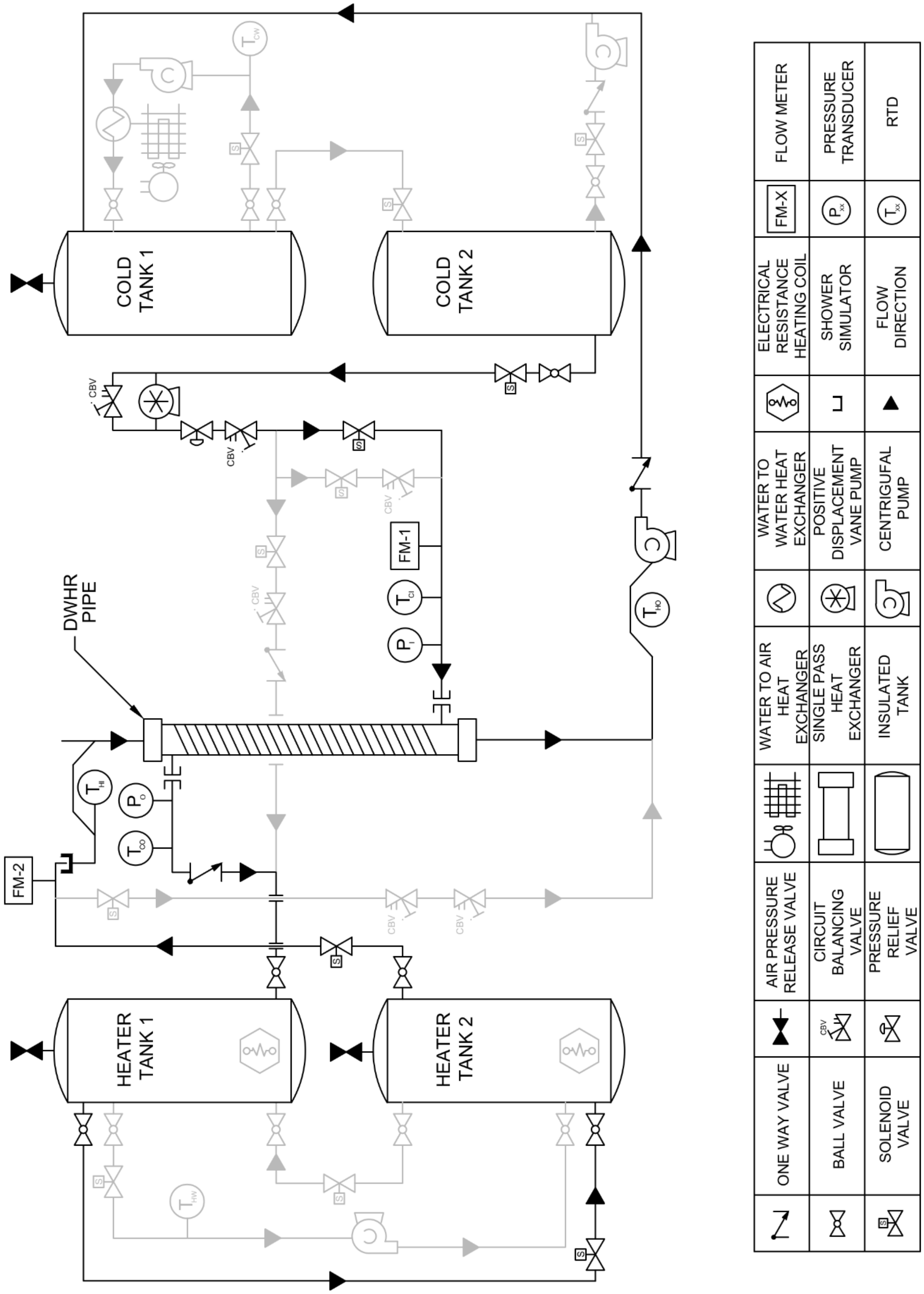


**Figure 2-2: Schematic of HXTP [10]**

### 2.2.2 HXTP Operational Overview

With reference to Figure 2-2, the HXTP operated as follows. To determine DWHR operation, constant inlet temperatures are required. The HXTP provides this constant temperature by pre-conditioning a large volume of cold and hot water prior to conducting a test. In this regard, *Cold Tank 1* was conditioned to the desired mains-side inlet water temperature ($T_{ci}$), while *Heater Tanks 1* and *2* were conditioned to the desired drain-side inlet water temperature ($T_{hi}$). All tanks were capable of providing a well-mixed and stable water source to within ±0.2$^0$C of the desired set point for the duration of a test. The water from *Cold Tank 1* was transferred to *Cold Tank 2* before the start of the test to ensure that the tank was well mixed, and to make sure that *Cold Tank 1* was empty as it was used as a reservoir for water that had been used during the test process.

Once the tanks were conditioned, the DWHR test began. In reference to Figure 2-2, the flow followed a single path through the system. Starting at *Cold Tank 2*, a pump moved the mains-side water to the mains-inlet of the DWHR system. A bypass near the pump, allowed for control of the system flowrate. This water passed through the mains-side coils of the DWHR system, collecting heat from the drain-side, and then made its way to the bottom of *Heater Tank 1* pre-heated to $T_{co}$.

This water pushed hot water out of the top of the *Heater Tank 2* at the same flowrate. It is important to note that the Heater Tanks were designed such that mixing of the hot and cold water streams occurred very slowly, and had little impact on *Heater Tank 2's* outlet temperature. Water from the *Heater Tank 2* was then sent to the drain-side of the DWHR system. It formed an annular film around the inner surface area of the drain-side and dissipated its heat to the mains-side water. The water leaving the drain-side of the DWHR system was pumped into *Cold Tank 1* at $T_{ho}$.

### 2.2.3 HXTP Data Collection

Instrumentation was installed at various locations in the system (Figure 2-2). A flowmeter (FM-1) located after the pump allowed for the measurement of flowrate. Resistance Temperature Devices (RTDs) were situated at the inlets ($T_{ci}$ and $T_{hi}$) and outlets ($T_{co}$ and $T_{ho}$) of the DWHR system in immersion wells designed to provide well mixed fluid at the site of temperature measurement. They were used for measuring the mains and drain-side inlet and outlet water temperatures. Finally, pressure transducers were located on the mains-side inlet ($P_{ci}$) and outlet ($P_{co}$) to determine the pressure drop across the system. These pressure transducers are a requirement of the CSA testing process, and were not used in the current work.

### 2.2.4 HXTP Measurement Equipment Uncertainty

For this research, the main measurement equipment were the flowmeter and the RTDs. The flowmeter could measure flowrates with an overall accuracy of ±1% of the reading [23]. Uncertainty in RTD measurements was calculated as shown by Equation 2.6 [24]:

$$u_d = \pm\sqrt{{u_0}^2 + {u_c}^2} \quad (95\%) \tag{2.6}$$

Where $u_c$ was instrument uncertainty and $u_0$ was the random error from instrument reading. Based on the specification sheets provided with the instruments, $u_0$ and $u_c$ were estimated to be $\pm 0.1^0$C and $\pm 0.016^0$C respectively [25]. The uncertainty of the RTD measurements was estimated to be $\pm 0.1003^0$C.

Error bars are only shown for some temperature plots in this thesis. The main purpose is to demonstrate the measurement error that inherit in temperature readings. Both the flowmeter and RTD uncertainty is applicable to all the experiments performed in this thesis.

## 2.3 DWHR System Test Conditions

### 2.3.1 General Requirements

The tests for this work were performed at the specified CSA flowrates and inlet temperatures [26]. For all the experiments described here, the mains and drain-side inlet water temperatures were set to $10^0$C and $38^0$C respectively, to mimic water temperatures typically specified during CSA ratings [26].

All of the DWHR systems used in this study have been CSA certified and extensively studied under steady-state conditions, and therefore, there has been a significant amount of data collected about their steady-state performance. The test flow and temperature conditions for the current work are somewhat arbitrary, so it was decided to match test conditions to this existing data.

Table 2-1 shows the summary of CSA flowrates [26] along with mains and drain-side inlet temperatures. All experiments are conducted at equal-flow conditions (i.e. the mains and drain-side flowrates are the same).

**Table 2-1: CSA flowrates and inlet conditions**

| CSA Flowrates (LPM) | | | | | | $T_{ci}$ ($^0$C) | $T_{hi}$ ($^0$C) |
|---|---|---|---|---|---|---|---|
| 14 | 12 | 10 | 9 | 7 | 5.5 | 10 | 38 |

There is no evidence that ambient conditions have any impact on DWHR performance. Still, efforts were made to keep the ambient room temperature at 22±2$^0$C in order to establish a common starting temperature point for all the experiments.

### 2.3.2 LabVIEW Interface and Data Acquisition

A LabVIEW interface was built based on the schematic shown in Figure 2-2. The temperature RTDs and the flowmeter were connected to a LabVIEW DAQ, which acquired data such as flowrate, inlet and outlet temperatures after one second intervals for both the drain and mains-side. The LabVIEW interface is shown in Figure 2-3.

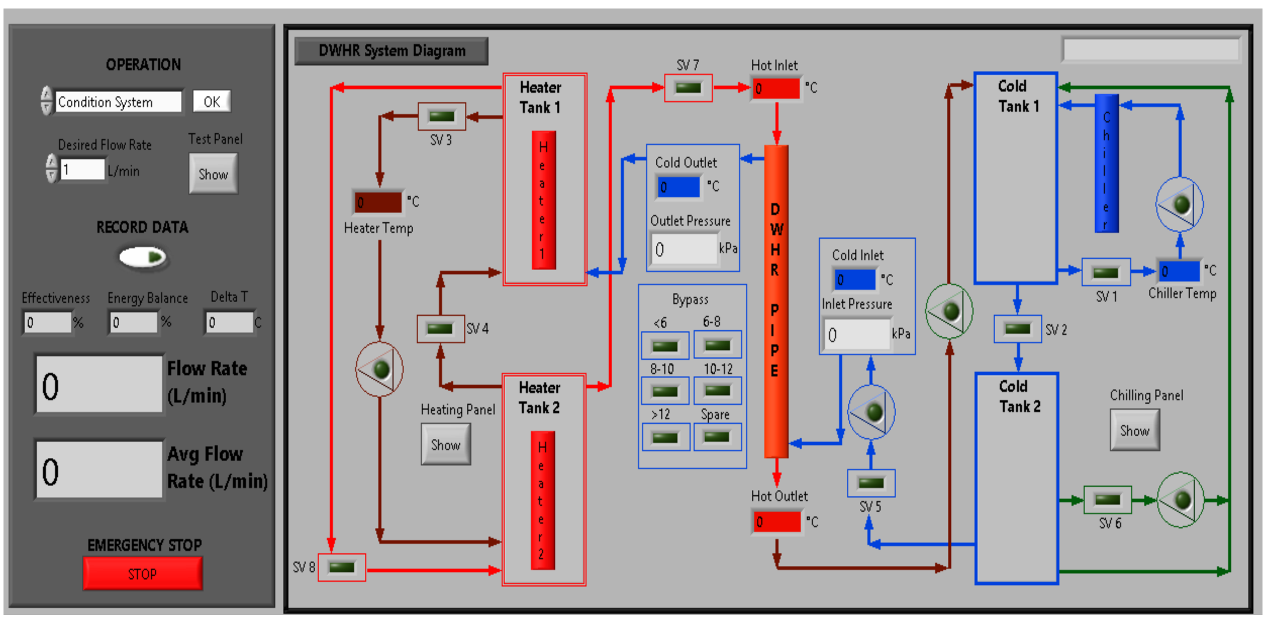


**Figure 2-3: The LabVIEW interface used to collect the data**

Once the test started and the HXTP operated according to Section 2.2.2, the RTDs, flowmeter and pressure transducers measured the inlet and outlet water temperatures, flowrates and inlet and outlet pressures, respectively. All of the measurements were sampled once per second. Data measurements were acquired once the "Record Data" button was pressed. The raw data was then stored as an excel file and analyzed as required. The button could be pressed again to stop data acquisition. Once a test was complete, HXTP operation was terminated by pressing the "Stop" button. At that point the water pump along with all measuring devices would stop.

## 2.4 Data Analysis of Steady-State DWHR Operation

To determine the steady-state performance of a DWHR system, the system operated exactly as described in Section 2.2.2 and 2.3.2. After the DWHR system was installed on the HXTP and the test was initiated, mains and drain-side water flowed, until the temperature readings stabilized around $10^0$C and $38^0$C respectively, with no trending in the recorded data. At that point, data was acquired in the form of temperature, pressure and flowrate measurements, which were recorded in the excel file.

Effectiveness is the ratio of heat transfer to the mains-side water, and the maximum heat transfer that could occur in the DWHR system. For steady-state tests, it is calculated for equal mass flowrate and equal fluid specific heats using Equation 2.7 [27].

$$\varepsilon_c = \left(\frac{T_{co}-T_{ci}}{T_{hi}-T_{ci}}\right) X100\% \tag{2.7}$$

A random sample of collected raw data is shown in Table 2-2, where effectiveness is the only calculated value. The water flowrate was measured in LPM. All of the raw data acquired and the temperature profiles generated for this thesis are available from the STRL at UW.

**Table 2-2: Sample of raw data collection with calculated effectiveness**

| Time (s) | $T_{ci}$ ($^0$C) | $T_{co}$ ($^0$C) | $T_{hi}$ ($^0$C) | $T_{ho}$ ($^0$C) | $P_{in}$ (kPa) | $P_{out}$ (kPa) | LPM | $\varepsilon_c$ |
|---|---|---|---|---|---|---|---|---|
| 10 | 20.22 | 19.83 | 20.11 | 19.79 | 72.86 | 42.72 | 11.80 | **354.55** |
| 11 | 20.14 | 19.84 | 20.18 | 19.80 | 74.85 | 42.33 | 13.57 | **-750.00** |
| 12 | 20.01 | 19.86 | 20.23 | 19.83 | 73.62 | 41.88 | 13.70 | **-68.18** |
| 13 | 18.58 | 19.98 | 20.74 | 19.95 | 73.41 | 43.11 | 13.86 | **64.81** |
| ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | **⋮** |
| 163 | 9.78 | 20.97 | 38.27 | 26.91 | 74.74 | 40.58 | 13.86 | **39.28** |
| 164 | 9.78 | 20.97 | 38.27 | 26.90 | 74.95 | 40.84 | 13.83 | **39.28** |
| 165 | 9.78 | 20.97 | 38.27 | 26.90 | 74.87 | 41.21 | 13.81 | **39.28** |
| 166 | 9.78 | 20.97 | 38.27 | 26.90 | 75.31 | 42.02 | 13.77 | **39.28** |
| 167 | 9.78 | 20.97 | 38.27 | 26.92 | 71.95 | 40.16 | 13.77 | **39.28** |

## 2.5 Analysis of Transient DWHR System Performance

### 2.5.1 Collection of Transient Data using the HXTP

The transient operation of the HXTP was similar to its steady-state operation. The main differences being the initiation of data acquisition. Since transient effects of DWHR systems occurred during the beginning phases of a test, data acquisition had to be initiated at the same instant when the test started. Hence, for all of the transient experiments conducted in this thesis, the “Record Data” button was pressed at the same time when the test was initiated. Data was collected for a long enough time period to include pre-test conditions, through to start-up, and transient and steady-state operation. For all the tests, this meant that data was acquired for roughly 4-5 minutes. The HXTP would remain inactive for the next 5-6 hours to ensure that it had returned to ambient conditions.

During steady-state testing, the flowrate could be adjusted to achieve a desired flowrate. Once the flowrate and inlet temperatures reached steady-state conditions, data could be collected at the desired conditions. Unfortunately, data acquisition during transient analysis was more challenging. To assist in reaching the desired test flowrates, the flowrates for a test were set immediately after the previous test, and before the HXTP was shut down. While this did provide a good test starting point, it was not always perfect due to changes in the HXTP.

### 2.5.2 Unresponsive Time Periods

After a test started, it was expected that conditioned water would not instantaneously reach the inlets of DWHR system. There would be a short unresponsive period of time in which the conditioned flow made its way through the HXTP to the DWHR inlets. It was after this time period that the inlet RTDs would start to respond to temperature change.

To determine the unresponsive portion of the inlet water temperatures, time periods to reach the mains-side inlet from the HXTP water pump was estimated for each flowrate. The hose length between the pump and mains-side water inlet was measured to be 6.235m. The hose had an ID of 0.75” or 0.01905m. The unresponsive time period was therefore calculated by converting the CSA flowrate into a volumetric flowrate, and dividing it by the volume of the hose.

The unresponsive time periods of temperature profile are summarized for all CSA flowrates in Table 2-3. It is important to note that a decrease in flowrate resulted in longer unresponsive time periods, since the water would take longer to reach DWHR system inlets.

**Table 2-3: Estimated time intervals of unresponsive temperature profiles at different flowrates**

| Flowrate (LPM) | Unresponsive time period (s) |
|---|---|
| 14 | 8 |
| 12 | 9 |
| 10 | 11 |
| 9 | 13 |
| 7 | 16 |
| 5.5 | 21 |

The unresponsive time periods were between 8-21 seconds depending on the flowrate. Once the conditioned flow reached this point, adjustments could not be made without influencing the collected data.

### 2.5.3 Transient Data Analysis

The underlying assumptions surrounding the derivation of Equation 2.7 assumes steady-state operation. For this reason, effectiveness was not used for the purpose of determining the transient responses. Instead, analysis of transient performance will be based on the recorded temperature and $q_{flow}$ histories from each test.

### 2.5.4 Experimental Uncertainty in Heat Transfer Rates

The uncertainty in transient measurements was determined. To do so, Equation 2.4 was first expanded to Equation 2.8 as follows:

$$q_{flow} = \rho_c c_{p,c} \dot{V}(T_{co} - T_{ci}) \tag{2.8}$$

Where $\dot{V}$ represented the volumetric flowrate in $m^3$/s which was derived from the measured CSA flowrate.

The uncertainty in the estimated mains-side flow energy transfer rate ($q_{flow}$) was calculated using Moffat's method [24]. Based on Equation 2.8, the uncertainty was calculated as:

$$\frac{\delta q}{q} = \pm\sqrt{\left(\frac{\delta \Delta T_{cold}}{\Delta T_{cold}}\right)^2 + \left(\frac{\delta \dot{V}_{cold}}{\Delta \dot{V}_{cold}}\right)^2 + \left(\frac{\delta \rho c_p}{\Delta \rho c_p}\right)^2} \tag{2.9}$$

The mains-side water temperatures were known to range from 9-30$^0$C in most extreme cases, from the prior experience with the HXTP. Table 2-4 shows the water properties at extreme temperature ranges.

**Table 2-4: Maximum and minimum range of expected water properties [28]**

| Temperature $^0$C/K | Specific heat capacity $c_{p,c}$ kJ/kg.K | Density $\rho_c$ kg/m$^3$ |
|---|---|---|
| **9$^0$C/282.15K** | 4.19413 | 1000 |
| **30$^0$C/303.15K** | 4.17837 | 995.76 |

In Equation 2.8, the ratio of maximum to minimum $\rho_c c_{p,c}$ was calculated based on the water properties in Table 2-4.

$$\frac{(\rho_c c_{p,c})_{min}}{(\rho_c c_{p,c})_{max}} = \frac{(\rho_c c_{p,c})_{30^0C}}{(\rho_c c_{p,c})_{9^0C}} = \frac{4160.65\,\frac{kJ}{m^3K}}{4194.13\,\frac{kJ}{m^3K}} = 99.2\%$$

The above calculation showed that there would be a maximum difference of 0.8% between the maximum and minimum calculated values of $q_{flow}$, if variable properties for density and specific heats were used. Since the difference was not significant, density and specific heat of water were assumed constant to be 997.6 kg/m$^3$ and 4.18 kJ/kgK respectively for test method 1.

In Equation 2.9, $\delta\Delta T_{cold}$ and $\left(\frac{\delta\dot{V}_{cold}}{\Delta\dot{V}_{cold}}\right)$ were the uncertainty in RTD measurements and flowmeter as shown in Section 2.2.4. $\Delta T_{cold}$ was the difference between mains-side outlet and inlet temperature. $\left(\frac{\delta\rho c_p}{\Delta\rho c_p}\right)$ represented the percent error in the fluid properties and has been estimated to be 0.8% in this section.

Uncertainty was calculated for every one second time step for all tests. The maximum uncertainty value was estimated to be ±2.60% of the calculated $q_{flow}$ values. The estimated uncertainty is applicable for all the calculated mains-side flow energy and heat transfer rates in this thesis. The uncertainty bars are only shown for the flow energy transfer rate plots in Chapter 3 of this thesis to demonstrate their application. The flow energy and heat transfer rate plots in the appendix section do not include uncertainty bars for clarity.

# Chapter 3 Analysis, Results and Discussions for Test Method 1

## 3.1 Data Analysis for Test Method 1

All of the DWHR systems used in this thesis were provided by RenewABILITY Energy Inc. RenewABILITY DWHR systems are named based on the ID and length of the drain-side pipe. For example, a residential DWHR system with drain-side ID of 4” and drain-side length of 36” would be named as R4-36. The outer (mains-side) coils were the same for all DWHR systems. Outer coils loop around the drain-side in a set of 4 copper tubes. Mains-side coils on all DWHR systems used in this thesis were 1.5” ASTM B88 TYPE L copper tubes.

### 3.1.1 Shakedown Testing of DWHR Systems

Shakedown tests were performed to validate the generalized experimental approach. In particular, the shakedown tests were intended to determine if test conditions could be set as desired, and to ensure if the entirety of the test process was feasible. It was also intended to ensure the data would be suitable for analysis, and to ensure that the test process produced repeatable results.

In order to observe the temperature response, a DWHR system was tested. Temperature profiles for the randomly selected DWHR system at a random flowrate are shown in Figure 3-1. The DWHR was R3-48, tested at a flowrate of 7LPM. ΔT was the difference between the drain-side inlet ($T_{hi}$) and mains-side inlet ($T_{ci}$) temperatures. The uncertainty error bars calculated in Section 2.2.4 were relatively small as compared to the measured temperature readings. They are represented by the black markers on the temperature curves.

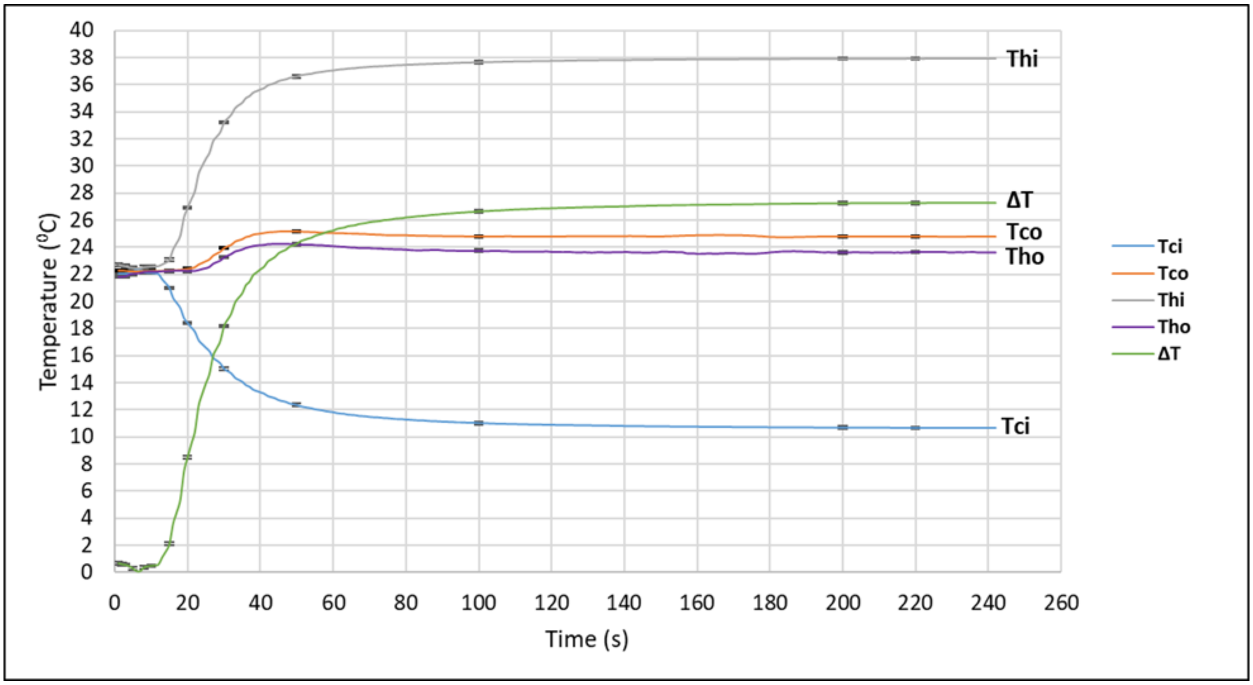


**Figure 3-1: Shakedown test temperature profiles of R3-48 at 7LPM**

Temperature responses from Figure 3-1 shows that at the start of the test, all the inlet and outlet temperatures were approximately at the ambient temperature conditions of about 22±2$^0$C. Once the test was initiated and water flow began at 7LPM, no system temperatures changed for almost 15 seconds. The inlet temperature profiles started to diverge at the same time at 15 seconds, indicating that the mains and drain-side flows were reaching the DWHR system at approximately the same time. Mains and drain-side inlet temperatures became steady at around 120 seconds at 10 and 38$^0$C respectively, which was the same as the pre-set inlet temperature conditions for all the tests. Mains and drain-side outlet temperatures reached steady temperatures of 25 and 24$^0$C at about 160 seconds. The final steady outlet temperatures varied for each test based on the amount of induced heat transfer.

### 3.1.2 Repeatability of DWHR System Temperature Response

Repeatability is the closeness or agreement between the successive measurements obtained by different tests, when performed at the same input and ambient conditions. It is important to establish test repeatability during experimental work to provide confidence in the data collected. In case of DWHR systems, it means conducting tests at the same flowrate, along with the same inlet and ambient temperature conditions.

Since the transient analysis brings time into the equation, it is very important to make sure that repeatability between the measured quantities could be established for the entire test duration. The experimental approach would be completely invalid if repeatability wasn't established.

In order to determine repeatability, a random DWHR system was tested twice at the same flowrate and inlet temperature conditions. In this test, the system was R3-48 at the flowrates of 14 and 9LPM. The main focus was to observe how well the temperature profiles for both tests overlapped with each other. Each complete repeatability test consisted of running the random DWHR system at the flowrates of 14 and 9LPM. Figure 3-2 and Figure 3-3 shows the measured temperature profiles, after running the DWHR system 2 times at the same inlet conditions. Solid and dashed lines represents 2 different tests.

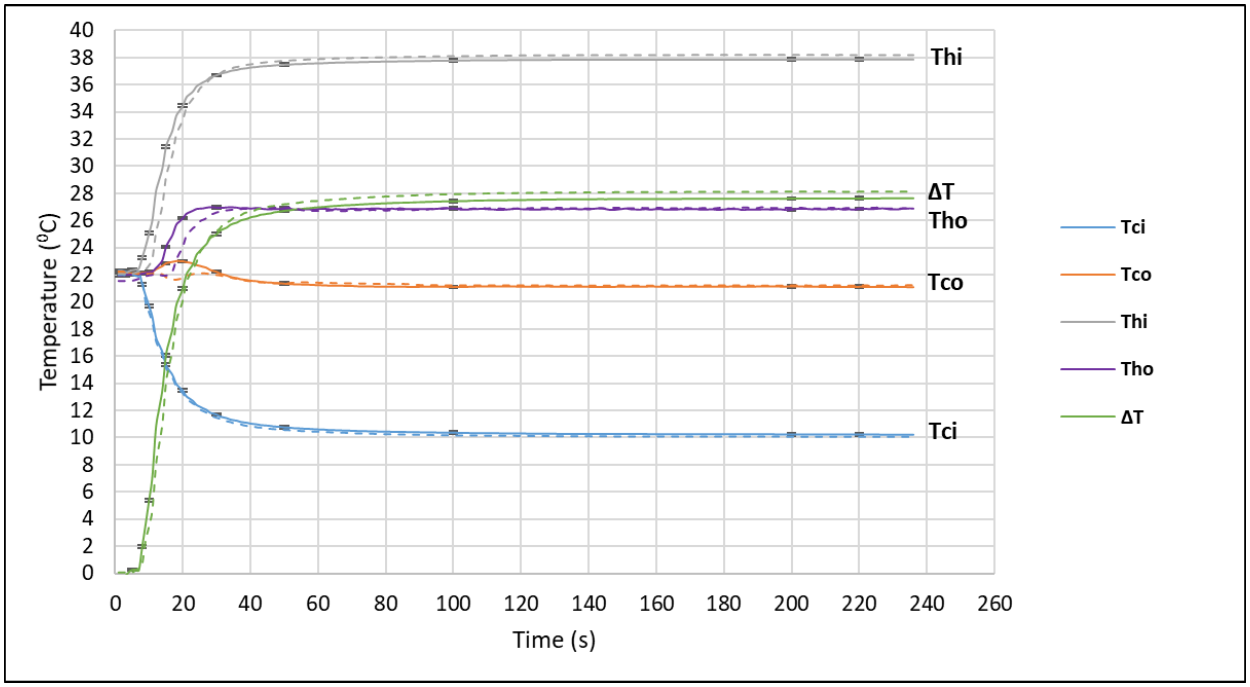


**Figure 3-2: Repeatability of temperature profiles of R3-48 at 14LPM**

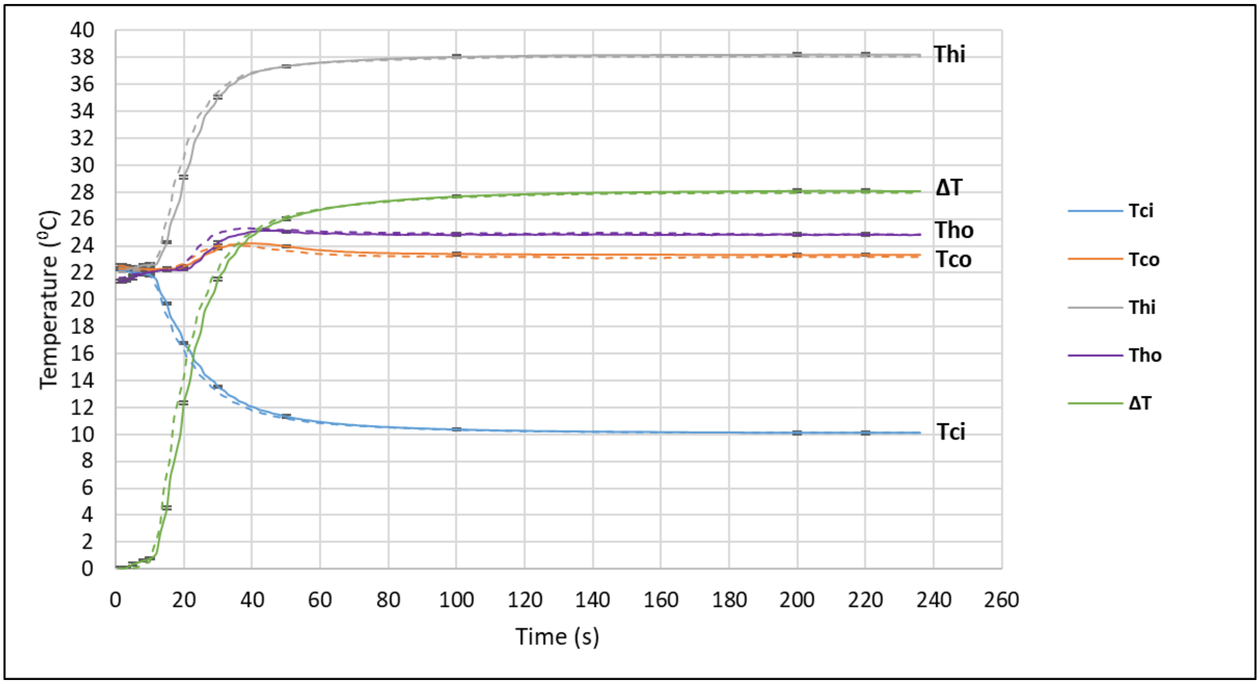


**Figure 3-3: Repeatability of temperature profiles of R3-48 at 9LPM**

For both the tests, the temperature profiles followed each other very closely. The slight deviations at the starting points in the transient portion were due to the inability to maintain the exact same ambient conditions for all of the tests. The ambient conditions in the lab drifted slightly all the time. The difference between both temperature profiles was under 4% for the majority of test duration. Since temperature profiles for both tests followed each other very closely, it was determined that excellent repeatability was achieved. Each temperature profile from both tests had the same shape during the beginning transient region, and reached steady-state at about the same time.

### 3.1.3 Removal of Unresponsive Time Periods

The unresponsive time periods estimated in Section 2.5.2 could be observed in Figure 3-1, Figure 3-2 and Figure 3-3, where the temperatures did not start to respond immediately once the experiments were initiated. All those figures showed that there was about a 10-15 second delay before any temperature response was observed. This delay was due to presence of water in the hoses and mains-side coils from previous tests, which had now reached ambient conditions. Temperature response would only be observed once all of the pre-existing water in the hoses and coils was cleared out and the conditioned water reached the inlet RTDs.

In order to compare the transient temperature response of different DWHR systems at different flowrates, it was necessary to make sure that the temperature profiles started to respond at the same time for all DWHR systems, after the water at ambient temperature had cleared out of DWHR system coils.

The best way to do that, was to remove the data for unresponsive time. A case is presented for R4-36 at 12LPM. Figure 3-4 shows the temperature profiles for R4-36 at 12LPM as plotted from the raw data. Based on the unresponsive time periods stated in Table 2-3, the first 9 seconds of data was eliminated from Figure 3-4.

After the removal of unresponsive time periods as seen in Figure 3-5, the zero-time point was reset at the location where the first response was observed in the inlet and outlet temperature profiles. This step enabled having the same starting point for all tests, which was required to be able to compare the temperature profiles for different cases.

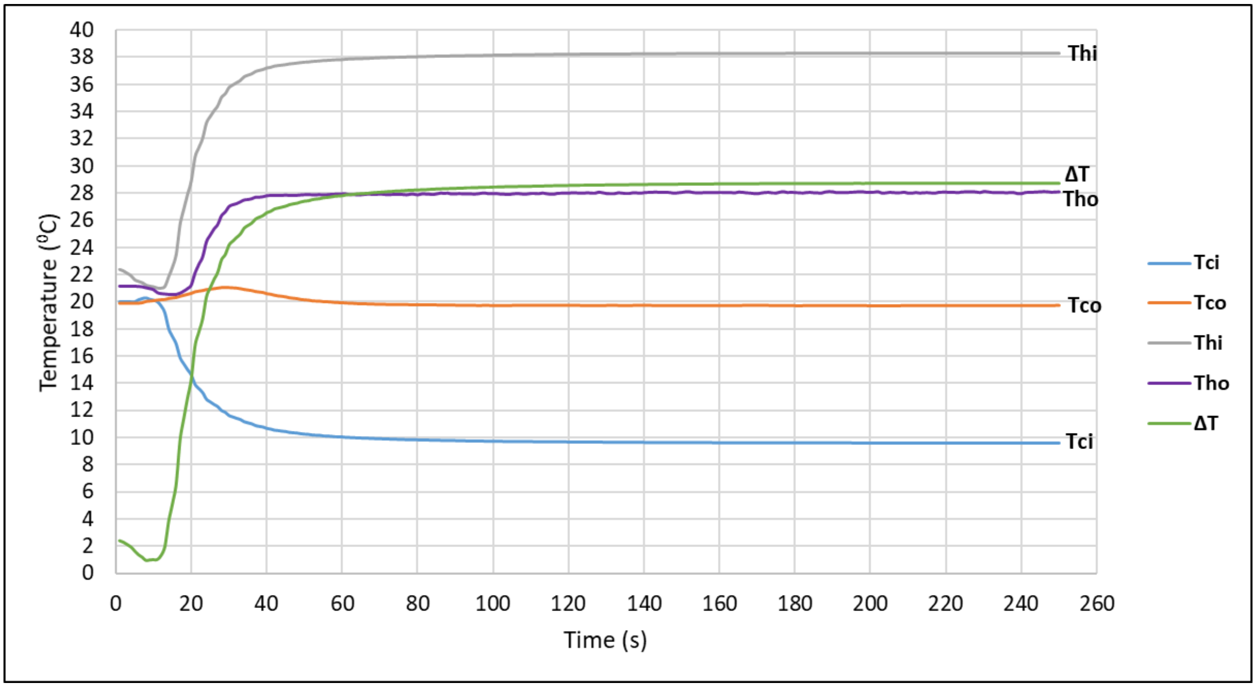


**Figure 3-4: Original temperature response for R4-36 at 12LPM**

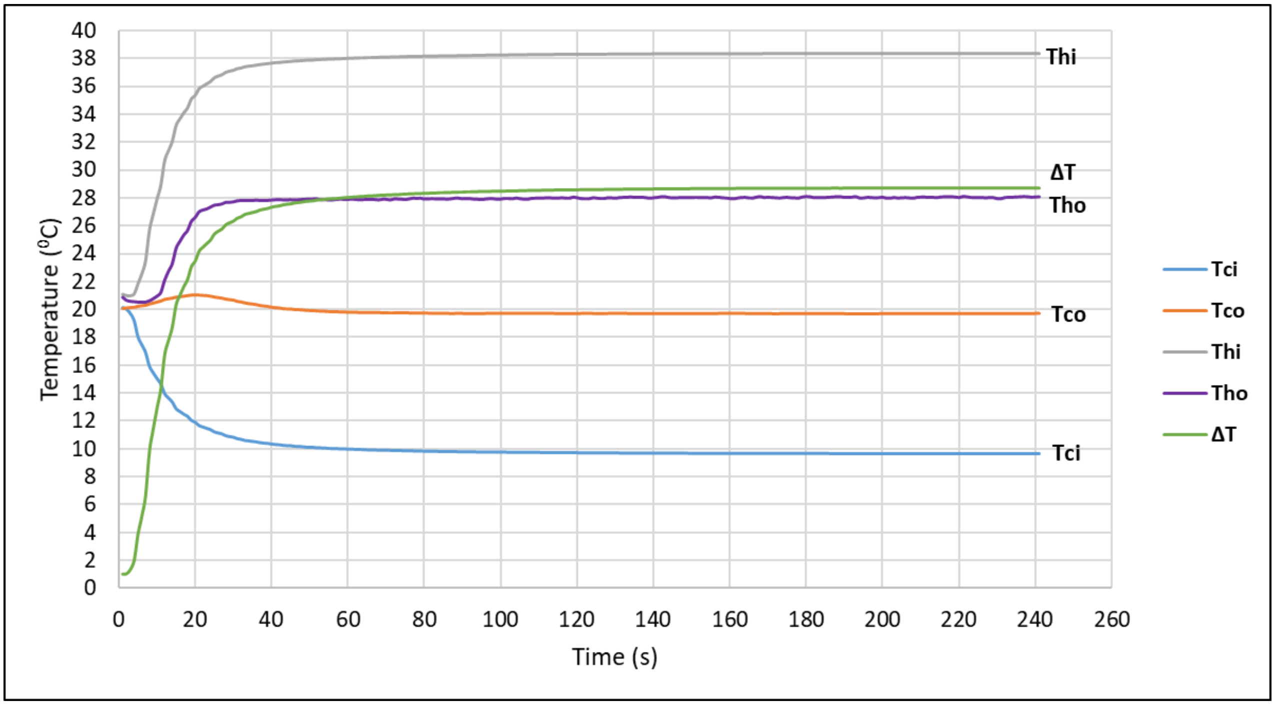


**Figure 3-5: Corrected temperature response for R4-36 at 12LPM**

From Figure 3-5, most of the temperature change was observed within the first 50 seconds of the corrected temperature response. For most of the test cases, a common diverging temperature point, close to $T_{ambient}$ (22±2$^0$C) was observed, which resulted due to providing enough time (5-6 hours) for the HXTP to cool down.

## 3.2 Results for Test Method 1

### 3.2.1 Selection of Sample Sizes

In order to investigate $q_{flow}$ and time responses, it was important to make sure that the selected sample size covered a range of DWHR systems. DWHR systems are usually available in the drain-side diameters of 2, 3 and 4”. The drain-side length of the DWHR systems varied from 36” up to 84” with an increment of 12”. STRL had DWHR systems of all available diameters but not all lengths. Table 3-1 shows the matrix of DWHR systems that were available and used for this investigation.

**Table 3-1: Matrix of DWHR systems selected for determining transient response**

| | | Length (INCHES) | | | | |
|---|---|---|---|---|---|---|
| | | 36" | 48" | 60" | 72" | 84" |
| Diameter (INCHES) | 2" | ✓ | ✓ | ✓ | X | X |
| | 3" | ✓ | ✓ | ✓ | ✓ | ✓ |
| | 4" | ✓ | ✓ | ✓ | X | X |

Based on Table 3-1, 11 DWHR systems were tested. Each DWHR system was tested at all 6 CSA flowrates. About 4-5 minutes of raw data was collected for each of the tests. In total, 66 tests were conducted. Only 2 tests were conducted per day to make sure that the inlet and outlet temperatures, along with the HXTP could reach ambient room temperature conditions before the next test was initiated.

### 3.2.2 Estimation of Mains-Side Flow Energy Transfer Rate

The generalized approach consisted of determining the mains-side flow energy transfer rate ($q_{flow}$) of DWHR systems, by using the difference in the mains-side outlet and inlet temperature as shown in Equation 2.4, which was further converted to Equation 2.8.

The main purpose of this section is to show the results of the generalized test procedure along with establishing some information about $q_{flow}$ during the transient portions of any DWHR related experiment. The time responses of the DWHR systems could then be determined based on the nature of $q_{flow}$ and the time taken to reach quasi-steady conditions.

It is important to note that the nature of the observations and conclusions made in this section were similar for all the cases. Hence, any conclusions made for the demonstrated sample were applicable to all the test cases.

Test case of R4-36 at 12LPM was used for calculation and demonstration purposes. Table 3-2 shows a sample of collected data, along with the estimated $q_{flow}$ values for R4-36 at 12LPM. The calculation sample below is shown for the time, t = 132(s) after the temperature profiles started to respond. $q_{flow}$ calculation procedure was exactly the same for all of the tests conducted.

**Table 3-2: Processed data sample for R4-36 at 12LPM**

| Time (s) | $T_{ci}$ (⁰C) | $T_{co}$ (⁰C) | $T_{hi}$ (⁰C) | $T_{ho}$ (⁰C) | Flow Rate LPM | $T_{co}$-$T_{ci}$ (⁰C) | $q_{flow}$ (kW) |
|---|---|---|---|---|---|---|---|
| **7** | 16.89 | 20.29 | 23.51 | 20.54 | 11.69 | 3.4 | **2.7623** |
| **8** | 15.91 | 20.38 | 25.67 | 20.63 | 11.76 | 4.47 | **3.6534** |
| **9** | 15.44 | 20.45 | 26.83 | 20.79 | 11.89 | 5.01 | **4.1400** |
| **10** | 15.02 | 20.52 | 27.91 | 20.97 | 11.99 | 5.5 | **4.5831** |
| **11** | 14.62 | 20.6 | 28.92 | 21.24 | 12.03 | 5.98 | **4.9997** |
| **12** | 13.93 | 20.71 | 30.67 | 22.13 | 12.15 | 6.78 | **5.7252** |
| **13** | 13.62 | 20.76 | 31.37 | 22.76 | 12.15 | 7.14 | **6.0291** |
| ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ |
| **130** | 9.67 | 19.71 | 38.27 | 28.01 | 11.99 | 10.04 | **8.3663** |
| **131** | 9.67 | 19.71 | 38.27 | 28.05 | 11.99 | 10.04 | **8.3663** |
| **132** | 9.66 | 19.71 | 38.27 | 28.07 | 11.99 | 10.05 | **8.3747** |
| **133** | 9.66 | 19.71 | 38.28 | 28.08 | 11.98 | 10.05 | **8.3677** |
| **134** | 9.66 | 19.7 | 38.28 | 28.09 | 11.98 | 10.04 | **8.3593** |

Constant values for density and specific heat capacity of water has been assumed in Section 2.5.4. Hence, the only unknown parameter from Equation 2.8 was volumetric flowrate $\dot{V}$, which was calculated from the CSA flowrate as follows:

$$11.99\ \frac{\mathrm{L}}{\mathrm{min}}\mathrm{x}\frac{1\ \mathrm{m}^3}{1000\ \mathrm{L}}\mathrm{x}\frac{1\ \mathrm{min}}{60\ \mathrm{s}} = 0.0001998\frac{\mathrm{m}^3}{\mathrm{s}}$$

Substituting all known values in Equation 2.8 yielded:

$$q_{\mathrm{flow}} = 997.6\frac{\mathrm{kg}}{\mathrm{m}^3}\mathrm{x}4.18\frac{\mathrm{kJ}}{\mathrm{kg.K}}\mathrm{x}0.0001998\frac{\mathrm{m}^3}{\mathrm{s}}\mathrm{x}(19.71-9.66)\mathrm{K} = 8.3747\mathrm{kW}$$

Two different plots of $q_{flow}$ including uncertainty bars, with respect to time for R4-36 and R3-36 at all flowrates, which were representative of the entire data set are shown in Figure 3-6 and Figure 3-7 . Both figures show that the response time is DWHR system dependent. The plots for all other DWHR systems are shown in Appendix A. Full results are summarized later in the current chapter. Based on the shape of both the plots, it was assumed that the DWHR systems behaved as first order systems.

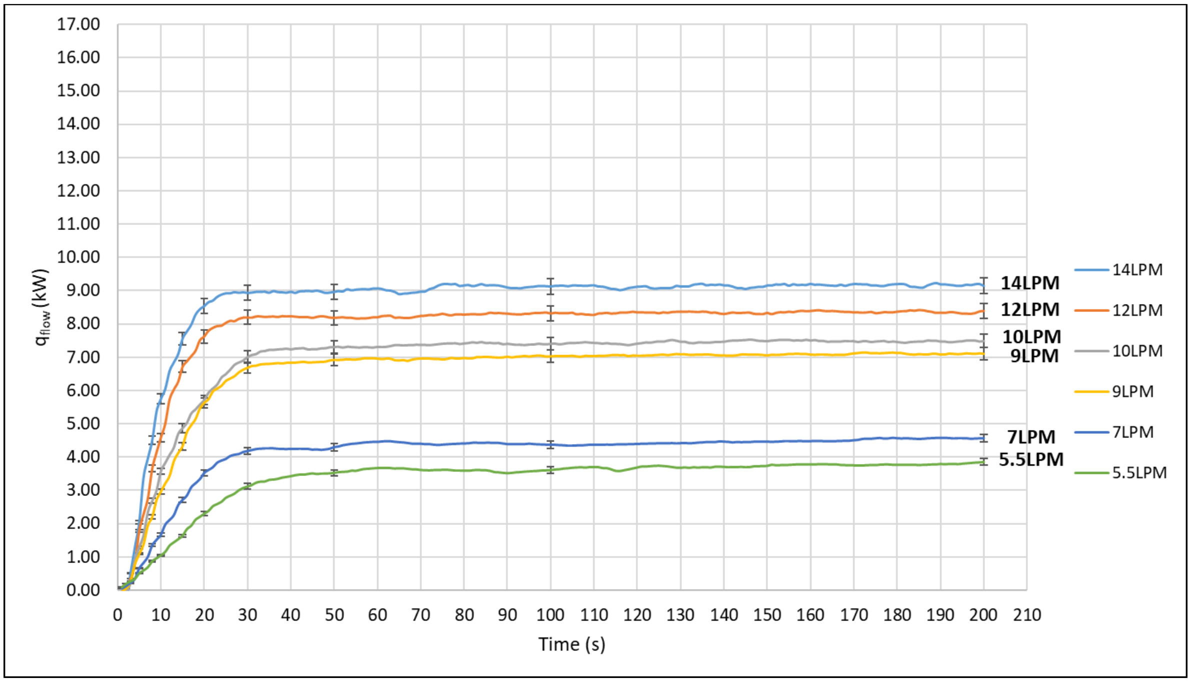


**Figure 3-6: Calculated mains-side flow energy transfer rate for R4-36**

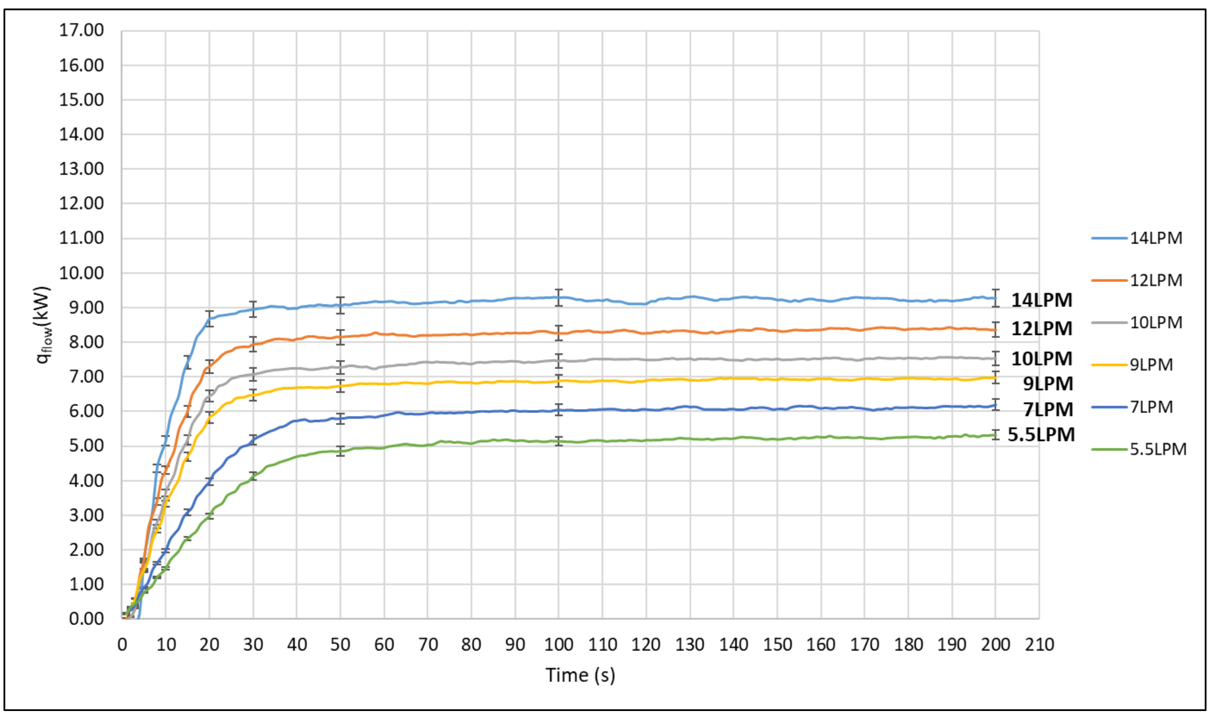


**Figure 3-7: Calculated mains-side flow energy transfer rate for R3-36**

Flowrate and flow energy transfer rate ($q_{flow}$) increased and decreased in the same direction. The highest $q_{flow}$ was associated with 14LPM. Based on that observation, $q_{flow}$ at 12LPM was represented in the colour red as the 2nd flow energy transfer rate curve from the top.

Even though lower flowrates generally result in higher mains-side outlet temperatures, the volumetric flowrate in Equation 2.8 seems to have a much stronger impact on $q_{flow}$, as compared to the temperature difference on the mains-side entry and exit. The energy balance performed in this section to calculate $q_{flow}$, did not take into account any heat losses or heat transfer to the surrounding copper pipe. Moreover, no DWHR system energy storage was taken into account.

Figure 3-6 and Figure 3-7 showed that $q_{flow}$ profiles for all 6 flowrates had the same shape, which started with a sharp increase and eventually reached quasi-steady-state. Most of the change in $q_{flow}$ was observed before the first 50 seconds.

The flow energy transfer rate only reached quasi-steady-state conditions when it was relatively stable and didn't increase or decrease significantly in magnitude. This was evident from slight fluctuations in the steady-state region where $q_{flow}$ lines were almost horizontal. Even the measured raw data had slight fluctuations in the flowrate and inlet and outlet temperatures at steady-state operating conditions as well. The RTD and flowmeter readings were only accurate to 2 decimal places. All these factors had an impact on the calculated uneven readings of $q_{flow}$.

Figure 3-6 and Figure 3-7 also showed that the time taken for $q_{flow}$ to stabilize was inversely related to flowrate. For faster flowrates, it would take less time to reach quasi-steady-state conditions, as the mains-side coils were able to get rid of the ambient water much faster and responded to incoming mains and drain-side water.

### 3.2.3 Estimation of Thermal Time Response

The flow energy transfer rate ($q_{flow}$) was used to determine the thermal time response for all the test cases because of its exponential nature as seen from Figure 3-6 and Figure 3-7. A constant magnitude of $q_{flow}$ wasn't established due to experimental fluctuations.

The 99% and 95% steady-state response times could not be established directly due to the uneven nature of $q_{flow}$ curves during steady-state operation. Since $q_{flow}$ increased rapidly during the beginning phase of the test before it reached quasi-steady-state conditions, it was decided to estimate the lower order thermal time response of DWHR systems. Due to the unpredicted nature of $q_{flow}$ around the steady-state mark, 63.2% and 86.5% steady-state time responses were determined for all the tested DWHR systems. 63.2% time response is a good representation of the first time constant in transient systems [29].

Sample calculations were only shown for the derivation of 63.2% time responses. The calculation procedure and derived conclusions for 63.2% time response were fully applicable for 86.5% response as well. All of the relevant derived results for 86.5% response are presented in Appendix C.

Time response derivation was also shown for a single case of R4-36 at the flowrate of 12LPM. $q_{flow}$ was relatively stable and steady after the 2 minute mark for all the tests. Hence, in order to estimate a constant steady-state value for mains-side flow energy transfer rate, average of $q_{flow}$ was taken for all data points after the 3$^{rd}$ minute mark. This was done to make sure that the values being averaged were completely around the steady-state. The averaged value of $q_{flow}$ after bypassing 3 minutes of data would serve as the steady-state reference point, around which the 63.2% and 86.5% time responses were estimated for all the tests. A portion of the averaged data for the sample calculation case is shown in Table 3-3.

**Table 3-3: Portion of averaged mains-side flow energy transfer rate for R4-36 at 12LPM**

| Time (s) | $T_{co}$-$T_{ci}$ ($^0$C) | $q_{flow,SS}$ (kW) |
|---|---|---|
| 181 | 10.07 | 8.3843 |
| 182 | 10.07 | 8.3843 |
| 183 | 10.07 | 8.4123 |
| 184 | 10.07 | 8.3983 |
| 185 | 10.07 | 8.4193 |
| ⋮ | ⋮ | ⋮ |
| 238 | 10.08 | 8.3086 |
| 239 | 10.09 | 8.3238 |
| 240 | 10.09 | 8.3519 |
| 241 | 10.09 | 8.3449 |

The averaged steady-state value of $q_{flow}$ was therefore computed as:

$$q_{flow,SS} = \frac{8.3843 + 8.3843 + \cdots + 8.3519 + 8.3449}{241 - 181} = 8.3669\text{kW}$$

From the averaged steady-state flow energy transfer rate, 63.2% response time was derived as follows:

$$q_{flow,63.2\%} = 0.632\left(q_{flow,SS}\right)$$

$$q_{flow,63.2\%} = 0.632(8.3669) = 5.2879\text{kW}$$

From Table 3-2, it was observed that $q_{flow}$ at 63.2% time response was between 11 and 12 seconds. Since data was acquired after 1 second intervals, it was not possible to determine the exact response time to the fraction of a second. An approximation was made by linear interpolation during the selected time interval.

$$\frac{t_{63.2\%} - 11}{12 - 11} = \frac{5.2879 - 4.9997}{5.7252 - 4.9997}$$

$$t_{63.2\%} = 11.40 \text{ seconds } \approx 12 \text{ seconds}$$

The final response time was estimated to be around 12 seconds by rounding up to the nearest number. The mains-side flow energy transfer rates and 63.2% thermal time responses for all the DWHR systems and tests conducted are shown in Table 3-4.

**Table 3-4: Summarized mains-side flow energy rate and 63.2% time responses**

| | 14LPM | | | 12LPM | | | 10LPM | | |
|---|---|---|---|---|---|---|---|---|---|
| | $q_{flow, SS}$ (kW) | $q_{flow, 63.2\%}$ (kW) | $t_{63.2\%}$ (s) | $q_{flow, SS}$ (kW) | $q_{flow, 63.2\%}$ (kW) | $t_{63.2\%}$ (s) | $q_{flow, SS}$ (kW) | $q_{flow, 63.2\%}$ (kW) | $t_{63.2\%}$ (s) |
| **R2-36** | 7.0634 | 4.4641 | 12.09 | 6.5590 | 4.1453 | 10.60 | 5.8895 | 3.7222 | 9.50 |
| **R2-48** | 9.3638 | 5.9179 | 6.57 | 8.7810 | 5.5496 | 8.541 | 7.7948 | 4.9263 | 10.89 |
| **R2-60** | 10.5090 | 6.6417 | 10.15 | 9.5071 | 6.0085 | 13.94 | 8.4508 | 5.3409 | 13.94 |
| **R3-36** | 9.2588 | 5.8516 | 11.17 | 8.3857 | 5.2998 | 12.71 | 7.5334 | 4.7611 | 13.25 |
| **R3-48** | 10.6157 | 6.7091 | 6.3499 | 9.9115 | 6.2641 | 10.35 | 8.7781 | 5.5478 | 12.03 |
| **R3-60** | 12.2646 | 7.7512 | 11.54 | 11.3902 | 7.1986 | 12.74 | 9.8698 | 6.2377 | 14.14 |
| **R3-72** | 13.5054 | 8.5354 | 13.04 | 12.2686 | 7.7538 | 15.67 | 10.7084 | 6.7677 | 19.01 |
| **R3-84** | 15.7138 | 9.9311 | 14.84 | 13.8137 | 8.7302 | 17.52 | 12.2496 | 7.7417 | 19.85 |
| **R4-36** | 9.1926 | 5.8097 | 10.21 | 8.3669 | 5.2879 | 11.40 | 7.4888 | 4.7329 | 14.20 |
| **R4-48** | 12.1702 | 7.6915 | 8.2758 | 11.0910 | 7.0095 | 9.273 | 9.7894 | 6.1869 | 9.231 |
| **R4-60** | 13.1833 | 8.3318 | 15.07 | 12.2273 | 7.7277 | 14.67 | 10.7212 | 6.7758 | 17.15 |
| | **9LPM** | | | **7LPM** | | | **5.5LPM** | | |
| | $q_{flow, SS}$ (kW) | $q_{flow, 63.2\%}$ (kW) | $t_{63.2\%}$ (s) | $q_{flow, SS}$ (kW) | $q_{flow, 63.2\%}$ (kW) | $t_{63.2\%}$ (s) | $q_{flow, SS}$ (kW) | $q_{flow, 63.2\%}$ (kW) | $t_{63.2\%}$ (s) |
| **R2-36** | 5.4296 | 3.4315 | 15.02 | 4.7779 | 3.0197 | 14.90 | 4.0817 | 2.5797 | 23.35 |
| **R2-48** | 7.3167 | 4.6242 | 8.123 | 6.0842 | 3.8452 | 13.01 | 5.2565 | 3.3221 | 20.56 |
| **R2-60** | 7.8195 | 4.9419 | 15.32 | 6.5915 | 4.1658 | 20.53 | 5.5835 | 3.5288 | 28.39 |
| **R3-36** | 6.9465 | 4.3902 | 13.76 | 6.1160 | 3.8653 | 19.28 | 5.2744 | 3.3334 | 22.66 |
| **R3-48** | 8.2330 | 5.2033 | 12.49 | 6.9507 | 4.3928 | 13.86 | 6.0107 | 3.7988 | 21.63 |
| **R3-60** | 9.3487 | 5.9084 | 16.88 | 7.9195 | 5.0051 | 21.87 | 6.7050 | 4.2376 | 26.66 |
| **R3-72** | 10.0905 | 6.3772 | 20.66 | 8.3953 | 5.3058 | 27.37 | 7.0852 | 4.4779 | 31.81 |
| **R3-84** | 11.2903 | 7.1355 | 22.21 | 9.2137 | 5.8231 | 24.72 | 7.5622 | 4.7793 | 37.69 |
| **R4-36** | 7.0996 | 4.4870 | 15.38 | 4.5884 | 2.8999 | 16.23 | 3.8422 | 2.4283 | 21.32 |
| **R4-48** | 9.2791 | 5.8644 | 11.43 | 7.5757 | 4.7878 | 15.63 | 5.9036 | 3.7311 | 19.61 |
| **R4-60** | 10.1566 | 6.4189 | 19.60 | 8.1510 | 5.1514 | 24.34 | 4.8278 | 3.0511 | 21.74 |

## 3.3 Discussions for Test Method 1

### 3.3.1 Limitations of Test Results

One of the major problems faced during conducting the experiments was the unavailability of some of the DWHR system dimensions as shown in Table 3-1. A complete set of DWHR system lengths were only available for the 3" drain-side diameter. Secondly, when the estimated time responses were compared against the drain-side diameters of 2, 3 and 4", no relationship was observed. A relationship of time response as a function of diameter couldn't be defined with 3 only data points. Hence, it was not possible to convey how the drain-side diameter would impact the time response of the selected DWHR systems.

Larger drain-side diameters would result in more surface area available for heat transfer and a higher thermal mass. Hence, the DWHR systems with larger diameters would take a longer time to stabilize and reach steady-state. This could be verified if DWHR systems with drain-side diameters larger than 4" were available.

### 3.3.2 Relationship between Time Response and CSA Flowrate

CSA flowrates were used to understand the behaviour of the estimated time responses. Data from Table 3-4 was used to determine the impact of CSA flowrates on the estimated time responses. Figure 3-8 to Figure 3-10 shows the plots for 63.2% thermal time responses as a function of CSA flowrates, for all the DWHR systems used in this experiment.

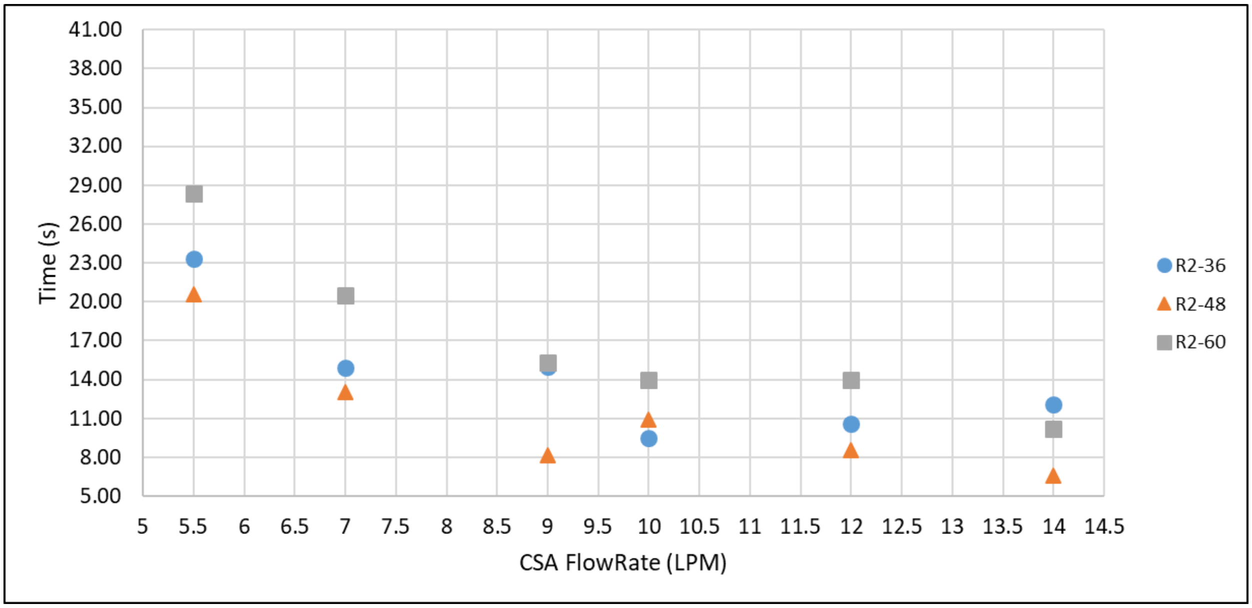


**Figure 3-8: Experimental 63.2% time response vs CSA flowrate of 2" drain-side diameter DWHR systems**

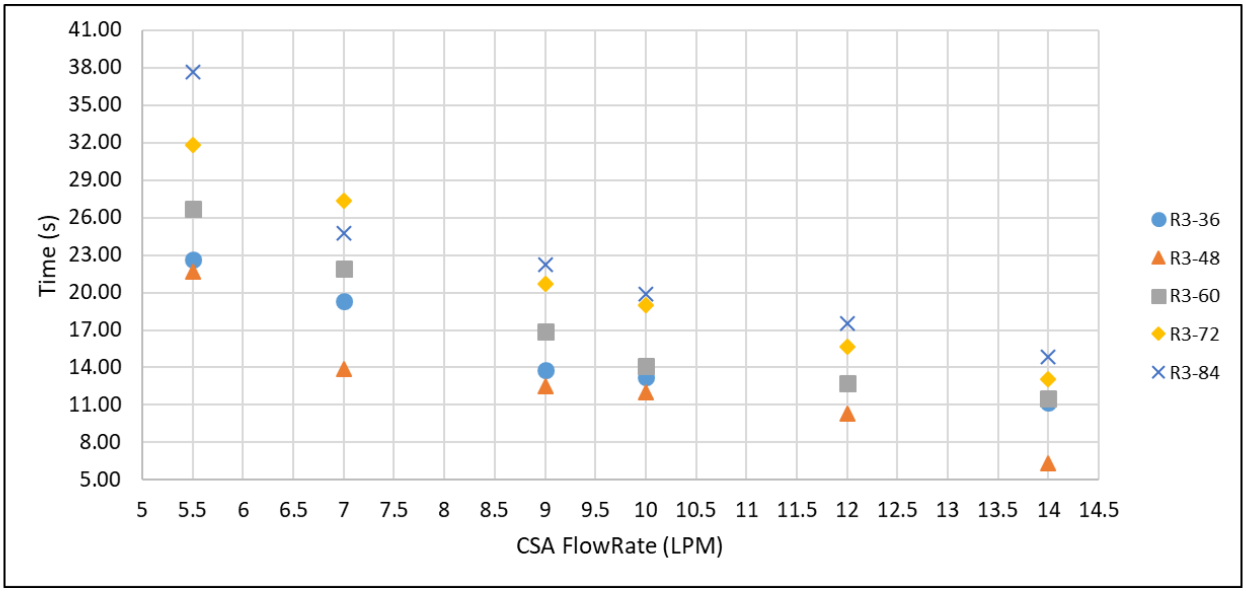


**Figure 3-9: Experimental 63.2% time response vs CSA flowrate of 3" drain-side diameter DWHR systems**

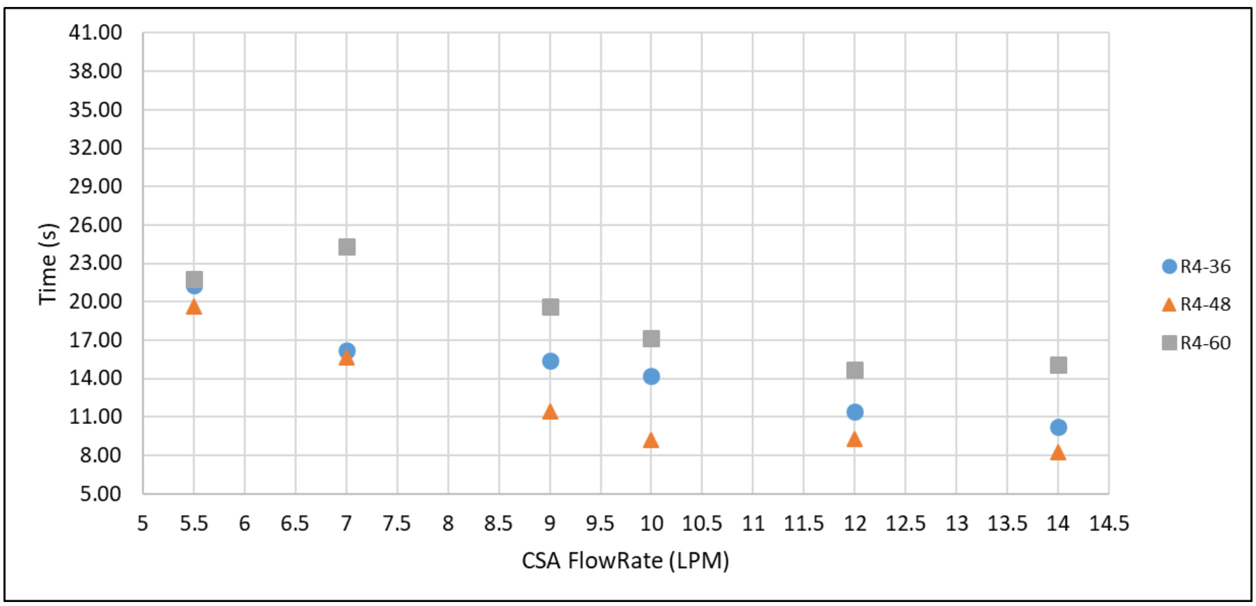


**Figure 3-10: Experimental 63.2% time response vs CSA flowrate of 4" drain-side diameter DWHR systems**

All of the 3 figures above showed that in most cases, the 63.2% time response generally decreased with increasing flowrate. This was because at higher flowrates, any pre-existing water at ambient conditions that was present in the mains-side coils would clear out faster. Hence, the conditioned incoming water entered the coils in a shorter period of time, and the DWHR system would start to stabilize and reach steady-state more quickly. This was the general pattern, which was observed for most of the DWHR systems that were tested. It was observed that the transient response time was highly dependent on DWHR systems and hence could be a reason for slight deviations from the patterns observed. The measurement and estimation of the response time was approximate.

Based on the time responses established, linear fit could describe the relationship between time response and flowrates. The relationships established for all 11 DWHR systems were of the form shown in Equation 3.1.

$$t_{63.2\%} = A\dot{V}_{CSA} + B \tag{3.1}$$

Where $\dot{V}_{CSA}$ was the CSA flowrate in LPM. $A$ and $B$ were the coefficients for each specific DWHR system. Figure 3-11 shows the experimental and correlated values for one of the DWHR systems. Coefficients of Equation 3.1 for all 11 DWHR systems are shown in Table 3-5. Plots for the 63.2% experimental and correlational time responses for all of the 11 DWHR systems are presented in Appendix B.

**Table 3-5: Correlation coefficients for all DWHR systems as a function of CSA flowrate**

| | **A** $\frac{s}{\left(\frac{L}{min}\right)}$ | **B** s | $R^2$ |
|---|---|---|---|
| **R2-36** | -1.21 | 25.86 | 0.5809 |
| **R2-48** | -1.38 | 24.54 | 0.7310 |
| **R2-60** | -1.90 | 35.27 | 0.8447 |
| **R3-36** | -1.32 | 28.09 | 0.8516 |
| **R3-48** | -1.49 | 27.07 | 0.8581 |
| **R3-60** | -1.78 | 34.36 | 0.9025 |
| **R3-72** | -2.22 | 42.54 | 0.9594 |
| **R3-84** | -2.33 | 45.12 | 0.8189 |
| **R4-36** | -1.21 | 26.36 | 0.9205 |
| **R4-48** | -1.31 | 24.76 | 0.8400 |
| **R4-60** | -1.10 | 29.26 | 0.8023 |

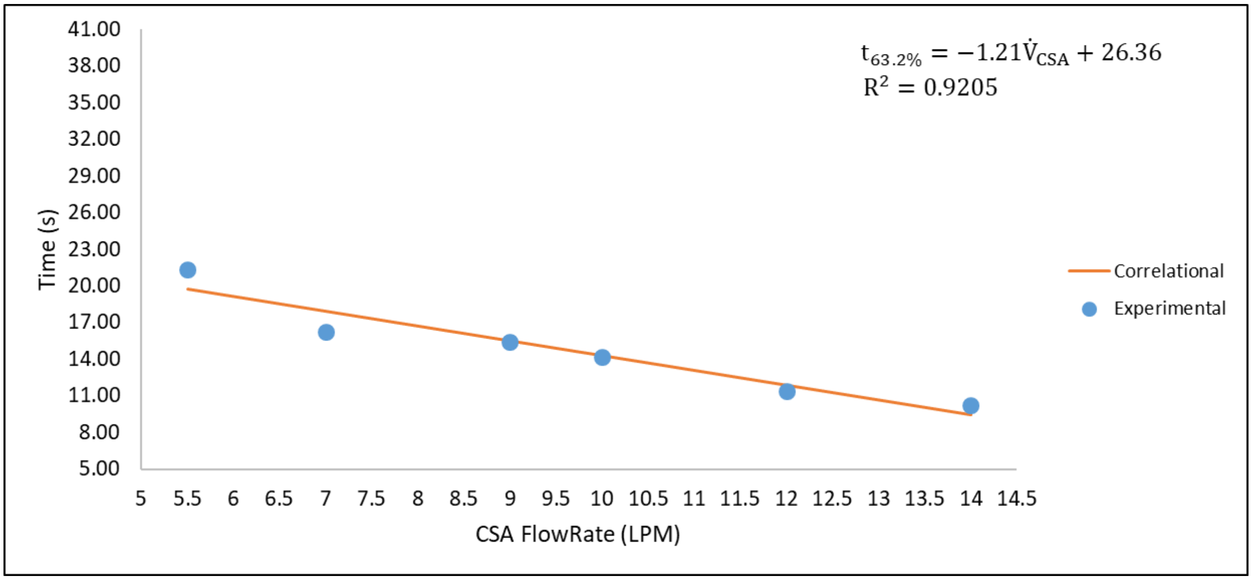


**Figure 3-11: Experimental and correlational time response of R4-36 at different flowrates**

The difference between the actual experimental time responses in Table 3-4 and the correlational time responses, were found by substituting the CSA flowrates into Equation 3.1 for all the DWHR systems, and then by finding the difference between both values. Table 3-6 shows the differences for R4-36.

**Table 3-6: Difference between experimental and correlational time response of R4-36 at CSA flowrates**

| Flowrate LPM | R4-36 | | |
|---|---|---|---|
| | Experimental (s) | Correlational (s) | Δt (s) |
| **14** | 10.21 | 9.42 | 0.79 |
| **12** | 11.40 | 11.84 | -0.44 |
| **10** | 14.20 | 14.26 | -0.06 |
| **9** | 15.38 | 15.47 | -0.09 |
| **7** | 16.23 | 17.89 | -1.66 |
| **5.5** | 21.32 | 19.71 | 1.62 |

### 3.3.3 Relationship between Time Response and Drain-Side Length

Only the 3” drain-side diameter DWHR systems had a bigger sample set of 5 and were used to establish trends for time response as a function of drain-side length. For both 2” and 4” diameter DWHR systems, no such trends could be established. Figure 3-12 shows the plot of the estimated time responses for 3” drain-side diameter DWHR systems from Table 3-4, when compared with drain-side length.

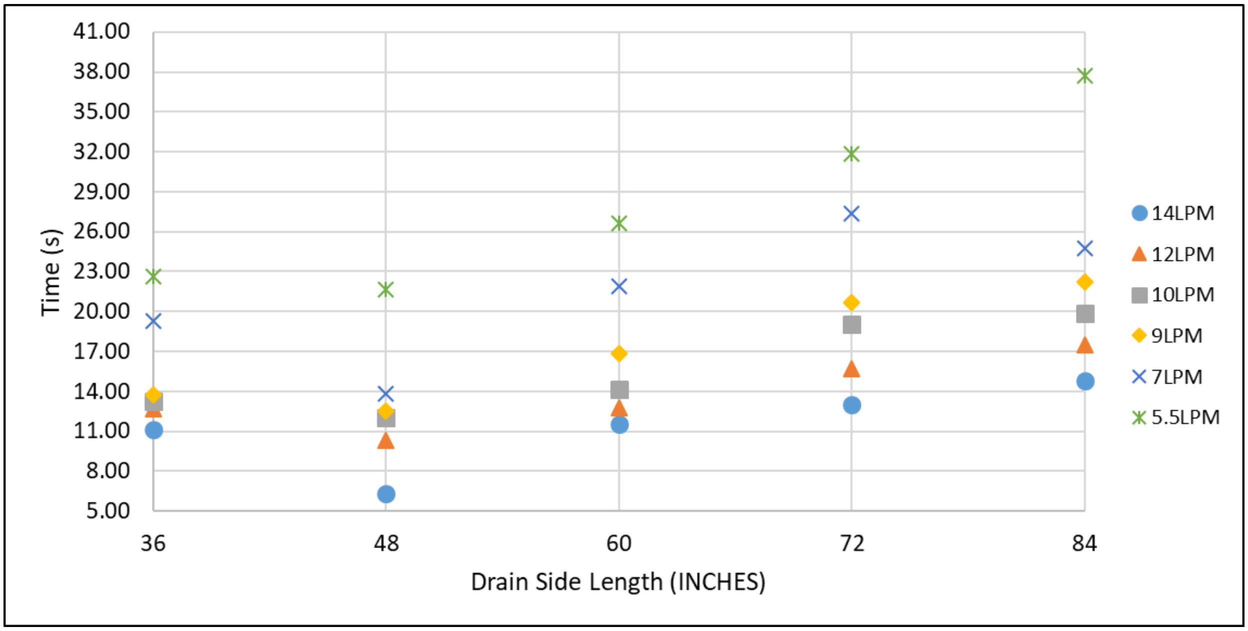


**Figure 3-12: Experimental 63.2% time response vs drain-side length of 3" drain-side diameter DWHR systems at CSA flowrates**

Figure 3-12 indicated that the time response generally increased for longer drain-side lengths at all flowrates. The key point in understanding this relationship was the fact that the DWHR systems with longer drain-side lengths had more coils. Hence, at a particular flowrate, as the drain-side length increased, any pre-existing water in the coils had to travel a longer distance to exit the DWHR system.

Even though a general increasing trend was observed, R3-48 behaved slightly differently at all flowrates. The time response was generally lower for R3-48 as compared R3-36. This could have been due to any unnoticeable manufacturing defects (specific to DWHR system) that might be present. No other exact same R3-48 was available in the lab to investigate this issue. The only other unexplained discrepancy in the data trend was observed for R3-84 at 7LPM, which could have resulted from experimental error and could be corrected if the same test is repeated again in the future.

Even for this case, a linear fit gave the best results when comparing time response to the drain-side length. The relationship between drain-side length and time response was of the form shown in Equation 3.2.

$$t_{63.2\%} = ML_{DS} + N \tag{3.2}$$

Figure 3-13 shows the plot of experimental and correlational time responses of all 3" diameter DWHR systems. In the above equation, $L_{DS}$ represented the drain-side length in inches, whereas M and N were the coefficients specific to particular CSA flowrates. All of the coefficients for the above equation are stated in Table 3-7.

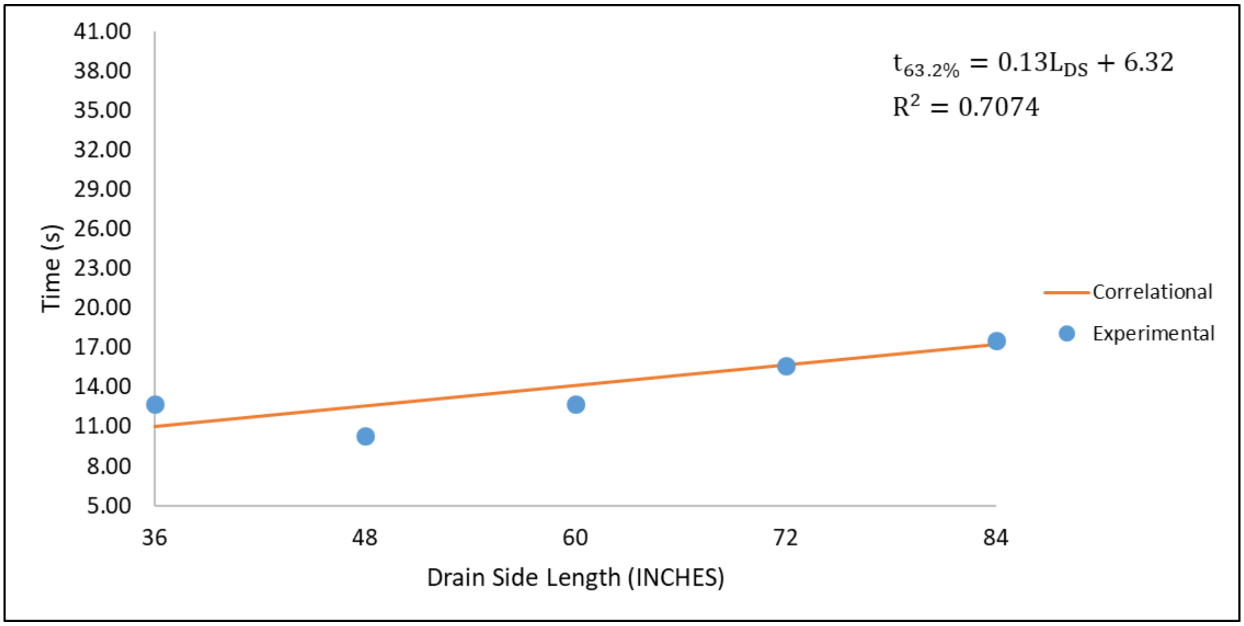


**Figure 3-13: Experimental and correlational time response at 12LPM for all 3" drain-side diameter DWHR systems**

**Table 3-7: Correlation coefficients for all 3" drain-side diameter DWHR systems as a function of drain-side length**

| Flowrate LPM | M $\frac{s}{in}$ | N $s$ | $R^2$ |
|---|---|---|---|
| **14LPM** | 0.12 | 4.37 | 0.4912 |
| **12LPM** | 0.13 | 6.32 | 0.7074 |
| **10LPM** | 0.17 | 5.57 | 0.8133 |
| **9LPM** | 0.21 | 4.67 | 0.8824 |
| **7LPM** | 0.20 | 9.22 | 0.5502 |
| **5.5LPM** | 0.34 | 7.97 | 0.9036 |

The correlational time response at different flowrates and the time differences were found using Equation 3.2 and Table 3-7. Table 3-8 shows the difference between the experimental and correlational time responses at 12LPM for different 3" diameter DWHR systems.

**Table 3-8: Difference between experimental and correlational time response at 12LPM for 3" drain-side diameter DWHR systems**

| DrainSide Length (INCHES) | 12LPM | | |
|---|---|---|---|
| | Experimental (s) | Correlational (s) | Δt (s) |
| **36** | 12.71 | 11.00 | 1.71 |
| **48** | 10.35 | 12.56 | -2.21 |
| **60** | 12.74 | 14.12 | -1.38 |
| **72** | 15.67 | 15.68 | -0.01 |
| **84** | 17.52 | 17.24 | 0.28 |

### 3.3.4 Relationship between Time Response and DWHR System Mass

The relationship between time response and DWHR system mass was briefly investigated, since it was exactly the same as the relationship between time response and drain-side length as shown in Section 3.3.3. The only difference would be in the x-axis of Figure 3-12 and Figure 3-13, which would be replaced by the mass of DWHR system. The overall shape of the curve would stay the same because the magnitude of the measured time responses did not change.

The time response was expected to increase because as the mass of the DWHR system increased, it would take more thermal energy to reach quasi-steady-state conditions. More energy and time would be required to firstly heat up the DWHR system, and then the mains-side water flowing in the coils.

Since the shape of the curve would be exactly the same as compared to drain-side length, linear equations similar to Equation 3.2 would be used to describe the best fit. The only difference would be between the correlation coefficients as compared to Table 3-7.

## 3.4 Validation of Derived Results

Validation of the derived results is an important part of any experimental research. It is important to note that a combined correlation for time response as a function of both flowrate and drain-side length couldn't be developed. The major reason was due to the uncontrolled instability that arose during the beginning transient portion of any test. Hence, validation of correlations developed for flowrate and drain-side length in Section 3.3.2 and Section 3.3.3, were performed separately to determine how well they could be used to predict 63.2% time response under a specified set of conditions.

### 3.4.1 Validation of Drain-Side Length Based Correlations for 3" Diameter DWHR systems

In order to validate the correlations developed for different drain-side lengths of 3" drain-side diameter DWHR systems at different CSA flowrates, arbitrary tests were conducted at standard CSA flowrates, and the predicted time responses were compared to the measured experimental time responses. The procedure for correlation validation was exactly the same as Section 3.3.3.

A total of 13 different test points were used for the purpose of validation, which included testing 2 DWHR systems at all 6 CSA flowrates and also performing some tests on other 3" drain-side diameter DWHR systems. Not all of the 3" drain-side diameter DWHR systems were tested again due to the timing constraint posed by transient analysis, which required leaving the HXTP idle for a long period of time. Table 3-9 shows the validation data for some cases of 3" drain-side diameter DWHR systems.

All of the linear equations coefficients to calculate the time response as a function of drain-side length are shown in Table 3-7. The method for calculation of the experimental time response was exactly the same as shown from Section 3.2.2 to 3.2.3 by using the acquired raw data. The procedures for removing unresponsive temperature periods and time interpolation were all performed in the same way.

**Table 3-9: Correlation validation for 3" drain-side diameter DWHR systems as a function of drain-side length**

| | Flowrate (LPM) | Measured | | Predicted | Δt (sec) | % error | $t_{99\%}$ (sec) |
|---|---|---|---|---|---|---|---|
| | | $q_{flow}$ (kW) | $t_{63.2\%}$ (sec) | $t_{63.2\%}$ (sec) | | | |
| R3-36 | **14** | 5.7119 | 9.81 | 8.69 | 1.12 | 11.42% | 44.67 |
| | **12** | 5.3662 | 11.82 | 11.00 | 0.82 | 6.94% | 52.96 |
| | **10** | 4.7942 | 15.51 | 11.69 | 3.82 | 24.63% | 54.34 |
| | **9** | 4.4417 | 15.97 | 12.23 | 3.74 | 23.42% | 57.56 |
| | **7** | 3.9275 | 21.05 | 16.42 | 4.63 | 22.00% | 90.72 |
| | **5.5** | 3.3076 | 21.68 | 20.21 | 1.47 | 6.79% | 105.00 |
| R3-48 | **14** | 6.8826 | 8.68 | 10.13 | -1.45 | -16.71% | 27.17 |
| | **12** | 6.3449 | 9.58 | 12.56 | -2.98 | -31.11% | 43.75 |
| | **10** | 5.6085 | 10.43 | 13.73 | -3.30 | -31.64% | 56.18 |
| | **9** | 5.2140 | 10.09 | 14.75 | -4.66 | -46.18% | 62.17 |
| | **7** | 4.4885 | 17.04 | 18.82 | -1.78 | -10.45% | 72.76 |
| | **5.5** | 3.7804 | 21.09 | 24.29 | -3.20 | -15.17% | 122.04 |
| R3-60 | **14** | 7.9570 | 11.25 | 11.57 | -0.32 | -2.84% | 48.81 |
| | **7** | 4.9815 | 21.83 | 21.22 | 0.61 | 2.79% | 108.22 |
| R3-72 | **12** | 7.8114 | 14.82 | 15.68 | -0.86 | -5.80% | 71.84 |

It was observed from Table 3-9 that the maximum deviation in the measured and predicted time response was less than 3 seconds. In any practical scenario, the transient response can never achieve 100% accuracy between the measured and estimated values. This is due to the unpredicted nature of transient experiments. Hence, a difference of a few seconds was reasonable for such types of estimations. This was the main reason why the percent error between the measured and predicted time response was higher in some cases. Another reason for a higher percent error was due to the smaller magnitude of the measured $t_{63.2\%}$ time response as compared to the Δt term.

Since transient response represented a very small portion of any DWHR system testing, the difference of a few seconds between the measured and predicted time responses would not be significant. Hence, it could be established that the correlations developed could predict the 63.2% steady-state time response for 3” diameter DWHR systems within reasonable accuracy of a few seconds.

### 3.4.2 Validation of Flowrate Based Correlations

The validation of flowrate based correlations for different DWHR systems was completed using the same methodology as Section 3.4.1. The exact same procedure was followed except the linear equations whose coefficients were derived from Table 3-5. All of the cases for validation are summarized in Table 3-10.

**Table 3-10: Correlation validation for different DWHR systems as a function of flowrates**

| | Flowrate (LPM) | Measured | | Predicted | Δt (sec) | % error | $t_{99\%}$ (sec) |
|---|---|---|---|---|---|---|---|
| | | $q_{flow}$ (kW) | $t_{63.2\%}$ (sec) | $t_{63.2\%}$ (sec) | | | |
| **R3-48** | **6.07** | 4.1022 | 24.1 | 18.03 | 6.07 | 25.19% | 92.10 |
| | **11.35** | 6.1244 | 13.16 | 10.16 | 3.00 | 22.80% | 57.56 |
| **R2-48** | **13.67** | 5.9884 | 10.17 | 5.68 | 4.49 | 44.15% | 41.91 |
| | **9.36** | 4.7618 | 14.24 | 11.62 | 2.62 | 18.40% | 60.33 |
| **R4-60** | **8.98** | 6.4188 | 20.32 | 19.38 | 0.94 | 4.63% | 89.80 |
| | **7.96** | 5.9066 | 22.00 | 20.50 | 1.50 | 6.82% | 99.93 |
| **R3-72** | **12.08** | 7.8114 | 14.82 | 15.72 | -0.90 | -6.07% | 64.47 |
| | **7.55** | 5.5686 | 23.69 | 25.78 | -2.09 | -8.82% | 92.10 |
| **R2-60** | **11.27** | 5.7809 | 13.37 | 13.86 | -0.49 | -3.66% | 58.49 |
| | **9.36** | 5.0307 | 16.00 | 17.49 | -1.49 | -9.31% | 68.62 |
| **R4-36** | **9.01** | 4.4071 | 13.85 | 15.46 | -1.61 | -11.62% | 62.63 |
| | **7.06** | 3.6545 | 20.59 | 17.82 | 2.77 | 13.45% | 92.10 |

The maximum deviation between measured and predicted time responses was around 5 seconds. Uncertainty would always be present in any type of transient experiments. The larger % error arose from the same reasons stated in the previous sub-sections.

### 3.4.3 Limitations of Test Method 1

The major limitation of test method 1 was the inability to directly calculate the 99% time response from the experimental data, as stated in Section 3.2.3. The only way to estimate $t_{99\%}$ was by fitting the first order exponential equation, of the form shown in Equation 3.3, to $q_{flow}$ vs time plots.

$q_{flow,SS}$ would be calculated in the same way as shown in Section 3.2.3. $\tau_{flow}$ represents the flow energy time constant which would be varied to obtain a good fit. Once the best possible first order exponential equation was derived, $t_{99\%}$ would be estimated by substituting 99% of $q_{flow,SS}$ in Equation 3.3.

$$q_{flow} = q_{flow,SS}\left(1 - e^{\frac{-t}{\tau_{flow}}}\right) \tag{3.3}$$

The last column of Table 3-9 and Table 3-10 shows the estimated steady-state time response ($t_{99\%}$) for some of the cases. Both the tables shows that the complete steady-state was reached around 2 minutes for the lowest flowrates.

Secondly, having a unique correlation for each test condition is another limitation of test method 1. This approach was also used by Gao et al. [18], where second order polynomial equations for temperature responses were developed as a function of time, for each unique case of cross flow heat exchangers. Since it has been established in this chapter that transient effects occur during the earliest phases of a transient test, the correlations developed could provide a good approximation of estimated time response for different DWHR systems.

Another limitation of this test method was the inability to determine the energy storage effects shown in Equation 2.3. Since storage effects play a crucial role during the beginning phases of a test due to quick temperature responses, they must be included when heat transfer rates are calculated for DWHR systems. This is the scope for the second test method.

# Chapter 4 Test Method 2

## 4.1 Background

The generalized approach (test method 1) discussed in Chapter 2 only focused on the mains-side inlet and outlet temperatures to estimate $q_{flow}$. Test method 2 includes the use of infrared thermography, which can provide the surface temperature profiles across the entire DWHR system.

In general, the rate of heat addition and water temperature change across DWHR length have not been studied extensively. The ability of test method 2 to determine surface temperatures, would lead to the estimation of mains-side water temperature across the entire DWHR system length, and in turn estimating the mains-side heat transfer rate ($q_c$) in Equation 2.3, by including energy storage effects ($q_{storage}$).

## 4.2 Initial Equipment Selection

Due to the geometry and design of DWHR systems, it was impossible to directly measure the temperature of water inside the coils. RTDs or thermocouples could not be inserted through the copper tube walls without interfering with the heat transfer characteristics, or increasing the risk of leakage.

This is the reason why the mains-side temperature measurement has been limited at water inlet and outlet points. Since DWHR systems are made completely of copper, which has high thermal conductivity of about 401 W/mK [30], surface temperature measurements at different locations across the length could provide some useful insight at the fluid temperature inside the mains-side coils. Using an infrared thermography camera was determined to be an excellent option available to conduct such an analysis, due to its ability to instantaneously resolve the temperature profile of the entire surface of DWHR systems.

Even though thermal camera was a great choice, it has issues related to emissivity and accuracy. Thermal cameras are very sensitive to its surrounding environment and any improper emissivity settings can have a severe impact on the measured temperature readings. Hence, thermocouples were also added at points to verify the temperatures being measured by the thermal camera itself. In order to investigate the water temperature versus surface temperature, two thermocouples were placed near the mains-side inlet and outlet along with the immersion RTDs and provided a good comparison between temperature readings. Hence, the main equipment used for thermography included a thermal camera and thermocouples. More details about the equipment used is presented in upcoming sections.

The measurement method proposed for the mains-side surface temperature consisted of using Type T thermocouples made of copper and constantan. Type T are one of the most common types of thermocouples used for applications including different laboratory environments. The operating temperature range of Type T thermocouples is extensive and hence it was a preferred choice for temperature data acquisition [31].

### 4.2.1 Thermocouples Set-Up and DAQ Programming

It has been mentioned in Chapter 2 that data was acquired using LabVIEW. LabVIEW DAQs had already been programmed by previous research students when the HXTP was first set-up, but it has only been limited to measuring the water temperature at the inlets and outlets of DWHR systems by the immersion RTDs.

An additional DAQ chassis NI 9213 from National Instruments [32] was available and used as a source of voltage input to the LabVIEW DAQ from the thermocouple junctions. The number of thermocouples that were used was limited to 12 because of chassis capacity. Once soldered thermocouples junctions and labelling was completed, the inputs were extended and fed into the chassis.

The DAQ chassis was programmed in LabVIEW in order to acquire temperature readings at different point locations across DWHR system length. Programming data inputs and outputs in LabVIEW was relatively straightforward and mostly required forming connections of different components.

LabVIEW is a visual programming language. The DAQ chassis is configured with LabVIEW and then used for any required data acquisition. Variables $T_1$ to $T_{12}$ were created to capture temperature readings for every thermocouple. Once the temperature signals were acquired by the DAQ assistant and retained in the data collector, they were then stored in 12 different arrays each corresponding to different thermocouples. The stored temperature readings were then written to a comma separated value (CSV) file which could be analyzed as required. All of the data was collected at 1 second intervals which is the same as the main LabVIEW program, which has been used to acquire RTD readings. Moreover, standard date and time were stored for readings at each instant.

The programming page and user interface are interconnected. The user interface image appears for any input/output component variables created on programming page. Figure 4-1 and Figure 4-2 shows the programming page and the user interface respectively. In order to acquire the temperature readings, the play button on Figure 4-2 had to be pressed once. Time counter would start under the "Time Elapsed" and temperature readings would display and change every second. The temperature was recorded in the units of $^0$C. The "Stop" button could be pressed to terminate thermocouple temperature acquisition.

Even though the temperature readings by Type T thermocouples are reasonably accurate, calibration was still a crucial step that had to be performed before using thermocouples. All four RTDs on the HXTP had already been calibrated for research purposes. RTDs were used as a reference point to calibrate all 12 thermocouples. Calibration and verification of all the thermocouples are shown in Appendix D.

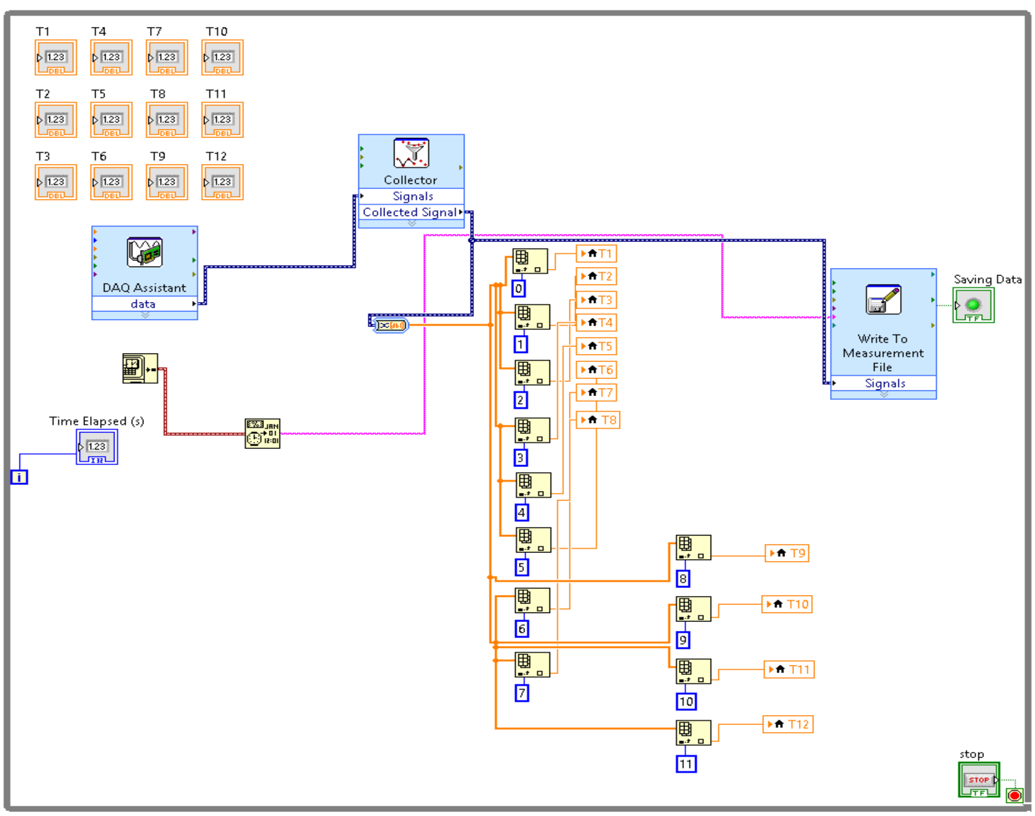


**Figure 4-1: Data acquisition program for thermocouples**

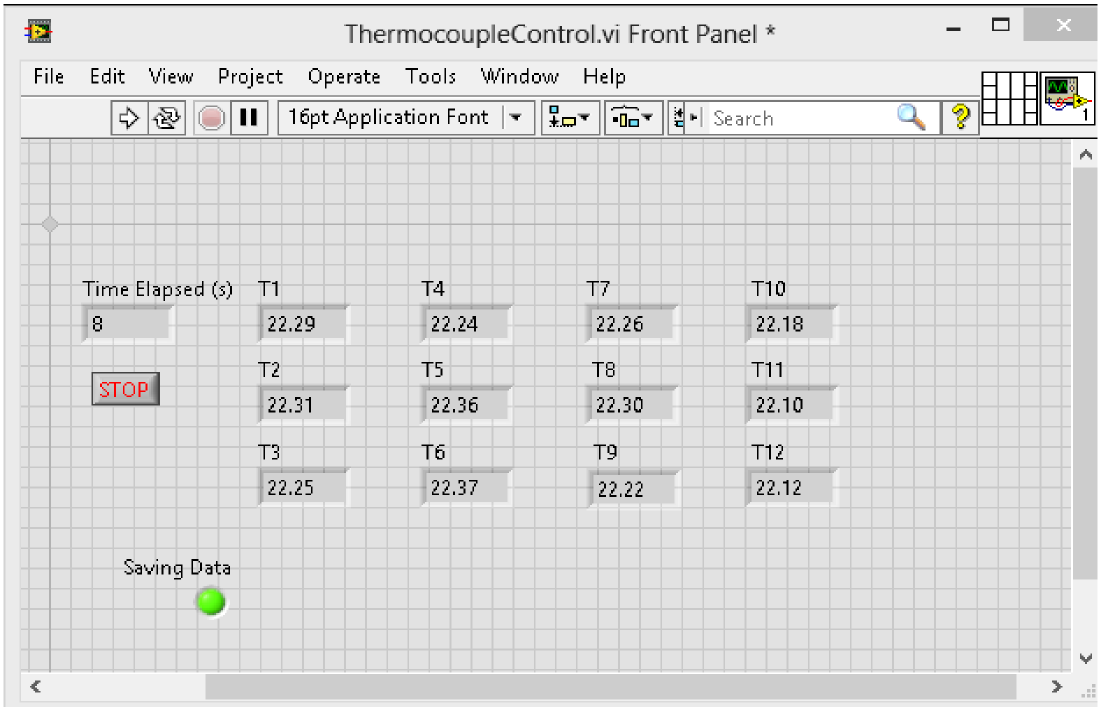


**Figure 4-2: User interface of thermocouple inputs and readings**

### 4.2.2 Thermocouple Placement Plan and Potential Issues

A thermocouple was placed on the mains-side inlet and outlet to ensure meaningful temperature readings. It was expected that the readings of thermocouples at entry and exit would be very close to what was reported by the immersion RTDs. Hence, this placement at inlet and outlet was also a check on the validity of temperature outputs of the thermocouples. The remaining eight thermocouples were evenly spaced across the mains-side coils.

The coils of all DWHR systems used in this experimental study were divided into sets of 4 as shown in Figure 4-3. This is how most of the DWHR systems are manufactured by RenewABILITY Energy Inc. Each set of 4 coils was called a "coil set" in this thesis.

**Figure 4-3: Coil set of 4 coils on a random DWHR system**

Even though it had been well established that the thermocouples would provide very accurate readings, there was one problem with using them. The smallest DWHR system available in STRL was 36” long drain-side and had 14 coil sets. Dividing 8 thermocouples over 14 coil sets would not be the best idea as a lot of information regarding temperature change would not be captured. Moreover, thermocouples are only able to provide measurements at a single point. This is another reason why it was decided to use a thermal camera. As was stated previously, the thermal imaging camera allows the analysis of the entire surface, with temperature validation at the thermocouple measurement points.

## 4.3 Thermography Camera Set-up and Finalized Equipment Selection

Thermal imaging cameras are a powerful tool which can provide a lot of detailed information regarding temperature change on the targeted surface. They detect and convert infrared energy (heat) into electronic signals, which can then be processed to produce thermal images. Very detailed temperature pattern arrays known as thermograms can then be generated [20]. The processed thermal image can be broken down into temperature measurements across the entire thermal imaging frame [33]. The key benefit of using thermal imaging camera is its ability to generate thermograms for the entire DWHR system surface. More information on how data from the thermal camera was analyzed is shown in upcoming sections.

### 4.3.1 Thermal Camera Description and Benefits

A FLIR T-400 series camera was used for this analysis. This research grade camera had the thermal sensitivity of $0.05^0$C. It was 320 columns x 240 rows pixel IR with a frame rate of 6 Hz [34]. The camera had 3.1 mega pixel of clarity and could simultaneously capture thermal and visible images.

One benefit of using the FLIR T-400 was its compatibility with the ResearchIR software [35]. It was able to output a 320 x 240 CSV file per frame showing temperature for each pixel, and a thermal image for each single frame, at the rate of about 6 frames per second. For example, if a test was run for 50 seconds, ResearchIR would generate approximately 300 CSV files and infrared images which could be processed as needed. Lot of temperature data availability was another major benefit of using the thermal camera. Hence, the thermal camera would provide more than enough data which would have to be processed to derive any useful results.

The use of a thermal camera could only be justified if the temperature readings were similar to that of thermocouples. Hence, the proposed plan was to run both the thermocouples and camera together on selected DWHR systems to ensure that temperature readings agreed for both. If it could be proved that both the measuring devices showed very similar temperature readings, data given by the camera would most likely be used for any location of the DWHR system. It would help to get rid of point measurement constraint posed by the thermocouples.

### 4.3.2 Surface Conditioning Approximations

Thermal cameras work by capturing infrared light emitted, reflected and transmitted by the objects in view of the camera lens [36]. There is no transmission since DWHR systems are made up of copper. Higher emissivity of the system surface would therefore result in higher amount of infrared light collected by the camera. This would lead to more precise infrared images and thermograms.

Good thermal conductive properties of copper is one major reason why it is used in the manufacturing of DWHR systems. It also has high reflectivity and very low emissivity. The radiative properties of any material is defined by Equation 4.1 [37]:

$$\rho + \alpha + \tau = 1 \tag{4.1}$$

Where $\rho$, $\alpha$ and $\tau$ are reflectivity, absorptivity and transmissivity of the material being used. Due to no transmissivity, Equation 4.1 was reduced to Equation 4.2 as follows:

$$\rho + \alpha = 1 \tag{4.2}$$

It was assumed that copper was at thermodynamic equilibrium in order to simplify the problem. The assumption of grey body which allowed to establish constant emissivity over all wavelengths, simplified the use of Kirchhoff's law of thermal radiation which states that emissivity is equal to absorptivity [38]. Therefore $\alpha$ in Equation 4.2 was substituted with emissivity $\varepsilon$. The final result is shown in Equation 4.3 which was used to experimentally estimate the emissivity of copper.

$$\rho + \varepsilon = 1 \tag{4.3}$$

The emissivity of copper was estimated using a Gier Dunkle DB-100. The DB-100 is an infrared reflectometer which measures infrared reflectance of any sample [39]. Once reflectance is measured, emissivity of a sample is estimated using Equation 4.3.

In order to measure reflectance of copper, a flat square copper plate of dimensions 4”x4” was cut out and measurements were made evenly throughout the entire surface. Figure 4-4 shows the approximate reflectivity measurement locations on the flat copper plate.

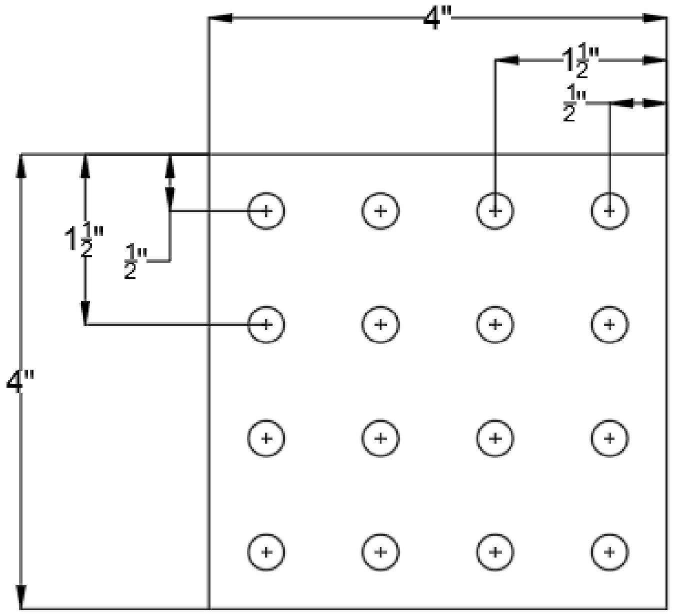


**Figure 4-4: Approximate reflectivity measurement locations on flat copper plate (Not to Scale)**

The average reflectivity and emissivity of copper plate were determined to be 0.935 and 0.065 respectively. This meant that very little infrared radiation would be captured by the thermal camera lens, if the DWHR systems were used as they were. Hence, the thermograms obtained would not be very accurate.

The copper surface is very reflective, and this is not good for infrared thermography. The DWHR systems therefore were painted flat black. A black surface would be a better emitter of radiation [40].

Initially, a single coat of spray paint was applied but it didn’t completely cover the surface of the copper plate since some spots were visible. Hence, another coat was applied to ensure no surface exposure of copper. The applied double layer of spray paint was very thin and wouldn’t significantly impact the infrared heat coming off the DWHR systems. Table 4-1 shows the estimated emissivity at different spots of the copper plate with no layer, single layer and double layer of black stove paint.

**Table 4-1: Emissivity of copper plate with no, single and double coat of black paint**

| | Emissivity ε | | | |
|---|---|---|---|---|
| Copper Surface | 0.069 | 0.068 | 0.055 | 0.062 |
| | 0.071 | 0.062 | 0.040 | 0.052 |
| | 0.063 | 0.067 | 0.050 | 0.103 |
| | 0.050 | 0.061 | 0.073 | 0.094 |
| Single coat | 0.872 | 0.861 | 0.846 | 0.862 |
| | 0.840 | 0.832 | 0.856 | 0.853 |
| | 0.863 | 0.872 | 0.841 | 0.854 |
| | 0.818 | 0.851 | 0.866 | 0.856 |
| Double coat | 0.870 | 0.866 | 0.856 | 0.873 |
| | 0.853 | 0.862 | 0.860 | 0.864 |
| | 0.868 | 0.871 | 0.858 | 0.854 |
| | 0.845 | 0.865 | 0.868 | 0.859 |

The average emissivity values of single coat and double coat were estimated to be 0.853 and 0.862 respectively. This led to a conclusion of applying a double coat of black stove paint to the selected DWHR systems before performing infrared thermography. It would significantly enhance the emissivity of infrared radiation from the DWHR system surface.

### 4.3.3 Selection of DWHR systems for Infrared Thermography

It was expected that post processing would take a long time to derive any useful results due to the abundance of data collected by the thermal camera as mentioned in Section 4.3.1. Therefore, it was desirable to select a small set of DWHR systems. A sample size of 3 DWHR systems were selected. R3-36, R3-60 and R4-36 were the DWHR systems chosen because it gave degrees of freedom for both drain-side diameter and length. Another reason for a smaller sample selection was the limited availability of the thermal camera.

R3-36 and R4-36 had 14 coil sets and a total of 56 coils, while the R3-60 had 24 coil sets and a total of 96 coils. The coil sets were numbered in ascending order from the bottom of the drain-side pipe at mains-side water inlet to the top at mains-side water outlet. For the purpose of this research work, coil set 1 was referred to as "entry coil set", whereas coil set 14 or 24 depending on the DWHR system was referred to as "exit coil set".

Figure 4-5 shows the painted DWHR systems used for infrared thermography. A total of 18 tests were to be completed for the entire infrared thermography analysis. Fixed temperatures of 10$^0$C and 38$^0$C as mentioned in Chapter 2, were used for the mains and drain-side inlets. All tests were run at equal-flow conditions.

**Figure 4-5: Double coated DWHR systems used for infrared thermography**

### 4.3.4 Finalized List of Materials

It was determined that a total of 8 essential components were required in order to successfully conduct infrared thermography experiments on DWHR systems. The list of those essential components is as follows:

1. 12 Type T thermocouples.
2. Thermally conductive paste to ensure proper conduction from DWHR system surface to thermocouple junction.
3. Infrared thermography camera.
4. Tripod for mounting and fixing camera location.
5. Thermal insulation to block the exposure of any unwanted drain-side surface to the thermal camera lens. This will be discussed in Section 4.4.1.
6. Black background for blocking any unwanted exposure of surroundings to the camera lens.
7. Selected DWHR systems.
8. Black stove paint to double coat selected DWHR systems.

For the infrared thermography approach, an infrared thermography camera and Type T thermocouples were the key additional pieces of equipment, which were used along with the HXTP. Test method 2 was similar to test method 1, but with the inclusion of thermal camera and thermocouples.

## 4.4 Test Methodology

### 4.4.1 Experimental Set-Up

After the DWHR system was placed on the HXTP, thermocouples were attached on its surface. 8 thermocouples were divided evenly across 56 or 96 coils depending on the drain-side length of the DWHR system. Each thermocouple junction was first coated with thermally conductive paste and then placed on the mains-side coils in a way that the junction was always in contact with the surface. The junction was covered with thermally insulating material and duct tape to secure its position. All the thermocouples were attached on the back side of the DWHR systems, such that a complete unobstructed view of the front side was captured by the thermal camera. Figure 4-6 shows the thermocouples attached on the back side of R3-36. This rear view was not captured by the thermal camera.

**Figure 4-6: R3-36 with attached thermocouples**

In Figure 4-6, it is observed that thermal insulation was applied at the top and bottom of the DWHR system to block any exposure of drain-side pipe to the thermal camera. A problem with the thermal camera was its inability to fix minimum and maximum temperature scales. The temperature scales would increase if a hotter object came under the scope of camera lens. Since the experiments were focused only on the mains-side coils, any excessive variation in the temperature scales was not desirable.

The next step was to cover the background in black to ensure that the camera didn't capture background radiation sources. Figure 4-7 shows the set-up of R3-36 with thermocouples and black opaque background. A square mark was placed on the first coil of each coil set so that they could be easily differentiated.

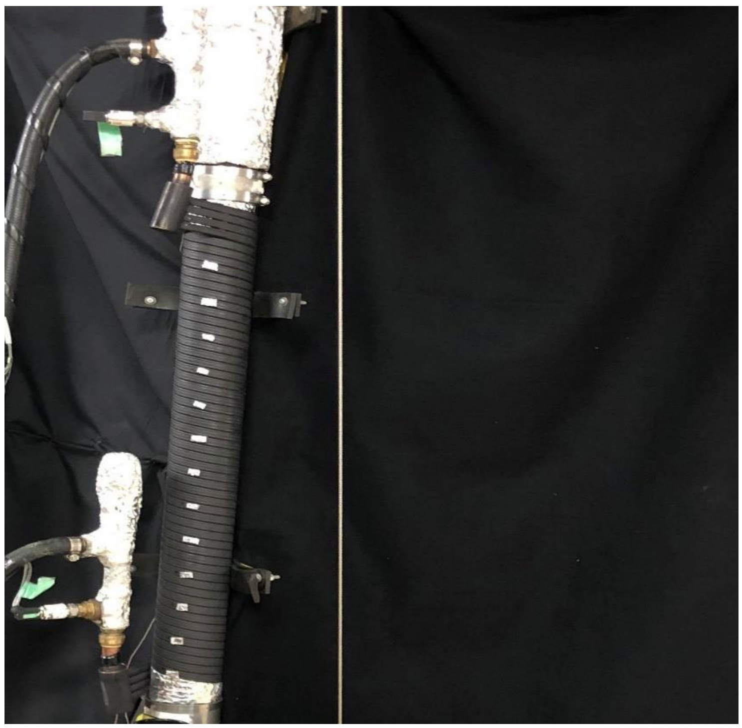

**Figure 4-7: R3-36 with thermocouples and opaque black background**

Finally, the thermal camera was set-up in front of the DWHR system. A lot of attention was given to make sure the images captured by the camera were not blurry and could provide enough details in the thermograms. For R3-36 and R4-36, the distance between the camera lens and system surface was 2.1m. In case of R3-60, this distance increased to 3.4m to ensure that the entire DWHR system was visible in the frame. Figure 4-8 shows the final set-up of R3-60 with thermocouples, opaque black background and the thermal camera placed on a tripod facing the surface.

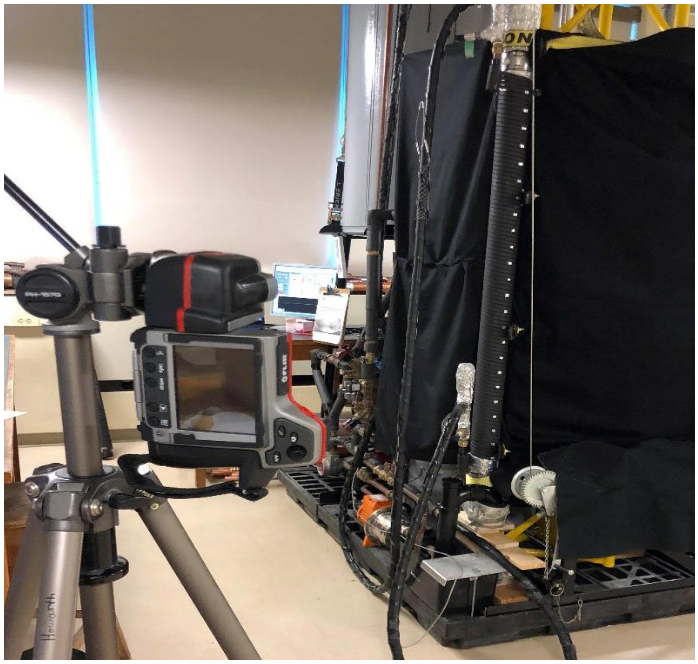

**Figure 4-8: R3-60 final set-up with thermocouples, opaque black background and thermal camera**

### 4.4.2 Standard Testing Procedure

After each DWHR system was prepared as per experimental set-up procedure in Section 4.4.1, the last steps needed for accurate temperature data acquisition are as follows:

1. Set emissivity of camera to the estimated value of 0.862 as shown in Section 4.3.2.
2. Place camera at required distance from the surface as mentioned in Section 4.4.1.
3. Calibrate camera date and time with LabVIEW computer to ensure that the RTDs, thermocouples and the thermal camera would acquire temperature readings at the exact same time. This was important to ensure accuracy between measurement timings for all 3 measuring devices.
4. Ensure complete darkness in the lab by lowering all the blinds and turning the lights off. All of the experiments were performed in complete darkness to generate clear and precise thermograms and temperature readings.
5. Start data acquisition for the RTDs, thermocouples and the thermal camera at exactly the same time when the main pump of the HXTP turns on.
6. Acquire data for 4-5 minutes.

### 4.4.3 Data Storage and Organization

Collected raw data for each test consisted of an excel file each for the RTD and thermocouples which were later combined, a thermal imaging video provided by the camera, a thermal image for each frame, and a CSV temperature file of 320 columns x 240 rows for each frame. Data was collected for about 200 seconds for each test. At the pre-set frame rate of about 6 frames per second, each test provided about 1200 thermal images and CSV files containing temperature readings at each pixel location. All of the raw data including the CSV files is accessible from the STRL at UW. Table 4-2 shows a sample of RTDs and thermocouple raw data collection for one of the tests.

**Table 4-2: Raw RTD and thermocouple data sample for R4-36 at 12LPM**

| Date | GMT -5 hrs | Time (s) | RTD's | | | THERMOCOUPLES | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | $T_{ci}$ ($^0$C) | $T_{co}$ ($^0$C) | LPM | $T_{ci}$ ($^0$C) | T1 ($^0$C) | $T_2$ ($^0$C) | $T_3$ ($^0$C) | $T_4$ ($^0$C) | $T_5$ ($^0$C) | $T_6$ ($^0$C) | $T_7$ ($^0$C) | $T_8$ ($^0$C) | $T_{co}$ ($^0$C) |
| 2018-12-12 | 5:51:19 PM | 1 | 22.36 | 22.57 | 11.75 | 21.83 | 22.09 | 22.17 | 22.32 | 22.40 | 22.42 | 22.46 | 22.52 | 22.59 | 22.38 |
| 2018-12-12 | 5:51:20 PM | 2 | 21.61 | 22.58 | 11.8 | 21.28 | 21.57 | 21.68 | 22.22 | 22.39 | 22.44 | 22.48 | 22.53 | 22.62 | 22.40 |
| 2018-12-12 | 5:51:21 PM | 3 | 20.98 | 22.59 | 11.81 | 20.64 | 20.92 | 21.07 | 21.85 | 22.29 | 22.42 | 22.48 | 22.53 | 22.61 | 22.40 |
| 2018-12-12 | 5:51:22 PM | 4 | 20.28 | 22.59 | 11.77 | 19.96 | 20.19 | 20.42 | 21.36 | 21.99 | 22.35 | 22.50 | 22.57 | 22.64 | 22.42 |
| 2018-12-12 | 5:51:23 PM | 5 | 18.92 | 22.61 | 11.8 | 19.30 | 19.51 | 19.77 | 20.79 | 21.59 | 22.16 | 22.51 | 22.66 | 22.73 | 22.45 |
| ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ |
| ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ |
| 2018-12-12 | 5:54:37 PM | 199 | 10.14 | 19.73 | 12.05 | 10.12 | 10.91 | 12.73 | 13.67 | 14.67 | 17.03 | 18.76 | 20.23 | 21.35 | 19.64 |
| 2018-12-12 | 5:54:38 PM | 200 | 10.13 | 19.73 | 12.08 | 10.13 | 10.90 | 12.72 | 13.67 | 14.66 | 16.99 | 18.71 | 20.19 | 21.34 | 19.62 |

Figure 4-9 and Figure 4-10 shows two samples of the thermal images for R4-36 at 12LPM related to time instants shown in Table 4-2. The camera was pitched vertically to capture the entire DWHR system. For all infrared thermography experiments performed in this thesis, the left side of all thermal images represents the bottom cold mains inlet side of DWHR systems.

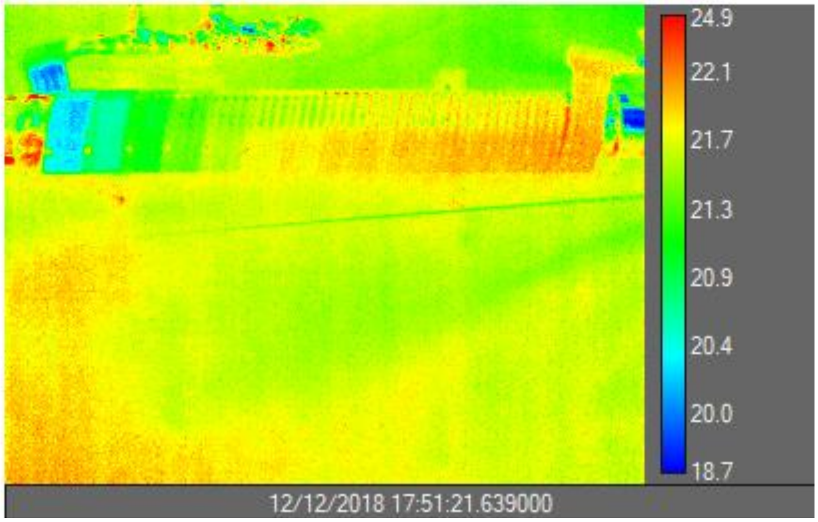

**Figure 4-9: Thermal image sample 1 at 12LPM for R4-36 at 3 seconds ($^oC$)**

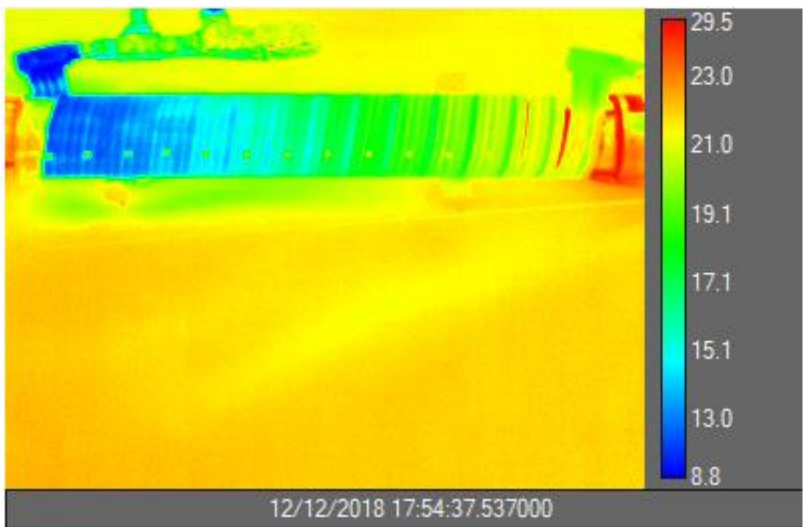

**Figure 4-10: Thermal image sample 2 at 12LPM for R4-36 at 200 seconds ($^oC$)**

The date and time readings for Figure 4-9 and Figure 4-10 match the time instants in Table 4-2. The camera reads temperature in units of $^0$C. It is important to note that the temperature scale for both figures do not match each other. This is because the camera didn't have a fixed temperature scale. It fluctuated based on the intensity of heat sensation from the DWHR system surface.

Figure 4-9 and Figure 4-10 both show different instances of the same test. Mains-side inlet for all the frames was on the left side. The blue coloured lines indicated that water entered at a lower temperature and heated up as it flowed towards the outlet on right side of the frames. The DWHR system was at ambient room temperature of about 22±2$^0$C at the start as is observed in Figure 4-9, but as water flow continued, temperature profile changed throughout the entire length. This is evident in Figure 4-10 where the temperature of the DWHR system surface was different at the entry and exit locations. The colour change indicated heating of the surface and water from inlet to outlet.

### 4.4.4 Time Instants Selection

In transient response experiments, it is extremely challenging to analyze thermal images and CSV files for temperature data extraction at each and every time instant of 1 second. The initial discussion of the transient temperature response of DWHR systems in Chapter 3 shows that most of the change in temperature profiles occurred within the first 50 seconds of the observed DWHR system response. This is the period where temperature readings fluctuated drastically with time. After the initial 50 seconds, the temperature profiles started to reach steady-state and almost negligible change in temperature was observed. Based on that, it was decided to select most of the observational time instants before the first 50 seconds.

Table 4-3 shows the selected time instants for temperature data extraction and analysis. Even though all the raw data is available from STRL, summarized version of raw data for all time instants from all 18 tests is shown in Appendix E.

**Table 4-3: Selected time instants for temperature data extraction**

| Time (seconds) | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 2 | 3 | 5 | 8 | 10 | 15 | 20 | 30 | 50 | 100 | 200 |

Enough temperature data extraction points were selected for the beginning phase of a test in order to capture most of the temperature data in transient part. As time increased, the gap between the selected instants was also increased since less variation in temperature profile was expected.

### 4.4.5 Surface and Water Temperature Extraction from Raw Data

Extraction of temperature readings from the RTDs and thermocouples was straightforward. For all 18 tests, temperature values were picked up from the raw data at each time instants stated in Table 4-3.

Table 4-4 shows the summarized form of the extracted temperature values in $^0C$ for R4-36 at 12LPM at the selected time instants. Columns of the "Thermocouple surface temperature" section in Table 4-4 were derived from the rows of raw data shown in Table 4-2. Summarized form of the extracted temperature values for all cases are shown in Appendix F.

The distance column in Table 4-4 was non-dimensionalized, since all temperature measuring instruments (RTDs, thermocouples and camera measurements at each coil set) were available in different quantities. Mains-side inlet and outlet were marked 0 and 1 as they represented the entry and exit points of DWHR systems. For thermocouples, all divisions in the middle were derived by dividing the entire non-dimensionalized length by 8. It is important to note that all the thermocouples in the middle were placed at equal distances from each other. Divisions for coil sets were derived by dividing non-dimensionalized length by number of coil sets. For example, non-dimensional distance of 0.07 represents coil set 1 and so on.

Table 4-4: R4-36 mains-side temperature values at 12LPM for selected time instants

| | Dist | 1 sec | 2 sec | 3 sec | 5 sec | 8 sec | 10 sec | 15 sec | 20 sec | 30 sec | 50 sec | 100 sec | 200 sec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ESTIMATED WATER TEMPERATURE ($^0$C) | **0.00** | 22.36 | 21.61 | 20.98 | 18.92 | 16.60 | 15.69 | 14.00 | 12.57 | 11.48 | 10.66 | 10.26 | 10.13 |
| | **0.07** | 22.37 | 21.67 | 21.09 | 19.17 | 17.01 | 16.17 | 14.57 | 13.20 | 12.12 | 11.29 | 10.90 | 10.77 |
| | **0.13** | 22.39 | 21.74 | 21.19 | 19.41 | 17.42 | 16.64 | 15.15 | 13.83 | 12.77 | 11.92 | 11.54 | 11.41 |
| | **0.20** | 22.40 | 21.80 | 21.30 | 19.66 | 17.83 | 17.12 | 15.72 | 14.46 | 13.41 | 12.55 | 12.18 | 12.05 |
| | **0.27** | 22.42 | 21.87 | 21.41 | 19.90 | 18.25 | 17.60 | 16.30 | 15.10 | 14.05 | 13.19 | 12.81 | 12.69 |
| | **0.33** | 22.43 | 21.93 | 21.52 | 20.15 | 18.66 | 18.07 | 16.87 | 15.73 | 14.69 | 13.82 | 13.45 | 13.33 |
| | **0.40** | 22.44 | 22.00 | 21.62 | 20.40 | 19.07 | 18.55 | 17.44 | 16.36 | 15.34 | 14.45 | 14.09 | 13.97 |
| | **0.47** | 22.46 | 22.06 | 21.73 | 20.64 | 19.48 | 19.03 | 18.02 | 16.99 | 15.98 | 15.08 | 14.73 | 14.61 |
| | **0.53** | 22.47 | 22.13 | 21.84 | 20.89 | 19.89 | 19.50 | 18.59 | 17.62 | 16.62 | 15.71 | 15.37 | 15.25 |
| | **0.60** | 22.49 | 22.19 | 21.95 | 21.13 | 20.30 | 19.98 | 19.17 | 18.25 | 17.26 | 16.34 | 16.01 | 15.89 |
| | **0.67** | 22.50 | 22.26 | 22.05 | 21.38 | 20.71 | 20.46 | 19.74 | 18.88 | 17.91 | 16.97 | 16.65 | 16.53 |
| | **0.73** | 22.51 | 22.32 | 22.16 | 21.63 | 21.12 | 20.93 | 20.31 | 19.51 | 18.55 | 17.60 | 17.29 | 17.17 |
| | **0.80** | 22.53 | 22.39 | 22.27 | 21.87 | 21.54 | 21.41 | 20.89 | 20.15 | 19.19 | 18.24 | 17.92 | 17.81 |
| | **0.87** | 22.54 | 22.45 | 22.38 | 22.12 | 21.95 | 21.89 | 21.46 | 20.78 | 19.83 | 18.87 | 18.56 | 18.45 |
| | **0.93** | 22.56 | 22.52 | 22.48 | 22.36 | 22.36 | 22.36 | 22.04 | 21.41 | 20.48 | 19.50 | 19.20 | 19.09 |
| | **1.00** | 22.57 | 22.58 | 22.59 | 22.61 | 22.77 | 22.84 | 22.61 | 22.04 | 21.12 | 20.13 | 19.84 | 19.73 |
| THERMOCOUPLE SURFACE TEMPERATURE ($^0$C) | **0.00** | 21.83 | 21.28 | 20.64 | 19.30 | 17.45 | 16.37 | 14.34 | 13.07 | 11.75 | 10.80 | 10.36 | 10.13 |
| | **0.11** | 22.09 | 21.57 | 20.92 | 19.51 | 17.61 | 16.54 | 14.63 | 13.46 | 12.31 | 11.53 | 11.11 | 10.90 |
| | **0.22** | 22.17 | 21.68 | 21.07 | 19.77 | 18.12 | 17.35 | 15.82 | 14.91 | 14.08 | 13.53 | 13.06 | 12.72 |
| | **0.33** | 22.32 | 22.22 | 21.85 | 20.79 | 19.16 | 18.37 | 16.84 | 15.92 | 15.06 | 14.55 | 14.06 | 13.67 |
| | **0.44** | 22.40 | 22.39 | 22.29 | 21.59 | 20.18 | 19.41 | 17.92 | 16.97 | 16.03 | 15.51 | 15.03 | 14.66 |
| | **0.56** | 22.42 | 22.44 | 22.42 | 22.16 | 21.38 | 20.90 | 19.80 | 19.08 | 18.39 | 17.94 | 17.51 | 16.99 |
| | **0.67** | 22.46 | 22.48 | 22.48 | 22.51 | 22.24 | 21.99 | 21.22 | 20.63 | 19.99 | 19.53 | 19.21 | 18.71 |
| | **0.78** | 22.52 | 22.53 | 22.53 | 22.66 | 22.84 | 22.80 | 22.37 | 21.96 | 21.31 | 20.85 | 20.61 | 20.19 |
| | **0.89** | 22.59 | 22.62 | 22.61 | 22.73 | 23.05 | 23.15 | 23.13 | 22.85 | 22.19 | 21.69 | 21.47 | 21.34 |
| | **1.00** | 22.38 | 22.40 | 22.40 | 22.45 | 22.64 | 22.63 | 22.27 | 21.75 | 20.83 | 20.01 | 19.80 | 19.62 |
| COILSET SURFACE TEMPERATURE ($^0$C) | **0.00** | 22.36 | 21.61 | 20.98 | 18.92 | 16.60 | 15.69 | 14.00 | 12.57 | 11.48 | 10.66 | 10.26 | 10.13 |
| | **0.07** | 21.44 | 20.95 | 20.33 | 18.99 | 17.29 | 16.42 | 15.01 | 14.01 | 13.03 | 12.38 | 12.17 | 12.02 |
| | **0.13** | 21.56 | 21.24 | 20.67 | 19.34 | 17.55 | 16.64 | 15.21 | 14.16 | 13.11 | 12.42 | 12.25 | 12.12 |
| | **0.20** | 21.62 | 21.50 | 21.09 | 19.91 | 18.25 | 17.37 | 16.03 | 15.03 | 13.99 | 13.36 | 13.20 | 13.05 |
| | **0.27** | 21.64 | 21.64 | 21.37 | 20.32 | 18.72 | 17.83 | 16.53 | 15.53 | 14.46 | 13.79 | 13.63 | 13.55 |
| | **0.33** | 21.62 | 21.63 | 21.54 | 20.70 | 19.21 | 18.38 | 17.12 | 16.15 | 15.09 | 14.42 | 14.25 | 14.17 |
| | **0.40** | 21.65 | 21.67 | 21.67 | 21.12 | 19.86 | 19.11 | 17.98 | 17.06 | 16.01 | 15.37 | 15.21 | 15.08 |
| | **0.47** | 21.67 | 21.70 | 21.74 | 21.43 | 20.40 | 19.71 | 18.68 | 17.79 | 16.73 | 16.09 | 15.93 | 15.82 |
| | **0.53** | 21.69 | 21.73 | 21.78 | 21.70 | 20.95 | 20.38 | 19.50 | 18.67 | 17.62 | 16.98 | 16.88 | 16.75 |
| | **0.60** | 21.72 | 21.76 | 21.82 | 21.87 | 21.39 | 20.91 | 20.18 | 19.41 | 18.40 | 17.79 | 17.69 | 17.58 |
| | **0.67** | 21.72 | 21.76 | 21.83 | 21.95 | 21.76 | 21.41 | 20.84 | 20.16 | 19.21 | 18.64 | 18.59 | 18.47 |
| | **0.73** | 21.73 | 21.76 | 21.84 | 21.98 | 22.05 | 21.81 | 21.42 | 20.82 | 19.92 | 19.38 | 19.35 | 19.26 |
| | **0.80** | 21.75 | 21.80 | 21.87 | 22.06 | 22.38 | 22.27 | 22.03 | 21.49 | 20.62 | 20.11 | 20.07 | 19.92 |
| | **0.87** | 21.80 | 21.85 | 21.92 | 22.10 | 22.59 | 22.62 | 22.54 | 22.05 | 21.20 | 20.69 | 20.66 | 20.51 |
| | **0.93** | 21.81 | 21.87 | 21.94 | 22.08 | 22.70 | 22.86 | 22.98 | 22.57 | 21.81 | 21.30 | 21.28 | 21.16 |
| | **1.00** | 22.57 | 22.58 | 22.59 | 22.61 | 22.77 | 22.84 | 22.61 | 22.04 | 21.12 | 20.13 | 19.84 | 19.73 |

Deriving surface temperatures at the coil sets from the CSV files was more challenging than for the RTDs and thermocouples. Since the ResearchIR software gave locations for each pixel on the frames, temperatures for the entire surface of the DWHR system facing the camera were known. Even on the coil set surface, temperature readings were not constant. There were slight variations in temperature for the entire coil sets. In order to simplify this problem of more data, an average of temperature readings for each coil set was taken in the middle of the DWHR system by assuming a uniform surface temperature. This assumption of a uniform surface temperature is validated in Section 4.4.6. Figure 4-11 shows a schematic of the camera frame, and approximate coil set temperature measurement locations in the middle of the DWHR system.

Since the camera had a frame rate of 6 frames per second, average of temperature pixels in the centreline of DWHR system were taken throughout all 6 frames for each coil set. The dark lines on Figure 4-11 shows the approximate locations of targeted pixels for each test. A script was programmed in MATLAB in order to streamline the process of estimating temperature in the middle. The inputs for the script were frame numbers and coil set pixel locations for each time instant. Appendix G shows the script used for temperature extraction from camera CSV files. All of the averaged surface temperature readings are represented in the "Coil set surface temperature" rows of Table 4-4.

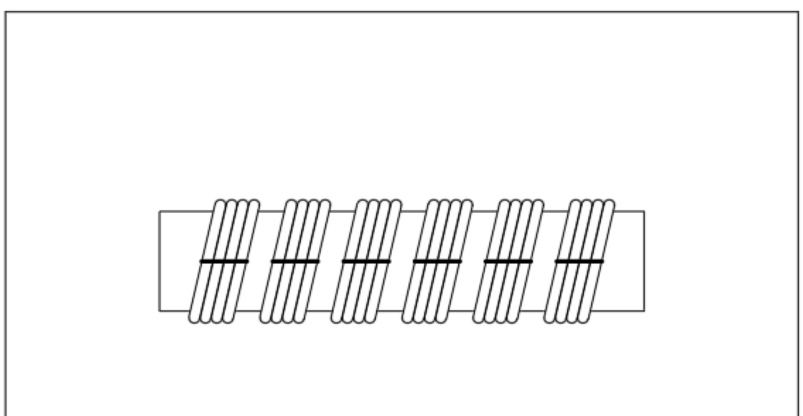

**Figure 4-11: Schematic of pixel selection for coil set temperature determination**

### 4.4.6 Isothermal Surface Temperature Validation at Coil Sets

The assumption of uniform surface temperature across each coil set made in Section 4.4.5, was validated using the principle of lumped capacitance method. It enabled the assumption of a solid surface to have a spatially uniform temperature and negligible temperature gradients [41]. The critical parameter for lumped capacitance is Biot number ($\mathrm{Bi}$) which is the ratio of surface convection to internal conduction over the solid body of interest and can be estimated by Equation 4.4 as:

$$\mathrm{Bi} = \frac{\mathrm{hL_c}}{\mathrm{k}} \tag{4.4}$$

This equation was applied on each coil set for all time instants and tests to justify the use of a single averaged surface temperature point. In the above equation, $\mathrm{h}$ represented the convection coefficient of water flowing through each coil set, which was calculated based on the estimated water temperature and flowrate. $\mathrm{k_{solid}}$ is the thermal conductivity of copper which was assumed to be constant at 401 W/mK. The last variable was characteristic length which represented the ratio of volume to surface area of coils.

If $\mathrm{Bi} << 1$, the temperature gradients within the solid were small and the assumption of uniform surface temperature would be reasonable [41]. Hence, the first step performed was to calculate $\mathrm{Bi}$ for all the tests and time instants at each coil set. The only 2 parameters that were needed to be calculated in Equation 4.4 were $\mathrm{L_c}$ and $\mathrm{h}$ which are shown below.

It is important to note that the calculations of any parameters like $\mathrm{h}$, $\mathrm{Bi}$, $\mathrm{d_h}$ etc. were performed on each coil and not the coil set. This was the case because it was much easier to determine the internal dimensions of the coils rather than coil sets. Hence, all the parameters calculated in Section 4.4.6 will be based on coil basis.

#### 4.4.6.1 Estimation of Characteristic Length and Hydraulic Diameter of Rectangular Helical Coils

There are a limited number of convection correlations when it comes to the flow in helical coils. More specifically, the correlations that are available apply only to circular helical coils. Hence, in order to be able to apply any correlations to the rectangular helical coils, the most important parameter needed was the hydraulic diameter $\mathrm{d_h}$. The overall cross-sectional schematic of any DWHR system and coil dimensions are shown in Figure 4-12 and Figure 4-13. All dimensional data for the 3 DWHR systems used in this experiment and the calculated $\mathrm{d_h}$ are shown in Table 4-5. The parameter $d_h$ was calculated only for R4-36 for demonstration purposes and is shown below.

$$a = a_o - [2(\text{wall thickness})] = 4.9\text{mm}$$

$$b = b_o - [2(\text{wall thickness})] = 9.67\text{mm}$$

$$d_h = \frac{4A_c}{P}$$

$$= \frac{(4ab)}{2(a+b)} = 6.50\text{mm}$$

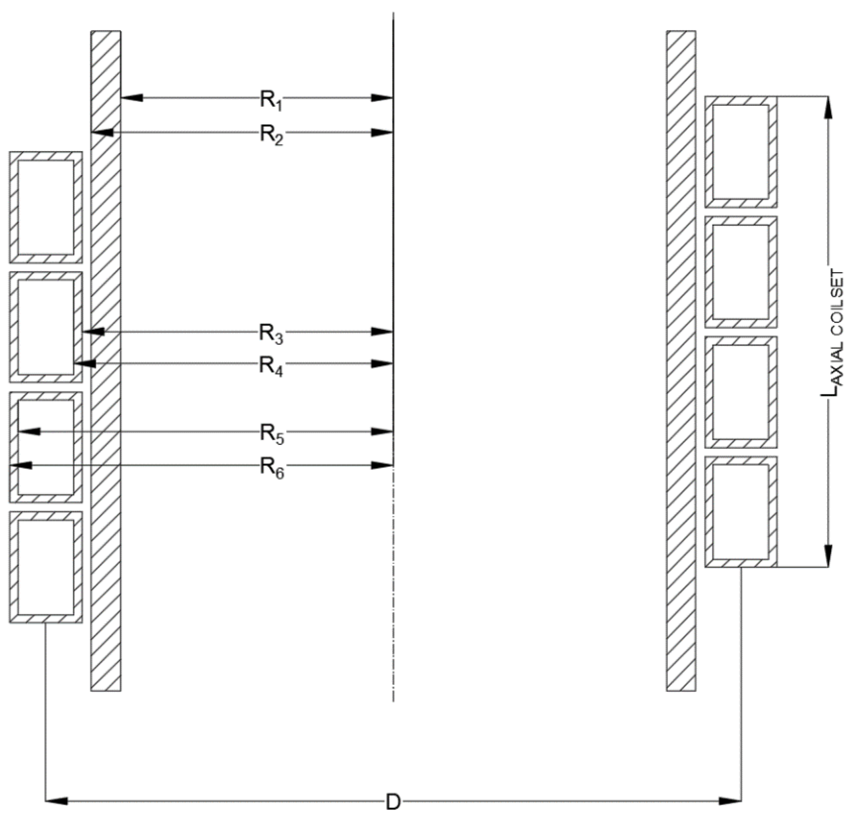


**Figure 4-12: Cross-sectional schematic of DWHR system**

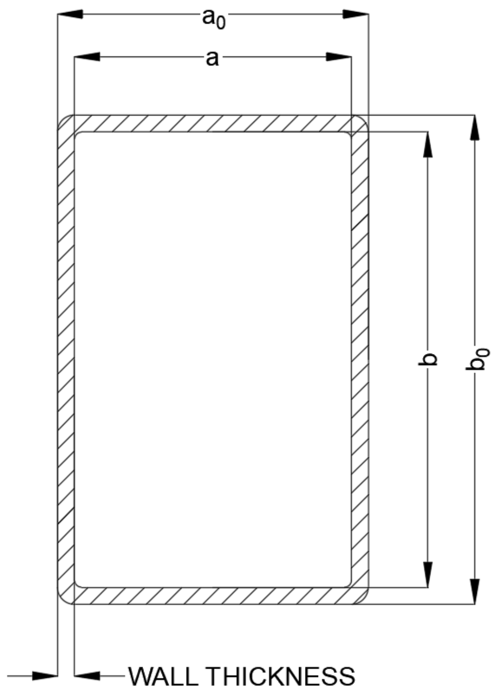


**Figure 4-13: Mains-side coils dimensions schematic**

**Table 4-5: Key dimensions of DWHR systems and mains-side coils**

| | R 3-36 | R 3-60 | R 4-36 |
|---|---|---|---|
| **R1 (mm)** | 38.66 | 38.17 | 50.30 |
| **R2 (mm)** | 39.49 | 39.67 | 52.64 |
| **R3 (mm)** | 39.54 | 39.72 | 52.69 |
| **R4 (mm)** | 41.06 | 41.24 | 54.21 |
| **R5 (mm)** | 44.10 | 44.47 | 58.70 |
| **R6 (mm)** | 45.62 | 45.99 | 60.22 |
| **$L_{axial\ Coilset}$ (mm)** | 57.61 | 57.61 | 55.80 |
| **$L_{coil\ circumference}$ (mm)** | 284.00 | 284.00 | 344.00 |
| **$a_O$ (mm)** | 7.23 | 7.23 | 7.94 |
| **$b_O$ (mm)** | 13.43 | 13.43 | 12.71 |
| **Wall thickness (mm)** | 1.52 | 1.52 | 1.52 |
| **a (mm)** | 4.19 | 4.19 | 4.90 |
| **b (mm)** | 10.39 | 10.39 | 9.67 |
| **D (mm)** | 84.01 | 84.76 | 112.50 |
| **$d_h$ (mm)** | 5.97 | 5.97 | 6.50 |

#### 4.4.6.2 Estimation of Laminar Convection Coefficients and Biot Number

It was unknown whether the water flow in the mains-side coils was laminar or turbulent. Hence, 2 different h values named as $h_{laminar}$ and $h_{turbulent}$ were calculated using the convection correlations for both laminar and turbulent flow. Only a single sample calculation is presented for $h_{laminar}$ and $h_{turbulent}$ for R4-36 at the flowrate of 12LPM during the 200 second time instant on the 4$^{th}$ coil set. Coil set 4 had non dimensionalized length of 0.27 when cross referenced with Table 4-4**.** This was called as the "sample calculation scenario" and was also used in the energy balance section of this thesis.

The laminar convection coefficient for the specified coil set was estimated using the correlation provided by Manlapaz and Churchill [42] which shows that:

$$h_{laminar} = (0.913)\left(\frac{k_{water}}{d_h}\right)(De^{0.476})(Pr^{0.2}) \tag{4.5}$$

Where De is the Dean's number which gives information about the secondary fluid motion in curved pipes and is estimated as [43]:

$$De = Re_D\sqrt{\frac{d_h}{D}} \tag{4.6}$$

$Re_D$ represents the Reynolds number of water flow in the coils and is calculated as [44]:

$$Re_D = \frac{\rho V d_h}{\mu} \tag{4.7}$$

Where V is the velocity of water in the coils. Since all the properties were being evaluated at the coils, the flowrate was divided by 4 before it was converted into fluid velocity. Substituting Equation 4.6 and 4.7 into Equation 4.5 yielded the final expression that was evaluated for estimating $h_{laminar}$.

$$h_{laminar} = [0.913]\left[\frac{k_{water}}{d_h}\right]\left[\left(\frac{\rho V d_h}{\mu}\right)\left(\sqrt{\frac{d_h}{D}}\right)\right]^{0.476}[Pr^{0.2}] \tag{4.8}$$

All of the variables in Equation 4.8, except $d_h$ and D represented water properties at a certain fixed temperature. From Table 4-4, it was observed that for the calculation parameters shown above, $T_{water}$ was estimated to be about 12.69$^0$C or 285.84K, at non-dimensionalized coil set distance of 0.27. All of the water properties were linearly interpolated at the specified temperature from the heat transfer textbook [28] and are summarized in Table 4-6.

**Table 4-6: Water properties for sample calculation scenario**

| Water properties | |
|---|---|
| ρ (kg/m$^3$) | 999.83 |
| $C_p$ (kJ/kgK) | 4.1882 |
| μ (Ns/m$^2$) | 0.0012 |
| k (W/mK) | 0.5913 |
| Pr | 8.6000 |

The only remaining parameter that had to be evaluated was the fluid velocity V in the coils. Summarized raw data in Table 4-2 at the selected time instants for the sample calculation scenario showed that the CSA flowrate across the DWHR system at 200 seconds was 12.08LPM. Since everything related to the convection coefficients was being calculated on a coil basis, the volumetric flowrate was divided by 4 assuming that the flowrate was equal in all coils of the coil sets. Hence, the volumetric flowrate per coil was about 3.02LPM. This was converted into fluid velocity and then used for estimating $h_{laminar}$ as shown below. It is important to note that "ab" represented the cross-sectional area of the rectangular coils in $m^2$.

$$V = \left(3.02\,\frac{L}{min}\right)\left(\frac{1\ min}{60\ s}\right)\left(\frac{1\ m^3}{1000\ L}\right)\left(\frac{1}{ab}\right) = 1.062\,\frac{m}{s}$$

All of the estimated parameters were finally substituted into Equation 4.8, which yielded $h_{laminar}$ for this specific case to be 3992.28 W/m$^2$K. This calculated $h_{laminar}$ was substituted into Equation 4.9 to estimate $Bi_{laminar}$.

$$Bi_{laminar} = \frac{h_{laminar} L_c}{k_{copper}} \tag{4.9}$$

It is important to note that the calculated h value would be constant through each coil of the specific coil set. The last unknown parameter to calculate Biot number was the characteristic length $L_c$, which is the ratio of volume to surface area of the solid body of interest [41]. Since the dimensions of DWHR systems were already known from Table 4-5, the volume and surface area were easily calculated at per coil basis and converted to $L_c$.

$$L_c = \frac{Vol}{Surface\ Area} = \frac{abL_{coil\ circumference}}{(Perimeter_{coil})(L_{coil\ circumference})} = \frac{abL_{coil\ circumference}}{2(a+b)L_{coil\ circumference}}$$

$$L_c = \frac{ab}{2(a+b)} = 0.001626m$$

At this point, all the known parameters were plugged into Equation 4.9 in order to determine $Bi_{laminar}$ which is estimated as follows:

$$Bi_{laminar} = \frac{(3992.28)(0.001626)}{(401)} = 0.01619$$

Since 0.01619 << 1, the approximation of uniform surface temperature could be assumed for this case. $Bi_{laminar}$ for all the tests was found to be significantly less than 1 which suggested that the approximation of uniform surface temperature was valid. The laminar convective heat transfer coefficients and Biot number values for all coil sets are shown in the next section. It is important to note that the calculated values for laminar case shown in Section 4.4.6.2 might be slightly different from the ones shown in Table 4-7 due to rounding errors. Very similar approach was used for the turbulent case which is shown in the next section. Both laminar and turbulent calculations for the sample calculation scenario are tabulated together in the next section.

#### 4.4.6.3 Estimation of Turbulent Convection Coefficients and Biot Number

The correlation used to estimate $h_{turbulent}$ was provided by Rogers and Mayhew and is shown in Equation 4.10 [45]. Same time instants and fluid properties were used as for the laminar section. The only difference is the actual correlation itself.

$$h_{turbulent} = [0.023]\left[\frac{k_{water}}{d_h}\right]\left[\frac{\rho V d_h}{\mu}\right]^{0.8}[Pr^{0.4}]\left[1 + 3.4\left(\frac{d_h}{D}\right)\right] \quad (4.10)$$

Evaluation of all the variables yielded $h_{turbulent}$ to be 6027.55 W/m$^2$K. Moreover, $Bi_{turbulent}$ was found using Equation 4.9 by using $h_{turbulent}$ instead of $h_{laminar}$. $Bi_{turbulent}$ was evaluated as 0.02444 which was significantly smaller than 1. Since all of the estimated laminar and turbulent Biot numbers were significantly smaller than 1, it was safe to assume isothermal surface temperature for coil sets for all the experiments. Table 4-7 shows the calculated laminar and turbulent convective heat transfer coefficients and Biot numbers of all coil sets in the sample calculation scenario.

**Table 4-7: Heat transfer coefficients and Biot number approximations at sample calculation scenario**

| Coilset | $h_{lam}$ (W/m²K) | $Bi_{lam}$ | $h_{turb}$ (W/m²K) | $Bi_{turb}$ |
|---|---|---|---|---|
| **1** | 3916 | 0.0159 | 5879 | 0.0238 |
| **2** | 3944 | 0.0160 | 5935 | 0.0241 |
| **3** | 3970 | 0.0161 | 5987 | 0.0243 |
| **4** | 3991 | 0.0162 | 6027 | 0.0244 |
| **5** | 4013 | 0.0163 | 6066 | 0.0246 |
| **6** | 4034 | 0.0164 | 6107 | 0.0248 |
| **7** | 4056 | 0.0164 | 6148 | 0.0249 |
| **8** | 4078 | 0.0165 | 6189 | 0.0251 |
| **9** | 4101 | 0.0166 | 6231 | 0.0253 |
| **10** | 4124 | 0.0167 | 6274 | 0.0254 |
| **11** | 4146 | 0.0168 | 6317 | 0.0256 |
| **12** | 4168 | 0.0169 | 6360 | 0.0258 |
| **13** | 4191 | 0.0170 | 6403 | 0.0260 |
| **14** | 4214 | 0.0171 | 6448 | 0.0261 |

The MATLAB script used to interpolate water properties and calculate $h$ and $Bi$ for both the laminar and turbulent cases is shown in Appendix K.

# Chapter 5 Analysis, Results and Discussions for Test Method 2

## 5.1 Results Declaration for Test Method 2

One of the most important points to be stated before data analysis is that since similar trends were observed for all experiments, all of the sample plots and tables shown in this chapter are representative of the entire data set. Only a single case of tables and plots were presented in this chapter. The remaining tables, plots and extra reference materials for all test cases can be accessed from the Appendix section of this thesis.

Unlike test method 1 where the energy balance was applied to the entire DWHR system, in this case energy balance calculations were performed individually on each coil set before adding the results.

## 5.2 Results for Test Method 2

### 5.2.1 Temperature Profile Plots across DWHR System Length at different Time Instants

The temperature plots for R4-36 at 12LPM will be shown in this section. The plots shown in this section serve the sole purpose of commenting on temperature profile observed across the DWHR system length for all 3 systems. These plots are relevant to the temperature data shown in Table 4-2 and Table 4-4. The plots of other cases are shown in Appendix I.

Figure 5-1 shows the temperature profile plots for R4-36 at 12LPM for selected time intervals. It shows the temperature readings from RTDs, thermocouples and camera at different time instants. The only true readings for water temperature were given by the RTDs. Both the thermocouples and infrared camera read the DWHR system surface temperature. Hence, the key purpose of this exercise was to understand how the mains water temperature changed across the DWHR system length, as it travelled through the mains-side coils.

It was observed that the temperature profiles started almost as flat horizontal lines at the start of the test, since water in the coil sets and the surface were at constant ambient temperature conditions. As the test proceeded, the water temperature at the mains-side inlet started to drop as the mains water entered the coils. This is evident from the vertical drop in Figure 5-1 at the non-dimensionalized length of 0 on the inlet side of DWHR system. Moreover, as the drain water reached the mains inlet side of the DWHR system, it had already lost most of its thermal energy and hence didn't provide enough heating to the mains water.

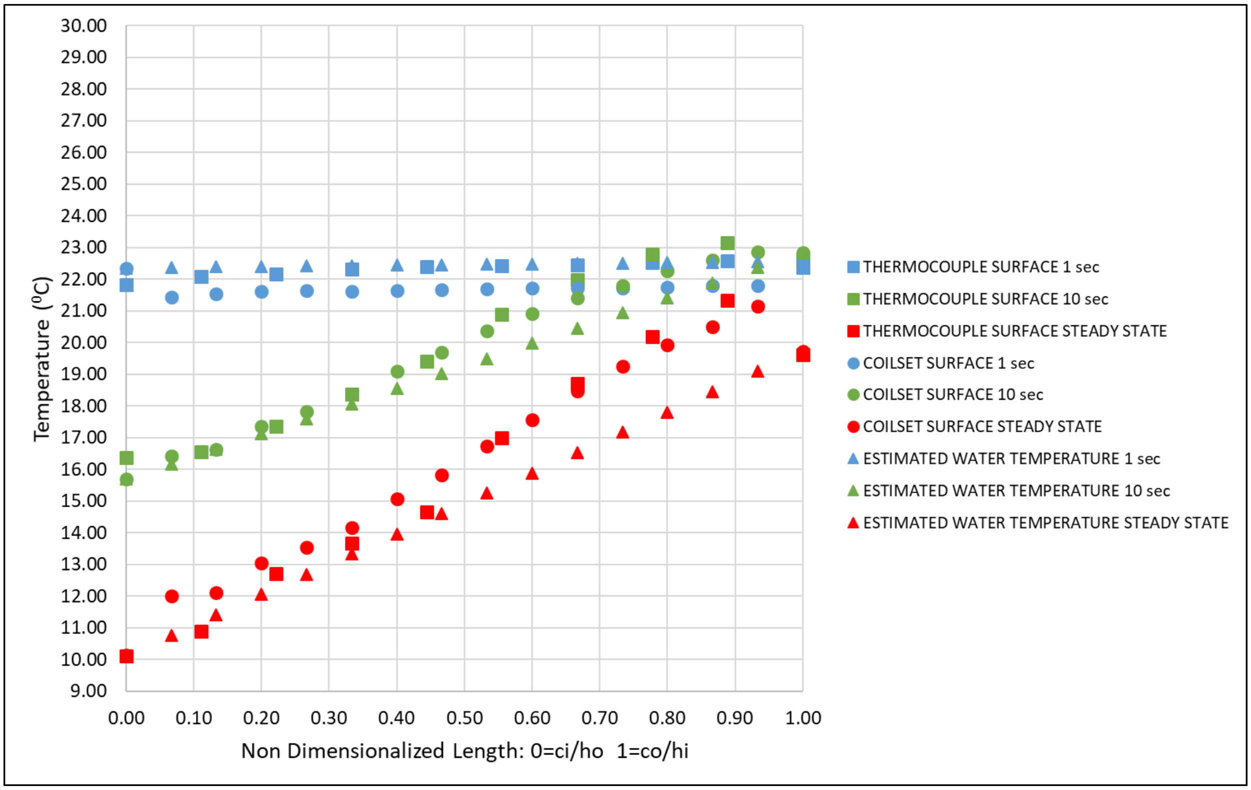


**Figure 5-1: Mains-side temperature profiles at different time instants for R4-36 at 12LPM**

The water temperature at the mains-side outlet didn't drop as much as the inlet side. Since the hot drain water entered the drain-side inlet of the DWHR system near the mains-side outlet and supplied most heat in that zone, the drop was much smaller on the mains-side outlet water temperature ($T_{co}$).

It is also evident from Figure 5-1 that both thermocouples and camera temperature readings (circular markers) were very similar near the inlet and outlet points. The temperature profile finally took a positive slope across the non-dimensionalized length indicating heating of the DWHR system from mains inlet to mains outlet side. The surface temperature readings given by the thermocouples and the camera were relatively similar and mostly followed the same pattern.

A linear increase in the surface temperature was observed to the end of DWHR system length where it dropped to the actual water temperature. This linear increase in the coil set surface temperature suggested that the mains water inside the coil sets gained heat in the same pattern as well. The camera was giving a higher temperature reading due to the effects of conduction in copper coil sets. Since the RTDs were the only source of water temperature and the nature of increase of coil set surface temperature was determined to be linear, it was assumed that the water temperature throughout the DWHR system across all coil sets would also increase linearly. Hence, a straight line was drawn between the RTD inlet and outlet temperatures for each time instant of all 18 tests that were conducted. Water temperatures across each coil set were estimated from the assumed linear behaviour. Figure 5-1 also shows the estimated water temperatures across each coil sets marked with a triangular marker. "Estimated water temperature" section of Table 4-4 shows the approximated readings for water temperature inside the coil sets.

The drop in the surface temperature at the end of the coils was due to the impact of warmer drain-side pipe. Heat conduction from the drain-side pipe to the coils induced a higher temperature reading. This is evident from the cold mains outlet section in Figure 4-10. Surface temperature of the coils were higher just before they lost contact with drain-side pipe. After the contact was lost, the surface temperature dropped near-to the actual water temperature because of negligible conduction from the drain-side pipe to the water coils. The bumps near the ends in Figure 5-1 for 200 seconds time instant is a good indication of surface temperatures falling near water temperatures after the drain-side pipe contact is lost.

Table 4-4 was also used to determine the surface and water temperature change across each coil set throughout the test duration which is shown in Figure 5-2 and Figure 5-3 for the case of R4-36 at 12LPM. All other plots are shown in Appendix J.

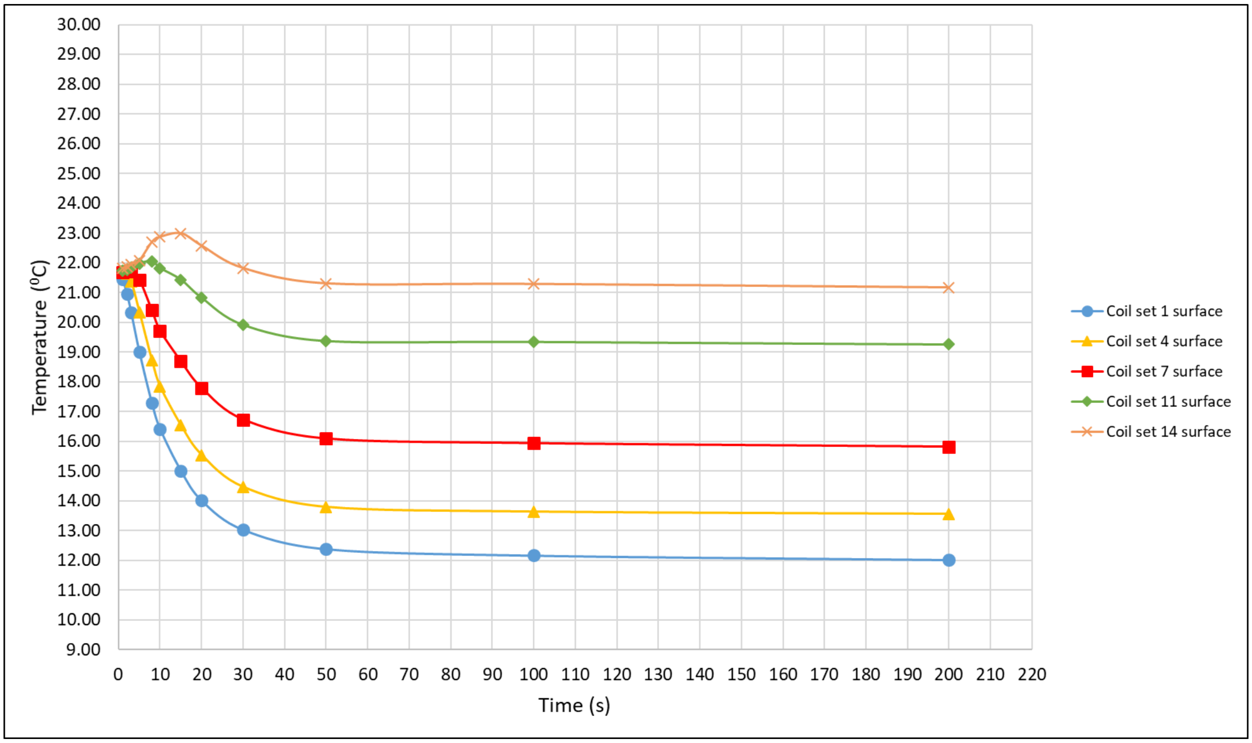


**Figure 5-2: Coil set surface temperature profiles at different time instants for R4-36 12LPM**

Based on Figure 5-2, the coil sets were almost isothermal at the start of the test since the temperature profiles diverge from a single temperature point. Coil set 1 was closest to the mains inlet. The coil set number increased as water approached the mains-side outlet, thus making coil set 14 just before the exit from the mains-side.

Figure 5-2 shows that the entry coil sets registered the maximum change in surface temperature as was observed from the temperature drop. The change in surface temperature decreased as the mains water travelled through the coil sets. This was an indication that the drain water had the least impact at the bottom of the DWHR system, where the surface temperature was the coldest. Hence, the warmer the drain water was, the more impact it would have on the coil surface.

The bumps at the beginning phase of the test were due to the introduction of warmer gray water in the drain-side pipe which resulted in a sharp increase in surface temperature. As the mains water started to flow in the coils, the surface temperature also began to drop and the bump was diminished. The bumps were visible more on the coils which were located towards the mains-side outlet (higher coil set numbers) as it was the zone where drain water was the hottest.

As stated before, the linear increase in the coil set temperatures have suggested that mains water temperature may also have gained thermal energy in the similar manner. It was assumed that the measured linear like surface temperature profile of the coil sets was the offset of water profile in the respective coil sets. Even though this discussion section is focused mainly on the coil set surface temperatures, the reasoning provided could be applied to water in the respective coil sets. Figure 5-3 shows the estimated water temperature profile in the coil sets based on the linear assumption. Comparing to Figure 5-2, it was observed that the water temperature profiles behaved in the same way as the coil set surface temperature profiles. It was observed that the water temperature was slightly lower in each coil set when compared to the surface temperature for the specific coil set, which stated that mains water was getting heated as it flowed upwards toward the mains-side outlet.

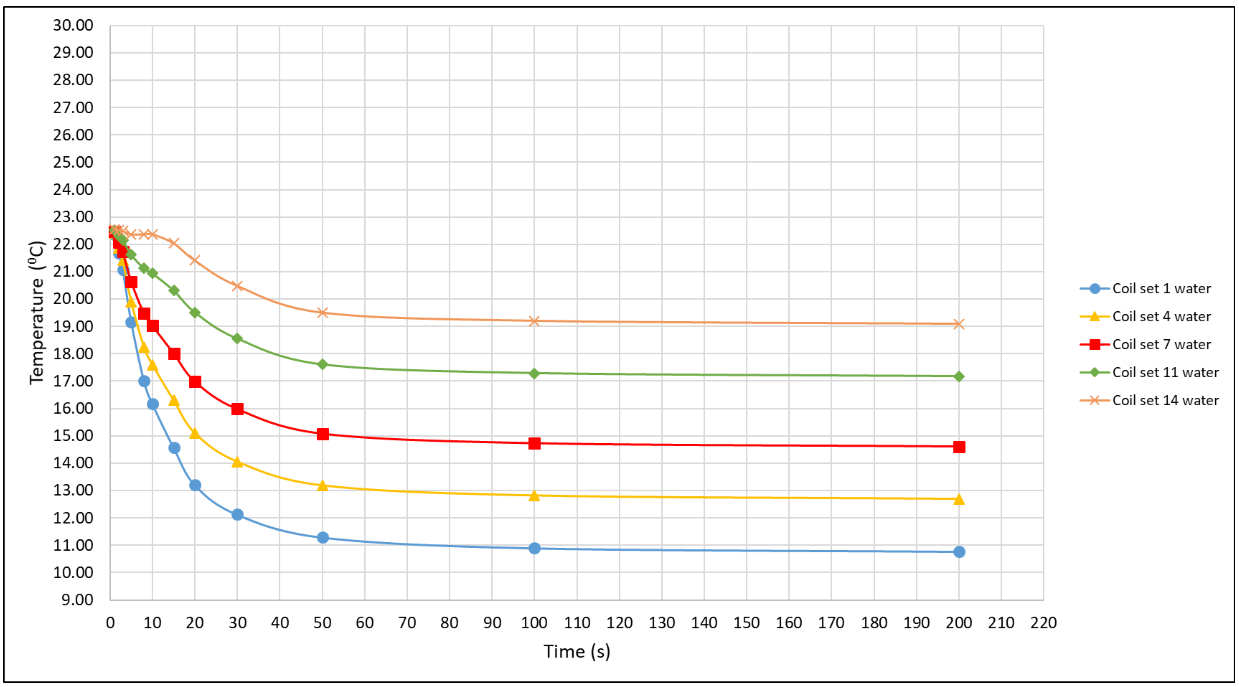


**Figure 5-3: Estimated coil set water temperature profiles at different time instants for R4-36 at 12LPM**

Figure 5-2 and Figure 5-3 shows that the magnitude of drop in surface temperature for the entry coil sets were similar due to the fixed mains inlet water conditions. This was not the case for the exit coil sets. In that case, the change in surface temperature was highly dependent on the DWHR system length and flowrate. When comparing coil set temperature profiles for R3-36 and R3-60, it was noticed that longer DWHR systems induced more heat transfer from drain water, because the mains water had to travel a longer distance until it reached its exit point.

Secondly, for longer DWHR systems, more surface area was available for heat transfer. Since the mains water was retaining more heat near its exit point, this was the reason why the surface temperature of the exit coil sets was warmer than the ambient conditions once quasi-steady-state like conditions were reached.

The surface area to induce heat transfer also increased with increasing the drain-side diameter of DWHR systems, but it didn't have a significant impact on the exiting coil sets surface temperatures. For both R3-36 and R4-36, very similar surface temperature profiles were observed. This could be a result of uneven drain-side wetting of R4-36 due to its larger diameter and surface area [5]. If the annular film was not formed completely on the drain-side, there would not be sufficient heat transfer to the mains-side water and coils.

Flowrate had a strong impact on the exiting coil set temperatures for R3-36 and R3-60 but a weak impact on R4-36. A comparison of coil set and water temperature profiles showed that as the flowrate decreased, the exit coil sets heated up more as compared to the higher flowrates for both R3-36 and R3-60. This was because at lower flowrates, water in the mains-side coils took a longer time period to exit the coils of DWHR system. This prolonged delay induced more heat transfer from the warmer drain-side water. In other words, the mains water in coils got more time to collect extra energy from the warmer drain water.

The wider drain-side diameter of R4-36 required complete drain-side wetting in order to maximize the heat transfer. It has been proven that for 4" drain-side diameter DWHR systems, a flowrate of 5.5LPM only achieved partial wetting [5]. All the steady-state tests conducted by Beentjes et al. started with a really high flowrate in order to achieve full wetting of the drain-side pipe. Thereafter, the flowrates were dropped as desired to estimate effectiveness. For all the transient experiments conducted in this thesis, the flowrate was adjusted before each test as mentioned in Section 2.5.1. Hence, there is no evidence that for the 4" drain-side diameter DWHR systems, complete wetting was achieved even for higher flowrates. This was one of the reasons why flowrate seems to have a weak impact on the surface temperature of the exit coil sets for R4-36.

### 5.2.2 Energy Balance on Selected DWHR Systems

#### 5.2.2.1 Energy Balance Overview

So far, the only useful information derived consisted of surface and water temperature profiles across the mains-side of the DWHR system. Temperature profiles behaved differently for all coil sets. Even though the coil set temperature profiles reached steady-state around the same time, there were still slight variations in the time to reach steady-state. This was because all the coil sets had slightly different thermal time response from each other. Hence, the conclusions derived about temperature response would not provide any useful insight about estimating the steady-state time response of DWHR systems. More information regarding the DWHR system behaviour was required in order to estimate that parameter. In other words, all coil set temperature profiles must be combined in a way such that the overall behaviour of the DWHR system could be analyzed.

Overall heat transfer to the mains-side water is one important parameter which has been used to characterize the performance of DWHR systems under steady-state conditions. It has been widely used to characterize heat recovery from the drain water. The same parameter can also be used to determine the time response of the selected DWHR systems in this experiment. Thermal time response is the time taken for the selected variable to reach quasi-steady-state conditions. So far, a generalized approach has been used to estimate $q_{flow}$ based only on $T_{ci}$ and $T_{co}$ at steady-state conditions. Constant flowrate and specific heat capacity of water were assumed and $q_{flow}$ was estimated using Equation 2.8. Energy storage effects were not considered. The main reason for such a simple approach was the lack of available information regarding temperature.

Infrared thermography provided detailed surface and estimated water temperatures across the entire DWHR system. Hence, the energy balance shown in Figure 2-1 was expanded to include the thermal storage effects (Equation 2.5). Once a detailed energy balance was applied to include those effects, heat recovery rate (shown by Equation 2.3) from the drain water was estimated with more precision.

### 5.2.2.2 Energy Balance Method Set-Up and Limitations

Energy storage is the combined effect of temperature change, flowrate, fluid properties and DWHR system's thermal properties. It is also dependent on the DWHR system response. Hence, all the derived information from the camera coil sets, RTDs and thermocouples in the previous sections were used to determine the energy storage in the selected DWHR systems. Once the heat energy recovery values were determined for each time instant and plotted against time, it was used to determine the time response in terms of energy recovered. The entire energy analysis was highly dependent on all measured surface and water properties. Therefore, expressing the time response of DWHR systems in terms of the system energy was the best approach. The first step to determine the energy terms was to simplify the overall energy balance equation.

It is important to note that energy balance in Figure 2-1 and Equation 2.3 was applied individually to each coil set. The resultant mains-side heat transfer rate ($q_c$) from each coil set was added throughout the DWHR system for each time instant to get the final result.

All variables in Equation 2.3 represents the properties of mains-side water at different time instants and coil set locations. Equation 2.3 is made up of 2 terms which represent the flow and storage energy associated with water in different coil sets respectively. In Equation 2.3, $\forall$ is the internal volume of each coil set in m$^3$, $\rho$ is density of water in each coil set with units of kg/m$^3$ and $dT/dt$ is the rate of change of water temperature in each coil set when compared to previous time instants.

$q_c$ is the mains-side heat transfer rate to the water in each coil set with units of $kW$. The only new term that has been added to $q_{flow}$ included storage effects.

To perform energy balance, a complete thermal network across the entire DWHR cross-section couldn't be drawn. The only available surface temperatures were at the coil sets exposed to the thermal camera. In order to draw a complete thermal network across the entire DWHR system cross-section, surface temperature profile of copper must be known for the entire cross-section which is not exposed to the thermal camera; along with the change in drain-side water temperature as the film falls and loses heat. Therefore, it was not possible to draw a thermal resistance network from the drain-side water through the coil set into the mains-side water at each coil set section. Since none of that information was available, a simplified energy balance (including storage) was applied with the available information of estimated mains-side water temperature in the coil sets.

Moreover, the water flow behaviour in the coil sets was also unknown. It could not be determined whether the water flow was laminar or turbulent across the coil sets. This was the limiting factor because flow in non-circular helical coils have not been studied extensively. Hence, the convection coefficients calculated in Section 4.4.6 were not used to find the convective heat transfer ($q_{conv}$) in water. This is the reason why it was also not included in the energy balance.

It was assumed that the flowrate and water properties were constant in each coil set. They were based on the water temperature in the coil set of interest at any given time instant. Moreover, the coil sets were presumed to be completely filled with water at all given time instants in order to simplify the energy balance analysis.

A calculation sample for both the terms in Equation 2.3 will be shown and combined to determine $q_c$. Calculations were performed for the same sample scenario which was shown in Section 4.4.6.2. The density (ρ) and specific heat capacity ($c_p$) of water for sample calculation scenario are stated in Table 4-6. All the calculations for the energy balance were performed on coil set to coil set basis.

### 5.2.2.3 Flow Energy Rate Calculations

The first energy term calculated from Equation 2.3 was the change in flow energy of mains-side water as it entered and exited each individual coil set. Since the mains-side water temperature was expected to increase as it travelled through each coil set and gained heat from the drain-side as shown in Figure 5-1, the change in energy transfer rate to the mains water would be positive. Flow energy transfer rate at coil sets was thus calculated using Equation 2.4.

In that equation, $\dot{m}$ is the mass flowrate of water and is calculated from the measured flowrate as follows:

$$\dot{m} = \left(\frac{12.08\ \text{L}}{\text{min}}\right)\left(\frac{1\ \text{min}}{60\ \text{s}}\right)\left(\frac{1\text{m}^3}{1000\ \text{L}}\right)\left(\frac{999.83\ \text{kg}}{\text{m}^3}\right) = 0.2012\,\frac{\text{kg}}{\text{s}}$$

In order to find the difference between coil set outlet and inlet temperature, it was assumed that the water temperature at the coil set entry and exit was the same as the temperature of water in the coil set prior and the current coil set. For example, since coil set 4 was being shown for sample calculation, $T_{in}$ and $T_{out}$ were the water temperatures at coil set 3 and 4 respectively. Hence, $T_{in}$ and $T_{out}$ were the water temperatures at the non-dimensionalized distance of 0.20 and 0.27 respectively as shown in Table 4-4 for the 200 seconds time instant. Based on all the known parameters, change in flow energy rate was calculated as:

$$q_{flow} = \left(\frac{0.2012\text{kg}}{\text{s}}\right)\left(4.1882\frac{\text{kJ}}{\text{kgK}}\right)(12.69 - 12.05)\text{K} = 0.5393\text{kW}$$

Hence, for R4-36 at 12LPM and 200 seconds time instant, coil set 4 experienced the flow energy rate change of 0.5393kW. The same procedure was applied to calculate energy for each coil set. Both flow and storage energy calculations for all the coil sets at sample calculation scenario are summarized in Table 5-2 at the end of Section 5.2.2.5.

#### 5.2.2.4 Energy Storage Rate Calculations

Energy storage in mains-side water is represented by the second term in Equation 2.3 and is shown in Equation 2.5 [46].

In Equation 2.5, ∀ represented the volume of water in the coil set of interest at a given time instant. The volume of water in the coil sets was measured physically for all 3 DWHR systems in order to improve accuracy of the storage terms. In order to do that, all 3 DWHR systems were weighed with and without water in the coil sets. Once the mass of water drained from the coil sets was determined, it was converted to the volume of water in each coil set. All the summarized data regarding the fluid mass and volume in the coil sets is shown in Table 5-1.

The density of water used to convert from mass to volume of water was based on the ambient room temperature of 23.8$^0$C on the specific date when these measurements were taken. Linear interpolation led to the approximate density of water to be 997.6 kg/m$^3$ [28].

**Table 5-1: Calculations of volume of water in coil sets for selected DWHR systems**

| DWHR pipe | Mass of Empty Pipe (kg) | Mass of Pipe and Water (kg) | Mass of Drained Water (kg) | Volume of Water in all Coil sets (m$^3$) | Volume of Water in each Coil sets (m$^3$) |
|---|---|---|---|---|---|
| **R3-36** | 7.847 | 8.666 | 0.819 | 8.21E-04 | 5.86E-05 |
| **R3-60** | 12.435 | 13.770 | 1.335 | 1.34E-03 | 5.57E-05 |
| **R4-36** | 10.834 | 12.150 | 1.317 | 1.32E-03 | 9.43E-05 |

For R4-36, calculations for volume of water in coil sets is shown as follows:

$$\text{Mass of Drained Water} = 12.150 - 10.834 = 1.316\text{kg}$$

$$\text{Volume of water in all Coil Sets} = \frac{1.316\text{ kg}}{997.6\text{ kg/m}^3} = 0.001319\text{m}^3$$

$$\text{Volume of Water in Each Coil Set} = \frac{0.001319\text{m}^3}{14\text{ coil sets}} = 9.43\text{x}10^{-5}\text{ m}^3$$

The last term to be determined for estimating the energy storage rate was $dT/dt$, which is the rate of change of water temperature at each coil set for different time steps. For the tests conducted in this experimental study, it represented the difference in water temperature between the current and the previous time instant. Based on the same calculation parameters used in previous sections, it was determined from Table 4-4 that:

$$\frac{dT}{dt} = \frac{T_{\text{water,200 sec}} - T_{\text{water,100 sec}}}{200 - 100} = \frac{12.69 - 12.81}{200 - 100} = -0.0012\frac{K}{s}$$

Hence, with all the given information and using Equation 2.5, the storage energy rate of change for R4-36 coil set 4 at 200 seconds time instant was determined to be -4.74x10$^{-4}$ kW or -0.474 W.

$$q_{\text{storage}} = \left(\frac{999.83\text{ kg}}{\text{m}^3}\right)\left(4.1882\frac{\text{kJ}}{\text{kgK}}\right)(9.43\text{x}10^{-5}\text{ m}^3)\left(-0.0012\frac{K}{s}\right) = -0.474\text{ W}$$

#### 5.2.2.5 Resultant Heat Transfer Rate

The resultant rate of heat transfer to water in coil set 4 was therefore computed by adding up both the calculated flow and storage energy terms in Equation 2.3.

$$q_c = \dot{m}c_p(T_{out} - T_{in}) + \rho c_p \forall \frac{dT}{dt} = 0.5393\text{kW} + (-0.000474\text{kW}) = 0.5388\text{kW}$$

Heat transfer rates for the sample calculation scenario and other coil sets are summarized in Table 5-2. MATLAB scripts used for interpolation of fluid properties and calculating the flow energy transfer and storage rate are shown in Appendix L.

**Table 5-2: Energy balance approximations at sample calculation scenario along with all other coil sets**

| Coilset | Flow (kW) | Storage (kW) | Coil set $q_c$ (kW) |
|---|---|---|---|
| **1** | 0.5400 | -0.0004 | 0.5396 |
| **2** | 0.5399 | -0.0004 | 0.5395 |
| **3** | 0.5397 | -0.0004 | 0.5393 |
| **4** | 0.5396 | -0.0004 | 0.5392 |
| **5** | 0.5394 | -0.0004 | 0.5390 |
| **6** | 0.5393 | -0.0004 | 0.5389 |
| **7** | 0.5391 | -0.0004 | 0.5387 |
| **8** | 0.5390 | -0.0004 | 0.5386 |
| **9** | 0.5388 | -0.0004 | 0.5384 |
| **10** | 0.5387 | -0.0004 | 0.5383 |
| **11** | 0.5385 | -0.0004 | 0.5381 |
| **12** | 0.5384 | -0.0004 | 0.5380 |
| **13** | 0.5383 | -0.0004 | 0.5379 |
| **14** | 0.5382 | -0.0004 | 0.5378 |
| **exit** | 0.5381 | 0.0000 | 0.5381 |
| **TOTAL $q_c$** | **8.0848** | **-0.0055** | **8.0793** |

The last column in Table 5-2 shows the overall mains-side heat transfer rate ($q_c$) in each coil set as derived from Equation 2.3. In order to compute the overall heat transfer rate for the entire DWHR system length for any time instant, all heat transfer rates for all coil sets were added up together.

Table 5-2 shows that for R4-36 at 200 seconds time instant when the flowrate was 12LPM, the overall heat transfer rate to the mains-side water was $8.0793\text{kW}$.

#### 5.2.2.6 Energy Balance Plots and Storage Effects

The total mains-side heat transfer rate ($q_c$) indicated in the last row of Table 5-2 is the key value of interest. It could be used to analyze the thermal time response for all 3 DWHR systems at the flowrates studied because it is a combined effect of flowrate, water inlet and outlet temperatures, surface temperature of coils etc. Table 5-3 shows the summarized overall heat transfer rates of R4-36 at 12LPM for all time instants. Figure 5-4 shows the energy balance plot which includes the calculation scenario and is the graphical representation of Table 5-3. Plots for all of the 18 tests are shown in Appendix O.

**Table 5-3: Energy balance approximations for R4-36 at 12LPM**

| Time (s) | Flow (kW) | Storage (kW) | Overall $q_c$ (kW) |
|---|---|---|---|
| **1** | 0.1716 | 0.0000 | 0.1716 |
| **2** | 0.7959 | -2.0377 | -1.2418 |
| **3** | 1.3223 | -1.7075 | -0.3852 |
| **5** | 3.0291 | -2.8104 | 0.2187 |
| **8** | 5.0710 | -1.9849 | 3.0861 |
| **10** | 5.9369 | -1.1581 | 4.7788 |
| **15** | 7.1637 | -1.0591 | 6.1045 |
| **20** | 7.9415 | -1.1036 | 6.8379 |
| **30** | 8.0268 | -0.5547 | 7.4721 |
| **50** | 7.9211 | -0.2500 | 7.6711 |
| **100** | 8.0008 | -0.0383 | 7.9626 |
| **200** | 8.0848 | -0.0055 | 8.0793 |

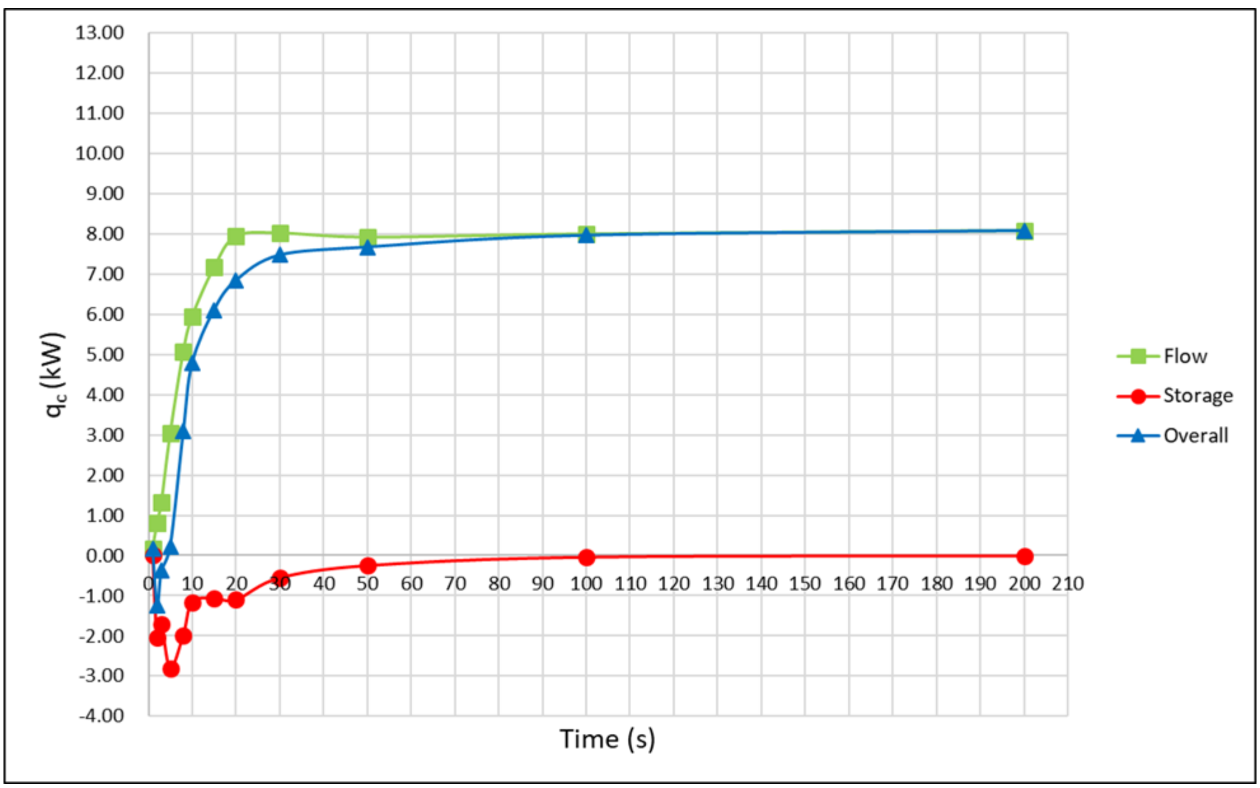


**Figure 5-4: Mains-side energy balance plot for R4-36 at 12LPM**

## 5.3 Discussions for Test Method 2

### 5.3.1 Overall Energy Balance Discussion

Figure 5-4 shows 3 different plots for 1 of the 18 tests conducted. The overall mains-side heat transfer rate ($q_c$) to the mains water was shown in blue triangular labels and was the summation of the flow energy input rate (green square labels) and storage energy rate (red circular labels). The slight overshoot in the flow energy term was most likely due to the time difference associated with fluid streams exiting the mains and drain-side. The ambient water in the mains-side would take longer to exit the system since it travels through the coils. Hence $T_{co}$ would take longer to stabilize, as compared to drain-side water.

It was observed that the rate of energy storage for all 18 tests conducted was small and negligible. It did not have a big impact on the overall heat transfer rate. At the beginning of each test, the magnitude of the energy storage rate started to decrease sharply and peaked out. Thereafter, it started to increase and eventually settled at 0.

Once the test started, the existing water in the coil sets at ambient temperature conditions began to flush out and was being replaced with the mains water at about $10^0$C. Since the mains-side inlet water being filled in the coil sets was much colder than the exiting ambient temperature water, it resulted in the negative energy storage term. This meant that the mains-side water entering the coil sets during the very beginning instances of any test doesn't result in any useful energy storage.

The impact of warmer drain water was observed, after the water at ambient temperature cleared out of the mains-side coils. This impact was observed in the form of heat recovery which resulted in the energy storage term to peak out, and a positive slope was observed in energy storage terms. It is important to note that the rate of energy storage was always negative throughout the duration of each test. It was due to the fact that for most of the coil sets of any tests conducted, the $dT/dt$ term which represented the change in water temperature in each coil set at different time instants ended up as a negative number. For example, if a test scenario had the exit coil set water temperature to drop from $22^0$C to $20^0$C from beginning to end of a test, the change in water temperature at that particular coil set would be negative throughout.

Since most of the $\mathrm{dT/dt}$ terms were negative, once the storage terms were added for all the coil sets to get the overall energy storage rate for any DWHR system at a specific time instant, the resultant value was negative energy storage rate. Even though energy was being recovered by the DWHR system in form of warmer water temperature at the mains outlet side, the negative $\mathrm{dT/dt}$ term indicated that at the coil set level, water temperature was decreasing throughout the test.

The nature of the energy storage terms seemed to be highly dependent on the pre-set starting initial conditions. It was presumed that if the remaining water from any previous tests in the coil sets could be kept at a much lower temperature as compared to the ambient, or if the mains-side inlet water was set to a much higher temperature, the rate of energy storage terms would turn out to be positive. This is because if the remaining colder water in the coil sets from the previous tests was replaced during the test duration with the warmer mains water, the $\mathrm{dT/dt}$ term would always be positive and in turn would result in positive storage terms.

From the energy balance plot shown in Figure 5-4, it was concluded that the general shape of the energy balance curves for all the tests conducted were very similar. It was observed that the energy storage rate term dropped and peaked out generally within the first 10 seconds of a test. Thereafter, it started to increase and converged to $0\mathrm{kW}$ around 1 minute mark of the test. This was the instant in time when the DWHR system had reached quasi-steady-state conditions, and the change in water temperature was negligible when compared at different time instants at a particular coil set location.

The magnitude of the storage term was small when compared with the flow energy terms. Flow energy transfer rate was the major component of the energy balance plots. It was observed that the storage terms played a major role in stabilizing the flow energy curves, to derive the overall energy balance plots especially for the higher flowrates. It was evident from Figure 5-4 where the slight uneven bump in the flow energy curve between 10 and 40 second mark was adjusted due to the addition of storage terms.

For all the cases, the flow energy rate and the overall energy transfer rate were very close to each other. This was even more visible for the lower flowrates because the storage terms were much smaller even during the beginning instances of the tests. For all the tests, as the system reached steady-state, both the flow and overall energy transfer rate profiles were almost identical due to negligible storage. Hence, it was concluded that the storage terms only played a major role during the beginning of the tests by slightly adjusting the overall energy balance profile and eventually vanished.

The overall rate of heat transfer to the mains-side water was the most crucial part of the infrared thermography experiments. It represented the estimated rate of thermal energy extracted from the gray water. The shape of the overall energy transfer rate curve was similar for all 18 tests. In general, $q_c$ seemed to increase exponentially at a much faster rate during the beginning instances of the test, and eventually reached steady-state condition.

It was observed that the change in the slope of $q_c$ with respect to time was very steep at the beginning of the tests. The slope eventually evened out as the system reached steady-state approximately around the 1 minute mark for all the tests. This was the point in time when the system reached quasi-steady-state, and eventually the lines representing overall $q_c$ flattened out. Another key observation made here was that due to the insignificant storage as compared to flow energy transfer rate, both the overall heat transfer rate and flow energy transfer rate were very similar to each other.

For each individual DWHR system, $q_c$ decreased as the flowrate of water decreased through the coil sets. The major reasoning behind such observation was the decrease in flow energy transfer rate due to lower $\dot{m}$ for lower flowrates. Since the flow energy transfer rate was a major component of the overall energy balance equation, any changes in the mass flowrate had a direct impact on $q_c$. The change in flowrate for each DWHR system also had an impact on the change in $q_c$ during the beginning transient instances of a test with respect to time. This was evident by observing the slope of $q_c$ during the first minute of each test for any particular DWHR system. For higher flowrates, $q_c$ increased very quickly and reached quasi-steady-state in a shorter period of time as compared to lower flowrates, where the slope became less shallower and the time period to stabilize and reach steady-state increased.

When $q_c$ was compared by varying the DWHR system drain-side length and keeping the same diameter as in case of R3-36 and R3-60, it was observed that increasing the drain-side length had a significant proportional impact on $q_c$ at all 6 flowrates. This was observed by comparing the energy balance plots for R3-36 and R3-60 at the same flowrates. This was due to the fact that the longer the DWHR system was, water in the coil sets would take much longer to exit at the mains-side outlet. This delay in the exit of mains water allowed for more heat to be extracted from the drain water. Moreover, longer DWHR systems had more surface area available for heat transfer to occur. As a result, at all flowrates $q_c$ was higher for the DWHR systems with the longer drain-side length.

For DWHR systems of different diameter and constant drain-side length, a minor inverse impact on $q_c$ was observed. This observation was made by comparing the energy balance plots for R3-36 and R4-36 at all flowrates. For a larger drain-side diameter DWHR systems, $q_c$ slightly decreased for all flowrates. Even though R4-36 had more surface area for heat transfer as compared to R3-36, improper drain-side wetting could have been the reason behind lower $q_c$ as compared to R3-36. Especially for the cases of lower flowrates, it was possible that the film of warmer drain water might not have been completely formed. This has already been explained in detail towards the end of Section 5.2.1 when the temperature profiles were discussed.

The drop in $q_c$ was most significant when comparing R3-36 and R4-36 at 5.5LPM. This suggested that at such lower flowrates, the film did not form completely for the bigger drain-side diameter DWHR system. Hence, the difference in $q_c$ was much larger as compared to all other flowrates. This also suggested that the quality of film formation diminished as the flowrate decreased, and the DWHR systems with bigger diameter were the most affected by it.

### 5.3.2 First Order Time Response Plots for $q_c$

The overall heat transfer rate ($q_c$) in Figure 5-4 resembled the first order exponential response of the form shown in Equation 5.1, where $q_{c,SS}$ represented the mains-side heat transfer rate at 200 seconds time instant, and $\tau_c$ was the time constant for mains-side heat transfer rate.

$$q_{c,correlation} = q_{c,SS}\left(1 - e^{\frac{-t}{\tau_c}}\right) \tag{5.1}$$

Figure 5-5 shows the first order $q_c$ vs time plot for R4-36 at 12LPM. $q_c$ and $q_{c,\ correlation}$ represents the experimental and correlational values of mains-side heat transfer rate. The coefficients for all 18 tests are shown in Table 5-4. $t_{99\%}$ in Table 5-4 represents the 99% steady-state time response of $q_c$ for all 18 tests. Plots for all 18 tests are shown in Appendix P.

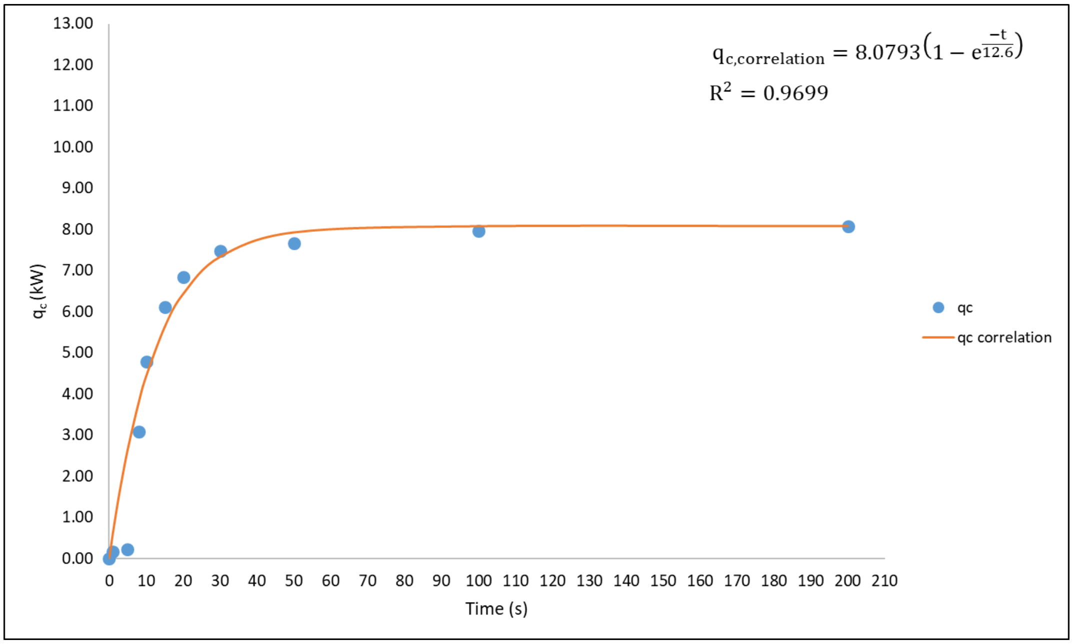


**Figure 5-5: First order time response for R4-36 at 12LPM**

**Table 5-4: Coefficients for first order $q_c$ vs time plots**

| | Flowrate (LPM) | $q_{c,SS}$ (kW) | $\tau_c$ (s) | $R^2$ | $t_{99\%}$ (s) |
|---|---|---|---|---|---|
| **R3-36** | 14 | 9.3534 | 10.0 | 0.9683 | 46.05 |
| | 12 | 8.3575 | 12.0 | 0.9641 | 55.26 |
| | 10 | 7.5465 | 13.5 | 0.9697 | 62.17 |
| | 9 | 7.0818 | 14.0 | 0.9833 | 64.47 |
| | 7 | 6.1279 | 18.0 | 0.9833 | 82.89 |
| | 5.5 | 5.2942 | 23.0 | 0.9779 | 105.92 |
| **R3-60** | 14 | 12.5457 | 9.50 | 0.9541 | 43.75 |
| | 12 | 11.3345 | 11.0 | 0.9605 | 50.66 |
| | 10 | 10.0763 | 14.0 | 0.9665 | 64.47 |
| | 9 | 9.2388 | 15.0 | 0.9746 | 69.08 |
| | 7 | 7.9102 | 19.0 | 0.9527 | 87.50 |
| | 5.5 | 6.5069 | 25.0 | 0.9677 | 115.13 |
| **R4-36** | 14 | 8.8437 | 10.0 | 0.9450 | 46.05 |
| | 12 | 8.0793 | 12.6 | 0.9699 | 58.03 |
| | 10 | 7.2982 | 13.5 | 0.9528 | 62.17 |
| | 9 | 7.0004 | 17.0 | 0.9715 | 78.29 |
| | 7 | 5.8290 | 20.0 | 0.9510 | 92.10 |
| | 5.5 | 3.8593 | 25.0 | 0.9637 | 115.13 |

Table 5-4 indicates that the steady-state time response could range from 45 seconds to about 2 minutes depending on the system flowrate. Even though most of the change in heat transfer rate occurs within the first 50 seconds, it may take up to 2 minutes for the system to reach complete steady-state.

### 5.3.3 Infrared Thermography Based Time Response

The last step in the study of infrared thermography of DWHR systems was the estimation of 63.2% and 86.5% time responses for all 18 tests, using thermography data. 63.2% and 86.5% $q_c$ values were found by multiplying the $q_c$ value at 200 seconds with 0.632 and 0.865 respectively. Linear interpolation was then applied to find $t_{63.2\%}$ and $t_{86.5\%}$ respectively. Table 5-5 shows the estimated time responses for the 3 DWHR systems based on the infrared thermography method.

**Table 5-5: Experimental time responses based on thermography approach**

| Time (s) | Response | 14LPM | 12LPM | 10LPM | 9LPM | 7LPM | 5.5LPM |
|---|---|---|---|---|---|---|---|
| R 3-36 | **63.2%** | 14.08 | 15.92 | 17.11 | 16.70 | 21.29 | 28.07 |
| | **86.5%** | 19.91 | 25.60 | 27.99 | 28.23 | 40.14 | 48.34 |
| R 3-60 | **63.2%** | 14.11 | 14.22 | 17.19 | 17.38 | 24.73 | 29.83 |
| | **86.5%** | 19.71 | 23.92 | 28.56 | 28.46 | 42.33 | 50.55 |
| R 4-36 | **63.2%** | 14.44 | 11.23 | 17.70 | 18.92 | 28.20 | 23.74 |
| | **86.5%** | 22.35 | 22.38 | 28.18 | 42.12 | 99.61 | 65.25 |

## 5.4 Comparison of Time Responses for Both Test Methods

All the relevant conclusions regarding time responses have been made in Chapter 3. The purpose of estimating the time responses for thermography based experiments was to compare the derived results for both experimental approaches. The difference between thermography based time responses in Table 5-5 and generalized time responses in Chapter 3 from Table 3-4 and Appendix C are shown in Table 5-6. The thermography approach resulted in higher time responses than the generalized approaches in almost all the cases. This was due to the thermal lag associated with thermography. Water temperatures were being measured with a second or two of thermal lag.

**Table 5-6: Difference between thermography based and generalized time responses**

| Time (s) | Response | 14LPM | 12LPM | 10LPM | 9LPM | 7LPM | 5.5LPM |
|---|---|---|---|---|---|---|---|
| **R 3-36** | **63.2%** | 2.91 | 3.21 | 3.86 | 2.94 | 2.01 | 5.41 |
| | **86.5%** | 3.17 | 6.06 | 7.18 | 6.36 | 8.56 | 11.54 |
| **R 3-60** | **63.2%** | 2.57 | 1.48 | 3.05 | 0.50 | 2.86 | 3.17 |
| | **86.5%** | 0.52 | 3.63 | 4.88 | 1.60 | 5.81 | 5.94 |
| **R 4-36** | **63.2%** | 4.23 | -0.17 | 3.50 | 3.54 | 11.97 | 2.42 |
| | **86.5%** | 5.47 | 4.25 | 3.33 | 18.18 | 74.35 | 29.48 |

Both methods resulted in very similar time response values for most of the cases. The time responses derived by both methods were off by only a few seconds for majority of the tests. This uncertainty will always be present for any measured transient time response due to its unpredicted nature.

The only problems observed were for the time responses of R4-36 at the lower flowrates. The significant time difference was solely based on the experimental error of the energy balance plot for R4-36 at lower flowrates, which could be accessed from Appendix O. All of the energy balance plots showed steady-state heat transfer during the ending phase of the thermography experiments, except for R4-36 at lower flowrates. This was most likely due to improper film formation and could be resolved if thermography is repeated on lower flowrates of R4-36.

Except for some cases, both approaches resulted in similar time responses. Hence, previous results from Chapter 3 were confirmed using the thermography approach. Any significant differences in results could be further investigated to remove any induced experimental errors.

# Chapter 6 Conclusions and Recommendations

## 6.1 Conclusions

The focus of this thesis was to lay the foundations for studying the transient response of DWHR systems using a purely experimental approach. In general, different methodologies were developed to investigate the transient behaviour and time response of DWHR systems at equal-flow, under a fixed set of water inlet and CSA flowrate conditions.

Repeatability of the inlet and outlet water temperatures for the transient and steady-state duration was the first point that was established. All of the derived temperature data concluded that the temperature profiles were fully repeatable for the entire duration of any test, provided that the water inlet and ambient conditions stayed relatively the same. The temperature profiles were exponential in nature.

The first test method dealt with studying the time response of 11 DWHR systems using a generalized approach, in which $q_{flow}$ was plotted as a function of time for the entire test duration. The profile of $q_{flow}$ with respect to time was exponential in nature. 63.2% and 86.5% steady-state time responses were estimated for all the experiments. It was found that all the DWHR systems reached 63.2% and 86.5% steady-state within 35 to 50 seconds respectively. It was also determined that the time responses increased with increasing DWHR system's drain-side length and decreasing flowrate. Any deviations from the patterns observed were specific to DWHR system characteristics. Linear equations were used to best describe the time response based on flowrate and drain-side length. Validation for the generalized approach was completed by running some random tests and comparing the calculated and predicted time responses. The correlation established could predict the time response within ±6 seconds.

The second test method focused on expanding the energy balance equation to include energy storage effects by using infrared thermography. Due to time consuming nature of transient testing and the limited availability of infrared camera, only 3 DWHR systems were tested once. The measured surface temperature of the mains-side coils was used to estimate the mains water temperature throughout the DWHR system length. It was concluded that the water temperature increased in a linear fashion throughout the length for all time instants.

A complete energy balance to estimate $q_c$, consisting of inlet and outlet and storage terms was performed on each set of coils for all the selected time instants. It was determined that storage only had an impact during the beginning phase of the tests. Storage played a role in stabilizing the energy balance curves by removing the uneven bump during the transient phases. For all the tests, the storage term was negative and eventually settled to $0\text{kW}$ as the system reached steady-state operating conditions. 63.2% and 86.5% time responses were derived and compared to the values in Chapter 3. It was concluded that even though both experimental methods resulted in similar time responses, thermography approach resulted in slightly higher time response values, due to thermal lag in the measured temperatures.

Fitting the first order exponential equation to the cold mains-side heat transfer rate ($q_c$) indicated that the DWHR systems would reach 99% steady-state response within the first 2 minutes for all the experiments.

## 6.2 Recommendations

There are several factors which could have had an impact on the estimation of time responses of DWHR systems. Firstly, the HXTP was primarily set-up to conduct steady-state testing. No modifications were done on the HXTP because of ongoing projects. All of the transient testing was conducted using the HXTP available in STRL and the data was analyzed to the best extent. This resulted in longer wait times in between different tests. Hence the first thing that should be done is HXTP modification such that more transient experiments could be conducted with minimal wait times.

Since all experiments started from 0 flowrate with a dry DWHR system, it was possible that complete annular film on the drain-side might not have been formed. Hence, it is highly recommended to modify the HXTP to ensure proper film formation. It will certainly improve the results and help in removing a significant portion of the experimental errors.

Transient analysis of DWHR systems is a very broad subject. Hence, a lot of experiments need to be conducted and results have to be validated for a lot of different cases, including different inlet conditions and flowrates. Some of the new cases could result from performing such analysis at unequal flowrates. More DWHR systems of different dimensions, especially drain-side length could be tested in future to further develop the relationships for time response.

Once the nature of time responses is fully established in the future, transient modelling of DWHR systems can be performed.

In addition to that, the availability of DWHR systems with varying dimensions from different manufacturers would greatly enhance in the development of the complete transient model.

It has been established that using infrared thermography is a good technique to determine DWHR system behaviour, since it removes the uneven bumps from energy balance plots. Hence more experiments can be conducted in the future using this approach, to further enhance research for DWHR system transient response and to model $q_c$ plots as first order time response equations.

The response time can be slightly different each time the same test is repeated. Currently, there is no benchmark to compare the thermography induced response time of DWHR systems. Hence, the time responses derived in this work serve as a good approximation and benchmark for any future work that will be completed in this field. Infrared thermography experiments could be repeated again on current DWHR systems, or performed on more samples of different dimensions and length. Once the time responses for more DWHR systems are derived, more precise conclusions can be drawn regarding transient behaviour.

Computational Fluid Dynamics modelling could also be performed on the DWHR systems in order to study the transient behaviour with more accuracy. It would provide with a clearer picture of how the DWHR systems and the fluid behaves, along with more precise estimations of heat transfer and time responses.

There is a lot of potential for future improvements when it comes to performing infrared thermography on DWHR systems. The literature on transient behaviour and time response of DWHR systems could be expanded.

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# Appendix A: Plots of Heat Transfer Rates for all 11 DWHR Systems

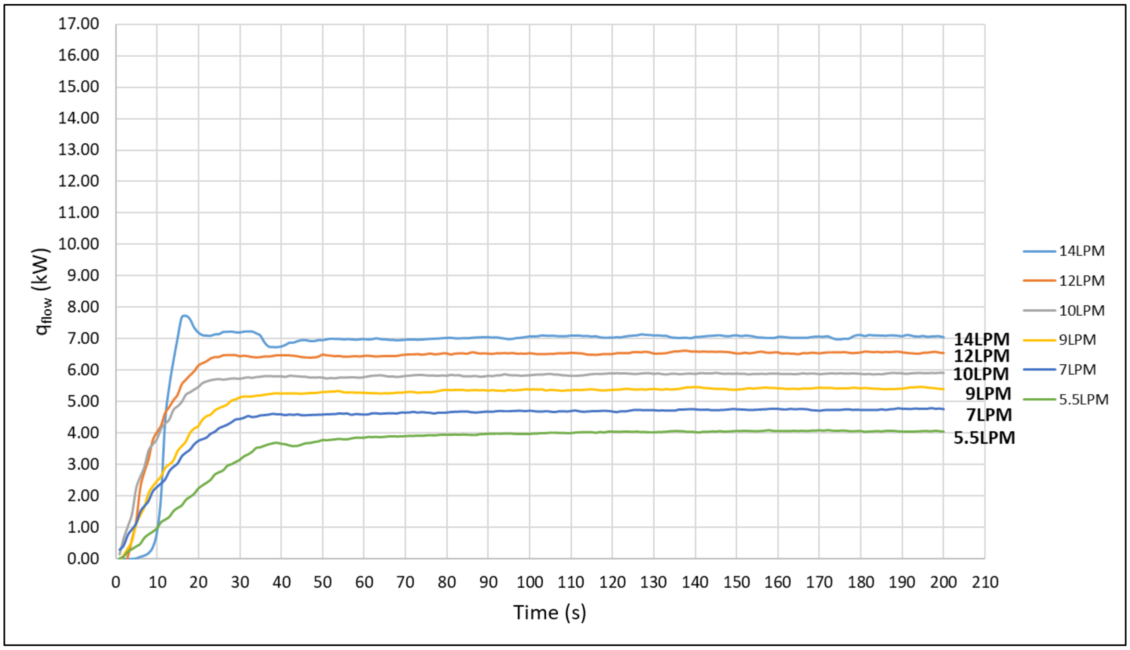


**Figure A1: Calculated mains-side heat transfer rate for R2-36**

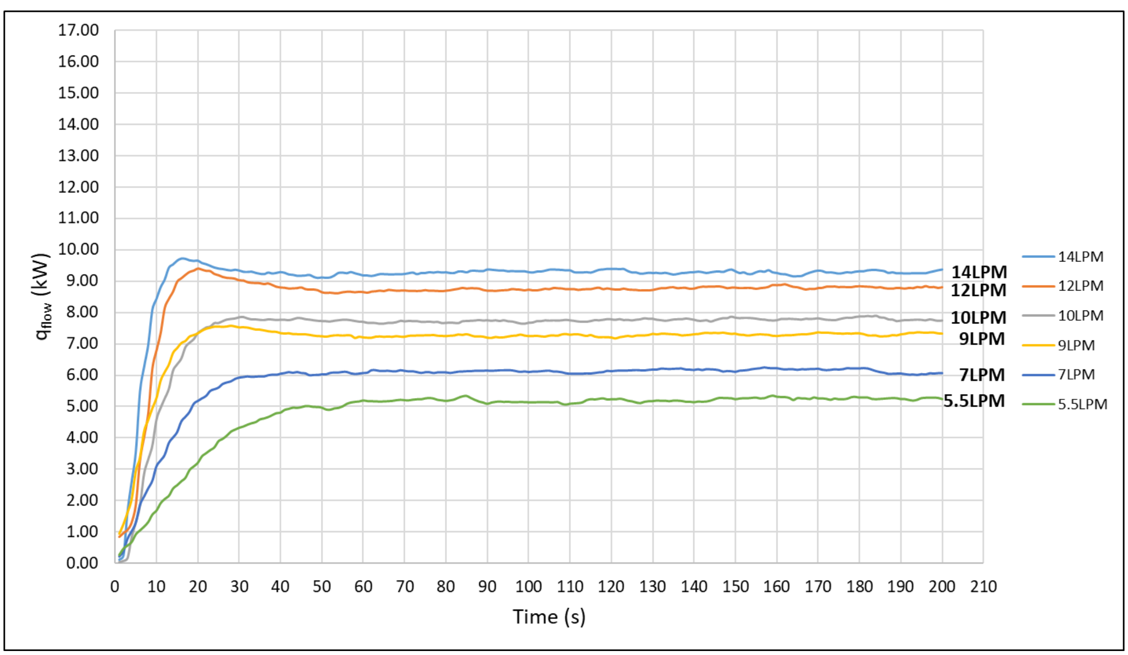


**Figure A2: Calculated mains-side heat transfer rate for R2-48**

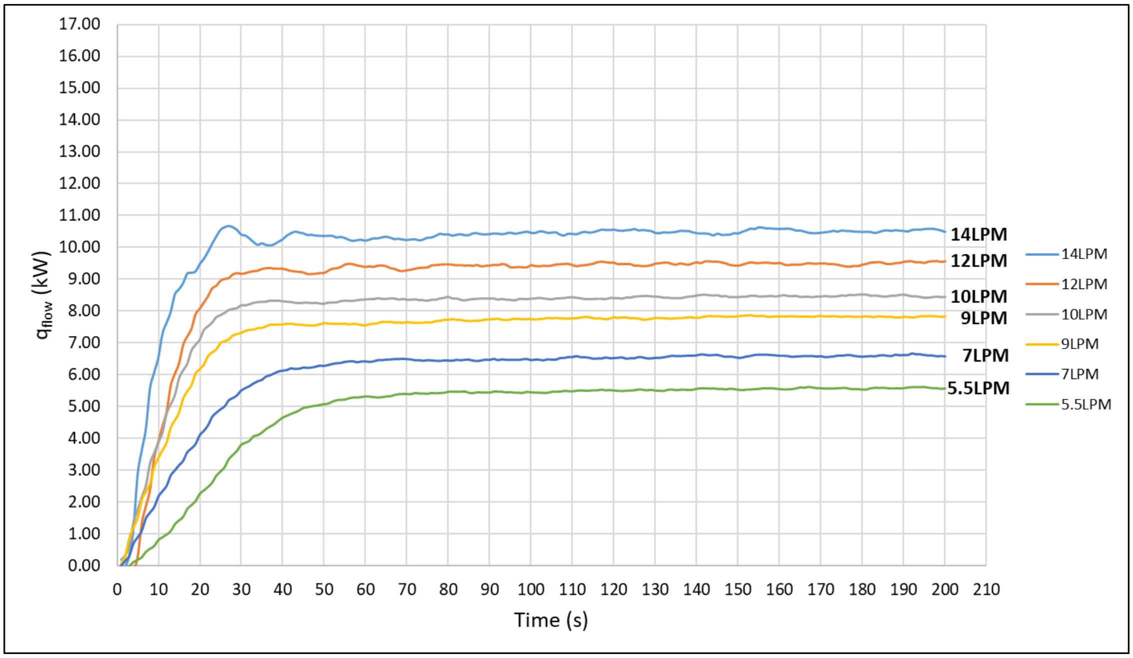


**Figure A3: Calculated mains-side heat transfer rate for R2-60**

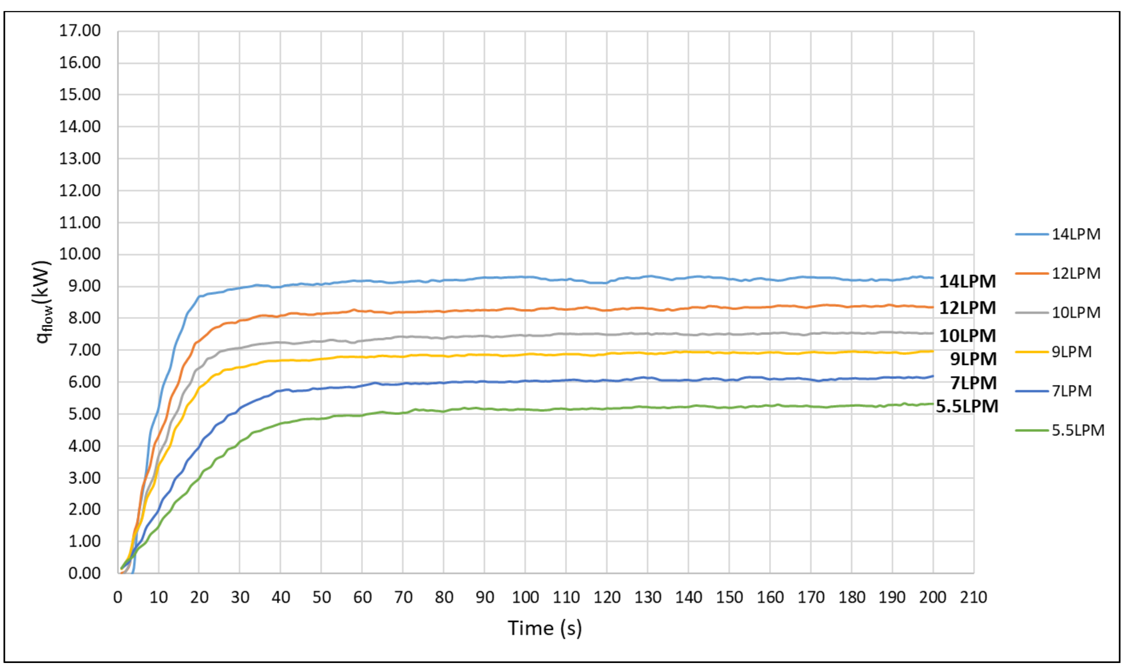


**Figure A4: Calculated mains-side heat transfer rate for R3-36**

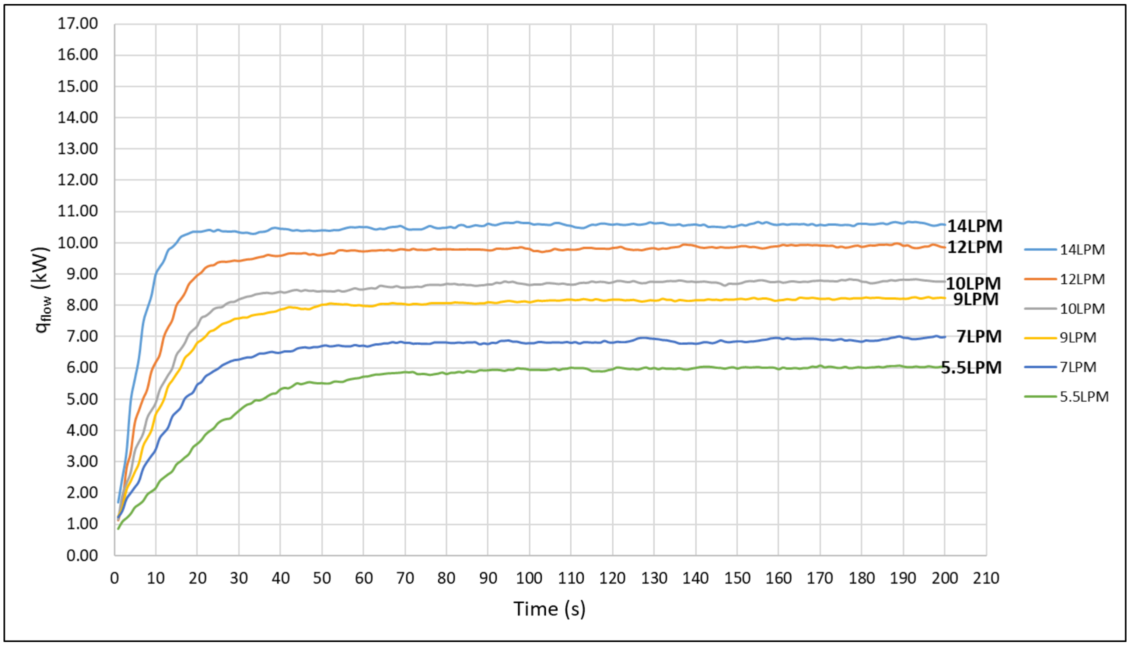


**Figure A5: Calculated mains-side heat transfer rate for R3-48**

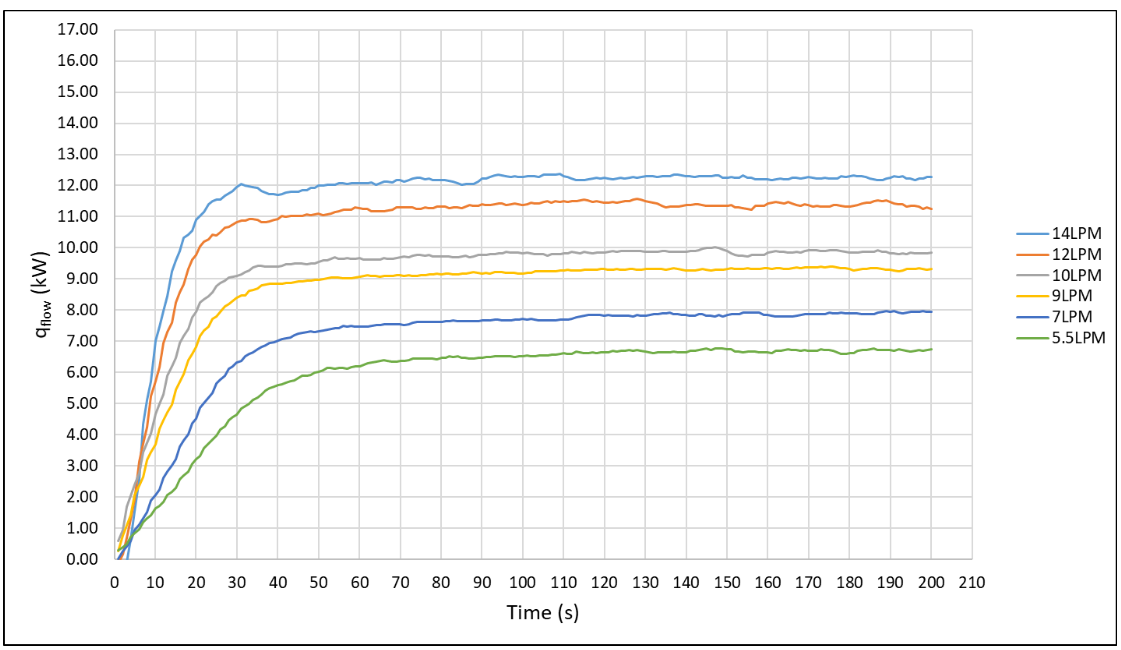


**Figure A6: Calculated mains-side heat transfer rate for R3-60**

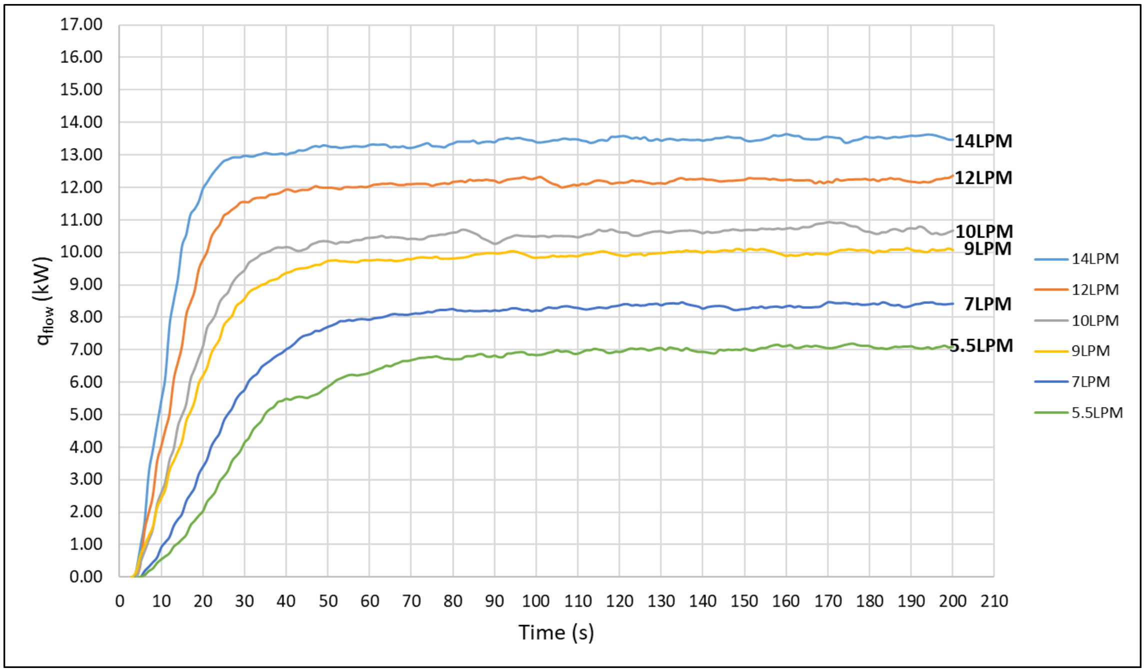


**Figure A7: Calculated mains-side heat transfer rate for R3-72**

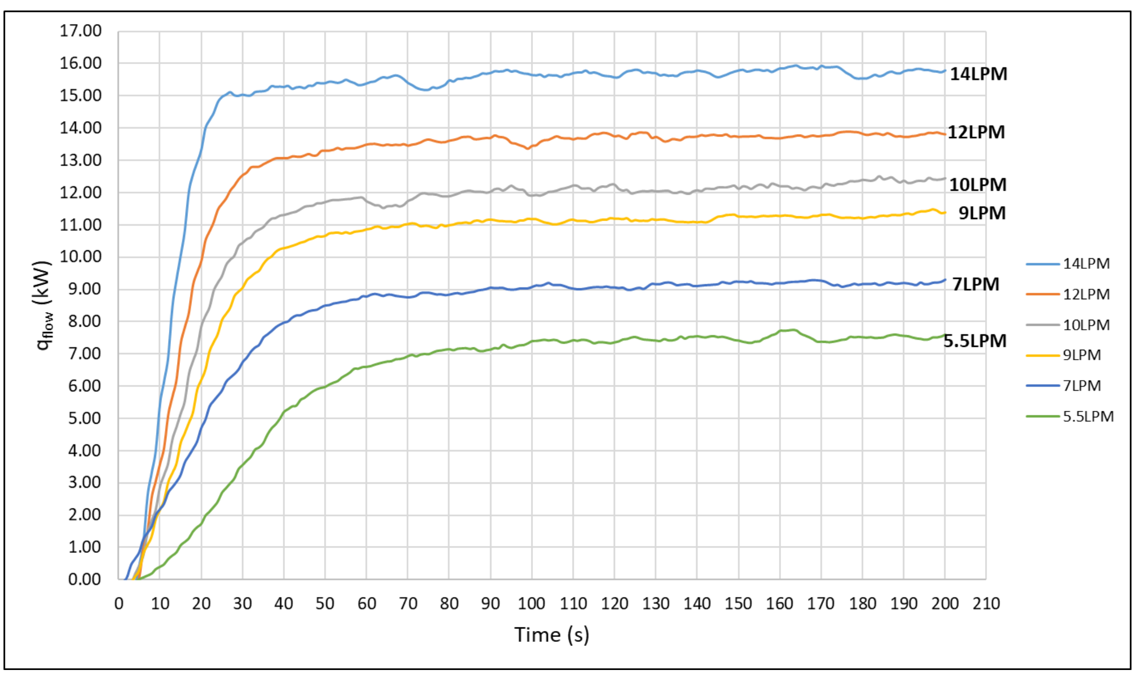


**Figure A8: Calculated mains-side heat transfer rate for R3-84**

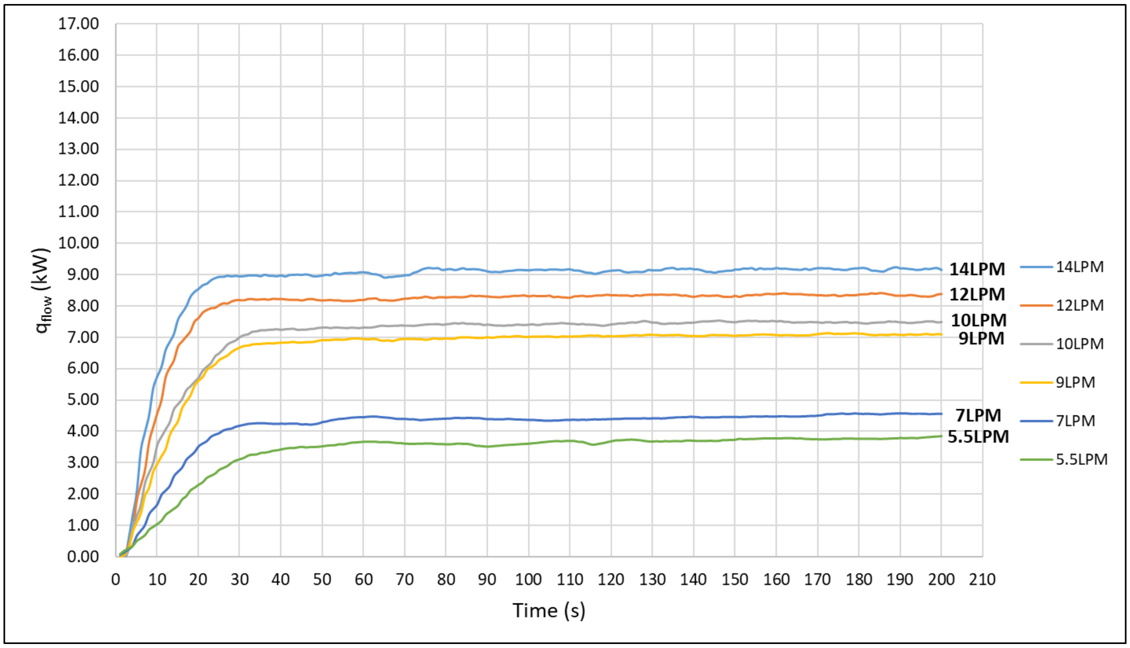


**Figure A9: Calculated mains-side heat transfer rate for R4-36**

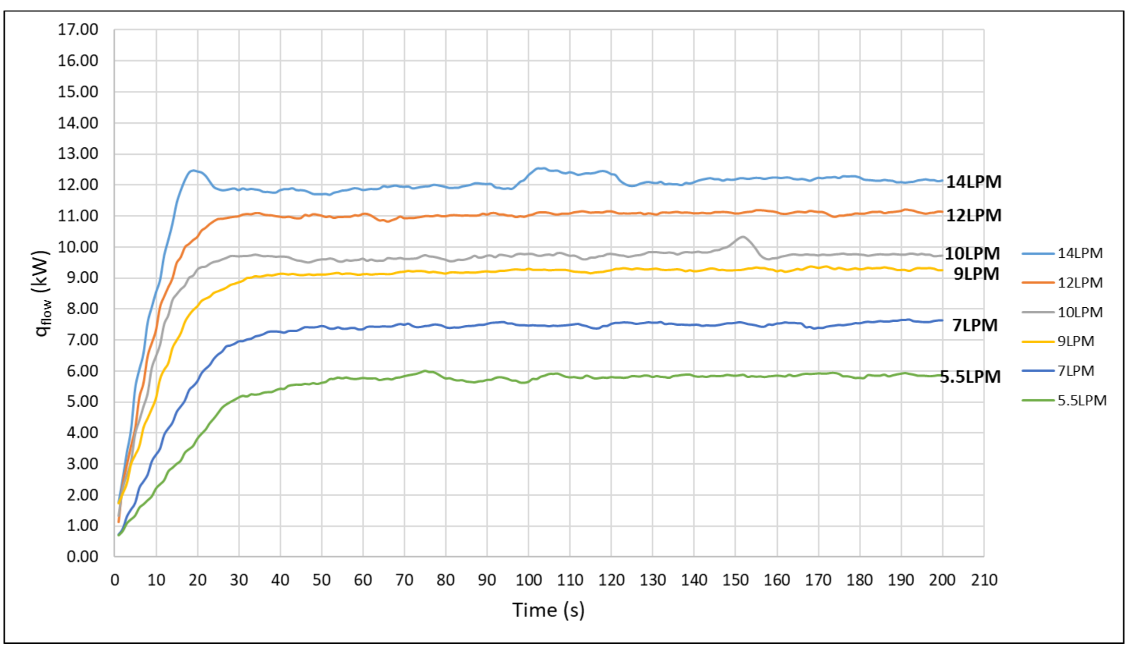


**Figure A10: Calculated mains-side heat transfer rate for R4-48**

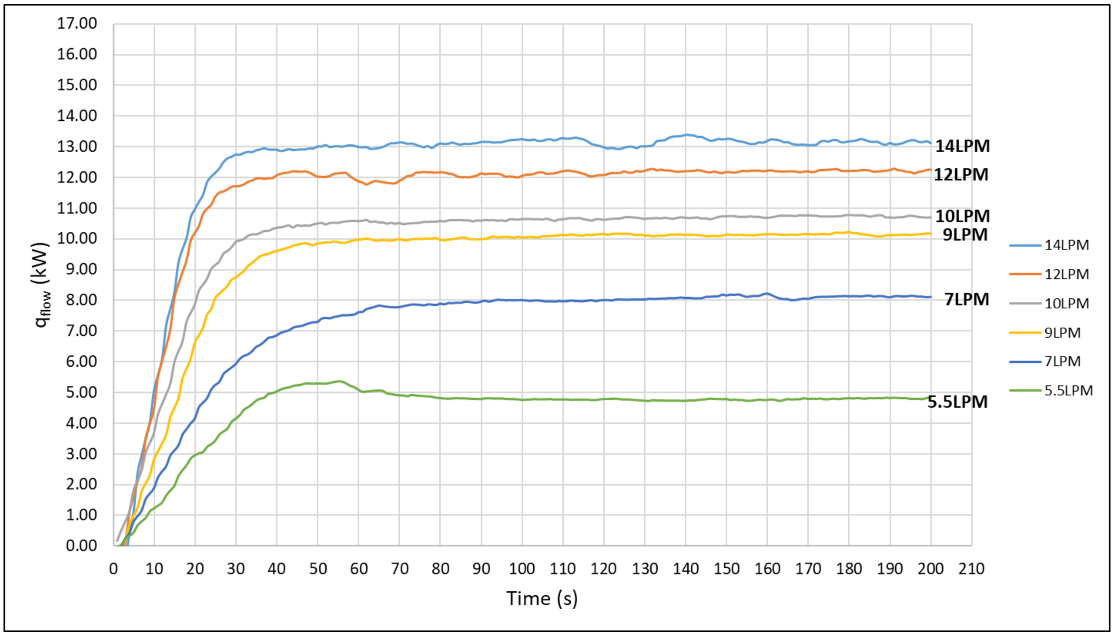


**Figure A11: Calculated mains-side heat transfer rate for R4-60**

# Appendix B: 63.2% Response Time Data Tables and Plots

**Note:** Plots showing overall trends of 63.2% time response in thesis Chapter 3 are not presented in Appendix B.

**Table B1: Difference between experimental and correlational time response all DWHR systems at CSA flowrates**

| Flowrate | R2-36 | | | R2-48 | | | R2-60 | | | R3-72 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Experimental (s) | Correlational (s) | Δt (s) | Experimental (s) | Correlational (s) | Δt (s) | Experimental (s) | Correlational (s) | Δt (s) | Experimental (s) | Correlational (s) | Δt (s) |
| **14** | 12.09 | 8.92 | 3.17 | 6.57 | 5.22 | 1.35 | 10.15 | 8.67 | 1.48 | 13.04 | 11.46 | 1.58 |
| **12** | 10.60 | 11.34 | -0.74 | 8.54 | 7.98 | 0.56 | 13.94 | 12.47 | 1.47 | 15.67 | 15.90 | -0.23 |
| **10** | 9.50 | 13.76 | -4.26 | 10.89 | 10.74 | 0.15 | 13.94 | 16.27 | -2.33 | 19.01 | 20.34 | -1.33 |
| **9** | 15.02 | 14.97 | 0.05 | 8.12 | 12.12 | -4.00 | 15.32 | 18.17 | -2.85 | 20.66 | 22.56 | -1.90 |
| **7** | 14.90 | 17.39 | -2.49 | 13.01 | 14.88 | -1.87 | 20.53 | 21.97 | -1.44 | 27.37 | 27.00 | 0.37 |
| **5.5** | 23.35 | 19.21 | 4.15 | 20.56 | 16.95 | 3.61 | 28.39 | 24.82 | 3.57 | 31.81 | 30.33 | 1.48 |
| **Flowrate** | **R3-36** | | | **R3-48** | | | **R3-60** | | | **R3-84** | | |
| | Experimental (s) | Correlational (s) | Δt (s) | Experimental (s) | Correlational (s) | Δt (s) | Experimental (s) | Correlational (s) | Δt (s) | Experimental (s) | Correlational (s) | Δt (s) |
| **14** | 11.17 | 9.61 | 1.56 | 6.35 | 6.21 | 0.14 | 11.54 | 9.44 | 2.10 | 14.84 | 12.50 | 2.34 |
| **12** | 12.71 | 12.25 | 0.46 | 10.35 | 9.19 | 1.16 | 12.74 | 13.00 | -0.26 | 17.52 | 17.16 | 0.36 |
| **10** | 13.25 | 14.89 | -1.64 | 12.03 | 12.17 | -0.14 | 14.14 | 16.56 | -2.42 | 19.85 | 21.82 | -1.97 |
| **9** | 13.76 | 16.21 | -2.45 | 12.49 | 13.66 | -1.17 | 16.88 | 18.34 | -1.46 | 22.21 | 24.15 | -1.94 |
| **7** | 19.28 | 18.85 | 0.43 | 13.86 | 16.64 | -2.78 | 21.87 | 21.90 | -0.03 | 24.72 | 28.81 | -4.09 |
| **5.5** | 22.66 | 20.83 | 1.83 | 21.63 | 18.88 | 2.76 | 26.66 | 24.57 | 2.09 | 37.69 | 32.31 | 5.39 |
| **Flowrate** | **R4-36** | | | **R4-48** | | | **R4-60** | | | | | |
| | Experimental (s) | Correlational (s) | Δt (s) | Experimental (s) | Correlational (s) | Δt (s) | Experimental (s) | Correlational (s) | Δt (s) | | | |
| **14** | 10.21 | 9.42 | 0.79 | 8.28 | 6.42 | 1.86 | 15.07 | 13.86 | 1.21 | | | |
| **12** | 11.40 | 11.84 | -0.44 | 9.27 | 9.04 | 0.23 | 14.67 | 16.06 | -1.39 | | | |
| **10** | 14.20 | 14.26 | -0.06 | 9.23 | 11.66 | -2.43 | 17.15 | 18.26 | -1.11 | | | |
| **9** | 15.38 | 15.47 | -0.09 | 11.43 | 12.97 | -1.54 | 19.60 | 19.36 | 0.24 | | | |
| **7** | 16.23 | 17.89 | -1.66 | 15.63 | 15.59 | 0.04 | 24.34 | 21.56 | 2.78 | | | |
| **5.5** | 21.32 | 19.71 | 1.62 | 19.61 | 17.56 | 2.06 | 21.74 | 23.21 | -1.47 | | | |

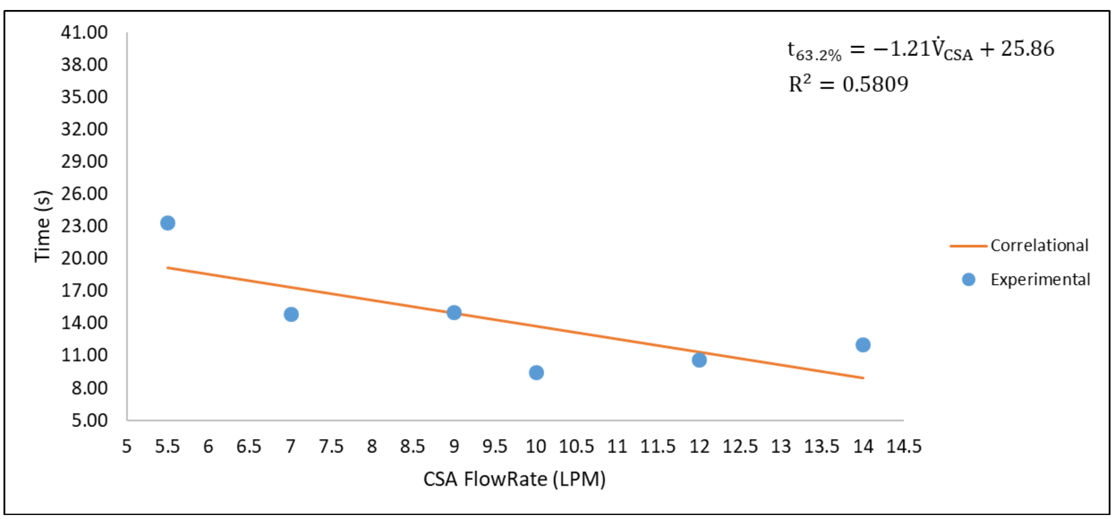


**Figure B1: Experimental and correlational time response of R2-36 at different flowrates**

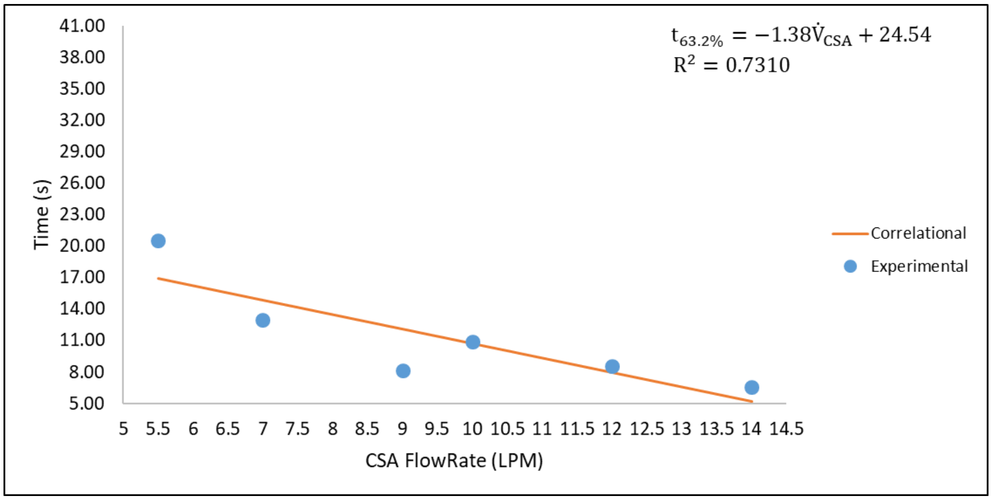

**Figure B2: Experimental and correlational time response of R2-48 at different flowrates**

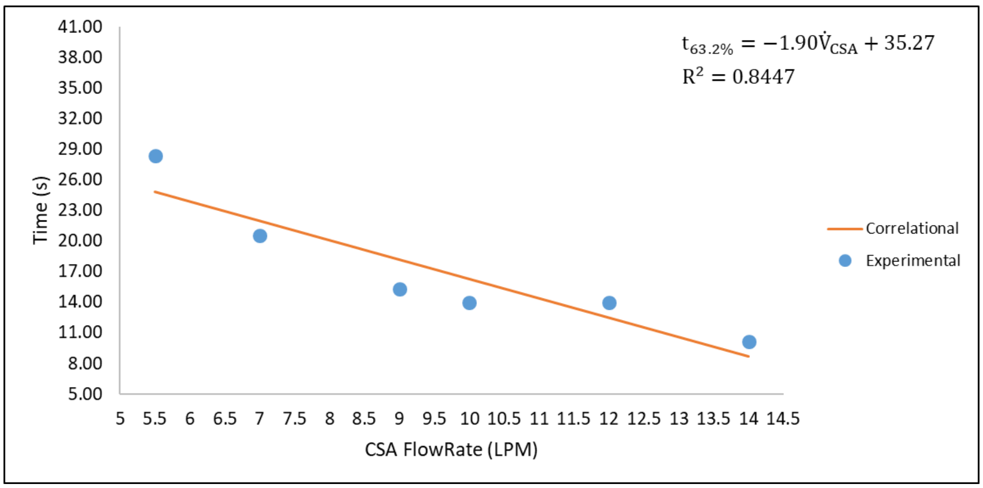

**Figure B3: Experimental and correlational time response of R2-60 at different flowrates**

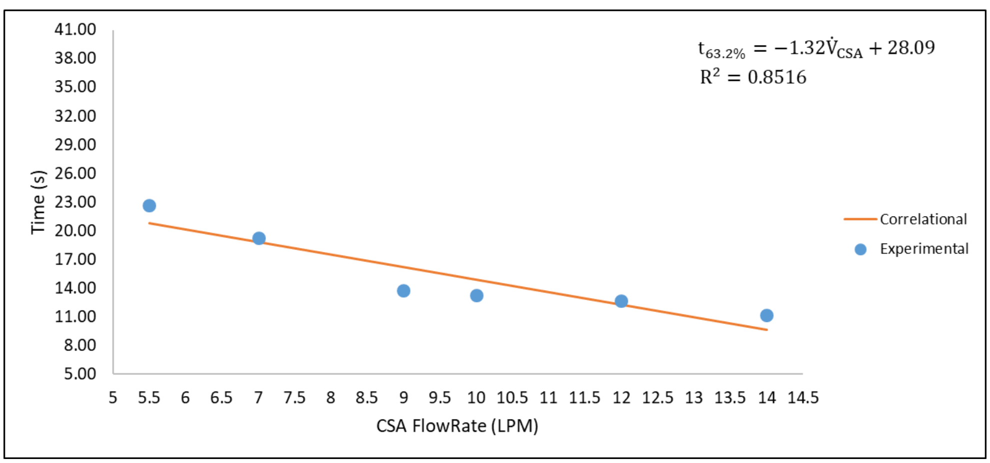

**Figure B4: Experimental and correlational time response of R3-36 at different flowrates**

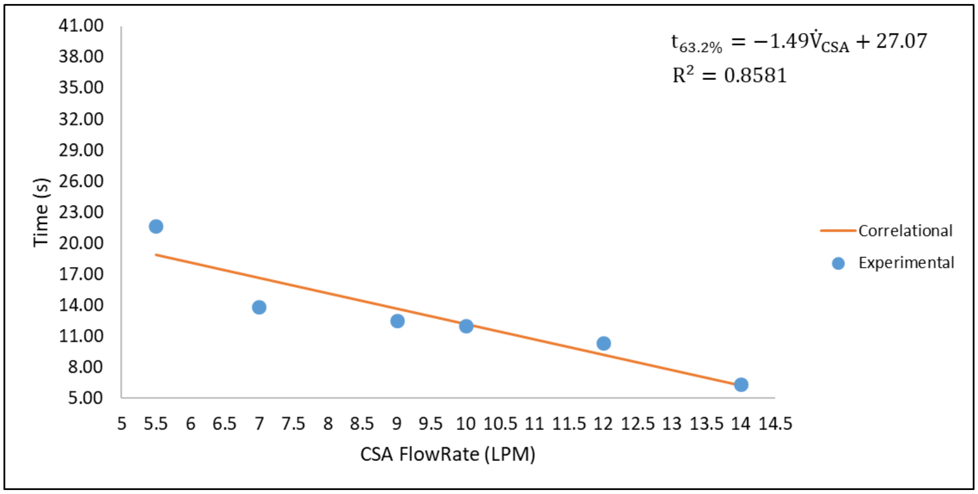


**Figure B5: Experimental and correlational time response of R3-48 at different flowrates**

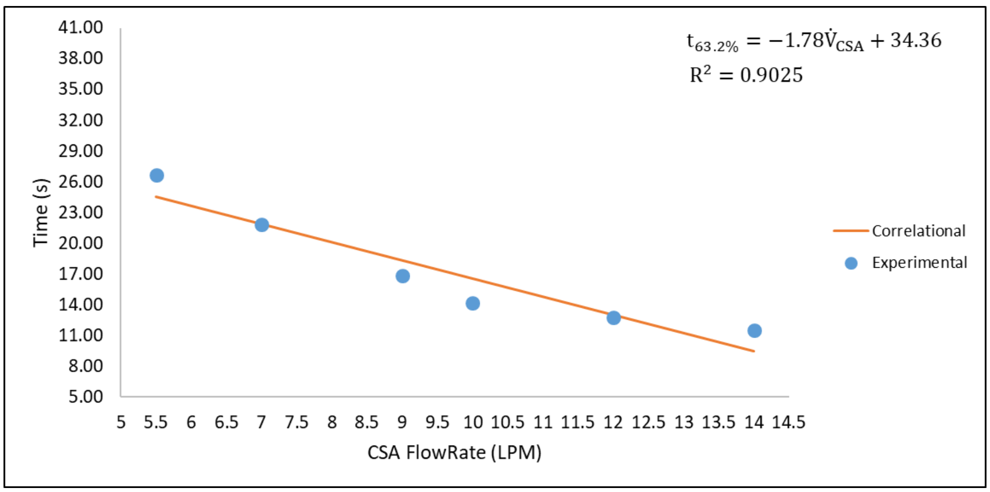


**Figure B6: Experimental and correlational time response of R3-60 at different flowrates**

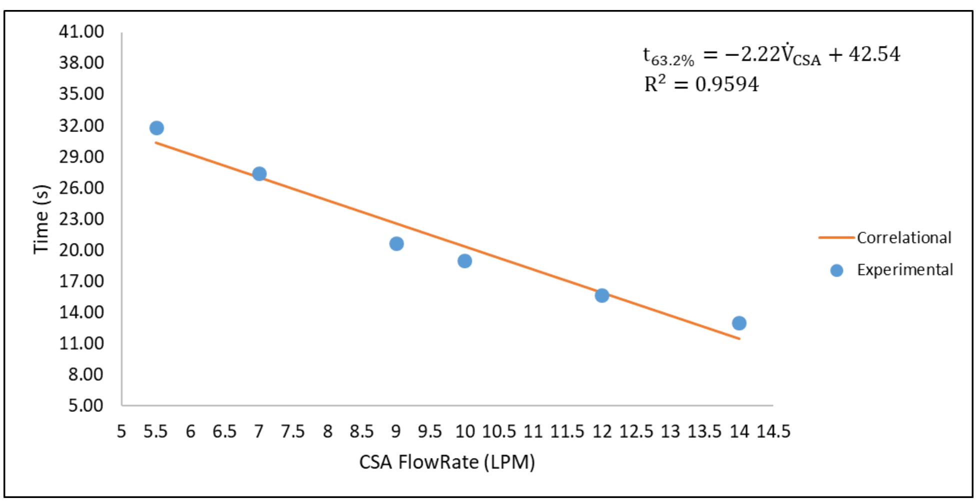


**Figure B7: Experimental and correlational time response of R3-72 at different flowrates**

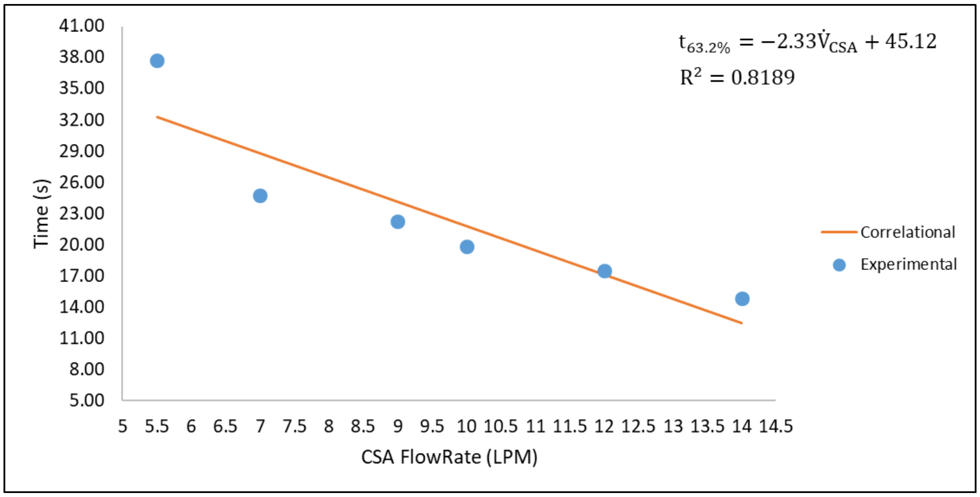


**Figure B8: Experimental and correlational time response of R3-84 at different flowrates**

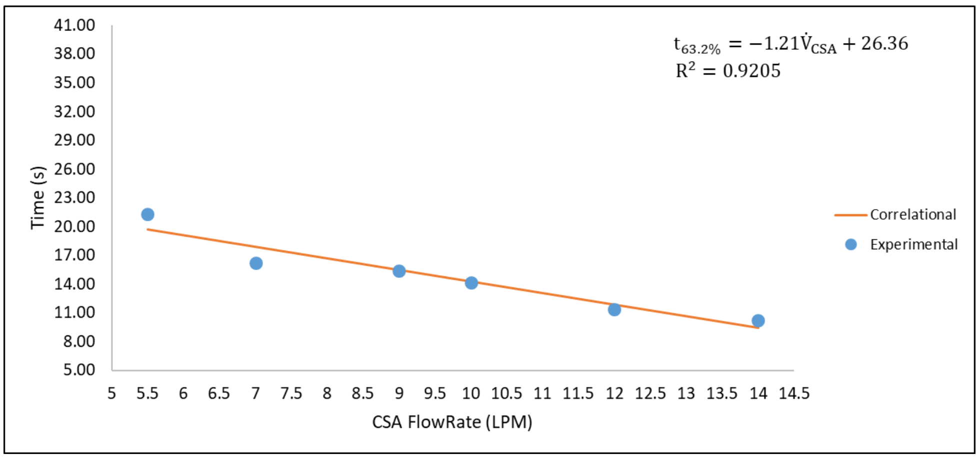


**Figure B9: Experimental and correlational time response of R4-36 at different flowrates**

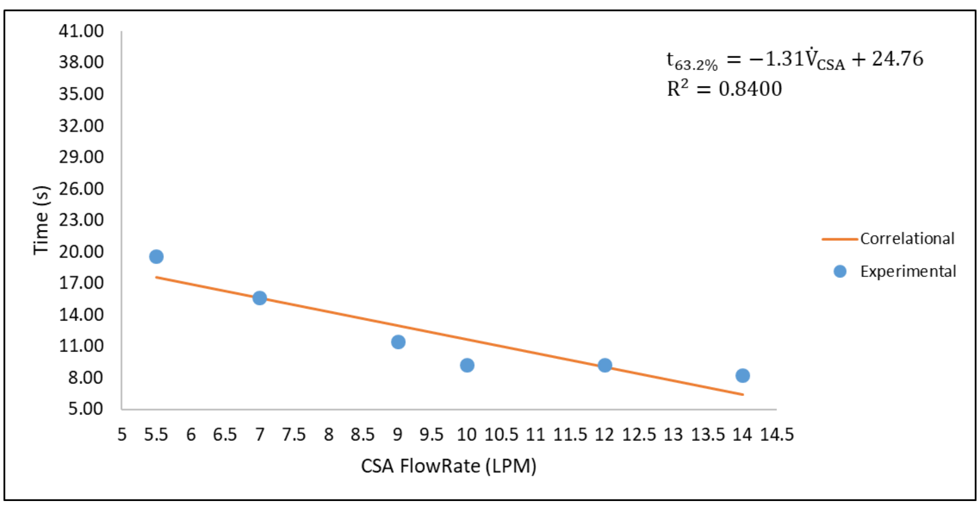


**Figure B10: Experimental and correlational time response of R4-48 at different flowrates**

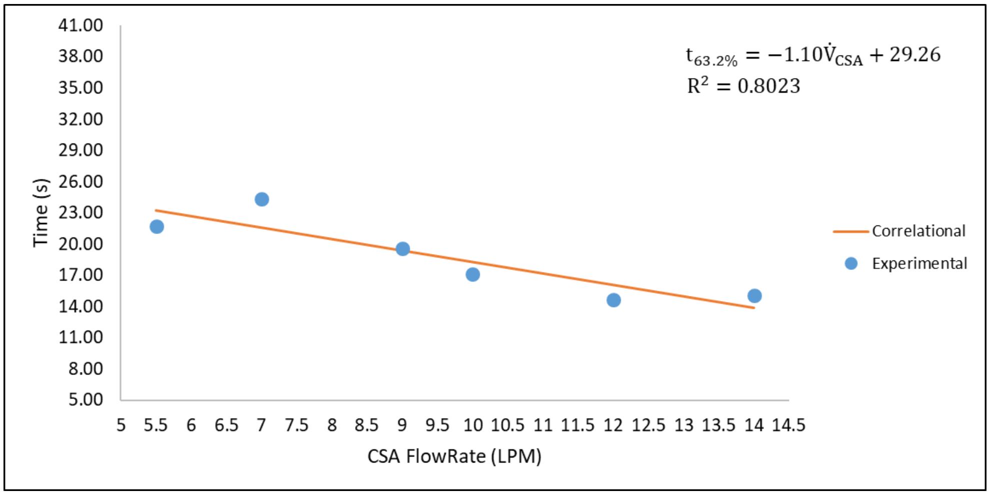


**Figure B11: Experimental and correlational time response of R4-60 at different flowrates**

**Table B2: Difference between experimental and correlational time response of 3" drain-side diameter DWHR systems at CSA flowrates as a function of drain-side length**

| DrainSide Length | 14LPM | | | 12LPM | | | 10LPM | | |
|---|---|---|---|---|---|---|---|---|---|
| | Experimental (s) | Correlational (s) | Δt (s) | Experimental (s) | Correlational (s) | Δt (s) | Experimental (s) | Correlational (s) | Δt (s) |
| **36** | 11.17 | 8.69 | 2.48 | 12.71 | 11.00 | 1.71 | 13.25 | 11.69 | 1.56 |
| **48** | 6.35 | 10.13 | -3.78 | 10.35 | 12.56 | -2.21 | 12.03 | 13.73 | -1.70 |
| **60** | 11.54 | 11.57 | -0.03 | 12.74 | 14.12 | -1.38 | 14.14 | 15.77 | -1.63 |
| **72** | 13.04 | 13.01 | 0.03 | 15.67 | 15.68 | -0.01 | 19.01 | 17.81 | 1.20 |
| **84** | 14.84 | 14.45 | 0.39 | 17.52 | 17.24 | 0.28 | 19.85 | 19.85 | 0.00 |
| **DrainSide Length** | **9LPM** | | | **7LPM** | | | **5.5LPM** | | |
| | Experimental (s) | Correlational (s) | Δt (s) | Experimental (s) | Correlational (s) | Δt (s) | Experimental (s) | Correlational (s) | Δt (s) |
| **36** | 13.76 | 12.23 | 1.53 | 19.28 | 16.42 | 2.86 | 22.66 | 20.21 | 2.45 |
| **48** | 12.49 | 14.75 | -2.27 | 13.86 | 18.82 | -4.96 | 21.63 | 24.29 | -2.66 |
| **60** | 16.88 | 17.27 | -0.39 | 21.87 | 21.22 | 0.65 | 26.66 | 28.37 | -1.71 |
| **72** | 20.66 | 19.79 | 0.87 | 27.37 | 23.62 | 3.75 | 31.81 | 32.45 | -0.65 |
| **84** | 22.21 | 22.31 | -0.10 | 24.72 | 26.02 | -1.30 | 37.69 | 36.53 | 1.16 |

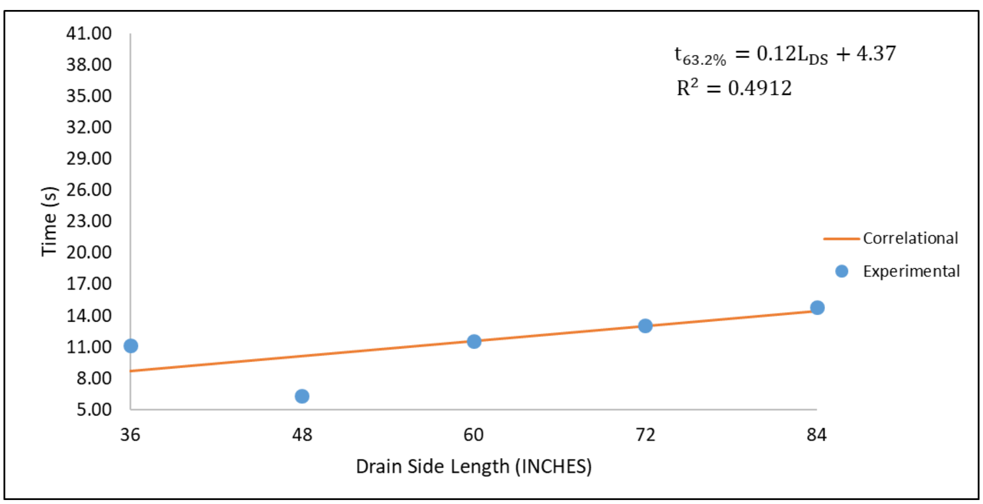


**Figure B12: Experimental and correlational time response at 14LPM for all 3" drain-side diameter DWHR systems**

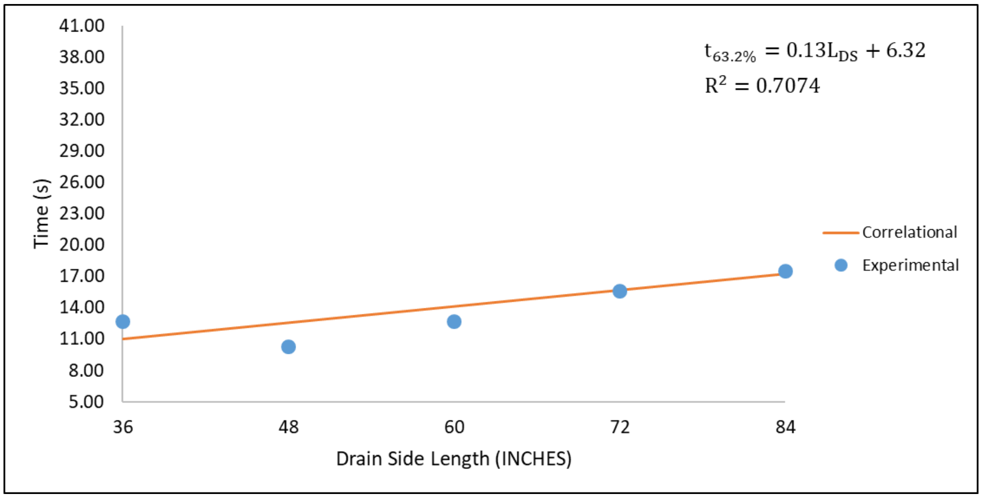


**Figure B13: Experimental and correlational time response at 12LPM for all 3" drain-side diameter DWHR systems**

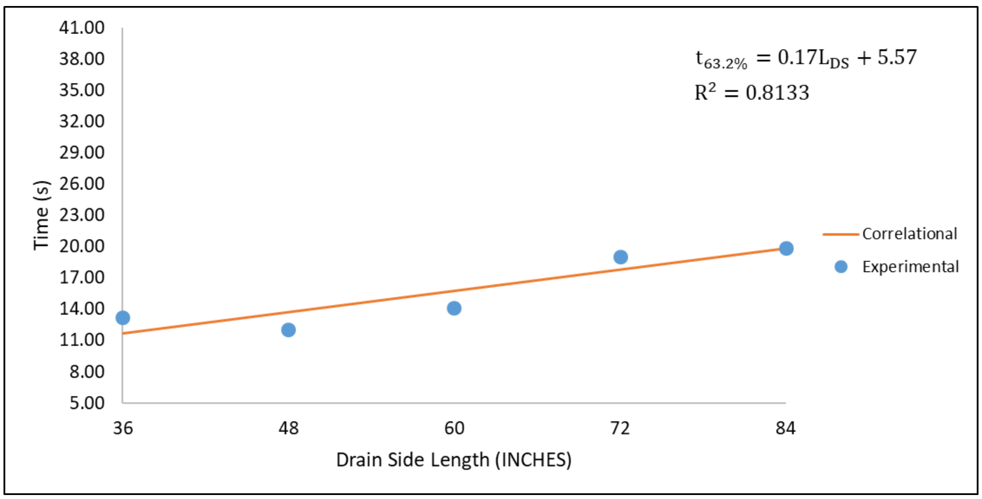


**Figure B14: Experimental and correlational time response at 10LPM for all 3" drain-side diameter DWHR systems**

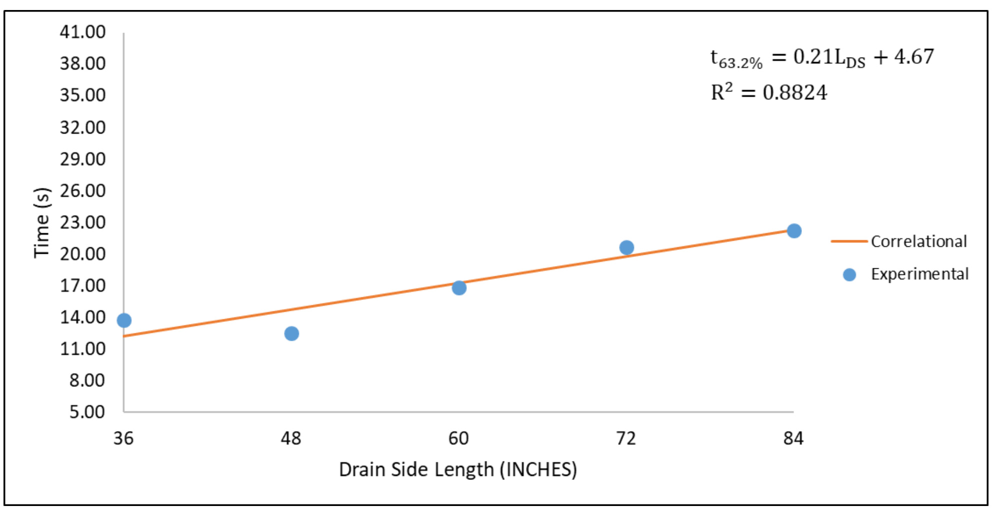


**Figure B15: Experimental and correlational time response at 9LPM for all 3" drain-side diameter DWHR systems**

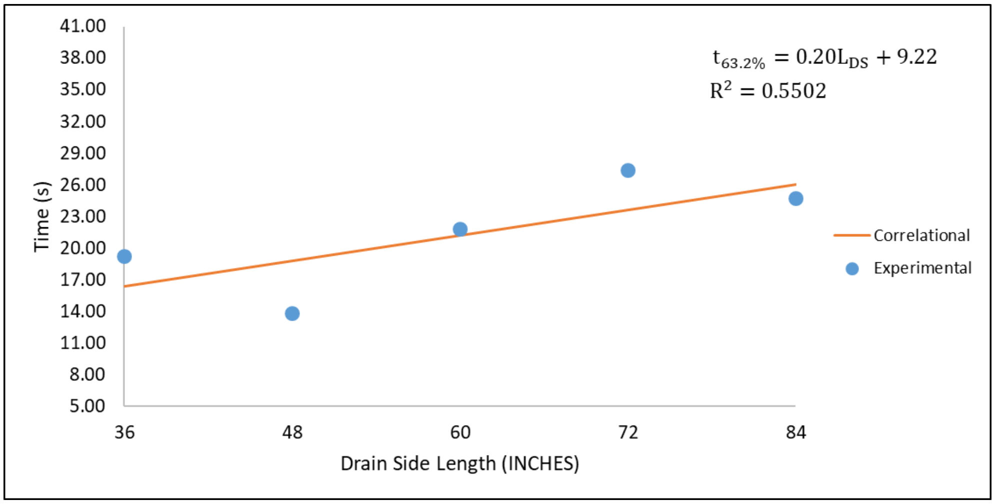


**Figure B16: Experimental and correlational time response at 7LPM for all 3" drain-side diameter DWHR systems**

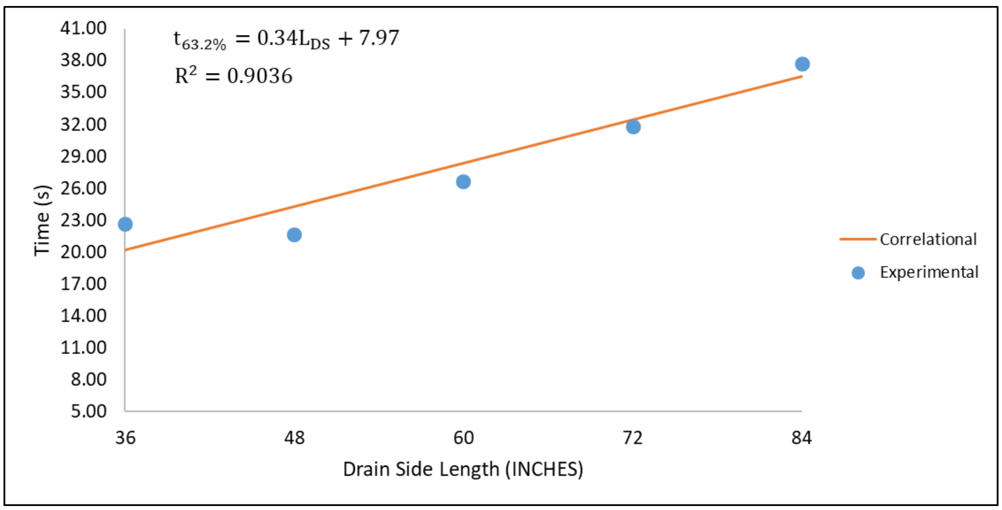


**Figure B17: Experimental and correlational time response at 5.5LPM for all 3" drain-side diameter DWHR systems**

# Appendix C: 86.5% Response Time Data Tables and Plots

**Table C1: Summarized mains-side heat transfer rate and 86.5% time responses**

| | 14LPM | | | 12LPM | | | 10LPM | | |
|---|---|---|---|---|---|---|---|---|---|
| | $q_{flow, ss}$ (kW) | $q_{flow, 86.5\%}$ (kW) | $t_{86.5\%}$ | $q_{flow, ss}$ (kW) | $q_{flow, 86.5\%}$ (kW) | $t_{86.5\%}$ | $q_{flow, ss}$ (kW) | $q_{flow, 86.5\%}$ (kW) | $t_{86.5\%}$ |
| **R2-36** | 7.0634 | 6.1098 | 13.77 | 6.5590 | 5.6735 | 16.90 | 5.8895 | 5.0944 | 16.45 |
| **R2-48** | 9.3638 | 8.0996 | 9.04 | 8.7810 | 7.5955 | 11.32 | 7.7948 | 6.7425 | 16.55 |
| **R2-60** | 10.5090 | 9.0903 | 16.74 | 9.5071 | 8.2237 | 20.77 | 8.4508 | 7.3100 | 20.70 |
| **R3-36** | 9.2588 | 8.0089 | 16.74 | 8.3857 | 7.2536 | 19.54 | 7.5334 | 6.5164 | 20.81 |
| **R3-48** | 10.6157 | 9.1826 | 10.81 | 9.9115 | 8.5734 | 17.65 | 8.7781 | 7.5931 | 20.99 |
| **R3-60** | 12.2646 | 10.6089 | 19.19 | 11.3902 | 9.8525 | 20.29 | 9.8698 | 8.5374 | 23.68 |
| **R3-72** | 13.5054 | 11.6821 | 19.31 | 12.2686 | 10.6124 | 22.71 | 10.7084 | 9.2628 | 28.32 |
| **R3-84** | 15.7138 | 13.5924 | 20.38 | 13.8137 | 11.9488 | 26.51 | 12.2496 | 10.5959 | 31.72 |
| **R4-36** | 9.1926 | 7.9516 | 16.88 | 8.3669 | 7.2373 | 18.13 | 7.4888 | 6.4778 | 24.85 |
| **R4-48** | 12.1702 | 10.5272 | 13.57 | 11.0910 | 9.5937 | 15.64 | 9.7894 | 8.4678 | 14.94 |
| **R4-60** | 13.1833 | 11.4036 | 21.87 | 12.2273 | 10.5766 | 21.39 | 10.7212 | 9.2738 | 25.93 |
| | **9LPM** | | | **7LPM** | | | **5.5LPM** | | |
| | $q_{flow, ss}$ (kW) | $q_{flow, 86.5\%}$ (kW) | $t_{86.5\%}$ | $q_{flow, ss}$ (kW) | $q_{flow, 86.5\%}$ (kW) | $t_{86.5\%}$ | $q_{flow, ss}$ (kW) | $q_{flow, 86.5\%}$ (kW) | $t_{86.5\%}$ |
| **R2-36** | 5.4296 | 4.6966 | 23.78 | 4.7779 | 4.1329 | 24.80 | 4.0817 | 3.5307 | 33.98 |
| **R2-48** | 7.3167 | 6.3290 | 12.93 | 6.0842 | 5.2628 | 21.01 | 5.2565 | 4.5469 | 34.56 |
| **R2-60** | 7.8195 | 6.7638 | 23.71 | 6.5915 | 5.7016 | 32.82 | 5.5835 | 4.8297 | 43.23 |
| **R3-36** | 6.9465 | 6.0087 | 21.87 | 6.1160 | 5.2903 | 31.58 | 5.2744 | 4.5624 | 36.80 |
| **R3-48** | 8.2330 | 7.1216 | 22.71 | 6.9507 | 6.0124 | 25.34 | 6.0107 | 5.1993 | 39.12 |
| **R3-60** | 9.3487 | 8.0866 | 26.86 | 7.9195 | 6.8504 | 36.52 | 6.7050 | 5.7998 | 44.61 |
| **R3-72** | 10.0905 | 8.7283 | 30.77 | 8.3953 | 7.2619 | 42.50 | 7.0852 | 6.1287 | 53.37 |
| **R3-84** | 11.2903 | 9.7661 | 34.93 | 9.2137 | 7.9698 | 39.89 | 7.5622 | 6.5413 | 57.25 |
| **R4-36** | 7.0996 | 6.1412 | 23.94 | 4.5884 | 3.9689 | 25.26 | 3.8422 | 3.3235 | 35.77 |
| **R4-48** | 9.2791 | 8.0264 | 19.55 | 7.5757 | 6.5529 | 25.26 | 5.9036 | 5.1066 | 29.37 |
| **R4-60** | 10.1566 | 8.7854 | 30.33 | 8.1510 | 7.0506 | 43.24 | 4.8278 | 4.1760 | 30.28 |

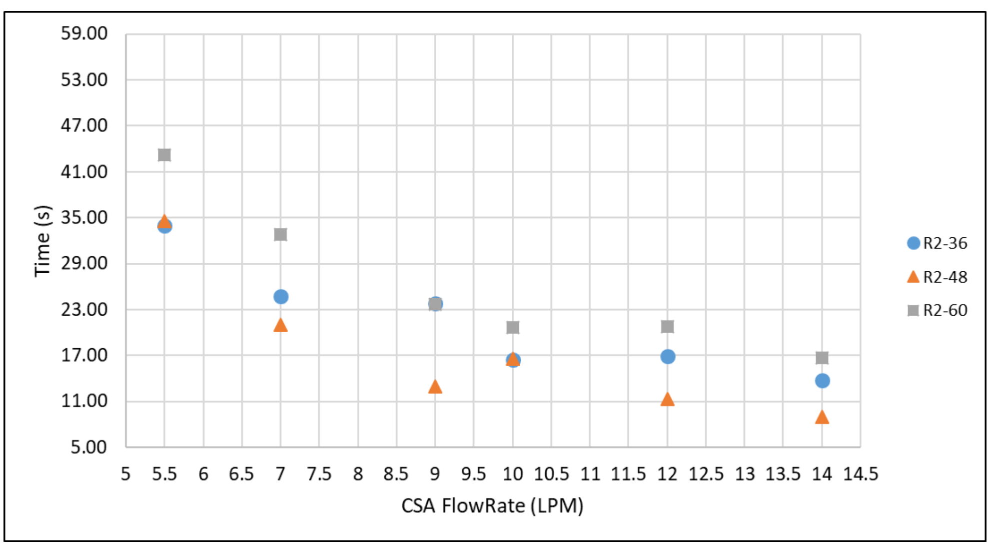


**Figure C1: Experimental 86.5% time response vs flowrate of 2" drain-side diameter DWHR systems**

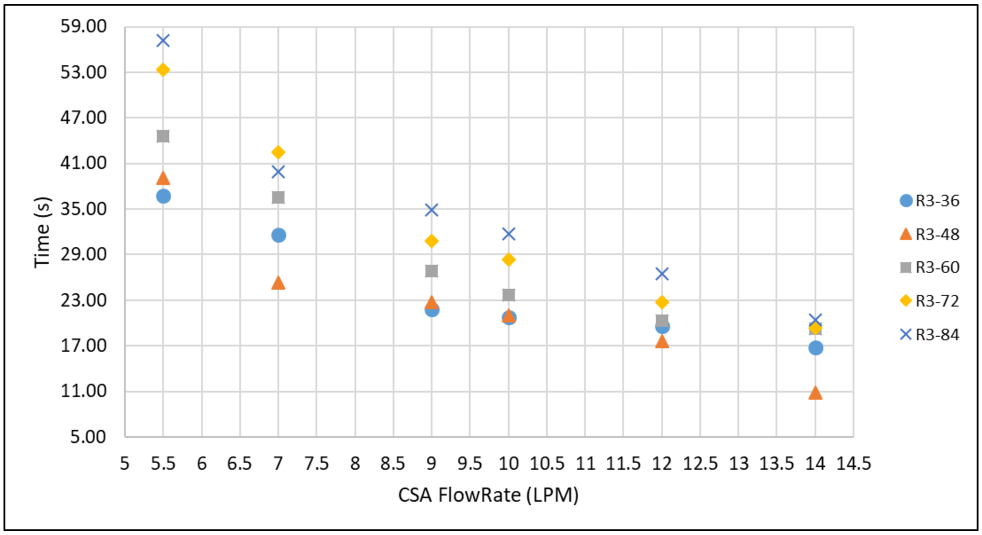


**Figure C2: Experimental 86.5% time response vs flowrate of 3" drain-side diameter DWHR systems**

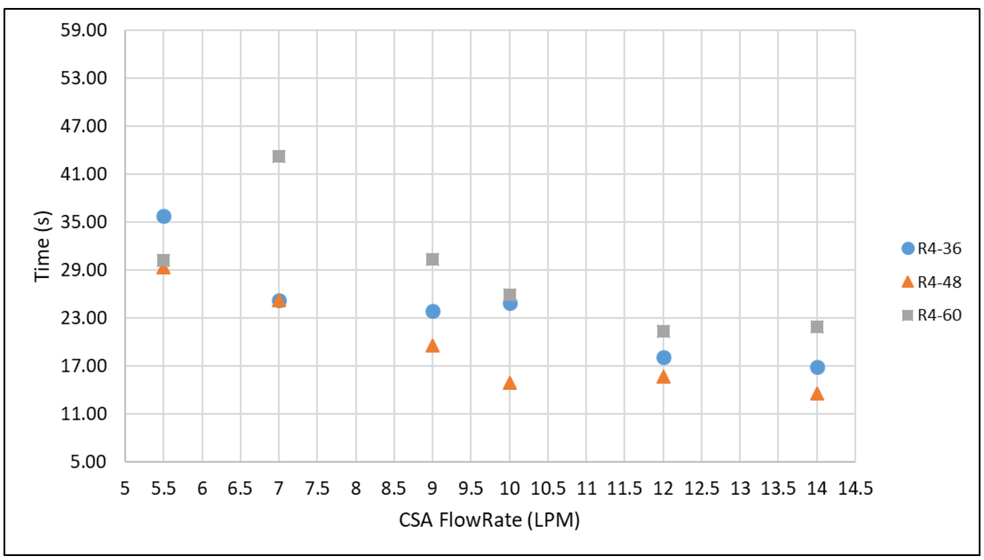


**Figure C3: Experimental 86.5% time response vs flowrate of 4" drain-side diameter DWHR systems**

**Table C2: Correlation coefficients for all DWHR systems as a function of CSA flowrate**

| | A<br>$\frac{s}{\left(\frac{L}{min}\right)}$ | B<br>s | $R^2$ |
|---|---|---|---|
| **R2-36** | -2.20 | 42.68 | 0.8549 |
| **R2-48** | -2.62 | 42.64 | 0.7747 |
| **R2-60** | -2.89 | 54.06 | 0.8422 |
| **R3-36** | -2.33 | 46.91 | 0.8729 |
| **R3-48** | -2.83 | 49.90 | 0.8836 |
| **R3-60** | -3.02 | 57.45 | 0.8896 |
| **R3-72** | -3.94 | 70.55 | 0.924 |
| **R3-84** | -3.86 | 72.10 | 0.8987 |
| **R4-36** | -1.96 | 42.95 | 0.8389 |
| **R4-48** | -1.88 | 37.76 | 0.8668 |
| **R4-60** | -1.91 | 47.14 | 0.5533 |

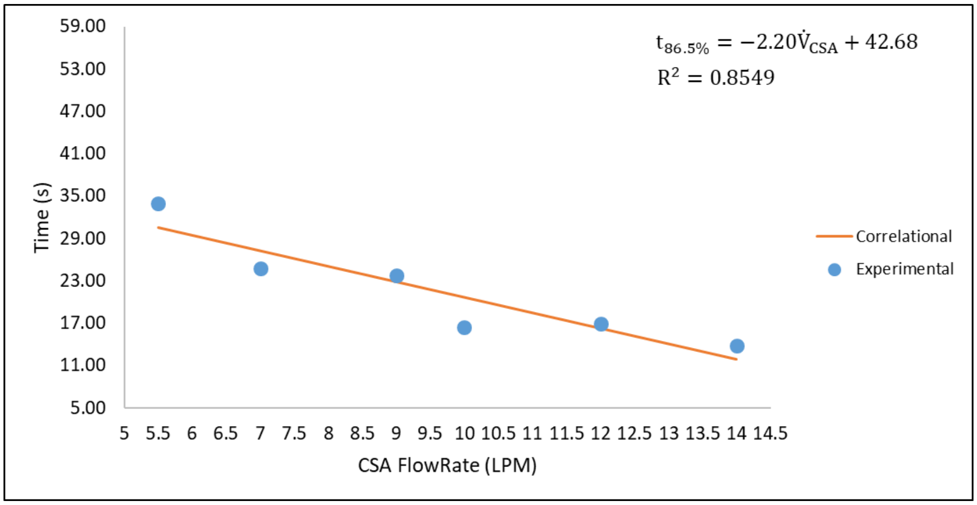


**Figure C4: Experimental and correlational time response of R2-36 at different flowrates**

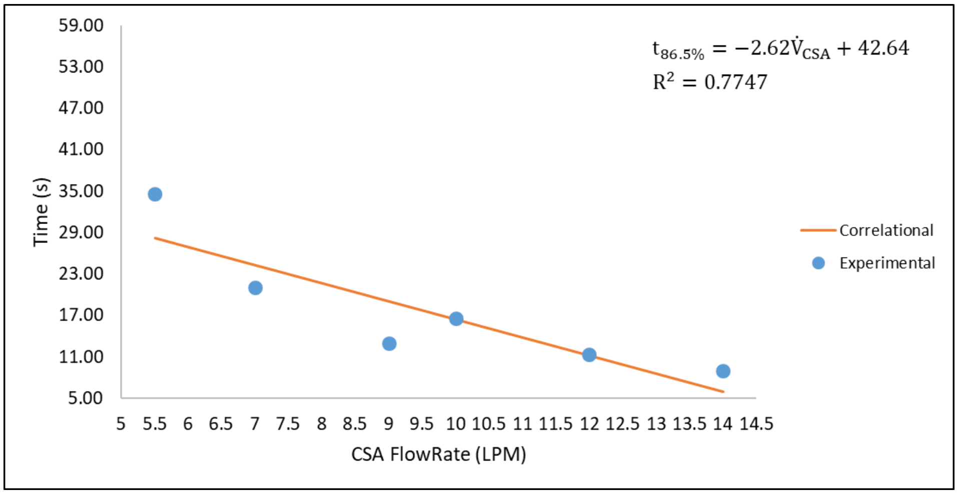


**Figure C5: Experimental and correlational time response of R2-48 at different flowrates**

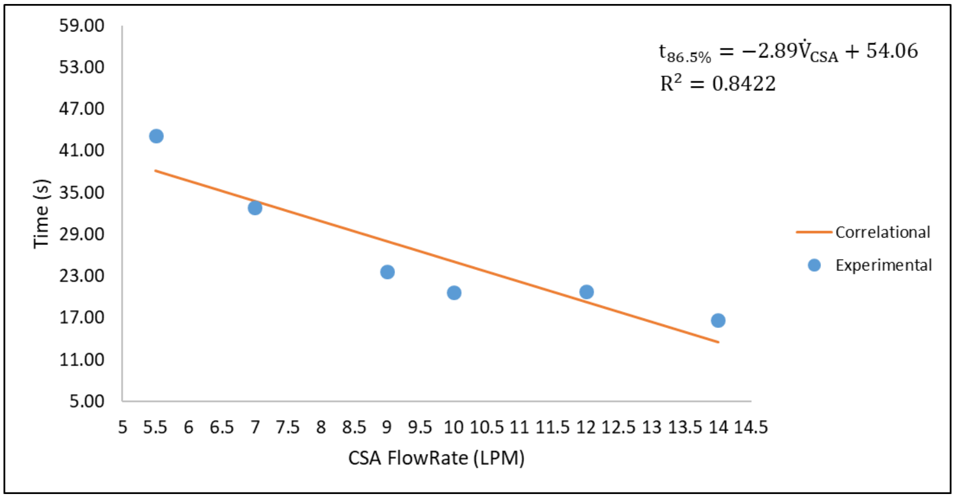


**Figure C6: Experimental and correlational time response of R2-60 at different flowrates**

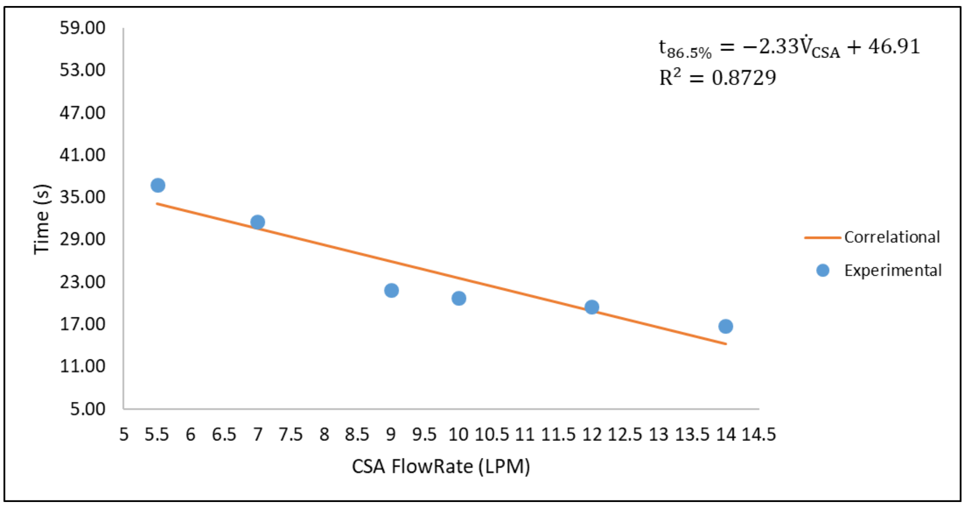


**Figure C7: Experimental and correlational time response of R3-36 at different flowrates**

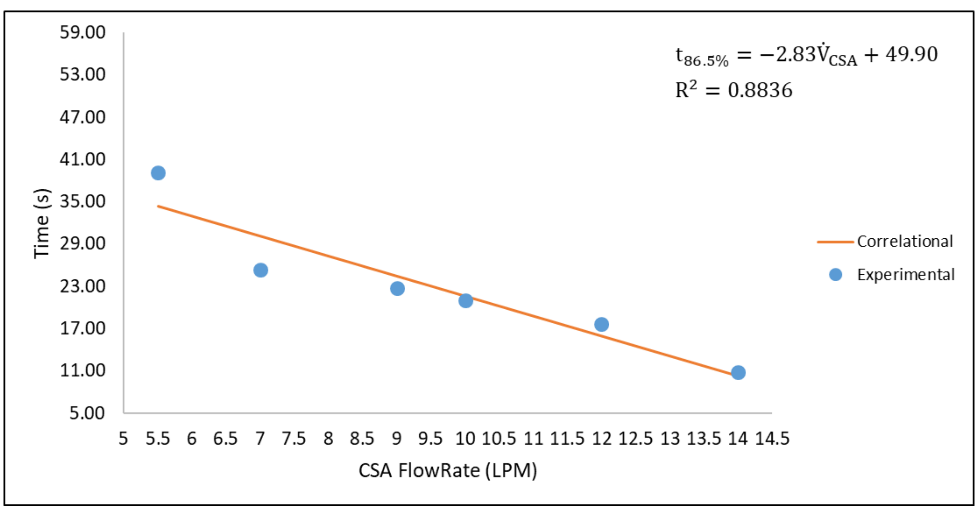


**Figure C8: Experimental and correlational time response of R3-48 at different flowrates**

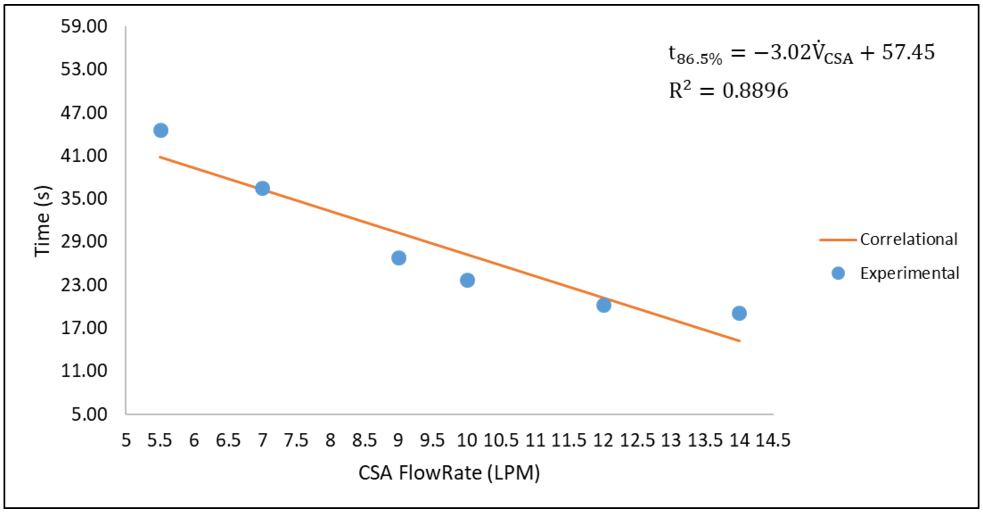


**Figure C9: Experimental and correlational time response of R3-60 at different flowrates**

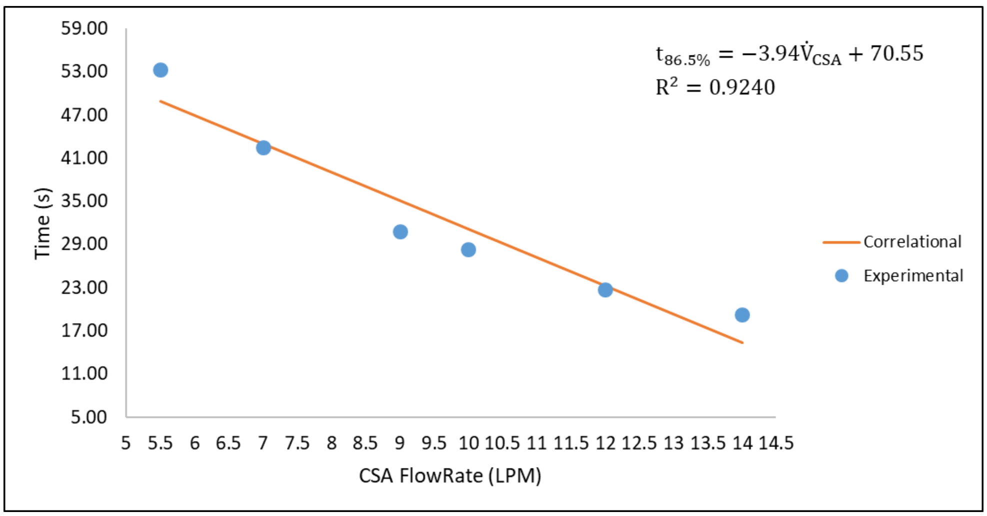


**Figure C10: Experimental and correlational time response of R3-72 at different flowrates**

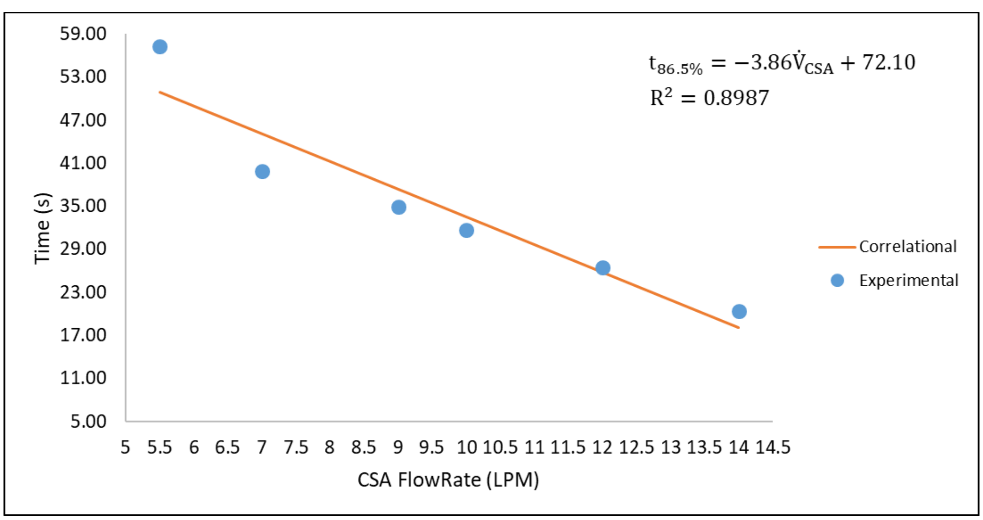


**Figure C11: Experimental and correlational time response of R3-84 at different flowrates**

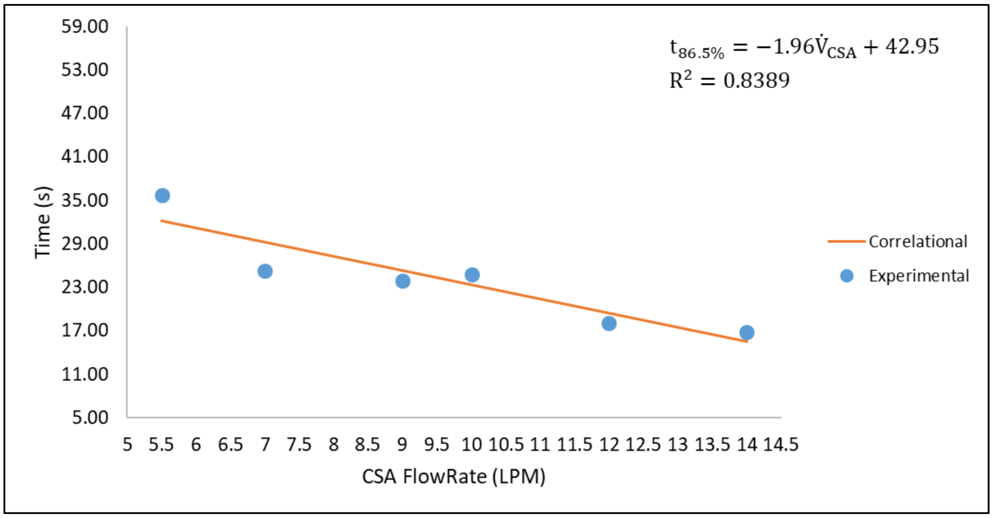


**Figure C12: Experimental and correlational time response of R4-36 at different flowrates**

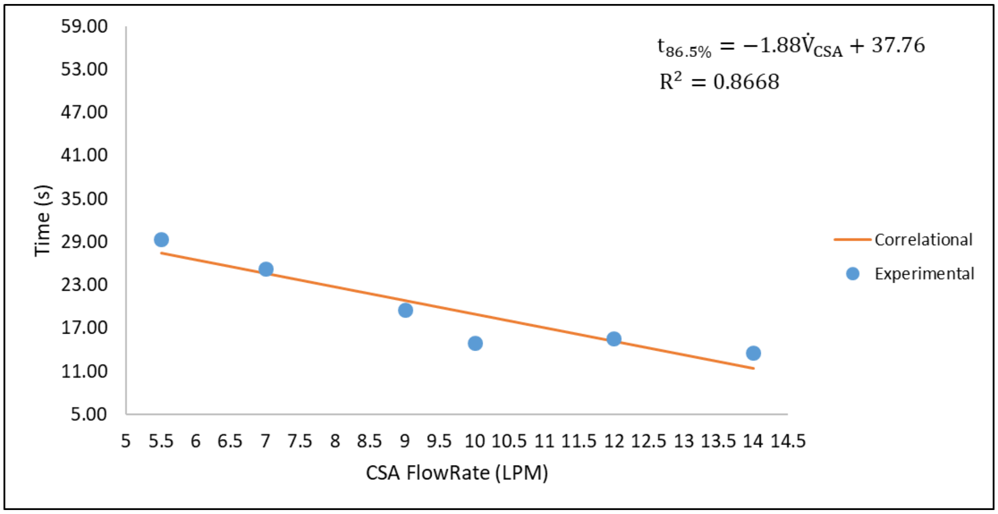


**Figure C13: Experimental and correlational time response of R4-48 at different flowrates**

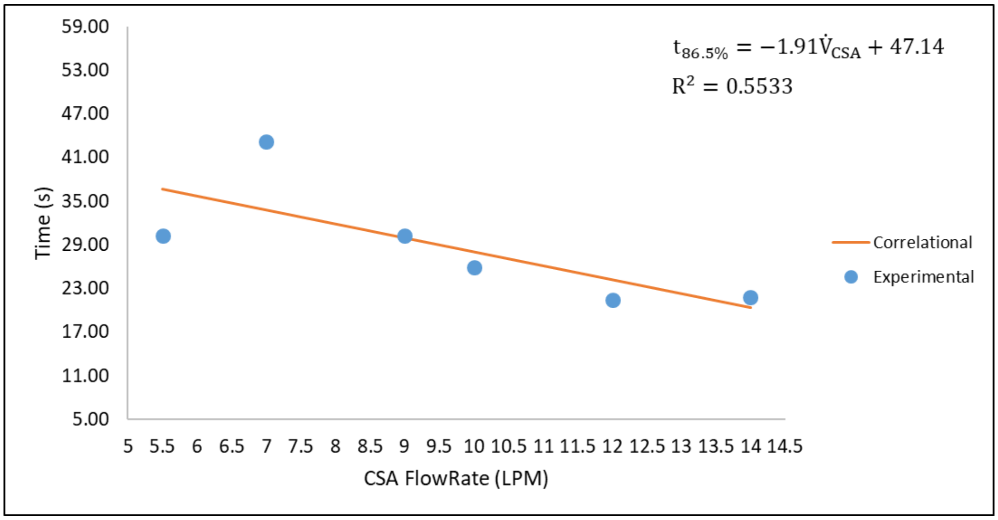


**Figure C14: Experimental and correlational time response of R4-60 at different flowrates**

**Table C3: Difference between experimental and correlational time response all DWHR systems at CSA flowrates**

| Flowrate | R2-36 | | | R2-48 | | | R2-60 | | | R3-72 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Experimental (s) | Correlational (s) | Δt (s) | Experimental (s) | Correlational (s) | Δt (s) | Experimental (s) | Correlational (s) | Δt (s) | Experimental (s) | Correlational (s) | Δt (s) |
| **14** | 13.77 | 11.88 | 1.89 | 9.04 | 5.96 | 3.08 | 16.74 | 13.60 | 3.14 | 19.31 | 15.39 | 3.92 |
| **12** | 16.90 | 16.28 | 0.62 | 11.32 | 11.20 | 0.12 | 20.77 | 19.38 | 1.39 | 22.71 | 23.27 | -0.56 |
| **10** | 16.45 | 20.68 | -4.23 | 16.55 | 16.44 | 0.11 | 20.70 | 25.16 | -4.46 | 28.32 | 31.15 | -2.83 |
| **9** | 23.78 | 22.88 | 0.90 | 12.93 | 19.06 | -6.13 | 23.71 | 28.05 | -4.34 | 30.77 | 35.09 | -4.32 |
| **7** | 24.80 | 27.28 | -2.48 | 21.01 | 24.30 | -3.29 | 32.82 | 33.83 | -1.01 | 42.50 | 42.97 | -0.47 |
| **5.5** | 33.98 | 30.58 | 3.40 | 34.56 | 28.23 | 6.33 | 43.23 | 38.17 | 5.07 | 53.37 | 48.88 | 4.49 |
| **Flowrate** | **R3-36** | | | **R3-48** | | | **R3-60** | | | **R3-84** | | |
| | Experimental (s) | Correlational (s) | Δt (s) | Experimental (s) | Correlational (s) | Δt (s) | Experimental (s) | Correlational (s) | Δt (s) | Experimental (s) | Correlational (s) | Δt (s) |
| **14** | 16.74 | 14.29 | 2.45 | 10.81 | 10.28 | 0.53 | 19.19 | 15.17 | 4.02 | 20.38 | 18.06 | 2.32 |
| **12** | 19.54 | 18.95 | 0.59 | 17.65 | 15.94 | 1.71 | 20.29 | 21.21 | -0.92 | 26.51 | 25.78 | 0.73 |
| **10** | 20.81 | 23.61 | -2.80 | 20.99 | 21.60 | -0.61 | 23.68 | 27.25 | -3.57 | 31.72 | 33.50 | -1.78 |
| **9** | 21.87 | 25.94 | -4.07 | 22.71 | 24.43 | -1.72 | 26.86 | 30.27 | -3.41 | 34.93 | 37.36 | -2.43 |
| **7** | 31.58 | 30.60 | 0.98 | 25.34 | 30.09 | -4.75 | 36.52 | 36.31 | 0.21 | 39.89 | 45.08 | -5.19 |
| **5.5** | 36.80 | 34.10 | 2.71 | 39.12 | 34.34 | 4.79 | 44.61 | 40.84 | 3.77 | 57.25 | 50.87 | 6.38 |
| **Flowrate** | **R4-36** | | | **R4-48** | | | **R4-60** | | | | | |
| | Experimental (s) | Correlational (s) | Δt (s) | Experimental (s) | Correlational (s) | Δt (s) | Experimental (s) | Correlational (s) | Δt (s) | | | |
| **14** | 16.88 | 15.51 | 1.36 | 13.57 | 11.44 | 2.13 | 21.87 | 20.40 | 1.47 | | | |
| **12** | 18.13 | 19.43 | -1.30 | 15.64 | 15.20 | 0.44 | 21.39 | 24.22 | -2.83 | | | |
| **10** | 24.85 | 23.35 | 1.50 | 14.94 | 18.96 | -4.02 | 25.93 | 28.04 | -2.11 | | | |
| **9** | 23.94 | 25.31 | -1.37 | 19.55 | 20.84 | -1.29 | 30.33 | 29.95 | 0.38 | | | |
| **7** | 25.26 | 29.23 | -3.97 | 25.26 | 24.60 | 0.66 | 43.24 | 33.77 | 9.47 | | | |
| **5.5** | 35.77 | 32.17 | 3.60 | 29.37 | 27.42 | 1.95 | 30.28 | 36.64 | -6.36 | | | |

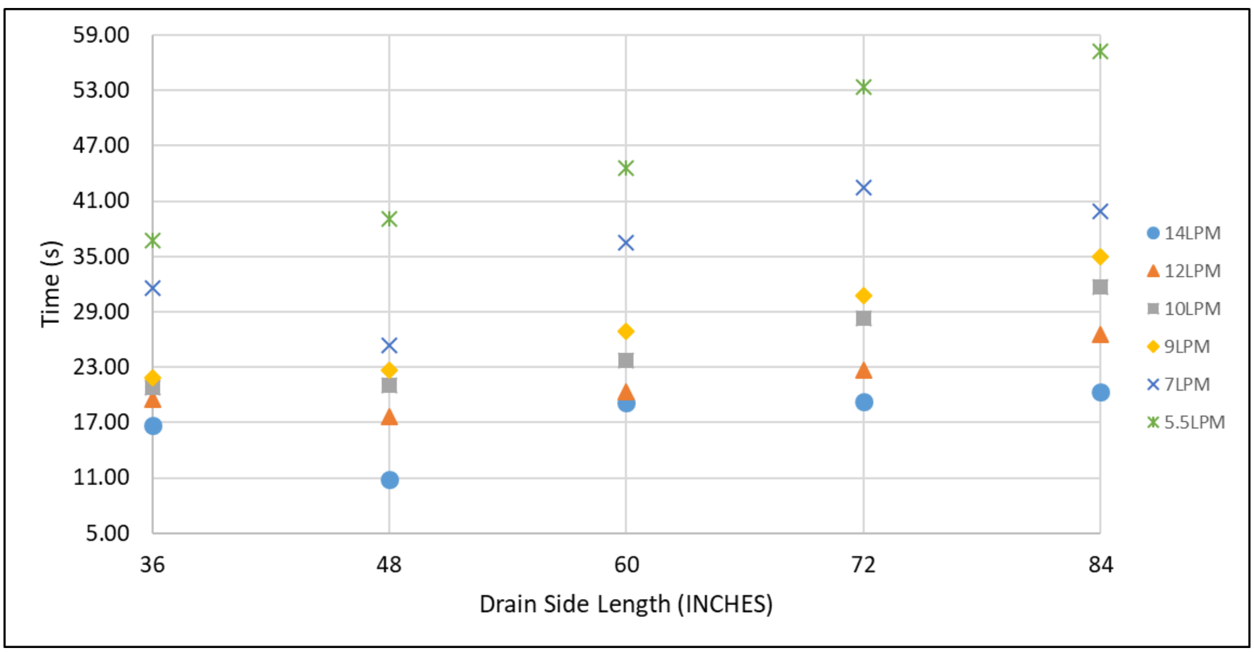


**Figure C15: Experimental 86.5% time response vs drain-side length of 3" drain-side diameter DWHR systems at CSA flowrates**

**Table C4: Correlation coefficients for all 3" drain-side diameter DWHR systems as a function of drain-side length**

| | M $\frac{s}{in}$ | N s | $R^2$ |
|---|---|---|---|
| **14LPM** | 0.13 | 9.39 | 0.4188 |
| **12LPM** | 0.16 | 11.84 | 0.7751 |
| **10LPM** | 0.24 | 10.53 | 0.9285 |
| **9LPM** | 0.28 | 10.34 | 0.9661 |
| **7LPM** | 0.28 | 18.28 | 0.6091 |
| **5.5LPM** | 0.46 | 18.66 | 0.9670 |

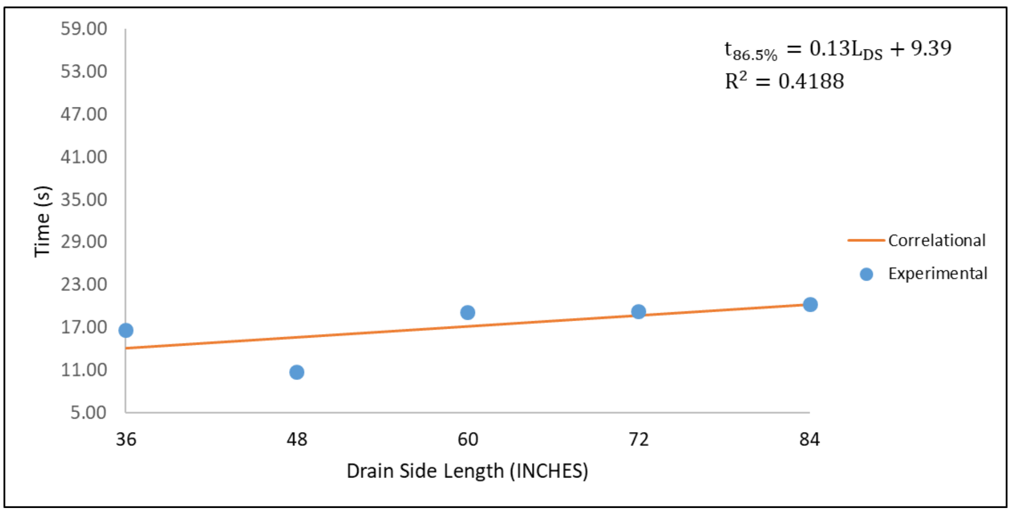


**Figure C16: Experimental and correlational time response at 14LPM for all 3" drain-side diameter DWHR systems**

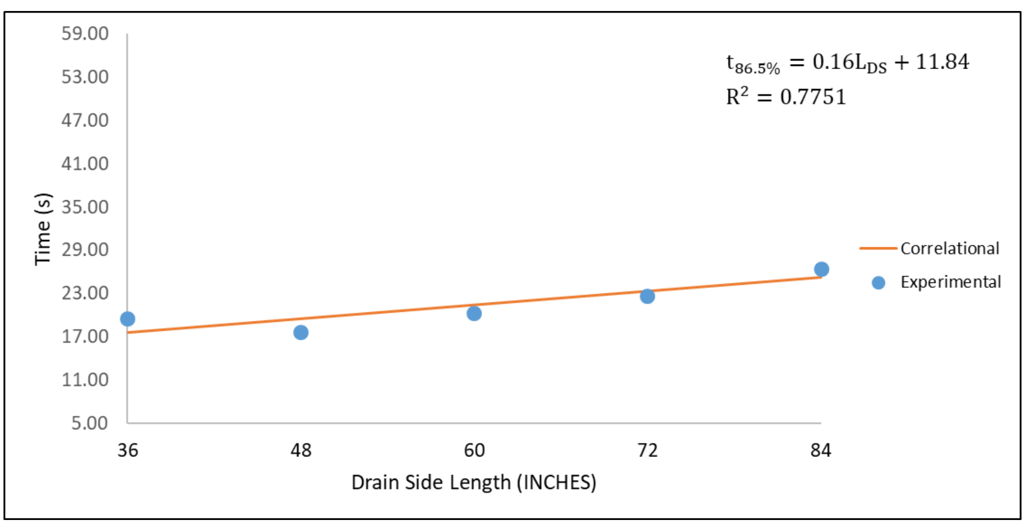


**Figure C17: Experimental and correlational time response at 12LPM for all 3" drain-side diameter DWHR systems**

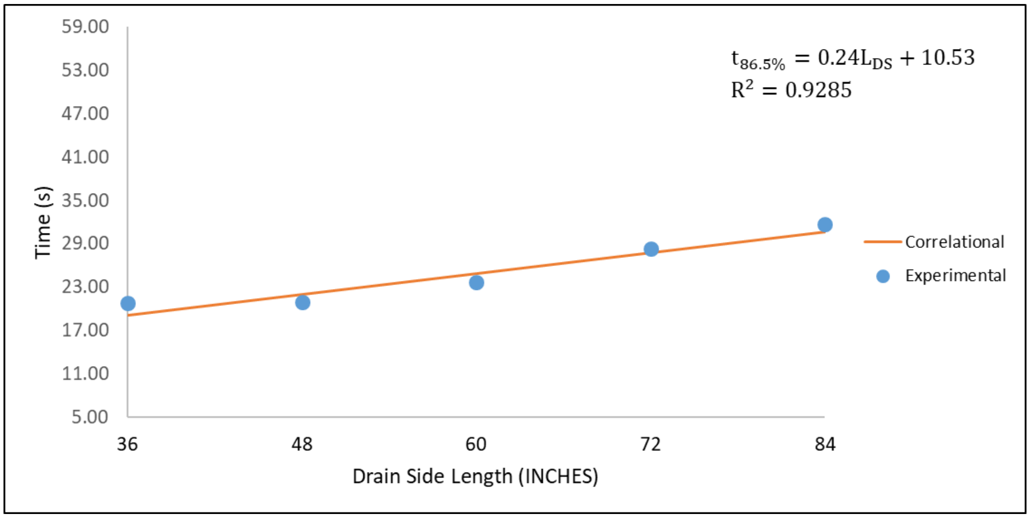


**Figure C18: Experimental and correlational time response at 10LPM for all 3" drain-side diameter DWHR systems**

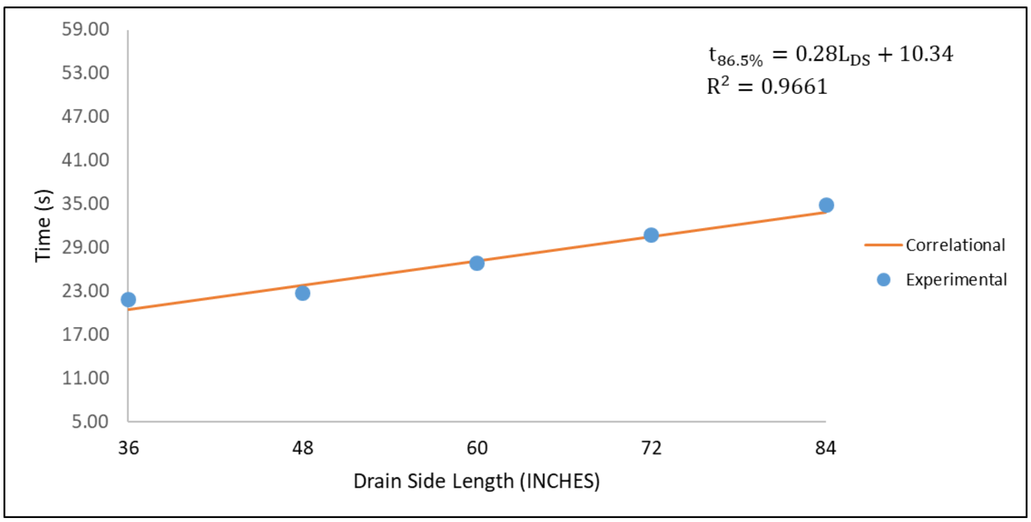


**Figure C19: Experimental and correlational time response at 9LPM for all 3" drain-side diameter DWHR systems**

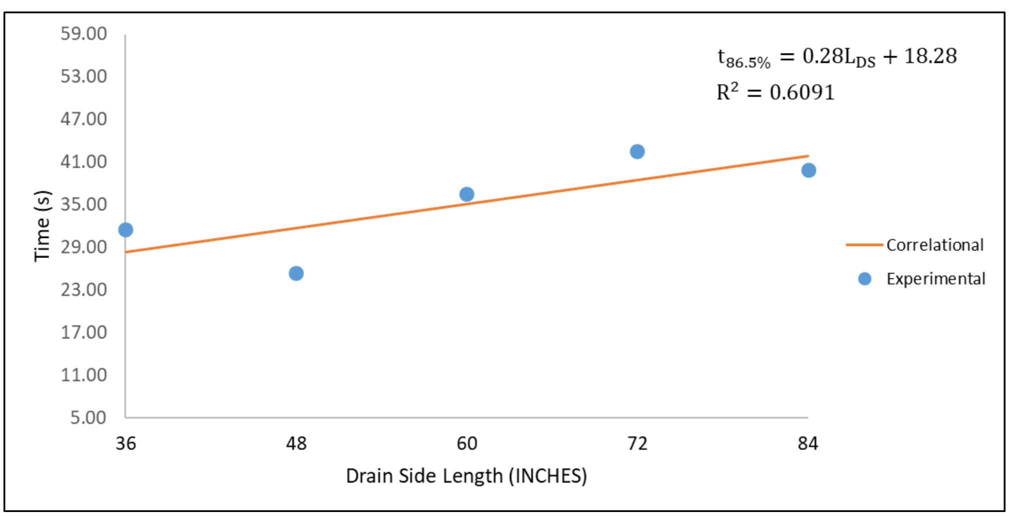


**Figure C20: Experimental and correlational time response at 7LPM for all 3" drain-side diameter DWHR systems**

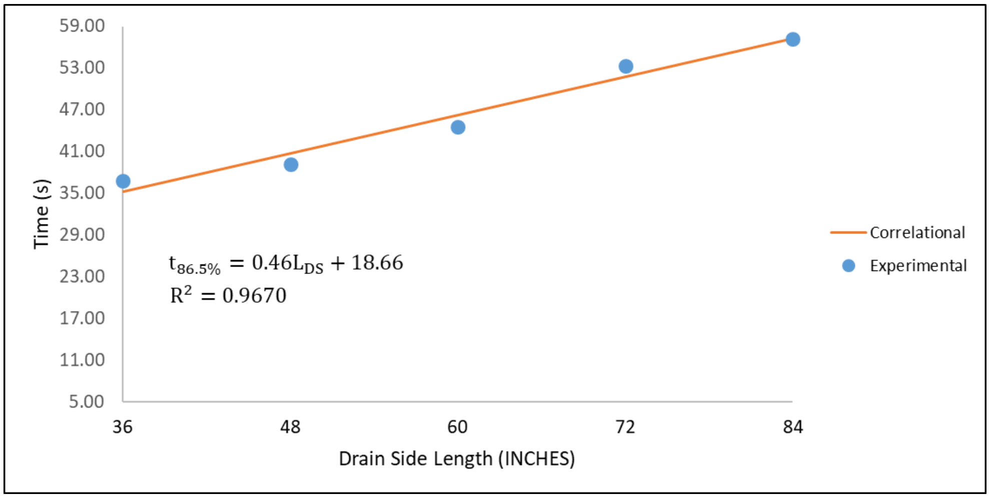


**Figure C21: Experimental and correlational time response at 5.5LPM for all 3" drain-side diameter DWHR systems**

**Table C5: Difference between experimental and correlational time response of 3" drain-side diameter DWHR systems at CSA flowrates as a function of length**

| DrainSide Length | 14LPM | | | 12LPM | | | 10LPM | | |
|---|---|---|---|---|---|---|---|---|---|
| | Experimental (s) | Correlational (s) | Δt (s) | Experimental (s) | Correlational (s) | Δt (s) | Experimental (s) | Correlational (s) | Δt (s) |
| **36** | 16.74 | 14.07 | 2.67 | 19.54 | 17.60 | 1.94 | 20.81 | 19.17 | 1.64 |
| **48** | 10.81 | 15.63 | -4.82 | 17.65 | 19.52 | -1.88 | 20.99 | 22.05 | -1.07 |
| **60** | 19.19 | 17.19 | 2.00 | 20.29 | 21.44 | -1.15 | 23.68 | 24.93 | -1.25 |
| **72** | 19.31 | 18.75 | 0.56 | 22.71 | 23.36 | -0.65 | 28.32 | 27.81 | 0.51 |
| **84** | 20.38 | 20.31 | 0.07 | 26.51 | 25.28 | 1.23 | 31.72 | 30.69 | 1.03 |
| **DrainSide Length** | **9LPM** | | | **7LPM** | | | **5.5LPM** | | |
| | Experimental (s) | Correlational (s) | Δt (s) | Experimental (s) | Correlational (s) | Δt (s) | Experimental (s) | Correlational (s) | Δt (s) |
| **36** | 21.87 | 20.42 | 1.45 | 31.58 | 28.36 | 3.22 | 36.80 | 35.22 | 1.58 |
| **48** | 22.71 | 23.78 | -1.07 | 25.34 | 31.72 | -6.38 | 39.12 | 40.74 | -1.62 |
| **60** | 26.86 | 27.14 | -0.28 | 36.52 | 35.08 | 1.44 | 44.61 | 46.26 | -1.65 |
| **72** | 30.77 | 30.50 | 0.27 | 42.50 | 38.44 | 4.06 | 53.37 | 51.78 | 1.59 |
| **84** | 34.93 | 33.86 | 1.07 | 39.89 | 41.80 | -1.91 | 57.25 | 57.30 | -0.05 |

**Table C6: Correlation validation for different DWHR systems as a function of flowrates**

| | Flowrate (LPM) | Measured | | Predicted | Δt (sec) | % error | $t_{99\%}$ (sec) |
|---|---|---|---|---|---|---|---|
| | | $q_{flow}$ (kW) | $t_{86.5\%}$ (sec) | $t_{86.5\%}$ (sec) | | | |
| R3-48 | **6.07** | 5.6146 | 38.46 | 32.72 | 5.74 | 14.92% | 92.10 |
| | **11.35** | 8.3823 | 20.65 | 17.78 | 2.87 | 13.90% | 57.56 |
| R2-48 | **13.67** | 8.1961 | 16.55 | 6.82 | 9.73 | 58.79% | 41.91 |
| | **9.36** | 6.5173 | 21.40 | 18.15 | 3.25 | 15.19% | 60.33 |
| R4-60 | **8.98** | 8.7852 | 89.03 | 29.93 | 59.10 | 66.38% | 89.80 |
| | **7.96** | 8.0842 | 33.18 | 31.94 | 1.24 | 3.74% | 99.93 |
| R3-72 | **12.08** | 10.6912 | 21.94 | 22.95 | -1.01 | -4.60% | 64.47 |
| | **7.55** | 7.6216 | 35.25 | 40.80 | -5.55 | -15.74% | 92.10 |
| R2-60 | **11.27** | 7.9122 | 20.85 | 21.49 | -0.64 | -3.07% | 58.49 |
| | **9.36** | 6.8853 | 23.45 | 27.00 | -3.55 | -15.14% | 68.62 |
| R4-36 | **9.01** | 6.0319 | 34.04 | 25.29 | 8.75 | 25.71% | 62.63 |
| | **7.06** | 5.0018 | 91.11 | 29.11 | 62.00 | 68.05% | 92.10 |

**Table C7: Correlation validation for 3" drain-side diameter DWHR systems as a function of length**

| | Flowrate (LPM) | Measured | | Predicted | Δt (sec) | % error | $t_{99\%}$ (sec) |
|---|---|---|---|---|---|---|---|
| | | $q_{flow}$ (kW) | $t_{86.5\%}$ (sec) | $t_{86.5\%}$ (sec) | | | |
| R3-36 | **14** | 7.8177 | 14.43 | 14.07 | 0.36 | 2.49% | 44.67 |
| | **12** | 7.3445 | 17.99 | 17.60 | 0.39 | 2.17% | 52.96 |
| | **10** | 6.5617 | 22.84 | 19.17 | 3.67 | 16.07% | 54.34 |
| | **9** | 6.0792 | 24.84 | 20.42 | 4.42 | 17.79% | 57.56 |
| | **7** | 5.3755 | 32.62 | 28.36 | 4.26 | 13.06% | 90.72 |
| | **5.5** | 4.5271 | 34.44 | 35.22 | -0.78 | -2.26% | 105.00 |
| R3-48 | **14** | 9.4200 | 15.67 | 15.63 | 0.04 | 0.26% | 27.17 |
| | **12** | 8.6841 | 16.80 | 19.52 | -2.72 | -16.19% | 43.75 |
| | **10** | 7.6762 | 18.51 | 22.05 | -3.54 | -19.12% | 56.18 |
| | **9** | 7.1363 | 18.83 | 23.78 | -4.95 | -26.29% | 62.17 |
| | **7** | 6.1433 | 29.46 | 31.72 | -2.26 | -7.67% | 72.76 |
| | **5.5** | 5.1742 | 36.75 | 40.74 | -3.99 | -10.86% | 122.04 |
| R3-60 | **14** | 10.8905 | 16.91 | 17.19 | -0.28 | -1.66% | 48.81 |
| | **7** | 6.8180 | 34.52 | 35.08 | -0.56 | -1.62% | 108.22 |
| R3-72 | **12** | 10.6912 | 21.94 | 23.36 | -1.42 | -6.47% | 71.84 |

# Appendix D: Thermocouple Calibration and Verification

**Thermocouple Calibration**

It is a known experience with DWHR systems that the temperature readings related to DWHR surface or water would always fall between $9^0C$ to $40^0C$. Hence all the thermocouples were calibrated at the increments of $5^0C$ between the $T_{setpoint}$ ranges of $5^0C$ to $45^0C$.

Calibration equipment consisted of a constant temperature bath connected to a container. RTDs require complete submersion in water in order to achieve an accurate reading, since they measure temperature by averaging over the entire length. The container used was large enough to ensure complete submersion of RTDs and thermocouples in water. Water was circulated from the temperature bath to the container. Sufficient mixing between the bath and the container ensured isothermal water temperature. Figure D1 shows the entire calibration equipment setup with the RTDs and thermocouples submerged in water. The transparent pipes in Figure D1 circulated the water from the bath to the container. All the thermocouples were tied together to restrict any movement in the container. Three different insertion slots were used to keep the thermocouples and RTD's apart from each other.

**Figure D1: Calibration equipment set-up with RTDs and thermocouples**

For each $T_{setpoint}$, once the RTDs and thermocouples were completely submerged in water, data acquisition was initiated exactly at the same time for both the measuring devices. Calibration equipment was run for a period of approximately 1 hour per $T_{setpoint}$ to ensure complete isothermal conditions. The estimated temperature reading for the RTDs and thermocouples is given by Equation D1. An average was taken for the last 10 minutes, since the temperature should have been completely isothermal and at steady-state after the long duration of 50 minutes.

$$T_{mean} = \frac{\sum_{n}^{600} T_n}{600} \qquad (D.1)$$

Table D1 and Table D2 shows the samples of data acquired for two of the nine set points. $T_{ci}$ and $T_{co}$ refer to the temperatures recorded by RTDs. $T_1$ through $T_{12}$ correspond to temperature readings for all 12 thermocouples.

**Table D1: Thermocouple calibration data at $T_{setpoint}$ = 17$^0$C**

| Time (s) | Date | GMT -5 hrs | $T_{ci}$ $^0$C | $T_{co}$ $^0$C | $T_1$ $^0$C | $T_2$ $^0$C | $T_3$ $^0$C | $T_4$ $^0$C | $T_5$ $^0$C | $T_6$ $^0$C | $T_7$ $^0$C | $T_8$ $^0$C | $T_9$ $^0$C | $T_{10}$ $^0$C | $T_{11}$ $^0$C | $T_{12}$ $^0$C |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **1** | 2018-11-09 | 11:44:51 AM | 17.89 | 17.85 | 17.40 | 17.40 | 17.38 | 17.35 | 17.30 | 17.25 | 17.23 | 17.12 | 17.06 | 17.14 | 17.17 | 17.21 |
| **2** | 2018-11-09 | 11:44:52 AM | 17.88 | 17.85 | 17.40 | 17.40 | 17.38 | 17.35 | 17.30 | 17.24 | 17.23 | 17.12 | 17.06 | 17.14 | 17.17 | 17.21 |
| **3** | 2018-11-09 | 11:44:53 AM | 17.88 | 17.85 | 17.40 | 17.41 | 17.39 | 17.36 | 17.32 | 17.25 | 17.23 | 17.12 | 17.07 | 17.14 | 17.18 | 17.21 |
| **4** | 2018-11-09 | 11:44:54 AM | 17.88 | 17.85 | 17.40 | 17.41 | 17.39 | 17.36 | 17.32 | 17.26 | 17.23 | 17.13 | 17.08 | 17.15 | 17.19 | 17.23 |
| **5** | 2018-11-09 | 11:44:55 AM | 17.88 | 17.85 | 17.40 | 17.40 | 17.38 | 17.35 | 17.29 | 17.24 | 17.23 | 17.13 | 17.05 | 17.14 | 17.18 | 17.20 |
| ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ |
| ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ |
| **3598** | 2018-11-09 | 12:44:48 PM | 17.88 | 17.85 | 17.51 | 17.52 | 17.49 | 17.45 | 17.39 | 17.31 | 17.29 | 17.18 | 17.13 | 17.22 | 17.27 | 17.29 |
| **3599** | 2018-11-09 | 12:44:49 PM | 17.88 | 17.85 | 17.51 | 17.52 | 17.48 | 17.45 | 17.40 | 17.32 | 17.29 | 17.18 | 17.14 | 17.22 | 17.27 | 17.30 |
| **3600** | 2018-11-09 | 12:44:50 PM | 17.88 | 17.85 | 17.51 | 17.52 | 17.50 | 17.44 | 17.38 | 17.31 | 17.28 | 17.17 | 17.13 | 17.22 | 17.26 | 17.30 |
| **3601** | 2018-11-09 | 12:44:51 PM | 17.88 | 17.85 | 17.51 | 17.51 | 17.48 | 17.45 | 17.38 | 17.32 | 17.29 | 17.17 | 17.13 | 17.21 | 17.26 | 17.29 |
| **Mean last 10 minutes** | | | **17.88** | **17.85** | **17.52** | **17.52** | **17.48** | **17.45** | **17.38** | **17.31** | **17.28** | **17.17** | **17.12** | **17.21** | **17.25** | **17.29** |

**Table D2: Thermocouple calibration data at $T_{setpoint}$ = 41$^0$C**

| Time (s) | Date | GMT -5 hrs | $T_{ci}$ $^0$C | $T_{co}$ $^0$C | $T_1$ $^0$C | $T_2$ $^0$C | $T_3$ $^0$C | $T_4$ $^0$C | $T_5$ $^0$C | $T_6$ $^0$C | $T_7$ $^0$C | $T_8$ $^0$C | $T_9$ $^0$C | $T_{10}$ $^0$C | $T_{11}$ $^0$C | $T_{12}$ $^0$C |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **1** | 2018-11-12 | 3:33:52 PM | 41.96 | 41.92 | 40.98 | 41.01 | 40.99 | 40.96 | 40.91 | 40.86 | 40.82 | 40.74 | 40.74 | 40.83 | 40.87 | 40.93 |
| **2** | 2018-11-12 | 3:33:53 PM | 41.96 | 41.92 | 40.98 | 41.01 | 40.98 | 40.96 | 40.92 | 40.86 | 40.83 | 40.74 | 40.75 | 40.83 | 40.88 | 40.92 |
| **3** | 2018-11-12 | 3:33:54 PM | 41.96 | 41.92 | 40.98 | 40.99 | 40.97 | 40.96 | 40.91 | 40.85 | 40.82 | 40.73 | 40.75 | 40.82 | 40.87 | 40.90 |
| **4** | 2018-11-12 | 3:33:55 PM | 41.96 | 41.92 | 40.98 | 41.00 | 40.98 | 40.96 | 40.91 | 40.85 | 40.82 | 40.74 | 40.74 | 40.83 | 40.87 | 40.91 |
| **5** | 2018-11-12 | 3:33:56 PM | 41.96 | 41.92 | 40.98 | 41.00 | 40.97 | 40.95 | 40.91 | 40.85 | 40.83 | 40.74 | 40.73 | 40.83 | 40.88 | 40.92 |
| ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ |
| ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ |
| **3598** | 2018-11-12 | 4:33:49 PM | 41.92 | 41.89 | 40.85 | 40.87 | 40.87 | 40.86 | 40.83 | 40.78 | 40.78 | 40.71 | 40.73 | 40.81 | 40.88 | 40.94 |
| **3599** | 2018-11-12 | 4:33:50 PM | 41.92 | 41.89 | 40.86 | 40.87 | 40.87 | 40.86 | 40.83 | 40.79 | 40.78 | 40.70 | 40.72 | 40.81 | 40.88 | 40.94 |
| **3600** | 2018-11-12 | 4:33:51 PM | 41.92 | 41.89 | 40.85 | 40.87 | 40.86 | 40.85 | 40.83 | 40.79 | 40.78 | 40.70 | 40.72 | 40.80 | 40.88 | 40.93 |
| **3601** | 2018-11-12 | 4:33:52 PM | 41.92 | 41.89 | 40.84 | 40.87 | 40.86 | 40.85 | 40.83 | 40.79 | 40.78 | 40.70 | 40.73 | 40.79 | 40.87 | 40.93 |
| **Mean last 10 minutes** | | | **41.92** | **41.89** | **40.86** | **40.88** | **40.87** | **40.86** | **40.84** | **40.79** | **40.78** | **40.71** | **40.71** | **40.81** | **40.87** | **40.92** |

Table D3 shows the summarized and condensed version of all of the calibration data collected. RTD 1 and RTD 2 represents $T_{ci}$ and $T_{co}$.

**Table D3: Summary of thermocouple calibration data**

| $T_{setpoint}$ ($^0C$) | RTD 1 ($^0C$) | RTD 2 ($^0C$) | RTD mean ($^0C$) | $T_1$ ($^0C$) | $T_2$ ($^0C$) | $T_3$ ($^0C$) | $T_4$ ($^0C$) | $T_5$ ($^0C$) | $T_6$ ($^0C$) | $T_7$ ($^0C$) | $T_8$ ($^0C$) | $T_9$ ($^0C$) | $T_{10}$ ($^0C$) | $T_{11}$ ($^0C$) | $T_{12}$ ($^0C$) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **5** | 5.63 | 5.60 | **5.61** | 5.48 | 5.48 | 5.45 | 5.43 | 5.37 | 5.31 | 5.28 | 5.17 | 5.12 | 5.21 | 5.26 | 5.32 |
| **9** | 9.80 | 9.76 | **9.78** | 9.58 | 9.59 | 9.55 | 9.52 | 9.47 | 9.40 | 9.37 | 9.25 | 9.21 | 9.30 | 9.35 | 9.40 |
| **13** | 13.83 | 13.79 | **13.81** | 13.68 | 13.67 | 13.62 | 13.58 | 13.50 | 13.42 | 13.40 | 13.27 | 13.26 | 13.37 | 13.43 | 13.47 |
| **17** | 17.88 | 17.85 | **17.87** | 17.52 | 17.52 | 17.48 | 17.45 | 17.38 | 17.31 | 17.28 | 17.17 | 17.12 | 17.21 | 17.25 | 17.29 |
| **21** | 21.98 | 21.94 | **21.96** | 21.56 | 21.56 | 21.53 | 21.50 | 21.42 | 21.35 | 21.33 | 21.21 | 21.20 | 21.30 | 21.36 | 21.40 |
| **25** | 26.05 | 26.01 | **26.03** | 25.52 | 25.53 | 25.50 | 25.47 | 25.40 | 25.33 | 25.31 | 25.20 | 25.18 | 25.28 | 25.34 | 25.38 |
| **29** | 30.14 | 30.10 | **30.12** | 29.42 | 29.43 | 29.41 | 29.40 | 29.36 | 29.30 | 29.27 | 29.17 | 29.12 | 29.21 | 29.24 | 29.28 |
| **33** | 33.82 | 33.78 | **33.80** | 33.18 | 33.18 | 33.14 | 33.10 | 33.03 | 32.96 | 32.93 | 32.81 | 32.76 | 32.85 | 32.90 | 32.93 |
| **37** | 37.96 | 37.93 | **37.94** | 37.03 | 37.03 | 37.01 | 36.99 | 36.95 | 36.89 | 36.87 | 36.79 | 36.79 | 36.88 | 36.94 | 36.98 |
| **41** | 41.92 | 41.89 | **41.90** | 40.86 | 40.88 | 40.87 | 40.86 | 40.84 | 40.79 | 40.78 | 40.71 | 40.71 | 40.81 | 40.87 | 40.92 |
| **45** | 45.87 | 45.84 | **45.86** | 44.84 | 44.86 | 44.85 | 44.83 | 44.79 | 44.73 | 44.70 | 44.61 | 44.59 | 44.69 | 44.74 | 44.78 |

Since both the RTD's readings were almost identical, an average was taken to derive a single calibration reference temperature. It is displayed in RTD mean column in Table D3. All twelve thermocouples were calibrated through comparison with RTD mean. It could be noted that the rows showing $T_{mean}$ for last 10 minutes in Table D1 and Table D2 corresponded to the rows for $T_{setpoint}$ of $17^0C$ and $41^0C$ respectively in Table D3.

The last step in completing calibration was to input the summarized thermocouple calibration data from Table D3 into the LabVIEW calibration wizard. Figure D2 shows the calibration wizard for thermocouple 6.

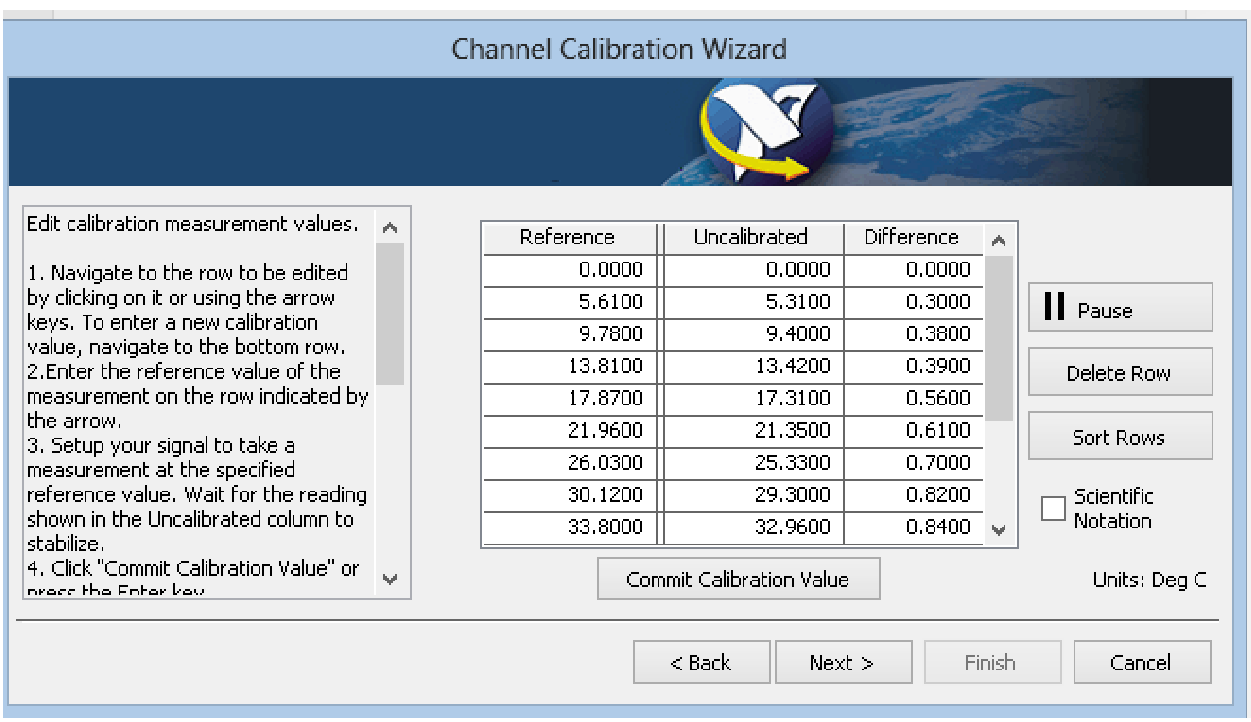


**Figure D2: Channel calibration wizard for Thermocouple 6**

“Reference” and “Uncalibrated” columns in Figure D2 corresponded to “RTD mean” and “T6” columns in Table D3. The same process was used to input calibration data for all twelve thermocouples by clicking back and next button. Calibration was completed at the end by clicking “Finish”.

This calibration is only valid for thermocouple temperature readings between 5$^0$C and 45$^0$C. Hence if in the future any tests are to be conducted outside the specified range, further calibration would be required to ensure accuracy.

**Thermocouple Calibration Verification**

Calibration verification was completed by gathering data for both the thermocouples and RTDs at random temperatures to ensure similarity. Once it was determined that the RTDs and thermocouples were providing very similar temperature outputs, it was concluded that the thermocouples could be used for experiments related to DWHR surface temperature estimation. Table D4 and Table D5 represent the RTD/thermocouple data collection and difference between the two readings respectively.

**Table D4: RTD and thermocouple data collection for calibration verification**

| Date | GMT -5 hrs | $T_{ci}$ $^0$C | $T_{co}$ $^0$C | Tmean ($^0$C) | $T_1$ $^0$C | $T_2$ $^0$C | $T_3$ $^0$C | $T_4$ $^0$C | $T_5$ $^0$C | $T_6$ $^0$C | $T_7$ $^0$C | $T_8$ $^0$C | $T_9$ $^0$C | $T_{10}$ $^0$C | $T_{11}$ $^0$C | $T_{12}$ $^0$C |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2018-11-14 | 2:04:00 PM | 14.04 | 14.01 | 14.03 | 13.89 | 13.91 | 13.91 | 13.95 | 14.00 | 14.01 | 14.07 | 14.07 | 14.00 | 14.07 | 14.09 | 14.17 |
| 2018-11-14 | 2:04:01 PM | 14.04 | 14.01 | 14.03 | 13.89 | 13.91 | 13.91 | 13.95 | 14.00 | 14.02 | 14.05 | 14.07 | 14.01 | 14.06 | 14.07 | 14.16 |
| 2018-11-14 | 2:04:02 PM | 14.04 | 14.01 | 14.03 | 13.87 | 13.89 | 13.90 | 13.95 | 13.97 | 14.02 | 14.03 | 14.06 | 14.01 | 14.06 | 14.06 | 14.15 |
| 2018-11-14 | 2:04:03 PM | 14.04 | 14.01 | 14.03 | 13.85 | 13.89 | 13.91 | 13.96 | 13.98 | 14.02 | 14.03 | 14.07 | 14.02 | 14.08 | 14.07 | 14.16 |
| ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ |
| ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ |
| 2018-11-14 | 3:39:38 PM | 36.73 | 36.74 | 36.74 | 36.46 | 36.63 | 36.51 | 36.41 | 36.49 | 36.78 | 36.55 | 36.55 | 36.75 | 36.59 | 36.65 | 36.58 |
| 2018-11-14 | 3:39:39 PM | 36.73 | 36.75 | 36.74 | 36.51 | 36.64 | 36.49 | 36.43 | 36.48 | 36.77 | 36.53 | 36.54 | 36.79 | 36.60 | 36.64 | 36.66 |
| 2018-11-14 | 3:39:40 PM | 36.74 | 36.75 | 36.75 | 36.54 | 36.48 | 36.59 | 36.43 | 36.48 | 36.71 | 36.59 | 36.54 | 36.79 | 36.64 | 36.63 | 36.77 |

**Table D5: RTD and thermocouple data collection for calibration verification – temperature differences**

| Date | GMT -5 hrs | $\Delta T_1$ $^0$C | $\Delta T_2$ $^0$C | $\Delta T_3$ $^0$C | $\Delta T_4$ $^0$C | $\Delta T_5$ $^0$C | $\Delta T_6$ $^0$C | $\Delta T_7$ $^0$C | $\Delta T_8$ $^0$C | $\Delta T_9$ $^0$C | $\Delta T_{10}$ $^0$C | $\Delta T_{11}$ $^0$C | $\Delta T_{12}$ $^0$C |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2018-11-14 | 2:04:00 PM | 0.14 | 0.12 | 0.11 | 0.08 | 0.03 | 0.01 | -0.04 | -0.05 | 0.03 | -0.05 | -0.06 | -0.14 |
| 2018-11-14 | 2:04:01 PM | 0.14 | 0.12 | 0.11 | 0.07 | 0.02 | 0.01 | -0.03 | -0.04 | 0.01 | -0.04 | -0.05 | -0.13 |
| 2018-11-14 | 2:04:02 PM | 0.16 | 0.14 | 0.13 | 0.08 | 0.06 | 0.01 | -0.01 | -0.04 | 0.01 | -0.04 | -0.04 | -0.12 |
| 2018-11-14 | 2:04:03 PM | 0.18 | 0.13 | 0.12 | 0.07 | 0.04 | 0.00 | -0.01 | -0.04 | 0.01 | -0.06 | -0.05 | -0.13 |
| ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ |
| ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ |
| 2018-11-14 | 3:39:38 PM | 0.27 | 0.10 | 0.22 | 0.32 | 0.25 | -0.04 | 0.18 | 0.19 | -0.01 | 0.14 | 0.08 | 0.15 |
| 2018-11-14 | 3:39:39 PM | 0.22 | 0.09 | 0.24 | 0.30 | 0.26 | -0.04 | 0.20 | 0.20 | -0.05 | 0.13 | 0.10 | 0.07 |
| 2018-11-14 | 3:39:40 PM | 0.19 | 0.26 | 0.14 | 0.31 | 0.25 | 0.02 | 0.14 | 0.19 | -0.06 | 0.10 | 0.10 | -0.04 |
| **Minimum ΔT** | | **0.09** | **0.07** | **0.05** | **0.00** | **-0.05** | **-0.11** | **-0.16** | **-0.14** | **-0.13** | **-0.17** | **-0.27** | **-0.35** |
| **Maximum ΔT** | | **0.36** | **0.44** | **0.36** | **0.47** | **0.37** | **0.27** | **0.41** | **0.31** | **0.36** | **0.40** | **0.44** | **0.41** |

Data collection in Table D4 is similar to Table D1 and Table D2, where the columns display RTD and thermocouple temperature readings. Table D5 shows the difference between RTD mean and thermocouple temperature. It was observed that the min and max temperature difference ranged from -0.35$^0$C to 0.47$^0$C of RTDs. Hence the calibration error of the thermocouples was about ±0.5$^0$C. This deviation was not significant since any calibration will still induce minor measurement errors. At this point, it was concluded that the thermocouples were correctly calibrated and could be used for experimentation.

# Appendix E: Raw Data Tables at Selected Time Instants

**Table E1: Raw RTD and thermocouple data sample for R3-36 at 14LPM**

| Date | GMT -5hrs | Time (s) | RTD's | | | | | THERMOCOUPLES | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | $T_{ci}$(°C) | $T_{co}$(°C) | $T_{hi}$(°C) | $T_{ho}$(°C) | Flow LPM | $T_{ci}$(°C) | $T_1$(°C) | $T_2$(°C) | $T_3$(°C) | $T_4$(°C) | $T_5$(°C) | $T_6$(°C) | $T_7$(°C) | $T_8$(°C) | $T_{co}$(°C) |
| 2018-12-05 | 10:50:04 AM | 1 | 22.51 | 22.7 | 23.05 | 22.4 | 9.18 | 22.36 | 22.40 | 22.42 | 22.42 | 22.46 | 22.43 | 22.44 | 22.46 | 22.50 | 22.45 |
| 2018-12-05 | 10:50:05 AM | 2 | 22.49 | 22.66 | 23.09 | 22.43 | 11.91 | 22.33 | 22.36 | 22.39 | 22.40 | 22.43 | 22.41 | 22.41 | 22.43 | 22.48 | 22.42 |
| 2018-12-05 | 10:50:06 AM | 3 | 22.47 | 22.65 | 23.04 | 22.47 | 13.8 | 22.26 | 22.32 | 22.33 | 22.39 | 22.45 | 22.41 | 22.43 | 22.46 | 22.50 | 22.44 |
| 2018-12-05 | 10:50:08 AM | 5 | 20.99 | 22.63 | 24.88 | 22.58 | 13.85 | 21.14 | 21.06 | 21.14 | 21.67 | 22.01 | 22.33 | 22.41 | 22.48 | 22.50 | 22.44 |
| 2018-12-05 | 10:50:11 AM | 8 | 17.74 | 22.58 | 30.65 | 22.7 | 13.81 | 18.83 | 18.71 | 18.77 | 19.59 | 20.12 | 20.98 | 21.53 | 21.93 | 22.36 | 22.25 |
| 2018-12-05 | 10:50:13 AM | 10 | 16.43 | 22.3 | 32.84 | 22.85 | 13.86 | 17.42 | 17.44 | 17.49 | 18.50 | 19.14 | 20.12 | 21.05 | 21.64 | 22.14 | 21.85 |
| 2018-12-05 | 10:50:18 AM | 15 | 13.75 | 21.54 | 36.07 | 25.47 | 13.74 | 14.73 | 15.35 | 15.37 | 16.87 | 17.77 | 19.01 | 20.71 | 21.62 | 21.88 | 21.24 |
| 2018-12-05 | 10:50:23 AM | 20 | 12.18 | 21.11 | 37.13 | 27.49 | 14.16 | 13.09 | 14.13 | 14.09 | 15.75 | 16.79 | 18.15 | 20.19 | 21.24 | 21.65 | 20.77 |
| 2018-12-05 | 10:50:33 AM | 30 | 10.79 | 20.03 | 37.69 | 28.47 | 14.23 | 11.47 | 12.89 | 12.85 | 14.60 | 15.72 | 17.11 | 19.40 | 20.55 | 21.00 | 19.77 |
| 2018-12-05 | 10:50:53 AM | 50 | 10 | 19.35 | 37.99 | 28.5 | 14.08 | 10.39 | 12.16 | 12.16 | 13.96 | 15.13 | 16.50 | 18.94 | 20.14 | 20.56 | 19.15 |
| 2018-12-05 | 10:51:43 AM | 100 | 9.63 | 19.13 | 38.21 | 28.57 | 14.08 | 9.80 | 11.86 | 11.80 | 13.67 | 14.92 | 16.33 | 18.83 | 20.04 | 20.43 | 18.92 |
| 2018-12-05 | 10:53:23 AM | 200 | 9.51 | 19.06 | 38.28 | 28.58 | 14.05 | 9.65 | 11.70 | 11.70 | 13.54 | 14.78 | 16.19 | 18.75 | 20.01 | 20.41 | 18.86 |

**Table E2: Raw RTD and thermocouple data sample for R3-36 at 12LPM**

| Date | GMT -5hrs | Time (s) | RTD's | | | | | THERMOCOUPLES | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | $T_{ci}$(°C) | $T_{co}$(°C) | $T_{hi}$(°C) | $T_{ho}$(°C) | Flow LPM | $T_{ci}$(°C) | $T_1$(°C) | $T_2$(°C) | $T_3$(°C) | $T_4$(°C) | $T_5$(°C) | $T_6$(°C) | $T_7$(°C) | $T_8$(°C) | $T_{co}$(°C) |
| 2018-12-06 | 10:31:42 AM | 1 | 22.47 | 22.65 | 23.17 | 22.5 | 9.65 | 22.33 | 22.40 | 22.42 | 22.42 | 22.45 | 22.45 | 22.45 | 22.49 | 22.53 | 22.46 |
| 2018-12-06 | 10:31:43 AM | 2 | 22.46 | 22.64 | 23.12 | 22.52 | 11.66 | 22.31 | 22.38 | 22.41 | 22.42 | 22.45 | 22.44 | 22.46 | 22.49 | 22.53 | 22.46 |
| 2018-12-06 | 10:31:44 AM | 3 | 22.43 | 22.64 | 23.11 | 22.54 | 11.79 | 22.29 | 22.36 | 22.39 | 22.41 | 22.46 | 22.43 | 22.46 | 22.49 | 22.53 | 22.45 |
| 2018-12-06 | 10:31:46 AM | 5 | 21.08 | 22.63 | 25.11 | 22.63 | 11.82 | 21.63 | 21.60 | 21.79 | 22.14 | 22.34 | 22.44 | 22.49 | 22.53 | 22.54 | 22.46 |
| 2018-12-06 | 10:31:49 AM | 8 | 19.69 | 22.65 | 27.93 | 22.72 | 11.88 | 19.85 | 19.72 | 19.99 | 20.65 | 21.04 | 21.71 | 22.08 | 22.38 | 22.55 | 22.46 |
| 2018-12-06 | 10:31:51 AM | 10 | 17.76 | 22.59 | 31.47 | 22.77 | 11.9 | 18.60 | 18.52 | 18.82 | 19.67 | 20.17 | 21.03 | 21.69 | 22.18 | 22.51 | 22.28 |
| 2018-12-06 | 10:31:56 AM | 15 | 14.67 | 22.09 | 35.68 | 24.78 | 11.97 | 16.02 | 16.46 | 16.67 | 18.02 | 18.83 | 19.95 | 21.41 | 22.23 | 22.49 | 21.89 |
| 2018-12-06 | 10:32:01 AM | 20 | 13.35 | 22 | 36.65 | 26.67 | 12 | 14.23 | 15.25 | 15.36 | 17.01 | 18.03 | 19.34 | 21.23 | 22.26 | 22.59 | 21.76 |
| 2018-12-06 | 10:32:11 AM | 30 | 11.81 | 21.36 | 37.4 | 27.94 | 12 | 12.42 | 13.89 | 13.97 | 15.80 | 16.94 | 18.33 | 20.53 | 21.71 | 22.35 | 21.01 |
| 2018-12-06 | 10:32:31 AM | 50 | 10.74 | 20.46 | 37.8 | 28 | 12.03 | 11.12 | 12.97 | 13.02 | 14.91 | 16.10 | 17.54 | 19.92 | 21.16 | 21.81 | 20.25 |
| 2018-12-06 | 10:33:21 AM | 100 | 10.28 | 20.1 | 38.06 | 28.08 | 12.09 | 10.43 | 12.58 | 12.59 | 14.51 | 15.77 | 17.22 | 19.68 | 20.98 | 21.59 | 19.92 |
| 2018-12-06 | 10:35:01 AM | 200 | 10.14 | 20.06 | 38.17 | 28.13 | 12.09 | 10.28 | 12.46 | 12.47 | 14.43 | 15.70 | 17.15 | 19.69 | 21.00 | 21.60 | 19.87 |

**Table E3: Raw RTD and thermocouple data sample for R3-36 at 10LPM**

| Date | GMT -5hrs | Time (s) | RTD's | | | | | THERMOCOUPLES | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | $T_{ci}$(°C) | $T_{co}$(°C) | $T_{hi}$(°C) | $T_{ho}$(°C) | Flow LPM | $T_{ci}$(°C) | $T_1$(°C) | $T_2$(°C) | $T_3$(°C) | $T_4$(°C) | $T_5$(°C) | $T_6$(°C) | $T_7$(°C) | $T_8$(°C) | $T_{co}$(°C) |
| 2018-12-06 | 5:10:40 PM | 1 | 22.44 | 22.88 | 23.29 | 23.14 | 9.84 | 22.35 | 22.46 | 22.47 | 22.53 | 22.60 | 22.61 | 22.66 | 22.70 | 22.72 | 22.73 |
| 2018-12-06 | 5:10:41 PM | 2 | 22.37 | 22.88 | 23.31 | 23.13 | 9.86 | 22.27 | 22.39 | 22.42 | 22.49 | 22.56 | 22.58 | 22.63 | 22.66 | 22.71 | 22.71 |
| 2018-12-06 | 5:10:42 PM | 3 | 22.29 | 22.88 | 23.33 | 23.12 | 9.88 | 22.03 | 22.16 | 22.26 | 22.44 | 22.55 | 22.57 | 22.63 | 22.66 | 22.71 | 22.70 |
| 2018-12-06 | 5:10:44 PM | 5 | 21.46 | 22.86 | 24.42 | 23.07 | 9.87 | 21.14 | 21.23 | 21.43 | 21.88 | 22.16 | 22.39 | 22.55 | 22.61 | 22.66 | 22.66 |
| 2018-12-06 | 5:10:47 PM | 8 | 19.09 | 22.8 | 29.3 | 22.99 | 9.98 | 19.50 | 19.58 | 19.81 | 20.56 | 21.00 | 21.58 | 22.14 | 22.44 | 22.61 | 22.58 |
| 2018-12-06 | 5:10:49 PM | 10 | 17.51 | 22.7 | 31.71 | 22.94 | 9.97 | 18.46 | 18.67 | 18.85 | 19.77 | 20.34 | 21.07 | 21.95 | 22.43 | 22.59 | 22.45 |
| 2018-12-06 | 5:10:54 PM | 15 | 15.12 | 22.44 | 35.04 | 24.2 | 9.95 | 16.18 | 16.85 | 17.00 | 18.39 | 19.23 | 20.26 | 21.78 | 22.59 | 22.78 | 22.24 |
| 2018-12-06 | 5:10:59 PM | 20 | 13.56 | 22.41 | 36.41 | 25.89 | 9.98 | 14.55 | 15.70 | 15.82 | 17.52 | 18.56 | 19.82 | 21.74 | 22.79 | 23.07 | 22.22 |
| 2018-12-06 | 5:11:09 PM | 30 | 11.99 | 22.13 | 37.19 | 27.08 | 10.02 | 12.69 | 14.29 | 14.39 | 16.34 | 17.55 | 18.93 | 21.20 | 22.43 | 22.94 | 21.82 |
| 2018-12-06 | 5:11:29 PM | 50 | 10.78 | 21.25 | 37.7 | 27.18 | 9.98 | 11.24 | 13.20 | 13.32 | 15.34 | 16.63 | 18.09 | 20.54 | 21.85 | 22.45 | 21.06 |
| 2018-12-06 | 5:12:19 PM | 100 | 10.14 | 20.82 | 38.03 | 27.2 | 10.01 | 10.37 | 12.64 | 12.74 | 14.84 | 16.18 | 17.70 | 20.24 | 21.60 | 22.21 | 20.66 |
| 2018-12-06 | 5:13:59 PM | 200 | 9.95 | 20.74 | 38.17 | 27.22 | 10.04 | 10.16 | 12.46 | 12.54 | 14.63 | 15.98 | 17.53 | 20.13 | 21.55 | 22.17 | 20.60 |

**Table E4: Raw RTD and thermocouple data sample for R3-36 at 9LPM**

| Date | GMT -5hrs | Time (s) | RTD's | | | | | THERMOCOUPLES | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | $T_{ci}$(°C) | $T_{co}$(°C) | $T_{hi}$(°C) | $T_{ho}$(°C) | Flow LPM | $T_{ci}$(°C) | $T_1$(°C) | $T_2$(°C) | $T_3$(°C) | $T_4$(°C) | $T_5$(°C) | $T_6$(°C) | $T_7$(°C) | $T_8$(°C) | $T_{co}$(°C) |
| 2018-12-07 | 10:29:36 AM | 1 | 21.66 | 22.68 | 23.68 | 22.64 | 8.83 | 21.96 | 21.95 | 22.08 | 22.23 | 22.35 | 22.39 | 22.44 | 22.47 | 22.50 | 22.49 |
| 2018-12-07 | 10:29:37 AM | 2 | 21.22 | 22.68 | 24.65 | 22.66 | 8.87 | 21.68 | 21.60 | 21.80 | 22.07 | 22.25 | 22.35 | 22.42 | 22.46 | 22.51 | 22.49 |
| 2018-12-07 | 10:29:38 AM | 3 | 20.97 | 22.68 | 25.19 | 22.68 | 8.90 | 21.31 | 21.15 | 21.42 | 21.79 | 22.04 | 22.26 | 22.38 | 22.44 | 22.49 | 22.48 |
| 2018-12-07 | 10:29:40 AM | 5 | 19.65 | 22.66 | 27.29 | 22.73 | 8.96 | 20.45 | 20.15 | 20.49 | 21.05 | 21.43 | 21.89 | 22.23 | 22.41 | 22.48 | 22.46 |
| 2018-12-07 | 10:29:43 AM | 8 | 18.14 | 22.62 | 30.45 | 22.72 | 9.04 | 19.05 | 18.89 | 19.19 | 20.01 | 20.54 | 21.21 | 21.95 | 22.35 | 22.52 | 22.36 |
| 2018-12-07 | 10:29:45 AM | 10 | 16.82 | 22.52 | 32.72 | 22.86 | 9.06 | 18.17 | 18.15 | 18.42 | 19.41 | 20.04 | 20.84 | 21.83 | 22.36 | 22.56 | 22.25 |
| 2018-12-07 | 10:29:50 AM | 15 | 14.84 | 22.39 | 35.45 | 23.93 | 9.06 | 16.25 | 16.79 | 16.98 | 18.44 | 19.32 | 20.40 | 21.98 | 22.81 | 23.06 | 22.26 |
| 2018-12-07 | 10:29:55 AM | 20 | 13.51 | 22.61 | 36.42 | 25.67 | 9.01 | 14.79 | 15.77 | 15.95 | 17.74 | 18.83 | 20.11 | 22.06 | 23.10 | 23.47 | 22.44 |
| 2018-12-07 | 10:30:05 AM | 30 | 12.01 | 22.47 | 37.18 | 26.74 | 9.03 | 13.00 | 14.52 | 14.68 | 16.69 | 17.92 | 19.34 | 21.62 | 22.88 | 23.41 | 22.19 |
| 2018-12-07 | 10:30:25 AM | 50 | 10.91 | 21.74 | 37.66 | 26.76 | 9.11 | 11.49 | 13.39 | 13.59 | 15.69 | 17.01 | 18.52 | 20.98 | 22.36 | 22.97 | 21.49 |
| 2018-12-07 | 10:31:15 AM | 100 | 10.27 | 21.32 | 38.02 | 26.77 | 9.1 | 10.53 | 12.85 | 12.94 | 15.14 | 16.56 | 18.09 | 20.70 | 22.13 | 22.77 | 21.10 |
| 2018-12-07 | 10:32:55 AM | 200 | 10.07 | 21.28 | 38.16 | 26.8 | 9.07 | 10.29 | 12.70 | 12.84 | 15.05 | 16.47 | 18.05 | 20.69 | 22.15 | 22.80 | 21.07 |

**Table E5: Raw RTD and thermocouple data sample for R3-36 at 7LPM**

| Date | GMT -5hrs | Time (s) | RTD's | | | | | THERMOCOUPLES | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | $T_{ci}$(°C) | $T_{co}$(°C) | $T_{hi}$(°C) | $T_{ho}$(°C) | Flow LPM | $T_{ci}$(°C) | $T_1$(°C) | $T_2$(°C) | $T_3$(°C) | $T_4$(°C) | $T_5$(°C) | $T_6$(°C) | $T_7$(°C) | $T_8$(°C) | $T_{co}$(°C) |
| 2018-12-07 | 5:14:25 PM | 1 | 21.89 | 22.95 | 23.59 | 22.99 | 6.76 | 22.07 | 22.17 | 22.29 | 22.49 | 22.59 | 22.64 | 22.72 | 22.76 | 22.81 | 22.76 |
| 2018-12-07 | 5:14:26 PM | 2 | 21.59 | 22.94 | 24.03 | 22.97 | 6.73 | 21.86 | 21.94 | 22.11 | 22.37 | 22.53 | 22.60 | 22.70 | 22.74 | 22.79 | 22.76 |
| 2018-12-07 | 5:14:27 PM | 3 | 21.22 | 22.93 | 24.66 | 22.96 | 6.76 | 21.63 | 21.64 | 21.86 | 22.21 | 22.42 | 22.57 | 22.67 | 22.71 | 22.77 | 22.74 |
| 2018-12-07 | 5:14:29 PM | 5 | 20.06 | 22.89 | 27.41 | 22.93 | 6.79 | 21.02 | 20.97 | 21.27 | 21.77 | 22.08 | 22.40 | 22.61 | 22.71 | 22.76 | 22.71 |
| 2018-12-07 | 5:14:32 PM | 8 | 18.88 | 22.86 | 30 | 22.85 | 6.84 | 19.99 | 19.89 | 20.26 | 21.01 | 21.47 | 22.00 | 22.54 | 22.80 | 22.81 | 22.68 |
| 2018-12-07 | 5:14:34 PM | 10 | 18.15 | 22.85 | 31.07 | 22.79 | 6.84 | 19.28 | 19.31 | 19.67 | 20.58 | 21.13 | 21.81 | 22.58 | 22.98 | 22.94 | 22.69 |
| 2018-12-07 | 5:14:39 PM | 15 | 16.26 | 22.95 | 34.01 | 23.13 | 6.97 | 17.63 | 18.10 | 18.43 | 19.77 | 20.55 | 21.50 | 22.84 | 23.54 | 23.45 | 22.86 |
| 2018-12-07 | 5:14:44 PM | 20 | 14.82 | 23.25 | 35.44 | 24.1 | 7 | 16.21 | 17.21 | 17.50 | 19.17 | 20.18 | 21.33 | 23.13 | 24.05 | 24.06 | 23.16 |
| 2018-12-07 | 5:14:54 PM | 30 | 13 | 23.61 | 36.68 | 25.19 | 7.02 | 14.16 | 15.89 | 16.13 | 18.24 | 19.40 | 20.84 | 23.05 | 24.27 | 24.65 | 23.38 |
| 2018-12-07 | 5:15:14 PM | 50 | 11.47 | 23.28 | 37.41 | 25.54 | 7.07 | 12.18 | 14.47 | 14.74 | 17.12 | 18.43 | 20.05 | 22.57 | 23.98 | 24.61 | 23.02 |
| 2018-12-07 | 5:16:04 PM | 100 | 10.44 | 22.77 | 37.9 | 25.34 | 7 | 10.78 | 13.65 | 13.85 | 16.36 | 17.82 | 19.48 | 22.19 | 23.70 | 24.40 | 22.57 |
| 2018-12-07 | 5:17:44 PM | 200 | 10.13 | 22.69 | 38.1 | 25.36 | 7.01 | 10.39 | 13.40 | 13.57 | 16.13 | 17.65 | 19.36 | 22.11 | 23.66 | 24.45 | 22.48 |

**Table E6: Raw RTD and thermocouple data sample for R3-36 at 5.5LPM**

| Date | GMT -5hrs | Time (s) | RTD's | | | | | THERMOCOUPLES | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | $T_{ci}$(°C) | $T_{co}$(°C) | $T_{hi}$(°C) | $T_{ho}$(°C) | Flow LPM | $T_{ci}$(°C) | $T_1$(°C) | $T_2$(°C) | $T_3$(°C) | $T_4$(°C) | $T_5$(°C) | $T_6$(°C) | $T_7$(°C) | $T_8$(°C) | $T_{co}$(°C) |
| 2018-12-08 | 12:22:35 PM | 1 | 22.05 | 22.81 | 23.61 | 22.78 | 4.99 | 22.12 | 22.22 | 22.37 | 22.48 | 22.56 | 22.57 | 22.60 | 22.63 | 22.66 | 22.63 |
| 2018-12-08 | 12:22:36 PM | 2 | 21.85 | 22.81 | 23.84 | 22.79 | 5.01 | 21.98 | 22.09 | 22.26 | 22.43 | 22.53 | 22.56 | 22.59 | 22.65 | 22.67 | 22.63 |
| 2018-12-08 | 12:22:37 PM | 3 | 21.36 | 22.82 | 24.46 | 22.82 | 5.03 | 21.77 | 21.88 | 22.12 | 22.35 | 22.48 | 22.54 | 22.58 | 22.64 | 22.67 | 22.63 |
| 2018-12-08 | 12:22:39 PM | 5 | 20.83 | 22.82 | 25.35 | 22.83 | 5.04 | 21.35 | 21.42 | 21.76 | 22.12 | 22.35 | 22.49 | 22.59 | 22.65 | 22.70 | 22.65 |
| 2018-12-08 | 12:22:42 PM | 8 | 19.94 | 22.84 | 27.24 | 22.84 | 5.09 | 20.58 | 20.58 | 21.07 | 21.57 | 21.91 | 22.27 | 22.53 | 22.68 | 22.73 | 22.68 |
| 2018-12-08 | 12:22:44 PM | 10 | 19.03 | 22.88 | 29.03 | 22.86 | 5.16 | 20.03 | 20.01 | 20.52 | 21.14 | 21.56 | 22.05 | 22.45 | 22.71 | 22.78 | 22.73 |
| 2018-12-08 | 12:22:49 PM | 15 | 17.54 | 23.02 | 31.74 | 23.15 | 5.39 | 18.61 | 18.52 | 19.16 | 19.97 | 20.59 | 21.41 | 22.20 | 22.78 | 22.99 | 22.90 |
| 2018-12-08 | 12:22:54 PM | 20 | 16.24 | 23.22 | 33.51 | 23.74 | 5.48 | 17.30 | 17.88 | 18.28 | 19.64 | 20.53 | 21.51 | 22.90 | 23.79 | 23.91 | 23.16 |
| 2018-12-08 | 12:23:04 PM | 30 | 14.17 | 23.92 | 35.96 | 24.06 | 5.65 | 15.08 | 16.60 | 17.10 | 18.91 | 20.02 | 21.36 | 23.34 | 24.56 | 25.05 | 23.81 |
| 2018-12-08 | 12:23:24 PM | 50 | 12.03 | 24.41 | 37.1 | 24.72 | 5.58 | 12.66 | 14.91 | 15.46 | 17.79 | 19.12 | 20.84 | 23.29 | 24.86 | 25.74 | 24.17 |
| 2018-12-08 | 12:24:14 PM | 100 | 10.58 | 23.87 | 37.79 | 24.27 | 5.54 | 10.82 | 13.73 | 14.19 | 16.74 | 18.24 | 20.05 | 22.75 | 24.48 | 25.53 | 23.62 |
| 2018-12-08 | 12:25:54 PM | 200 | 10.1 | 23.7 | 38.05 | 24.25 | 5.6 | 10.27 | 13.34 | 13.79 | 16.39 | 17.92 | 19.76 | 22.58 | 24.38 | 25.50 | 23.46 |

**Table E7: Raw RTD and thermocouple data sample for R3-60 at 14LPM**

| Date | GMT -5hrs | Time (s) | RTD's | | | | | THERMOCOUPLES | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | $T_{ci}$(°C) | $T_{co}$(°C) | $T_{hi}$(°C) | $T_{ho}$(°C) | Flow LPM | $T_{ci}$(°C) | $T_1$(°C) | $T_2$(°C) | $T_3$(°C) | $T_4$(°C) | $T_5$(°C) | $T_6$(°C) | $T_7$(°C) | $T_8$(°C) | $T_{co}$(°C) |
| 2018-12-08 | 6:07:32 PM | 1 | 22.04 | 23.03 | 23.53 | 22.71 | 11.91 | 21.87 | 21.97 | 22.17 | 22.43 | 22.56 | 22.59 | 22.69 | 22.86 | 23.03 | 22.93 |
| 2018-12-08 | 6:07:33 PM | 2 | 21.9 | 23.06 | 23.6 | 22.83 | 12.96 | 21.80 | 21.93 | 22.09 | 22.30 | 22.50 | 22.60 | 22.67 | 22.81 | 22.97 | 22.91 |
| 2018-12-08 | 6:07:34 PM | 3 | 21.58 | 23.05 | 23.81 | 22.88 | 13.65 | 21.42 | 21.51 | 22.00 | 22.24 | 22.42 | 22.54 | 22.67 | 22.80 | 22.92 | 22.89 |
| 2018-12-08 | 6:07:36 PM | 5 | 19.94 | 22.99 | 25.96 | 22.95 | 13.69 | 19.87 | 19.79 | 20.71 | 21.62 | 22.14 | 22.39 | 22.58 | 22.73 | 22.84 | 22.82 |
| 2018-12-08 | 6:07:39 PM | 8 | 17.01 | 22.92 | 32.03 | 22.84 | 13.68 | 17.63 | 17.51 | 18.50 | 19.75 | 20.67 | 21.50 | 22.30 | 22.79 | 23.10 | 22.82 |
| 2018-12-08 | 6:07:41 PM | 10 | 15.85 | 23.01 | 33.71 | 22.78 | 13.65 | 16.34 | 16.33 | 17.34 | 18.77 | 19.83 | 20.89 | 21.96 | 22.90 | 23.57 | 23.06 |
| 2018-12-08 | 6:07:46 PM | 15 | 13.47 | 23.56 | 36.13 | 24.04 | 13.55 | 13.92 | 14.35 | 15.32 | 17.21 | 18.53 | 19.92 | 21.30 | 22.99 | 24.15 | 23.52 |
| 2018-12-08 | 6:07:51 PM | 20 | 12.11 | 23.69 | 37.01 | 25.05 | 14.49 | 12.51 | 13.14 | 14.04 | 16.11 | 17.53 | 19.10 | 20.64 | 22.65 | 23.98 | 23.44 |
| 2018-12-08 | 6:08:01 PM | 30 | 10.92 | 23.23 | 37.61 | 25.56 | 14.35 | 11.20 | 12.09 | 12.93 | 15.09 | 16.60 | 18.22 | 19.78 | 22.10 | 23.55 | 22.91 |
| 2018-12-08 | 6:08:21 PM | 50 | 10.21 | 22.81 | 37.97 | 25.28 | 13.9 | 10.43 | 11.54 | 12.38 | 14.62 | 16.13 | 17.84 | 19.41 | 21.94 | 23.51 | 22.64 |
| 2018-12-08 | 6:09:11 PM | 100 | 9.87 | 22.73 | 38.22 | 25.22 | 13.84 | 9.99 | 11.20 | 12.07 | 14.34 | 15.88 | 17.62 | 19.19 | 21.84 | 23.42 | 22.55 |
| 2018-12-08 | 6:10:51 PM | 200 | 9.75 | 22.68 | 38.29 | 25.25 | 13.93 | 9.79 | 11.07 | 11.91 | 14.17 | 15.75 | 17.54 | 19.12 | 21.82 | 23.45 | 22.46 |

**Table E8: Raw RTD and thermocouple data sample for R3-60 at 12LPM**

| Date | GMT -5hrs | Time (s) | RTD's | | | | | THERMOCOUPLES | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | $T_{ci}$(°C) | $T_{co}$(°C) | $T_{hi}$(°C) | $T_{ho}$(°C) | Flow LPM | $T_{ci}$(°C) | $T_1$(°C) | $T_2$(°C) | $T_3$(°C) | $T_4$(°C) | $T_5$(°C) | $T_6$(°C) | $T_7$(°C) | $T_8$(°C) | $T_{co}$(°C) |
| 2018-12-09 | 2:44:14 PM | 1 | 22.51 | 22.99 | 23.32 | 22.66 | 11.52 | 22.19 | 22.27 | 22.52 | 22.64 | 22.73 | 22.74 | 22.77 | 22.82 | 22.88 | 22.78 |
| 2018-12-09 | 2:44:15 PM | 2 | 22.34 | 22.98 | 23.51 | 22.71 | 11.7 | 21.69 | 21.70 | 22.32 | 22.59 | 22.69 | 22.73 | 22.77 | 22.84 | 22.90 | 22.80 |
| 2018-12-09 | 2:44:16 PM | 3 | 21.15 | 22.98 | 25.3 | 22.81 | 11.67 | 21.09 | 21.02 | 21.84 | 22.40 | 22.62 | 22.69 | 22.76 | 22.84 | 22.91 | 22.79 |
| 2018-12-09 | 2:44:18 PM | 5 | 19.79 | 22.99 | 26.54 | 22.88 | 11.77 | 19.73 | 19.61 | 20.56 | 21.60 | 22.04 | 22.46 | 22.71 | 22.88 | 23.02 | 22.83 |
| 2018-12-09 | 2:44:21 PM | 8 | 17.32 | 23.08 | 31.84 | 22.84 | 11.84 | 17.78 | 17.72 | 18.71 | 20.06 | 20.82 | 21.64 | 22.43 | 23.04 | 23.42 | 23.00 |
| 2018-12-09 | 2:44:23 PM | 10 | 15.8 | 23.32 | 34.11 | 22.82 | 11.93 | 16.64 | 16.69 | 17.68 | 19.25 | 20.18 | 21.19 | 22.19 | 23.27 | 23.96 | 23.25 |
| 2018-12-09 | 2:44:28 PM | 15 | 14.05 | 23.96 | 35.93 | 23.79 | 12.01 | 14.46 | 14.94 | 15.94 | 17.97 | 19.22 | 20.59 | 21.86 | 23.72 | 24.91 | 23.98 |
| 2018-12-09 | 2:44:33 PM | 20 | 12.76 | 24.47 | 36.9 | 24.79 | 12.04 | 13.14 | 13.90 | 14.87 | 17.12 | 18.52 | 20.09 | 21.56 | 23.74 | 25.15 | 24.26 |
| 2018-12-09 | 2:44:43 PM | 30 | 11.47 | 24.29 | 37.5 | 25.1 | 12.18 | 11.76 | 12.75 | 13.64 | 16.03 | 17.51 | 19.19 | 20.77 | 23.22 | 24.80 | 23.89 |
| 2018-12-09 | 2:45:03 PM | 50 | 10.67 | 23.74 | 37.85 | 24.75 | 11.98 | 10.84 | 12.00 | 12.87 | 15.25 | 16.83 | 18.59 | 20.17 | 22.82 | 24.51 | 23.43 |
| 2018-12-09 | 2:45:53 PM | 100 | 10.25 | 23.56 | 38.13 | 24.65 | 12.04 | 10.32 | 11.59 | 12.50 | 14.92 | 16.54 | 18.36 | 19.93 | 22.71 | 24.47 | 23.29 |
| 2018-12-09 | 2:47:33 PM | 200 | 10.11 | 23.56 | 38.22 | 24.68 | 12.1 | 10.12 | 11.45 | 12.35 | 14.74 | 16.39 | 18.22 | 19.83 | 22.63 | 24.43 | 23.26 |

**Table E9: Raw RTD and thermocouple data sample for R3-60 at 10LPM**

| Date | GMT -5hrs | Time (s) | RTD's | | | | | THERMOCOUPLES | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | $T_{ci}$(°C) | $T_{co}$(°C) | $T_{hi}$(°C) | $T_{ho}$(°C) | Flow LPM | $T_{ci}$(°C) | $T_1$(°C) | $T_2$(°C) | $T_3$(°C) | $T_4$(°C) | $T_5$(°C) | $T_6$(°C) | $T_7$(°C) | $T_8$(°C) | $T_{co}$(°C) |
| 2018-12-09 | 7:14:20 PM | 1 | 22.14 | 23.17 | 23.46 | 22.91 | 9.85 | 22.04 | 22.18 | 22.42 | 22.64 | 22.77 | 22.83 | 22.88 | 22.97 | 23.06 | 22.97 |
| 2018-12-09 | 7:14:21 PM | 2 | 21.83 | 23.17 | 23.6 | 22.97 | 9.91 | 21.70 | 21.81 | 22.30 | 22.58 | 22.71 | 22.79 | 22.86 | 22.96 | 23.05 | 22.96 |
| 2018-12-09 | 7:14:22 PM | 3 | 21.36 | 23.16 | 23.99 | 22.99 | 9.92 | 21.24 | 21.32 | 22.01 | 22.49 | 22.66 | 22.75 | 22.85 | 22.96 | 23.04 | 22.96 |
| 2018-12-09 | 7:14:24 PM | 5 | 20.21 | 23.15 | 25.86 | 23.01 | 9.94 | 20.14 | 20.15 | 21.08 | 21.99 | 22.35 | 22.60 | 22.78 | 22.91 | 23.02 | 22.93 |
| 2018-12-09 | 7:14:27 PM | 8 | 18.43 | 23.13 | 29.41 | 22.96 | 9.9 | 18.44 | 18.44 | 19.46 | 20.81 | 21.46 | 22.12 | 22.64 | 23.08 | 23.38 | 23.00 |
| 2018-12-09 | 7:14:29 PM | 10 | 16.88 | 23.2 | 32.06 | 22.83 | 9.91 | 17.37 | 17.45 | 18.48 | 20.03 | 20.84 | 21.73 | 22.49 | 23.31 | 23.87 | 23.25 |
| 2018-12-09 | 7:14:34 PM | 15 | 14.58 | 23.91 | 35.14 | 23.18 | 9.99 | 15.19 | 15.59 | 16.67 | 18.65 | 19.82 | 21.10 | 22.25 | 23.85 | 24.97 | 24.01 |
| 2018-12-09 | 7:14:39 PM | 20 | 13.32 | 24.5 | 36.1 | 23.8 | 9.93 | 13.66 | 14.36 | 15.43 | 17.70 | 19.11 | 20.64 | 22.02 | 24.08 | 25.52 | 24.56 |
| 2018-12-09 | 7:14:49 PM | 30 | 11.57 | 24.97 | 37.23 | 24.2 | 9.97 | 12.02 | 12.98 | 14.00 | 16.46 | 18.05 | 19.77 | 21.46 | 23.87 | 25.62 | 24.72 |
| 2018-12-09 | 7:15:09 PM | 50 | 10.47 | 24.48 | 37.73 | 23.83 | 9.92 | 10.79 | 11.97 | 12.94 | 15.46 | 17.16 | 19.04 | 20.71 | 23.41 | 25.34 | 24.24 |
| 2018-12-09 | 7:15:59 PM | 100 | 9.84 | 24.19 | 38.12 | 23.62 | 9.92 | 10.03 | 11.33 | 12.33 | 14.86 | 16.61 | 18.56 | 20.28 | 23.14 | 25.22 | 24.00 |
| 2018-12-09 | 7:17:39 PM | 200 | 9.67 | 24.17 | 38.25 | 23.61 | 9.98 | 9.79 | 11.19 | 12.18 | 14.71 | 16.53 | 18.48 | 20.21 | 23.13 | 25.19 | 23.97 |

**Table E10: Raw RTD and thermocouple data sample for R3-60 at 9LPM**

| Date | GMT -5hrs | Time (s) | RTD's | | | | | THERMOCOUPLES | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | $T_{ci}$(°C) | $T_{co}$(°C) | $T_{hi}$(°C) | $T_{ho}$(°C) | Flow LPM | $T_{ci}$(°C) | $T_1$(°C) | $T_2$(°C) | $T_3$(°C) | $T_4$(°C) | $T_5$(°C) | $T_6$(°C) | $T_7$(°C) | $T_8$(°C) | $T_{co}$(°C) |
| 2018-12-10 | 10:38:56 AM | 1 | 21.81 | 22.75 | 23.79 | 22.64 | 8.81 | 21.80 | 21.91 | 22.36 | 22.53 | 22.59 | 22.60 | 22.61 | 22.67 | 22.73 | 22.57 |
| 2018-12-10 | 10:38:57 AM | 2 | 21.32 | 22.76 | 24.58 | 22.66 | 8.83 | 21.39 | 21.46 | 22.12 | 22.48 | 22.58 | 22.60 | 22.61 | 22.68 | 22.75 | 22.65 |
| 2018-12-10 | 10:38:58 AM | 3 | 20.82 | 22.77 | 25.37 | 22.68 | 8.85 | 20.92 | 20.96 | 21.76 | 22.35 | 22.53 | 22.59 | 22.62 | 22.70 | 22.78 | 22.59 |
| 2018-12-10 | 10:39:00 AM | 5 | 19.73 | 22.79 | 26.38 | 22.7 | 8.93 | 19.91 | 19.92 | 20.87 | 21.84 | 22.20 | 22.50 | 22.62 | 22.77 | 22.92 | 22.65 |
| 2018-12-10 | 10:39:03 AM | 8 | 17.76 | 22.89 | 30.83 | 22.67 | 8.92 | 18.44 | 18.41 | 19.45 | 20.81 | 21.42 | 22.09 | 22.58 | 23.02 | 23.34 | 22.81 |
| 2018-12-10 | 10:39:05 AM | 10 | 16.48 | 23.1 | 33.22 | 22.55 | 8.9 | 17.50 | 17.58 | 18.62 | 20.14 | 20.90 | 21.77 | 22.45 | 23.21 | 23.78 | 23.04 |
| 2018-12-10 | 10:39:10 AM | 15 | 14.84 | 23.77 | 35.09 | 22.68 | 8.94 | 15.51 | 15.92 | 17.04 | 18.99 | 20.12 | 21.38 | 22.37 | 23.99 | 25.16 | 23.96 |
| 2018-12-10 | 10:39:15 AM | 20 | 13.48 | 24.67 | 36.19 | 23.47 | 8.99 | 14.09 | 14.78 | 15.89 | 18.19 | 19.54 | 21.06 | 22.35 | 24.40 | 25.88 | 24.65 |
| 2018-12-10 | 10:39:25 AM | 30 | 11.91 | 25.37 | 37.03 | 23.92 | 9.03 | 12.38 | 13.37 | 14.47 | 17.01 | 18.62 | 20.37 | 21.97 | 24.44 | 26.23 | 25.14 |
| 2018-12-10 | 10:39:45 AM | 50 | 10.75 | 25.01 | 37.56 | 23.46 | 8.99 | 11.05 | 12.28 | 13.31 | 15.90 | 17.66 | 19.51 | 21.19 | 23.93 | 25.93 | 24.72 |
| 2018-12-10 | 10:40:35 AM | 100 | 10.08 | 24.71 | 37.96 | 23.13 | 9.02 | 10.23 | 11.61 | 12.64 | 15.23 | 17.07 | 19.07 | 20.79 | 23.66 | 25.80 | 24.49 |
| 2018-12-10 | 10:42:15 AM | 200 | 9.86 | 24.69 | 38.12 | 23.12 | 8.95 | 9.92 | 11.42 | 12.46 | 15.11 | 16.96 | 18.96 | 20.70 | 23.69 | 25.85 | 24.45 |

**Table E11: Raw RTD and thermocouple data sample for R3-60 at 7LPM**

| Date | GMT -5hrs | Time (s) | RTD's | | | | | THERMOCOUPLES | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | $T_{ci}$(°C) | $T_{co}$(°C) | $T_{hi}$(°C) | $T_{ho}$(°C) | Flow LPM | $T_{ci}$(°C) | $T_1$(°C) | $T_2$(°C) | $T_3$(°C) | $T_4$(°C) | $T_5$(°C) | $T_6$(°C) | $T_7$(°C) | $T_8$(°C) | $T_{co}$(°C) |
| 2018-12-10 | 4:18:29 PM | 1 | 22.15 | 22.6 | 22.88 | 22.37 | 6.93 | 22.12 | 22.20 | 22.27 | 22.35 | 22.42 | 22.43 | 22.44 | 22.45 | 22.51 | 22.51 |
| 2018-12-10 | 4:18:30 PM | 2 | 22.06 | 22.59 | 22.9 | 22.39 | 6.95 | 22.00 | 22.10 | 22.25 | 22.31 | 22.39 | 22.40 | 22.42 | 22.45 | 22.50 | 22.51 |
| 2018-12-10 | 4:18:31 PM | 3 | 21.62 | 22.6 | 23.33 | 22.42 | 7 | 21.82 | 21.92 | 22.21 | 22.31 | 22.39 | 22.40 | 22.42 | 22.47 | 22.51 | 22.50 |
| 2018-12-10 | 4:18:33 PM | 5 | 21.3 | 22.6 | 23.78 | 22.43 | 7.02 | 21.24 | 21.30 | 21.93 | 22.26 | 22.36 | 22.37 | 22.41 | 22.47 | 22.51 | 22.51 |
| 2018-12-10 | 4:18:36 PM | 8 | 19.7 | 22.62 | 27.29 | 22.44 | 7.13 | 20.17 | 20.16 | 21.07 | 21.84 | 22.15 | 22.33 | 22.41 | 22.50 | 22.61 | 22.54 |
| 2018-12-10 | 4:18:38 PM | 10 | 18.93 | 22.63 | 28.33 | 22.43 | 7.14 | 19.41 | 19.40 | 20.39 | 21.44 | 21.88 | 22.25 | 22.45 | 22.66 | 22.87 | 22.61 |
| 2018-12-10 | 4:18:43 PM | 15 | 16.5 | 23.02 | 33 | 22.25 | 7.05 | 17.58 | 17.68 | 18.81 | 20.33 | 21.18 | 22.01 | 22.60 | 23.47 | 24.11 | 23.17 |
| 2018-12-10 | 4:18:48 PM | 20 | 15.21 | 23.77 | 34.32 | 22.31 | 7.09 | 16.02 | 16.40 | 17.61 | 19.55 | 20.72 | 21.92 | 22.88 | 24.40 | 25.48 | 24.15 |
| 2018-12-10 | 4:18:58 PM | 30 | 13.03 | 25.61 | 36.09 | 22.9 | 7.19 | 13.81 | 14.60 | 15.93 | 18.37 | 19.90 | 21.56 | 23.07 | 25.27 | 26.84 | 25.64 |
| 2018-12-10 | 4:19:18 PM | 50 | 11.42 | 26.26 | 37.28 | 22.59 | 7.14 | 11.94 | 13.09 | 14.41 | 17.18 | 18.94 | 20.90 | 22.67 | 25.35 | 27.27 | 26.13 |
| 2018-12-10 | 4:20:08 PM | 100 | 10.43 | 26.06 | 37.85 | 22.02 | 7.13 | 10.75 | 12.10 | 13.42 | 16.24 | 18.17 | 20.23 | 22.15 | 25.05 | 27.19 | 25.93 |
| 2018-12-10 | 4:21:48 PM | 200 | 10.12 | 26.09 | 38.06 | 21.91 | 7.12 | 10.34 | 11.85 | 13.14 | 16.01 | 18.00 | 20.10 | 22.08 | 25.08 | 27.29 | 25.96 |

**Table E12: Raw RTD and thermocouple data sample for R3-60 at 5.5LPM**

| Date | GMT -5hrs | Time (s) | RTD's | | | | | THERMOCOUPLES | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | $T_{ci}$(°C) | $T_{co}$(°C) | $T_{hi}$(°C) | $T_{ho}$(°C) | Flow LPM | $T_{ci}$(°C) | $T_1$(°C) | $T_2$(°C) | $T_3$(°C) | $T_4$(°C) | $T_5$(°C) | $T_6$(°C) | $T_7$(°C) | $T_8$(°C) | $T_{co}$(°C) |
| 2018-12-11 | 11:40:44 AM | 1 | 21.09 | 21.49 | 22.27 | 21.46 | 5.22 | 21.16 | 21.21 | 21.38 | 21.41 | 21.46 | 21.43 | 21.42 | 21.42 | 21.44 | 21.47 |
| 2018-12-11 | 11:40:45 AM | 2 | 20.93 | 21.49 | 22.56 | 21.46 | 5.21 | 21.05 | 21.09 | 21.35 | 21.42 | 21.46 | 21.44 | 21.43 | 21.43 | 21.45 | 21.48 |
| 2018-12-11 | 11:40:46 AM | 3 | 20.54 | 21.5 | 23.58 | 21.46 | 5.23 | 20.89 | 20.94 | 21.29 | 21.41 | 21.46 | 21.44 | 21.44 | 21.44 | 21.47 | 21.49 |
| 2018-12-11 | 11:40:48 AM | 5 | 20.08 | 21.52 | 25.14 | 21.47 | 5.21 | 20.50 | 20.50 | 21.08 | 21.35 | 21.45 | 21.44 | 21.45 | 21.46 | 21.50 | 21.49 |
| 2018-12-11 | 11:40:51 AM | 8 | 19.19 | 21.55 | 27.68 | 21.47 | 5.25 | 19.83 | 19.76 | 20.55 | 21.12 | 21.36 | 21.45 | 21.49 | 21.54 | 21.65 | 21.54 |
| 2018-12-11 | 11:40:53 AM | 10 | 18.54 | 21.6 | 29.19 | 21.45 | 5.25 | 19.33 | 19.24 | 20.14 | 20.92 | 21.27 | 21.47 | 21.57 | 21.72 | 21.92 | 21.65 |
| 2018-12-11 | 11:40:58 AM | 15 | 17.08 | 22 | 31.62 | 21.4 | 5.34 | 18.11 | 18.12 | 19.18 | 20.38 | 21.05 | 21.65 | 21.98 | 22.66 | 23.30 | 22.24 |
| 2018-12-11 | 11:41:03 AM | 20 | 15.71 | 23.07 | 33.22 | 21.47 | 5.37 | 16.97 | 17.11 | 18.33 | 19.90 | 20.87 | 21.83 | 22.55 | 23.72 | 24.75 | 23.25 |
| 2018-12-11 | 11:41:13 AM | 30 | 14.15 | 24.97 | 35.12 | 21.74 | 5.37 | 15.11 | 15.63 | 17.04 | 19.15 | 20.54 | 21.99 | 23.33 | 25.14 | 26.71 | 25.16 |
| 2018-12-11 | 11:41:33 AM | 50 | 12.34 | 26.94 | 36.78 | 21.77 | 5.51 | 12.98 | 13.88 | 15.41 | 18.01 | 19.78 | 21.70 | 23.69 | 26.15 | 28.23 | 26.90 |
| 2018-12-11 | 11:42:23 AM | 100 | 10.97 | 27.22 | 37.78 | 21.21 | 5.64 | 11.35 | 12.60 | 14.15 | 16.95 | 18.93 | 21.07 | 23.36 | 26.18 | 28.44 | 27.14 |
| 2018-12-11 | 11:44:03 AM | 200 | 10.56 | 27.36 | 38.08 | 21.03 | 5.57 | 10.81 | 12.19 | 13.75 | 16.59 | 18.68 | 20.86 | 23.28 | 26.18 | 28.60 | 27.23 |

**Table E13: Raw RTD and thermocouple data sample for 4-36 at 14LPM**

| Date | GMT -5hrs | Time (s) | RTD's | | | | | THERMOCOUPLES | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | $T_{ci}$(°C) | $T_{co}$(°C) | $T_{hi}$(°C) | $T_{ho}$(°C) | Flow LPM | $T_{ci}$(°C) | $T_1$(°C) | $T_2$(°C) | $T_3$(°C) | $T_4$(°C) | $T_5$(°C) | $T_6$(°C) | $T_7$(°C) | $T_8$(°C) | $T_{co}$(°C) |
| 2018-12-12 | 10:31:16 AM | 1 | 22.26 | 22.32 | 22.52 | 21.8 | 9.17 | 22.14 | 22.21 | 22.22 | 22.19 | 22.21 | 22.15 | 22.12 | 22.11 | 22.14 | 22.12 |
| 2018-12-12 | 10:31:17 AM | 2 | 22.28 | 22.3 | 22.7 | 21.85 | 11.88 | 22.13 | 22.20 | 22.21 | 22.20 | 22.19 | 22.14 | 22.12 | 22.13 | 22.14 | 22.10 |
| 2018-12-12 | 10:31:18 AM | 3 | 22.26 | 22.28 | 22.76 | 22 | 13.47 | 21.92 | 22.10 | 22.14 | 22.21 | 22.22 | 22.16 | 22.14 | 22.14 | 22.17 | 22.12 |
| 2018-12-12 | 10:31:20 AM | 5 | 21.12 | 22.29 | 23.42 | 22.12 | 13.68 | 20.37 | 20.62 | 20.75 | 21.67 | 22.11 | 22.20 | 22.19 | 22.20 | 22.22 | 22.15 |
| 2018-12-12 | 10:31:23 AM | 8 | 18.57 | 22.32 | 27.34 | 22.34 | 13.74 | 17.94 | 18.03 | 18.36 | 19.47 | 20.41 | 21.30 | 21.90 | 22.28 | 22.40 | 22.27 |
| 2018-12-12 | 10:31:25 AM | 10 | 17.04 | 22.38 | 30.72 | 22.48 | 13.82 | 16.55 | 16.60 | 17.15 | 18.24 | 19.25 | 20.57 | 21.47 | 22.18 | 22.49 | 22.25 |
| 2018-12-12 | 10:31:30 AM | 15 | 13.74 | 22 | 35.66 | 25.56 | 13.79 | 14.04 | 14.24 | 15.33 | 16.34 | 17.35 | 19.12 | 20.41 | 21.46 | 22.14 | 21.55 |
| 2018-12-12 | 10:31:35 AM | 20 | 12.28 | 21.26 | 36.88 | 27.88 | 13.84 | 12.65 | 12.95 | 14.35 | 15.35 | 16.30 | 18.35 | 19.79 | 20.96 | 21.79 | 20.90 |
| 2018-12-12 | 10:31:45 AM | 30 | 11.01 | 20.13 | 37.55 | 28.89 | 14.13 | 11.27 | 11.72 | 13.24 | 14.12 | 15.00 | 17.11 | 18.69 | 20.04 | 20.96 | 19.83 |
| 2018-12-12 | 10:32:05 AM | 50 | 10.16 | 19 | 37.92 | 28.98 | 14.27 | 10.34 | 10.91 | 12.52 | 13.38 | 14.29 | 16.50 | 18.14 | 19.45 | 20.36 | 18.93 |
| 2018-12-12 | 10:32:55 AM | 100 | 9.8 | 18.83 | 38.15 | 28.99 | 13.93 | 9.81 | 10.53 | 12.26 | 13.14 | 14.06 | 16.34 | 18.00 | 19.36 | 20.30 | 18.76 |
| 2018-12-12 | 10:34:35 AM | 200 | 9.69 | 18.83 | 38.24 | 28.99 | 13.88 | 9.68 | 10.42 | 12.21 | 13.11 | 13.98 | 16.29 | 18.02 | 19.41 | 20.34 | 18.75 |

**Table E14: Raw RTD and thermocouple data sample for 4-36 at 12LPM**

| Date | GMT -5hrs | Time (s) | RTD's | | | | | THERMOCOUPLES | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | $T_{ci}$(°C) | $T_{co}$(°C) | $T_{hi}$(°C) | $T_{ho}$(°C) | Flow LPM | $T_{ci}$(°C) | $T_1$(°C) | $T_2$(°C) | $T_3$(°C) | $T_4$(°C) | $T_5$(°C) | $T_6$(°C) | $T_7$(°C) | $T_8$(°C) | $T_{co}$(°C) |
| 2018-12-12 | 5:51:19 PM | 1 | 22.36 | 22.57 | 23.1 | 22.81 | 11.75 | 21.83 | 22.09 | 22.17 | 22.32 | 22.40 | 22.42 | 22.46 | 22.52 | 22.59 | 22.38 |
| 2018-12-12 | 5:51:20 PM | 2 | 21.61 | 22.58 | 23.75 | 22.8 | 11.8 | 21.28 | 21.57 | 21.68 | 22.22 | 22.39 | 22.44 | 22.48 | 22.53 | 22.62 | 22.40 |
| 2018-12-12 | 5:51:21 PM | 3 | 20.98 | 22.59 | 24.81 | 22.8 | 11.81 | 20.64 | 20.92 | 21.07 | 21.85 | 22.29 | 22.42 | 22.48 | 22.53 | 22.61 | 22.40 |
| 2018-12-12 | 5:51:23 PM | 5 | 18.92 | 22.61 | 28.62 | 22.83 | 11.8 | 19.30 | 19.51 | 19.77 | 20.79 | 21.59 | 22.16 | 22.51 | 22.66 | 22.73 | 22.45 |
| 2018-12-12 | 5:51:26 PM | 8 | 16.6 | 22.77 | 33.16 | 23.32 | 11.81 | 17.45 | 17.61 | 18.12 | 19.16 | 20.18 | 21.38 | 22.24 | 22.84 | 23.05 | 22.64 |
| 2018-12-12 | 5:51:28 PM | 10 | 15.69 | 22.84 | 34.53 | 24.11 | 11.93 | 16.37 | 16.54 | 17.35 | 18.37 | 19.41 | 20.90 | 21.99 | 22.80 | 23.15 | 22.63 |
| 2018-12-12 | 5:51:33 PM | 15 | 14 | 22.61 | 36.06 | 26.07 | 11.95 | 14.34 | 14.63 | 15.82 | 16.84 | 17.92 | 19.80 | 21.22 | 22.37 | 23.13 | 22.27 |
| 2018-12-12 | 5:51:38 PM | 20 | 12.57 | 22.04 | 37.02 | 27.99 | 12.04 | 13.07 | 13.46 | 14.91 | 15.92 | 16.97 | 19.08 | 20.63 | 21.96 | 22.85 | 21.75 |
| 2018-12-12 | 5:51:48 PM | 30 | 11.48 | 21.12 | 37.53 | 28.49 | 11.95 | 11.75 | 12.31 | 14.08 | 15.06 | 16.03 | 18.39 | 19.99 | 21.31 | 22.19 | 20.83 |
| 2018-12-12 | 5:52:08 PM | 50 | 10.66 | 20.13 | 37.87 | 28.35 | 12 | 10.80 | 11.53 | 13.53 | 14.55 | 15.51 | 17.94 | 19.53 | 20.85 | 21.69 | 20.01 |
| 2018-12-12 | 5:52:58 PM | 100 | 10.26 | 19.84 | 38.14 | 28.41 | 11.98 | 10.36 | 11.11 | 13.06 | 14.06 | 15.03 | 17.51 | 19.21 | 20.61 | 21.47 | 19.80 |
| 2018-12-12 | 5:54:38 PM | 200 | 10.13 | 19.73 | 38.25 | 28.61 | 12.08 | 10.13 | 10.90 | 12.72 | 13.67 | 14.66 | 16.99 | 18.71 | 20.19 | 21.34 | 19.62 |

**Table E15: Raw RTD and thermocouple data sample for 4-36 at 10LPM**

| Date | GMT -5hrs | Time (s) | RTD's | | | | | THERMOCOUPLES | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | $T_{ci}$(°C) | $T_{co}$(°C) | $T_{hi}$(°C) | $T_{ho}$(°C) | Flow LPM | $T_{ci}$(°C) | $T_1$(°C) | $T_2$(°C) | $T_3$(°C) | $T_4$(°C) | $T_5$(°C) | $T_6$(°C) | $T_7$(°C) | $T_8$(°C) | $T_{co}$(°C) |
| 2018-12-13 | 10:51:20 AM | 1 | 22.41 | 22.41 | 23.01 | 22.22 | 9.57 | 22.19 | 22.31 | 22.31 | 22.31 | 22.34 | 22.28 | 22.26 | 22.26 | 22.28 | 22.18 |
| 2018-12-13 | 10:51:21 AM | 2 | 22.39 | 22.41 | 22.98 | 22.24 | 9.61 | 22.21 | 22.29 | 22.30 | 22.32 | 22.35 | 22.32 | 22.29 | 22.29 | 22.31 | 22.20 |
| 2018-12-13 | 10:51:22 AM | 3 | 22.37 | 22.41 | 22.98 | 22.26 | 9.67 | 21.95 | 22.17 | 22.23 | 22.30 | 22.36 | 22.33 | 22.32 | 22.32 | 22.34 | 22.23 |
| 2018-12-13 | 10:51:24 AM | 5 | 21.34 | 22.45 | 24.22 | 22.36 | 9.76 | 21.13 | 21.44 | 21.57 | 22.11 | 22.34 | 22.37 | 22.37 | 22.38 | 22.41 | 22.29 |
| 2018-12-13 | 10:51:27 AM | 8 | 19.04 | 22.53 | 27.3 | 22.6 | 9.83 | 19.50 | 19.72 | 20.02 | 20.98 | 21.71 | 22.14 | 22.38 | 22.50 | 22.54 | 22.38 |
| 2018-12-13 | 10:51:29 AM | 10 | 18.02 | 22.59 | 29.92 | 22.68 | 9.84 | 18.48 | 18.58 | 19.00 | 20.02 | 20.94 | 21.74 | 22.32 | 22.64 | 22.70 | 22.46 |
| 2018-12-13 | 10:51:34 AM | 15 | 15.53 | 22.77 | 34.82 | 23.53 | 9.98 | 16.16 | 16.35 | 17.40 | 18.39 | 19.46 | 21.03 | 22.18 | 23.03 | 23.28 | 22.59 |
| 2018-12-13 | 10:51:39 AM | 20 | 13.88 | 22.8 | 36.14 | 26.01 | 10.04 | 14.49 | 14.85 | 16.37 | 17.43 | 18.56 | 20.53 | 21.99 | 23.11 | 23.67 | 22.62 |
| 2018-12-13 | 10:51:49 AM | 30 | 12.29 | 22.43 | 37.1 | 27.55 | 10.01 | 12.63 | 13.16 | 15.08 | 16.14 | 17.27 | 19.57 | 21.20 | 22.53 | 23.39 | 22.09 |
| 2018-12-13 | 10:52:09 AM | 50 | 11.05 | 21.32 | 37.65 | 27.48 | 9.96 | 11.23 | 11.96 | 14.00 | 15.09 | 16.26 | 18.72 | 20.43 | 21.82 | 22.74 | 21.13 |
| 2018-12-13 | 10:52:59 AM | 100 | 10.43 | 20.79 | 38 | 27.43 | 9.99 | 10.49 | 11.34 | 13.53 | 14.62 | 15.71 | 18.28 | 20.02 | 21.47 | 22.46 | 20.70 |
| 2018-12-13 | 10:54:39 AM | 200 | 10.26 | 20.74 | 38.14 | 27.5 | 10 | 10.31 | 11.20 | 13.45 | 14.52 | 15.63 | 18.30 | 20.08 | 21.51 | 22.45 | 20.69 |

**Table E16: Raw RTD and thermocouple data sample for 4-36 at 9LPM**

| Date | GMT -5hrs | Time (s) | RTD's | | | | | THERMOCOUPLES | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | $T_{ci}$(°C) | $T_{co}$(°C) | $T_{hi}$(°C) | $T_{ho}$(°C) | Flow LPM | $T_{ci}$(°C) | $T_1$(°C) | $T_2$(°C) | $T_3$(°C) | $T_4$(°C) | $T_5$(°C) | $T_6$(°C) | $T_7$(°C) | $T_8$(°C) | $T_{co}$(°C) |
| 2018-12-13 | 5:40:19 PM | 1 | 22.33 | 22.58 | 23.18 | 22.94 | 8.9 | 22.08 | 22.25 | 22.30 | 22.29 | 22.34 | 22.37 | 22.42 | 22.50 | 22.58 | 22.38 |
| 2018-12-13 | 5:40:20 PM | 2 | 22.12 | 22.59 | 23.2 | 22.93 | 8.93 | 21.90 | 22.11 | 22.19 | 22.30 | 22.35 | 22.37 | 22.43 | 22.50 | 22.58 | 22.42 |
| 2018-12-13 | 5:40:21 PM | 3 | 21.3 | 22.61 | 23.8 | 22.92 | 9.01 | 21.55 | 21.81 | 21.92 | 22.25 | 22.35 | 22.37 | 22.41 | 22.49 | 22.59 | 22.41 |
| 2018-12-13 | 5:40:23 PM | 5 | 20.52 | 22.62 | 24.93 | 22.93 | 9.06 | 20.67 | 20.90 | 21.08 | 21.84 | 22.23 | 22.36 | 22.41 | 22.50 | 22.59 | 22.43 |
| 2018-12-13 | 5:40:26 PM | 8 | 18.67 | 22.62 | 28.67 | 22.95 | 9.1 | 19.11 | 19.27 | 19.53 | 20.56 | 21.38 | 21.93 | 22.31 | 22.54 | 22.65 | 22.46 |
| 2018-12-13 | 5:40:28 PM | 10 | 17.74 | 22.64 | 30.69 | 23.06 | 9.1 | 18.17 | 18.25 | 18.53 | 19.61 | 20.56 | 21.35 | 22.02 | 22.53 | 22.74 | 22.53 |
| 2018-12-13 | 5:40:33 PM | 15 | 15.2 | 22.77 | 34.72 | 24.91 | 9.19 | 16.03 | 16.10 | 16.41 | 17.50 | 18.52 | 19.73 | 20.97 | 22.12 | 22.87 | 22.55 |
| 2018-12-13 | 5:40:38 PM | 20 | 13.94 | 22.56 | 35.86 | 26.73 | 9.14 | 14.57 | 14.53 | 14.91 | 15.91 | 16.97 | 18.43 | 19.95 | 21.54 | 22.74 | 22.21 |
| 2018-12-13 | 5:40:48 PM | 30 | 12.18 | 21.48 | 37.01 | 28.64 | 9.21 | 12.66 | 12.80 | 13.47 | 14.32 | 15.45 | 17.73 | 19.50 | 21.29 | 22.43 | 21.21 |
| 2018-12-13 | 5:41:08 PM | 50 | 11.03 | 21.69 | 37.56 | 26.86 | 9.09 | 11.30 | 12.01 | 14.03 | 15.20 | 16.47 | 18.99 | 20.74 | 22.22 | 23.26 | 21.58 |
| 2018-12-13 | 5:41:58 PM | 100 | 10.35 | 21.28 | 37.94 | 26.81 | 9.06 | 10.43 | 11.31 | 13.51 | 14.67 | 15.91 | 18.57 | 20.39 | 21.95 | 23.03 | 21.19 |
| 2018-12-13 | 5:43:38 PM | 200 | 10.16 | 21.28 | 38.09 | 26.79 | 9.04 | 10.20 | 11.13 | 13.38 | 14.55 | 15.78 | 18.49 | 20.36 | 21.97 | 23.10 | 21.19 |

**Table E17: Raw RTD and thermocouple data sample for 4-36 at 7LPM**

| Date | GMT -5hrs | Time (s) | RTD's | | | | | THERMOCOUPLES | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | $T_{ci}$(°C) | $T_{co}$(°C) | $T_{hi}$(°C) | $T_{ho}$(°C) | Flow LPM | $T_{ci}$(°C) | $T_1$(°C) | $T_2$(°C) | $T_3$(°C) | $T_4$(°C) | $T_5$(°C) | $T_6$(°C) | $T_7$(°C) | $T_8$(°C) | $T_{co}$(°C) |
| 2018-12-14 | 10:23:29 AM | 1 | 22.35 | 22.36 | 23.02 | 22.3 | 6.53 | 22.27 | 22.36 | 22.38 | 22.37 | 22.36 | 22.31 | 22.29 | 22.29 | 22.33 | 22.14 |
| 2018-12-14 | 10:23:30 AM | 2 | 22.35 | 22.37 | 23.03 | 22.31 | 6.54 | 22.24 | 22.34 | 22.37 | 22.38 | 22.38 | 22.34 | 22.30 | 22.31 | 22.34 | 22.15 |
| 2018-12-14 | 10:23:31 AM | 3 | 22.34 | 22.37 | 23.1 | 22.34 | 6.61 | 22.16 | 22.29 | 22.35 | 22.37 | 22.40 | 22.36 | 22.32 | 22.32 | 22.35 | 22.17 |
| 2018-12-14 | 10:23:33 AM | 5 | 21.63 | 22.41 | 24.14 | 22.46 | 6.65 | 21.80 | 22.01 | 22.12 | 22.34 | 22.39 | 22.39 | 22.36 | 22.38 | 22.40 | 22.20 |
| 2018-12-14 | 10:23:36 AM | 8 | 20.17 | 22.47 | 27.23 | 22.63 | 6.76 | 20.92 | 21.13 | 21.31 | 21.96 | 22.30 | 22.39 | 22.40 | 22.44 | 22.47 | 22.26 |
| 2018-12-14 | 10:23:38 AM | 10 | 19.6 | 22.5 | 28.18 | 22.69 | 6.83 | 20.23 | 20.38 | 20.61 | 21.47 | 22.03 | 22.32 | 22.43 | 22.51 | 22.55 | 22.33 |
| 2018-12-14 | 10:23:43 AM | 15 | 17.35 | 22.79 | 32.35 | 23.6 | 6.92 | 18.46 | 18.45 | 18.75 | 19.80 | 20.74 | 21.56 | 22.21 | 22.71 | 22.95 | 22.65 |
| 2018-12-14 | 10:23:48 AM | 20 | 15.74 | 23.14 | 34.68 | 25.38 | 6.96 | 16.87 | 16.78 | 17.11 | 18.16 | 19.21 | 20.35 | 21.48 | 22.58 | 23.30 | 22.94 |
| 2018-12-14 | 10:23:58 AM | 30 | 13.8 | 22.89 | 36.43 | 28.12 | 7.05 | 14.53 | 14.45 | 14.76 | 15.71 | 16.78 | 18.23 | 19.80 | 21.60 | 23.16 | 22.58 |
| 2018-12-14 | 10:24:18 AM | 50 | 11.99 | 21.13 | 37.33 | 29.06 | 7.03 | 12.35 | 12.39 | 12.67 | 13.41 | 14.35 | 15.81 | 17.57 | 19.78 | 21.71 | 20.89 |
| 2018-12-14 | 10:25:08 AM | 100 | 10.88 | 21.23 | 37.89 | 25.92 | 7.08 | 10.98 | 11.49 | 12.91 | 13.94 | 15.21 | 17.64 | 19.67 | 21.74 | 23.30 | 21.28 |
| 2018-12-14 | 10:26:48 AM | 200 | 10.55 | 22.34 | 38.11 | 26.31 | 7.07 | 10.61 | 11.23 | 12.72 | 13.92 | 15.32 | 17.87 | 20.06 | 22.22 | 24.00 | 22.23 |

**Table E18: Raw RTD and thermocouple data sample for 4-36 at 5.5LPM**

| Date | GMT -5hrs | Time (s) | RTD's | | | | | THERMOCOUPLES | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | $T_{ci}$(°C) | $T_{co}$(°C) | $T_{hi}$(°C) | $T_{ho}$(°C) | Flow LPM | $T_{ci}$(°C) | $T_1$(°C) | $T_2$(°C) | $T_3$(°C) | $T_4$(°C) | $T_5$(°C) | $T_6$(°C) | $T_7$(°C) | $T_8$(°C) | $T_{co}$(°C) |
| 2018-12-15 | 3:48:30 PM | 1 | 22.05 | 22.46 | 23.44 | 22.48 | 5.18 | 22.24 | 22.33 | 22.38 | 22.42 | 22.42 | 22.35 | 22.32 | 22.29 | 22.30 | 22.40 |
| 2018-12-15 | 3:48:31 PM | 2 | 21.83 | 22.46 | 23.68 | 22.52 | 5.19 | 22.09 | 22.25 | 22.30 | 22.40 | 22.42 | 22.35 | 22.33 | 22.31 | 22.31 | 22.41 |
| 2018-12-15 | 3:48:32 PM | 3 | 21.6 | 22.47 | 24.11 | 22.55 | 5.19 | 21.94 | 22.12 | 22.20 | 22.39 | 22.43 | 22.37 | 22.35 | 22.33 | 22.32 | 22.42 |
| 2018-12-15 | 3:48:34 PM | 5 | 21.07 | 22.49 | 24.95 | 22.61 | 5.23 | 21.51 | 21.72 | 21.87 | 22.27 | 22.41 | 22.38 | 22.36 | 22.35 | 22.34 | 22.43 |
| 2018-12-15 | 3:48:37 PM | 8 | 20.18 | 22.52 | 26.71 | 22.71 | 5.29 | 20.74 | 20.91 | 21.14 | 21.86 | 22.26 | 22.36 | 22.40 | 22.41 | 22.41 | 22.49 |
| 2018-12-15 | 3:48:39 PM | 10 | 19.22 | 22.58 | 28.66 | 22.84 | 5.3 | 20.18 | 20.33 | 20.58 | 21.45 | 22.05 | 22.30 | 22.42 | 22.48 | 22.49 | 22.57 |
| 2018-12-15 | 3:48:44 PM | 15 | 17.56 | 22.84 | 31.8 | 23.7 | 5.42 | 18.74 | 18.74 | 19.08 | 20.13 | 21.08 | 21.77 | 22.30 | 22.65 | 22.80 | 22.87 |
| 2018-12-15 | 3:48:49 PM | 20 | 16.35 | 23.19 | 33.56 | 24.97 | 5.43 | 17.42 | 17.36 | 17.70 | 18.77 | 19.88 | 20.90 | 21.85 | 22.63 | 23.11 | 23.26 |
| 2018-12-15 | 3:48:59 PM | 30 | 14.17 | 23.36 | 35.84 | 28.07 | 5.54 | 15.23 | 15.17 | 15.44 | 16.46 | 17.59 | 18.87 | 20.29 | 21.66 | 22.93 | 23.24 |
| 2018-12-15 | 3:49:19 PM | 50 | 12.08 | 21.51 | 37.06 | 28.74 | 5.8 | 12.75 | 12.78 | 13.08 | 13.83 | 14.81 | 16.15 | 17.76 | 19.61 | 21.40 | 21.48 |
| 2018-12-15 | 3:50:09 PM | 100 | 10.71 | 20.11 | 37.69 | 28.19 | 5.58 | 11.03 | 11.17 | 11.47 | 12.19 | 13.06 | 14.42 | 16.05 | 18.32 | 20.84 | 20.19 |
| 2018-12-15 | 3:51:49 PM | 200 | 10.21 | 20.18 | 37.98 | 27.83 | 5.57 | 10.45 | 10.64 | 10.98 | 11.71 | 12.62 | 14.10 | 15.94 | 18.65 | 21.65 | 20.26 |

# Appendix F: Coil Set Surface and Estimated Water Temperature Data Tables

**Table F1: R3-36 mains-side temperature values at 14LPM for selected time instants**

| | Dist | 1 sec | 2 sec | 3 sec | 5 sec | 8 sec | 10 sec | 15 sec | 20 sec | 30 sec | 50 sec | 100 sec | 200 sec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ESTIMATED WATER TEMPERATURE ($^0$C) | **0.00** | 22.51 | 22.49 | 22.47 | 20.99 | 17.74 | 16.43 | 13.75 | 12.18 | 10.79 | 10.00 | 9.63 | 9.51 |
| | **0.07** | 22.52 | 22.50 | 22.48 | 21.10 | 18.06 | 16.82 | 14.27 | 12.78 | 11.41 | 10.62 | 10.26 | 10.15 |
| | **0.13** | 22.54 | 22.51 | 22.49 | 21.21 | 18.39 | 17.21 | 14.79 | 13.37 | 12.02 | 11.25 | 10.90 | 10.78 |
| | **0.20** | 22.55 | 22.52 | 22.51 | 21.32 | 18.71 | 17.60 | 15.31 | 13.97 | 12.64 | 11.87 | 11.53 | 11.42 |
| | **0.27** | 22.56 | 22.54 | 22.52 | 21.43 | 19.03 | 18.00 | 15.83 | 14.56 | 13.25 | 12.49 | 12.16 | 12.06 |
| | **0.33** | 22.57 | 22.55 | 22.53 | 21.54 | 19.35 | 18.39 | 16.35 | 15.16 | 13.87 | 13.12 | 12.80 | 12.69 |
| | **0.40** | 22.59 | 22.56 | 22.54 | 21.65 | 19.68 | 18.78 | 16.87 | 15.75 | 14.49 | 13.74 | 13.43 | 13.33 |
| | **0.47** | 22.60 | 22.57 | 22.55 | 21.76 | 20.00 | 19.17 | 17.39 | 16.35 | 15.10 | 14.36 | 14.06 | 13.97 |
| | **0.53** | 22.61 | 22.58 | 22.57 | 21.86 | 20.32 | 19.56 | 17.90 | 16.94 | 15.72 | 14.99 | 14.70 | 14.60 |
| | **0.60** | 22.62 | 22.59 | 22.58 | 21.97 | 20.64 | 19.95 | 18.42 | 17.54 | 16.33 | 15.61 | 15.33 | 15.24 |
| | **0.67** | 22.64 | 22.60 | 22.59 | 22.08 | 20.97 | 20.34 | 18.94 | 18.13 | 16.95 | 16.23 | 15.96 | 15.88 |
| | **0.73** | 22.65 | 22.61 | 22.60 | 22.19 | 21.29 | 20.73 | 19.46 | 18.73 | 17.57 | 16.86 | 16.60 | 16.51 |
| | **0.80** | 22.66 | 22.63 | 22.61 | 22.30 | 21.61 | 21.13 | 19.98 | 19.32 | 18.18 | 17.48 | 17.23 | 17.15 |
| | **0.87** | 22.67 | 22.64 | 22.63 | 22.41 | 21.93 | 21.52 | 20.50 | 19.92 | 18.80 | 18.10 | 17.86 | 17.79 |
| | **0.93** | 22.69 | 22.65 | 22.64 | 22.52 | 22.26 | 21.91 | 21.02 | 20.51 | 19.41 | 18.73 | 18.50 | 18.42 |
| | **1.00** | 22.70 | 22.66 | 22.65 | 22.63 | 22.58 | 22.30 | 21.54 | 21.11 | 20.03 | 19.35 | 19.13 | 19.06 |
| THERMOCOUPLE SURFACE TEMPERATURE ($^0$C) | **0.00** | 22.36 | 22.33 | 22.26 | 21.14 | 18.83 | 17.42 | 14.73 | 13.09 | 11.47 | 10.39 | 9.80 | 9.65 |
| | **0.11** | 22.40 | 22.36 | 22.32 | 21.06 | 18.71 | 17.44 | 15.35 | 14.13 | 12.89 | 12.16 | 11.86 | 11.70 |
| | **0.22** | 22.42 | 22.39 | 22.33 | 21.14 | 18.77 | 17.49 | 15.37 | 14.09 | 12.85 | 12.16 | 11.80 | 11.70 |
| | **0.33** | 22.42 | 22.40 | 22.39 | 21.67 | 19.59 | 18.50 | 16.87 | 15.75 | 14.60 | 13.96 | 13.67 | 13.54 |
| | **0.44** | 22.46 | 22.43 | 22.45 | 22.01 | 20.12 | 19.14 | 17.77 | 16.79 | 15.72 | 15.13 | 14.92 | 14.78 |
| | **0.56** | 22.43 | 22.41 | 22.41 | 22.33 | 20.98 | 20.12 | 19.01 | 18.15 | 17.11 | 16.50 | 16.33 | 16.19 |
| | **0.67** | 22.44 | 22.41 | 22.43 | 22.41 | 21.53 | 21.05 | 20.71 | 20.19 | 19.40 | 18.94 | 18.83 | 18.75 |
| | **0.78** | 22.46 | 22.43 | 22.46 | 22.48 | 21.93 | 21.64 | 21.62 | 21.24 | 20.55 | 20.14 | 20.04 | 20.01 |
| | **0.89** | 22.50 | 22.48 | 22.50 | 22.50 | 22.36 | 22.14 | 21.88 | 21.65 | 21.00 | 20.56 | 20.43 | 20.41 |
| | **1.00** | 22.45 | 22.42 | 22.44 | 22.44 | 22.25 | 21.85 | 21.24 | 20.77 | 19.77 | 19.15 | 18.92 | 18.86 |
| COILSET SURFACE TEMPERATURE ($^0$C) | **0.00** | 22.51 | 22.49 | 22.47 | 20.99 | 17.74 | 16.43 | 13.75 | 12.18 | 10.79 | 10.00 | 9.63 | 9.51 |
| | **0.07** | 21.84 | 21.86 | 21.72 | 20.00 | 17.62 | 16.50 | 14.74 | 13.67 | 12.57 | 11.77 | 11.67 | 11.35 |
| | **0.13** | 21.89 | 21.88 | 21.82 | 20.34 | 18.00 | 16.92 | 15.22 | 14.15 | 13.02 | 12.28 | 12.17 | 11.78 |
| | **0.20** | 21.87 | 21.89 | 21.89 | 20.70 | 18.46 | 17.46 | 15.98 | 14.99 | 13.90 | 13.16 | 13.05 | 12.72 |
| | **0.27** | 21.85 | 21.86 | 21.86 | 21.00 | 18.92 | 18.01 | 16.66 | 15.68 | 14.68 | 13.98 | 13.92 | 13.55 |
| | **0.33** | 21.83 | 21.86 | 21.88 | 21.26 | 19.29 | 18.44 | 17.25 | 16.32 | 15.32 | 14.64 | 14.58 | 14.21 |
| | **0.40** | 21.85 | 21.85 | 21.89 | 21.48 | 19.71 | 18.93 | 17.89 | 17.00 | 16.04 | 15.39 | 15.36 | 14.98 |
| | **0.47** | 21.86 | 21.88 | 21.91 | 21.67 | 20.08 | 19.38 | 18.48 | 17.65 | 16.70 | 16.07 | 16.02 | 15.69 |
| | **0.53** | 21.84 | 21.86 | 21.90 | 21.78 | 20.42 | 19.81 | 19.10 | 18.33 | 17.44 | 16.81 | 16.77 | 16.46 |
| | **0.60** | 21.84 | 21.86 | 21.91 | 21.85 | 20.72 | 20.20 | 19.62 | 18.91 | 18.06 | 17.45 | 17.46 | 17.11 |
| | **0.67** | 21.84 | 21.87 | 21.90 | 21.89 | 20.99 | 20.55 | 20.11 | 19.48 | 18.66 | 18.02 | 18.06 | 17.76 |
| | **0.73** | 21.85 | 21.85 | 21.90 | 21.93 | 21.30 | 20.96 | 20.70 | 20.14 | 19.39 | 18.75 | 18.78 | 18.50 |
| | **0.80** | 21.81 | 21.84 | 21.89 | 21.92 | 21.55 | 21.30 | 21.22 | 20.75 | 20.04 | 19.44 | 19.53 | 19.20 |
| | **0.87** | 21.82 | 21.86 | 21.91 | 21.95 | 21.81 | 21.73 | 21.90 | 21.56 | 20.90 | 20.32 | 20.40 | 20.12 |
| | **0.93** | 21.94 | 21.98 | 22.01 | 22.07 | 21.92 | 21.80 | 21.91 | 21.63 | 20.89 | 20.31 | 20.42 | 20.17 |
| | **1.00** | 22.70 | 22.66 | 22.65 | 22.63 | 22.58 | 22.30 | 21.54 | 21.11 | 20.03 | 19.35 | 19.13 | 19.06 |

**Table F2: R3-36 mains-side temperature values at 12LPM for selected time instants**

| | Dist | 1 sec | 2 sec | 3 sec | 5 sec | 8 sec | 10 sec | 15 sec | 20 sec | 30 sec | 50 sec | 100 sec | 200 sec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ESTIMATED WATER TEMPERATURE ($^0C$) | **0.00** | 22.47 | 22.46 | 22.43 | 21.08 | 19.69 | 17.76 | 14.67 | 13.35 | 11.81 | 10.74 | 10.28 | 10.14 |
| | **0.07** | 22.48 | 22.47 | 22.44 | 21.18 | 19.89 | 18.08 | 15.16 | 13.93 | 12.45 | 11.39 | 10.93 | 10.80 |
| | **0.13** | 22.49 | 22.48 | 22.46 | 21.29 | 20.08 | 18.40 | 15.66 | 14.50 | 13.08 | 12.04 | 11.59 | 11.46 |
| | **0.20** | 22.51 | 22.50 | 22.47 | 21.39 | 20.28 | 18.73 | 16.15 | 15.08 | 13.72 | 12.68 | 12.24 | 12.12 |
| | **0.27** | 22.52 | 22.51 | 22.49 | 21.49 | 20.48 | 19.05 | 16.65 | 15.66 | 14.36 | 13.33 | 12.90 | 12.79 |
| | **0.33** | 22.53 | 22.52 | 22.50 | 21.60 | 20.68 | 19.37 | 17.14 | 16.23 | 14.99 | 13.98 | 13.55 | 13.45 |
| | **0.40** | 22.54 | 22.53 | 22.51 | 21.70 | 20.87 | 19.69 | 17.64 | 16.81 | 15.63 | 14.63 | 14.21 | 14.11 |
| | **0.47** | 22.55 | 22.54 | 22.53 | 21.80 | 21.07 | 20.01 | 18.13 | 17.39 | 16.27 | 15.28 | 14.86 | 14.77 |
| | **0.53** | 22.57 | 22.56 | 22.54 | 21.91 | 21.27 | 20.34 | 18.63 | 17.96 | 16.90 | 15.92 | 15.52 | 15.43 |
| | **0.60** | 22.58 | 22.57 | 22.56 | 22.01 | 21.47 | 20.66 | 19.12 | 18.54 | 17.54 | 16.57 | 16.17 | 16.09 |
| | **0.67** | 22.59 | 22.58 | 22.57 | 22.11 | 21.66 | 20.98 | 19.62 | 19.12 | 18.18 | 17.22 | 16.83 | 16.75 |
| | **0.73** | 22.60 | 22.59 | 22.58 | 22.22 | 21.86 | 21.30 | 20.11 | 19.69 | 18.81 | 17.87 | 17.48 | 17.41 |
| | **0.80** | 22.61 | 22.60 | 22.60 | 22.32 | 22.06 | 21.62 | 20.61 | 20.27 | 19.45 | 18.52 | 18.14 | 18.08 |
| | **0.87** | 22.63 | 22.62 | 22.61 | 22.42 | 22.26 | 21.95 | 21.10 | 20.85 | 20.09 | 19.16 | 18.79 | 18.74 |
| | **0.93** | 22.64 | 22.63 | 22.63 | 22.53 | 22.45 | 22.27 | 21.60 | 21.42 | 20.72 | 19.81 | 19.45 | 19.40 |
| | **1.00** | 22.65 | 22.64 | 22.64 | 22.63 | 22.65 | 22.59 | 22.09 | 22.00 | 21.36 | 20.46 | 20.10 | 20.06 |
| THERMOCOUPLE SURFACE TEMPERATURE ($^0C$) | **0.00** | 22.33 | 22.31 | 22.29 | 21.63 | 19.85 | 18.60 | 16.02 | 14.23 | 12.42 | 11.12 | 10.43 | 10.28 |
| | **0.11** | 22.40 | 22.38 | 22.36 | 21.60 | 19.72 | 18.52 | 16.46 | 15.25 | 13.89 | 12.97 | 12.58 | 12.46 |
| | **0.22** | 22.42 | 22.41 | 22.39 | 21.79 | 19.99 | 18.82 | 16.67 | 15.36 | 13.97 | 13.02 | 12.59 | 12.47 |
| | **0.33** | 22.42 | 22.42 | 22.41 | 22.14 | 20.65 | 19.67 | 18.02 | 17.01 | 15.80 | 14.91 | 14.51 | 14.43 |
| | **0.44** | 22.45 | 22.45 | 22.46 | 22.34 | 21.04 | 20.17 | 18.83 | 18.03 | 16.94 | 16.10 | 15.77 | 15.70 |
| | **0.56** | 22.45 | 22.44 | 22.43 | 22.44 | 21.71 | 21.03 | 19.95 | 19.34 | 18.33 | 17.54 | 17.22 | 17.15 |
| | **0.67** | 22.45 | 22.46 | 22.46 | 22.49 | 22.08 | 21.69 | 21.41 | 21.23 | 20.53 | 19.92 | 19.68 | 19.69 |
| | **0.78** | 22.49 | 22.49 | 22.49 | 22.53 | 22.38 | 22.18 | 22.23 | 22.26 | 21.71 | 21.16 | 20.98 | 21.00 |
| | **0.89** | 22.53 | 22.53 | 22.53 | 22.54 | 22.55 | 22.51 | 22.49 | 22.59 | 22.35 | 21.81 | 21.59 | 21.60 |
| | **1.00** | 22.46 | 22.46 | 22.45 | 22.46 | 22.46 | 22.28 | 21.89 | 21.76 | 21.01 | 20.25 | 19.92 | 19.87 |
| COILSET SURFACE TEMPERATURE ($^0C$) | **0.00** | 22.47 | 22.46 | 22.43 | 21.08 | 19.69 | 17.76 | 14.67 | 13.35 | 11.81 | 10.74 | 10.28 | 10.14 |
| | **0.07** | 21.85 | 21.86 | 21.78 | 20.77 | 18.99 | 17.80 | 16.08 | 14.88 | 13.66 | 12.77 | 12.47 | 12.26 |
| | **0.13** | 21.84 | 21.85 | 21.79 | 21.01 | 19.25 | 18.11 | 16.47 | 15.31 | 14.07 | 13.20 | 12.89 | 12.73 |
| | **0.20** | 21.88 | 21.90 | 21.85 | 21.30 | 19.67 | 18.64 | 17.19 | 16.15 | 14.97 | 14.12 | 13.83 | 13.61 |
| | **0.27** | 21.88 | 21.91 | 21.85 | 21.49 | 20.05 | 19.10 | 17.85 | 16.90 | 15.76 | 14.94 | 14.66 | 14.47 |
| | **0.33** | 21.85 | 21.86 | 21.83 | 21.61 | 20.36 | 19.47 | 18.36 | 17.50 | 16.41 | 15.60 | 15.32 | 15.19 |
| | **0.40** | 21.86 | 21.87 | 21.86 | 21.73 | 20.70 | 19.90 | 18.98 | 18.22 | 17.17 | 16.38 | 16.10 | 15.99 |
| | **0.47** | 21.90 | 21.91 | 21.88 | 21.81 | 20.99 | 20.30 | 19.54 | 18.89 | 17.87 | 17.10 | 16.87 | 16.69 |
| | **0.53** | 21.89 | 21.89 | 21.86 | 21.82 | 21.22 | 20.60 | 19.99 | 19.42 | 18.47 | 17.73 | 17.50 | 17.35 |
| | **0.60** | 21.92 | 21.93 | 21.90 | 21.88 | 21.49 | 20.97 | 20.53 | 20.07 | 19.16 | 18.43 | 18.23 | 18.06 |
| | **0.67** | 21.93 | 21.95 | 21.91 | 21.88 | 21.69 | 21.27 | 21.03 | 20.69 | 19.87 | 19.16 | 18.98 | 18.80 |
| | **0.73** | 21.94 | 21.94 | 21.91 | 21.88 | 21.88 | 21.59 | 21.53 | 21.33 | 20.56 | 19.92 | 19.75 | 19.59 |
| | **0.80** | 21.94 | 21.94 | 21.93 | 21.88 | 22.06 | 21.88 | 22.01 | 21.93 | 21.24 | 20.61 | 20.49 | 20.30 |
| | **0.87** | 21.92 | 21.96 | 21.93 | 21.88 | 22.18 | 22.15 | 22.53 | 22.56 | 21.98 | 21.37 | 21.28 | 21.13 |
| | **0.93** | 21.93 | 21.96 | 21.93 | 21.91 | 22.21 | 22.21 | 22.62 | 22.76 | 22.20 | 21.60 | 21.52 | 21.36 |
| | **1.00** | 22.65 | 22.64 | 22.64 | 22.63 | 22.65 | 22.59 | 22.09 | 22.00 | 21.36 | 20.46 | 20.10 | 20.06 |

**Table F3: R3-36 mains-side temperature values at 10LPM for selected time instants**

| | Dist | 1 sec | 2 sec | 3 sec | 5 sec | 8 sec | 10 sec | 15 sec | 20 sec | 30 sec | 50 sec | 100 sec | 200 sec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ESTIMATED WATER TEMPERATURE ($^0$C) | **0.00** | 22.44 | 22.37 | 22.29 | 21.46 | 19.09 | 17.51 | 15.12 | 13.56 | 11.99 | 10.78 | 10.14 | 9.95 |
| | **0.07** | 22.47 | 22.40 | 22.33 | 21.55 | 19.34 | 17.86 | 15.61 | 14.15 | 12.67 | 11.48 | 10.85 | 10.67 |
| | **0.13** | 22.50 | 22.44 | 22.37 | 21.65 | 19.58 | 18.20 | 16.10 | 14.74 | 13.34 | 12.18 | 11.56 | 11.39 |
| | **0.20** | 22.53 | 22.47 | 22.41 | 21.74 | 19.83 | 18.55 | 16.58 | 15.33 | 14.02 | 12.87 | 12.28 | 12.11 |
| | **0.27** | 22.56 | 22.51 | 22.45 | 21.83 | 20.08 | 18.89 | 17.07 | 15.92 | 14.69 | 13.57 | 12.99 | 12.83 |
| | **0.33** | 22.59 | 22.54 | 22.49 | 21.93 | 20.33 | 19.24 | 17.56 | 16.51 | 15.37 | 14.27 | 13.70 | 13.55 |
| | **0.40** | 22.62 | 22.57 | 22.53 | 22.02 | 20.57 | 19.59 | 18.05 | 17.10 | 16.05 | 14.97 | 14.41 | 14.27 |
| | **0.47** | 22.65 | 22.61 | 22.57 | 22.11 | 20.82 | 19.93 | 18.54 | 17.69 | 16.72 | 15.67 | 15.12 | 14.99 |
| | **0.53** | 22.67 | 22.64 | 22.60 | 22.21 | 21.07 | 20.28 | 19.02 | 18.28 | 17.40 | 16.36 | 15.84 | 15.70 |
| | **0.60** | 22.70 | 22.68 | 22.64 | 22.30 | 21.32 | 20.62 | 19.51 | 18.87 | 18.07 | 17.06 | 16.55 | 16.42 |
| | **0.67** | 22.73 | 22.71 | 22.68 | 22.39 | 21.56 | 20.97 | 20.00 | 19.46 | 18.75 | 17.76 | 17.26 | 17.14 |
| | **0.73** | 22.76 | 22.74 | 22.72 | 22.49 | 21.81 | 21.32 | 20.49 | 20.05 | 19.43 | 18.46 | 17.97 | 17.86 |
| | **0.80** | 22.79 | 22.78 | 22.76 | 22.58 | 22.06 | 21.66 | 20.98 | 20.64 | 20.10 | 19.16 | 18.68 | 18.58 |
| | **0.87** | 22.82 | 22.81 | 22.80 | 22.67 | 22.31 | 22.01 | 21.46 | 21.23 | 20.78 | 19.85 | 19.40 | 19.30 |
| | **0.93** | 22.85 | 22.85 | 22.84 | 22.77 | 22.55 | 22.35 | 21.95 | 21.82 | 21.45 | 20.55 | 20.11 | 20.02 |
| | **1.00** | 22.88 | 22.88 | 22.88 | 22.86 | 22.80 | 22.70 | 22.44 | 22.41 | 22.13 | 21.25 | 20.82 | 20.74 |
| THERMOCOUPLE SURFACE TEMPERATURE ($^0$C) | **0.00** | 22.35 | 22.27 | 22.03 | 21.14 | 19.50 | 18.46 | 16.18 | 14.55 | 12.69 | 11.24 | 10.37 | 10.16 |
| | **0.11** | 22.46 | 22.39 | 22.16 | 21.23 | 19.58 | 18.67 | 16.85 | 15.70 | 14.29 | 13.20 | 12.64 | 12.46 |
| | **0.22** | 22.47 | 22.42 | 22.26 | 21.43 | 19.81 | 18.85 | 17.00 | 15.82 | 14.39 | 13.32 | 12.74 | 12.54 |
| | **0.33** | 22.53 | 22.49 | 22.44 | 21.88 | 20.56 | 19.77 | 18.39 | 17.52 | 16.34 | 15.34 | 14.84 | 14.63 |
| | **0.44** | 22.60 | 22.56 | 22.55 | 22.16 | 21.00 | 20.34 | 19.23 | 18.56 | 17.55 | 16.63 | 16.18 | 15.98 |
| | **0.56** | 22.61 | 22.58 | 22.57 | 22.39 | 21.58 | 21.07 | 20.26 | 19.82 | 18.93 | 18.09 | 17.70 | 17.53 |
| | **0.67** | 22.66 | 22.63 | 22.63 | 22.55 | 22.14 | 21.95 | 21.78 | 21.74 | 21.20 | 20.54 | 20.24 | 20.13 |
| | **0.78** | 22.70 | 22.66 | 22.66 | 22.61 | 22.44 | 22.43 | 22.59 | 22.79 | 22.43 | 21.85 | 21.60 | 21.55 |
| | **0.89** | 22.72 | 22.71 | 22.71 | 22.66 | 22.61 | 22.59 | 22.78 | 23.07 | 22.94 | 22.45 | 22.21 | 22.17 |
| | **1.00** | 22.73 | 22.71 | 22.70 | 22.66 | 22.58 | 22.45 | 22.24 | 22.22 | 21.82 | 21.06 | 20.66 | 20.60 |
| COILSET SURFACE TEMPERATURE ($^0$C) | **0.00** | 22.44 | 22.37 | 22.29 | 21.46 | 19.09 | 17.51 | 15.12 | 13.56 | 11.99 | 10.78 | 10.14 | 9.95 |
| | **0.07** | 21.75 | 21.63 | 21.18 | 20.11 | 18.45 | 17.62 | 16.06 | 15.07 | 13.78 | 12.95 | 12.47 | 12.34 |
| | **0.13** | 21.81 | 21.73 | 21.37 | 20.43 | 18.83 | 18.03 | 16.53 | 15.60 | 14.31 | 13.44 | 13.00 | 12.87 |
| | **0.20** | 21.81 | 21.74 | 21.50 | 20.70 | 19.20 | 18.49 | 17.17 | 16.34 | 15.15 | 14.34 | 13.93 | 13.85 |
| | **0.27** | 21.85 | 21.80 | 21.62 | 20.99 | 19.64 | 19.01 | 17.87 | 17.15 | 16.04 | 15.19 | 14.81 | 14.73 |
| | **0.33** | 21.86 | 21.81 | 21.66 | 21.19 | 19.97 | 19.40 | 18.43 | 17.80 | 16.74 | 15.96 | 15.58 | 15.53 |
| | **0.40** | 21.90 | 21.85 | 21.70 | 21.38 | 20.34 | 19.83 | 19.02 | 18.51 | 17.50 | 16.75 | 16.40 | 16.32 |
| | **0.47** | 21.92 | 21.87 | 21.75 | 21.53 | 20.65 | 20.23 | 19.55 | 19.12 | 18.19 | 17.49 | 17.17 | 17.12 |
| | **0.53** | 21.92 | 21.89 | 21.76 | 21.63 | 20.93 | 20.58 | 20.07 | 19.78 | 18.91 | 18.26 | 17.95 | 17.88 |
| | **0.60** | 21.95 | 21.91 | 21.78 | 21.71 | 21.19 | 20.92 | 20.60 | 20.39 | 19.62 | 18.99 | 18.74 | 18.68 |
| | **0.67** | 22.03 | 21.98 | 21.85 | 21.80 | 21.48 | 21.29 | 21.13 | 21.03 | 20.33 | 19.73 | 19.46 | 19.45 |
| | **0.73** | 22.06 | 22.01 | 21.88 | 21.87 | 21.70 | 21.63 | 21.63 | 21.66 | 21.08 | 20.49 | 20.26 | 20.30 |
| | **0.80** | 22.05 | 22.00 | 21.87 | 21.86 | 21.88 | 21.90 | 22.13 | 22.28 | 21.80 | 21.27 | 21.07 | 21.12 |
| | **0.87** | 22.08 | 22.03 | 21.91 | 21.91 | 22.06 | 22.21 | 22.65 | 22.95 | 22.60 | 22.11 | 21.94 | 21.99 |
| | **0.93** | 22.09 | 22.02 | 21.90 | 21.89 | 22.04 | 22.19 | 22.65 | 23.04 | 22.75 | 22.31 | 22.16 | 22.24 |
| | **1.00** | 22.88 | 22.88 | 22.88 | 22.86 | 22.80 | 22.70 | 22.44 | 22.41 | 22.13 | 21.25 | 20.82 | 20.74 |

Table F4: R3-36 mains-side temperature values at 9LPM for selected time instants

| | Dist | 1 sec | 2 sec | 3 sec | 5 sec | 8 sec | 10 sec | 15 sec | 20 sec | 30 sec | 50 sec | 100 sec | 200 sec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ESTIMATED WATER TEMPERATURE ($^0$C) | **0.00** | 21.66 | 21.22 | 20.97 | 19.65 | 18.14 | 16.82 | 14.84 | 13.51 | 12.01 | 10.91 | 10.27 | 10.07 |
| | **0.07** | 21.73 | 21.32 | 21.08 | 19.85 | 18.44 | 17.20 | 15.34 | 14.12 | 12.71 | 11.63 | 11.01 | 10.82 |
| | **0.13** | 21.80 | 21.41 | 21.20 | 20.05 | 18.74 | 17.58 | 15.85 | 14.72 | 13.40 | 12.35 | 11.74 | 11.56 |
| | **0.20** | 21.86 | 21.51 | 21.31 | 20.25 | 19.04 | 17.96 | 16.35 | 15.33 | 14.10 | 13.08 | 12.48 | 12.31 |
| | **0.27** | 21.93 | 21.61 | 21.43 | 20.45 | 19.33 | 18.34 | 16.85 | 15.94 | 14.80 | 13.80 | 13.22 | 13.06 |
| | **0.33** | 22.00 | 21.71 | 21.54 | 20.65 | 19.63 | 18.72 | 17.36 | 16.54 | 15.50 | 14.52 | 13.95 | 13.81 |
| | **0.40** | 22.07 | 21.80 | 21.65 | 20.85 | 19.93 | 19.10 | 17.86 | 17.15 | 16.19 | 15.24 | 14.69 | 14.55 |
| | **0.47** | 22.14 | 21.90 | 21.77 | 21.05 | 20.23 | 19.48 | 18.36 | 17.76 | 16.89 | 15.96 | 15.43 | 15.30 |
| | **0.53** | 22.20 | 22.00 | 21.88 | 21.26 | 20.53 | 19.86 | 18.87 | 18.36 | 17.59 | 16.69 | 16.16 | 16.05 |
| | **0.60** | 22.27 | 22.10 | 22.00 | 21.46 | 20.83 | 20.24 | 19.37 | 18.97 | 18.29 | 17.41 | 16.90 | 16.80 |
| | **0.67** | 22.34 | 22.19 | 22.11 | 21.66 | 21.13 | 20.62 | 19.87 | 19.58 | 18.98 | 18.13 | 17.64 | 17.54 |
| | **0.73** | 22.41 | 22.29 | 22.22 | 21.86 | 21.43 | 21.00 | 20.38 | 20.18 | 19.68 | 18.85 | 18.37 | 18.29 |
| | **0.80** | 22.48 | 22.39 | 22.34 | 22.06 | 21.72 | 21.38 | 20.88 | 20.79 | 20.38 | 19.57 | 19.11 | 19.04 |
| | **0.87** | 22.54 | 22.49 | 22.45 | 22.26 | 22.02 | 21.76 | 21.38 | 21.40 | 21.08 | 20.30 | 19.85 | 19.79 |
| | **0.93** | 22.61 | 22.58 | 22.57 | 22.46 | 22.32 | 22.14 | 21.89 | 22.00 | 21.77 | 21.02 | 20.58 | 20.53 |
| | **1.00** | 22.68 | 22.68 | 22.68 | 22.66 | 22.62 | 22.52 | 22.39 | 22.61 | 22.47 | 21.74 | 21.32 | 21.28 |
| THERMOCOUPLE SURFACE TEMPERATURE ($^0$C) | **0.00** | 21.96 | 21.68 | 21.31 | 20.45 | 19.05 | 18.17 | 16.25 | 14.79 | 13.00 | 11.49 | 10.53 | 10.29 |
| | **0.11** | 21.95 | 21.60 | 21.15 | 20.15 | 18.89 | 18.15 | 16.79 | 15.77 | 14.52 | 13.39 | 12.85 | 12.70 |
| | **0.22** | 22.08 | 21.80 | 21.42 | 20.49 | 19.19 | 18.42 | 16.98 | 15.95 | 14.68 | 13.59 | 12.94 | 12.84 |
| | **0.33** | 22.23 | 22.07 | 21.79 | 21.05 | 20.01 | 19.41 | 18.44 | 17.74 | 16.69 | 15.69 | 15.14 | 15.05 |
| | **0.44** | 22.35 | 22.25 | 22.04 | 21.43 | 20.54 | 20.04 | 19.32 | 18.83 | 17.92 | 17.01 | 16.56 | 16.47 |
| | **0.56** | 22.39 | 22.35 | 22.26 | 21.89 | 21.21 | 20.84 | 20.40 | 20.11 | 19.34 | 18.52 | 18.09 | 18.05 |
| | **0.67** | 22.44 | 22.42 | 22.38 | 22.23 | 21.95 | 21.83 | 21.98 | 22.06 | 21.62 | 20.98 | 20.70 | 20.69 |
| | **0.78** | 22.47 | 22.46 | 22.44 | 22.41 | 22.35 | 22.36 | 22.81 | 23.10 | 22.88 | 22.36 | 22.13 | 22.15 |
| | **0.89** | 22.50 | 22.51 | 22.49 | 22.48 | 22.52 | 22.56 | 23.06 | 23.47 | 23.41 | 22.97 | 22.77 | 22.80 |
| | **1.00** | 22.49 | 22.49 | 22.48 | 22.46 | 22.36 | 22.25 | 22.26 | 22.44 | 22.19 | 21.49 | 21.10 | 21.07 |
| COILSET SURFACE TEMPERATURE ($^0$C) | **0.00** | 21.66 | 21.22 | 20.97 | 19.65 | 18.14 | 16.82 | 14.84 | 13.51 | 12.01 | 10.91 | 10.27 | 10.07 |
| | **0.07** | 21.13 | 20.64 | 20.12 | 19.09 | 17.87 | 17.18 | 16.02 | 15.11 | 14.01 | 13.10 | 12.57 | 12.41 |
| | **0.13** | 21.34 | 20.89 | 20.43 | 19.43 | 18.28 | 17.62 | 16.56 | 15.72 | 14.61 | 13.76 | 13.21 | 13.03 |
| | **0.20** | 21.50 | 21.13 | 20.72 | 19.81 | 18.73 | 18.16 | 17.31 | 16.57 | 15.52 | 14.72 | 14.17 | 14.03 |
| | **0.27** | 21.65 | 21.36 | 21.02 | 20.20 | 19.25 | 18.74 | 18.06 | 17.43 | 16.46 | 15.66 | 15.13 | 15.03 |
| | **0.33** | 21.69 | 21.47 | 21.19 | 20.47 | 19.59 | 19.17 | 18.59 | 18.06 | 17.14 | 16.37 | 15.89 | 15.80 |
| | **0.40** | 21.74 | 21.59 | 21.37 | 20.75 | 20.00 | 19.64 | 19.26 | 18.80 | 17.94 | 17.22 | 16.76 | 16.71 |
| | **0.47** | 21.80 | 21.68 | 21.53 | 21.00 | 20.35 | 20.05 | 19.78 | 19.41 | 18.64 | 17.94 | 17.49 | 17.41 |
| | **0.53** | 21.83 | 21.75 | 21.63 | 21.24 | 20.71 | 20.48 | 20.34 | 20.10 | 19.36 | 18.67 | 18.27 | 18.22 |
| | **0.60** | 21.85 | 21.78 | 21.71 | 21.44 | 21.03 | 20.87 | 20.91 | 20.75 | 20.13 | 19.54 | 19.15 | 19.06 |
| | **0.67** | 21.90 | 21.84 | 21.80 | 21.62 | 21.33 | 21.27 | 21.46 | 21.42 | 20.87 | 20.25 | 19.90 | 19.86 |
| | **0.73** | 21.94 | 21.88 | 21.86 | 21.76 | 21.64 | 21.67 | 22.06 | 22.13 | 21.69 | 21.11 | 20.80 | 20.73 |
| | **0.80** | 21.94 | 21.89 | 21.89 | 21.87 | 21.89 | 22.00 | 22.53 | 22.72 | 22.38 | 21.83 | 21.58 | 21.54 |
| | **0.87** | 21.99 | 21.95 | 21.94 | 22.01 | 22.19 | 22.40 | 23.14 | 23.48 | 23.23 | 22.71 | 22.52 | 22.50 |
| | **0.93** | 21.99 | 21.97 | 21.96 | 22.02 | 22.25 | 22.46 | 23.24 | 23.67 | 23.52 | 23.03 | 22.88 | 22.81 |
| | **1.00** | 22.68 | 22.68 | 22.68 | 22.66 | 22.62 | 22.52 | 22.39 | 22.61 | 22.47 | 21.74 | 21.32 | 21.28 |

**Table F5: R3-36 mains-side temperature values at 7LPM for selected time instants**

| | Dist | 1 sec | 2 sec | 3 sec | 5 sec | 8 sec | 10 sec | 15 sec | 20 sec | 30 sec | 50 sec | 100 sec | 200 sec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ESTIMATED WATER TEMPERATURE ($^0$C) | **0.00** | 21.89 | 21.59 | 21.22 | 20.06 | 18.88 | 18.15 | 16.26 | 14.82 | 13.00 | 11.47 | 10.44 | 10.13 |
| | **0.07** | 21.96 | 21.68 | 21.33 | 20.25 | 19.15 | 18.46 | 16.71 | 15.38 | 13.71 | 12.26 | 11.26 | 10.97 |
| | **0.13** | 22.03 | 21.77 | 21.45 | 20.44 | 19.41 | 18.78 | 17.15 | 15.94 | 14.41 | 13.04 | 12.08 | 11.80 |
| | **0.20** | 22.10 | 21.86 | 21.56 | 20.63 | 19.68 | 19.09 | 17.60 | 16.51 | 15.12 | 13.83 | 12.91 | 12.64 |
| | **0.27** | 22.17 | 21.95 | 21.68 | 20.81 | 19.94 | 19.40 | 18.04 | 17.07 | 15.83 | 14.62 | 13.73 | 13.48 |
| | **0.33** | 22.24 | 22.04 | 21.79 | 21.00 | 20.21 | 19.72 | 18.49 | 17.63 | 16.54 | 15.41 | 14.55 | 14.32 |
| | **0.40** | 22.31 | 22.13 | 21.90 | 21.19 | 20.47 | 20.03 | 18.94 | 18.19 | 17.24 | 16.19 | 15.37 | 15.15 |
| | **0.47** | 22.38 | 22.22 | 22.02 | 21.38 | 20.74 | 20.34 | 19.38 | 18.75 | 17.95 | 16.98 | 16.19 | 15.99 |
| | **0.53** | 22.46 | 22.31 | 22.13 | 21.57 | 21.00 | 20.66 | 19.83 | 19.32 | 18.66 | 17.77 | 17.02 | 16.83 |
| | **0.60** | 22.53 | 22.40 | 22.25 | 21.76 | 21.27 | 20.97 | 20.27 | 19.88 | 19.37 | 18.56 | 17.84 | 17.67 |
| | **0.67** | 22.60 | 22.49 | 22.36 | 21.95 | 21.53 | 21.28 | 20.72 | 20.44 | 20.07 | 19.34 | 18.66 | 18.50 |
| | **0.73** | 22.67 | 22.58 | 22.47 | 22.14 | 21.80 | 21.60 | 21.17 | 21.00 | 20.78 | 20.13 | 19.48 | 19.34 |
| | **0.80** | 22.74 | 22.67 | 22.59 | 22.32 | 22.06 | 21.91 | 21.61 | 21.56 | 21.49 | 20.92 | 20.30 | 20.18 |
| | **0.87** | 22.81 | 22.76 | 22.70 | 22.51 | 22.33 | 22.22 | 22.06 | 22.13 | 22.20 | 21.71 | 21.13 | 21.02 |
| | **0.93** | 22.88 | 22.85 | 22.82 | 22.70 | 22.59 | 22.54 | 22.50 | 22.69 | 22.90 | 22.49 | 21.95 | 21.85 |
| | **1.00** | 22.95 | 22.94 | 22.93 | 22.89 | 22.86 | 22.85 | 22.95 | 23.25 | 23.61 | 23.28 | 22.77 | 22.69 |
| THERMOCOUPLE SURFACE TEMPERATURE ($^0$C) | **0.00** | 22.07 | 21.86 | 21.63 | 21.02 | 19.99 | 19.28 | 17.63 | 16.21 | 14.16 | 12.18 | 10.78 | 10.39 |
| | **0.11** | 22.17 | 21.94 | 21.64 | 20.97 | 19.89 | 19.31 | 18.10 | 17.21 | 15.89 | 14.47 | 13.65 | 13.40 |
| | **0.22** | 22.29 | 22.11 | 21.86 | 21.27 | 20.26 | 19.67 | 18.43 | 17.50 | 16.13 | 14.74 | 13.85 | 13.57 |
| | **0.33** | 22.49 | 22.37 | 22.21 | 21.77 | 21.01 | 20.58 | 19.77 | 19.17 | 18.24 | 17.12 | 16.36 | 16.13 |
| | **0.44** | 22.59 | 22.53 | 22.42 | 22.08 | 21.47 | 21.13 | 20.55 | 20.18 | 19.40 | 18.43 | 17.82 | 17.65 |
| | **0.56** | 22.64 | 22.60 | 22.57 | 22.40 | 22.00 | 21.81 | 21.50 | 21.33 | 20.84 | 20.05 | 19.48 | 19.36 |
| | **0.67** | 22.72 | 22.70 | 22.67 | 22.61 | 22.54 | 22.58 | 22.84 | 23.13 | 23.05 | 22.57 | 22.19 | 22.11 |
| | **0.78** | 22.76 | 22.74 | 22.71 | 22.71 | 22.80 | 22.98 | 23.54 | 24.05 | 24.27 | 23.98 | 23.70 | 23.66 |
| | **0.89** | 22.81 | 22.79 | 22.77 | 22.76 | 22.81 | 22.94 | 23.45 | 24.06 | 24.65 | 24.61 | 24.40 | 24.45 |
| | **1.00** | 22.76 | 22.76 | 22.74 | 22.71 | 22.68 | 22.69 | 22.86 | 23.16 | 23.38 | 23.02 | 22.57 | 22.48 |
| COILSET SURFACE TEMPERATURE ($^0$C) | **0.00** | 21.89 | 21.59 | 21.22 | 20.06 | 18.88 | 18.15 | 16.26 | 14.82 | 13.00 | 11.47 | 10.44 | 10.13 |
| | **0.07** | 21.48 | 21.28 | 21.01 | 20.35 | 19.17 | 18.37 | 17.22 | 16.26 | 14.87 | 13.49 | 12.69 | 12.40 |
| | **0.13** | 21.61 | 21.46 | 21.25 | 20.66 | 19.54 | 18.81 | 17.73 | 16.84 | 15.51 | 14.20 | 13.39 | 13.18 |
| | **0.20** | 21.76 | 21.65 | 21.48 | 20.98 | 19.97 | 19.31 | 18.40 | 17.65 | 16.44 | 15.22 | 14.47 | 14.28 |
| | **0.27** | 21.83 | 21.77 | 21.67 | 21.25 | 20.38 | 19.78 | 19.02 | 18.42 | 17.33 | 16.21 | 15.50 | 15.34 |
| | **0.33** | 21.87 | 21.86 | 21.78 | 21.48 | 20.69 | 20.16 | 19.56 | 19.08 | 18.13 | 17.07 | 16.45 | 16.23 |
| | **0.40** | 21.91 | 21.92 | 21.87 | 21.65 | 20.98 | 20.54 | 20.10 | 19.75 | 18.92 | 17.93 | 17.34 | 17.17 |
| | **0.47** | 21.98 | 21.99 | 21.97 | 21.83 | 21.27 | 20.89 | 20.58 | 20.37 | 19.65 | 18.77 | 18.19 | 18.04 |
| | **0.53** | 22.01 | 22.03 | 22.02 | 21.95 | 21.50 | 21.19 | 21.05 | 20.95 | 20.41 | 19.59 | 19.08 | 18.97 |
| | **0.60** | 22.03 | 22.05 | 22.05 | 22.02 | 21.71 | 21.47 | 21.56 | 21.58 | 21.20 | 20.48 | 19.99 | 19.91 |
| | **0.67** | 22.06 | 22.09 | 22.09 | 22.11 | 21.90 | 21.74 | 21.99 | 22.20 | 21.96 | 21.34 | 20.93 | 20.84 |
| | **0.73** | 22.12 | 22.15 | 22.14 | 22.19 | 22.08 | 22.02 | 22.44 | 22.78 | 22.73 | 22.25 | 21.87 | 21.76 |
| | **0.80** | 22.13 | 22.16 | 22.16 | 22.23 | 22.22 | 22.26 | 22.88 | 23.37 | 23.47 | 23.13 | 22.76 | 22.70 |
| | **0.87** | 22.19 | 22.19 | 22.21 | 22.28 | 22.37 | 22.49 | 23.32 | 24.00 | 24.31 | 24.07 | 23.81 | 23.74 |
| | **0.93** | 22.17 | 22.21 | 22.20 | 22.27 | 22.36 | 22.49 | 23.39 | 24.13 | 24.59 | 24.44 | 24.28 | 24.26 |
| | **1.00** | 22.95 | 22.94 | 22.93 | 22.89 | 22.86 | 22.85 | 22.95 | 23.25 | 23.61 | 23.28 | 22.77 | 22.69 |

**Table F6: R3-36 mains-side temperature values at 5.5LPM for selected time instants**

| | Dist | 1 sec | 2 sec | 3 sec | 5 sec | 8 sec | 10 sec | 15 sec | 20 sec | 30 sec | 50 sec | 100 sec | 200 sec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ESTIMATED WATER TEMPERATURE ($^0$C) | **0.00** | 22.05 | 21.85 | 21.36 | 20.83 | 19.94 | 19.03 | 17.54 | 16.24 | 14.17 | 12.03 | 10.58 | 10.10 |
| | **0.07** | 22.10 | 21.91 | 21.46 | 20.96 | 20.13 | 19.29 | 17.91 | 16.71 | 14.82 | 12.86 | 11.47 | 11.01 |
| | **0.13** | 22.15 | 21.98 | 21.55 | 21.10 | 20.33 | 19.55 | 18.27 | 17.17 | 15.47 | 13.68 | 12.35 | 11.91 |
| | **0.20** | 22.20 | 22.04 | 21.65 | 21.23 | 20.52 | 19.80 | 18.64 | 17.64 | 16.12 | 14.51 | 13.24 | 12.82 |
| | **0.27** | 22.25 | 22.11 | 21.75 | 21.36 | 20.71 | 20.06 | 19.00 | 18.10 | 16.77 | 15.33 | 14.12 | 13.73 |
| | **0.33** | 22.30 | 22.17 | 21.85 | 21.49 | 20.91 | 20.32 | 19.37 | 18.57 | 17.42 | 16.16 | 15.01 | 14.63 |
| | **0.40** | 22.35 | 22.23 | 21.94 | 21.63 | 21.10 | 20.58 | 19.73 | 19.03 | 18.07 | 16.98 | 15.90 | 15.54 |
| | **0.47** | 22.40 | 22.30 | 22.04 | 21.76 | 21.29 | 20.84 | 20.10 | 19.50 | 18.72 | 17.81 | 16.78 | 16.45 |
| | **0.53** | 22.46 | 22.36 | 22.14 | 21.89 | 21.49 | 21.09 | 20.46 | 19.96 | 19.37 | 18.63 | 17.67 | 17.35 |
| | **0.60** | 22.51 | 22.43 | 22.24 | 22.02 | 21.68 | 21.35 | 20.83 | 20.43 | 20.02 | 19.46 | 18.55 | 18.26 |
| | **0.67** | 22.56 | 22.49 | 22.33 | 22.16 | 21.87 | 21.61 | 21.19 | 20.89 | 20.67 | 20.28 | 19.44 | 19.17 |
| | **0.73** | 22.61 | 22.55 | 22.43 | 22.29 | 22.07 | 21.87 | 21.56 | 21.36 | 21.32 | 21.11 | 20.33 | 20.07 |
| | **0.80** | 22.66 | 22.62 | 22.53 | 22.42 | 22.26 | 22.13 | 21.92 | 21.82 | 21.97 | 21.93 | 21.21 | 20.98 |
| | **0.87** | 22.71 | 22.68 | 22.63 | 22.55 | 22.45 | 22.38 | 22.29 | 22.29 | 22.62 | 22.76 | 22.10 | 21.89 |
| | **0.93** | 22.76 | 22.75 | 22.72 | 22.69 | 22.65 | 22.64 | 22.65 | 22.75 | 23.27 | 23.58 | 22.98 | 22.79 |
| | **1.00** | 22.81 | 22.81 | 22.82 | 22.82 | 22.84 | 22.90 | 23.02 | 23.22 | 23.92 | 24.41 | 23.87 | 23.70 |
| THERMOCOUPLE SURFACE TEMPERATURE ($^0$C) | **0.00** | 22.12 | 21.98 | 21.77 | 21.35 | 20.58 | 20.03 | 18.61 | 17.30 | 15.08 | 12.66 | 10.82 | 10.27 |
| | **0.11** | 22.22 | 22.09 | 21.88 | 21.42 | 20.58 | 20.01 | 18.52 | 17.88 | 16.60 | 14.91 | 13.73 | 13.34 |
| | **0.22** | 22.37 | 22.26 | 22.12 | 21.76 | 21.07 | 20.52 | 19.16 | 18.28 | 17.10 | 15.46 | 14.19 | 13.79 |
| | **0.33** | 22.48 | 22.43 | 22.35 | 22.12 | 21.57 | 21.14 | 19.97 | 19.64 | 18.91 | 17.79 | 16.74 | 16.39 |
| | **0.44** | 22.56 | 22.53 | 22.48 | 22.35 | 21.91 | 21.56 | 20.59 | 20.53 | 20.02 | 19.12 | 18.24 | 17.92 |
| | **0.56** | 22.57 | 22.56 | 22.54 | 22.49 | 22.27 | 22.05 | 21.41 | 21.51 | 21.36 | 20.84 | 20.05 | 19.76 |
| | **0.67** | 22.60 | 22.59 | 22.58 | 22.59 | 22.53 | 22.45 | 22.20 | 22.90 | 23.34 | 23.29 | 22.75 | 22.58 |
| | **0.78** | 22.63 | 22.65 | 22.64 | 22.65 | 22.68 | 22.71 | 22.78 | 23.79 | 24.56 | 24.86 | 24.48 | 24.38 |
| | **0.89** | 22.66 | 22.67 | 22.67 | 22.70 | 22.73 | 22.78 | 22.99 | 23.91 | 25.05 | 25.74 | 25.53 | 25.50 |
| | **1.00** | 22.63 | 22.63 | 22.63 | 22.65 | 22.68 | 22.73 | 22.90 | 23.16 | 23.81 | 24.17 | 23.62 | 23.46 |
| COILSET SURFACE TEMPERATURE ($^0$C) | **0.00** | 22.05 | 21.85 | 21.36 | 20.83 | 19.94 | 19.03 | 17.54 | 16.24 | 14.17 | 12.03 | 10.58 | 10.10 |
| | **0.07** | 21.67 | 21.49 | 21.33 | 20.78 | 19.95 | 19.49 | 18.45 | 17.26 | 15.67 | 13.94 | 12.80 | 12.39 |
| | **0.13** | 21.79 | 21.67 | 21.53 | 21.03 | 20.29 | 19.88 | 18.90 | 17.81 | 16.36 | 14.75 | 13.64 | 13.25 |
| | **0.20** | 21.89 | 21.80 | 21.71 | 21.29 | 20.62 | 20.24 | 19.39 | 18.45 | 17.22 | 15.78 | 14.72 | 14.39 |
| | **0.27** | 21.94 | 21.88 | 21.82 | 21.47 | 20.92 | 20.62 | 19.89 | 19.09 | 18.10 | 16.79 | 15.82 | 15.50 |
| | **0.33** | 21.98 | 21.96 | 21.93 | 21.65 | 21.19 | 20.92 | 20.32 | 19.65 | 18.84 | 17.73 | 16.81 | 16.51 |
| | **0.40** | 22.01 | 21.99 | 22.00 | 21.77 | 21.40 | 21.20 | 20.73 | 20.18 | 19.58 | 18.60 | 17.77 | 17.51 |
| | **0.47** | 22.03 | 22.03 | 22.05 | 21.87 | 21.60 | 21.45 | 21.11 | 20.71 | 20.27 | 19.47 | 18.71 | 18.46 |
| | **0.53** | 22.06 | 22.06 | 22.08 | 21.95 | 21.78 | 21.70 | 21.51 | 21.23 | 20.99 | 20.35 | 19.67 | 19.48 |
| | **0.60** | 22.07 | 22.08 | 22.11 | 22.02 | 21.92 | 21.90 | 21.89 | 21.74 | 21.72 | 21.29 | 20.66 | 20.48 |
| | **0.67** | 22.13 | 22.15 | 22.17 | 22.10 | 22.03 | 22.08 | 22.23 | 22.26 | 22.45 | 22.20 | 21.67 | 21.50 |
| | **0.73** | 22.15 | 22.17 | 22.21 | 22.15 | 22.13 | 22.25 | 22.57 | 22.78 | 23.17 | 23.09 | 22.72 | 22.53 |
| | **0.80** | 22.16 | 22.18 | 22.24 | 22.20 | 22.24 | 22.38 | 22.90 | 23.26 | 23.87 | 24.01 | 23.71 | 23.56 |
| | **0.87** | 22.17 | 22.18 | 22.23 | 22.19 | 22.31 | 22.55 | 23.25 | 23.82 | 24.67 | 25.02 | 24.86 | 24.76 |
| | **0.93** | 22.18 | 22.20 | 22.25 | 22.21 | 22.28 | 22.51 | 23.26 | 23.93 | 24.90 | 25.43 | 25.40 | 25.37 |
| | **1.00** | 22.81 | 22.81 | 22.82 | 22.82 | 22.84 | 22.90 | 23.02 | 23.22 | 23.92 | 24.41 | 23.87 | 23.70 |

**Table F7: R3-60 mains-side temperature values at 14LPM for selected time instants**

| | Dist | 1 sec | 2 sec | 3 sec | 5 sec | 8 sec | 10 sec | 15 sec | 20 sec | 30 sec | 50 sec | 100 sec | 200 sec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ESTIMATED WATER TEMPERATURE ($^0$C) | **0.00** | 22.04 | 21.90 | 21.58 | 19.94 | 17.01 | 15.85 | 13.47 | 12.11 | 10.92 | 10.21 | 9.87 | 9.75 |
| | **0.04** | 22.08 | 21.95 | 21.64 | 20.06 | 17.25 | 16.14 | 13.87 | 12.57 | 11.41 | 10.71 | 10.38 | 10.27 |
| | **0.08** | 22.12 | 21.99 | 21.70 | 20.18 | 17.48 | 16.42 | 14.28 | 13.04 | 11.90 | 11.22 | 10.90 | 10.78 |
| | **0.12** | 22.16 | 22.04 | 21.76 | 20.31 | 17.72 | 16.71 | 14.68 | 13.50 | 12.40 | 11.72 | 11.41 | 11.30 |
| | **0.16** | 22.20 | 22.09 | 21.82 | 20.43 | 17.96 | 17.00 | 15.08 | 13.96 | 12.89 | 12.23 | 11.93 | 11.82 |
| | **0.20** | 22.24 | 22.13 | 21.87 | 20.55 | 18.19 | 17.28 | 15.49 | 14.43 | 13.38 | 12.73 | 12.44 | 12.34 |
| | **0.24** | 22.28 | 22.18 | 21.93 | 20.67 | 18.43 | 17.57 | 15.89 | 14.89 | 13.87 | 13.23 | 12.96 | 12.85 |
| | **0.28** | 22.32 | 22.22 | 21.99 | 20.79 | 18.66 | 17.85 | 16.30 | 15.35 | 14.37 | 13.74 | 13.47 | 13.37 |
| | **0.32** | 22.36 | 22.27 | 22.05 | 20.92 | 18.90 | 18.14 | 16.70 | 15.82 | 14.86 | 14.24 | 13.99 | 13.89 |
| | **0.36** | 22.40 | 22.32 | 22.11 | 21.04 | 19.14 | 18.43 | 17.10 | 16.28 | 15.35 | 14.75 | 14.50 | 14.40 |
| | **0.40** | 22.44 | 22.36 | 22.17 | 21.16 | 19.37 | 18.71 | 17.51 | 16.74 | 15.84 | 15.25 | 15.01 | 14.92 |
| | **0.44** | 22.48 | 22.41 | 22.23 | 21.28 | 19.61 | 19.00 | 17.91 | 17.21 | 16.34 | 15.75 | 15.53 | 15.44 |
| | **0.48** | 22.52 | 22.46 | 22.29 | 21.40 | 19.85 | 19.29 | 18.31 | 17.67 | 16.83 | 16.26 | 16.04 | 15.96 |
| | **0.52** | 22.55 | 22.50 | 22.34 | 21.53 | 20.08 | 19.57 | 18.72 | 18.13 | 17.32 | 16.76 | 16.56 | 16.47 |
| | **0.56** | 22.59 | 22.55 | 22.40 | 21.65 | 20.32 | 19.86 | 19.12 | 18.59 | 17.81 | 17.27 | 17.07 | 16.99 |
| | **0.60** | 22.63 | 22.60 | 22.46 | 21.77 | 20.56 | 20.15 | 19.52 | 19.06 | 18.31 | 17.77 | 17.59 | 17.51 |
| | **0.64** | 22.67 | 22.64 | 22.52 | 21.89 | 20.79 | 20.43 | 19.93 | 19.52 | 18.80 | 18.27 | 18.10 | 18.03 |
| | **0.68** | 22.71 | 22.69 | 22.58 | 22.01 | 21.03 | 20.72 | 20.33 | 19.98 | 19.29 | 18.78 | 18.61 | 18.54 |
| | **0.72** | 22.75 | 22.74 | 22.64 | 22.14 | 21.27 | 21.01 | 20.73 | 20.45 | 19.78 | 19.28 | 19.13 | 19.06 |
| | **0.76** | 22.79 | 22.78 | 22.70 | 22.26 | 21.50 | 21.29 | 21.14 | 20.91 | 20.28 | 19.79 | 19.64 | 19.58 |
| | **0.80** | 22.83 | 22.83 | 22.76 | 22.38 | 21.74 | 21.58 | 21.54 | 21.37 | 20.77 | 20.29 | 20.16 | 20.09 |
| | **0.84** | 22.87 | 22.87 | 22.81 | 22.50 | 21.97 | 21.86 | 21.95 | 21.84 | 21.26 | 20.79 | 20.67 | 20.61 |
| | **0.88** | 22.91 | 22.92 | 22.87 | 22.62 | 22.21 | 22.15 | 22.35 | 22.30 | 21.75 | 21.30 | 21.19 | 21.13 |
| | **0.92** | 22.95 | 22.97 | 22.93 | 22.75 | 22.45 | 22.44 | 22.75 | 22.76 | 22.25 | 21.80 | 21.70 | 21.65 |
| | **0.96** | 22.99 | 23.01 | 22.99 | 22.87 | 22.68 | 22.72 | 23.16 | 23.23 | 22.74 | 22.31 | 22.22 | 22.16 |
| | **1.00** | 23.03 | 23.06 | 23.05 | 22.99 | 22.92 | 23.01 | 23.56 | 23.69 | 23.23 | 22.81 | 22.73 | 22.68 |
| THERMOCOUPLE SURFACE TEMPERATURE ($^0$C) | **0.00** | 21.87 | 21.80 | 21.42 | 19.87 | 17.63 | 16.34 | 13.92 | 12.51 | 11.20 | 10.43 | 9.99 | 9.79 |
| | **0.11** | 21.97 | 21.93 | 21.51 | 19.79 | 17.51 | 16.33 | 14.35 | 13.14 | 12.09 | 11.54 | 11.20 | 11.07 |
| | **0.22** | 22.17 | 22.09 | 22.00 | 20.71 | 18.50 | 17.34 | 15.32 | 14.04 | 12.93 | 12.38 | 12.07 | 11.91 |
| | **0.33** | 22.43 | 22.30 | 22.24 | 21.62 | 19.75 | 18.77 | 17.21 | 16.11 | 15.09 | 14.62 | 14.34 | 14.17 |
| | **0.44** | 22.56 | 22.50 | 22.42 | 22.14 | 20.67 | 19.83 | 18.53 | 17.53 | 16.60 | 16.13 | 15.88 | 15.75 |
| | **0.56** | 22.59 | 22.60 | 22.54 | 22.39 | 21.50 | 20.89 | 19.92 | 19.10 | 18.22 | 17.84 | 17.62 | 17.54 |
| | **0.67** | 22.69 | 22.67 | 22.67 | 22.58 | 22.30 | 21.96 | 21.30 | 20.64 | 19.78 | 19.41 | 19.19 | 19.12 |
| | **0.78** | 22.86 | 22.81 | 22.80 | 22.73 | 22.79 | 22.90 | 22.99 | 22.65 | 22.10 | 21.94 | 21.84 | 21.82 |
| | **0.89** | 23.03 | 22.97 | 22.92 | 22.84 | 23.10 | 23.57 | 24.15 | 23.98 | 23.55 | 23.51 | 23.42 | 23.45 |
| | **1.00** | 22.93 | 22.91 | 22.89 | 22.82 | 22.82 | 23.06 | 23.52 | 23.44 | 22.91 | 22.64 | 22.55 | 22.46 |
| COILSET SURFACE TEMPERATURE ($^0$C) | **0.00** | 22.04 | 21.90 | 21.58 | 19.94 | 17.01 | 15.85 | 13.47 | 12.11 | 10.92 | 10.21 | 9.87 | 9.75 |
| | **0.04** | 21.47 | 21.42 | 20.94 | 19.30 | 17.21 | 16.19 | 14.57 | 13.43 | 12.57 | 12.13 | 11.82 | 11.74 |
| | **0.08** | 21.56 | 21.50 | 21.21 | 19.67 | 17.56 | 16.48 | 14.87 | 13.73 | 12.87 | 12.42 | 12.11 | 12.03 |
| | **0.12** | 21.60 | 21.54 | 21.37 | 20.01 | 18.01 | 16.97 | 15.43 | 14.33 | 13.46 | 13.05 | 12.77 | 12.67 |
| | **0.16** | 21.64 | 21.54 | 21.44 | 20.14 | 18.00 | 16.88 | 15.20 | 13.98 | 13.02 | 12.57 | 12.24 | 12.16 |
| | **0.20** | 21.70 | 21.59 | 21.51 | 20.47 | 18.37 | 17.29 | 15.71 | 14.53 | 13.58 | 13.12 | 12.85 | 12.76 |
| | **0.24** | 21.82 | 21.66 | 21.61 | 20.79 | 18.84 | 17.83 | 16.37 | 15.24 | 14.34 | 13.91 | 13.66 | 13.56 |
| | **0.28** | 21.86 | 21.70 | 21.65 | 21.04 | 19.21 | 18.25 | 16.86 | 15.75 | 14.89 | 14.47 | 14.20 | 14.12 |
| | **0.32** | 21.94 | 21.78 | 21.71 | 21.27 | 19.53 | 18.62 | 17.30 | 16.21 | 15.33 | 14.93 | 14.65 | 14.58 |
| | **0.36** | 21.98 | 21.86 | 21.78 | 21.45 | 19.89 | 19.04 | 17.84 | 16.80 | 15.95 | 15.55 | 15.32 | 15.23 |
| | **0.40** | 22.00 | 21.94 | 21.84 | 21.60 | 20.22 | 19.43 | 18.29 | 17.26 | 16.42 | 16.04 | 15.80 | 15.73 |
| | **0.44** | 21.99 | 21.96 | 21.87 | 21.70 | 20.53 | 19.80 | 18.78 | 17.81 | 17.03 | 16.63 | 16.43 | 16.36 |
| | **0.48** | 22.00 | 22.00 | 21.93 | 21.78 | 20.80 | 20.15 | 19.23 | 18.31 | 17.50 | 17.15 | 16.94 | 16.88 |
| | **0.52** | 22.03 | 22.02 | 21.98 | 21.83 | 21.07 | 20.52 | 19.74 | 18.88 | 18.12 | 17.78 | 17.59 | 17.55 |
| | **0.56** | 22.08 | 22.07 | 22.04 | 21.92 | 21.37 | 20.90 | 20.27 | 19.45 | 18.72 | 18.45 | 18.30 | 18.24 |
| | **0.60** | 22.09 | 22.06 | 22.06 | 21.95 | 21.56 | 21.18 | 20.62 | 19.89 | 19.16 | 18.91 | 18.75 | 18.75 |
| | **0.64** | 22.14 | 22.09 | 22.09 | 22.00 | 21.79 | 21.51 | 21.15 | 20.45 | 19.79 | 19.57 | 19.41 | 19.41 |
| | **0.68** | 22.16 | 22.12 | 22.13 | 22.05 | 21.98 | 21.79 | 21.58 | 20.95 | 20.31 | 20.12 | 19.96 | 19.94 |
| | **0.72** | 22.26 | 22.20 | 22.20 | 22.13 | 22.22 | 22.14 | 22.07 | 21.51 | 20.89 | 20.73 | 20.59 | 20.61 |
| | **0.76** | 22.27 | 22.20 | 22.19 | 22.14 | 22.35 | 22.41 | 22.50 | 22.04 | 21.45 | 21.33 | 21.23 | 21.25 |
| | **0.80** | 22.29 | 22.22 | 22.20 | 22.16 | 22.46 | 22.64 | 22.89 | 22.51 | 21.97 | 21.89 | 21.79 | 21.80 |
| | **0.84** | 22.34 | 22.25 | 22.23 | 22.21 | 22.61 | 22.87 | 23.31 | 22.99 | 22.53 | 22.45 | 22.35 | 22.38 |
| | **0.88** | 22.37 | 22.29 | 22.25 | 22.24 | 22.68 | 23.07 | 23.67 | 23.42 | 22.99 | 22.96 | 22.87 | 22.88 |
| | **0.92** | 22.43 | 22.35 | 22.31 | 22.28 | 22.73 | 23.17 | 23.91 | 23.72 | 23.34 | 23.30 | 23.28 | 23.22 |
| | **0.96** | 22.42 | 22.36 | 22.31 | 22.27 | 22.68 | 23.18 | 24.08 | 24.02 | 23.71 | 23.66 | 23.68 | 23.67 |
| | **1.00** | 23.03 | 23.06 | 23.05 | 22.99 | 22.92 | 23.01 | 23.56 | 23.69 | 23.23 | 22.81 | 22.73 | 22.68 |

**Table F8: R3-60 mains-side temperature values at 12LPM for selected time instants**

| | Dist | 1 sec | 2 sec | 3 sec | 5 sec | 8 sec | 10 sec | 15 sec | 20 sec | 30 sec | 50 sec | 100 sec | 200 sec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ESTIMATED WATER TEMPERATURE ($^0$C) | **0.00** | 22.51 | 22.34 | 21.15 | 19.79 | 17.32 | 15.80 | 14.05 | 12.76 | 11.47 | 10.67 | 10.25 | 10.11 |
| | **0.04** | 22.53 | 22.37 | 21.22 | 19.92 | 17.55 | 16.10 | 14.45 | 13.23 | 11.98 | 11.19 | 10.78 | 10.65 |
| | **0.08** | 22.55 | 22.39 | 21.30 | 20.05 | 17.78 | 16.40 | 14.84 | 13.70 | 12.50 | 11.72 | 11.31 | 11.19 |
| | **0.12** | 22.57 | 22.42 | 21.37 | 20.17 | 18.01 | 16.70 | 15.24 | 14.17 | 13.01 | 12.24 | 11.85 | 11.72 |
| | **0.16** | 22.59 | 22.44 | 21.44 | 20.30 | 18.24 | 17.00 | 15.64 | 14.63 | 13.52 | 12.76 | 12.38 | 12.26 |
| | **0.20** | 22.61 | 22.47 | 21.52 | 20.43 | 18.47 | 17.30 | 16.03 | 15.10 | 14.03 | 13.28 | 12.91 | 12.80 |
| | **0.24** | 22.63 | 22.49 | 21.59 | 20.56 | 18.70 | 17.60 | 16.43 | 15.57 | 14.55 | 13.81 | 13.44 | 13.34 |
| | **0.28** | 22.64 | 22.52 | 21.66 | 20.69 | 18.93 | 17.91 | 16.82 | 16.04 | 15.06 | 14.33 | 13.98 | 13.88 |
| | **0.32** | 22.66 | 22.54 | 21.74 | 20.81 | 19.16 | 18.21 | 17.22 | 16.51 | 15.57 | 14.85 | 14.51 | 14.41 |
| | **0.36** | 22.68 | 22.57 | 21.81 | 20.94 | 19.39 | 18.51 | 17.62 | 16.98 | 16.09 | 15.38 | 15.04 | 14.95 |
| | **0.40** | 22.70 | 22.60 | 21.88 | 21.07 | 19.62 | 18.81 | 18.01 | 17.44 | 16.60 | 15.90 | 15.57 | 15.49 |
| | **0.44** | 22.72 | 22.62 | 21.96 | 21.20 | 19.85 | 19.11 | 18.41 | 17.91 | 17.11 | 16.42 | 16.11 | 16.03 |
| | **0.48** | 22.74 | 22.65 | 22.03 | 21.33 | 20.08 | 19.41 | 18.81 | 18.38 | 17.62 | 16.94 | 16.64 | 16.57 |
| | **0.52** | 22.76 | 22.67 | 22.10 | 21.45 | 20.32 | 19.71 | 19.20 | 18.85 | 18.14 | 17.47 | 17.17 | 17.10 |
| | **0.56** | 22.78 | 22.70 | 22.17 | 21.58 | 20.55 | 20.01 | 19.60 | 19.32 | 18.65 | 17.99 | 17.70 | 17.64 |
| | **0.60** | 22.80 | 22.72 | 22.25 | 21.71 | 20.78 | 20.31 | 20.00 | 19.79 | 19.16 | 18.51 | 18.24 | 18.18 |
| | **0.64** | 22.82 | 22.75 | 22.32 | 21.84 | 21.01 | 20.61 | 20.39 | 20.25 | 19.67 | 19.03 | 18.77 | 18.72 |
| | **0.68** | 22.84 | 22.78 | 22.39 | 21.97 | 21.24 | 20.91 | 20.79 | 20.72 | 20.19 | 19.56 | 19.30 | 19.26 |
| | **0.72** | 22.86 | 22.80 | 22.47 | 22.09 | 21.47 | 21.21 | 21.19 | 21.19 | 20.70 | 20.08 | 19.83 | 19.79 |
| | **0.76** | 22.87 | 22.83 | 22.54 | 22.22 | 21.70 | 21.52 | 21.58 | 21.66 | 21.21 | 20.60 | 20.37 | 20.33 |
| | **0.80** | 22.89 | 22.85 | 22.61 | 22.35 | 21.93 | 21.82 | 21.98 | 22.13 | 21.73 | 21.13 | 20.90 | 20.87 |
| | **0.84** | 22.91 | 22.88 | 22.69 | 22.48 | 22.16 | 22.12 | 22.37 | 22.60 | 22.24 | 21.65 | 21.43 | 21.41 |
| | **0.88** | 22.93 | 22.90 | 22.76 | 22.61 | 22.39 | 22.42 | 22.77 | 23.06 | 22.75 | 22.17 | 21.96 | 21.95 |
| | **0.92** | 22.95 | 22.93 | 22.83 | 22.73 | 22.62 | 22.72 | 23.17 | 23.53 | 23.26 | 22.69 | 22.50 | 22.48 |
| | **0.96** | 22.97 | 22.95 | 22.91 | 22.86 | 22.85 | 23.02 | 23.56 | 24.00 | 23.78 | 23.22 | 23.03 | 23.02 |
| | **1.00** | 22.99 | 22.98 | 22.98 | 22.99 | 23.08 | 23.32 | 23.96 | 24.47 | 24.29 | 23.74 | 23.56 | 23.56 |
| THERMOCOUPLE SURFACE TEMPERATURE ($^0$C) | **0.00** | 22.19 | 21.69 | 21.09 | 19.73 | 17.78 | 16.64 | 14.46 | 13.14 | 11.76 | 10.84 | 10.32 | 10.12 |
| | **0.11** | 22.27 | 21.70 | 21.02 | 19.61 | 17.72 | 16.69 | 14.94 | 13.90 | 12.75 | 12.00 | 11.59 | 11.45 |
| | **0.22** | 22.52 | 22.32 | 21.84 | 20.56 | 18.71 | 17.68 | 15.94 | 14.87 | 13.64 | 12.87 | 12.50 | 12.35 |
| | **0.33** | 22.64 | 22.59 | 22.40 | 21.60 | 20.06 | 19.25 | 17.97 | 17.12 | 16.03 | 15.25 | 14.92 | 14.74 |
| | **0.44** | 22.73 | 22.69 | 22.62 | 22.04 | 20.82 | 20.18 | 19.22 | 18.52 | 17.51 | 16.83 | 16.54 | 16.39 |
| | **0.56** | 22.74 | 22.73 | 22.69 | 22.46 | 21.64 | 21.19 | 20.59 | 20.09 | 19.19 | 18.59 | 18.36 | 18.22 |
| | **0.67** | 22.77 | 22.77 | 22.76 | 22.71 | 22.43 | 22.19 | 21.86 | 21.56 | 20.77 | 20.17 | 19.93 | 19.83 |
| | **0.78** | 22.82 | 22.84 | 22.84 | 22.88 | 23.04 | 23.27 | 23.72 | 23.74 | 23.22 | 22.82 | 22.71 | 22.63 |
| | **0.89** | 22.88 | 22.90 | 22.91 | 23.02 | 23.42 | 23.96 | 24.91 | 25.15 | 24.80 | 24.51 | 24.47 | 24.43 |
| | **1.00** | 22.78 | 22.80 | 22.79 | 22.83 | 23.00 | 23.25 | 23.98 | 24.26 | 23.89 | 23.43 | 23.29 | 23.26 |
| COILSET SURFACE TEMPERATURE ($^0$C) | **0.00** | 22.51 | 22.34 | 21.15 | 19.79 | 17.32 | 15.80 | 14.05 | 12.76 | 11.47 | 10.67 | 10.25 | 10.11 |
| | **0.04** | 21.88 | 21.53 | 20.90 | 19.71 | 17.86 | 16.93 | 15.45 | 14.37 | 13.37 | 12.64 | 12.22 | 12.27 |
| | **0.08** | 21.96 | 21.73 | 21.15 | 19.99 | 18.02 | 17.03 | 15.46 | 14.33 | 13.23 | 12.53 | 12.03 | 12.14 |
| | **0.12** | 22.00 | 21.86 | 21.40 | 20.30 | 18.41 | 17.39 | 15.90 | 14.76 | 13.70 | 12.97 | 12.57 | 12.62 |
| | **0.16** | 21.99 | 21.91 | 21.58 | 20.53 | 18.61 | 17.61 | 16.10 | 14.99 | 13.88 | 13.12 | 12.78 | 12.82 |
| | **0.20** | 22.04 | 21.98 | 21.76 | 20.83 | 19.00 | 18.06 | 16.67 | 15.58 | 14.50 | 13.78 | 13.40 | 13.45 |
| | **0.24** | 22.07 | 22.03 | 21.89 | 21.12 | 19.43 | 18.54 | 17.28 | 16.26 | 15.25 | 14.54 | 14.21 | 14.30 |
| | **0.28** | 22.10 | 22.07 | 22.00 | 21.38 | 19.78 | 18.98 | 17.80 | 16.81 | 15.80 | 15.13 | 14.77 | 14.83 |
| | **0.32** | 22.12 | 22.09 | 22.04 | 21.58 | 20.11 | 19.36 | 18.30 | 17.38 | 16.37 | 15.72 | 15.38 | 15.47 |
| | **0.36** | 22.15 | 22.12 | 22.08 | 21.77 | 20.45 | 19.76 | 18.80 | 17.97 | 16.97 | 16.30 | 16.00 | 16.12 |
| | **0.40** | 22.17 | 22.14 | 22.11 | 21.92 | 20.74 | 20.12 | 19.30 | 18.51 | 17.53 | 16.90 | 16.60 | 16.68 |
| | **0.44** | 22.16 | 22.12 | 22.11 | 22.00 | 20.95 | 20.40 | 19.69 | 18.97 | 18.01 | 17.41 | 17.14 | 17.25 |
| | **0.48** | 22.19 | 22.15 | 22.12 | 22.12 | 21.21 | 20.72 | 20.13 | 19.46 | 18.54 | 17.94 | 17.68 | 17.82 |
| | **0.52** | 22.22 | 22.21 | 22.18 | 22.22 | 21.50 | 21.10 | 20.65 | 20.08 | 19.20 | 18.63 | 18.36 | 18.49 |
| | **0.56** | 22.21 | 22.22 | 22.19 | 22.26 | 21.70 | 21.41 | 21.09 | 20.60 | 19.75 | 19.19 | 18.97 | 19.04 |
| | **0.60** | 22.24 | 22.25 | 22.23 | 22.31 | 21.90 | 21.71 | 21.52 | 21.07 | 20.28 | 19.75 | 19.50 | 19.60 |
| | **0.64** | 22.25 | 22.26 | 22.25 | 22.37 | 22.11 | 22.02 | 21.99 | 21.63 | 20.93 | 20.42 | 20.15 | 20.28 |
| | **0.68** | 22.29 | 22.31 | 22.30 | 22.42 | 22.30 | 22.31 | 22.44 | 22.14 | 21.45 | 20.95 | 20.74 | 20.84 |
| | **0.72** | 22.25 | 22.27 | 22.29 | 22.42 | 22.40 | 22.54 | 22.83 | 22.63 | 22.01 | 21.53 | 21.35 | 21.40 |
| | **0.76** | 22.29 | 22.30 | 22.33 | 22.46 | 22.55 | 22.80 | 23.24 | 23.13 | 22.57 | 22.12 | 21.92 | 22.03 |
| | **0.80** | 22.27 | 22.28 | 22.28 | 22.47 | 22.64 | 22.98 | 23.60 | 23.58 | 23.10 | 22.68 | 22.53 | 22.65 |
| | **0.84** | 22.30 | 22.33 | 22.33 | 22.53 | 22.76 | 23.23 | 24.04 | 24.11 | 23.70 | 23.30 | 23.13 | 23.27 |
| | **0.88** | 22.29 | 22.30 | 22.30 | 22.52 | 22.82 | 23.40 | 24.38 | 24.53 | 24.20 | 23.84 | 23.70 | 23.84 |
| | **0.92** | 22.25 | 22.27 | 22.28 | 22.49 | 22.84 | 23.42 | 24.53 | 24.76 | 24.44 | 24.13 | 24.02 | 24.15 |
| | **0.96** | 22.33 | 22.33 | 22.34 | 22.54 | 22.87 | 23.50 | 24.84 | 25.18 | 24.98 | 24.67 | 24.55 | 24.69 |
| | **1.00** | 22.99 | 22.98 | 22.98 | 22.99 | 23.08 | 23.32 | 23.96 | 24.47 | 24.29 | 23.74 | 23.56 | 23.56 |

**Table F9: R3-60 mains-side temperature values at 10LPM for selected time instants**

| | Dist | 1 sec | 2 sec | 3 sec | 5 sec | 8 sec | 10 sec | 15 sec | 20 sec | 30 sec | 50 sec | 100 sec | 200 sec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ESTIMATED WATER TEMPERATURE ($^0C$) | **0.00** | 22.14 | 21.83 | 21.36 | 20.21 | 18.43 | 16.88 | 14.58 | 13.32 | 11.57 | 10.47 | 9.84 | 9.67 |
| | **0.04** | 22.18 | 21.88 | 21.43 | 20.33 | 18.62 | 17.13 | 14.95 | 13.77 | 12.11 | 11.03 | 10.41 | 10.25 |
| | **0.08** | 22.22 | 21.94 | 21.50 | 20.45 | 18.81 | 17.39 | 15.33 | 14.21 | 12.64 | 11.59 | 10.99 | 10.83 |
| | **0.12** | 22.26 | 21.99 | 21.58 | 20.56 | 18.99 | 17.64 | 15.70 | 14.66 | 13.18 | 12.15 | 11.56 | 11.41 |
| | **0.16** | 22.30 | 22.04 | 21.65 | 20.68 | 19.18 | 17.89 | 16.07 | 15.11 | 13.71 | 12.71 | 12.14 | 11.99 |
| | **0.20** | 22.35 | 22.10 | 21.72 | 20.80 | 19.37 | 18.14 | 16.45 | 15.56 | 14.25 | 13.27 | 12.71 | 12.57 |
| | **0.24** | 22.39 | 22.15 | 21.79 | 20.92 | 19.56 | 18.40 | 16.82 | 16.00 | 14.79 | 13.83 | 13.28 | 13.15 |
| | **0.28** | 22.43 | 22.21 | 21.86 | 21.03 | 19.75 | 18.65 | 17.19 | 16.45 | 15.32 | 14.39 | 13.86 | 13.73 |
| | **0.32** | 22.47 | 22.26 | 21.94 | 21.15 | 19.93 | 18.90 | 17.57 | 16.90 | 15.86 | 14.95 | 14.43 | 14.31 |
| | **0.36** | 22.51 | 22.31 | 22.01 | 21.27 | 20.12 | 19.16 | 17.94 | 17.34 | 16.39 | 15.51 | 15.01 | 14.89 |
| | **0.40** | 22.55 | 22.37 | 22.08 | 21.39 | 20.31 | 19.41 | 18.31 | 17.79 | 16.93 | 16.07 | 15.58 | 15.47 |
| | **0.44** | 22.59 | 22.42 | 22.15 | 21.50 | 20.50 | 19.66 | 18.69 | 18.24 | 17.47 | 16.63 | 16.15 | 16.05 |
| | **0.48** | 22.63 | 22.47 | 22.22 | 21.62 | 20.69 | 19.91 | 19.06 | 18.69 | 18.00 | 17.19 | 16.73 | 16.63 |
| | **0.52** | 22.68 | 22.53 | 22.30 | 21.74 | 20.87 | 20.17 | 19.43 | 19.13 | 18.54 | 17.76 | 17.30 | 17.21 |
| | **0.56** | 22.72 | 22.58 | 22.37 | 21.86 | 21.06 | 20.42 | 19.80 | 19.58 | 19.07 | 18.32 | 17.88 | 17.79 |
| | **0.60** | 22.76 | 22.63 | 22.44 | 21.97 | 21.25 | 20.67 | 20.18 | 20.03 | 19.61 | 18.88 | 18.45 | 18.37 |
| | **0.64** | 22.80 | 22.69 | 22.51 | 22.09 | 21.44 | 20.92 | 20.55 | 20.48 | 20.15 | 19.44 | 19.02 | 18.95 |
| | **0.68** | 22.84 | 22.74 | 22.58 | 22.21 | 21.63 | 21.18 | 20.92 | 20.92 | 20.68 | 20.00 | 19.60 | 19.53 |
| | **0.72** | 22.88 | 22.79 | 22.66 | 22.33 | 21.81 | 21.43 | 21.30 | 21.37 | 21.22 | 20.56 | 20.17 | 20.11 |
| | **0.76** | 22.92 | 22.85 | 22.73 | 22.44 | 22.00 | 21.68 | 21.67 | 21.82 | 21.75 | 21.12 | 20.75 | 20.69 |
| | **0.80** | 22.96 | 22.90 | 22.80 | 22.56 | 22.19 | 21.94 | 22.04 | 22.26 | 22.29 | 21.68 | 21.32 | 21.27 |
| | **0.84** | 23.01 | 22.96 | 22.87 | 22.68 | 22.38 | 22.19 | 22.42 | 22.71 | 22.83 | 22.24 | 21.89 | 21.85 |
| | **0.88** | 23.05 | 23.01 | 22.94 | 22.80 | 22.57 | 22.44 | 22.79 | 23.16 | 23.36 | 22.80 | 22.47 | 22.43 |
| | **0.92** | 23.09 | 23.06 | 23.02 | 22.91 | 22.75 | 22.69 | 23.16 | 23.61 | 23.90 | 23.36 | 23.04 | 23.01 |
| | **0.96** | 23.13 | 23.12 | 23.09 | 23.03 | 22.94 | 22.95 | 23.54 | 24.05 | 24.43 | 23.92 | 23.62 | 23.59 |
| | **1.00** | 23.17 | 23.17 | 23.16 | 23.15 | 23.13 | 23.20 | 23.91 | 24.50 | 24.97 | 24.48 | 24.19 | 24.17 |
| THERMOCOUPLE SURFACE TEMPERATURE ($^0C$) | **0.00** | 22.04 | 21.70 | 21.24 | 20.14 | 18.44 | 17.37 | 15.19 | 13.66 | 12.02 | 10.79 | 10.03 | 9.79 |
| | **0.11** | 22.18 | 21.81 | 21.32 | 20.15 | 18.44 | 17.45 | 15.59 | 14.36 | 12.98 | 11.97 | 11.33 | 11.19 |
| | **0.22** | 22.42 | 22.30 | 22.01 | 21.08 | 19.46 | 18.48 | 16.67 | 15.43 | 14.00 | 12.94 | 12.33 | 12.18 |
| | **0.33** | 22.64 | 22.58 | 22.49 | 21.99 | 20.81 | 20.03 | 18.65 | 17.70 | 16.46 | 15.46 | 14.86 | 14.71 |
| | **0.44** | 22.77 | 22.71 | 22.66 | 22.35 | 21.46 | 20.84 | 19.82 | 19.11 | 18.05 | 17.16 | 16.61 | 16.53 |
| | **0.56** | 22.83 | 22.79 | 22.75 | 22.60 | 22.12 | 21.73 | 21.10 | 20.64 | 19.77 | 19.04 | 18.56 | 18.48 |
| | **0.67** | 22.88 | 22.86 | 22.85 | 22.78 | 22.64 | 22.49 | 22.25 | 22.02 | 21.46 | 20.71 | 20.28 | 20.21 |
| | **0.78** | 22.97 | 22.96 | 22.96 | 22.91 | 23.08 | 23.31 | 23.85 | 24.08 | 23.87 | 23.41 | 23.14 | 23.13 |
| | **0.89** | 23.06 | 23.05 | 23.04 | 23.02 | 23.38 | 23.87 | 24.97 | 25.52 | 25.62 | 25.34 | 25.22 | 25.19 |
| | **1.00** | 22.97 | 22.96 | 22.96 | 22.93 | 23.00 | 23.25 | 24.01 | 24.56 | 24.72 | 24.24 | 24.00 | 23.97 |
| COILSET SURFACE TEMPERATURE ($^0C$) | **0.00** | 22.14 | 21.83 | 21.36 | 20.21 | 18.43 | 16.88 | 14.58 | 13.32 | 11.57 | 10.47 | 9.84 | 9.67 |
| | **0.04** | 21.74 | 21.52 | 21.09 | 20.16 | 18.59 | 17.77 | 16.08 | 14.93 | 13.68 | 12.80 | 12.23 | 12.00 |
| | **0.08** | 21.78 | 21.63 | 21.28 | 20.36 | 18.71 | 17.82 | 16.06 | 14.86 | 13.51 | 12.60 | 12.00 | 11.78 |
| | **0.12** | 21.86 | 21.73 | 21.49 | 20.73 | 19.19 | 18.34 | 16.63 | 15.50 | 14.20 | 13.33 | 12.74 | 12.57 |
| | **0.16** | 21.90 | 21.79 | 21.63 | 20.95 | 19.39 | 18.53 | 16.74 | 15.55 | 14.15 | 13.25 | 12.63 | 12.36 |
| | **0.20** | 22.01 | 21.90 | 21.78 | 21.21 | 19.78 | 18.99 | 17.34 | 16.25 | 14.89 | 14.00 | 13.41 | 13.18 |
| | **0.24** | 22.06 | 21.97 | 21.86 | 21.44 | 20.16 | 19.44 | 17.94 | 16.93 | 15.65 | 14.77 | 14.22 | 13.98 |
| | **0.28** | 22.07 | 22.00 | 21.92 | 21.61 | 20.48 | 19.80 | 18.39 | 17.43 | 16.18 | 15.33 | 14.76 | 14.56 |
| | **0.32** | 22.12 | 22.04 | 21.98 | 21.76 | 20.76 | 20.13 | 18.84 | 17.94 | 16.75 | 15.90 | 15.38 | 15.12 |
| | **0.36** | 22.16 | 22.08 | 22.00 | 21.88 | 21.03 | 20.51 | 19.34 | 18.54 | 17.40 | 16.57 | 16.04 | 15.85 |
| | **0.40** | 22.21 | 22.12 | 22.06 | 21.97 | 21.28 | 20.82 | 19.75 | 18.98 | 17.90 | 17.09 | 16.56 | 16.40 |
| | **0.44** | 22.25 | 22.17 | 22.12 | 22.07 | 21.52 | 21.12 | 20.25 | 19.59 | 18.55 | 17.76 | 17.27 | 17.09 |
| | **0.48** | 22.25 | 22.21 | 22.15 | 22.13 | 21.71 | 21.42 | 20.65 | 20.07 | 19.14 | 18.36 | 17.87 | 17.74 |
| | **0.52** | 22.27 | 22.24 | 22.19 | 22.17 | 21.90 | 21.69 | 21.08 | 20.58 | 19.75 | 18.98 | 18.56 | 18.41 |
| | **0.56** | 22.32 | 22.28 | 22.26 | 22.25 | 22.06 | 21.97 | 21.53 | 21.13 | 20.38 | 19.68 | 19.28 | 19.10 |
| | **0.60** | 22.31 | 22.29 | 22.28 | 22.27 | 22.19 | 22.21 | 21.93 | 21.62 | 20.98 | 20.29 | 19.91 | 19.80 |
| | **0.64** | 22.34 | 22.33 | 22.30 | 22.33 | 22.34 | 22.43 | 22.35 | 22.16 | 21.62 | 20.99 | 20.64 | 20.45 |
| | **0.68** | 22.36 | 22.33 | 22.31 | 22.34 | 22.42 | 22.59 | 22.71 | 22.62 | 22.14 | 21.53 | 21.24 | 21.05 |
| | **0.72** | 22.40 | 22.35 | 22.35 | 22.38 | 22.51 | 22.79 | 23.08 | 23.10 | 22.74 | 22.18 | 21.90 | 21.74 |
| | **0.76** | 22.40 | 22.39 | 22.36 | 22.42 | 22.59 | 22.95 | 23.45 | 23.55 | 23.33 | 22.82 | 22.54 | 22.39 |
| | **0.80** | 22.41 | 22.39 | 22.37 | 22.42 | 22.63 | 23.08 | 23.78 | 23.98 | 23.88 | 23.41 | 23.15 | 23.01 |
| | **0.84** | 22.43 | 22.41 | 22.39 | 22.46 | 22.72 | 23.22 | 24.13 | 24.47 | 24.45 | 24.07 | 23.86 | 23.68 |
| | **0.88** | 22.46 | 22.42 | 22.43 | 22.51 | 22.78 | 23.33 | 24.40 | 24.86 | 24.95 | 24.58 | 24.41 | 24.24 |
| | **0.92** | 22.48 | 22.44 | 22.43 | 22.51 | 22.77 | 23.35 | 24.53 | 25.12 | 25.29 | 24.99 | 24.80 | 24.68 |
| | **0.96** | 22.43 | 22.38 | 22.38 | 22.45 | 22.66 | 23.14 | 24.29 | 24.91 | 25.22 | 25.07 | 24.97 | 24.88 |
| | **1.00** | 23.17 | 23.17 | 23.16 | 23.15 | 23.13 | 23.20 | 23.91 | 24.50 | 24.97 | 24.48 | 24.19 | 24.17 |

**Table F10: R3-60 mains-side temperature values at 9LPM for selected time instants**

| | Dist | 1 sec | 2 sec | 3 sec | 5 sec | 8 sec | 10 sec | 15 sec | 20 sec | 30 sec | 50 sec | 100 sec | 200 sec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ESTIMATED WATER TEMPERATURE ($^oC$) | **0.00** | 21.81 | 21.32 | 20.82 | 19.73 | 17.76 | 16.48 | 14.84 | 13.48 | 11.91 | 10.75 | 10.08 | 9.86 |
| | **0.04** | 21.85 | 21.38 | 20.90 | 19.85 | 17.97 | 16.74 | 15.20 | 13.93 | 12.45 | 11.32 | 10.67 | 10.45 |
| | **0.08** | 21.89 | 21.44 | 20.98 | 19.97 | 18.17 | 17.01 | 15.55 | 14.38 | 12.99 | 11.89 | 11.25 | 11.05 |
| | **0.12** | 21.92 | 21.49 | 21.05 | 20.10 | 18.38 | 17.27 | 15.91 | 14.82 | 13.53 | 12.46 | 11.84 | 11.64 |
| | **0.16** | 21.96 | 21.55 | 21.13 | 20.22 | 18.58 | 17.54 | 16.27 | 15.27 | 14.06 | 13.03 | 12.42 | 12.23 |
| | **0.20** | 22.00 | 21.61 | 21.21 | 20.34 | 18.79 | 17.80 | 16.63 | 15.72 | 14.60 | 13.60 | 13.01 | 12.83 |
| | **0.24** | 22.04 | 21.67 | 21.29 | 20.46 | 18.99 | 18.07 | 16.98 | 16.17 | 15.14 | 14.17 | 13.59 | 13.42 |
| | **0.28** | 22.07 | 21.72 | 21.37 | 20.59 | 19.20 | 18.33 | 17.34 | 16.61 | 15.68 | 14.74 | 14.18 | 14.01 |
| | **0.32** | 22.11 | 21.78 | 21.44 | 20.71 | 19.40 | 18.60 | 17.70 | 17.06 | 16.22 | 15.31 | 14.76 | 14.61 |
| | **0.36** | 22.15 | 21.84 | 21.52 | 20.83 | 19.61 | 18.86 | 18.05 | 17.51 | 16.76 | 15.88 | 15.35 | 15.20 |
| | **0.40** | 22.19 | 21.90 | 21.60 | 20.95 | 19.81 | 19.13 | 18.41 | 17.96 | 17.29 | 16.45 | 15.93 | 15.79 |
| | **0.44** | 22.22 | 21.95 | 21.68 | 21.08 | 20.02 | 19.39 | 18.77 | 18.40 | 17.83 | 17.02 | 16.52 | 16.39 |
| | **0.48** | 22.26 | 22.01 | 21.76 | 21.20 | 20.22 | 19.66 | 19.13 | 18.85 | 18.37 | 17.59 | 17.10 | 16.98 |
| | **0.52** | 22.30 | 22.07 | 21.83 | 21.32 | 20.43 | 19.92 | 19.48 | 19.30 | 18.91 | 18.17 | 17.69 | 17.57 |
| | **0.56** | 22.34 | 22.13 | 21.91 | 21.44 | 20.63 | 20.19 | 19.84 | 19.75 | 19.45 | 18.74 | 18.27 | 18.16 |
| | **0.60** | 22.37 | 22.18 | 21.99 | 21.57 | 20.84 | 20.45 | 20.20 | 20.19 | 19.99 | 19.31 | 18.86 | 18.76 |
| | **0.64** | 22.41 | 22.24 | 22.07 | 21.69 | 21.04 | 20.72 | 20.56 | 20.64 | 20.52 | 19.88 | 19.44 | 19.35 |
| | **0.68** | 22.45 | 22.30 | 22.15 | 21.81 | 21.25 | 20.98 | 20.91 | 21.09 | 21.06 | 20.45 | 20.03 | 19.94 |
| | **0.72** | 22.49 | 22.36 | 22.22 | 21.93 | 21.45 | 21.25 | 21.27 | 21.54 | 21.60 | 21.02 | 20.61 | 20.54 |
| | **0.76** | 22.52 | 22.41 | 22.30 | 22.06 | 21.66 | 21.51 | 21.63 | 21.98 | 22.14 | 21.59 | 21.20 | 21.13 |
| | **0.80** | 22.56 | 22.47 | 22.38 | 22.18 | 21.86 | 21.78 | 21.98 | 22.43 | 22.68 | 22.16 | 21.78 | 21.72 |
| | **0.84** | 22.60 | 22.53 | 22.46 | 22.30 | 22.07 | 22.04 | 22.34 | 22.88 | 23.22 | 22.73 | 22.37 | 22.32 |
| | **0.88** | 22.64 | 22.59 | 22.54 | 22.42 | 22.27 | 22.31 | 22.70 | 23.33 | 23.75 | 23.30 | 22.95 | 22.91 |
| | **0.92** | 22.67 | 22.64 | 22.61 | 22.55 | 22.48 | 22.57 | 23.06 | 23.77 | 24.29 | 23.87 | 23.54 | 23.50 |
| | **0.96** | 22.71 | 22.70 | 22.69 | 22.67 | 22.68 | 22.84 | 23.41 | 24.22 | 24.83 | 24.44 | 24.12 | 24.10 |
| | **1.00** | 22.75 | 22.76 | 22.77 | 22.79 | 22.89 | 23.10 | 23.77 | 24.67 | 25.37 | 25.01 | 24.71 | 24.69 |
| THERMOCOUPLE SURFACE TEMPERATURE ($^oC$) | **0.00** | 21.80 | 21.39 | 20.92 | 19.91 | 18.44 | 17.50 | 15.51 | 14.09 | 12.38 | 11.05 | 10.23 | 9.92 |
| | **0.11** | 21.91 | 21.46 | 20.96 | 19.92 | 18.41 | 17.58 | 15.92 | 14.78 | 13.37 | 12.28 | 11.61 | 11.42 |
| | **0.22** | 22.36 | 22.12 | 21.76 | 20.87 | 19.45 | 18.62 | 17.04 | 15.89 | 14.47 | 13.31 | 12.64 | 12.46 |
| | **0.33** | 22.53 | 22.48 | 22.35 | 21.84 | 20.81 | 20.14 | 18.99 | 18.19 | 17.01 | 15.90 | 15.23 | 15.11 |
| | **0.44** | 22.59 | 22.58 | 22.53 | 22.20 | 21.42 | 20.90 | 20.12 | 19.54 | 18.62 | 17.66 | 17.07 | 16.96 |
| | **0.56** | 22.60 | 22.60 | 22.59 | 22.50 | 22.09 | 21.77 | 21.38 | 21.06 | 20.37 | 19.51 | 19.07 | 18.96 |
| | **0.67** | 22.61 | 22.61 | 22.62 | 22.62 | 22.58 | 22.45 | 22.37 | 22.35 | 21.97 | 21.19 | 20.79 | 20.70 |
| | **0.78** | 22.67 | 22.68 | 22.70 | 22.77 | 23.02 | 23.21 | 23.99 | 24.40 | 24.44 | 23.93 | 23.66 | 23.69 |
| | **0.89** | 22.73 | 22.75 | 22.78 | 22.92 | 23.34 | 23.78 | 25.16 | 25.88 | 26.23 | 25.93 | 25.80 | 25.85 |
| | **1.00** | 22.57 | 22.65 | 22.59 | 22.65 | 22.81 | 23.04 | 23.96 | 24.65 | 25.14 | 24.72 | 24.49 | 24.45 |
| COILSET SURFACE TEMPERATURE ($^oC$) | **0.00** | 21.81 | 21.32 | 20.82 | 19.73 | 17.76 | 16.48 | 14.84 | 13.48 | 11.91 | 10.75 | 10.08 | 9.86 |
| | **0.04** | 21.78 | 21.23 | 20.70 | 19.62 | 18.29 | 17.49 | 16.21 | 15.09 | 13.90 | 12.89 | 12.25 | 12.05 |
| | **0.08** | 21.95 | 21.43 | 20.93 | 19.86 | 18.55 | 17.72 | 16.38 | 15.31 | 14.05 | 13.06 | 12.42 | 12.26 |
| | **0.12** | 22.14 | 21.62 | 21.18 | 20.19 | 18.91 | 18.10 | 16.85 | 15.78 | 14.53 | 13.59 | 12.94 | 12.74 |
| | **0.16** | 22.18 | 21.74 | 21.37 | 20.41 | 19.11 | 18.28 | 16.96 | 15.85 | 14.57 | 13.52 | 12.89 | 12.71 |
| | **0.20** | 22.21 | 21.84 | 21.55 | 20.71 | 19.47 | 18.68 | 17.48 | 16.47 | 15.23 | 14.17 | 13.56 | 13.43 |
| | **0.24** | 22.27 | 21.93 | 21.71 | 21.00 | 19.92 | 19.19 | 18.18 | 17.30 | 16.11 | 15.13 | 14.57 | 14.39 |
| | **0.28** | 22.29 | 21.98 | 21.81 | 21.20 | 20.23 | 19.51 | 18.60 | 17.77 | 16.67 | 15.67 | 15.11 | 14.99 |
| | **0.32** | 22.29 | 21.99 | 21.88 | 21.37 | 20.51 | 19.86 | 19.03 | 18.27 | 17.22 | 16.25 | 15.67 | 15.56 |
| | **0.36** | 22.35 | 22.04 | 21.95 | 21.56 | 20.82 | 20.23 | 19.52 | 18.85 | 17.86 | 16.88 | 16.37 | 16.25 |
| | **0.40** | 22.40 | 22.06 | 21.96 | 21.68 | 21.05 | 20.53 | 19.97 | 19.38 | 18.44 | 17.42 | 16.99 | 16.82 |
| | **0.44** | 22.35 | 22.06 | 21.98 | 21.78 | 21.29 | 20.84 | 20.40 | 19.91 | 19.06 | 18.10 | 17.66 | 17.52 |
| | **0.48** | 22.40 | 22.08 | 22.04 | 21.86 | 21.51 | 21.12 | 20.83 | 20.43 | 19.65 | 18.72 | 18.32 | 18.14 |
| | **0.52** | 22.39 | 22.10 | 22.05 | 21.92 | 21.70 | 21.38 | 21.23 | 20.90 | 20.21 | 19.31 | 18.90 | 18.73 |
| | **0.56** | 22.43 | 22.12 | 22.05 | 21.98 | 21.89 | 21.64 | 21.64 | 21.41 | 20.83 | 19.96 | 19.60 | 19.43 |
| | **0.60** | 22.42 | 22.14 | 22.08 | 22.02 | 22.05 | 21.88 | 22.07 | 21.96 | 21.48 | 20.64 | 20.30 | 20.17 |
| | **0.64** | 22.41 | 22.13 | 22.08 | 22.03 | 22.16 | 22.05 | 22.42 | 22.42 | 22.07 | 21.28 | 20.98 | 20.87 |
| | **0.68** | 22.46 | 22.15 | 22.10 | 22.05 | 22.27 | 22.27 | 22.81 | 22.88 | 22.65 | 21.91 | 21.65 | 21.52 |
| | **0.72** | 22.43 | 22.13 | 22.09 | 22.07 | 22.36 | 22.43 | 23.19 | 23.39 | 23.24 | 22.52 | 22.32 | 22.21 |
| | **0.76** | 22.48 | 22.15 | 22.10 | 22.09 | 22.43 | 22.57 | 23.50 | 23.83 | 23.79 | 23.13 | 22.92 | 22.87 |
| | **0.80** | 22.39 | 22.12 | 22.08 | 22.09 | 22.48 | 22.69 | 23.80 | 24.25 | 24.32 | 23.73 | 23.56 | 23.53 |
| | **0.84** | 22.46 | 22.15 | 22.12 | 22.13 | 22.56 | 22.84 | 24.15 | 24.70 | 24.90 | 24.36 | 24.22 | 24.21 |
| | **0.88** | 22.43 | 22.15 | 22.09 | 22.11 | 22.57 | 22.88 | 24.38 | 25.04 | 25.37 | 24.87 | 24.76 | 24.78 |
| | **0.92** | 22.46 | 22.14 | 22.09 | 22.11 | 22.60 | 22.99 | 24.60 | 25.35 | 25.76 | 25.36 | 25.22 | 25.29 |
| | **0.96** | 22.44 | 22.14 | 22.10 | 22.09 | 22.56 | 22.87 | 24.57 | 25.42 | 25.94 | 25.36 | 25.59 | 25.63 |
| | **1.00** | 22.75 | 22.76 | 22.77 | 22.79 | 22.89 | 23.10 | 23.77 | 24.67 | 25.37 | 25.01 | 24.71 | 24.69 |

**Table F11: R3-60 mains-side temperature values at 7LPM for selected time instants**

| | Dist | 1 sec | 2 sec | 3 sec | 5 sec | 8 sec | 10 sec | 15 sec | 20 sec | 30 sec | 50 sec | 100 sec | 200 sec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ESTIMATED WATER TEMPERATURE ($^oC$) | **0.00** | 22.15 | 22.06 | 21.62 | 21.30 | 19.70 | 18.93 | 16.50 | 15.21 | 13.03 | 11.42 | 10.43 | 10.12 |
| | **0.04** | 22.17 | 22.08 | 21.66 | 21.35 | 19.82 | 19.08 | 16.76 | 15.55 | 13.53 | 12.01 | 11.06 | 10.76 |
| | **0.08** | 22.19 | 22.10 | 21.70 | 21.40 | 19.93 | 19.23 | 17.02 | 15.89 | 14.04 | 12.61 | 11.68 | 11.40 |
| | **0.12** | 22.20 | 22.12 | 21.74 | 21.46 | 20.05 | 19.37 | 17.28 | 16.24 | 14.54 | 13.20 | 12.31 | 12.04 |
| | **0.16** | 22.22 | 22.14 | 21.78 | 21.51 | 20.17 | 19.52 | 17.54 | 16.58 | 15.04 | 13.79 | 12.93 | 12.68 |
| | **0.20** | 22.24 | 22.17 | 21.82 | 21.56 | 20.28 | 19.67 | 17.80 | 16.92 | 15.55 | 14.39 | 13.56 | 13.31 |
| | **0.24** | 22.26 | 22.19 | 21.86 | 21.61 | 20.40 | 19.82 | 18.06 | 17.26 | 16.05 | 14.98 | 14.18 | 13.95 |
| | **0.28** | 22.28 | 22.21 | 21.89 | 21.66 | 20.52 | 19.97 | 18.33 | 17.61 | 16.55 | 15.58 | 14.81 | 14.59 |
| | **0.32** | 22.29 | 22.23 | 21.93 | 21.72 | 20.63 | 20.11 | 18.59 | 17.95 | 17.06 | 16.17 | 15.43 | 15.23 |
| | **0.36** | 22.31 | 22.25 | 21.97 | 21.77 | 20.75 | 20.26 | 18.85 | 18.29 | 17.56 | 16.76 | 16.06 | 15.87 |
| | **0.40** | 22.33 | 22.27 | 22.01 | 21.82 | 20.87 | 20.41 | 19.11 | 18.63 | 18.06 | 17.36 | 16.68 | 16.51 |
| | **0.44** | 22.35 | 22.29 | 22.05 | 21.87 | 20.98 | 20.56 | 19.37 | 18.98 | 18.57 | 17.95 | 17.31 | 17.15 |
| | **0.48** | 22.37 | 22.31 | 22.09 | 21.92 | 21.10 | 20.71 | 19.63 | 19.32 | 19.07 | 18.54 | 17.93 | 17.79 |
| | **0.52** | 22.38 | 22.34 | 22.13 | 21.98 | 21.22 | 20.85 | 19.89 | 19.66 | 19.57 | 19.14 | 18.56 | 18.42 |
| | **0.56** | 22.40 | 22.36 | 22.17 | 22.03 | 21.34 | 21.00 | 20.15 | 20.00 | 20.07 | 19.73 | 19.18 | 19.06 |
| | **0.60** | 22.42 | 22.38 | 22.21 | 22.08 | 21.45 | 21.15 | 20.41 | 20.35 | 20.58 | 20.32 | 19.81 | 19.70 |
| | **0.64** | 22.44 | 22.40 | 22.25 | 22.13 | 21.57 | 21.30 | 20.67 | 20.69 | 21.08 | 20.92 | 20.43 | 20.34 |
| | **0.68** | 22.46 | 22.42 | 22.29 | 22.18 | 21.69 | 21.45 | 20.93 | 21.03 | 21.58 | 21.51 | 21.06 | 20.98 |
| | **0.72** | 22.47 | 22.44 | 22.33 | 22.24 | 21.80 | 21.59 | 21.19 | 21.37 | 22.09 | 22.10 | 21.68 | 21.62 |
| | **0.76** | 22.49 | 22.46 | 22.36 | 22.29 | 21.92 | 21.74 | 21.46 | 21.72 | 22.59 | 22.70 | 22.31 | 22.26 |
| | **0.80** | 22.51 | 22.48 | 22.40 | 22.34 | 22.04 | 21.89 | 21.72 | 22.06 | 23.09 | 23.29 | 22.93 | 22.90 |
| | **0.84** | 22.53 | 22.51 | 22.44 | 22.39 | 22.15 | 22.04 | 21.98 | 22.40 | 23.60 | 23.89 | 23.56 | 23.53 |
| | **0.88** | 22.55 | 22.53 | 22.48 | 22.44 | 22.27 | 22.19 | 22.24 | 22.74 | 24.10 | 24.48 | 24.18 | 24.17 |
| | **0.92** | 22.56 | 22.55 | 22.52 | 22.50 | 22.39 | 22.33 | 22.50 | 23.09 | 24.60 | 25.07 | 24.81 | 24.81 |
| | **0.96** | 22.58 | 22.57 | 22.56 | 22.55 | 22.50 | 22.48 | 22.76 | 23.43 | 25.11 | 25.67 | 25.43 | 25.45 |
| | **1.00** | 22.60 | 22.59 | 22.60 | 22.60 | 22.62 | 22.63 | 23.02 | 23.77 | 25.61 | 26.26 | 26.06 | 26.09 |
| THERMOCOUPLE SURFACE TEMPERATURE ($^oC$) | **0.00** | 22.12 | 22.00 | 21.82 | 21.24 | 20.17 | 19.41 | 17.58 | 16.02 | 13.81 | 11.94 | 10.75 | 10.34 |
| | **0.11** | 22.20 | 22.10 | 21.92 | 21.30 | 20.16 | 19.40 | 17.68 | 16.40 | 14.60 | 13.09 | 12.10 | 11.85 |
| | **0.22** | 22.27 | 22.25 | 22.21 | 21.93 | 21.07 | 20.39 | 18.81 | 17.61 | 15.93 | 14.41 | 13.42 | 13.14 |
| | **0.33** | 22.35 | 22.31 | 22.31 | 22.26 | 21.84 | 21.44 | 20.33 | 19.55 | 18.37 | 17.18 | 16.24 | 16.01 |
| | **0.44** | 22.42 | 22.39 | 22.39 | 22.36 | 22.15 | 21.88 | 21.18 | 20.72 | 19.90 | 18.94 | 18.17 | 18.00 |
| | **0.56** | 22.43 | 22.40 | 22.40 | 22.37 | 22.33 | 22.25 | 22.01 | 21.92 | 21.56 | 20.90 | 20.23 | 20.10 |
| | **0.67** | 22.44 | 22.42 | 22.42 | 22.41 | 22.41 | 22.45 | 22.60 | 22.88 | 23.07 | 22.67 | 22.15 | 22.08 |
| | **0.78** | 22.45 | 22.45 | 22.47 | 22.47 | 22.50 | 22.66 | 23.47 | 24.40 | 25.27 | 25.35 | 25.05 | 25.08 |
| | **0.89** | 22.51 | 22.50 | 22.51 | 22.51 | 22.61 | 22.87 | 24.11 | 25.48 | 26.84 | 27.27 | 27.19 | 27.29 |
| | **1.00** | 22.51 | 22.51 | 22.50 | 22.51 | 22.54 | 22.61 | 23.17 | 24.15 | 25.64 | 26.13 | 25.93 | 25.96 |
| COILSET SURFACE TEMPERATURE ($^oC$) | **0.00** | 22.15 | 22.06 | 21.62 | 21.30 | 19.70 | 18.93 | 16.50 | 15.21 | 13.03 | 11.42 | 10.43 | 10.12 |
| | **0.04** | 21.78 | 21.76 | 21.61 | 21.07 | 19.92 | 19.21 | 17.48 | 16.34 | 14.78 | 12.96 | 12.12 | 11.85 |
| | **0.08** | 21.83 | 21.81 | 21.73 | 21.32 | 20.35 | 19.73 | 18.13 | 17.10 | 15.61 | 13.93 | 13.14 | 12.82 |
| | **0.12** | 21.82 | 21.81 | 21.74 | 21.43 | 20.55 | 19.95 | 18.37 | 17.34 | 15.90 | 14.22 | 13.45 | 13.19 |
| | **0.16** | 21.82 | 21.82 | 21.78 | 21.55 | 20.71 | 20.08 | 18.43 | 17.30 | 15.74 | 13.90 | 13.01 | 12.69 |
| | **0.20** | 21.84 | 21.83 | 21.79 | 21.65 | 20.96 | 20.41 | 18.88 | 17.87 | 16.43 | 14.69 | 13.87 | 13.52 |
| | **0.24** | 21.91 | 21.90 | 21.86 | 21.75 | 21.21 | 20.77 | 19.44 | 18.59 | 17.38 | 15.72 | 14.99 | 14.67 |
| | **0.28** | 21.93 | 21.92 | 21.87 | 21.81 | 21.38 | 21.01 | 19.79 | 19.02 | 17.88 | 16.24 | 15.50 | 15.22 |
| | **0.32** | 21.92 | 21.90 | 21.83 | 21.77 | 21.46 | 21.14 | 20.05 | 19.35 | 18.31 | 16.75 | 16.03 | 15.80 |
| | **0.36** | 21.91 | 21.88 | 21.83 | 21.77 | 21.53 | 21.29 | 20.34 | 19.75 | 18.86 | 17.45 | 16.76 | 16.50 |
| | **0.40** | 21.96 | 21.94 | 21.88 | 21.81 | 21.62 | 21.48 | 20.68 | 20.19 | 19.40 | 18.01 | 17.33 | 17.10 |
| | **0.44** | 21.99 | 21.97 | 21.91 | 21.83 | 21.67 | 21.57 | 20.95 | 20.62 | 20.03 | 18.77 | 18.11 | 17.95 |
| | **0.48** | 22.05 | 22.02 | 21.96 | 21.87 | 21.77 | 21.73 | 21.27 | 21.08 | 20.62 | 19.43 | 18.81 | 18.61 |
| | **0.52** | 22.00 | 22.00 | 21.94 | 21.87 | 21.79 | 21.82 | 21.50 | 21.46 | 21.15 | 20.08 | 19.52 | 19.36 |
| | **0.56** | 22.00 | 22.01 | 21.95 | 21.88 | 21.79 | 21.83 | 21.70 | 21.81 | 21.68 | 20.72 | 20.20 | 20.10 |
| | **0.60** | 22.02 | 22.02 | 22.00 | 21.94 | 21.84 | 21.92 | 21.96 | 22.21 | 22.23 | 21.37 | 20.89 | 20.82 |
| | **0.64** | 22.05 | 22.07 | 22.02 | 21.98 | 21.89 | 22.00 | 22.20 | 22.59 | 22.83 | 22.07 | 21.67 | 21.55 |
| | **0.68** | 22.04 | 22.06 | 22.02 | 21.97 | 21.89 | 22.00 | 22.36 | 22.91 | 23.30 | 22.71 | 22.31 | 22.17 |
| | **0.72** | 22.04 | 22.05 | 22.02 | 21.98 | 21.89 | 22.02 | 22.50 | 23.24 | 23.83 | 23.35 | 23.01 | 22.91 |
| | **0.76** | 22.05 | 22.03 | 22.02 | 21.97 | 21.89 | 22.05 | 22.65 | 23.54 | 24.36 | 24.01 | 23.73 | 23.68 |
| | **0.80** | 22.09 | 22.08 | 22.05 | 22.02 | 21.95 | 22.11 | 22.84 | 23.91 | 24.92 | 24.66 | 24.47 | 24.40 |
| | **0.84** | 22.07 | 22.08 | 22.06 | 22.02 | 21.96 | 22.15 | 23.00 | 24.24 | 25.48 | 25.39 | 25.26 | 25.18 |
| | **0.88** | 22.09 | 22.08 | 22.06 | 22.04 | 22.00 | 22.20 | 23.12 | 24.53 | 25.95 | 25.98 | 25.88 | 25.83 |
| | **0.92** | 22.08 | 22.08 | 22.06 | 22.06 | 22.01 | 22.21 | 23.19 | 24.72 | 26.34 | 26.44 | 26.36 | 26.43 |
| | **0.96** | 22.07 | 22.06 | 22.06 | 22.04 | 21.99 | 22.17 | 23.12 | 24.64 | 26.29 | 26.52 | 26.58 | 26.66 |
| | **1.00** | 22.60 | 22.59 | 22.60 | 22.60 | 22.62 | 22.63 | 23.02 | 23.77 | 25.61 | 26.26 | 26.06 | 26.09 |

**Table F12: R3-60 mains-side temperature values at 5.5LPM for selected time instants**

| | Dist | 1 sec | 2 sec | 3 sec | 5 sec | 8 sec | 10 sec | 15 sec | 20 sec | 30 sec | 50 sec | 100 sec | 200 sec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ESTIMATED WATER TEMPERATURE ($^oC$) | **0.00** | 21.09 | 20.93 | 20.54 | 20.08 | 19.19 | 18.54 | 17.08 | 15.71 | 14.15 | 12.34 | 10.97 | 10.56 |
| | **0.04** | 21.11 | 20.95 | 20.58 | 20.14 | 19.28 | 18.66 | 17.28 | 16.00 | 14.58 | 12.92 | 11.62 | 11.23 |
| | **0.08** | 21.12 | 20.97 | 20.62 | 20.20 | 19.38 | 18.78 | 17.47 | 16.30 | 15.02 | 13.51 | 12.27 | 11.90 |
| | **0.12** | 21.14 | 21.00 | 20.66 | 20.25 | 19.47 | 18.91 | 17.67 | 16.59 | 15.45 | 14.09 | 12.92 | 12.58 |
| | **0.16** | 21.15 | 21.02 | 20.69 | 20.31 | 19.57 | 19.03 | 17.87 | 16.89 | 15.88 | 14.68 | 13.57 | 13.25 |
| | **0.20** | 21.17 | 21.04 | 20.73 | 20.37 | 19.66 | 19.15 | 18.06 | 17.18 | 16.31 | 15.26 | 14.22 | 13.92 |
| | **0.24** | 21.19 | 21.06 | 20.77 | 20.43 | 19.76 | 19.27 | 18.26 | 17.48 | 16.75 | 15.84 | 14.87 | 14.59 |
| | **0.28** | 21.20 | 21.09 | 20.81 | 20.48 | 19.85 | 19.40 | 18.46 | 17.77 | 17.18 | 16.43 | 15.52 | 15.26 |
| | **0.32** | 21.22 | 21.11 | 20.85 | 20.54 | 19.95 | 19.52 | 18.65 | 18.07 | 17.61 | 17.01 | 16.17 | 15.94 |
| | **0.36** | 21.23 | 21.13 | 20.89 | 20.60 | 20.04 | 19.64 | 18.85 | 18.36 | 18.05 | 17.60 | 16.82 | 16.61 |
| | **0.40** | 21.25 | 21.15 | 20.92 | 20.66 | 20.13 | 19.76 | 19.05 | 18.65 | 18.48 | 18.18 | 17.47 | 17.28 |
| | **0.44** | 21.27 | 21.18 | 20.96 | 20.71 | 20.23 | 19.89 | 19.24 | 18.95 | 18.91 | 18.76 | 18.12 | 17.95 |
| | **0.48** | 21.28 | 21.20 | 21.00 | 20.77 | 20.32 | 20.01 | 19.44 | 19.24 | 19.34 | 19.35 | 18.77 | 18.62 |
| | **0.52** | 21.30 | 21.22 | 21.04 | 20.83 | 20.42 | 20.13 | 19.64 | 19.54 | 19.78 | 19.93 | 19.42 | 19.30 |
| | **0.56** | 21.31 | 21.24 | 21.08 | 20.89 | 20.51 | 20.25 | 19.84 | 19.83 | 20.21 | 20.52 | 20.07 | 19.97 |
| | **0.60** | 21.33 | 21.27 | 21.12 | 20.94 | 20.61 | 20.38 | 20.03 | 20.13 | 20.64 | 21.10 | 20.72 | 20.64 |
| | **0.64** | 21.35 | 21.29 | 21.15 | 21.00 | 20.70 | 20.50 | 20.23 | 20.42 | 21.07 | 21.68 | 21.37 | 21.31 |
| | **0.68** | 21.36 | 21.31 | 21.19 | 21.06 | 20.79 | 20.62 | 20.43 | 20.71 | 21.51 | 22.27 | 22.02 | 21.98 |
| | **0.72** | 21.38 | 21.33 | 21.23 | 21.12 | 20.89 | 20.74 | 20.62 | 21.01 | 21.94 | 22.85 | 22.67 | 22.66 |
| | **0.76** | 21.39 | 21.36 | 21.27 | 21.17 | 20.98 | 20.87 | 20.82 | 21.30 | 22.37 | 23.44 | 23.32 | 23.33 |
| | **0.80** | 21.41 | 21.38 | 21.31 | 21.23 | 21.08 | 20.99 | 21.02 | 21.60 | 22.81 | 24.02 | 23.97 | 24.00 |
| | **0.84** | 21.43 | 21.40 | 21.35 | 21.29 | 21.17 | 21.11 | 21.21 | 21.89 | 23.24 | 24.60 | 24.62 | 24.67 |
| | **0.88** | 21.44 | 21.42 | 21.38 | 21.35 | 21.27 | 21.23 | 21.41 | 22.19 | 23.67 | 25.19 | 25.27 | 25.34 |
| | **0.92** | 21.46 | 21.45 | 21.42 | 21.40 | 21.36 | 21.36 | 21.61 | 22.48 | 24.10 | 25.77 | 25.92 | 26.02 |
| | **0.96** | 21.47 | 21.47 | 21.46 | 21.46 | 21.46 | 21.48 | 21.80 | 22.78 | 24.54 | 26.36 | 26.57 | 26.69 |
| | **1.00** | 21.49 | 21.49 | 21.50 | 21.52 | 21.55 | 21.60 | 22.00 | 23.07 | 24.97 | 26.94 | 27.22 | 27.36 |
| THERMOCOUPLE SURFACE TEMPERATURE ($^oC$) | **0.00** | 21.16 | 21.05 | 20.89 | 20.50 | 19.83 | 19.33 | 18.11 | 16.97 | 15.11 | 12.98 | 11.35 | 10.81 |
| | **0.11** | 21.21 | 21.09 | 20.94 | 20.50 | 19.76 | 19.24 | 18.12 | 17.11 | 15.63 | 13.88 | 12.60 | 12.19 |
| | **0.22** | 21.38 | 21.35 | 21.29 | 21.08 | 20.55 | 20.14 | 19.18 | 18.33 | 17.04 | 15.41 | 14.15 | 13.75 |
| | **0.33** | 21.41 | 21.42 | 21.41 | 21.35 | 21.12 | 20.92 | 20.38 | 19.90 | 19.15 | 18.01 | 16.95 | 16.59 |
| | **0.44** | 21.46 | 21.46 | 21.46 | 21.45 | 21.36 | 21.27 | 21.05 | 20.87 | 20.54 | 19.78 | 18.93 | 18.68 |
| | **0.56** | 21.43 | 21.44 | 21.44 | 21.44 | 21.45 | 21.47 | 21.65 | 21.83 | 21.99 | 21.70 | 21.07 | 20.86 |
| | **0.67** | 21.42 | 21.43 | 21.44 | 21.45 | 21.49 | 21.57 | 21.98 | 22.55 | 23.33 | 23.69 | 23.36 | 23.28 |
| | **0.78** | 21.42 | 21.43 | 21.44 | 21.46 | 21.54 | 21.72 | 22.66 | 23.72 | 25.14 | 26.15 | 26.18 | 26.18 |
| | **0.89** | 21.44 | 21.45 | 21.47 | 21.50 | 21.65 | 21.92 | 23.30 | 24.75 | 26.71 | 28.23 | 28.44 | 28.60 |
| | **1.00** | 21.47 | 21.48 | 21.49 | 21.49 | 21.54 | 21.65 | 22.24 | 23.25 | 25.16 | 26.90 | 27.14 | 27.23 |
| COILSET SURFACE TEMPERATURE ($^oC$) | **0.00** | 21.09 | 20.93 | 20.54 | 20.08 | 19.19 | 18.54 | 17.08 | 15.71 | 14.15 | 12.34 | 10.97 | 10.56 |
| | **0.04** | 20.45 | 20.32 | 20.22 | 19.86 | 19.10 | 18.66 | 17.55 | 16.73 | 15.52 | 14.09 | 12.73 | 12.37 |
| | **0.08** | 20.59 | 20.48 | 20.38 | 20.08 | 19.34 | 18.93 | 17.80 | 17.00 | 15.74 | 14.32 | 12.86 | 12.50 |
| | **0.12** | 20.66 | 20.59 | 20.56 | 20.29 | 19.65 | 19.27 | 18.30 | 17.54 | 16.43 | 15.13 | 13.74 | 13.39 |
| | **0.16** | 20.60 | 20.56 | 20.55 | 20.34 | 19.75 | 19.37 | 18.39 | 17.63 | 16.47 | 15.08 | 13.63 | 13.30 |
| | **0.20** | 20.62 | 20.60 | 20.60 | 20.46 | 19.93 | 19.60 | 18.70 | 18.06 | 16.99 | 15.71 | 14.26 | 13.91 |
| | **0.24** | 20.66 | 20.62 | 20.68 | 20.57 | 20.15 | 19.88 | 19.15 | 18.63 | 17.79 | 16.65 | 15.35 | 15.03 |
| | **0.28** | 20.70 | 20.67 | 20.72 | 20.67 | 20.32 | 20.13 | 19.50 | 19.08 | 18.32 | 17.29 | 16.06 | 15.81 |
| | **0.32** | 20.67 | 20.64 | 20.70 | 20.67 | 20.41 | 20.24 | 19.76 | 19.40 | 18.80 | 17.85 | 16.63 | 16.37 |
| | **0.36** | 20.64 | 20.64 | 20.69 | 20.69 | 20.49 | 20.37 | 20.00 | 19.78 | 19.33 | 18.57 | 17.35 | 17.14 |
| | **0.40** | 20.66 | 20.64 | 20.72 | 20.73 | 20.56 | 20.50 | 20.26 | 20.17 | 19.86 | 19.18 | 18.04 | 17.81 |
| | **0.44** | 20.66 | 20.66 | 20.72 | 20.73 | 20.62 | 20.62 | 20.50 | 20.53 | 20.38 | 19.89 | 18.82 | 18.63 |
| | **0.48** | 20.69 | 20.67 | 20.73 | 20.76 | 20.67 | 20.72 | 20.75 | 20.90 | 20.91 | 20.53 | 19.47 | 19.32 |
| | **0.52** | 20.65 | 20.64 | 20.70 | 20.73 | 20.67 | 20.77 | 20.91 | 21.20 | 21.39 | 21.20 | 20.30 | 20.16 |
| | **0.56** | 20.69 | 20.68 | 20.73 | 20.78 | 20.74 | 20.86 | 21.12 | 21.53 | 21.89 | 21.83 | 21.00 | 20.89 |
| | **0.60** | 20.70 | 20.69 | 20.76 | 20.80 | 20.77 | 20.93 | 21.32 | 21.85 | 22.40 | 22.50 | 21.76 | 21.74 |
| | **0.64** | 20.72 | 20.71 | 20.78 | 20.81 | 20.81 | 20.99 | 21.50 | 22.17 | 22.89 | 23.20 | 22.46 | 22.47 |
| | **0.68** | 20.70 | 20.68 | 20.75 | 20.80 | 20.80 | 21.01 | 21.61 | 22.40 | 23.33 | 23.78 | 23.18 | 23.22 |
| | **0.72** | 20.70 | 20.69 | 20.76 | 20.81 | 20.81 | 21.05 | 21.77 | 22.72 | 23.80 | 24.42 | 23.93 | 23.96 |
| | **0.76** | 20.71 | 20.70 | 20.77 | 20.82 | 20.85 | 21.10 | 21.90 | 22.97 | 24.22 | 25.05 | 24.68 | 24.73 |
| | **0.80** | 20.68 | 20.66 | 20.76 | 20.80 | 20.86 | 21.14 | 22.03 | 23.22 | 24.67 | 25.67 | 25.42 | 25.47 |
| | **0.84** | 20.68 | 20.67 | 20.75 | 20.80 | 20.87 | 21.18 | 22.19 | 23.49 | 25.12 | 26.31 | 26.18 | 26.28 |
| | **0.88** | 20.66 | 20.67 | 20.74 | 20.80 | 20.89 | 21.23 | 22.30 | 23.70 | 25.52 | 26.89 | 26.79 | 26.91 |
| | **0.92** | 20.68 | 20.67 | 20.74 | 20.80 | 20.91 | 21.26 | 22.38 | 23.89 | 25.85 | 27.38 | 27.39 | 27.57 |
| | **0.96** | 20.65 | 20.65 | 20.73 | 20.79 | 20.89 | 21.24 | 22.39 | 23.86 | 25.83 | 27.42 | 27.55 | 27.70 |
| | **1.00** | 21.49 | 21.49 | 21.50 | 21.52 | 21.55 | 21.60 | 22.00 | 23.07 | 24.97 | 26.94 | 27.22 | 27.36 |

**Table F13: R4-36 mains-side temperature values at 14LPM for selected time instants**

| | Dist | 1 sec | 2 sec | 3 sec | 5 sec | 8 sec | 10 sec | 15 sec | 20 sec | 30 sec | 50 sec | 100 sec | 200 sec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ESTIMATED WATER TEMPERATURE ($^0C$) | **0.00** | 22.26 | 22.28 | 22.26 | 21.12 | 18.57 | 17.04 | 13.74 | 12.28 | 11.01 | 10.16 | 9.80 | 9.69 |
| | **0.07** | 22.26 | 22.28 | 22.26 | 21.20 | 18.82 | 17.40 | 14.29 | 12.88 | 11.62 | 10.75 | 10.40 | 10.30 |
| | **0.13** | 22.27 | 22.28 | 22.26 | 21.28 | 19.07 | 17.75 | 14.84 | 13.48 | 12.23 | 11.34 | 11.00 | 10.91 |
| | **0.20** | 22.27 | 22.28 | 22.26 | 21.35 | 19.32 | 18.11 | 15.39 | 14.08 | 12.83 | 11.93 | 11.61 | 11.52 |
| | **0.27** | 22.28 | 22.29 | 22.27 | 21.43 | 19.57 | 18.46 | 15.94 | 14.67 | 13.44 | 12.52 | 12.21 | 12.13 |
| | **0.33** | 22.28 | 22.29 | 22.27 | 21.51 | 19.82 | 18.82 | 16.49 | 15.27 | 14.05 | 13.11 | 12.81 | 12.74 |
| | **0.40** | 22.28 | 22.29 | 22.27 | 21.59 | 20.07 | 19.18 | 17.04 | 15.87 | 14.66 | 13.70 | 13.41 | 13.35 |
| | **0.47** | 22.29 | 22.29 | 22.27 | 21.67 | 20.32 | 19.53 | 17.59 | 16.47 | 15.27 | 14.29 | 14.01 | 13.96 |
| | **0.53** | 22.29 | 22.29 | 22.27 | 21.74 | 20.57 | 19.89 | 18.15 | 17.07 | 15.87 | 14.87 | 14.62 | 14.56 |
| | **0.60** | 22.30 | 22.29 | 22.27 | 21.82 | 20.82 | 20.24 | 18.70 | 17.67 | 16.48 | 15.46 | 15.22 | 15.17 |
| | **0.67** | 22.30 | 22.29 | 22.27 | 21.90 | 21.07 | 20.60 | 19.25 | 18.27 | 17.09 | 16.05 | 15.82 | 15.78 |
| | **0.73** | 22.30 | 22.29 | 22.27 | 21.98 | 21.32 | 20.96 | 19.80 | 18.87 | 17.70 | 16.64 | 16.42 | 16.39 |
| | **0.80** | 22.31 | 22.30 | 22.28 | 22.06 | 21.57 | 21.31 | 20.35 | 19.46 | 18.31 | 17.23 | 17.02 | 17.00 |
| | **0.87** | 22.31 | 22.30 | 22.28 | 22.13 | 21.82 | 21.67 | 20.90 | 20.06 | 18.91 | 17.82 | 17.63 | 17.61 |
| | **0.93** | 22.32 | 22.30 | 22.28 | 22.21 | 22.07 | 22.02 | 21.45 | 20.66 | 19.52 | 18.41 | 18.23 | 18.22 |
| | **1.00** | 22.32 | 22.30 | 22.28 | 22.29 | 22.32 | 22.38 | 22.00 | 21.26 | 20.13 | 19.00 | 18.83 | 18.83 |
| THERMOCOUPLE SURFACE TEMPERATURE ($^0C$) | **0.00** | 22.14 | 22.13 | 21.92 | 20.37 | 17.94 | 16.55 | 14.04 | 12.65 | 11.27 | 10.34 | 9.81 | 9.68 |
| | **0.11** | 22.21 | 22.20 | 22.10 | 20.62 | 18.03 | 16.60 | 14.24 | 12.95 | 11.72 | 10.91 | 10.53 | 10.42 |
| | **0.22** | 22.22 | 22.21 | 22.14 | 20.75 | 18.36 | 17.15 | 15.33 | 14.35 | 13.24 | 12.52 | 12.26 | 12.21 |
| | **0.33** | 22.19 | 22.20 | 22.21 | 21.67 | 19.47 | 18.24 | 16.34 | 15.35 | 14.12 | 13.38 | 13.14 | 13.11 |
| | **0.44** | 22.21 | 22.19 | 22.22 | 22.11 | 20.41 | 19.25 | 17.35 | 16.30 | 15.00 | 14.29 | 14.06 | 13.98 |
| | **0.56** | 22.15 | 22.14 | 22.16 | 22.20 | 21.30 | 20.57 | 19.12 | 18.35 | 17.11 | 16.50 | 16.34 | 16.29 |
| | **0.67** | 22.12 | 22.12 | 22.14 | 22.19 | 21.90 | 21.47 | 20.41 | 19.79 | 18.69 | 18.14 | 18.00 | 18.02 |
| | **0.78** | 22.11 | 22.13 | 22.14 | 22.20 | 22.28 | 22.18 | 21.46 | 20.96 | 20.04 | 19.45 | 19.36 | 19.41 |
| | **0.89** | 22.14 | 22.14 | 22.17 | 22.22 | 22.40 | 22.49 | 22.14 | 21.79 | 20.96 | 20.36 | 20.30 | 20.34 |
| | **1.00** | 22.12 | 22.10 | 22.12 | 22.15 | 22.27 | 22.25 | 21.55 | 20.90 | 19.83 | 18.93 | 18.76 | 18.75 |
| COILSET SURFACE TEMPERATURE ($^0C$) | **0.00** | 22.26 | 22.28 | 22.26 | 21.12 | 18.57 | 17.04 | 13.74 | 12.28 | 11.01 | 10.16 | 9.80 | 9.69 |
| | **0.07** | 21.48 | 21.51 | 21.50 | 20.61 | 18.11 | 16.79 | 14.80 | 13.66 | 12.47 | 11.84 | 11.46 | 11.45 |
| | **0.13** | 21.46 | 21.50 | 21.52 | 20.98 | 18.40 | 16.98 | 14.87 | 13.69 | 12.41 | 11.75 | 11.41 | 11.39 |
| | **0.20** | 21.43 | 21.46 | 21.48 | 21.27 | 19.02 | 17.66 | 15.63 | 14.51 | 13.25 | 12.64 | 12.35 | 12.39 |
| | **0.27** | 21.43 | 21.43 | 21.46 | 21.41 | 19.43 | 18.05 | 16.00 | 14.86 | 13.53 | 12.90 | 12.59 | 12.65 |
| | **0.33** | 21.43 | 21.42 | 21.44 | 21.47 | 19.90 | 18.58 | 16.65 | 15.56 | 14.27 | 13.65 | 13.34 | 13.38 |
| | **0.40** | 21.42 | 21.42 | 21.42 | 21.49 | 20.40 | 19.26 | 17.47 | 16.46 | 15.19 | 14.59 | 14.30 | 14.33 |
| | **0.47** | 21.39 | 21.39 | 21.40 | 21.47 | 20.76 | 19.76 | 18.12 | 17.14 | 15.87 | 15.28 | 15.04 | 15.06 |
| | **0.53** | 21.38 | 21.38 | 21.39 | 21.47 | 21.11 | 20.29 | 18.82 | 17.92 | 16.66 | 16.07 | 15.87 | 15.86 |
| | **0.60** | 21.37 | 21.38 | 21.40 | 21.47 | 21.37 | 20.72 | 19.45 | 18.61 | 17.40 | 16.81 | 16.61 | 16.63 |
| | **0.67** | 21.31 | 21.32 | 21.35 | 21.40 | 21.48 | 21.07 | 20.05 | 19.32 | 18.20 | 17.63 | 17.43 | 17.49 |
| | **0.73** | 21.30 | 21.32 | 21.35 | 21.41 | 21.61 | 21.44 | 20.70 | 20.09 | 19.04 | 18.48 | 18.29 | 18.33 |
| | **0.80** | 21.31 | 21.32 | 21.36 | 21.42 | 21.69 | 21.74 | 21.20 | 20.59 | 19.54 | 18.93 | 18.79 | 18.83 |
| | **0.87** | 21.34 | 21.35 | 21.40 | 21.46 | 21.80 | 22.05 | 21.78 | 21.27 | 20.27 | 19.63 | 19.50 | 19.55 |
| | **0.93** | 21.43 | 21.44 | 21.46 | 21.54 | 21.77 | 22.13 | 22.01 | 21.52 | 20.54 | 19.86 | 19.73 | 19.76 |
| | **1.00** | 22.32 | 22.30 | 22.28 | 22.29 | 22.32 | 22.38 | 22.00 | 21.26 | 20.13 | 19.00 | 18.83 | 18.83 |

**Table F14: R4-36 mains-side temperature values at 12LPM for selected time instants**

| | Dist | 1 sec | 2 sec | 3 sec | 5 sec | 8 sec | 10 sec | 15 sec | 20 sec | 30 sec | 50 sec | 100 sec | 200 sec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ESTIMATED WATER TEMPERATURE ($^0$C) | **0.00** | 22.36 | 21.61 | 20.98 | 18.92 | 16.60 | 15.69 | 14.00 | 12.57 | 11.48 | 10.66 | 10.26 | 10.13 |
| | **0.07** | 22.37 | 21.67 | 21.09 | 19.17 | 17.01 | 16.17 | 14.57 | 13.20 | 12.12 | 11.29 | 10.90 | 10.77 |
| | **0.13** | 22.39 | 21.74 | 21.19 | 19.41 | 17.42 | 16.64 | 15.15 | 13.83 | 12.77 | 11.92 | 11.54 | 11.41 |
| | **0.20** | 22.40 | 21.80 | 21.30 | 19.66 | 17.83 | 17.12 | 15.72 | 14.46 | 13.41 | 12.55 | 12.18 | 12.05 |
| | **0.27** | 22.42 | 21.87 | 21.41 | 19.90 | 18.25 | 17.60 | 16.30 | 15.10 | 14.05 | 13.19 | 12.81 | 12.69 |
| | **0.33** | 22.43 | 21.93 | 21.52 | 20.15 | 18.66 | 18.07 | 16.87 | 15.73 | 14.69 | 13.82 | 13.45 | 13.33 |
| | **0.40** | 22.44 | 22.00 | 21.62 | 20.40 | 19.07 | 18.55 | 17.44 | 16.36 | 15.34 | 14.45 | 14.09 | 13.97 |
| | **0.47** | 22.46 | 22.06 | 21.73 | 20.64 | 19.48 | 19.03 | 18.02 | 16.99 | 15.98 | 15.08 | 14.73 | 14.61 |
| | **0.53** | 22.47 | 22.13 | 21.84 | 20.89 | 19.89 | 19.50 | 18.59 | 17.62 | 16.62 | 15.71 | 15.37 | 15.25 |
| | **0.60** | 22.49 | 22.19 | 21.95 | 21.13 | 20.30 | 19.98 | 19.17 | 18.25 | 17.26 | 16.34 | 16.01 | 15.89 |
| | **0.67** | 22.50 | 22.26 | 22.05 | 21.38 | 20.71 | 20.46 | 19.74 | 18.88 | 17.91 | 16.97 | 16.65 | 16.53 |
| | **0.73** | 22.51 | 22.32 | 22.16 | 21.63 | 21.12 | 20.93 | 20.31 | 19.51 | 18.55 | 17.60 | 17.29 | 17.17 |
| | **0.80** | 22.53 | 22.39 | 22.27 | 21.87 | 21.54 | 21.41 | 20.89 | 20.15 | 19.19 | 18.24 | 17.92 | 17.81 |
| | **0.87** | 22.54 | 22.45 | 22.38 | 22.12 | 21.95 | 21.89 | 21.46 | 20.78 | 19.83 | 18.87 | 18.56 | 18.45 |
| | **0.93** | 22.56 | 22.52 | 22.48 | 22.36 | 22.36 | 22.36 | 22.04 | 21.41 | 20.48 | 19.50 | 19.20 | 19.09 |
| | **1.00** | 22.57 | 22.58 | 22.59 | 22.61 | 22.77 | 22.84 | 22.61 | 22.04 | 21.12 | 20.13 | 19.84 | 19.73 |
| THERMOCOUPLE SURFACE TEMPERATURE ($^0$C) | **0.00** | 21.83 | 21.28 | 20.64 | 19.30 | 17.45 | 16.37 | 14.34 | 13.07 | 11.75 | 10.80 | 10.36 | 10.13 |
| | **0.11** | 22.09 | 21.57 | 20.92 | 19.51 | 17.61 | 16.54 | 14.63 | 13.46 | 12.31 | 11.53 | 11.11 | 10.90 |
| | **0.22** | 22.17 | 21.68 | 21.07 | 19.77 | 18.12 | 17.35 | 15.82 | 14.91 | 14.08 | 13.53 | 13.06 | 12.72 |
| | **0.33** | 22.32 | 22.22 | 21.85 | 20.79 | 19.16 | 18.37 | 16.84 | 15.92 | 15.06 | 14.55 | 14.06 | 13.67 |
| | **0.44** | 22.40 | 22.39 | 22.29 | 21.59 | 20.18 | 19.41 | 17.92 | 16.97 | 16.03 | 15.51 | 15.03 | 14.66 |
| | **0.56** | 22.42 | 22.44 | 22.42 | 22.16 | 21.38 | 20.90 | 19.80 | 19.08 | 18.39 | 17.94 | 17.51 | 16.99 |
| | **0.67** | 22.46 | 22.48 | 22.48 | 22.51 | 22.24 | 21.99 | 21.22 | 20.63 | 19.99 | 19.53 | 19.21 | 18.71 |
| | **0.78** | 22.52 | 22.53 | 22.53 | 22.66 | 22.84 | 22.80 | 22.37 | 21.96 | 21.31 | 20.85 | 20.61 | 20.19 |
| | **0.89** | 22.59 | 22.62 | 22.61 | 22.73 | 23.05 | 23.15 | 23.13 | 22.85 | 22.19 | 21.69 | 21.47 | 21.34 |
| | **1.00** | 22.38 | 22.40 | 22.40 | 22.45 | 22.64 | 22.63 | 22.27 | 21.75 | 20.83 | 20.01 | 19.80 | 19.62 |
| COILSET SURFACE TEMPERATURE ($^0$C) | **0.00** | 22.36 | 21.61 | 20.98 | 18.92 | 16.60 | 15.69 | 14.00 | 12.57 | 11.48 | 10.66 | 10.26 | 10.13 |
| | **0.07** | 21.44 | 20.95 | 20.33 | 18.99 | 17.29 | 16.42 | 15.01 | 14.01 | 13.03 | 12.38 | 12.17 | 12.02 |
| | **0.13** | 21.56 | 21.24 | 20.67 | 19.34 | 17.55 | 16.64 | 15.21 | 14.16 | 13.11 | 12.42 | 12.25 | 12.12 |
| | **0.20** | 21.62 | 21.50 | 21.09 | 19.91 | 18.25 | 17.37 | 16.03 | 15.03 | 13.99 | 13.36 | 13.20 | 13.05 |
| | **0.27** | 21.64 | 21.64 | 21.37 | 20.32 | 18.72 | 17.83 | 16.53 | 15.53 | 14.46 | 13.79 | 13.63 | 13.55 |
| | **0.33** | 21.62 | 21.63 | 21.54 | 20.70 | 19.21 | 18.38 | 17.12 | 16.15 | 15.09 | 14.42 | 14.25 | 14.17 |
| | **0.40** | 21.65 | 21.67 | 21.67 | 21.12 | 19.86 | 19.11 | 17.98 | 17.06 | 16.01 | 15.37 | 15.21 | 15.08 |
| | **0.47** | 21.67 | 21.70 | 21.74 | 21.43 | 20.40 | 19.71 | 18.68 | 17.79 | 16.73 | 16.09 | 15.93 | 15.82 |
| | **0.53** | 21.69 | 21.73 | 21.78 | 21.70 | 20.95 | 20.38 | 19.50 | 18.67 | 17.62 | 16.98 | 16.88 | 16.75 |
| | **0.60** | 21.72 | 21.76 | 21.82 | 21.87 | 21.39 | 20.91 | 20.18 | 19.41 | 18.40 | 17.79 | 17.69 | 17.58 |
| | **0.67** | 21.72 | 21.76 | 21.83 | 21.95 | 21.76 | 21.41 | 20.84 | 20.16 | 19.21 | 18.64 | 18.59 | 18.47 |
| | **0.73** | 21.73 | 21.76 | 21.84 | 21.98 | 22.05 | 21.81 | 21.42 | 20.82 | 19.92 | 19.38 | 19.35 | 19.26 |
| | **0.80** | 21.75 | 21.80 | 21.87 | 22.06 | 22.38 | 22.27 | 22.03 | 21.49 | 20.62 | 20.11 | 20.07 | 19.92 |
| | **0.87** | 21.80 | 21.85 | 21.92 | 22.10 | 22.59 | 22.62 | 22.54 | 22.05 | 21.20 | 20.69 | 20.66 | 20.51 |
| | **0.93** | 21.81 | 21.87 | 21.94 | 22.08 | 22.70 | 22.86 | 22.98 | 22.57 | 21.81 | 21.30 | 21.28 | 21.16 |
| | **1.00** | 22.57 | 22.58 | 22.59 | 22.61 | 22.77 | 22.84 | 22.61 | 22.04 | 21.12 | 20.13 | 19.84 | 19.73 |

**Table F15: R4-36 mains-side temperature values at 10LPM for selected time instants**

| | Dist | 1 sec | 2 sec | 3 sec | 5 sec | 8 sec | 10 sec | 15 sec | 20 sec | 30 sec | 50 sec | 100 sec | 200 sec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ESTIMATED WATER TEMPERATURE ($^0$C) | **0.00** | 22.41 | 22.39 | 22.37 | 21.34 | 19.04 | 18.02 | 15.53 | 13.88 | 12.29 | 11.05 | 10.43 | 10.26 |
| | **0.07** | 22.41 | 22.39 | 22.37 | 21.41 | 19.27 | 18.32 | 16.01 | 14.47 | 12.97 | 11.73 | 11.12 | 10.96 |
| | **0.13** | 22.41 | 22.39 | 22.38 | 21.49 | 19.51 | 18.63 | 16.50 | 15.07 | 13.64 | 12.42 | 11.81 | 11.66 |
| | **0.20** | 22.41 | 22.39 | 22.38 | 21.56 | 19.74 | 18.93 | 16.98 | 15.66 | 14.32 | 13.10 | 12.50 | 12.36 |
| | **0.27** | 22.41 | 22.40 | 22.38 | 21.64 | 19.97 | 19.24 | 17.46 | 16.26 | 14.99 | 13.79 | 13.19 | 13.05 |
| | **0.33** | 22.41 | 22.40 | 22.38 | 21.71 | 20.20 | 19.54 | 17.94 | 16.85 | 15.67 | 14.47 | 13.88 | 13.75 |
| | **0.40** | 22.41 | 22.40 | 22.39 | 21.78 | 20.44 | 19.85 | 18.43 | 17.45 | 16.35 | 15.16 | 14.57 | 14.45 |
| | **0.47** | 22.41 | 22.40 | 22.39 | 21.86 | 20.67 | 20.15 | 18.91 | 18.04 | 17.02 | 15.84 | 15.26 | 15.15 |
| | **0.53** | 22.41 | 22.40 | 22.39 | 21.93 | 20.90 | 20.46 | 19.39 | 18.64 | 17.70 | 16.53 | 15.96 | 15.85 |
| | **0.60** | 22.41 | 22.40 | 22.39 | 22.01 | 21.13 | 20.76 | 19.87 | 19.23 | 18.37 | 17.21 | 16.65 | 16.55 |
| | **0.67** | 22.41 | 22.40 | 22.40 | 22.08 | 21.37 | 21.07 | 20.36 | 19.83 | 19.05 | 17.90 | 17.34 | 17.25 |
| | **0.73** | 22.41 | 22.40 | 22.40 | 22.15 | 21.60 | 21.37 | 20.84 | 20.42 | 19.73 | 18.58 | 18.03 | 17.95 |
| | **0.80** | 22.41 | 22.41 | 22.40 | 22.23 | 21.83 | 21.68 | 21.32 | 21.02 | 20.40 | 19.27 | 18.72 | 18.64 |
| | **0.87** | 22.41 | 22.41 | 22.40 | 22.30 | 22.06 | 21.98 | 21.80 | 21.61 | 21.08 | 19.95 | 19.41 | 19.34 |
| | **0.93** | 22.41 | 22.41 | 22.41 | 22.38 | 22.30 | 22.29 | 22.29 | 22.21 | 21.75 | 20.64 | 20.10 | 20.04 |
| | **1.00** | 22.41 | 22.41 | 22.41 | 22.45 | 22.53 | 22.59 | 22.77 | 22.80 | 22.43 | 21.32 | 20.79 | 20.74 |
| THERMOCOUPLE SURFACE TEMPERATURE ($^0$C) | **0.00** | 22.19 | 22.21 | 21.95 | 21.13 | 19.50 | 18.48 | 16.16 | 14.49 | 12.63 | 11.23 | 10.49 | 10.31 |
| | **0.11** | 22.31 | 22.29 | 22.17 | 21.44 | 19.72 | 18.58 | 16.35 | 14.85 | 13.16 | 11.96 | 11.34 | 11.20 |
| | **0.22** | 22.31 | 22.30 | 22.23 | 21.57 | 20.02 | 19.00 | 17.40 | 16.37 | 15.08 | 14.00 | 13.53 | 13.45 |
| | **0.33** | 22.31 | 22.32 | 22.30 | 22.11 | 20.98 | 20.02 | 18.39 | 17.43 | 16.14 | 15.09 | 14.62 | 14.52 |
| | **0.44** | 22.34 | 22.35 | 22.36 | 22.34 | 21.71 | 20.94 | 19.46 | 18.56 | 17.27 | 16.26 | 15.71 | 15.63 |
| | **0.56** | 22.28 | 22.32 | 22.33 | 22.37 | 22.14 | 21.74 | 21.03 | 20.53 | 19.57 | 18.72 | 18.28 | 18.30 |
| | **0.67** | 22.26 | 22.29 | 22.32 | 22.37 | 22.38 | 22.32 | 22.18 | 21.99 | 21.20 | 20.43 | 20.02 | 20.08 |
| | **0.78** | 22.26 | 22.29 | 22.32 | 22.38 | 22.50 | 22.64 | 23.03 | 23.11 | 22.53 | 21.82 | 21.47 | 21.51 |
| | **0.89** | 22.28 | 22.31 | 22.34 | 22.41 | 22.54 | 22.70 | 23.28 | 23.67 | 23.39 | 22.74 | 22.46 | 22.45 |
| | **1.00** | 22.18 | 22.20 | 22.23 | 22.29 | 22.38 | 22.46 | 22.59 | 22.62 | 22.09 | 21.13 | 20.70 | 20.69 |
| COILSET SURFACE TEMPERATURE ($^0$C) | **0.00** | 22.41 | 22.39 | 22.37 | 21.34 | 19.04 | 18.02 | 15.53 | 13.88 | 12.29 | 11.05 | 10.43 | 10.26 |
| | **0.07** | 21.71 | 21.68 | 21.63 | 21.15 | 19.55 | 18.47 | 16.39 | 15.22 | 13.85 | 12.71 | 11.93 | 11.97 |
| | **0.13** | 21.72 | 21.69 | 21.66 | 21.41 | 19.96 | 18.85 | 16.72 | 15.48 | 14.10 | 12.87 | 12.06 | 12.06 |
| | **0.20** | 21.70 | 21.67 | 21.66 | 21.56 | 20.42 | 19.44 | 17.41 | 16.30 | 14.95 | 13.76 | 13.03 | 13.07 |
| | **0.27** | 21.69 | 21.66 | 21.66 | 21.64 | 20.79 | 19.87 | 17.88 | 16.80 | 15.47 | 14.27 | 13.52 | 13.66 |
| | **0.33** | 21.67 | 21.64 | 21.63 | 21.64 | 21.08 | 20.26 | 18.41 | 17.41 | 16.17 | 14.95 | 14.24 | 14.37 |
| | **0.40** | 21.64 | 21.62 | 21.63 | 21.65 | 21.33 | 20.72 | 19.12 | 18.24 | 17.07 | 15.90 | 15.22 | 15.37 |
| | **0.47** | 21.63 | 21.61 | 21.64 | 21.66 | 21.53 | 21.07 | 19.70 | 18.96 | 17.87 | 16.72 | 16.04 | 16.17 |
| | **0.53** | 21.65 | 21.65 | 21.66 | 21.69 | 21.69 | 21.44 | 20.37 | 19.81 | 18.81 | 17.70 | 17.02 | 17.18 |
| | **0.60** | 21.61 | 21.61 | 21.64 | 21.69 | 21.76 | 21.65 | 20.85 | 20.45 | 19.55 | 18.48 | 17.84 | 17.90 |
| | **0.67** | 21.61 | 21.60 | 21.62 | 21.68 | 21.78 | 21.81 | 21.36 | 21.16 | 20.42 | 19.46 | 18.83 | 18.90 |
| | **0.73** | 21.58 | 21.58 | 21.61 | 21.66 | 21.80 | 21.93 | 21.85 | 21.84 | 21.28 | 20.40 | 19.86 | 19.87 |
| | **0.80** | 21.56 | 21.57 | 21.60 | 21.65 | 21.83 | 22.03 | 22.26 | 22.48 | 22.05 | 21.22 | 20.66 | 20.69 |
| | **0.87** | 21.56 | 21.56 | 21.58 | 21.65 | 21.83 | 22.08 | 22.58 | 22.89 | 22.56 | 21.75 | 21.22 | 21.25 |
| | **0.93** | 21.62 | 21.60 | 21.63 | 21.71 | 21.88 | 22.15 | 22.86 | 23.37 | 23.23 | 22.48 | 21.95 | 22.01 |
| | **1.00** | 22.41 | 22.41 | 22.41 | 22.45 | 22.53 | 22.59 | 22.77 | 22.80 | 22.43 | 21.32 | 20.79 | 20.74 |

Table F16: R4-36 mains-side temperature values at 9LPM for selected time instants

| | Dist | 1 sec | 2 sec | 3 sec | 5 sec | 8 sec | 10 sec | 15 sec | 20 sec | 30 sec | 50 sec | 100 sec | 200 sec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ESTIMATED WATER TEMPERATURE ($^0$C) | **0.00** | 22.33 | 22.12 | 21.30 | 20.52 | 18.67 | 17.74 | 15.20 | 13.94 | 12.18 | 11.03 | 10.35 | 10.16 |
| | **0.07** | 22.35 | 22.15 | 21.39 | 20.66 | 18.93 | 18.07 | 15.70 | 14.51 | 12.80 | 11.74 | 11.08 | 10.90 |
| | **0.13** | 22.36 | 22.18 | 21.47 | 20.80 | 19.20 | 18.39 | 16.21 | 15.09 | 13.42 | 12.45 | 11.81 | 11.64 |
| | **0.20** | 22.38 | 22.21 | 21.56 | 20.94 | 19.46 | 18.72 | 16.71 | 15.66 | 14.04 | 13.16 | 12.54 | 12.38 |
| | **0.27** | 22.40 | 22.25 | 21.65 | 21.08 | 19.72 | 19.05 | 17.22 | 16.24 | 14.66 | 13.87 | 13.26 | 13.13 |
| | **0.33** | 22.41 | 22.28 | 21.74 | 21.22 | 19.99 | 19.37 | 17.72 | 16.81 | 15.28 | 14.58 | 13.99 | 13.87 |
| | **0.40** | 22.43 | 22.31 | 21.82 | 21.36 | 20.25 | 19.70 | 18.23 | 17.39 | 15.90 | 15.29 | 14.72 | 14.61 |
| | **0.47** | 22.45 | 22.34 | 21.91 | 21.50 | 20.51 | 20.03 | 18.73 | 17.96 | 16.52 | 16.00 | 15.45 | 15.35 |
| | **0.53** | 22.46 | 22.37 | 22.00 | 21.64 | 20.78 | 20.35 | 19.24 | 18.54 | 17.14 | 16.72 | 16.18 | 16.09 |
| | **0.60** | 22.48 | 22.40 | 22.09 | 21.78 | 21.04 | 20.68 | 19.74 | 19.11 | 17.76 | 17.43 | 16.91 | 16.83 |
| | **0.67** | 22.50 | 22.43 | 22.17 | 21.92 | 21.30 | 21.01 | 20.25 | 19.69 | 18.38 | 18.14 | 17.64 | 17.57 |
| | **0.73** | 22.51 | 22.46 | 22.26 | 22.06 | 21.57 | 21.33 | 20.75 | 20.26 | 19.00 | 18.85 | 18.37 | 18.31 |
| | **0.80** | 22.53 | 22.50 | 22.35 | 22.20 | 21.83 | 21.66 | 21.26 | 20.84 | 19.62 | 19.56 | 19.09 | 19.06 |
| | **0.87** | 22.55 | 22.53 | 22.44 | 22.34 | 22.09 | 21.99 | 21.76 | 21.41 | 20.24 | 20.27 | 19.82 | 19.80 |
| | **0.93** | 22.56 | 22.56 | 22.52 | 22.48 | 22.36 | 22.31 | 22.27 | 21.99 | 20.86 | 20.98 | 20.55 | 20.54 |
| | **1.00** | 22.58 | 22.59 | 22.61 | 22.62 | 22.62 | 22.64 | 22.77 | 22.56 | 21.48 | 21.69 | 21.28 | 21.28 |
| THERMOCOUPLE SURFACE TEMPERATURE ($^0$C) | **0.00** | 22.08 | 21.90 | 21.55 | 20.67 | 19.11 | 18.17 | 16.03 | 14.57 | 12.66 | 11.30 | 10.43 | 10.20 |
| | **0.11** | 22.25 | 22.11 | 21.81 | 20.90 | 19.27 | 18.25 | 16.10 | 14.53 | 12.80 | 12.01 | 11.31 | 11.13 |
| | **0.22** | 22.30 | 22.19 | 21.92 | 21.08 | 19.53 | 18.53 | 16.41 | 14.91 | 13.47 | 14.03 | 13.51 | 13.38 |
| | **0.33** | 22.29 | 22.30 | 22.25 | 21.84 | 20.56 | 19.61 | 17.50 | 15.91 | 14.32 | 15.20 | 14.67 | 14.55 |
| | **0.44** | 22.34 | 22.35 | 22.35 | 22.23 | 21.38 | 20.56 | 18.52 | 16.97 | 15.45 | 16.47 | 15.91 | 15.78 |
| | **0.56** | 22.37 | 22.37 | 22.37 | 22.36 | 21.93 | 21.35 | 19.73 | 18.43 | 17.73 | 18.99 | 18.57 | 18.49 |
| | **0.67** | 22.42 | 22.43 | 22.41 | 22.41 | 22.31 | 22.02 | 20.97 | 19.95 | 19.50 | 20.74 | 20.39 | 20.36 |
| | **0.78** | 22.50 | 22.50 | 22.49 | 22.50 | 22.54 | 22.53 | 22.12 | 21.54 | 21.29 | 22.22 | 21.95 | 21.97 |
| | **0.89** | 22.58 | 22.58 | 22.59 | 22.59 | 22.65 | 22.74 | 22.87 | 22.74 | 22.43 | 23.26 | 23.03 | 23.10 |
| | **1.00** | 22.38 | 22.42 | 22.41 | 22.43 | 22.46 | 22.53 | 22.55 | 22.21 | 21.21 | 21.58 | 21.19 | 21.19 |
| COILSET SURFACE TEMPERATURE ($^0$C) | **0.00** | 22.33 | 22.12 | 21.30 | 20.52 | 18.67 | 17.74 | 15.20 | 13.94 | 12.18 | 11.03 | 10.35 | 10.16 |
| | **0.07** | 21.75 | 21.57 | 21.20 | 20.30 | 18.74 | 17.98 | 16.26 | 15.08 | 13.86 | 12.85 | 12.30 | 12.19 |
| | **0.13** | 21.78 | 21.73 | 21.47 | 20.65 | 19.08 | 18.25 | 16.43 | 15.20 | 13.88 | 12.93 | 12.37 | 12.27 |
| | **0.20** | 21.81 | 21.80 | 21.67 | 21.06 | 19.61 | 18.85 | 17.13 | 15.91 | 14.62 | 13.87 | 13.39 | 13.21 |
| | **0.27** | 21.77 | 21.78 | 21.74 | 21.31 | 20.02 | 19.29 | 17.56 | 16.35 | 15.03 | 14.46 | 14.01 | 13.83 |
| | **0.33** | 21.77 | 21.78 | 21.76 | 21.52 | 20.40 | 19.74 | 18.07 | 16.92 | 15.58 | 15.17 | 14.74 | 14.57 |
| | **0.40** | 21.80 | 21.82 | 21.81 | 21.72 | 20.85 | 20.27 | 18.79 | 17.68 | 16.40 | 16.15 | 15.75 | 15.60 |
| | **0.47** | 21.84 | 21.83 | 21.85 | 21.84 | 21.21 | 20.75 | 19.43 | 18.39 | 17.11 | 17.00 | 16.60 | 16.43 |
| | **0.53** | 21.84 | 21.84 | 21.85 | 21.87 | 21.50 | 21.20 | 20.10 | 19.18 | 17.96 | 17.99 | 17.59 | 17.50 |
| | **0.60** | 21.88 | 21.88 | 21.87 | 21.88 | 21.73 | 21.56 | 20.71 | 19.89 | 18.75 | 18.90 | 18.46 | 18.45 |
| | **0.67** | 21.90 | 21.90 | 21.88 | 21.90 | 21.90 | 21.85 | 21.23 | 20.53 | 19.49 | 19.74 | 19.31 | 19.35 |
| | **0.73** | 21.89 | 21.90 | 21.88 | 21.90 | 21.99 | 22.11 | 21.79 | 21.24 | 20.40 | 20.73 | 20.39 | 20.45 |
| | **0.80** | 21.96 | 21.98 | 21.96 | 21.98 | 22.14 | 22.36 | 22.30 | 21.89 | 21.12 | 21.48 | 21.16 | 21.23 |
| | **0.87** | 21.95 | 21.97 | 21.96 | 21.98 | 22.18 | 22.51 | 22.73 | 22.47 | 21.77 | 22.21 | 21.88 | 21.98 |
| | **0.93** | 21.97 | 22.00 | 22.00 | 22.03 | 22.20 | 22.60 | 23.10 | 23.01 | 22.44 | 22.91 | 22.65 | 22.76 |
| | **1.00** | 22.58 | 22.59 | 22.61 | 22.62 | 22.62 | 22.64 | 22.77 | 22.56 | 21.48 | 21.69 | 21.28 | 21.28 |

Table F17: R4-36 mains-side temperature values at 7LPM for selected time instants

| | Dist | 1 sec | 2 sec | 3 sec | 5 sec | 8 sec | 10 sec | 15 sec | 20 sec | 30 sec | 50 sec | 100 sec | 200 sec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ESTIMATED WATER TEMPERATURE ($^0$C) | **0.00** | 22.35 | 22.35 | 22.34 | 21.63 | 20.17 | 19.60 | 17.35 | 15.74 | 13.80 | 11.99 | 10.88 | 10.55 |
| | **0.07** | 22.35 | 22.35 | 22.34 | 21.68 | 20.32 | 19.79 | 17.71 | 16.23 | 14.41 | 12.60 | 11.57 | 11.34 |
| | **0.13** | 22.35 | 22.35 | 22.34 | 21.73 | 20.48 | 19.99 | 18.08 | 16.73 | 15.01 | 13.21 | 12.26 | 12.12 |
| | **0.20** | 22.35 | 22.35 | 22.35 | 21.79 | 20.63 | 20.18 | 18.44 | 17.22 | 15.62 | 13.82 | 12.95 | 12.91 |
| | **0.27** | 22.35 | 22.36 | 22.35 | 21.84 | 20.78 | 20.37 | 18.80 | 17.71 | 16.22 | 14.43 | 13.64 | 13.69 |
| | **0.33** | 22.35 | 22.36 | 22.35 | 21.89 | 20.94 | 20.57 | 19.16 | 18.21 | 16.83 | 15.04 | 14.33 | 14.48 |
| | **0.40** | 22.35 | 22.36 | 22.35 | 21.94 | 21.09 | 20.76 | 19.53 | 18.70 | 17.44 | 15.65 | 15.02 | 15.27 |
| | **0.47** | 22.35 | 22.36 | 22.35 | 21.99 | 21.24 | 20.95 | 19.89 | 19.19 | 18.04 | 16.26 | 15.71 | 16.05 |
| | **0.53** | 22.36 | 22.36 | 22.36 | 22.05 | 21.40 | 21.15 | 20.25 | 19.69 | 18.65 | 16.86 | 16.40 | 16.84 |
| | **0.60** | 22.36 | 22.36 | 22.36 | 22.10 | 21.55 | 21.34 | 20.61 | 20.18 | 19.25 | 17.47 | 17.09 | 17.62 |
| | **0.67** | 22.36 | 22.36 | 22.36 | 22.15 | 21.70 | 21.53 | 20.98 | 20.67 | 19.86 | 18.08 | 17.78 | 18.41 |
| | **0.73** | 22.36 | 22.36 | 22.36 | 22.20 | 21.86 | 21.73 | 21.34 | 21.17 | 20.47 | 18.69 | 18.47 | 19.20 |
| | **0.80** | 22.36 | 22.37 | 22.36 | 22.25 | 22.01 | 21.92 | 21.70 | 21.66 | 21.07 | 19.30 | 19.16 | 19.98 |
| | **0.87** | 22.36 | 22.37 | 22.37 | 22.31 | 22.16 | 22.11 | 22.06 | 22.15 | 21.68 | 19.91 | 19.85 | 20.77 |
| | **0.93** | 22.36 | 22.37 | 22.37 | 22.36 | 22.32 | 22.31 | 22.43 | 22.65 | 22.28 | 20.52 | 20.54 | 21.55 |
| | **1.00** | 22.36 | 22.37 | 22.37 | 22.41 | 22.47 | 22.50 | 22.79 | 23.14 | 22.89 | 21.13 | 21.23 | 22.34 |
| THERMOCOUPLE SURFACE TEMPERATURE ($^0$C) | **0.00** | 22.27 | 22.24 | 22.16 | 21.80 | 20.92 | 20.23 | 18.46 | 16.87 | 14.53 | 12.35 | 10.98 | 10.61 |
| | **0.11** | 22.36 | 22.34 | 22.29 | 22.01 | 21.13 | 20.38 | 18.45 | 16.78 | 14.45 | 12.39 | 11.49 | 11.23 |
| | **0.22** | 22.38 | 22.37 | 22.35 | 22.12 | 21.31 | 20.61 | 18.75 | 17.11 | 14.76 | 12.67 | 12.91 | 12.72 |
| | **0.33** | 22.37 | 22.38 | 22.37 | 22.34 | 21.96 | 21.47 | 19.80 | 18.16 | 15.71 | 13.41 | 13.94 | 13.92 |
| | **0.44** | 22.36 | 22.38 | 22.40 | 22.39 | 22.30 | 22.03 | 20.74 | 19.21 | 16.78 | 14.35 | 15.21 | 15.32 |
| | **0.56** | 22.31 | 22.34 | 22.36 | 22.39 | 22.39 | 22.32 | 21.56 | 20.35 | 18.23 | 15.81 | 17.64 | 17.87 |
| | **0.67** | 22.29 | 22.30 | 22.32 | 22.36 | 22.40 | 22.43 | 22.21 | 21.48 | 19.80 | 17.57 | 19.67 | 20.06 |
| | **0.78** | 22.29 | 22.31 | 22.32 | 22.38 | 22.44 | 22.51 | 22.71 | 22.58 | 21.60 | 19.78 | 21.74 | 22.22 |
| | **0.89** | 22.33 | 22.34 | 22.35 | 22.40 | 22.47 | 22.55 | 22.95 | 23.30 | 23.16 | 21.71 | 23.30 | 24.00 |
| | **1.00** | 22.14 | 22.15 | 22.17 | 22.20 | 22.26 | 22.33 | 22.65 | 22.94 | 22.58 | 20.89 | 21.28 | 22.23 |
| COILSET SURFACE TEMPERATURE ($^0$C) | **0.00** | 22.35 | 22.35 | 22.34 | 21.63 | 20.17 | 19.60 | 17.35 | 15.74 | 13.80 | 11.99 | 10.88 | 10.55 |
| | **0.07** | 21.57 | 21.57 | 21.41 | 21.11 | 20.22 | 19.54 | 17.96 | 16.84 | 15.12 | 13.78 | 12.84 | 12.75 |
| | **0.13** | 21.58 | 21.58 | 21.48 | 21.32 | 20.57 | 19.89 | 18.24 | 17.07 | 15.21 | 13.71 | 12.96 | 12.85 |
| | **0.20** | 21.60 | 21.59 | 21.50 | 21.47 | 20.91 | 20.35 | 18.82 | 17.68 | 15.85 | 14.39 | 13.89 | 13.85 |
| | **0.27** | 21.56 | 21.56 | 21.48 | 21.52 | 21.17 | 20.72 | 19.32 | 18.18 | 16.35 | 14.94 | 14.61 | 14.60 |
| | **0.33** | 21.55 | 21.56 | 21.48 | 21.55 | 21.36 | 21.02 | 19.77 | 18.66 | 16.85 | 15.43 | 15.27 | 15.35 |
| | **0.40** | 21.54 | 21.56 | 21.49 | 21.57 | 21.50 | 21.32 | 20.35 | 19.38 | 17.69 | 16.31 | 16.33 | 16.42 |
| | **0.47** | 21.51 | 21.54 | 21.48 | 21.55 | 21.58 | 21.53 | 20.82 | 19.99 | 18.41 | 17.03 | 17.19 | 17.33 |
| | **0.53** | 21.48 | 21.53 | 21.45 | 21.54 | 21.62 | 21.69 | 21.28 | 20.65 | 19.19 | 17.88 | 18.20 | 18.46 |
| | **0.60** | 21.46 | 21.50 | 21.44 | 21.54 | 21.65 | 21.80 | 21.65 | 21.19 | 19.87 | 18.51 | 18.89 | 19.18 |
| | **0.67** | 21.42 | 21.45 | 21.39 | 21.51 | 21.63 | 21.80 | 21.94 | 21.72 | 20.63 | 19.38 | 19.86 | 20.29 |
| | **0.73** | 21.42 | 21.45 | 21.37 | 21.47 | 21.62 | 21.85 | 22.23 | 22.25 | 21.45 | 20.28 | 20.85 | 21.32 |
| | **0.80** | 21.43 | 21.46 | 21.39 | 21.50 | 21.67 | 21.93 | 22.51 | 22.75 | 22.14 | 20.96 | 21.60 | 22.16 |
| | **0.87** | 21.42 | 21.46 | 21.40 | 21.50 | 21.69 | 21.94 | 22.70 | 23.19 | 22.82 | 21.65 | 22.33 | 22.94 |
| | **0.93** | 21.45 | 21.48 | 21.43 | 21.53 | 21.71 | 21.96 | 22.79 | 23.52 | 23.47 | 22.33 | 23.02 | 23.75 |
| | **1.00** | 22.36 | 22.37 | 22.37 | 22.41 | 22.47 | 22.50 | 22.79 | 23.14 | 22.89 | 21.13 | 21.23 | 22.34 |

Table F18: R4-36 mains-side temperature values at 5.5LPM for selected time instants

| | Dist | 1 sec | 2 sec | 3 sec | 5 sec | 8 sec | 10 sec | 15 sec | 20 sec | 30 sec | 50 sec | 100 sec | 200 sec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ESTIMATED WATER TEMPERATURE ($^0$C) | **0.00** | 22.05 | 21.83 | 21.60 | 21.07 | 20.18 | 19.22 | 17.56 | 16.35 | 14.17 | 12.08 | 10.71 | 10.21 |
| | **0.07** | 22.08 | 21.87 | 21.66 | 21.16 | 20.34 | 19.44 | 17.91 | 16.81 | 14.78 | 12.71 | 11.34 | 10.87 |
| | **0.13** | 22.10 | 21.91 | 21.72 | 21.26 | 20.49 | 19.67 | 18.26 | 17.26 | 15.40 | 13.34 | 11.96 | 11.54 |
| | **0.20** | 22.13 | 21.96 | 21.77 | 21.35 | 20.65 | 19.89 | 18.62 | 17.72 | 16.01 | 13.97 | 12.59 | 12.20 |
| | **0.27** | 22.16 | 22.00 | 21.83 | 21.45 | 20.80 | 20.12 | 18.97 | 18.17 | 16.62 | 14.59 | 13.22 | 12.87 |
| | **0.33** | 22.19 | 22.04 | 21.89 | 21.54 | 20.96 | 20.34 | 19.32 | 18.63 | 17.23 | 15.22 | 13.84 | 13.53 |
| | **0.40** | 22.21 | 22.08 | 21.95 | 21.64 | 21.12 | 20.56 | 19.67 | 19.09 | 17.85 | 15.85 | 14.47 | 14.20 |
| | **0.47** | 22.24 | 22.12 | 22.01 | 21.73 | 21.27 | 20.79 | 20.02 | 19.54 | 18.46 | 16.48 | 15.10 | 14.86 |
| | **0.53** | 22.27 | 22.17 | 22.06 | 21.83 | 21.43 | 21.01 | 20.38 | 20.00 | 19.07 | 17.11 | 15.72 | 15.53 |
| | **0.60** | 22.30 | 22.21 | 22.12 | 21.92 | 21.58 | 21.24 | 20.73 | 20.45 | 19.68 | 17.74 | 16.35 | 16.19 |
| | **0.67** | 22.32 | 22.25 | 22.18 | 22.02 | 21.74 | 21.46 | 21.08 | 20.91 | 20.30 | 18.37 | 16.98 | 16.86 |
| | **0.73** | 22.35 | 22.29 | 22.24 | 22.11 | 21.90 | 21.68 | 21.43 | 21.37 | 20.91 | 19.00 | 17.60 | 17.52 |
| | **0.80** | 22.38 | 22.33 | 22.30 | 22.21 | 22.05 | 21.91 | 21.78 | 21.82 | 21.52 | 19.62 | 18.23 | 18.19 |
| | **0.87** | 22.41 | 22.38 | 22.35 | 22.30 | 22.21 | 22.13 | 22.14 | 22.28 | 22.13 | 20.25 | 18.86 | 18.85 |
| | **0.93** | 22.43 | 22.42 | 22.41 | 22.40 | 22.36 | 22.36 | 22.49 | 22.73 | 22.75 | 20.88 | 19.48 | 19.52 |
| | **1.00** | 22.46 | 22.46 | 22.47 | 22.49 | 22.52 | 22.58 | 22.84 | 23.19 | 23.36 | 21.51 | 20.11 | 20.18 |
| THERMOCOUPLE SURFACE TEMPERATURE ($^0$C) | **0.00** | 22.24 | 22.09 | 21.94 | 21.51 | 20.74 | 20.18 | 18.74 | 17.42 | 15.23 | 12.75 | 11.03 | 10.45 |
| | **0.11** | 22.33 | 22.25 | 22.12 | 21.72 | 20.91 | 20.33 | 18.74 | 17.36 | 15.17 | 12.78 | 11.17 | 10.64 |
| | **0.22** | 22.38 | 22.30 | 22.20 | 21.87 | 21.14 | 20.58 | 19.08 | 17.70 | 15.44 | 13.08 | 11.47 | 10.98 |
| | **0.33** | 22.42 | 22.40 | 22.39 | 22.27 | 21.86 | 21.45 | 20.13 | 18.77 | 16.46 | 13.83 | 12.19 | 11.71 |
| | **0.44** | 22.42 | 22.42 | 22.43 | 22.41 | 22.26 | 22.05 | 21.08 | 19.88 | 17.59 | 14.81 | 13.06 | 12.62 |
| | **0.56** | 22.35 | 22.35 | 22.37 | 22.38 | 22.36 | 22.30 | 21.77 | 20.90 | 18.87 | 16.15 | 14.42 | 14.10 |
| | **0.67** | 22.32 | 22.33 | 22.35 | 22.36 | 22.40 | 22.42 | 22.30 | 21.85 | 20.29 | 17.76 | 16.05 | 15.94 |
| | **0.78** | 22.29 | 22.31 | 22.33 | 22.35 | 22.41 | 22.48 | 22.65 | 22.63 | 21.66 | 19.61 | 18.32 | 18.65 |
| | **0.89** | 22.30 | 22.31 | 22.32 | 22.34 | 22.41 | 22.49 | 22.80 | 23.11 | 22.93 | 21.40 | 20.84 | 21.65 |
| | **1.00** | 22.40 | 22.41 | 22.42 | 22.43 | 22.49 | 22.57 | 22.87 | 23.26 | 23.24 | 21.48 | 20.19 | 20.26 |
| COILSET SURFACE TEMPERATURE ($^0$C) | **0.00** | 22.05 | 21.83 | 21.60 | 21.07 | 20.18 | 19.22 | 17.56 | 16.35 | 14.17 | 12.08 | 10.71 | 10.21 |
| | **0.07** | 21.52 | 21.48 | 21.33 | 20.88 | 20.09 | 19.46 | 18.28 | 17.22 | 15.62 | 13.71 | 12.95 | 12.60 |
| | **0.13** | 21.59 | 21.58 | 21.49 | 21.14 | 20.43 | 19.83 | 18.65 | 17.52 | 15.82 | 13.72 | 12.89 | 12.49 |
| | **0.20** | 21.61 | 21.63 | 21.60 | 21.36 | 20.84 | 20.31 | 19.29 | 18.25 | 16.58 | 14.45 | 13.64 | 13.27 |
| | **0.27** | 21.63 | 21.67 | 21.66 | 21.54 | 21.18 | 20.74 | 19.90 | 18.95 | 17.31 | 15.04 | 14.21 | 13.80 |
| | **0.33** | 21.63 | 21.66 | 21.66 | 21.60 | 21.39 | 21.05 | 20.38 | 19.53 | 17.92 | 15.61 | 14.75 | 14.38 |
| | **0.40** | 21.63 | 21.69 | 21.69 | 21.67 | 21.59 | 21.38 | 21.00 | 20.32 | 18.86 | 16.58 | 15.74 | 15.43 |
| | **0.47** | 21.63 | 21.68 | 21.69 | 21.69 | 21.73 | 21.62 | 21.52 | 21.03 | 19.71 | 17.41 | 16.56 | 16.32 |
| | **0.53** | 21.62 | 21.68 | 21.70 | 21.70 | 21.81 | 21.81 | 21.96 | 21.62 | 20.47 | 18.20 | 17.34 | 17.22 |
| | **0.60** | 21.63 | 21.70 | 21.70 | 21.72 | 21.86 | 21.89 | 22.30 | 22.18 | 21.21 | 18.99 | 18.10 | 18.06 |
| | **0.67** | 21.57 | 21.62 | 21.65 | 21.68 | 21.85 | 21.92 | 22.50 | 22.55 | 21.81 | 19.75 | 18.92 | 18.90 |
| | **0.73** | 21.55 | 21.61 | 21.62 | 21.65 | 21.83 | 21.95 | 22.71 | 23.00 | 22.53 | 20.72 | 19.90 | 20.06 |
| | **0.80** | 21.53 | 21.59 | 21.63 | 21.66 | 21.88 | 22.01 | 22.93 | 23.42 | 23.17 | 21.38 | 20.63 | 20.82 |
| | **0.87** | 21.60 | 21.65 | 21.68 | 21.71 | 21.93 | 22.10 | 23.12 | 23.80 | 23.82 | 22.10 | 21.35 | 21.59 |
| | **0.93** | 21.61 | 21.66 | 21.69 | 21.71 | 21.93 | 22.10 | 23.18 | 24.03 | 24.37 | 22.84 | 22.22 | 22.49 |
| | **1.00** | 22.46 | 22.46 | 22.47 | 22.49 | 22.52 | 22.58 | 22.84 | 23.19 | 23.36 | 21.51 | 20.11 | 20.18 |

# Appendix G: MATLAB Script for Centre-Line Temperature Estimation

```
% load file for 1st frame
M = csvread ('Rec-000018_1371.csv');
for n = 25:40     % Set 1
    value1 = M(70,n);
    counter1 = counter1 + 1;
    Tcoilset1 = Tcoilset1 + value1;
end
 for n = 45:60    % Set 2
    value1 = M(70,n);
    counter2 = counter2 + 1;
    Tcoilset2 = Tcoilset2 + value1;
 end
for n = 65:81     % Set 3
    value1 = M(70,n);
    counter3 = counter3 + 1;
    Tcoilset3 = Tcoilset3 + value1;
end

% Do this till coil set 14 or 24 depending on pipe

% load file for 2nd frame
M = csvread ('Rec-000018_1372.csv');
% Run All For Loops as Above

% load file for 3rd frame
M = csvread ('Rec-000018_1373.csv');
% Run All For Loops as Above

% load file for 4th frame
M = csvread ('Rec-000018_1374.csv');
% Run All For Loops as Above

% load file for 5th frame
M = csvread ('Rec-000018_1375.csv');
% Run All For Loops as Above

% load file for 6th frame
M = csvread ('Rec-000018_1376.csv');
% Run All For Loops as Above

% load file for 7th frame
M = csvread ('Rec-000018_1377.csv');
% Run All For Loops as Above

% load files for all frames in the specific time instant.
% usually each time instant had 6 or 7 frames.

Tcoilset1 = Tcoilset1/counter1;
Tcoilset2 = Tcoilset2/counter2;
Tcoilset3 = Tcoilset3/counter3;
Tcoilset4 = Tcoilset4/counter4;
Tcoilset5 = Tcoilset5/counter5;
Tcoilset6 = Tcoilset6/counter6;
Tcoilset7 = Tcoilset7/counter7;
Tcoilset8 = Tcoilset8/counter8;
Tcoilset9 = Tcoilset9/counter9;
Tcoilset10 = Tcoilset10/counter10;
Tcoilset11 = Tcoilset11/counter11;
Tcoilset12 = Tcoilset12/counter12;
Tcoilset13 = Tcoilset13/counter13;
Tcoilset14 = Tcoilset14/counter14;
```

# Appendix H: Biot Number and Convection Coefficient Tables at Coil Sets

**Table H1: Heat transfer coefficients and Biot number approximations for R3-36 at 14LPM**

| Coilset | 1 second | | | | 2 seconds | | | | 3 seconds | | | | 5 seconds | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $h_{lam}$ | $Bi_{lam}$ | $h_{turb}$ | $Bi_{turb}$ | $h_{lam}$ | $Bi_{lam}$ | $h_{turb}$ | $Bi_{turb}$ | $h_{lam}$ | $Bi_{lam}$ | $h_{turb}$ | $Bi_{turb}$ | $h_{lam}$ | $Bi_{lam}$ | $h_{turb}$ | $Bi_{turb}$ |
| **1** | 4355 | 0.0162 | 6072 | 0.0226 | 4929 | 0.0183 | 7476 | 0.0278 | 5286 | 0.0197 | 8409 | 0.0313 | 5234 | 0.0195 | 8310 | 0.0309 |
| **2** | 4355 | 0.0162 | 6073 | 0.0226 | 4929 | 0.0184 | 7477 | 0.0278 | 5286 | 0.0197 | 8410 | 0.0313 | 5239 | 0.0195 | 8320 | 0.0310 |
| **3** | 4356 | 0.0162 | 6073 | 0.0226 | 4929 | 0.0184 | 7477 | 0.0278 | 5287 | 0.0197 | 8412 | 0.0313 | 5244 | 0.0195 | 8331 | 0.0310 |
| **4** | 4356 | 0.0162 | 6074 | 0.0226 | 4930 | 0.0184 | 7479 | 0.0278 | 5287 | 0.0197 | 8413 | 0.0313 | 5249 | 0.0195 | 8341 | 0.0311 |
| **5** | 4356 | 0.0162 | 6075 | 0.0226 | 4930 | 0.0184 | 7480 | 0.0278 | 5288 | 0.0197 | 8413 | 0.0313 | 5254 | 0.0196 | 8351 | 0.0311 |
| **6** | 4357 | 0.0162 | 6076 | 0.0226 | 4931 | 0.0184 | 7480 | 0.0279 | 5288 | 0.0197 | 8414 | 0.0313 | 5259 | 0.0196 | 8362 | 0.0311 |
| **7** | 4358 | 0.0162 | 6076 | 0.0226 | 4931 | 0.0184 | 7481 | 0.0279 | 5289 | 0.0197 | 8415 | 0.0313 | 5265 | 0.0196 | 8372 | 0.0312 |
| **8** | 4358 | 0.0162 | 6077 | 0.0226 | 4932 | 0.0184 | 7482 | 0.0279 | 5289 | 0.0197 | 8417 | 0.0313 | 5269 | 0.0196 | 8381 | 0.0312 |
| **9** | 4358 | 0.0162 | 6078 | 0.0226 | 4932 | 0.0184 | 7483 | 0.0279 | 5290 | 0.0197 | 8418 | 0.0313 | 5274 | 0.0196 | 8391 | 0.0312 |
| **10** | 4359 | 0.0162 | 6079 | 0.0226 | 4932 | 0.0184 | 7483 | 0.0279 | 5290 | 0.0197 | 8418 | 0.0313 | 5278 | 0.0197 | 8400 | 0.0313 |
| **11** | 4359 | 0.0162 | 6079 | 0.0226 | 4933 | 0.0184 | 7484 | 0.0279 | 5291 | 0.0197 | 8419 | 0.0313 | 5283 | 0.0197 | 8409 | 0.0313 |
| **12** | 4360 | 0.0162 | 6080 | 0.0226 | 4934 | 0.0184 | 7486 | 0.0279 | 5291 | 0.0197 | 8420 | 0.0313 | 5287 | 0.0197 | 8418 | 0.0313 |
| **13** | 4360 | 0.0162 | 6081 | 0.0226 | 4934 | 0.0184 | 7486 | 0.0279 | 5292 | 0.0197 | 8422 | 0.0314 | 5292 | 0.0197 | 8428 | 0.0314 |
| **14** | 4361 | 0.0162 | 6082 | 0.0226 | 4934 | 0.0184 | 7487 | 0.0279 | 5292 | 0.0197 | 8423 | 0.0314 | 5296 | 0.0197 | 8437 | 0.0314 |

| Coilset | 8 seconds | | | | 10 seconds | | | | 15 seconds | | | | 20 seconds | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $h_{lam}$ | $Bi_{lam}$ | $h_{turb}$ | $Bi_{turb}$ | $h_{lam}$ | $Bi_{lam}$ | $h_{turb}$ | $Bi_{turb}$ | $h_{lam}$ | $Bi_{lam}$ | $h_{turb}$ | $Bi_{turb}$ | $h_{lam}$ | $Bi_{lam}$ | $h_{turb}$ | $Bi_{turb}$ |
| **1** | 5092 | 0.0190 | 8020 | 0.0299 | 5048 | 0.0188 | 7939 | 0.0296 | 4918 | 0.0183 | 7673 | 0.0286 | 4928 | 0.0183 | 7740 | 0.0288 |
| **2** | 5106 | 0.0190 | 8049 | 0.0300 | 5065 | 0.0189 | 7971 | 0.0297 | 4940 | 0.0184 | 7715 | 0.0287 | 4952 | 0.0184 | 7787 | 0.0290 |
| **3** | 5120 | 0.0191 | 8076 | 0.0301 | 5081 | 0.0189 | 8004 | 0.0298 | 4962 | 0.0185 | 7758 | 0.0289 | 4977 | 0.0185 | 7836 | 0.0292 |
| **4** | 5134 | 0.0191 | 8104 | 0.0302 | 5098 | 0.0190 | 8038 | 0.0299 | 4984 | 0.0186 | 7800 | 0.0290 | 5002 | 0.0186 | 7884 | 0.0294 |
| **5** | 5148 | 0.0192 | 8133 | 0.0303 | 5115 | 0.0190 | 8072 | 0.0301 | 5007 | 0.0186 | 7844 | 0.0292 | 5027 | 0.0187 | 7934 | 0.0295 |
| **6** | 5163 | 0.0192 | 8162 | 0.0304 | 5132 | 0.0191 | 8106 | 0.0302 | 5030 | 0.0187 | 7888 | 0.0294 | 5053 | 0.0188 | 7984 | 0.0297 |
| **7** | 5177 | 0.0193 | 8191 | 0.0305 | 5149 | 0.0192 | 8140 | 0.0303 | 5051 | 0.0188 | 7931 | 0.0295 | 5079 | 0.0189 | 8035 | 0.0299 |
| **8** | 5191 | 0.0193 | 8219 | 0.0306 | 5166 | 0.0192 | 8175 | 0.0304 | 5073 | 0.0189 | 7974 | 0.0297 | 5105 | 0.0190 | 8086 | 0.0301 |
| **9** | 5206 | 0.0194 | 8249 | 0.0307 | 5184 | 0.0193 | 8210 | 0.0306 | 5095 | 0.0190 | 8019 | 0.0299 | 5131 | 0.0191 | 8137 | 0.0303 |
| **10** | 5221 | 0.0194 | 8279 | 0.0308 | 5201 | 0.0194 | 8245 | 0.0307 | 5118 | 0.0191 | 8064 | 0.0300 | 5156 | 0.0192 | 8189 | 0.0305 |
| **11** | 5236 | 0.0195 | 8309 | 0.0309 | 5219 | 0.0194 | 8281 | 0.0308 | 5141 | 0.0191 | 8109 | 0.0302 | 5182 | 0.0193 | 8241 | 0.0307 |
| **12** | 5250 | 0.0195 | 8339 | 0.0310 | 5237 | 0.0195 | 8318 | 0.0310 | 5164 | 0.0192 | 8156 | 0.0304 | 5209 | 0.0194 | 8294 | 0.0309 |
| **13** | 5265 | 0.0196 | 8368 | 0.0312 | 5255 | 0.0196 | 8354 | 0.0311 | 5187 | 0.0193 | 8202 | 0.0305 | 5235 | 0.0195 | 8349 | 0.0311 |
| **14** | 5278 | 0.0197 | 8395 | 0.0313 | 5273 | 0.0196 | 8390 | 0.0312 | 5211 | 0.0194 | 8250 | 0.0307 | 5262 | 0.0196 | 8403 | 0.0313 |

| Coilset | 30 seconds | | | | 50 seconds | | | | 100 seconds | | | | 200 seconds | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $h_{lam}$ | $Bi_{lam}$ | $h_{turb}$ | $Bi_{turb}$ | $h_{lam}$ | $Bi_{lam}$ | $h_{turb}$ | $Bi_{turb}$ | $h_{lam}$ | $Bi_{lam}$ | $h_{turb}$ | $Bi_{turb}$ | $h_{lam}$ | $Bi_{lam}$ | $h_{turb}$ | $Bi_{turb}$ |
| **1** | 4877 | 0.0182 | 7646 | 0.0285 | 4810 | 0.0179 | 7492 | 0.0279 | 4790 | 0.0178 | 7453 | 0.0277 | 4780 | 0.0178 | 7428 | 0.0277 |
| **2** | 4908 | 0.0183 | 7711 | 0.0287 | 4844 | 0.0180 | 7563 | 0.0282 | 4825 | 0.0180 | 7524 | 0.0280 | 4813 | 0.0179 | 7497 | 0.0279 |
| **3** | 4933 | 0.0184 | 7760 | 0.0289 | 4878 | 0.0182 | 7634 | 0.0284 | 4859 | 0.0181 | 7595 | 0.0283 | 4848 | 0.0180 | 7570 | 0.0282 |
| **4** | 4959 | 0.0185 | 7808 | 0.0291 | 4902 | 0.0183 | 7682 | 0.0286 | 4889 | 0.0182 | 7656 | 0.0285 | 4880 | 0.0182 | 7636 | 0.0284 |
| **5** | 4984 | 0.0186 | 7859 | 0.0293 | 4928 | 0.0183 | 7732 | 0.0288 | 4915 | 0.0183 | 7707 | 0.0287 | 4906 | 0.0183 | 7685 | 0.0286 |
| **6** | 5011 | 0.0187 | 7910 | 0.0294 | 4954 | 0.0184 | 7782 | 0.0290 | 4941 | 0.0184 | 7757 | 0.0289 | 4932 | 0.0184 | 7736 | 0.0288 |
| **7** | 5037 | 0.0188 | 7960 | 0.0296 | 4980 | 0.0185 | 7832 | 0.0292 | 4967 | 0.0185 | 7808 | 0.0291 | 4958 | 0.0185 | 7787 | 0.0290 |
| **8** | 5063 | 0.0189 | 8013 | 0.0298 | 5007 | 0.0186 | 7884 | 0.0294 | 4994 | 0.0186 | 7860 | 0.0293 | 4985 | 0.0186 | 7838 | 0.0292 |
| **9** | 5090 | 0.0190 | 8065 | 0.0300 | 5033 | 0.0187 | 7936 | 0.0295 | 5021 | 0.0187 | 7912 | 0.0295 | 5012 | 0.0187 | 7891 | 0.0294 |
| **10** | 5118 | 0.0191 | 8119 | 0.0302 | 5060 | 0.0188 | 7988 | 0.0297 | 5048 | 0.0188 | 7965 | 0.0297 | 5040 | 0.0188 | 7945 | 0.0296 |
| **11** | 5144 | 0.0192 | 8172 | 0.0304 | 5088 | 0.0189 | 8043 | 0.0299 | 5077 | 0.0189 | 8020 | 0.0299 | 5067 | 0.0189 | 7999 | 0.0298 |
| **12** | 5171 | 0.0192 | 8225 | 0.0306 | 5114 | 0.0190 | 8095 | 0.0301 | 5104 | 0.0190 | 8074 | 0.0301 | 5095 | 0.0190 | 8053 | 0.0300 |
| **13** | 5198 | 0.0194 | 8280 | 0.0308 | 5141 | 0.0191 | 8149 | 0.0303 | 5131 | 0.0191 | 8128 | 0.0303 | 5122 | 0.0191 | 8108 | 0.0302 |
| **14** | 5225 | 0.0195 | 8335 | 0.0310 | 5168 | 0.0192 | 8204 | 0.0305 | 5158 | 0.0192 | 8184 | 0.0305 | 5150 | 0.0192 | 8163 | 0.0304 |

**Table H2: Heat transfer coefficients and Biot number approximations for R3-36 at 12LPM**

| Coilset | 1 second | | | | 2 seconds | | | | 3 seconds | | | | 5 seconds | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $h_{lam}$ | $Bi_{lam}$ | $h_{turb}$ | $Bi_{turb}$ | $h_{lam}$ | $Bi_{lam}$ | $h_{turb}$ | $Bi_{turb}$ | $h_{lam}$ | $Bi_{lam}$ | $h_{turb}$ | $Bi_{turb}$ | $h_{lam}$ | $Bi_{lam}$ | $h_{turb}$ | $Bi_{turb}$ |
| 1 | 4458 | 0.0166 | 6316 | 0.0235 | 4878 | 0.0182 | 7348 | 0.0274 | 4903 | 0.0183 | 7411 | 0.0276 | 4857 | 0.0181 | 7327 | 0.0273 |
| 2 | 4458 | 0.0166 | 6317 | 0.0235 | 4878 | 0.0182 | 7349 | 0.0274 | 4903 | 0.0183 | 7413 | 0.0276 | 4862 | 0.0181 | 7336 | 0.0273 |
| 3 | 4459 | 0.0166 | 6318 | 0.0235 | 4879 | 0.0182 | 7350 | 0.0274 | 4904 | 0.0183 | 7413 | 0.0276 | 4866 | 0.0181 | 7344 | 0.0273 |
| 4 | 4460 | 0.0166 | 6319 | 0.0235 | 4879 | 0.0182 | 7351 | 0.0274 | 4904 | 0.0183 | 7415 | 0.0276 | 4870 | 0.0181 | 7353 | 0.0274 |
| 5 | 4460 | 0.0166 | 6320 | 0.0235 | 4880 | 0.0182 | 7352 | 0.0274 | 4905 | 0.0183 | 7416 | 0.0276 | 4875 | 0.0182 | 7362 | 0.0274 |
| 6 | 4460 | 0.0166 | 6320 | 0.0235 | 4880 | 0.0182 | 7352 | 0.0274 | 4905 | 0.0183 | 7416 | 0.0276 | 4879 | 0.0182 | 7370 | 0.0274 |
| 7 | 4461 | 0.0166 | 6321 | 0.0235 | 4881 | 0.0182 | 7353 | 0.0274 | 4906 | 0.0183 | 7418 | 0.0276 | 4884 | 0.0182 | 7378 | 0.0275 |
| 8 | 4461 | 0.0166 | 6322 | 0.0235 | 4881 | 0.0182 | 7355 | 0.0274 | 4906 | 0.0183 | 7419 | 0.0276 | 4888 | 0.0182 | 7387 | 0.0275 |
| 9 | 4462 | 0.0166 | 6323 | 0.0235 | 4882 | 0.0182 | 7355 | 0.0274 | 4907 | 0.0183 | 7420 | 0.0276 | 4892 | 0.0182 | 7394 | 0.0275 |
| 10 | 4462 | 0.0166 | 6323 | 0.0235 | 4882 | 0.0182 | 7356 | 0.0274 | 4908 | 0.0183 | 7421 | 0.0276 | 4896 | 0.0182 | 7402 | 0.0276 |
| 11 | 4462 | 0.0166 | 6324 | 0.0235 | 4882 | 0.0182 | 7357 | 0.0274 | 4908 | 0.0183 | 7422 | 0.0276 | 4900 | 0.0182 | 7410 | 0.0276 |
| 12 | 4463 | 0.0166 | 6325 | 0.0235 | 4883 | 0.0182 | 7358 | 0.0274 | 4909 | 0.0183 | 7423 | 0.0276 | 4904 | 0.0183 | 7417 | 0.0276 |
| 13 | 4463 | 0.0166 | 6326 | 0.0236 | 4884 | 0.0182 | 7359 | 0.0274 | 4909 | 0.0183 | 7424 | 0.0276 | 4908 | 0.0183 | 7425 | 0.0276 |
| 14 | 4464 | 0.0166 | 6327 | 0.0236 | 4884 | 0.0182 | 7360 | 0.0274 | 4910 | 0.0183 | 7425 | 0.0276 | 4912 | 0.0183 | 7433 | 0.0277 |

| Coilset | 8 seconds | | | | 10 seconds | | | | 15 seconds | | | | 20 seconds | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $h_{lam}$ | $Bi_{lam}$ | $h_{turb}$ | $Bi_{turb}$ | $h_{lam}$ | $Bi_{lam}$ | $h_{turb}$ | $Bi_{turb}$ | $h_{lam}$ | $Bi_{lam}$ | $h_{turb}$ | $Bi_{turb}$ | $h_{lam}$ | $Bi_{lam}$ | $h_{turb}$ | $Bi_{turb}$ |
| 1 | 4814 | 0.0179 | 7252 | 0.0270 | 4745 | 0.0177 | 7121 | 0.0265 | 4641 | 0.0173 | 6936 | 0.0258 | 4598 | 0.0171 | 6861 | 0.0255 |
| 2 | 4822 | 0.0180 | 7268 | 0.0271 | 4757 | 0.0177 | 7146 | 0.0266 | 4661 | 0.0174 | 6973 | 0.0260 | 4620 | 0.0172 | 6902 | 0.0257 |
| 3 | 4831 | 0.0180 | 7284 | 0.0271 | 4771 | 0.0178 | 7171 | 0.0267 | 4681 | 0.0174 | 7009 | 0.0261 | 4643 | 0.0173 | 6944 | 0.0259 |
| 4 | 4839 | 0.0180 | 7300 | 0.0272 | 4784 | 0.0178 | 7196 | 0.0268 | 4701 | 0.0175 | 7047 | 0.0262 | 4666 | 0.0174 | 6987 | 0.0260 |
| 5 | 4848 | 0.0180 | 7316 | 0.0272 | 4797 | 0.0179 | 7221 | 0.0269 | 4721 | 0.0176 | 7084 | 0.0264 | 4690 | 0.0175 | 7030 | 0.0262 |
| 6 | 4856 | 0.0181 | 7331 | 0.0273 | 4810 | 0.0179 | 7246 | 0.0270 | 4740 | 0.0176 | 7121 | 0.0265 | 4713 | 0.0175 | 7073 | 0.0263 |
| 7 | 4864 | 0.0181 | 7348 | 0.0274 | 4823 | 0.0180 | 7272 | 0.0271 | 4760 | 0.0177 | 7159 | 0.0267 | 4736 | 0.0176 | 7117 | 0.0265 |
| 8 | 4873 | 0.0181 | 7364 | 0.0274 | 4837 | 0.0180 | 7298 | 0.0272 | 4780 | 0.0178 | 7197 | 0.0268 | 4759 | 0.0177 | 7160 | 0.0267 |
| 9 | 4881 | 0.0182 | 7381 | 0.0275 | 4851 | 0.0181 | 7324 | 0.0273 | 4800 | 0.0179 | 7235 | 0.0269 | 4782 | 0.0178 | 7205 | 0.0268 |
| 10 | 4889 | 0.0182 | 7397 | 0.0275 | 4864 | 0.0181 | 7350 | 0.0274 | 4821 | 0.0179 | 7275 | 0.0271 | 4806 | 0.0179 | 7250 | 0.0270 |
| 11 | 4898 | 0.0182 | 7413 | 0.0276 | 4878 | 0.0182 | 7377 | 0.0275 | 4841 | 0.0180 | 7314 | 0.0272 | 4829 | 0.0180 | 7295 | 0.0272 |
| 12 | 4906 | 0.0183 | 7428 | 0.0277 | 4892 | 0.0182 | 7403 | 0.0276 | 4862 | 0.0181 | 7355 | 0.0274 | 4853 | 0.0181 | 7342 | 0.0273 |
| 13 | 4913 | 0.0183 | 7443 | 0.0277 | 4905 | 0.0183 | 7430 | 0.0277 | 4883 | 0.0182 | 7395 | 0.0275 | 4878 | 0.0182 | 7389 | 0.0275 |
| 14 | 4921 | 0.0183 | 7457 | 0.0278 | 4918 | 0.0183 | 7454 | 0.0278 | 4904 | 0.0183 | 7436 | 0.0277 | 4903 | 0.0183 | 7436 | 0.0277 |

| Coilset | 30 seconds | | | | 50 seconds | | | | 100 seconds | | | | 200 seconds | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $h_{lam}$ | $Bi_{lam}$ | $h_{turb}$ | $Bi_{turb}$ | $h_{lam}$ | $Bi_{lam}$ | $h_{turb}$ | $Bi_{turb}$ | $h_{lam}$ | $Bi_{lam}$ | $h_{turb}$ | $Bi_{turb}$ | $h_{lam}$ | $Bi_{lam}$ | $h_{turb}$ | $Bi_{turb}$ |
| 1 | 4542 | 0.0169 | 6757 | 0.0252 | 4501 | 0.0168 | 6683 | 0.0249 | 4489 | 0.0167 | 6663 | 0.0248 | 4482 | 0.0167 | 6650 | 0.0248 |
| 2 | 4566 | 0.0170 | 6801 | 0.0253 | 4532 | 0.0169 | 6743 | 0.0251 | 4522 | 0.0168 | 6730 | 0.0251 | 4515 | 0.0168 | 6717 | 0.0250 |
| 3 | 4590 | 0.0171 | 6846 | 0.0255 | 4556 | 0.0170 | 6787 | 0.0253 | 4550 | 0.0169 | 6783 | 0.0253 | 4546 | 0.0169 | 6775 | 0.0252 |
| 4 | 4615 | 0.0172 | 6892 | 0.0257 | 4581 | 0.0171 | 6832 | 0.0254 | 4575 | 0.0170 | 6829 | 0.0254 | 4571 | 0.0170 | 6822 | 0.0254 |
| 5 | 4640 | 0.0173 | 6938 | 0.0258 | 4606 | 0.0171 | 6878 | 0.0256 | 4600 | 0.0171 | 6875 | 0.0256 | 4596 | 0.0171 | 6868 | 0.0256 |
| 6 | 4665 | 0.0174 | 6985 | 0.0260 | 4631 | 0.0172 | 6925 | 0.0258 | 4626 | 0.0172 | 6922 | 0.0258 | 4622 | 0.0172 | 6915 | 0.0257 |
| 7 | 4691 | 0.0175 | 7033 | 0.0262 | 4657 | 0.0173 | 6973 | 0.0260 | 4651 | 0.0173 | 6970 | 0.0259 | 4648 | 0.0173 | 6963 | 0.0259 |
| 8 | 4717 | 0.0176 | 7080 | 0.0264 | 4683 | 0.0174 | 7020 | 0.0261 | 4677 | 0.0174 | 7018 | 0.0261 | 4674 | 0.0174 | 7012 | 0.0261 |
| 9 | 4742 | 0.0177 | 7128 | 0.0265 | 4709 | 0.0175 | 7069 | 0.0263 | 4704 | 0.0175 | 7067 | 0.0263 | 4701 | 0.0175 | 7061 | 0.0263 |
| 10 | 4768 | 0.0177 | 7177 | 0.0267 | 4735 | 0.0176 | 7118 | 0.0265 | 4731 | 0.0176 | 7117 | 0.0265 | 4728 | 0.0176 | 7111 | 0.0265 |
| 11 | 4793 | 0.0178 | 7226 | 0.0269 | 4761 | 0.0177 | 7167 | 0.0267 | 4757 | 0.0177 | 7166 | 0.0267 | 4754 | 0.0177 | 7161 | 0.0267 |
| 12 | 4819 | 0.0179 | 7276 | 0.0271 | 4787 | 0.0178 | 7217 | 0.0269 | 4783 | 0.0178 | 7217 | 0.0269 | 4781 | 0.0178 | 7212 | 0.0269 |
| 13 | 4846 | 0.0180 | 7327 | 0.0273 | 4813 | 0.0179 | 7268 | 0.0271 | 4809 | 0.0179 | 7267 | 0.0271 | 4807 | 0.0179 | 7263 | 0.0270 |
| 14 | 4873 | 0.0181 | 7378 | 0.0275 | 4840 | 0.0180 | 7319 | 0.0272 | 4836 | 0.0180 | 7320 | 0.0273 | 4834 | 0.0180 | 7316 | 0.0272 |

**Table H3: Heat transfer coefficients and Biot number approximations for R3-36 at 10LPM**

| Coilset | 1 second | | | | 2 seconds | | | | 3 seconds | | | | 5 seconds | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $h_{lam}$ | $Bi_{lam}$ | $h_{turb}$ | $Bi_{turb}$ | $h_{lam}$ | $Bi_{lam}$ | $h_{turb}$ | $Bi_{turb}$ | $h_{lam}$ | $Bi_{lam}$ | $h_{turb}$ | $Bi_{turb}$ | $h_{lam}$ | $Bi_{lam}$ | $h_{turb}$ | $Bi_{turb}$ |
| 1 | 4499 | 0.0168 | 6415 | 0.0239 | 4501 | 0.0168 | 6421 | 0.0239 | 4503 | 0.0168 | 6427 | 0.0239 | 4472 | 0.0167 | 6369 | 0.0237 |
| 2 | 4500 | 0.0168 | 6417 | 0.0239 | 4503 | 0.0168 | 6424 | 0.0239 | 4505 | 0.0168 | 6429 | 0.0239 | 4476 | 0.0167 | 6377 | 0.0237 |
| 3 | 4501 | 0.0168 | 6419 | 0.0239 | 4504 | 0.0168 | 6426 | 0.0239 | 4506 | 0.0168 | 6432 | 0.0239 | 4480 | 0.0167 | 6383 | 0.0238 |
| 4 | 4503 | 0.0168 | 6421 | 0.0239 | 4505 | 0.0168 | 6428 | 0.0239 | 4507 | 0.0168 | 6435 | 0.0240 | 4483 | 0.0167 | 6390 | 0.0238 |
| 5 | 4504 | 0.0168 | 6423 | 0.0239 | 4506 | 0.0168 | 6430 | 0.0239 | 4509 | 0.0168 | 6437 | 0.0240 | 4487 | 0.0167 | 6396 | 0.0238 |
| 6 | 4505 | 0.0168 | 6425 | 0.0239 | 4507 | 0.0168 | 6432 | 0.0239 | 4510 | 0.0168 | 6440 | 0.0240 | 4490 | 0.0167 | 6402 | 0.0238 |
| 7 | 4506 | 0.0168 | 6427 | 0.0239 | 4509 | 0.0168 | 6435 | 0.0240 | 4512 | 0.0168 | 6442 | 0.0240 | 4493 | 0.0167 | 6408 | 0.0239 |
| 8 | 4506 | 0.0168 | 6428 | 0.0239 | 4510 | 0.0168 | 6436 | 0.0240 | 4513 | 0.0168 | 6444 | 0.0240 | 4497 | 0.0167 | 6414 | 0.0239 |
| 9 | 4507 | 0.0168 | 6430 | 0.0239 | 4511 | 0.0168 | 6439 | 0.0240 | 4514 | 0.0168 | 6447 | 0.0240 | 4500 | 0.0168 | 6420 | 0.0239 |
| 10 | 4509 | 0.0168 | 6432 | 0.0239 | 4512 | 0.0168 | 6441 | 0.0240 | 4515 | 0.0168 | 6450 | 0.0240 | 4503 | 0.0168 | 6426 | 0.0239 |
| 11 | 4510 | 0.0168 | 6434 | 0.0240 | 4513 | 0.0168 | 6443 | 0.0240 | 4517 | 0.0168 | 6452 | 0.0240 | 4507 | 0.0168 | 6432 | 0.0239 |
| 12 | 4511 | 0.0168 | 6436 | 0.0240 | 4515 | 0.0168 | 6446 | 0.0240 | 4518 | 0.0168 | 6455 | 0.0240 | 4510 | 0.0168 | 6438 | 0.0240 |
| 13 | 4512 | 0.0168 | 6438 | 0.0240 | 4516 | 0.0168 | 6448 | 0.0240 | 4520 | 0.0168 | 6457 | 0.0240 | 4513 | 0.0168 | 6444 | 0.0240 |
| 14 | 4513 | 0.0168 | 6440 | 0.0240 | 4517 | 0.0168 | 6450 | 0.0240 | 4521 | 0.0168 | 6460 | 0.0241 | 4516 | 0.0168 | 6450 | 0.0240 |

| Coilset | 8 seconds | | | | 10 seconds | | | | 15 seconds | | | | 20 seconds | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $h_{lam}$ | $Bi_{lam}$ | $h_{turb}$ | $Bi_{turb}$ | $h_{lam}$ | $Bi_{lam}$ | $h_{turb}$ | $Bi_{turb}$ | $h_{lam}$ | $Bi_{lam}$ | $h_{turb}$ | $Bi_{turb}$ | $h_{lam}$ | $Bi_{lam}$ | $h_{turb}$ | $Bi_{turb}$ |
| 1 | 4410 | 0.0164 | 6271 | 0.0233 | 4353 | 0.0162 | 6167 | 0.0230 | 4267 | 0.0159 | 6011 | 0.0224 | 4220 | 0.0157 | 5934 | 0.0221 |
| 2 | 4419 | 0.0165 | 6287 | 0.0234 | 4366 | 0.0163 | 6189 | 0.0230 | 4285 | 0.0160 | 6043 | 0.0225 | 4241 | 0.0158 | 5971 | 0.0222 |
| 3 | 4429 | 0.0165 | 6305 | 0.0235 | 4379 | 0.0163 | 6213 | 0.0231 | 4303 | 0.0160 | 6074 | 0.0226 | 4262 | 0.0159 | 6008 | 0.0224 |
| 4 | 4438 | 0.0165 | 6322 | 0.0235 | 4391 | 0.0163 | 6235 | 0.0232 | 4321 | 0.0161 | 6106 | 0.0227 | 4284 | 0.0159 | 6046 | 0.0225 |
| 5 | 4448 | 0.0166 | 6339 | 0.0236 | 4404 | 0.0164 | 6259 | 0.0233 | 4338 | 0.0162 | 6137 | 0.0228 | 4306 | 0.0160 | 6084 | 0.0227 |
| 6 | 4457 | 0.0166 | 6356 | 0.0237 | 4418 | 0.0164 | 6283 | 0.0234 | 4356 | 0.0162 | 6169 | 0.0230 | 4328 | 0.0161 | 6122 | 0.0228 |
| 7 | 4467 | 0.0166 | 6374 | 0.0237 | 4431 | 0.0165 | 6306 | 0.0235 | 4374 | 0.0163 | 6202 | 0.0231 | 4349 | 0.0162 | 6161 | 0.0229 |
| 8 | 4477 | 0.0167 | 6392 | 0.0238 | 4444 | 0.0165 | 6331 | 0.0236 | 4392 | 0.0164 | 6234 | 0.0232 | 4371 | 0.0163 | 6200 | 0.0231 |
| 9 | 4487 | 0.0167 | 6410 | 0.0239 | 4457 | 0.0166 | 6355 | 0.0237 | 4410 | 0.0164 | 6267 | 0.0233 | 4393 | 0.0164 | 6239 | 0.0232 |
| 10 | 4496 | 0.0167 | 6427 | 0.0239 | 4471 | 0.0166 | 6379 | 0.0238 | 4429 | 0.0165 | 6301 | 0.0235 | 4415 | 0.0164 | 6279 | 0.0234 |
| 11 | 4506 | 0.0168 | 6445 | 0.0240 | 4485 | 0.0167 | 6404 | 0.0238 | 4448 | 0.0166 | 6335 | 0.0236 | 4437 | 0.0165 | 6320 | 0.0235 |
| 12 | 4515 | 0.0168 | 6461 | 0.0241 | 4498 | 0.0167 | 6429 | 0.0239 | 4467 | 0.0166 | 6370 | 0.0237 | 4460 | 0.0166 | 6361 | 0.0237 |
| 13 | 4524 | 0.0168 | 6478 | 0.0241 | 4511 | 0.0168 | 6453 | 0.0240 | 4486 | 0.0167 | 6404 | 0.0238 | 4483 | 0.0167 | 6403 | 0.0238 |
| 14 | 4533 | 0.0169 | 6493 | 0.0242 | 4523 | 0.0168 | 6475 | 0.0241 | 4505 | 0.0168 | 6439 | 0.0240 | 4507 | 0.0168 | 6446 | 0.0240 |

| Coilset | 30 seconds | | | | 50 seconds | | | | 100 seconds | | | | 200 seconds | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $h_{lam}$ | $Bi_{lam}$ | $h_{turb}$ | $Bi_{turb}$ | $h_{lam}$ | $Bi_{lam}$ | $h_{turb}$ | $Bi_{turb}$ | $h_{lam}$ | $Bi_{lam}$ | $h_{turb}$ | $Bi_{turb}$ | $h_{lam}$ | $Bi_{lam}$ | $h_{turb}$ | $Bi_{turb}$ |
| 1 | 4176 | 0.0155 | 5863 | 0.0218 | 4122 | 0.0153 | 5763 | 0.0215 | 4099 | 0.0153 | 5722 | 0.0213 | 4097 | 0.0153 | 5721 | 0.0213 |
| 2 | 4199 | 0.0156 | 5903 | 0.0220 | 4151 | 0.0155 | 5815 | 0.0216 | 4132 | 0.0154 | 5784 | 0.0215 | 4130 | 0.0154 | 5783 | 0.0215 |
| 3 | 4223 | 0.0157 | 5945 | 0.0221 | 4175 | 0.0155 | 5856 | 0.0218 | 4160 | 0.0155 | 5835 | 0.0217 | 4160 | 0.0155 | 5839 | 0.0217 |
| 4 | 4247 | 0.0158 | 5987 | 0.0223 | 4199 | 0.0156 | 5898 | 0.0220 | 4185 | 0.0156 | 5877 | 0.0219 | 4185 | 0.0156 | 5882 | 0.0219 |
| 5 | 4272 | 0.0159 | 6030 | 0.0224 | 4224 | 0.0157 | 5941 | 0.0221 | 4210 | 0.0157 | 5921 | 0.0220 | 4211 | 0.0157 | 5926 | 0.0221 |
| 6 | 4297 | 0.0160 | 6074 | 0.0226 | 4249 | 0.0158 | 5985 | 0.0223 | 4235 | 0.0158 | 5964 | 0.0222 | 4236 | 0.0158 | 5970 | 0.0222 |
| 7 | 4322 | 0.0161 | 6117 | 0.0228 | 4275 | 0.0159 | 6030 | 0.0224 | 4261 | 0.0159 | 6009 | 0.0224 | 4262 | 0.0159 | 6015 | 0.0224 |
| 8 | 4347 | 0.0162 | 6161 | 0.0229 | 4300 | 0.0160 | 6074 | 0.0226 | 4287 | 0.0160 | 6055 | 0.0225 | 4288 | 0.0160 | 6061 | 0.0226 |
| 9 | 4371 | 0.0163 | 6205 | 0.0231 | 4326 | 0.0161 | 6120 | 0.0228 | 4314 | 0.0161 | 6101 | 0.0227 | 4315 | 0.0161 | 6107 | 0.0227 |
| 10 | 4397 | 0.0164 | 6251 | 0.0233 | 4352 | 0.0162 | 6165 | 0.0230 | 4340 | 0.0162 | 6147 | 0.0229 | 4342 | 0.0162 | 6154 | 0.0229 |
| 11 | 4422 | 0.0165 | 6297 | 0.0234 | 4377 | 0.0163 | 6212 | 0.0231 | 4366 | 0.0163 | 6194 | 0.0231 | 4368 | 0.0163 | 6201 | 0.0231 |
| 12 | 4448 | 0.0166 | 6344 | 0.0236 | 4404 | 0.0164 | 6259 | 0.0233 | 4392 | 0.0164 | 6241 | 0.0232 | 4394 | 0.0164 | 6249 | 0.0233 |
| 13 | 4474 | 0.0167 | 6391 | 0.0238 | 4430 | 0.0165 | 6306 | 0.0235 | 4419 | 0.0165 | 6290 | 0.0234 | 4421 | 0.0165 | 6298 | 0.0234 |
| 14 | 4500 | 0.0168 | 6439 | 0.0240 | 4457 | 0.0166 | 6355 | 0.0237 | 4446 | 0.0166 | 6339 | 0.0236 | 4449 | 0.0166 | 6348 | 0.0236 |

**Table H4: Heat transfer coefficients and Biot number approximations for R3-36 at 9LPM**

| Coilset | 1 second | | | | 2 seconds | | | | 3 seconds | | | | 5 seconds | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $h_{lam}$ | $Bi_{lam}$ | $h_{turb}$ | $Bi_{turb}$ | $h_{lam}$ | $Bi_{lam}$ | $h_{turb}$ | $Bi_{turb}$ | $h_{lam}$ | $Bi_{lam}$ | $h_{turb}$ | $Bi_{turb}$ | $h_{lam}$ | $Bi_{lam}$ | $h_{turb}$ | $Bi_{turb}$ |
| **1** | 4248 | 0.0158 | 5838 | 0.0217 | 4242 | 0.0158 | 5833 | 0.0217 | 4240 | 0.0158 | 5833 | 0.0217 | 4208 | 0.0157 | 5785 | 0.0215 |
| **2** | 4251 | 0.0158 | 5843 | 0.0218 | 4245 | 0.0158 | 5838 | 0.0217 | 4244 | 0.0158 | 5840 | 0.0217 | 4215 | 0.0157 | 5798 | 0.0216 |
| **3** | 4253 | 0.0158 | 5847 | 0.0218 | 4249 | 0.0158 | 5845 | 0.0218 | 4248 | 0.0158 | 5848 | 0.0218 | 4223 | 0.0157 | 5810 | 0.0216 |
| **4** | 4255 | 0.0158 | 5851 | 0.0218 | 4253 | 0.0158 | 5852 | 0.0218 | 4253 | 0.0158 | 5856 | 0.0218 | 4230 | 0.0157 | 5823 | 0.0217 |
| **5** | 4258 | 0.0159 | 5855 | 0.0218 | 4257 | 0.0158 | 5858 | 0.0218 | 4257 | 0.0158 | 5863 | 0.0218 | 4237 | 0.0158 | 5836 | 0.0217 |
| **6** | 4260 | 0.0159 | 5859 | 0.0218 | 4260 | 0.0159 | 5864 | 0.0218 | 4261 | 0.0159 | 5870 | 0.0219 | 4245 | 0.0158 | 5849 | 0.0218 |
| **7** | 4262 | 0.0159 | 5863 | 0.0218 | 4263 | 0.0159 | 5870 | 0.0219 | 4266 | 0.0159 | 5878 | 0.0219 | 4252 | 0.0158 | 5862 | 0.0218 |
| **8** | 4264 | 0.0159 | 5867 | 0.0218 | 4267 | 0.0159 | 5876 | 0.0219 | 4270 | 0.0159 | 5885 | 0.0219 | 4260 | 0.0159 | 5876 | 0.0219 |
| **9** | 4267 | 0.0159 | 5871 | 0.0219 | 4270 | 0.0159 | 5882 | 0.0219 | 4274 | 0.0159 | 5892 | 0.0219 | 4268 | 0.0159 | 5889 | 0.0219 |
| **10** | 4269 | 0.0159 | 5875 | 0.0219 | 4273 | 0.0159 | 5887 | 0.0219 | 4277 | 0.0159 | 5899 | 0.0220 | 4275 | 0.0159 | 5902 | 0.0220 |
| **11** | 4271 | 0.0159 | 5879 | 0.0219 | 4276 | 0.0159 | 5893 | 0.0219 | 4281 | 0.0159 | 5905 | 0.0220 | 4283 | 0.0159 | 5916 | 0.0220 |
| **12** | 4274 | 0.0159 | 5883 | 0.0219 | 4280 | 0.0159 | 5899 | 0.0220 | 4285 | 0.0160 | 5912 | 0.0220 | 4289 | 0.0160 | 5927 | 0.0221 |
| **13** | 4276 | 0.0159 | 5887 | 0.0219 | 4283 | 0.0159 | 5905 | 0.0220 | 4289 | 0.0160 | 5919 | 0.0220 | 4296 | 0.0160 | 5939 | 0.0221 |
| **14** | 4278 | 0.0159 | 5891 | 0.0219 | 4286 | 0.0160 | 5911 | 0.0220 | 4293 | 0.0160 | 5926 | 0.0221 | 4303 | 0.0160 | 5951 | 0.0222 |

| Coilset | 8 seconds | | | | 10 seconds | | | | 15 seconds | | | | 20 seconds | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $h_{lam}$ | $Bi_{lam}$ | $h_{turb}$ | $Bi_{turb}$ | $h_{lam}$ | $Bi_{lam}$ | $h_{turb}$ | $Bi_{turb}$ | $h_{lam}$ | $Bi_{lam}$ | $h_{turb}$ | $Bi_{turb}$ | $h_{lam}$ | $Bi_{lam}$ | $h_{turb}$ | $Bi_{turb}$ |
| **1** | 4175 | 0.0155 | 5738 | 0.0214 | 4137 | 0.0154 | 5672 | 0.0211 | 4071 | 0.0152 | 5561 | 0.0207 | 4018 | 0.0150 | 5466 | 0.0204 |
| **2** | 4186 | 0.0156 | 5756 | 0.0214 | 4150 | 0.0154 | 5695 | 0.0212 | 4089 | 0.0152 | 5591 | 0.0208 | 4039 | 0.0150 | 5501 | 0.0205 |
| **3** | 4197 | 0.0156 | 5775 | 0.0215 | 4163 | 0.0155 | 5718 | 0.0213 | 4107 | 0.0153 | 5621 | 0.0209 | 4060 | 0.0151 | 5536 | 0.0206 |
| **4** | 4207 | 0.0157 | 5793 | 0.0216 | 4176 | 0.0155 | 5742 | 0.0214 | 4125 | 0.0154 | 5652 | 0.0210 | 4081 | 0.0152 | 5572 | 0.0207 |
| **5** | 4218 | 0.0157 | 5812 | 0.0216 | 4190 | 0.0156 | 5765 | 0.0215 | 4142 | 0.0154 | 5682 | 0.0212 | 4103 | 0.0153 | 5608 | 0.0209 |
| **6** | 4229 | 0.0157 | 5831 | 0.0217 | 4203 | 0.0156 | 5789 | 0.0216 | 4159 | 0.0155 | 5712 | 0.0213 | 4124 | 0.0154 | 5644 | 0.0210 |
| **7** | 4240 | 0.0158 | 5850 | 0.0218 | 4217 | 0.0157 | 5813 | 0.0216 | 4177 | 0.0156 | 5743 | 0.0214 | 4145 | 0.0154 | 5681 | 0.0212 |
| **8** | 4251 | 0.0158 | 5870 | 0.0219 | 4231 | 0.0158 | 5837 | 0.0217 | 4195 | 0.0156 | 5774 | 0.0215 | 4166 | 0.0155 | 5717 | 0.0213 |
| **9** | 4262 | 0.0159 | 5889 | 0.0219 | 4245 | 0.0158 | 5861 | 0.0218 | 4213 | 0.0157 | 5806 | 0.0216 | 4188 | 0.0156 | 5755 | 0.0214 |
| **10** | 4273 | 0.0159 | 5909 | 0.0220 | 4259 | 0.0159 | 5886 | 0.0219 | 4231 | 0.0158 | 5838 | 0.0217 | 4209 | 0.0157 | 5793 | 0.0216 |
| **11** | 4285 | 0.0160 | 5929 | 0.0221 | 4273 | 0.0159 | 5911 | 0.0220 | 4250 | 0.0158 | 5871 | 0.0219 | 4231 | 0.0158 | 5832 | 0.0217 |
| **12** | 4296 | 0.0160 | 5949 | 0.0221 | 4287 | 0.0160 | 5936 | 0.0221 | 4268 | 0.0159 | 5903 | 0.0220 | 4254 | 0.0158 | 5871 | 0.0219 |
| **13** | 4306 | 0.0160 | 5967 | 0.0222 | 4302 | 0.0160 | 5962 | 0.0222 | 4287 | 0.0160 | 5936 | 0.0221 | 4277 | 0.0159 | 5911 | 0.0220 |
| **14** | 4316 | 0.0161 | 5985 | 0.0223 | 4315 | 0.0161 | 5985 | 0.0223 | 4306 | 0.0160 | 5970 | 0.0222 | 4299 | 0.0160 | 5950 | 0.0222 |

| Coilset | 30 seconds | | | | 50 seconds | | | | 100 seconds | | | | 200 seconds | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $h_{lam}$ | $Bi_{lam}$ | $h_{turb}$ | $Bi_{turb}$ | $h_{lam}$ | $Bi_{lam}$ | $h_{turb}$ | $Bi_{turb}$ | $h_{lam}$ | $Bi_{lam}$ | $h_{turb}$ | $Bi_{turb}$ | $h_{lam}$ | $Bi_{lam}$ | $h_{turb}$ | $Bi_{turb}$ |
| **1** | 3975 | 0.0148 | 5397 | 0.0201 | 3954 | 0.0147 | 5370 | 0.0200 | 3924 | 0.0146 | 5315 | 0.0198 | 3910 | 0.0146 | 5286 | 0.0197 |
| **2** | 3998 | 0.0149 | 5435 | 0.0202 | 3980 | 0.0148 | 5415 | 0.0202 | 3957 | 0.0147 | 5374 | 0.0200 | 3943 | 0.0147 | 5345 | 0.0199 |
| **3** | 4022 | 0.0150 | 5475 | 0.0204 | 4004 | 0.0149 | 5456 | 0.0203 | 3982 | 0.0148 | 5417 | 0.0202 | 3971 | 0.0148 | 5394 | 0.0201 |
| **4** | 4046 | 0.0151 | 5515 | 0.0205 | 4029 | 0.0150 | 5496 | 0.0205 | 4007 | 0.0149 | 5459 | 0.0203 | 3995 | 0.0149 | 5435 | 0.0202 |
| **5** | 4070 | 0.0152 | 5556 | 0.0207 | 4053 | 0.0151 | 5538 | 0.0206 | 4032 | 0.0150 | 5500 | 0.0205 | 4021 | 0.0150 | 5478 | 0.0204 |
| **6** | 4094 | 0.0152 | 5597 | 0.0208 | 4078 | 0.0152 | 5580 | 0.0208 | 4057 | 0.0151 | 5543 | 0.0206 | 4046 | 0.0151 | 5520 | 0.0206 |
| **7** | 4119 | 0.0153 | 5639 | 0.0210 | 4104 | 0.0153 | 5623 | 0.0209 | 4083 | 0.0152 | 5586 | 0.0208 | 4072 | 0.0152 | 5564 | 0.0207 |
| **8** | 4143 | 0.0154 | 5681 | 0.0211 | 4130 | 0.0154 | 5667 | 0.0211 | 4108 | 0.0153 | 5630 | 0.0210 | 4098 | 0.0153 | 5608 | 0.0209 |
| **9** | 4168 | 0.0155 | 5723 | 0.0213 | 4155 | 0.0155 | 5710 | 0.0213 | 4135 | 0.0154 | 5675 | 0.0211 | 4125 | 0.0154 | 5654 | 0.0210 |
| **10** | 4192 | 0.0156 | 5766 | 0.0215 | 4180 | 0.0156 | 5754 | 0.0214 | 4160 | 0.0155 | 5719 | 0.0213 | 4150 | 0.0155 | 5698 | 0.0212 |
| **11** | 4218 | 0.0157 | 5810 | 0.0216 | 4205 | 0.0157 | 5799 | 0.0216 | 4186 | 0.0156 | 5764 | 0.0215 | 4177 | 0.0155 | 5744 | 0.0214 |
| **12** | 4243 | 0.0158 | 5855 | 0.0218 | 4231 | 0.0158 | 5844 | 0.0218 | 4212 | 0.0157 | 5810 | 0.0216 | 4203 | 0.0156 | 5790 | 0.0216 |
| **13** | 4269 | 0.0159 | 5901 | 0.0220 | 4258 | 0.0159 | 5891 | 0.0219 | 4239 | 0.0158 | 5857 | 0.0218 | 4230 | 0.0157 | 5838 | 0.0217 |
| **14** | 4295 | 0.0160 | 5947 | 0.0221 | 4285 | 0.0160 | 5939 | 0.0221 | 4266 | 0.0159 | 5904 | 0.0220 | 4258 | 0.0159 | 5885 | 0.0219 |

**Table H5: Heat transfer coefficients and Biot number approximations for R3-36 at 7LPM**

| Coilset | 1 second | | | | 2 seconds | | | | 3 seconds | | | | 5 seconds | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $h_{lam}$ | $Bi_{lam}$ | $h_{turb}$ | $Bi_{turb}$ | $h_{lam}$ | $Bi_{lam}$ | $h_{turb}$ | $Bi_{turb}$ | $h_{lam}$ | $Bi_{lam}$ | $h_{turb}$ | $Bi_{turb}$ | $h_{lam}$ | $Bi_{lam}$ | $h_{turb}$ | $Bi_{turb}$ |
| 1 | 3748 | 0.0140 | 4727 | 0.0176 | 3731 | 0.0139 | 4696 | 0.0175 | 3728 | 0.0139 | 4694 | 0.0175 | 3700 | 0.0138 | 4654 | 0.0173 |
| 2 | 3750 | 0.0140 | 4730 | 0.0176 | 3734 | 0.0139 | 4700 | 0.0175 | 3732 | 0.0139 | 4700 | 0.0175 | 3707 | 0.0138 | 4664 | 0.0174 |
| 3 | 3752 | 0.0140 | 4733 | 0.0176 | 3737 | 0.0139 | 4705 | 0.0175 | 3735 | 0.0139 | 4706 | 0.0175 | 3713 | 0.0138 | 4674 | 0.0174 |
| 4 | 3754 | 0.0140 | 4736 | 0.0176 | 3740 | 0.0139 | 4709 | 0.0175 | 3739 | 0.0139 | 4712 | 0.0175 | 3719 | 0.0138 | 4683 | 0.0174 |
| 5 | 3756 | 0.0140 | 4740 | 0.0176 | 3742 | 0.0139 | 4714 | 0.0175 | 3743 | 0.0139 | 4718 | 0.0176 | 3725 | 0.0139 | 4693 | 0.0175 |
| 6 | 3758 | 0.0140 | 4743 | 0.0177 | 3745 | 0.0139 | 4718 | 0.0176 | 3746 | 0.0139 | 4724 | 0.0176 | 3731 | 0.0139 | 4703 | 0.0175 |
| 7 | 3760 | 0.0140 | 4746 | 0.0177 | 3748 | 0.0140 | 4722 | 0.0176 | 3750 | 0.0140 | 4729 | 0.0176 | 3737 | 0.0139 | 4713 | 0.0175 |
| 8 | 3763 | 0.0140 | 4750 | 0.0177 | 3750 | 0.0140 | 4726 | 0.0176 | 3753 | 0.0140 | 4735 | 0.0176 | 3743 | 0.0139 | 4723 | 0.0176 |
| 9 | 3765 | 0.0140 | 4754 | 0.0177 | 3753 | 0.0140 | 4731 | 0.0176 | 3757 | 0.0140 | 4740 | 0.0176 | 3750 | 0.0140 | 4733 | 0.0176 |
| 10 | 3767 | 0.0140 | 4757 | 0.0177 | 3756 | 0.0140 | 4735 | 0.0176 | 3760 | 0.0140 | 4746 | 0.0177 | 3756 | 0.0140 | 4743 | 0.0177 |
| 11 | 3769 | 0.0140 | 4760 | 0.0177 | 3758 | 0.0140 | 4739 | 0.0176 | 3763 | 0.0140 | 4751 | 0.0177 | 3761 | 0.0140 | 4752 | 0.0177 |
| 12 | 3771 | 0.0140 | 4764 | 0.0177 | 3761 | 0.0140 | 4743 | 0.0177 | 3767 | 0.0140 | 4756 | 0.0177 | 3767 | 0.0140 | 4760 | 0.0177 |
| 13 | 3773 | 0.0140 | 4767 | 0.0177 | 3764 | 0.0140 | 4748 | 0.0177 | 3770 | 0.0140 | 4762 | 0.0177 | 3772 | 0.0140 | 4770 | 0.0178 |
| 14 | 3775 | 0.0141 | 4770 | 0.0178 | 3766 | 0.0140 | 4752 | 0.0177 | 3773 | 0.0140 | 4768 | 0.0177 | 3778 | 0.0141 | 4779 | 0.0178 |

| Coilset | 8 seconds | | | | 10 seconds | | | | 15 seconds | | | | 20 seconds | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $h_{lam}$ | $Bi_{lam}$ | $h_{turb}$ | $Bi_{turb}$ | $h_{lam}$ | $Bi_{lam}$ | $h_{turb}$ | $Bi_{turb}$ | $h_{lam}$ | $Bi_{lam}$ | $h_{turb}$ | $Bi_{turb}$ | $h_{lam}$ | $Bi_{lam}$ | $h_{turb}$ | $Bi_{turb}$ |
| 1 | 3678 | 0.0137 | 4626 | 0.0172 | 3657 | 0.0136 | 4591 | 0.0171 | 3636 | 0.0135 | 4575 | 0.0170 | 3602 | 0.0134 | 4526 | 0.0169 |
| 2 | 3687 | 0.0137 | 4639 | 0.0173 | 3667 | 0.0137 | 4607 | 0.0172 | 3650 | 0.0136 | 4596 | 0.0171 | 3619 | 0.0135 | 4553 | 0.0170 |
| 3 | 3695 | 0.0138 | 4652 | 0.0173 | 3677 | 0.0137 | 4623 | 0.0172 | 3663 | 0.0136 | 4618 | 0.0172 | 3637 | 0.0135 | 4581 | 0.0171 |
| 4 | 3703 | 0.0138 | 4666 | 0.0174 | 3686 | 0.0137 | 4638 | 0.0173 | 3677 | 0.0137 | 4640 | 0.0173 | 3655 | 0.0136 | 4608 | 0.0172 |
| 5 | 3712 | 0.0138 | 4680 | 0.0174 | 3696 | 0.0138 | 4654 | 0.0173 | 3691 | 0.0137 | 4662 | 0.0174 | 3672 | 0.0137 | 4636 | 0.0173 |
| 6 | 3721 | 0.0139 | 4693 | 0.0175 | 3706 | 0.0138 | 4670 | 0.0174 | 3705 | 0.0138 | 4685 | 0.0174 | 3689 | 0.0137 | 4664 | 0.0174 |
| 7 | 3729 | 0.0139 | 4707 | 0.0175 | 3716 | 0.0138 | 4686 | 0.0174 | 3719 | 0.0138 | 4708 | 0.0175 | 3707 | 0.0138 | 4692 | 0.0175 |
| 8 | 3738 | 0.0139 | 4721 | 0.0176 | 3727 | 0.0139 | 4703 | 0.0175 | 3733 | 0.0139 | 4731 | 0.0176 | 3725 | 0.0139 | 4721 | 0.0176 |
| 9 | 3747 | 0.0139 | 4735 | 0.0176 | 3737 | 0.0139 | 4719 | 0.0176 | 3747 | 0.0140 | 4754 | 0.0177 | 3743 | 0.0139 | 4750 | 0.0177 |
| 10 | 3755 | 0.0140 | 4749 | 0.0177 | 3747 | 0.0140 | 4736 | 0.0176 | 3762 | 0.0140 | 4777 | 0.0178 | 3761 | 0.0140 | 4779 | 0.0178 |
| 11 | 3764 | 0.0140 | 4763 | 0.0177 | 3758 | 0.0140 | 4753 | 0.0177 | 3777 | 0.0141 | 4802 | 0.0179 | 3779 | 0.0141 | 4809 | 0.0179 |
| 12 | 3772 | 0.0140 | 4776 | 0.0178 | 3768 | 0.0140 | 4769 | 0.0178 | 3792 | 0.0141 | 4825 | 0.0180 | 3798 | 0.0141 | 4839 | 0.0180 |
| 13 | 3780 | 0.0141 | 4789 | 0.0178 | 3777 | 0.0141 | 4784 | 0.0178 | 3806 | 0.0142 | 4849 | 0.0181 | 3816 | 0.0142 | 4869 | 0.0181 |
| 14 | 3788 | 0.0141 | 4801 | 0.0179 | 3786 | 0.0141 | 4799 | 0.0179 | 3819 | 0.0142 | 4870 | 0.0181 | 3833 | 0.0143 | 4896 | 0.0182 |

| Coilset | 30 seconds | | | | 50 seconds | | | | 100 seconds | | | | 200 seconds | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $h_{lam}$ | $Bi_{lam}$ | $h_{turb}$ | $Bi_{turb}$ | $h_{lam}$ | $Bi_{lam}$ | $h_{turb}$ | $Bi_{turb}$ | $h_{lam}$ | $Bi_{lam}$ | $h_{turb}$ | $Bi_{turb}$ | $h_{lam}$ | $Bi_{lam}$ | $h_{turb}$ | $Bi_{turb}$ |
| 1 | 3556 | 0.0132 | 4458 | 0.0166 | 3525 | 0.0131 | 4417 | 0.0164 | 3473 | 0.0129 | 4325 | 0.0161 | 3464 | 0.0129 | 4311 | 0.0161 |
| 2 | 3577 | 0.0133 | 4491 | 0.0167 | 3548 | 0.0132 | 4452 | 0.0166 | 3503 | 0.0130 | 4374 | 0.0163 | 3497 | 0.0130 | 4365 | 0.0163 |
| 3 | 3599 | 0.0134 | 4524 | 0.0168 | 3572 | 0.0133 | 4489 | 0.0167 | 3527 | 0.0131 | 4411 | 0.0164 | 3522 | 0.0131 | 4404 | 0.0164 |
| 4 | 3621 | 0.0135 | 4558 | 0.0170 | 3596 | 0.0134 | 4526 | 0.0169 | 3552 | 0.0132 | 4449 | 0.0166 | 3547 | 0.0132 | 4442 | 0.0165 |
| 5 | 3643 | 0.0136 | 4593 | 0.0171 | 3620 | 0.0135 | 4564 | 0.0170 | 3576 | 0.0133 | 4487 | 0.0167 | 3572 | 0.0133 | 4481 | 0.0167 |
| 6 | 3665 | 0.0136 | 4627 | 0.0172 | 3644 | 0.0136 | 4602 | 0.0171 | 3602 | 0.0134 | 4526 | 0.0168 | 3597 | 0.0134 | 4520 | 0.0168 |
| 7 | 3687 | 0.0137 | 4662 | 0.0174 | 3669 | 0.0137 | 4641 | 0.0173 | 3627 | 0.0135 | 4565 | 0.0170 | 3623 | 0.0135 | 4561 | 0.0170 |
| 8 | 3709 | 0.0138 | 4698 | 0.0175 | 3693 | 0.0138 | 4680 | 0.0174 | 3653 | 0.0136 | 4606 | 0.0171 | 3650 | 0.0136 | 4602 | 0.0171 |
| 9 | 3731 | 0.0139 | 4734 | 0.0176 | 3718 | 0.0138 | 4719 | 0.0176 | 3678 | 0.0137 | 4646 | 0.0173 | 3675 | 0.0137 | 4643 | 0.0173 |
| 10 | 3754 | 0.0140 | 4770 | 0.0178 | 3743 | 0.0139 | 4759 | 0.0177 | 3704 | 0.0138 | 4687 | 0.0175 | 3701 | 0.0138 | 4684 | 0.0174 |
| 11 | 3777 | 0.0141 | 4808 | 0.0179 | 3768 | 0.0140 | 4801 | 0.0179 | 3730 | 0.0139 | 4729 | 0.0176 | 3728 | 0.0139 | 4727 | 0.0176 |
| 12 | 3801 | 0.0141 | 4846 | 0.0180 | 3794 | 0.0141 | 4843 | 0.0180 | 3756 | 0.0140 | 4772 | 0.0178 | 3755 | 0.0140 | 4771 | 0.0178 |
| 13 | 3823 | 0.0142 | 4883 | 0.0182 | 3821 | 0.0142 | 4886 | 0.0182 | 3783 | 0.0141 | 4816 | 0.0179 | 3782 | 0.0141 | 4815 | 0.0179 |
| 14 | 3844 | 0.0143 | 4918 | 0.0183 | 3845 | 0.0143 | 4925 | 0.0183 | 3811 | 0.0142 | 4860 | 0.0181 | 3810 | 0.0142 | 4861 | 0.0181 |

**Table H6: Heat transfer coefficients and Biot number approximations for R3-36 at 5.5LPM**

| Coilset | 1 second | | | | 2 seconds | | | | 3 seconds | | | | 5 seconds | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $h_{lam}$ | $Bi_{lam}$ | $h_{turb}$ | $Bi_{turb}$ | $h_{lam}$ | $Bi_{lam}$ | $h_{turb}$ | $Bi_{turb}$ | $h_{lam}$ | $Bi_{lam}$ | $h_{turb}$ | $Bi_{turb}$ | $h_{lam}$ | $Bi_{lam}$ | $h_{turb}$ | $Bi_{turb}$ |
| **1** | 3247 | 0.0121 | 3713 | 0.0138 | 3249 | 0.0121 | 3717 | 0.0138 | 3242 | 0.0121 | 3711 | 0.0138 | 3231 | 0.0120 | 3696 | 0.0138 |
| **2** | 3249 | 0.0121 | 3714 | 0.0138 | 3250 | 0.0121 | 3720 | 0.0138 | 3245 | 0.0121 | 3714 | 0.0138 | 3235 | 0.0120 | 3702 | 0.0138 |
| **3** | 3250 | 0.0121 | 3716 | 0.0138 | 3252 | 0.0121 | 3722 | 0.0139 | 3248 | 0.0121 | 3719 | 0.0138 | 3239 | 0.0121 | 3707 | 0.0138 |
| **4** | 3251 | 0.0121 | 3718 | 0.0138 | 3254 | 0.0121 | 3725 | 0.0139 | 3250 | 0.0121 | 3723 | 0.0139 | 3242 | 0.0121 | 3712 | 0.0138 |
| **5** | 3252 | 0.0121 | 3720 | 0.0138 | 3255 | 0.0121 | 3727 | 0.0139 | 3253 | 0.0121 | 3727 | 0.0139 | 3246 | 0.0121 | 3718 | 0.0138 |
| **6** | 3254 | 0.0121 | 3722 | 0.0139 | 3257 | 0.0121 | 3729 | 0.0139 | 3256 | 0.0121 | 3730 | 0.0139 | 3250 | 0.0121 | 3724 | 0.0139 |
| **7** | 3255 | 0.0121 | 3724 | 0.0139 | 3259 | 0.0121 | 3732 | 0.0139 | 3258 | 0.0121 | 3734 | 0.0139 | 3254 | 0.0121 | 3729 | 0.0139 |
| **8** | 3256 | 0.0121 | 3726 | 0.0139 | 3260 | 0.0121 | 3734 | 0.0139 | 3261 | 0.0121 | 3738 | 0.0139 | 3257 | 0.0121 | 3734 | 0.0139 |
| **9** | 3258 | 0.0121 | 3728 | 0.0139 | 3262 | 0.0121 | 3737 | 0.0139 | 3263 | 0.0121 | 3742 | 0.0139 | 3261 | 0.0121 | 3739 | 0.0139 |
| **10** | 3259 | 0.0121 | 3730 | 0.0139 | 3263 | 0.0121 | 3739 | 0.0139 | 3266 | 0.0122 | 3745 | 0.0139 | 3264 | 0.0122 | 3745 | 0.0139 |
| **11** | 3260 | 0.0121 | 3732 | 0.0139 | 3265 | 0.0122 | 3741 | 0.0139 | 3268 | 0.0122 | 3749 | 0.0140 | 3268 | 0.0122 | 3749 | 0.0140 |
| **12** | 3262 | 0.0121 | 3733 | 0.0139 | 3267 | 0.0122 | 3744 | 0.0139 | 3271 | 0.0122 | 3753 | 0.0140 | 3271 | 0.0122 | 3754 | 0.0140 |
| **13** | 3263 | 0.0121 | 3735 | 0.0139 | 3268 | 0.0122 | 3746 | 0.0139 | 3273 | 0.0122 | 3756 | 0.0140 | 3274 | 0.0122 | 3759 | 0.0140 |
| **14** | 3264 | 0.0122 | 3737 | 0.0139 | 3270 | 0.0122 | 3749 | 0.0140 | 3276 | 0.0122 | 3760 | 0.0140 | 3278 | 0.0122 | 3765 | 0.0140 |

| Coilset | 8 seconds | | | | 10 seconds | | | | 15 seconds | | | | 20 seconds | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $h_{lam}$ | $Bi_{lam}$ | $h_{turb}$ | $Bi_{turb}$ | $h_{lam}$ | $Bi_{lam}$ | $h_{turb}$ | $Bi_{turb}$ | $h_{lam}$ | $Bi_{lam}$ | $h_{turb}$ | $Bi_{turb}$ | $h_{lam}$ | $Bi_{lam}$ | $h_{turb}$ | $Bi_{turb}$ |
| **1** | 3223 | 0.0120 | 3691 | 0.0137 | 3220 | 0.0120 | 3697 | 0.0138 | 3250 | 0.0121 | 3772 | 0.0140 | 3243 | 0.0121 | 3774 | 0.0141 |
| **2** | 3228 | 0.0120 | 3699 | 0.0138 | 3228 | 0.0120 | 3708 | 0.0138 | 3260 | 0.0121 | 3787 | 0.0141 | 3255 | 0.0121 | 3793 | 0.0141 |
| **3** | 3234 | 0.0120 | 3707 | 0.0138 | 3235 | 0.0120 | 3718 | 0.0138 | 3270 | 0.0122 | 3802 | 0.0142 | 3268 | 0.0122 | 3812 | 0.0142 |
| **4** | 3239 | 0.0121 | 3715 | 0.0138 | 3242 | 0.0121 | 3729 | 0.0139 | 3280 | 0.0122 | 3817 | 0.0142 | 3281 | 0.0122 | 3830 | 0.0143 |
| **5** | 3245 | 0.0121 | 3723 | 0.0139 | 3249 | 0.0121 | 3739 | 0.0139 | 3290 | 0.0122 | 3832 | 0.0143 | 3294 | 0.0123 | 3850 | 0.0143 |
| **6** | 3250 | 0.0121 | 3731 | 0.0139 | 3257 | 0.0121 | 3750 | 0.0140 | 3300 | 0.0123 | 3847 | 0.0143 | 3307 | 0.0123 | 3869 | 0.0144 |
| **7** | 3256 | 0.0121 | 3739 | 0.0139 | 3264 | 0.0122 | 3761 | 0.0140 | 3311 | 0.0123 | 3863 | 0.0144 | 3320 | 0.0124 | 3889 | 0.0145 |
| **8** | 3261 | 0.0121 | 3747 | 0.0140 | 3271 | 0.0122 | 3772 | 0.0140 | 3321 | 0.0124 | 3878 | 0.0144 | 3333 | 0.0124 | 3908 | 0.0146 |
| **9** | 3267 | 0.0122 | 3755 | 0.0140 | 3279 | 0.0122 | 3783 | 0.0141 | 3332 | 0.0124 | 3894 | 0.0145 | 3347 | 0.0125 | 3929 | 0.0146 |
| **10** | 3272 | 0.0122 | 3763 | 0.0140 | 3286 | 0.0122 | 3794 | 0.0141 | 3343 | 0.0124 | 3910 | 0.0146 | 3360 | 0.0125 | 3949 | 0.0147 |
| **11** | 3277 | 0.0122 | 3771 | 0.0140 | 3294 | 0.0123 | 3805 | 0.0142 | 3354 | 0.0125 | 3926 | 0.0146 | 3374 | 0.0126 | 3970 | 0.0148 |
| **12** | 3282 | 0.0122 | 3778 | 0.0141 | 3300 | 0.0123 | 3815 | 0.0142 | 3364 | 0.0125 | 3942 | 0.0147 | 3388 | 0.0126 | 3990 | 0.0149 |
| **13** | 3287 | 0.0122 | 3785 | 0.0141 | 3307 | 0.0123 | 3824 | 0.0142 | 3374 | 0.0126 | 3956 | 0.0147 | 3400 | 0.0127 | 4009 | 0.0149 |
| **14** | 3292 | 0.0123 | 3793 | 0.0141 | 3313 | 0.0123 | 3834 | 0.0143 | 3383 | 0.0126 | 3971 | 0.0148 | 3413 | 0.0127 | 4028 | 0.0150 |

| Coilset | 30 seconds | | | | 50 seconds | | | | 100 seconds | | | | 200 seconds | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $h_{lam}$ | $Bi_{lam}$ | $h_{turb}$ | $Bi_{turb}$ | $h_{lam}$ | $Bi_{lam}$ | $h_{turb}$ | $Bi_{turb}$ | $h_{lam}$ | $Bi_{lam}$ | $h_{turb}$ | $Bi_{turb}$ | $h_{lam}$ | $Bi_{lam}$ | $h_{turb}$ | $Bi_{turb}$ |
| **1** | 3237 | 0.0121 | 3791 | 0.0141 | 3165 | 0.0118 | 3678 | 0.0137 | 3115 | 0.0116 | 3598 | 0.0134 | 3115 | 0.0116 | 3604 | 0.0134 |
| **2** | 3255 | 0.0121 | 3817 | 0.0142 | 3187 | 0.0119 | 3709 | 0.0138 | 3141 | 0.0117 | 3637 | 0.0135 | 3146 | 0.0117 | 3653 | 0.0136 |
| **3** | 3273 | 0.0122 | 3843 | 0.0143 | 3209 | 0.0119 | 3741 | 0.0139 | 3164 | 0.0118 | 3671 | 0.0137 | 3170 | 0.0118 | 3687 | 0.0137 |
| **4** | 3292 | 0.0123 | 3870 | 0.0144 | 3232 | 0.0120 | 3773 | 0.0140 | 3188 | 0.0119 | 3704 | 0.0138 | 3194 | 0.0119 | 3721 | 0.0139 |
| **5** | 3310 | 0.0123 | 3897 | 0.0145 | 3255 | 0.0121 | 3807 | 0.0142 | 3212 | 0.0120 | 3739 | 0.0139 | 3218 | 0.0120 | 3756 | 0.0140 |
| **6** | 3328 | 0.0124 | 3924 | 0.0146 | 3278 | 0.0122 | 3840 | 0.0143 | 3237 | 0.0121 | 3775 | 0.0141 | 3243 | 0.0121 | 3793 | 0.0141 |
| **7** | 3346 | 0.0125 | 3951 | 0.0147 | 3301 | 0.0123 | 3874 | 0.0144 | 3262 | 0.0121 | 3810 | 0.0142 | 3269 | 0.0122 | 3830 | 0.0143 |
| **8** | 3365 | 0.0125 | 3979 | 0.0148 | 3324 | 0.0124 | 3908 | 0.0146 | 3286 | 0.0122 | 3846 | 0.0143 | 3294 | 0.0123 | 3866 | 0.0144 |
| **9** | 3384 | 0.0126 | 4008 | 0.0149 | 3348 | 0.0125 | 3944 | 0.0147 | 3310 | 0.0123 | 3883 | 0.0145 | 3319 | 0.0124 | 3904 | 0.0145 |
| **10** | 3403 | 0.0127 | 4037 | 0.0150 | 3371 | 0.0126 | 3979 | 0.0148 | 3336 | 0.0124 | 3920 | 0.0146 | 3345 | 0.0125 | 3942 | 0.0147 |
| **11** | 3422 | 0.0127 | 4066 | 0.0151 | 3396 | 0.0126 | 4016 | 0.0150 | 3361 | 0.0125 | 3959 | 0.0147 | 3371 | 0.0126 | 3981 | 0.0148 |
| **12** | 3442 | 0.0128 | 4095 | 0.0152 | 3420 | 0.0127 | 4053 | 0.0151 | 3387 | 0.0126 | 3998 | 0.0149 | 3398 | 0.0126 | 4022 | 0.0150 |
| **13** | 3459 | 0.0129 | 4122 | 0.0153 | 3442 | 0.0128 | 4087 | 0.0152 | 3413 | 0.0127 | 4036 | 0.0150 | 3425 | 0.0128 | 4063 | 0.0151 |
| **14** | 3477 | 0.0129 | 4149 | 0.0154 | 3465 | 0.0129 | 4121 | 0.0153 | 3437 | 0.0128 | 4072 | 0.0152 | 3449 | 0.0128 | 4100 | 0.0153 |

**Table H7: Heat transfer coefficients and Biot number approximations for R3-60 at 14LPM**

| Coilset | 1 second | | | | 2 seconds | | | | 3 seconds | | | | 5 seconds | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $h_{lam}$ | $Bi_{lam}$ | $h_{turb}$ | $Bi_{turb}$ | $h_{lam}$ | $Bi_{lam}$ | $h_{turb}$ | $Bi_{turb}$ | $h_{lam}$ | $Bi_{lam}$ | $h_{turb}$ | $Bi_{turb}$ | $h_{lam}$ | $Bi_{lam}$ | $h_{turb}$ | $Bi_{turb}$ |
| 1 | 4902 | 0.0183 | 7432 | 0.0277 | 5098 | 0.0190 | 7941 | 0.0296 | 5212 | 0.0194 | 8250 | 0.0307 | 5147 | 0.0192 | 8125 | 0.0302 |
| 2 | 4904 | 0.0183 | 7435 | 0.0277 | 5100 | 0.0190 | 7944 | 0.0296 | 5214 | 0.0194 | 8255 | 0.0307 | 5153 | 0.0192 | 8136 | 0.0303 |
| 3 | 4905 | 0.0183 | 7438 | 0.0277 | 5102 | 0.0190 | 7948 | 0.0296 | 5217 | 0.0194 | 8261 | 0.0308 | 5158 | 0.0192 | 8147 | 0.0303 |
| 4 | 4907 | 0.0183 | 7441 | 0.0277 | 5104 | 0.0190 | 7952 | 0.0296 | 5220 | 0.0194 | 8267 | 0.0308 | 5164 | 0.0192 | 8158 | 0.0304 |
| 5 | 4908 | 0.0183 | 7444 | 0.0277 | 5105 | 0.0190 | 7955 | 0.0296 | 5222 | 0.0194 | 8271 | 0.0308 | 5169 | 0.0192 | 8169 | 0.0304 |
| 6 | 4910 | 0.0183 | 7447 | 0.0277 | 5107 | 0.0190 | 7959 | 0.0296 | 5225 | 0.0195 | 8276 | 0.0308 | 5175 | 0.0193 | 8180 | 0.0305 |
| 7 | 4911 | 0.0183 | 7450 | 0.0277 | 5109 | 0.0190 | 7963 | 0.0296 | 5227 | 0.0195 | 8281 | 0.0308 | 5180 | 0.0193 | 8191 | 0.0305 |
| 8 | 4913 | 0.0183 | 7453 | 0.0277 | 5111 | 0.0190 | 7967 | 0.0297 | 5230 | 0.0195 | 8286 | 0.0308 | 5186 | 0.0193 | 8203 | 0.0305 |
| 9 | 4914 | 0.0183 | 7456 | 0.0278 | 5113 | 0.0190 | 7971 | 0.0297 | 5232 | 0.0195 | 8291 | 0.0309 | 5191 | 0.0193 | 8214 | 0.0306 |
| 10 | 4916 | 0.0183 | 7459 | 0.0278 | 5114 | 0.0190 | 7974 | 0.0297 | 5234 | 0.0195 | 8296 | 0.0309 | 5197 | 0.0193 | 8225 | 0.0306 |
| 11 | 4917 | 0.0183 | 7462 | 0.0278 | 5116 | 0.0190 | 7978 | 0.0297 | 5237 | 0.0195 | 8301 | 0.0309 | 5202 | 0.0194 | 8236 | 0.0307 |
| 12 | 4919 | 0.0183 | 7465 | 0.0278 | 5118 | 0.0191 | 7982 | 0.0297 | 5239 | 0.0195 | 8306 | 0.0309 | 5208 | 0.0194 | 8247 | 0.0307 |
| 13 | 4920 | 0.0183 | 7467 | 0.0278 | 5120 | 0.0191 | 7985 | 0.0297 | 5241 | 0.0195 | 8310 | 0.0309 | 5214 | 0.0194 | 8259 | 0.0307 |
| 14 | 4922 | 0.0183 | 7470 | 0.0278 | 5122 | 0.0191 | 7989 | 0.0297 | 5244 | 0.0195 | 8315 | 0.0310 | 5219 | 0.0194 | 8270 | 0.0308 |
| 15 | 4923 | 0.0183 | 7473 | 0.0278 | 5124 | 0.0191 | 7993 | 0.0298 | 5246 | 0.0195 | 8320 | 0.0310 | 5225 | 0.0195 | 8281 | 0.0308 |
| 16 | 4925 | 0.0183 | 7476 | 0.0278 | 5126 | 0.0191 | 7996 | 0.0298 | 5249 | 0.0195 | 8325 | 0.0310 | 5230 | 0.0195 | 8292 | 0.0309 |
| 17 | 4926 | 0.0183 | 7479 | 0.0278 | 5128 | 0.0191 | 8000 | 0.0298 | 5251 | 0.0196 | 8330 | 0.0310 | 5235 | 0.0195 | 8302 | 0.0309 |
| 18 | 4928 | 0.0183 | 7482 | 0.0279 | 5130 | 0.0191 | 8004 | 0.0298 | 5254 | 0.0196 | 8335 | 0.0310 | 5240 | 0.0195 | 8313 | 0.0309 |
| 19 | 4929 | 0.0184 | 7485 | 0.0279 | 5131 | 0.0191 | 8007 | 0.0298 | 5256 | 0.0196 | 8340 | 0.0311 | 5245 | 0.0195 | 8323 | 0.0310 |
| 20 | 4931 | 0.0184 | 7488 | 0.0279 | 5133 | 0.0191 | 8012 | 0.0298 | 5259 | 0.0196 | 8345 | 0.0311 | 5250 | 0.0195 | 8333 | 0.0310 |
| 21 | 4932 | 0.0184 | 7491 | 0.0279 | 5135 | 0.0191 | 8015 | 0.0298 | 5261 | 0.0196 | 8349 | 0.0311 | 5255 | 0.0196 | 8343 | 0.0311 |
| 22 | 4934 | 0.0184 | 7494 | 0.0279 | 5137 | 0.0191 | 8019 | 0.0299 | 5263 | 0.0196 | 8354 | 0.0311 | 5260 | 0.0196 | 8353 | 0.0311 |
| 23 | 4936 | 0.0184 | 7497 | 0.0279 | 5139 | 0.0191 | 8023 | 0.0299 | 5266 | 0.0196 | 8359 | 0.0311 | 5266 | 0.0196 | 8364 | 0.0311 |
| 24 | 4937 | 0.0184 | 7500 | 0.0279 | 5141 | 0.0191 | 8026 | 0.0299 | 5268 | 0.0196 | 8365 | 0.0311 | 5271 | 0.0196 | 8374 | 0.0312 |

| Coilset | 8 seconds | | | | 10 seconds | | | | 15 seconds | | | | 20 seconds | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $h_{lam}$ | $Bi_{lam}$ | $h_{turb}$ | $Bi_{turb}$ | $h_{lam}$ | $Bi_{lam}$ | $h_{turb}$ | $Bi_{turb}$ | $h_{lam}$ | $Bi_{lam}$ | $h_{turb}$ | $Bi_{turb}$ | $h_{lam}$ | $Bi_{lam}$ | $h_{turb}$ | $Bi_{turb}$ |
| 1 | 5024 | 0.0187 | 7878 | 0.0293 | 4972 | 0.0185 | 7772 | 0.0289 | 4859 | 0.0181 | 7544 | 0.0281 | 4963 | 0.0185 | 7854 | 0.0292 |
| 2 | 5034 | 0.0187 | 7897 | 0.0294 | 4984 | 0.0186 | 7795 | 0.0290 | 4876 | 0.0182 | 7576 | 0.0282 | 4982 | 0.0185 | 7892 | 0.0294 |
| 3 | 5044 | 0.0188 | 7917 | 0.0295 | 4996 | 0.0186 | 7819 | 0.0291 | 4893 | 0.0182 | 7608 | 0.0283 | 5001 | 0.0186 | 7929 | 0.0295 |
| 4 | 5054 | 0.0188 | 7938 | 0.0296 | 5009 | 0.0186 | 7844 | 0.0292 | 4909 | 0.0183 | 7640 | 0.0284 | 5021 | 0.0187 | 7967 | 0.0297 |
| 5 | 5064 | 0.0189 | 7957 | 0.0296 | 5020 | 0.0187 | 7867 | 0.0293 | 4927 | 0.0183 | 7673 | 0.0286 | 5041 | 0.0188 | 8006 | 0.0298 |
| 6 | 5074 | 0.0189 | 7978 | 0.0297 | 5033 | 0.0187 | 7891 | 0.0294 | 4944 | 0.0184 | 7706 | 0.0287 | 5060 | 0.0188 | 8045 | 0.0300 |
| 7 | 5084 | 0.0189 | 7997 | 0.0298 | 5044 | 0.0188 | 7914 | 0.0295 | 4961 | 0.0185 | 7739 | 0.0288 | 5080 | 0.0189 | 8084 | 0.0301 |
| 8 | 5095 | 0.0190 | 8018 | 0.0299 | 5057 | 0.0188 | 7939 | 0.0296 | 4979 | 0.0185 | 7773 | 0.0289 | 5101 | 0.0190 | 8124 | 0.0302 |
| 9 | 5105 | 0.0190 | 8039 | 0.0299 | 5069 | 0.0189 | 7964 | 0.0296 | 4995 | 0.0186 | 7806 | 0.0291 | 5121 | 0.0191 | 8164 | 0.0304 |
| 10 | 5115 | 0.0190 | 8059 | 0.0300 | 5081 | 0.0189 | 7988 | 0.0297 | 5012 | 0.0187 | 7840 | 0.0292 | 5142 | 0.0191 | 8205 | 0.0305 |
| 11 | 5126 | 0.0191 | 8080 | 0.0301 | 5094 | 0.0190 | 8013 | 0.0298 | 5029 | 0.0187 | 7873 | 0.0293 | 5162 | 0.0192 | 8246 | 0.0307 |
| 12 | 5136 | 0.0191 | 8101 | 0.0302 | 5106 | 0.0190 | 8038 | 0.0299 | 5046 | 0.0188 | 7907 | 0.0294 | 5182 | 0.0193 | 8286 | 0.0308 |
| 13 | 5146 | 0.0192 | 8122 | 0.0302 | 5119 | 0.0191 | 8063 | 0.0300 | 5064 | 0.0189 | 7942 | 0.0296 | 5202 | 0.0194 | 8327 | 0.0310 |
| 14 | 5157 | 0.0192 | 8143 | 0.0303 | 5131 | 0.0191 | 8088 | 0.0301 | 5081 | 0.0189 | 7976 | 0.0297 | 5222 | 0.0194 | 8368 | 0.0312 |
| 15 | 5168 | 0.0192 | 8165 | 0.0304 | 5144 | 0.0192 | 8114 | 0.0302 | 5098 | 0.0190 | 8011 | 0.0298 | 5243 | 0.0195 | 8410 | 0.0313 |
| 16 | 5178 | 0.0193 | 8186 | 0.0305 | 5157 | 0.0192 | 8139 | 0.0303 | 5116 | 0.0190 | 8047 | 0.0300 | 5264 | 0.0196 | 8452 | 0.0315 |
| 17 | 5189 | 0.0193 | 8208 | 0.0306 | 5170 | 0.0192 | 8165 | 0.0304 | 5134 | 0.0191 | 8082 | 0.0301 | 5285 | 0.0197 | 8495 | 0.0316 |
| 18 | 5200 | 0.0194 | 8230 | 0.0306 | 5183 | 0.0193 | 8192 | 0.0305 | 5152 | 0.0192 | 8118 | 0.0302 | 5306 | 0.0198 | 8539 | 0.0318 |
| 19 | 5211 | 0.0194 | 8251 | 0.0307 | 5196 | 0.0193 | 8217 | 0.0306 | 5171 | 0.0193 | 8155 | 0.0304 | 5328 | 0.0198 | 8583 | 0.0320 |
| 20 | 5222 | 0.0194 | 8274 | 0.0308 | 5209 | 0.0194 | 8244 | 0.0307 | 5189 | 0.0193 | 8192 | 0.0305 | 5349 | 0.0199 | 8627 | 0.0321 |
| 21 | 5232 | 0.0195 | 8294 | 0.0309 | 5222 | 0.0194 | 8270 | 0.0308 | 5207 | 0.0194 | 8229 | 0.0306 | 5371 | 0.0200 | 8673 | 0.0323 |
| 22 | 5242 | 0.0195 | 8314 | 0.0310 | 5234 | 0.0195 | 8294 | 0.0309 | 5223 | 0.0194 | 8262 | 0.0308 | 5391 | 0.0201 | 8713 | 0.0324 |
| 23 | 5251 | 0.0196 | 8334 | 0.0310 | 5245 | 0.0195 | 8318 | 0.0310 | 5240 | 0.0195 | 8295 | 0.0309 | 5410 | 0.0201 | 8753 | 0.0326 |
| 24 | 5261 | 0.0196 | 8353 | 0.0311 | 5257 | 0.0196 | 8342 | 0.0311 | 5257 | 0.0196 | 8330 | 0.0310 | 5430 | 0.0202 | 8795 | 0.0327 |

| Coilset | 30 seconds | | | | 50 seconds | | | | 100 seconds | | | | 200 seconds | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $h_{lam}$ | $Bi_{lam}$ | $h_{turb}$ | $Bi_{turb}$ | $h_{lam}$ | $Bi_{lam}$ | $h_{turb}$ | $Bi_{turb}$ | $h_{lam}$ | $Bi_{lam}$ | $h_{turb}$ | $Bi_{turb}$ | $h_{lam}$ | $Bi_{lam}$ | $h_{turb}$ | $Bi_{turb}$ |
| 1 | 4886 | 0.0182 | 7684 | 0.0286 | 4775 | 0.0178 | 7413 | 0.0276 | 4748 | 0.0177 | 7351 | 0.0274 | 4756 | 0.0177 | 7378 | 0.0275 |
| 2 | 4913 | 0.0183 | 7740 | 0.0288 | 4802 | 0.0179 | 7470 | 0.0278 | 4775 | 0.0178 | 7408 | 0.0276 | 4783 | 0.0178 | 7433 | 0.0277 |
| 3 | 4933 | 0.0184 | 7779 | 0.0290 | 4830 | 0.0180 | 7526 | 0.0280 | 4803 | 0.0179 | 7465 | 0.0278 | 4811 | 0.0179 | 7491 | 0.0279 |
| 4 | 4953 | 0.0184 | 7818 | 0.0291 | 4852 | 0.0181 | 7570 | 0.0282 | 4830 | 0.0180 | 7521 | 0.0280 | 4840 | 0.0180 | 7551 | 0.0281 |
| 5 | 4973 | 0.0185 | 7858 | 0.0293 | 4872 | 0.0181 | 7609 | 0.0283 | 4850 | 0.0181 | 7560 | 0.0281 | 4861 | 0.0181 | 7592 | 0.0283 |
| 6 | 4994 | 0.0186 | 7898 | 0.0294 | 4892 | 0.0182 | 7648 | 0.0285 | 4871 | 0.0181 | 7601 | 0.0283 | 4882 | 0.0182 | 7632 | 0.0284 |
| 7 | 5015 | 0.0187 | 7939 | 0.0296 | 4913 | 0.0183 | 7689 | 0.0286 | 4892 | 0.0182 | 7641 | 0.0284 | 4903 | 0.0183 | 7673 | 0.0286 |
| 8 | 5036 | 0.0187 | 7980 | 0.0297 | 4934 | 0.0184 | 7729 | 0.0288 | 4913 | 0.0183 | 7682 | 0.0286 | 4924 | 0.0183 | 7714 | 0.0287 |
| 9 | 5057 | 0.0188 | 8021 | 0.0299 | 4955 | 0.0184 | 7770 | 0.0289 | 4935 | 0.0184 | 7723 | 0.0288 | 4946 | 0.0184 | 7755 | 0.0289 |
| 10 | 5078 | 0.0189 | 8063 | 0.0300 | 4977 | 0.0185 | 7811 | 0.0291 | 4956 | 0.0185 | 7765 | 0.0289 | 4968 | 0.0185 | 7798 | 0.0290 |
| 11 | 5100 | 0.0190 | 8106 | 0.0302 | 4998 | 0.0186 | 7853 | 0.0292 | 4978 | 0.0185 | 7807 | 0.0291 | 4990 | 0.0186 | 7841 | 0.0292 |
| 12 | 5122 | 0.0191 | 8149 | 0.0303 | 5020 | 0.0187 | 7896 | 0.0294 | 5000 | 0.0186 | 7850 | 0.0292 | 5012 | 0.0187 | 7884 | 0.0294 |
| 13 | 5143 | 0.0191 | 8191 | 0.0305 | 5042 | 0.0188 | 7938 | 0.0296 | 5023 | 0.0187 | 7894 | 0.0294 | 5034 | 0.0187 | 7927 | 0.0295 |
| 14 | 5164 | 0.0192 | 8234 | 0.0307 | 5064 | 0.0189 | 7981 | 0.0297 | 5045 | 0.0188 | 7937 | 0.0295 | 5057 | 0.0188 | 7971 | 0.0297 |
| 15 | 5186 | 0.0193 | 8278 | 0.0308 | 5085 | 0.0189 | 8023 | 0.0299 | 5067 | 0.0189 | 7980 | 0.0297 | 5079 | 0.0189 | 8015 | 0.0298 |
| 16 | 5207 | 0.0194 | 8322 | 0.0310 | 5106 | 0.0190 | 8066 | 0.0300 | 5088 | 0.0189 | 8024 | 0.0299 | 5101 | 0.0190 | 8059 | 0.0300 |
| 17 | 5229 | 0.0195 | 8366 | 0.0311 | 5128 | 0.0191 | 8111 | 0.0302 | 5110 | 0.0190 | 8068 | 0.0300 | 5123 | 0.0191 | 8104 | 0.0302 |
| 18 | 5251 | 0.0196 | 8411 | 0.0313 | 5150 | 0.0192 | 8155 | 0.0304 | 5133 | 0.0191 | 8113 | 0.0302 | 5146 | 0.0192 | 8149 | 0.0303 |
| 19 | 5274 | 0.0196 | 8457 | 0.0315 | 5173 | 0.0193 | 8200 | 0.0305 | 5155 | 0.0192 | 8158 | 0.0304 | 5169 | 0.0192 | 8195 | 0.0305 |
| 20 | 5297 | 0.0197 | 8503 | 0.0317 | 5195 | 0.0193 | 8245 | 0.0307 | 5179 | 0.0193 | 8205 | 0.0305 | 5191 | 0.0193 | 8241 | 0.0307 |
| 21 | 5319 | 0.0198 | 8550 | 0.0318 | 5218 | 0.0194 | 8291 | 0.0309 | 5202 | 0.0194 | 8251 | 0.0307 | 5215 | 0.0194 | 8289 | 0.0309 |
| 22 | 5342 | 0.0199 | 8597 | 0.0320 | 5241 | 0.0195 | 8338 | 0.0310 | 5225 | 0.0195 | 8299 | 0.0309 | 5239 | 0.0195 | 8337 | 0.0310 |
| 23 | 5364 | 0.0200 | 8641 | 0.0322 | 5264 | 0.0196 | 8386 | 0.0312 | 5249 | 0.0195 | 8347 | 0.0311 | 5263 | 0.0196 | 8386 | 0.0312 |
| 24 | 5384 | 0.0200 | 8684 | 0.0323 | 5286 | 0.0197 | 8429 | 0.0314 | 5271 | 0.0196 | 8392 | 0.0312 | 5285 | 0.0197 | 8431 | 0.0314 |

**Table H8: Heat transfer coefficients and Biot number approximations for R3-60 at 12LPM**

| Coilset | 1 second | | | | 2 seconds | | | | 3 seconds | | | | 5 seconds | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $h_{lam}$ | $Bi_{lam}$ | $h_{turb}$ | $Bi_{turb}$ | $h_{lam}$ | $Bi_{lam}$ | $h_{turb}$ | $Bi_{turb}$ | $h_{lam}$ | $Bi_{lam}$ | $h_{turb}$ | $Bi_{turb}$ | $h_{lam}$ | $Bi_{lam}$ | $h_{turb}$ | $Bi_{turb}$ |
| 1 | 4842 | 0.0180 | 7269 | 0.0271 | 4872 | 0.0181 | 7348 | 0.0274 | 4819 | 0.0179 | 7243 | 0.0270 | 4784 | 0.0178 | 7189 | 0.0268 |
| 2 | 4843 | 0.0180 | 7271 | 0.0271 | 4872 | 0.0181 | 7349 | 0.0274 | 4823 | 0.0180 | 7250 | 0.0270 | 4790 | 0.0178 | 7199 | 0.0268 |
| 3 | 4843 | 0.0180 | 7272 | 0.0271 | 4874 | 0.0181 | 7352 | 0.0274 | 4826 | 0.0180 | 7256 | 0.0270 | 4795 | 0.0179 | 7208 | 0.0268 |
| 4 | 4844 | 0.0180 | 7273 | 0.0271 | 4874 | 0.0181 | 7353 | 0.0274 | 4829 | 0.0180 | 7261 | 0.0270 | 4800 | 0.0179 | 7219 | 0.0269 |
| 5 | 4845 | 0.0180 | 7275 | 0.0271 | 4876 | 0.0182 | 7355 | 0.0274 | 4832 | 0.0180 | 7268 | 0.0271 | 4805 | 0.0179 | 7229 | 0.0269 |
| 6 | 4846 | 0.0180 | 7276 | 0.0271 | 4876 | 0.0182 | 7357 | 0.0274 | 4835 | 0.0180 | 7274 | 0.0271 | 4811 | 0.0179 | 7240 | 0.0270 |
| 7 | 4846 | 0.0180 | 7277 | 0.0271 | 4877 | 0.0182 | 7359 | 0.0274 | 4838 | 0.0180 | 7279 | 0.0271 | 4816 | 0.0179 | 7250 | 0.0270 |
| 8 | 4847 | 0.0180 | 7279 | 0.0271 | 4878 | 0.0182 | 7361 | 0.0274 | 4841 | 0.0180 | 7286 | 0.0271 | 4821 | 0.0180 | 7260 | 0.0270 |
| 9 | 4848 | 0.0180 | 7280 | 0.0271 | 4879 | 0.0182 | 7363 | 0.0274 | 4844 | 0.0180 | 7292 | 0.0271 | 4827 | 0.0180 | 7270 | 0.0271 |
| 10 | 4848 | 0.0181 | 7282 | 0.0271 | 4880 | 0.0182 | 7365 | 0.0274 | 4847 | 0.0180 | 7297 | 0.0272 | 4832 | 0.0180 | 7281 | 0.0271 |
| 11 | 4849 | 0.0181 | 7283 | 0.0271 | 4881 | 0.0182 | 7366 | 0.0274 | 4850 | 0.0181 | 7303 | 0.0272 | 4838 | 0.0180 | 7291 | 0.0271 |
| 12 | 4850 | 0.0181 | 7284 | 0.0271 | 4882 | 0.0182 | 7369 | 0.0274 | 4853 | 0.0181 | 7308 | 0.0272 | 4843 | 0.0180 | 7302 | 0.0272 |
| 13 | 4851 | 0.0181 | 7286 | 0.0271 | 4883 | 0.0182 | 7370 | 0.0274 | 4856 | 0.0181 | 7313 | 0.0272 | 4849 | 0.0181 | 7312 | 0.0272 |
| 14 | 4851 | 0.0181 | 7287 | 0.0271 | 4884 | 0.0182 | 7372 | 0.0274 | 4858 | 0.0181 | 7318 | 0.0272 | 4854 | 0.0181 | 7323 | 0.0273 |
| 15 | 4852 | 0.0181 | 7289 | 0.0271 | 4885 | 0.0182 | 7374 | 0.0275 | 4861 | 0.0181 | 7324 | 0.0273 | 4860 | 0.0181 | 7333 | 0.0273 |
| 16 | 4853 | 0.0181 | 7290 | 0.0271 | 4886 | 0.0182 | 7376 | 0.0275 | 4864 | 0.0181 | 7329 | 0.0273 | 4865 | 0.0181 | 7344 | 0.0273 |
| 17 | 4854 | 0.0181 | 7292 | 0.0271 | 4887 | 0.0182 | 7378 | 0.0275 | 4867 | 0.0181 | 7334 | 0.0273 | 4870 | 0.0181 | 7354 | 0.0274 |
| 18 | 4855 | 0.0181 | 7293 | 0.0272 | 4888 | 0.0182 | 7380 | 0.0275 | 4870 | 0.0181 | 7340 | 0.0273 | 4875 | 0.0181 | 7363 | 0.0274 |
| 19 | 4855 | 0.0181 | 7294 | 0.0272 | 4889 | 0.0182 | 7382 | 0.0275 | 4872 | 0.0181 | 7345 | 0.0273 | 4880 | 0.0182 | 7372 | 0.0274 |
| 20 | 4856 | 0.0181 | 7296 | 0.0272 | 4890 | 0.0182 | 7384 | 0.0275 | 4875 | 0.0181 | 7351 | 0.0274 | 4885 | 0.0182 | 7382 | 0.0275 |
| 21 | 4856 | 0.0181 | 7297 | 0.0272 | 4891 | 0.0182 | 7386 | 0.0275 | 4878 | 0.0182 | 7357 | 0.0274 | 4890 | 0.0182 | 7391 | 0.0275 |
| 22 | 4857 | 0.0181 | 7298 | 0.0272 | 4892 | 0.0182 | 7387 | 0.0275 | 4881 | 0.0182 | 7362 | 0.0274 | 4895 | 0.0182 | 7401 | 0.0276 |
| 23 | 4858 | 0.0181 | 7300 | 0.0272 | 4893 | 0.0182 | 7390 | 0.0275 | 4883 | 0.0182 | 7367 | 0.0274 | 4899 | 0.0182 | 7410 | 0.0276 |
| 24 | 4859 | 0.0181 | 7301 | 0.0272 | 4894 | 0.0182 | 7391 | 0.0275 | 4886 | 0.0182 | 7373 | 0.0274 | 4904 | 0.0183 | 7420 | 0.0276 |

| Coilset | 8 seconds | | | | 10 seconds | | | | 15 seconds | | | | 20 seconds | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $h_{lam}$ | $Bi_{lam}$ | $h_{turb}$ | $Bi_{turb}$ | $h_{lam}$ | $Bi_{lam}$ | $h_{turb}$ | $Bi_{turb}$ | $h_{lam}$ | $Bi_{lam}$ | $h_{turb}$ | $Bi_{turb}$ | $h_{lam}$ | $Bi_{lam}$ | $h_{turb}$ | $Bi_{turb}$ |
| 1 | 4702 | 0.0175 | 7041 | 0.0262 | 4661 | 0.0174 | 6975 | 0.0260 | 4611 | 0.0172 | 6891 | 0.0257 | 4569 | 0.0170 | 6818 | 0.0254 |
| 2 | 4711 | 0.0175 | 7058 | 0.0263 | 4674 | 0.0174 | 6997 | 0.0261 | 4626 | 0.0172 | 6919 | 0.0258 | 4587 | 0.0171 | 6851 | 0.0255 |
| 3 | 4720 | 0.0176 | 7075 | 0.0263 | 4686 | 0.0174 | 7020 | 0.0261 | 4642 | 0.0173 | 6949 | 0.0259 | 4605 | 0.0171 | 6885 | 0.0256 |
| 4 | 4730 | 0.0176 | 7093 | 0.0264 | 4698 | 0.0175 | 7042 | 0.0262 | 4658 | 0.0173 | 6978 | 0.0260 | 4623 | 0.0172 | 6918 | 0.0258 |
| 5 | 4739 | 0.0176 | 7110 | 0.0265 | 4709 | 0.0175 | 7065 | 0.0263 | 4673 | 0.0174 | 7007 | 0.0261 | 4642 | 0.0173 | 6952 | 0.0259 |
| 6 | 4748 | 0.0177 | 7128 | 0.0265 | 4721 | 0.0176 | 7087 | 0.0264 | 4690 | 0.0175 | 7037 | 0.0262 | 4660 | 0.0174 | 6987 | 0.0260 |
| 7 | 4757 | 0.0177 | 7145 | 0.0266 | 4734 | 0.0176 | 7111 | 0.0265 | 4706 | 0.0175 | 7067 | 0.0263 | 4679 | 0.0174 | 7022 | 0.0261 |
| 8 | 4767 | 0.0177 | 7163 | 0.0267 | 4745 | 0.0177 | 7133 | 0.0266 | 4721 | 0.0176 | 7097 | 0.0264 | 4698 | 0.0175 | 7057 | 0.0263 |
| 9 | 4776 | 0.0178 | 7181 | 0.0267 | 4758 | 0.0177 | 7156 | 0.0266 | 4737 | 0.0176 | 7127 | 0.0265 | 4718 | 0.0176 | 7093 | 0.0264 |
| 10 | 4785 | 0.0178 | 7199 | 0.0268 | 4770 | 0.0178 | 7179 | 0.0267 | 4753 | 0.0177 | 7156 | 0.0266 | 4736 | 0.0176 | 7127 | 0.0265 |
| 11 | 4795 | 0.0179 | 7217 | 0.0269 | 4782 | 0.0178 | 7203 | 0.0268 | 4769 | 0.0178 | 7187 | 0.0268 | 4754 | 0.0177 | 7163 | 0.0267 |
| 12 | 4804 | 0.0179 | 7236 | 0.0269 | 4794 | 0.0178 | 7226 | 0.0269 | 4785 | 0.0178 | 7218 | 0.0269 | 4773 | 0.0178 | 7199 | 0.0268 |
| 13 | 4814 | 0.0179 | 7255 | 0.0270 | 4806 | 0.0179 | 7250 | 0.0270 | 4801 | 0.0179 | 7249 | 0.0270 | 4792 | 0.0178 | 7236 | 0.0269 |
| 14 | 4824 | 0.0180 | 7273 | 0.0271 | 4819 | 0.0179 | 7274 | 0.0271 | 4817 | 0.0179 | 7280 | 0.0271 | 4811 | 0.0179 | 7272 | 0.0271 |
| 15 | 4834 | 0.0180 | 7292 | 0.0271 | 4831 | 0.0180 | 7298 | 0.0272 | 4834 | 0.0180 | 7312 | 0.0272 | 4831 | 0.0180 | 7310 | 0.0272 |
| 16 | 4844 | 0.0180 | 7311 | 0.0272 | 4844 | 0.0180 | 7322 | 0.0273 | 4850 | 0.0181 | 7344 | 0.0273 | 4850 | 0.0181 | 7347 | 0.0274 |
| 17 | 4853 | 0.0181 | 7329 | 0.0273 | 4857 | 0.0181 | 7347 | 0.0274 | 4867 | 0.0181 | 7376 | 0.0275 | 4870 | 0.0181 | 7385 | 0.0275 |
| 18 | 4863 | 0.0181 | 7348 | 0.0274 | 4870 | 0.0181 | 7371 | 0.0274 | 4884 | 0.0182 | 7409 | 0.0276 | 4890 | 0.0182 | 7424 | 0.0276 |
| 19 | 4873 | 0.0181 | 7367 | 0.0274 | 4883 | 0.0182 | 7397 | 0.0275 | 4901 | 0.0182 | 7442 | 0.0277 | 4910 | 0.0183 | 7463 | 0.0278 |
| 20 | 4883 | 0.0182 | 7386 | 0.0275 | 4896 | 0.0182 | 7422 | 0.0276 | 4918 | 0.0183 | 7474 | 0.0278 | 4929 | 0.0184 | 7500 | 0.0279 |
| 21 | 4891 | 0.0182 | 7403 | 0.0276 | 4907 | 0.0183 | 7445 | 0.0277 | 4933 | 0.0184 | 7503 | 0.0279 | 4947 | 0.0184 | 7536 | 0.0281 |
| 22 | 4900 | 0.0182 | 7420 | 0.0276 | 4919 | 0.0183 | 7467 | 0.0278 | 4948 | 0.0184 | 7534 | 0.0280 | 4965 | 0.0185 | 7571 | 0.0282 |
| 23 | 4909 | 0.0183 | 7437 | 0.0277 | 4931 | 0.0184 | 7490 | 0.0279 | 4964 | 0.0185 | 7564 | 0.0282 | 4984 | 0.0186 | 7607 | 0.0283 |
| 24 | 4918 | 0.0183 | 7454 | 0.0278 | 4942 | 0.0184 | 7512 | 0.0280 | 4979 | 0.0185 | 7594 | 0.0283 | 5003 | 0.0186 | 7644 | 0.0285 |

| Coilset | 30 seconds | | | | 50 seconds | | | | 100 seconds | | | | 200 seconds | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $h_{lam}$ | $Bi_{lam}$ | $h_{turb}$ | $Bi_{turb}$ | $h_{lam}$ | $Bi_{lam}$ | $h_{turb}$ | $Bi_{turb}$ | $h_{lam}$ | $Bi_{lam}$ | $h_{turb}$ | $Bi_{turb}$ | $h_{lam}$ | $Bi_{lam}$ | $h_{turb}$ | $Bi_{turb}$ |
| 1 | 4547 | 0.0169 | 6794 | 0.0253 | 4473 | 0.0167 | 6629 | 0.0247 | 4463 | 0.0166 | 6615 | 0.0246 | 4467 | 0.0166 | 6629 | 0.0247 |
| 2 | 4566 | 0.0170 | 6830 | 0.0254 | 4500 | 0.0168 | 6682 | 0.0249 | 4489 | 0.0167 | 6668 | 0.0248 | 4494 | 0.0167 | 6682 | 0.0249 |
| 3 | 4586 | 0.0171 | 6866 | 0.0256 | 4521 | 0.0168 | 6722 | 0.0250 | 4517 | 0.0168 | 6723 | 0.0250 | 4521 | 0.0168 | 6736 | 0.0251 |
| 4 | 4605 | 0.0171 | 6902 | 0.0257 | 4540 | 0.0169 | 6758 | 0.0252 | 4537 | 0.0169 | 6759 | 0.0252 | 4543 | 0.0169 | 6778 | 0.0252 |
| 5 | 4625 | 0.0172 | 6939 | 0.0258 | 4560 | 0.0170 | 6794 | 0.0253 | 4557 | 0.0170 | 6796 | 0.0253 | 4563 | 0.0170 | 6815 | 0.0254 |
| 6 | 4645 | 0.0173 | 6976 | 0.0260 | 4580 | 0.0171 | 6832 | 0.0254 | 4577 | 0.0170 | 6833 | 0.0254 | 4584 | 0.0171 | 6853 | 0.0255 |
| 7 | 4666 | 0.0174 | 7014 | 0.0261 | 4600 | 0.0171 | 6869 | 0.0256 | 4598 | 0.0171 | 6871 | 0.0256 | 4605 | 0.0171 | 6891 | 0.0257 |
| 8 | 4686 | 0.0174 | 7052 | 0.0263 | 4621 | 0.0172 | 6906 | 0.0257 | 4618 | 0.0172 | 6909 | 0.0257 | 4625 | 0.0172 | 6930 | 0.0258 |
| 9 | 4707 | 0.0175 | 7091 | 0.0264 | 4642 | 0.0173 | 6945 | 0.0259 | 4639 | 0.0173 | 6948 | 0.0259 | 4647 | 0.0173 | 6969 | 0.0259 |
| 10 | 4728 | 0.0176 | 7130 | 0.0265 | 4663 | 0.0174 | 6983 | 0.0260 | 4660 | 0.0174 | 6987 | 0.0260 | 4668 | 0.0174 | 7009 | 0.0261 |
| 11 | 4749 | 0.0177 | 7168 | 0.0267 | 4684 | 0.0174 | 7022 | 0.0261 | 4682 | 0.0174 | 7027 | 0.0262 | 4690 | 0.0175 | 7049 | 0.0262 |
| 12 | 4769 | 0.0178 | 7207 | 0.0268 | 4705 | 0.0175 | 7062 | 0.0263 | 4704 | 0.0175 | 7067 | 0.0263 | 4712 | 0.0175 | 7090 | 0.0264 |
| 13 | 4790 | 0.0178 | 7247 | 0.0270 | 4726 | 0.0176 | 7101 | 0.0264 | 4725 | 0.0176 | 7107 | 0.0265 | 4733 | 0.0176 | 7130 | 0.0265 |
| 14 | 4810 | 0.0179 | 7287 | 0.0271 | 4746 | 0.0177 | 7140 | 0.0266 | 4746 | 0.0177 | 7147 | 0.0266 | 4755 | 0.0177 | 7171 | 0.0267 |
| 15 | 4831 | 0.0180 | 7327 | 0.0273 | 4767 | 0.0177 | 7180 | 0.0267 | 4767 | 0.0177 | 7188 | 0.0268 | 4776 | 0.0178 | 7212 | 0.0269 |
| 16 | 4852 | 0.0181 | 7368 | 0.0274 | 4788 | 0.0178 | 7221 | 0.0269 | 4789 | 0.0178 | 7229 | 0.0269 | 4798 | 0.0179 | 7254 | 0.0270 |
| 17 | 4874 | 0.0181 | 7410 | 0.0276 | 4810 | 0.0179 | 7262 | 0.0270 | 4811 | 0.0179 | 7271 | 0.0271 | 4820 | 0.0179 | 7297 | 0.0272 |
| 18 | 4896 | 0.0182 | 7452 | 0.0277 | 4831 | 0.0180 | 7304 | 0.0272 | 4832 | 0.0180 | 7313 | 0.0272 | 4842 | 0.0180 | 7339 | 0.0273 |
| 19 | 4918 | 0.0183 | 7495 | 0.0279 | 4853 | 0.0181 | 7346 | 0.0273 | 4855 | 0.0181 | 7357 | 0.0274 | 4865 | 0.0181 | 7383 | 0.0275 |
| 20 | 4940 | 0.0184 | 7539 | 0.0281 | 4876 | 0.0182 | 7389 | 0.0275 | 4878 | 0.0182 | 7400 | 0.0276 | 4888 | 0.0182 | 7427 | 0.0277 |
| 21 | 4961 | 0.0185 | 7578 | 0.0282 | 4898 | 0.0182 | 7433 | 0.0277 | 4900 | 0.0182 | 7444 | 0.0277 | 4911 | 0.0183 | 7472 | 0.0278 |
| 22 | 4981 | 0.0185 | 7617 | 0.0284 | 4919 | 0.0183 | 7473 | 0.0278 | 4923 | 0.0183 | 7488 | 0.0279 | 4934 | 0.0184 | 7517 | 0.0280 |
| 23 | 5001 | 0.0186 | 7657 | 0.0285 | 4939 | 0.0184 | 7512 | 0.0280 | 4944 | 0.0184 | 7528 | 0.0280 | 4955 | 0.0184 | 7557 | 0.0281 |
| 24 | 5021 | 0.0187 | 7697 | 0.0287 | 4960 | 0.0185 | 7553 | 0.0281 | 4964 | 0.0185 | 7569 | 0.0282 | 4976 | 0.0185 | 7598 | 0.0283 |

**Table H9: Heat transfer coefficients and Biot number approximations for R3-60 at 10LPM**

| Coilset | 1 second | | | | 2 seconds | | | | 3 seconds | | | | 5 seconds | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $h_{lam}$ | $Bi_{lam}$ | $h_{turb}$ | $Bi_{turb}$ | $h_{lam}$ | $Bi_{lam}$ | $h_{turb}$ | $Bi_{turb}$ | $h_{lam}$ | $Bi_{lam}$ | $h_{turb}$ | $Bi_{turb}$ | $h_{lam}$ | $Bi_{lam}$ | $h_{turb}$ | $Bi_{turb}$ |
| 1 | 4482 | 0.0167 | 6391 | 0.0238 | 4484 | 0.0167 | 6403 | 0.0238 | 4469 | 0.0166 | 6376 | 0.0237 | 4430 | 0.0165 | 6308 | 0.0235 |
| 2 | 4483 | 0.0167 | 6393 | 0.0238 | 4486 | 0.0167 | 6406 | 0.0239 | 4472 | 0.0166 | 6381 | 0.0238 | 4435 | 0.0165 | 6316 | 0.0235 |
| 3 | 4485 | 0.0167 | 6396 | 0.0238 | 4488 | 0.0167 | 6410 | 0.0239 | 4475 | 0.0167 | 6386 | 0.0238 | 4439 | 0.0165 | 6324 | 0.0235 |
| 4 | 4486 | 0.0167 | 6398 | 0.0238 | 4490 | 0.0167 | 6413 | 0.0239 | 4477 | 0.0167 | 6391 | 0.0238 | 4444 | 0.0165 | 6333 | 0.0236 |
| 5 | 4488 | 0.0167 | 6402 | 0.0238 | 4492 | 0.0167 | 6417 | 0.0239 | 4480 | 0.0167 | 6396 | 0.0238 | 4448 | 0.0166 | 6341 | 0.0236 |
| 6 | 4489 | 0.0167 | 6404 | 0.0238 | 4494 | 0.0167 | 6420 | 0.0239 | 4483 | 0.0167 | 6401 | 0.0238 | 4453 | 0.0166 | 6350 | 0.0236 |
| 7 | 4491 | 0.0167 | 6407 | 0.0239 | 4496 | 0.0167 | 6424 | 0.0239 | 4486 | 0.0167 | 6406 | 0.0239 | 4457 | 0.0166 | 6357 | 0.0237 |
| 8 | 4492 | 0.0167 | 6409 | 0.0239 | 4498 | 0.0167 | 6427 | 0.0239 | 4489 | 0.0167 | 6412 | 0.0239 | 4462 | 0.0166 | 6366 | 0.0237 |
| 9 | 4493 | 0.0167 | 6412 | 0.0239 | 4499 | 0.0168 | 6430 | 0.0239 | 4491 | 0.0167 | 6416 | 0.0239 | 4467 | 0.0166 | 6374 | 0.0237 |
| 10 | 4495 | 0.0167 | 6414 | 0.0239 | 4501 | 0.0168 | 6434 | 0.0240 | 4493 | 0.0167 | 6421 | 0.0239 | 4471 | 0.0166 | 6383 | 0.0238 |
| 11 | 4496 | 0.0167 | 6417 | 0.0239 | 4503 | 0.0168 | 6437 | 0.0240 | 4496 | 0.0167 | 6425 | 0.0239 | 4476 | 0.0167 | 6391 | 0.0238 |
| 12 | 4498 | 0.0167 | 6420 | 0.0239 | 4505 | 0.0168 | 6440 | 0.0240 | 4498 | 0.0167 | 6430 | 0.0239 | 4481 | 0.0167 | 6400 | 0.0238 |
| 13 | 4499 | 0.0168 | 6423 | 0.0239 | 4507 | 0.0168 | 6444 | 0.0240 | 4501 | 0.0168 | 6435 | 0.0240 | 4485 | 0.0167 | 6408 | 0.0239 |
| 14 | 4501 | 0.0168 | 6425 | 0.0239 | 4509 | 0.0168 | 6448 | 0.0240 | 4504 | 0.0168 | 6439 | 0.0240 | 4490 | 0.0167 | 6417 | 0.0239 |
| 15 | 4502 | 0.0168 | 6428 | 0.0239 | 4511 | 0.0168 | 6451 | 0.0240 | 4506 | 0.0168 | 6444 | 0.0240 | 4494 | 0.0167 | 6424 | 0.0239 |
| 16 | 4504 | 0.0168 | 6431 | 0.0239 | 4513 | 0.0168 | 6455 | 0.0240 | 4509 | 0.0168 | 6448 | 0.0240 | 4498 | 0.0167 | 6432 | 0.0239 |
| 17 | 4505 | 0.0168 | 6433 | 0.0240 | 4515 | 0.0168 | 6458 | 0.0240 | 4511 | 0.0168 | 6453 | 0.0240 | 4502 | 0.0168 | 6439 | 0.0240 |
| 18 | 4506 | 0.0168 | 6436 | 0.0240 | 4516 | 0.0168 | 6461 | 0.0241 | 4514 | 0.0168 | 6458 | 0.0240 | 4507 | 0.0168 | 6447 | 0.0240 |
| 19 | 4508 | 0.0168 | 6438 | 0.0240 | 4518 | 0.0168 | 6465 | 0.0241 | 4516 | 0.0168 | 6463 | 0.0241 | 4510 | 0.0168 | 6454 | 0.0240 |
| 20 | 4509 | 0.0168 | 6441 | 0.0240 | 4520 | 0.0168 | 6468 | 0.0241 | 4519 | 0.0168 | 6467 | 0.0241 | 4515 | 0.0168 | 6462 | 0.0241 |
| 21 | 4511 | 0.0168 | 6444 | 0.0240 | 4522 | 0.0168 | 6472 | 0.0241 | 4521 | 0.0168 | 6472 | 0.0241 | 4519 | 0.0168 | 6470 | 0.0241 |
| 22 | 4513 | 0.0168 | 6447 | 0.0240 | 4524 | 0.0168 | 6476 | 0.0241 | 4524 | 0.0168 | 6476 | 0.0241 | 4523 | 0.0168 | 6478 | 0.0241 |
| 23 | 4514 | 0.0168 | 6449 | 0.0240 | 4526 | 0.0169 | 6479 | 0.0241 | 4527 | 0.0169 | 6482 | 0.0241 | 4527 | 0.0169 | 6485 | 0.0241 |
| 24 | 4515 | 0.0168 | 6452 | 0.0240 | 4528 | 0.0169 | 6483 | 0.0241 | 4529 | 0.0169 | 6486 | 0.0241 | 4531 | 0.0169 | 6493 | 0.0242 |

| Coilset | 8 seconds | | | | 10 seconds | | | | 15 seconds | | | | 20 seconds | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $h_{lam}$ | $Bi_{lam}$ | $h_{turb}$ | $Bi_{turb}$ | $h_{lam}$ | $Bi_{lam}$ | $h_{turb}$ | $Bi_{turb}$ | $h_{lam}$ | $Bi_{lam}$ | $h_{turb}$ | $Bi_{turb}$ | $h_{lam}$ | $Bi_{lam}$ | $h_{turb}$ | $Bi_{turb}$ |
| 1 | 4357 | 0.0162 | 6172 | 0.0230 | 4305 | 0.0160 | 6079 | 0.0226 | 4242 | 0.0158 | 5978 | 0.0223 | 4187 | 0.0156 | 5877 | 0.0219 |
| 2 | 4364 | 0.0162 | 6184 | 0.0230 | 4315 | 0.0161 | 6096 | 0.0227 | 4255 | 0.0158 | 6002 | 0.0223 | 4203 | 0.0156 | 5904 | 0.0220 |
| 3 | 4371 | 0.0163 | 6196 | 0.0231 | 4324 | 0.0161 | 6112 | 0.0228 | 4269 | 0.0159 | 6026 | 0.0224 | 4219 | 0.0157 | 5932 | 0.0221 |
| 4 | 4378 | 0.0163 | 6209 | 0.0231 | 4333 | 0.0161 | 6129 | 0.0228 | 4283 | 0.0159 | 6050 | 0.0225 | 4235 | 0.0158 | 5960 | 0.0222 |
| 5 | 4385 | 0.0163 | 6222 | 0.0232 | 4342 | 0.0162 | 6145 | 0.0229 | 4297 | 0.0160 | 6074 | 0.0226 | 4252 | 0.0158 | 5988 | 0.0223 |
| 6 | 4392 | 0.0164 | 6235 | 0.0232 | 4351 | 0.0162 | 6162 | 0.0229 | 4311 | 0.0160 | 6099 | 0.0227 | 4268 | 0.0159 | 6016 | 0.0224 |
| 7 | 4400 | 0.0164 | 6248 | 0.0233 | 4361 | 0.0162 | 6179 | 0.0230 | 4324 | 0.0161 | 6122 | 0.0228 | 4284 | 0.0160 | 6045 | 0.0225 |
| 8 | 4406 | 0.0164 | 6260 | 0.0233 | 4370 | 0.0163 | 6195 | 0.0231 | 4338 | 0.0161 | 6147 | 0.0229 | 4301 | 0.0160 | 6074 | 0.0226 |
| 9 | 4414 | 0.0164 | 6273 | 0.0234 | 4380 | 0.0163 | 6213 | 0.0231 | 4351 | 0.0162 | 6171 | 0.0230 | 4317 | 0.0161 | 6103 | 0.0227 |
| 10 | 4421 | 0.0165 | 6286 | 0.0234 | 4389 | 0.0163 | 6230 | 0.0232 | 4365 | 0.0163 | 6196 | 0.0231 | 4333 | 0.0161 | 6132 | 0.0228 |
| 11 | 4428 | 0.0165 | 6300 | 0.0235 | 4398 | 0.0164 | 6247 | 0.0233 | 4379 | 0.0163 | 6221 | 0.0232 | 4350 | 0.0162 | 6161 | 0.0229 |
| 12 | 4436 | 0.0165 | 6313 | 0.0235 | 4408 | 0.0164 | 6264 | 0.0233 | 4393 | 0.0164 | 6246 | 0.0233 | 4366 | 0.0163 | 6191 | 0.0231 |
| 13 | 4443 | 0.0165 | 6326 | 0.0236 | 4418 | 0.0164 | 6282 | 0.0234 | 4406 | 0.0164 | 6271 | 0.0233 | 4383 | 0.0163 | 6221 | 0.0232 |
| 14 | 4450 | 0.0166 | 6339 | 0.0236 | 4427 | 0.0165 | 6299 | 0.0235 | 4421 | 0.0165 | 6297 | 0.0234 | 4400 | 0.0164 | 6251 | 0.0233 |
| 15 | 4457 | 0.0166 | 6352 | 0.0237 | 4437 | 0.0165 | 6317 | 0.0235 | 4435 | 0.0165 | 6323 | 0.0235 | 4417 | 0.0164 | 6282 | 0.0234 |
| 16 | 4465 | 0.0166 | 6366 | 0.0237 | 4447 | 0.0166 | 6334 | 0.0236 | 4449 | 0.0166 | 6349 | 0.0236 | 4434 | 0.0165 | 6313 | 0.0235 |
| 17 | 4472 | 0.0167 | 6380 | 0.0238 | 4457 | 0.0166 | 6353 | 0.0237 | 4464 | 0.0166 | 6375 | 0.0237 | 4451 | 0.0166 | 6344 | 0.0236 |
| 18 | 4480 | 0.0167 | 6393 | 0.0238 | 4467 | 0.0166 | 6370 | 0.0237 | 4479 | 0.0167 | 6402 | 0.0238 | 4469 | 0.0166 | 6376 | 0.0237 |
| 19 | 4486 | 0.0167 | 6405 | 0.0238 | 4477 | 0.0167 | 6388 | 0.0238 | 4493 | 0.0167 | 6429 | 0.0239 | 4486 | 0.0167 | 6409 | 0.0239 |
| 20 | 4493 | 0.0167 | 6417 | 0.0239 | 4486 | 0.0167 | 6406 | 0.0239 | 4507 | 0.0168 | 6454 | 0.0240 | 4502 | 0.0168 | 6437 | 0.0240 |
| 21 | 4500 | 0.0168 | 6429 | 0.0239 | 4495 | 0.0167 | 6422 | 0.0239 | 4521 | 0.0168 | 6479 | 0.0241 | 4518 | 0.0168 | 6466 | 0.0241 |
| 22 | 4506 | 0.0168 | 6442 | 0.0240 | 4504 | 0.0168 | 6439 | 0.0240 | 4534 | 0.0169 | 6503 | 0.0242 | 4534 | 0.0169 | 6496 | 0.0242 |
| 23 | 4513 | 0.0168 | 6453 | 0.0240 | 4513 | 0.0168 | 6455 | 0.0240 | 4547 | 0.0169 | 6527 | 0.0243 | 4550 | 0.0169 | 6526 | 0.0243 |
| 24 | 4519 | 0.0168 | 6466 | 0.0241 | 4522 | 0.0168 | 6472 | 0.0241 | 4561 | 0.0170 | 6553 | 0.0244 | 4566 | 0.0170 | 6555 | 0.0244 |

| Coilset | 30 seconds | | | | 50 seconds | | | | 100 seconds | | | | 200 seconds | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $h_{lam}$ | $Bi_{lam}$ | $h_{turb}$ | $Bi_{turb}$ | $h_{lam}$ | $Bi_{lam}$ | $h_{turb}$ | $Bi_{turb}$ | $h_{lam}$ | $Bi_{lam}$ | $h_{turb}$ | $Bi_{turb}$ | $h_{lam}$ | $Bi_{lam}$ | $h_{turb}$ | $Bi_{turb}$ |
| 1 | 4138 | 0.0154 | 5796 | 0.0216 | 4081 | 0.0152 | 5687 | 0.0212 | 4053 | 0.0151 | 5635 | 0.0210 | 4057 | 0.0151 | 5648 | 0.0210 |
| 2 | 4156 | 0.0155 | 5828 | 0.0217 | 4107 | 0.0153 | 5735 | 0.0214 | 4079 | 0.0152 | 5683 | 0.0212 | 4084 | 0.0152 | 5697 | 0.0212 |
| 3 | 4175 | 0.0155 | 5860 | 0.0218 | 4129 | 0.0154 | 5775 | 0.0215 | 4106 | 0.0153 | 5732 | 0.0213 | 4110 | 0.0153 | 5747 | 0.0214 |
| 4 | 4193 | 0.0156 | 5892 | 0.0219 | 4149 | 0.0154 | 5808 | 0.0216 | 4129 | 0.0154 | 5775 | 0.0215 | 4136 | 0.0154 | 5794 | 0.0216 |
| 5 | 4212 | 0.0157 | 5925 | 0.0221 | 4168 | 0.0155 | 5842 | 0.0217 | 4149 | 0.0154 | 5808 | 0.0216 | 4156 | 0.0155 | 5828 | 0.0217 |
| 6 | 4232 | 0.0158 | 5959 | 0.0222 | 4188 | 0.0156 | 5876 | 0.0219 | 4168 | 0.0155 | 5842 | 0.0218 | 4176 | 0.0155 | 5863 | 0.0218 |
| 7 | 4251 | 0.0158 | 5992 | 0.0223 | 4207 | 0.0157 | 5910 | 0.0220 | 4189 | 0.0156 | 5878 | 0.0219 | 4196 | 0.0156 | 5898 | 0.0220 |
| 8 | 4271 | 0.0159 | 6027 | 0.0224 | 4227 | 0.0157 | 5945 | 0.0221 | 4209 | 0.0157 | 5913 | 0.0220 | 4217 | 0.0157 | 5934 | 0.0221 |
| 9 | 4290 | 0.0160 | 6061 | 0.0226 | 4248 | 0.0158 | 5980 | 0.0223 | 4230 | 0.0157 | 5949 | 0.0221 | 4237 | 0.0158 | 5970 | 0.0222 |
| 10 | 4311 | 0.0160 | 6096 | 0.0227 | 4268 | 0.0159 | 6016 | 0.0224 | 4250 | 0.0158 | 5985 | 0.0223 | 4259 | 0.0159 | 6007 | 0.0224 |
| 11 | 4330 | 0.0161 | 6131 | 0.0228 | 4289 | 0.0160 | 6052 | 0.0225 | 4271 | 0.0159 | 6021 | 0.0224 | 4280 | 0.0159 | 6044 | 0.0225 |
| 12 | 4349 | 0.0162 | 6165 | 0.0230 | 4310 | 0.0160 | 6088 | 0.0227 | 4293 | 0.0160 | 6059 | 0.0226 | 4301 | 0.0160 | 6081 | 0.0226 |
| 13 | 4369 | 0.0163 | 6201 | 0.0231 | 4330 | 0.0161 | 6125 | 0.0228 | 4313 | 0.0161 | 6095 | 0.0227 | 4323 | 0.0161 | 6119 | 0.0228 |
| 14 | 4389 | 0.0163 | 6237 | 0.0232 | 4351 | 0.0162 | 6162 | 0.0229 | 4334 | 0.0161 | 6133 | 0.0228 | 4344 | 0.0162 | 6157 | 0.0229 |
| 15 | 4409 | 0.0164 | 6273 | 0.0234 | 4371 | 0.0163 | 6199 | 0.0231 | 4355 | 0.0162 | 6170 | 0.0230 | 4365 | 0.0163 | 6195 | 0.0231 |
| 16 | 4430 | 0.0165 | 6311 | 0.0235 | 4392 | 0.0164 | 6237 | 0.0232 | 4376 | 0.0163 | 6208 | 0.0231 | 4386 | 0.0163 | 6234 | 0.0232 |
| 17 | 4450 | 0.0166 | 6348 | 0.0236 | 4413 | 0.0164 | 6275 | 0.0234 | 4398 | 0.0164 | 6248 | 0.0233 | 4408 | 0.0164 | 6273 | 0.0234 |
| 18 | 4471 | 0.0166 | 6386 | 0.0238 | 4435 | 0.0165 | 6314 | 0.0235 | 4420 | 0.0165 | 6287 | 0.0234 | 4430 | 0.0165 | 6313 | 0.0235 |
| 19 | 4492 | 0.0167 | 6424 | 0.0239 | 4457 | 0.0166 | 6353 | 0.0237 | 4442 | 0.0165 | 6327 | 0.0236 | 4453 | 0.0166 | 6354 | 0.0237 |
| 20 | 4512 | 0.0168 | 6460 | 0.0241 | 4479 | 0.0167 | 6394 | 0.0238 | 4464 | 0.0166 | 6368 | 0.0237 | 4475 | 0.0167 | 6395 | 0.0238 |
| 21 | 4531 | 0.0169 | 6495 | 0.0242 | 4499 | 0.0168 | 6431 | 0.0239 | 4487 | 0.0167 | 6408 | 0.0239 | 4498 | 0.0167 | 6437 | 0.0240 |
| 22 | 4550 | 0.0169 | 6530 | 0.0243 | 4519 | 0.0168 | 6467 | 0.0241 | 4507 | 0.0168 | 6446 | 0.0240 | 4519 | 0.0168 | 6474 | 0.0241 |
| 23 | 4569 | 0.0170 | 6566 | 0.0244 | 4539 | 0.0169 | 6504 | 0.0242 | 4527 | 0.0169 | 6483 | 0.0241 | 4539 | 0.0169 | 6512 | 0.0242 |
| 24 | 4589 | 0.0171 | 6602 | 0.0246 | 4559 | 0.0170 | 6541 | 0.0244 | 4548 | 0.0169 | 6521 | 0.0243 | 4560 | 0.0170 | 6551 | 0.0244 |

**Table H10: Heat transfer coefficients and Biot number approximations for R3-60 at 9LPM**

| Coilset | 1 second | | | | 2 seconds | | | | 3 seconds | | | | 5 seconds | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $h_{lam}$ | $Bi_{lam}$ | $h_{turb}$ | $Bi_{turb}$ | $h_{lam}$ | $Bi_{lam}$ | $h_{turb}$ | $Bi_{turb}$ | $h_{lam}$ | $Bi_{lam}$ | $h_{turb}$ | $Bi_{turb}$ | $h_{lam}$ | $Bi_{lam}$ | $h_{turb}$ | $Bi_{turb}$ |
| 1 | 4239 | 0.0158 | 5826 | 0.0217 | 4226 | 0.0157 | 5805 | 0.0216 | 4213 | 0.0157 | 5785 | 0.0215 | 4192 | 0.0156 | 5759 | 0.0214 |
| 2 | 4240 | 0.0158 | 5828 | 0.0217 | 4228 | 0.0157 | 5809 | 0.0216 | 4216 | 0.0157 | 5790 | 0.0216 | 4197 | 0.0156 | 5767 | 0.0215 |
| 3 | 4241 | 0.0158 | 5830 | 0.0217 | 4230 | 0.0157 | 5813 | 0.0216 | 4218 | 0.0157 | 5794 | 0.0216 | 4202 | 0.0156 | 5775 | 0.0215 |
| 4 | 4243 | 0.0158 | 5832 | 0.0217 | 4232 | 0.0158 | 5817 | 0.0217 | 4221 | 0.0157 | 5800 | 0.0216 | 4206 | 0.0157 | 5783 | 0.0215 |
| 5 | 4244 | 0.0158 | 5834 | 0.0217 | 4235 | 0.0158 | 5820 | 0.0217 | 4224 | 0.0157 | 5805 | 0.0216 | 4210 | 0.0157 | 5791 | 0.0216 |
| 6 | 4245 | 0.0158 | 5837 | 0.0217 | 4237 | 0.0158 | 5824 | 0.0217 | 4227 | 0.0157 | 5810 | 0.0216 | 4215 | 0.0157 | 5798 | 0.0216 |
| 7 | 4246 | 0.0158 | 5838 | 0.0217 | 4239 | 0.0158 | 5828 | 0.0217 | 4230 | 0.0157 | 5815 | 0.0217 | 4219 | 0.0157 | 5807 | 0.0216 |
| 8 | 4248 | 0.0158 | 5841 | 0.0217 | 4241 | 0.0158 | 5832 | 0.0217 | 4233 | 0.0158 | 5820 | 0.0217 | 4224 | 0.0157 | 5814 | 0.0216 |
| 9 | 4249 | 0.0158 | 5843 | 0.0218 | 4243 | 0.0158 | 5836 | 0.0217 | 4236 | 0.0158 | 5825 | 0.0217 | 4228 | 0.0157 | 5822 | 0.0217 |
| 10 | 4250 | 0.0158 | 5845 | 0.0218 | 4245 | 0.0158 | 5839 | 0.0217 | 4239 | 0.0158 | 5830 | 0.0217 | 4233 | 0.0158 | 5830 | 0.0217 |
| 11 | 4251 | 0.0158 | 5847 | 0.0218 | 4247 | 0.0158 | 5842 | 0.0218 | 4242 | 0.0158 | 5836 | 0.0217 | 4238 | 0.0158 | 5838 | 0.0217 |
| 12 | 4253 | 0.0158 | 5850 | 0.0218 | 4249 | 0.0158 | 5846 | 0.0218 | 4245 | 0.0158 | 5841 | 0.0217 | 4242 | 0.0158 | 5846 | 0.0218 |
| 13 | 4254 | 0.0158 | 5852 | 0.0218 | 4251 | 0.0158 | 5849 | 0.0218 | 4247 | 0.0158 | 5845 | 0.0218 | 4247 | 0.0158 | 5854 | 0.0218 |
| 14 | 4255 | 0.0158 | 5854 | 0.0218 | 4253 | 0.0158 | 5853 | 0.0218 | 4250 | 0.0158 | 5850 | 0.0218 | 4251 | 0.0158 | 5862 | 0.0218 |
| 15 | 4256 | 0.0158 | 5856 | 0.0218 | 4255 | 0.0158 | 5855 | 0.0218 | 4253 | 0.0158 | 5855 | 0.0218 | 4256 | 0.0158 | 5870 | 0.0219 |
| 16 | 4258 | 0.0159 | 5858 | 0.0218 | 4257 | 0.0158 | 5859 | 0.0218 | 4256 | 0.0158 | 5860 | 0.0218 | 4260 | 0.0159 | 5878 | 0.0219 |
| 17 | 4259 | 0.0159 | 5861 | 0.0218 | 4259 | 0.0159 | 5863 | 0.0218 | 4258 | 0.0159 | 5864 | 0.0218 | 4265 | 0.0159 | 5886 | 0.0219 |
| 18 | 4260 | 0.0159 | 5863 | 0.0218 | 4261 | 0.0159 | 5866 | 0.0218 | 4260 | 0.0159 | 5868 | 0.0218 | 4269 | 0.0159 | 5894 | 0.0219 |
| 19 | 4261 | 0.0159 | 5865 | 0.0218 | 4262 | 0.0159 | 5869 | 0.0219 | 4263 | 0.0159 | 5873 | 0.0219 | 4273 | 0.0159 | 5901 | 0.0220 |
| 20 | 4263 | 0.0159 | 5867 | 0.0218 | 4264 | 0.0159 | 5873 | 0.0219 | 4266 | 0.0159 | 5878 | 0.0219 | 4277 | 0.0159 | 5908 | 0.0220 |
| 21 | 4264 | 0.0159 | 5870 | 0.0219 | 4266 | 0.0159 | 5876 | 0.0219 | 4268 | 0.0159 | 5883 | 0.0219 | 4281 | 0.0159 | 5916 | 0.0220 |
| 22 | 4265 | 0.0159 | 5872 | 0.0219 | 4268 | 0.0159 | 5880 | 0.0219 | 4271 | 0.0159 | 5887 | 0.0219 | 4285 | 0.0160 | 5923 | 0.0221 |
| 23 | 4266 | 0.0159 | 5874 | 0.0219 | 4270 | 0.0159 | 5883 | 0.0219 | 4274 | 0.0159 | 5891 | 0.0219 | 4290 | 0.0160 | 5930 | 0.0221 |
| 24 | 4268 | 0.0159 | 5876 | 0.0219 | 4272 | 0.0159 | 5886 | 0.0219 | 4276 | 0.0159 | 5896 | 0.0220 | 4294 | 0.0160 | 5938 | 0.0221 |

| Coilset | 8 seconds | | | | 10 seconds | | | | 15 seconds | | | | 20 seconds | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $h_{lam}$ | $Bi_{lam}$ | $h_{turb}$ | $Bi_{turb}$ | $h_{lam}$ | $Bi_{lam}$ | $h_{turb}$ | $Bi_{turb}$ | $h_{lam}$ | $Bi_{lam}$ | $h_{turb}$ | $Bi_{turb}$ | $h_{lam}$ | $Bi_{lam}$ | $h_{turb}$ | $Bi_{turb}$ |
| 1 | 4124 | 0.0154 | 5638 | 0.0210 | 4077 | 0.0152 | 5555 | 0.0207 | 4032 | 0.0150 | 5485 | 0.0204 | 3999 | 0.0149 | 5436 | 0.0202 |
| 2 | 4131 | 0.0154 | 5650 | 0.0210 | 4087 | 0.0152 | 5571 | 0.0207 | 4044 | 0.0151 | 5505 | 0.0205 | 4014 | 0.0149 | 5462 | 0.0203 |
| 3 | 4138 | 0.0154 | 5663 | 0.0211 | 4095 | 0.0152 | 5587 | 0.0208 | 4057 | 0.0151 | 5526 | 0.0206 | 4029 | 0.0150 | 5487 | 0.0204 |
| 4 | 4145 | 0.0154 | 5675 | 0.0211 | 4105 | 0.0153 | 5603 | 0.0209 | 4069 | 0.0151 | 5547 | 0.0207 | 4045 | 0.0151 | 5513 | 0.0205 |
| 5 | 4152 | 0.0155 | 5688 | 0.0212 | 4114 | 0.0153 | 5618 | 0.0209 | 4082 | 0.0152 | 5569 | 0.0207 | 4061 | 0.0151 | 5540 | 0.0206 |
| 6 | 4159 | 0.0155 | 5701 | 0.0212 | 4123 | 0.0153 | 5634 | 0.0210 | 4094 | 0.0152 | 5590 | 0.0208 | 4076 | 0.0152 | 5566 | 0.0207 |
| 7 | 4167 | 0.0155 | 5714 | 0.0213 | 4132 | 0.0154 | 5650 | 0.0210 | 4106 | 0.0153 | 5611 | 0.0209 | 4092 | 0.0152 | 5593 | 0.0208 |
| 8 | 4174 | 0.0155 | 5726 | 0.0213 | 4141 | 0.0154 | 5666 | 0.0211 | 4119 | 0.0153 | 5632 | 0.0210 | 4108 | 0.0153 | 5619 | 0.0209 |
| 9 | 4182 | 0.0156 | 5739 | 0.0214 | 4150 | 0.0155 | 5682 | 0.0212 | 4131 | 0.0154 | 5653 | 0.0210 | 4123 | 0.0154 | 5646 | 0.0210 |
| 10 | 4189 | 0.0156 | 5752 | 0.0214 | 4160 | 0.0155 | 5699 | 0.0212 | 4144 | 0.0154 | 5675 | 0.0211 | 4139 | 0.0154 | 5673 | 0.0211 |
| 11 | 4196 | 0.0156 | 5765 | 0.0215 | 4169 | 0.0155 | 5715 | 0.0213 | 4156 | 0.0155 | 5697 | 0.0212 | 4154 | 0.0155 | 5700 | 0.0212 |
| 12 | 4204 | 0.0157 | 5778 | 0.0215 | 4179 | 0.0156 | 5732 | 0.0213 | 4169 | 0.0155 | 5719 | 0.0213 | 4170 | 0.0155 | 5728 | 0.0213 |
| 13 | 4211 | 0.0157 | 5791 | 0.0216 | 4188 | 0.0156 | 5748 | 0.0214 | 4181 | 0.0156 | 5741 | 0.0214 | 4186 | 0.0156 | 5756 | 0.0214 |
| 14 | 4219 | 0.0157 | 5804 | 0.0216 | 4198 | 0.0156 | 5765 | 0.0215 | 4194 | 0.0156 | 5764 | 0.0215 | 4202 | 0.0156 | 5784 | 0.0215 |
| 15 | 4226 | 0.0157 | 5817 | 0.0217 | 4208 | 0.0157 | 5782 | 0.0215 | 4207 | 0.0157 | 5787 | 0.0215 | 4218 | 0.0157 | 5812 | 0.0216 |
| 16 | 4234 | 0.0158 | 5830 | 0.0217 | 4217 | 0.0157 | 5799 | 0.0216 | 4221 | 0.0157 | 5810 | 0.0216 | 4235 | 0.0158 | 5841 | 0.0217 |
| 17 | 4242 | 0.0158 | 5844 | 0.0218 | 4227 | 0.0157 | 5816 | 0.0217 | 4234 | 0.0158 | 5832 | 0.0217 | 4251 | 0.0158 | 5870 | 0.0219 |
| 18 | 4249 | 0.0158 | 5857 | 0.0218 | 4237 | 0.0158 | 5834 | 0.0217 | 4247 | 0.0158 | 5856 | 0.0218 | 4268 | 0.0159 | 5900 | 0.0220 |
| 19 | 4257 | 0.0158 | 5871 | 0.0219 | 4247 | 0.0158 | 5851 | 0.0218 | 4260 | 0.0159 | 5880 | 0.0219 | 4284 | 0.0160 | 5928 | 0.0221 |
| 20 | 4265 | 0.0159 | 5884 | 0.0219 | 4257 | 0.0158 | 5869 | 0.0218 | 4273 | 0.0159 | 5902 | 0.0220 | 4299 | 0.0160 | 5955 | 0.0222 |
| 21 | 4272 | 0.0159 | 5897 | 0.0220 | 4266 | 0.0159 | 5884 | 0.0219 | 4285 | 0.0160 | 5923 | 0.0221 | 4315 | 0.0161 | 5982 | 0.0223 |
| 22 | 4278 | 0.0159 | 5909 | 0.0220 | 4275 | 0.0159 | 5900 | 0.0220 | 4297 | 0.0160 | 5945 | 0.0221 | 4330 | 0.0161 | 6010 | 0.0224 |
| 23 | 4285 | 0.0160 | 5921 | 0.0220 | 4284 | 0.0159 | 5916 | 0.0220 | 4309 | 0.0160 | 5966 | 0.0222 | 4345 | 0.0162 | 6037 | 0.0225 |
| 24 | 4292 | 0.0160 | 5933 | 0.0221 | 4293 | 0.0160 | 5932 | 0.0221 | 4321 | 0.0161 | 5988 | 0.0223 | 4361 | 0.0162 | 6065 | 0.0226 |

| Coilset | 30 seconds | | | | 50 seconds | | | | 100 seconds | | | | 200 seconds | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $h_{lam}$ | $Bi_{lam}$ | $h_{turb}$ | $Bi_{turb}$ | $h_{lam}$ | $Bi_{lam}$ | $h_{turb}$ | $Bi_{turb}$ | $h_{lam}$ | $Bi_{lam}$ | $h_{turb}$ | $Bi_{turb}$ | $h_{lam}$ | $Bi_{lam}$ | $h_{turb}$ | $Bi_{turb}$ |
| 1 | 3958 | 0.0147 | 5373 | 0.0200 | 3907 | 0.0145 | 5279 | 0.0197 | 3885 | 0.0145 | 5242 | 0.0195 | 3861 | 0.0144 | 5192 | 0.0193 |
| 2 | 3976 | 0.0148 | 5403 | 0.0201 | 3932 | 0.0146 | 5324 | 0.0198 | 3910 | 0.0146 | 5287 | 0.0197 | 3887 | 0.0145 | 5239 | 0.0195 |
| 3 | 3994 | 0.0149 | 5433 | 0.0202 | 3950 | 0.0147 | 5355 | 0.0199 | 3936 | 0.0147 | 5335 | 0.0199 | 3913 | 0.0146 | 5286 | 0.0197 |
| 4 | 4012 | 0.0149 | 5463 | 0.0203 | 3969 | 0.0148 | 5386 | 0.0201 | 3955 | 0.0147 | 5367 | 0.0200 | 3935 | 0.0146 | 5323 | 0.0198 |
| 5 | 4030 | 0.0150 | 5494 | 0.0205 | 3988 | 0.0148 | 5418 | 0.0202 | 3975 | 0.0148 | 5399 | 0.0201 | 3954 | 0.0147 | 5356 | 0.0199 |
| 6 | 4049 | 0.0151 | 5525 | 0.0206 | 4007 | 0.0149 | 5450 | 0.0203 | 3994 | 0.0149 | 5432 | 0.0202 | 3974 | 0.0148 | 5389 | 0.0201 |
| 7 | 4068 | 0.0151 | 5557 | 0.0207 | 4027 | 0.0150 | 5483 | 0.0204 | 4014 | 0.0149 | 5465 | 0.0203 | 3993 | 0.0149 | 5422 | 0.0202 |
| 8 | 4087 | 0.0152 | 5589 | 0.0208 | 4046 | 0.0151 | 5516 | 0.0205 | 4034 | 0.0150 | 5498 | 0.0205 | 4014 | 0.0149 | 5456 | 0.0203 |
| 9 | 4106 | 0.0153 | 5621 | 0.0209 | 4066 | 0.0151 | 5549 | 0.0207 | 4054 | 0.0151 | 5533 | 0.0206 | 4034 | 0.0150 | 5490 | 0.0204 |
| 10 | 4124 | 0.0154 | 5653 | 0.0210 | 4086 | 0.0152 | 5583 | 0.0208 | 4074 | 0.0152 | 5567 | 0.0207 | 4054 | 0.0151 | 5524 | 0.0206 |
| 11 | 4143 | 0.0154 | 5686 | 0.0212 | 4106 | 0.0153 | 5617 | 0.0209 | 4095 | 0.0152 | 5602 | 0.0209 | 4076 | 0.0152 | 5559 | 0.0207 |
| 12 | 4162 | 0.0155 | 5718 | 0.0213 | 4126 | 0.0154 | 5651 | 0.0210 | 4116 | 0.0153 | 5637 | 0.0210 | 4096 | 0.0153 | 5595 | 0.0208 |
| 13 | 4181 | 0.0156 | 5752 | 0.0214 | 4146 | 0.0154 | 5686 | 0.0212 | 4136 | 0.0154 | 5672 | 0.0211 | 4117 | 0.0153 | 5630 | 0.0210 |
| 14 | 4200 | 0.0156 | 5786 | 0.0215 | 4166 | 0.0155 | 5721 | 0.0213 | 4156 | 0.0155 | 5707 | 0.0212 | 4137 | 0.0154 | 5665 | 0.0211 |
| 15 | 4220 | 0.0157 | 5820 | 0.0217 | 4186 | 0.0156 | 5756 | 0.0214 | 4177 | 0.0156 | 5744 | 0.0214 | 4158 | 0.0155 | 5702 | 0.0212 |
| 16 | 4239 | 0.0158 | 5854 | 0.0218 | 4207 | 0.0157 | 5792 | 0.0216 | 4198 | 0.0156 | 5780 | 0.0215 | 4179 | 0.0156 | 5738 | 0.0214 |
| 17 | 4259 | 0.0159 | 5889 | 0.0219 | 4228 | 0.0157 | 5829 | 0.0217 | 4219 | 0.0157 | 5817 | 0.0217 | 4200 | 0.0156 | 5775 | 0.0215 |
| 18 | 4280 | 0.0159 | 5925 | 0.0221 | 4249 | 0.0158 | 5866 | 0.0218 | 4240 | 0.0158 | 5855 | 0.0218 | 4222 | 0.0157 | 5814 | 0.0216 |
| 19 | 4299 | 0.0160 | 5959 | 0.0222 | 4270 | 0.0159 | 5903 | 0.0220 | 4262 | 0.0159 | 5893 | 0.0219 | 4244 | 0.0158 | 5852 | 0.0218 |
| 20 | 4317 | 0.0161 | 5991 | 0.0223 | 4290 | 0.0160 | 5939 | 0.0221 | 4284 | 0.0160 | 5932 | 0.0221 | 4266 | 0.0159 | 5891 | 0.0219 |
| 21 | 4335 | 0.0161 | 6024 | 0.0224 | 4310 | 0.0160 | 5973 | 0.0222 | 4304 | 0.0160 | 5967 | 0.0222 | 4287 | 0.0160 | 5927 | 0.0221 |
| 22 | 4354 | 0.0162 | 6057 | 0.0225 | 4329 | 0.0161 | 6008 | 0.0224 | 4324 | 0.0161 | 6002 | 0.0223 | 4307 | 0.0160 | 5963 | 0.0222 |
| 23 | 4373 | 0.0163 | 6091 | 0.0227 | 4349 | 0.0162 | 6043 | 0.0225 | 4344 | 0.0162 | 6038 | 0.0225 | 4327 | 0.0161 | 5999 | 0.0223 |
| 24 | 4392 | 0.0164 | 6125 | 0.0228 | 4369 | 0.0163 | 6078 | 0.0226 | 4364 | 0.0162 | 6074 | 0.0226 | 4347 | 0.0162 | 6035 | 0.0225 |

**Table H11: Heat transfer coefficients and Biot number approximations for R3-60 at 7LPM**

| Coilset | 1 second | | | | 2 seconds | | | | 3 seconds | | | | 5 seconds | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $h_{lam}$ | $Bi_{lam}$ | $h_{turb}$ | $Bi_{turb}$ | $h_{lam}$ | $Bi_{lam}$ | $h_{turb}$ | $Bi_{turb}$ | $h_{lam}$ | $Bi_{lam}$ | $h_{turb}$ | $Bi_{turb}$ | $h_{lam}$ | $Bi_{lam}$ | $h_{turb}$ | $Bi_{turb}$ |
| 1 | 3791 | 0.0141 | 4823 | 0.0180 | 3793 | 0.0141 | 4830 | 0.0180 | 3793 | 0.0141 | 4836 | 0.0180 | 3788 | 0.0141 | 4830 | 0.0180 |
| 2 | 3791 | 0.0141 | 4824 | 0.0180 | 3794 | 0.0141 | 4831 | 0.0180 | 3794 | 0.0141 | 4838 | 0.0180 | 3790 | 0.0141 | 4833 | 0.0180 |
| 3 | 3792 | 0.0141 | 4825 | 0.0180 | 3795 | 0.0141 | 4832 | 0.0180 | 3796 | 0.0141 | 4841 | 0.0180 | 3792 | 0.0141 | 4836 | 0.0180 |
| 4 | 3792 | 0.0141 | 4826 | 0.0180 | 3795 | 0.0141 | 4833 | 0.0180 | 3797 | 0.0141 | 4843 | 0.0180 | 3793 | 0.0141 | 4839 | 0.0180 |
| 5 | 3793 | 0.0141 | 4827 | 0.0180 | 3796 | 0.0141 | 4834 | 0.0180 | 3799 | 0.0141 | 4845 | 0.0180 | 3795 | 0.0141 | 4842 | 0.0180 |
| 6 | 3793 | 0.0141 | 4828 | 0.0180 | 3797 | 0.0141 | 4835 | 0.0180 | 3800 | 0.0141 | 4847 | 0.0180 | 3797 | 0.0141 | 4845 | 0.0180 |
| 7 | 3794 | 0.0141 | 4829 | 0.0180 | 3797 | 0.0141 | 4836 | 0.0180 | 3801 | 0.0142 | 4849 | 0.0181 | 3798 | 0.0141 | 4847 | 0.0180 |
| 8 | 3794 | 0.0141 | 4829 | 0.0180 | 3798 | 0.0141 | 4837 | 0.0180 | 3802 | 0.0142 | 4851 | 0.0181 | 3800 | 0.0141 | 4851 | 0.0181 |
| 9 | 3795 | 0.0141 | 4830 | 0.0180 | 3798 | 0.0141 | 4838 | 0.0180 | 3803 | 0.0142 | 4852 | 0.0181 | 3802 | 0.0142 | 4853 | 0.0181 |
| 10 | 3796 | 0.0141 | 4831 | 0.0180 | 3799 | 0.0141 | 4839 | 0.0180 | 3804 | 0.0142 | 4854 | 0.0181 | 3804 | 0.0142 | 4856 | 0.0181 |
| 11 | 3796 | 0.0141 | 4832 | 0.0180 | 3800 | 0.0141 | 4840 | 0.0180 | 3805 | 0.0142 | 4856 | 0.0181 | 3805 | 0.0142 | 4859 | 0.0181 |
| 12 | 3797 | 0.0141 | 4833 | 0.0180 | 3800 | 0.0141 | 4841 | 0.0180 | 3807 | 0.0142 | 4858 | 0.0181 | 3807 | 0.0142 | 4861 | 0.0181 |
| 13 | 3797 | 0.0141 | 4833 | 0.0180 | 3801 | 0.0142 | 4843 | 0.0180 | 3808 | 0.0142 | 4860 | 0.0181 | 3809 | 0.0142 | 4864 | 0.0181 |
| 14 | 3798 | 0.0141 | 4834 | 0.0180 | 3802 | 0.0142 | 4844 | 0.0180 | 3809 | 0.0142 | 4862 | 0.0181 | 3810 | 0.0142 | 4866 | 0.0181 |
| 15 | 3798 | 0.0141 | 4835 | 0.0180 | 3802 | 0.0142 | 4845 | 0.0180 | 3810 | 0.0142 | 4864 | 0.0181 | 3812 | 0.0142 | 4869 | 0.0181 |
| 16 | 3799 | 0.0141 | 4836 | 0.0180 | 3803 | 0.0142 | 4846 | 0.0180 | 3811 | 0.0142 | 4866 | 0.0181 | 3813 | 0.0142 | 4871 | 0.0181 |
| 17 | 3799 | 0.0141 | 4837 | 0.0180 | 3803 | 0.0142 | 4846 | 0.0180 | 3813 | 0.0142 | 4868 | 0.0181 | 3814 | 0.0142 | 4874 | 0.0181 |
| 18 | 3800 | 0.0141 | 4838 | 0.0180 | 3804 | 0.0142 | 4847 | 0.0180 | 3814 | 0.0142 | 4870 | 0.0181 | 3816 | 0.0142 | 4877 | 0.0182 |
| 19 | 3800 | 0.0141 | 4839 | 0.0180 | 3805 | 0.0142 | 4848 | 0.0181 | 3815 | 0.0142 | 4871 | 0.0181 | 3818 | 0.0142 | 4879 | 0.0182 |
| 20 | 3801 | 0.0142 | 4840 | 0.0180 | 3805 | 0.0142 | 4849 | 0.0181 | 3816 | 0.0142 | 4873 | 0.0181 | 3819 | 0.0142 | 4882 | 0.0182 |
| 21 | 3802 | 0.0142 | 4841 | 0.0180 | 3806 | 0.0142 | 4851 | 0.0181 | 3817 | 0.0142 | 4875 | 0.0182 | 3821 | 0.0142 | 4884 | 0.0182 |
| 22 | 3802 | 0.0142 | 4842 | 0.0180 | 3807 | 0.0142 | 4852 | 0.0181 | 3818 | 0.0142 | 4877 | 0.0182 | 3822 | 0.0142 | 4886 | 0.0182 |
| 23 | 3802 | 0.0142 | 4842 | 0.0180 | 3807 | 0.0142 | 4853 | 0.0181 | 3819 | 0.0142 | 4879 | 0.0182 | 3824 | 0.0142 | 4889 | 0.0182 |
| 24 | 3803 | 0.0142 | 4843 | 0.0180 | 3808 | 0.0142 | 4854 | 0.0181 | 3821 | 0.0142 | 4881 | 0.0182 | 3826 | 0.0142 | 4892 | 0.0182 |

| Coilset | 8 seconds | | | | 10 seconds | | | | 15 seconds | | | | 20 seconds | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $h_{lam}$ | $Bi_{lam}$ | $h_{turb}$ | $Bi_{turb}$ | $h_{lam}$ | $Bi_{lam}$ | $h_{turb}$ | $Bi_{turb}$ | $h_{lam}$ | $Bi_{lam}$ | $h_{turb}$ | $Bi_{turb}$ | $h_{lam}$ | $Bi_{lam}$ | $h_{turb}$ | $Bi_{turb}$ |
| 1 | 3766 | 0.0140 | 4809 | 0.0179 | 3744 | 0.0139 | 4775 | 0.0178 | 3650 | 0.0136 | 4612 | 0.0172 | 3621 | 0.0135 | 4573 | 0.0170 |
| 2 | 3769 | 0.0140 | 4814 | 0.0179 | 3749 | 0.0140 | 4783 | 0.0178 | 3658 | 0.0136 | 4624 | 0.0172 | 3632 | 0.0135 | 4590 | 0.0171 |
| 3 | 3773 | 0.0140 | 4821 | 0.0179 | 3754 | 0.0140 | 4790 | 0.0178 | 3666 | 0.0136 | 4637 | 0.0173 | 3643 | 0.0136 | 4607 | 0.0172 |
| 4 | 3777 | 0.0141 | 4827 | 0.0180 | 3758 | 0.0140 | 4798 | 0.0179 | 3674 | 0.0137 | 4650 | 0.0173 | 3654 | 0.0136 | 4624 | 0.0172 |
| 5 | 3781 | 0.0141 | 4833 | 0.0180 | 3763 | 0.0140 | 4806 | 0.0179 | 3682 | 0.0137 | 4663 | 0.0174 | 3665 | 0.0136 | 4640 | 0.0173 |
| 6 | 3784 | 0.0141 | 4839 | 0.0180 | 3768 | 0.0140 | 4814 | 0.0179 | 3690 | 0.0137 | 4676 | 0.0174 | 3675 | 0.0137 | 4657 | 0.0173 |
| 7 | 3788 | 0.0141 | 4846 | 0.0180 | 3773 | 0.0140 | 4822 | 0.0180 | 3698 | 0.0138 | 4689 | 0.0175 | 3686 | 0.0137 | 4674 | 0.0174 |
| 8 | 3792 | 0.0141 | 4852 | 0.0181 | 3777 | 0.0141 | 4829 | 0.0180 | 3706 | 0.0138 | 4702 | 0.0175 | 3696 | 0.0138 | 4691 | 0.0175 |
| 9 | 3796 | 0.0141 | 4858 | 0.0181 | 3782 | 0.0141 | 4837 | 0.0180 | 3714 | 0.0138 | 4715 | 0.0176 | 3707 | 0.0138 | 4708 | 0.0175 |
| 10 | 3800 | 0.0141 | 4865 | 0.0181 | 3787 | 0.0141 | 4845 | 0.0180 | 3723 | 0.0139 | 4729 | 0.0176 | 3717 | 0.0138 | 4726 | 0.0176 |
| 11 | 3804 | 0.0142 | 4871 | 0.0181 | 3792 | 0.0141 | 4853 | 0.0181 | 3731 | 0.0139 | 4742 | 0.0177 | 3729 | 0.0139 | 4743 | 0.0177 |
| 12 | 3808 | 0.0142 | 4877 | 0.0182 | 3797 | 0.0141 | 4862 | 0.0181 | 3739 | 0.0139 | 4756 | 0.0177 | 3739 | 0.0139 | 4761 | 0.0177 |
| 13 | 3812 | 0.0142 | 4884 | 0.0182 | 3802 | 0.0142 | 4869 | 0.0181 | 3748 | 0.0140 | 4769 | 0.0178 | 3750 | 0.0140 | 4779 | 0.0178 |
| 14 | 3816 | 0.0142 | 4890 | 0.0182 | 3807 | 0.0142 | 4877 | 0.0182 | 3756 | 0.0140 | 4783 | 0.0178 | 3761 | 0.0140 | 4797 | 0.0179 |
| 15 | 3819 | 0.0142 | 4896 | 0.0182 | 3812 | 0.0142 | 4885 | 0.0182 | 3765 | 0.0140 | 4796 | 0.0179 | 3773 | 0.0140 | 4815 | 0.0179 |
| 16 | 3823 | 0.0142 | 4903 | 0.0183 | 3817 | 0.0142 | 4894 | 0.0182 | 3773 | 0.0140 | 4810 | 0.0179 | 3784 | 0.0141 | 4833 | 0.0180 |
| 17 | 3828 | 0.0143 | 4910 | 0.0183 | 3822 | 0.0142 | 4902 | 0.0182 | 3782 | 0.0141 | 4824 | 0.0180 | 3795 | 0.0141 | 4852 | 0.0181 |
| 18 | 3831 | 0.0143 | 4916 | 0.0183 | 3827 | 0.0142 | 4910 | 0.0183 | 3790 | 0.0141 | 4838 | 0.0180 | 3807 | 0.0142 | 4870 | 0.0181 |
| 19 | 3835 | 0.0143 | 4922 | 0.0183 | 3832 | 0.0143 | 4918 | 0.0183 | 3799 | 0.0141 | 4853 | 0.0181 | 3818 | 0.0142 | 4889 | 0.0182 |
| 20 | 3839 | 0.0143 | 4928 | 0.0183 | 3837 | 0.0143 | 4926 | 0.0183 | 3808 | 0.0142 | 4867 | 0.0181 | 3829 | 0.0143 | 4907 | 0.0183 |
| 21 | 3842 | 0.0143 | 4933 | 0.0184 | 3841 | 0.0143 | 4933 | 0.0184 | 3816 | 0.0142 | 4881 | 0.0182 | 3839 | 0.0143 | 4923 | 0.0183 |
| 22 | 3846 | 0.0143 | 4939 | 0.0184 | 3846 | 0.0143 | 4941 | 0.0184 | 3824 | 0.0142 | 4893 | 0.0182 | 3849 | 0.0143 | 4940 | 0.0184 |
| 23 | 3849 | 0.0143 | 4945 | 0.0184 | 3850 | 0.0143 | 4948 | 0.0184 | 3832 | 0.0143 | 4906 | 0.0183 | 3860 | 0.0144 | 4958 | 0.0185 |
| 24 | 3852 | 0.0143 | 4951 | 0.0184 | 3854 | 0.0144 | 4955 | 0.0184 | 3840 | 0.0143 | 4919 | 0.0183 | 3870 | 0.0144 | 4975 | 0.0185 |

| Coilset | 30 seconds | | | | 50 seconds | | | | 100 seconds | | | | 200 seconds | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $h_{lam}$ | $Bi_{lam}$ | $h_{turb}$ | $Bi_{turb}$ | $h_{lam}$ | $Bi_{lam}$ | $h_{turb}$ | $Bi_{turb}$ | $h_{lam}$ | $Bi_{lam}$ | $h_{turb}$ | $Bi_{turb}$ | $h_{lam}$ | $Bi_{lam}$ | $h_{turb}$ | $Bi_{turb}$ |
| 1 | 3584 | 0.0133 | 4528 | 0.0169 | 3527 | 0.0131 | 4433 | 0.0165 | 3489 | 0.0130 | 4368 | 0.0163 | 3475 | 0.0129 | 4344 | 0.0162 |
| 2 | 3599 | 0.0134 | 4552 | 0.0169 | 3545 | 0.0132 | 4460 | 0.0166 | 3513 | 0.0131 | 4409 | 0.0164 | 3500 | 0.0130 | 4386 | 0.0163 |
| 3 | 3614 | 0.0135 | 4576 | 0.0170 | 3562 | 0.0133 | 4487 | 0.0167 | 3533 | 0.0132 | 4442 | 0.0165 | 3523 | 0.0131 | 4424 | 0.0165 |
| 4 | 3630 | 0.0135 | 4600 | 0.0171 | 3580 | 0.0133 | 4515 | 0.0168 | 3552 | 0.0132 | 4470 | 0.0166 | 3542 | 0.0132 | 4453 | 0.0166 |
| 5 | 3646 | 0.0136 | 4625 | 0.0172 | 3598 | 0.0134 | 4543 | 0.0169 | 3570 | 0.0133 | 4499 | 0.0167 | 3560 | 0.0133 | 4482 | 0.0167 |
| 6 | 3661 | 0.0136 | 4649 | 0.0173 | 3616 | 0.0135 | 4571 | 0.0170 | 3589 | 0.0134 | 4528 | 0.0169 | 3580 | 0.0133 | 4512 | 0.0168 |
| 7 | 3677 | 0.0137 | 4674 | 0.0174 | 3634 | 0.0135 | 4600 | 0.0171 | 3608 | 0.0134 | 4558 | 0.0170 | 3599 | 0.0134 | 4542 | 0.0169 |
| 8 | 3693 | 0.0138 | 4700 | 0.0175 | 3653 | 0.0136 | 4629 | 0.0172 | 3627 | 0.0135 | 4588 | 0.0171 | 3619 | 0.0135 | 4573 | 0.0170 |
| 9 | 3709 | 0.0138 | 4725 | 0.0176 | 3672 | 0.0137 | 4659 | 0.0173 | 3647 | 0.0136 | 4619 | 0.0172 | 3639 | 0.0135 | 4604 | 0.0171 |
| 10 | 3724 | 0.0139 | 4750 | 0.0177 | 3690 | 0.0137 | 4688 | 0.0175 | 3667 | 0.0137 | 4649 | 0.0173 | 3659 | 0.0136 | 4636 | 0.0173 |
| 11 | 3740 | 0.0139 | 4776 | 0.0178 | 3709 | 0.0138 | 4718 | 0.0176 | 3686 | 0.0137 | 4681 | 0.0174 | 3679 | 0.0137 | 4667 | 0.0174 |
| 12 | 3756 | 0.0140 | 4802 | 0.0179 | 3727 | 0.0139 | 4748 | 0.0177 | 3705 | 0.0138 | 4711 | 0.0175 | 3699 | 0.0138 | 4699 | 0.0175 |
| 13 | 3772 | 0.0140 | 4828 | 0.0180 | 3746 | 0.0139 | 4778 | 0.0178 | 3725 | 0.0139 | 4743 | 0.0177 | 3718 | 0.0138 | 4731 | 0.0176 |
| 14 | 3789 | 0.0141 | 4854 | 0.0181 | 3765 | 0.0140 | 4809 | 0.0179 | 3745 | 0.0139 | 4775 | 0.0178 | 3739 | 0.0139 | 4764 | 0.0177 |
| 15 | 3806 | 0.0142 | 4882 | 0.0182 | 3784 | 0.0141 | 4841 | 0.0180 | 3765 | 0.0140 | 4808 | 0.0179 | 3759 | 0.0140 | 4797 | 0.0179 |
| 16 | 3822 | 0.0142 | 4909 | 0.0183 | 3804 | 0.0142 | 4873 | 0.0181 | 3785 | 0.0141 | 4841 | 0.0180 | 3780 | 0.0141 | 4831 | 0.0180 |
| 17 | 3839 | 0.0143 | 4937 | 0.0184 | 3824 | 0.0142 | 4905 | 0.0183 | 3806 | 0.0142 | 4875 | 0.0182 | 3801 | 0.0142 | 4865 | 0.0181 |
| 18 | 3855 | 0.0144 | 4963 | 0.0185 | 3843 | 0.0143 | 4936 | 0.0184 | 3827 | 0.0142 | 4909 | 0.0183 | 3823 | 0.0142 | 4900 | 0.0182 |
| 19 | 3871 | 0.0144 | 4988 | 0.0186 | 3861 | 0.0144 | 4966 | 0.0185 | 3847 | 0.0143 | 4941 | 0.0184 | 3843 | 0.0143 | 4933 | 0.0184 |
| 20 | 3886 | 0.0145 | 5014 | 0.0187 | 3879 | 0.0144 | 4996 | 0.0186 | 3865 | 0.0144 | 4972 | 0.0185 | 3862 | 0.0144 | 4965 | 0.0185 |
| 21 | 3902 | 0.0145 | 5040 | 0.0188 | 3898 | 0.0145 | 5027 | 0.0187 | 3885 | 0.0145 | 5004 | 0.0186 | 3881 | 0.0145 | 4997 | 0.0186 |
| 22 | 3917 | 0.0146 | 5066 | 0.0189 | 3916 | 0.0146 | 5057 | 0.0188 | 3904 | 0.0145 | 5036 | 0.0187 | 3901 | 0.0145 | 5030 | 0.0187 |
| 23 | 3933 | 0.0146 | 5092 | 0.0190 | 3935 | 0.0146 | 5088 | 0.0189 | 3924 | 0.0146 | 5069 | 0.0189 | 3921 | 0.0146 | 5063 | 0.0189 |
| 24 | 3949 | 0.0147 | 5119 | 0.0191 | 3954 | 0.0147 | 5121 | 0.0191 | 3944 | 0.0147 | 5102 | 0.0190 | 3942 | 0.0147 | 5097 | 0.0190 |

**Table H12: Heat transfer coefficients and Biot number approximations for R3-60 at 5.5LPM**

| Coilset | 1 second | | | | 2 seconds | | | | 3 seconds | | | | 5 seconds | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $h_{lam}$ | $Bi_{lam}$ | $h_{turb}$ | $Bi_{turb}$ | $h_{lam}$ | $Bi_{lam}$ | $h_{turb}$ | $Bi_{turb}$ | $h_{lam}$ | $Bi_{lam}$ | $h_{turb}$ | $Bi_{turb}$ | $h_{lam}$ | $Bi_{lam}$ | $h_{turb}$ | $Bi_{turb}$ |
| 1 | 3283 | 0.0122 | 3801 | 0.0142 | 3275 | 0.0122 | 3788 | 0.0141 | 3271 | 0.0122 | 3784 | 0.0141 | 3252 | 0.0121 | 3754 | 0.0140 |
| 2 | 3283 | 0.0122 | 3801 | 0.0142 | 3276 | 0.0122 | 3789 | 0.0141 | 3272 | 0.0122 | 3786 | 0.0141 | 3254 | 0.0121 | 3757 | 0.0140 |
| 3 | 3284 | 0.0122 | 3802 | 0.0142 | 3277 | 0.0122 | 3790 | 0.0141 | 3273 | 0.0122 | 3788 | 0.0141 | 3255 | 0.0121 | 3759 | 0.0140 |
| 4 | 3284 | 0.0122 | 3803 | 0.0142 | 3277 | 0.0122 | 3791 | 0.0141 | 3274 | 0.0122 | 3789 | 0.0141 | 3257 | 0.0121 | 3762 | 0.0140 |
| 5 | 3284 | 0.0122 | 3803 | 0.0142 | 3278 | 0.0122 | 3792 | 0.0141 | 3275 | 0.0122 | 3791 | 0.0141 | 3259 | 0.0121 | 3764 | 0.0140 |
| 6 | 3285 | 0.0122 | 3804 | 0.0142 | 3278 | 0.0122 | 3793 | 0.0141 | 3276 | 0.0122 | 3792 | 0.0141 | 3260 | 0.0121 | 3767 | 0.0140 |
| 7 | 3285 | 0.0122 | 3805 | 0.0142 | 3279 | 0.0122 | 3794 | 0.0141 | 3277 | 0.0122 | 3794 | 0.0141 | 3262 | 0.0121 | 3769 | 0.0140 |
| 8 | 3286 | 0.0122 | 3806 | 0.0142 | 3280 | 0.0122 | 3795 | 0.0141 | 3278 | 0.0122 | 3796 | 0.0141 | 3263 | 0.0121 | 3771 | 0.0140 |
| 9 | 3286 | 0.0122 | 3806 | 0.0142 | 3280 | 0.0122 | 3796 | 0.0141 | 3279 | 0.0122 | 3797 | 0.0141 | 3265 | 0.0122 | 3774 | 0.0140 |
| 10 | 3287 | 0.0122 | 3807 | 0.0142 | 3281 | 0.0122 | 3797 | 0.0141 | 3280 | 0.0122 | 3799 | 0.0141 | 3267 | 0.0122 | 3776 | 0.0141 |
| 11 | 3287 | 0.0122 | 3808 | 0.0142 | 3282 | 0.0122 | 3798 | 0.0141 | 3281 | 0.0122 | 3800 | 0.0141 | 3268 | 0.0122 | 3778 | 0.0141 |
| 12 | 3288 | 0.0122 | 3808 | 0.0142 | 3282 | 0.0122 | 3799 | 0.0141 | 3283 | 0.0122 | 3802 | 0.0142 | 3270 | 0.0122 | 3781 | 0.0141 |
| 13 | 3288 | 0.0122 | 3809 | 0.0142 | 3283 | 0.0122 | 3800 | 0.0141 | 3284 | 0.0122 | 3804 | 0.0142 | 3272 | 0.0122 | 3783 | 0.0141 |
| 14 | 3289 | 0.0122 | 3809 | 0.0142 | 3284 | 0.0122 | 3801 | 0.0141 | 3285 | 0.0122 | 3805 | 0.0142 | 3273 | 0.0122 | 3786 | 0.0141 |
| 15 | 3289 | 0.0122 | 3810 | 0.0142 | 3284 | 0.0122 | 3802 | 0.0142 | 3286 | 0.0122 | 3807 | 0.0142 | 3275 | 0.0122 | 3788 | 0.0141 |
| 16 | 3290 | 0.0122 | 3811 | 0.0142 | 3285 | 0.0122 | 3803 | 0.0142 | 3287 | 0.0122 | 3808 | 0.0142 | 3277 | 0.0122 | 3790 | 0.0141 |
| 17 | 3290 | 0.0122 | 3812 | 0.0142 | 3286 | 0.0122 | 3804 | 0.0142 | 3288 | 0.0122 | 3810 | 0.0142 | 3278 | 0.0122 | 3793 | 0.0141 |
| 18 | 3291 | 0.0123 | 3812 | 0.0142 | 3286 | 0.0122 | 3804 | 0.0142 | 3289 | 0.0122 | 3812 | 0.0142 | 3280 | 0.0122 | 3796 | 0.0141 |
| 19 | 3291 | 0.0123 | 3813 | 0.0142 | 3287 | 0.0122 | 3806 | 0.0142 | 3290 | 0.0123 | 3814 | 0.0142 | 3281 | 0.0122 | 3798 | 0.0141 |
| 20 | 3291 | 0.0123 | 3814 | 0.0142 | 3288 | 0.0122 | 3807 | 0.0142 | 3292 | 0.0123 | 3815 | 0.0142 | 3283 | 0.0122 | 3800 | 0.0141 |
| 21 | 3292 | 0.0123 | 3815 | 0.0142 | 3288 | 0.0122 | 3807 | 0.0142 | 3293 | 0.0123 | 3817 | 0.0142 | 3285 | 0.0122 | 3803 | 0.0142 |
| 22 | 3292 | 0.0123 | 3815 | 0.0142 | 3289 | 0.0122 | 3808 | 0.0142 | 3294 | 0.0123 | 3818 | 0.0142 | 3287 | 0.0122 | 3805 | 0.0142 |
| 23 | 3293 | 0.0123 | 3816 | 0.0142 | 3290 | 0.0122 | 3810 | 0.0142 | 3295 | 0.0123 | 3820 | 0.0142 | 3288 | 0.0122 | 3807 | 0.0142 |
| 24 | 3293 | 0.0123 | 3816 | 0.0142 | 3290 | 0.0122 | 3810 | 0.0142 | 3296 | 0.0123 | 3822 | 0.0142 | 3290 | 0.0122 | 3810 | 0.0142 |

| Coilset | 8 seconds | | | | 10 seconds | | | | 15 seconds | | | | 20 seconds | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $h_{lam}$ | $Bi_{lam}$ | $h_{turb}$ | $Bi_{turb}$ | $h_{lam}$ | $Bi_{lam}$ | $h_{turb}$ | $Bi_{turb}$ | $h_{lam}$ | $Bi_{lam}$ | $h_{turb}$ | $Bi_{turb}$ | $h_{lam}$ | $Bi_{lam}$ | $h_{turb}$ | $Bi_{turb}$ |
| 1 | 3240 | 0.0121 | 3742 | 0.0139 | 3223 | 0.0120 | 3717 | 0.0138 | 3212 | 0.0120 | 3713 | 0.0138 | 3185 | 0.0119 | 3679 | 0.0137 |
| 2 | 3243 | 0.0121 | 3746 | 0.0139 | 3226 | 0.0120 | 3722 | 0.0139 | 3217 | 0.0120 | 3720 | 0.0139 | 3193 | 0.0119 | 3691 | 0.0137 |
| 3 | 3245 | 0.0121 | 3750 | 0.0140 | 3230 | 0.0120 | 3727 | 0.0139 | 3222 | 0.0120 | 3728 | 0.0139 | 3201 | 0.0119 | 3702 | 0.0138 |
| 4 | 3248 | 0.0121 | 3754 | 0.0140 | 3233 | 0.0120 | 3732 | 0.0139 | 3228 | 0.0120 | 3736 | 0.0139 | 3210 | 0.0120 | 3714 | 0.0138 |
| 5 | 3251 | 0.0121 | 3758 | 0.0140 | 3236 | 0.0120 | 3737 | 0.0139 | 3233 | 0.0120 | 3744 | 0.0139 | 3218 | 0.0120 | 3726 | 0.0139 |
| 6 | 3253 | 0.0121 | 3762 | 0.0140 | 3240 | 0.0121 | 3742 | 0.0139 | 3238 | 0.0121 | 3752 | 0.0140 | 3226 | 0.0120 | 3738 | 0.0139 |
| 7 | 3256 | 0.0121 | 3765 | 0.0140 | 3243 | 0.0121 | 3747 | 0.0140 | 3244 | 0.0121 | 3760 | 0.0140 | 3233 | 0.0120 | 3749 | 0.0140 |
| 8 | 3259 | 0.0121 | 3770 | 0.0140 | 3247 | 0.0121 | 3752 | 0.0140 | 3249 | 0.0121 | 3768 | 0.0140 | 3242 | 0.0121 | 3761 | 0.0140 |
| 9 | 3261 | 0.0121 | 3773 | 0.0140 | 3250 | 0.0121 | 3757 | 0.0140 | 3254 | 0.0121 | 3776 | 0.0141 | 3249 | 0.0121 | 3773 | 0.0140 |
| 10 | 3264 | 0.0122 | 3777 | 0.0141 | 3253 | 0.0121 | 3762 | 0.0140 | 3260 | 0.0121 | 3784 | 0.0141 | 3257 | 0.0121 | 3785 | 0.0141 |
| 11 | 3267 | 0.0122 | 3781 | 0.0141 | 3257 | 0.0121 | 3767 | 0.0140 | 3265 | 0.0122 | 3792 | 0.0141 | 3266 | 0.0122 | 3797 | 0.0141 |
| 12 | 3269 | 0.0122 | 3785 | 0.0141 | 3260 | 0.0121 | 3772 | 0.0140 | 3271 | 0.0122 | 3800 | 0.0141 | 3274 | 0.0122 | 3809 | 0.0142 |
| 13 | 3272 | 0.0122 | 3789 | 0.0141 | 3264 | 0.0122 | 3777 | 0.0141 | 3276 | 0.0122 | 3808 | 0.0142 | 3282 | 0.0122 | 3821 | 0.0142 |
| 14 | 3275 | 0.0122 | 3793 | 0.0141 | 3267 | 0.0122 | 3782 | 0.0141 | 3282 | 0.0122 | 3817 | 0.0142 | 3290 | 0.0123 | 3833 | 0.0143 |
| 15 | 3277 | 0.0122 | 3797 | 0.0141 | 3271 | 0.0122 | 3788 | 0.0141 | 3287 | 0.0122 | 3825 | 0.0142 | 3299 | 0.0123 | 3846 | 0.0143 |
| 16 | 3280 | 0.0122 | 3801 | 0.0142 | 3274 | 0.0122 | 3793 | 0.0141 | 3293 | 0.0123 | 3833 | 0.0143 | 3307 | 0.0123 | 3858 | 0.0144 |
| 17 | 3283 | 0.0122 | 3805 | 0.0142 | 3278 | 0.0122 | 3798 | 0.0141 | 3299 | 0.0123 | 3842 | 0.0143 | 3316 | 0.0123 | 3871 | 0.0144 |
| 18 | 3285 | 0.0122 | 3809 | 0.0142 | 3281 | 0.0122 | 3803 | 0.0142 | 3304 | 0.0123 | 3850 | 0.0143 | 3324 | 0.0124 | 3884 | 0.0145 |
| 19 | 3288 | 0.0122 | 3813 | 0.0142 | 3285 | 0.0122 | 3808 | 0.0142 | 3310 | 0.0123 | 3858 | 0.0144 | 3333 | 0.0124 | 3896 | 0.0145 |
| 20 | 3291 | 0.0123 | 3817 | 0.0142 | 3288 | 0.0122 | 3813 | 0.0142 | 3316 | 0.0123 | 3867 | 0.0144 | 3342 | 0.0124 | 3909 | 0.0146 |
| 21 | 3293 | 0.0123 | 3821 | 0.0142 | 3292 | 0.0123 | 3818 | 0.0142 | 3321 | 0.0124 | 3875 | 0.0144 | 3350 | 0.0125 | 3922 | 0.0146 |
| 22 | 3296 | 0.0123 | 3825 | 0.0142 | 3295 | 0.0123 | 3824 | 0.0142 | 3327 | 0.0124 | 3884 | 0.0145 | 3358 | 0.0125 | 3934 | 0.0146 |
| 23 | 3299 | 0.0123 | 3829 | 0.0143 | 3299 | 0.0123 | 3829 | 0.0143 | 3333 | 0.0124 | 3892 | 0.0145 | 3366 | 0.0125 | 3945 | 0.0147 |
| 24 | 3302 | 0.0123 | 3833 | 0.0143 | 3302 | 0.0123 | 3834 | 0.0143 | 3339 | 0.0124 | 3901 | 0.0145 | 3374 | 0.0126 | 3957 | 0.0147 |

| Coilset | 30 seconds | | | | 50 seconds | | | | 100 seconds | | | | 200 seconds | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $h_{lam}$ | $Bi_{lam}$ | $h_{turb}$ | $Bi_{turb}$ | $h_{lam}$ | $Bi_{lam}$ | $h_{turb}$ | $Bi_{turb}$ | $h_{lam}$ | $Bi_{lam}$ | $h_{turb}$ | $Bi_{turb}$ | $h_{lam}$ | $Bi_{lam}$ | $h_{turb}$ | $Bi_{turb}$ |
| 1 | 3147 | 0.0117 | 3624 | 0.0135 | 3141 | 0.0117 | 3637 | 0.0135 | 3140 | 0.0117 | 3652 | 0.0136 | 3108 | 0.0116 | 3594 | 0.0134 |
| 2 | 3158 | 0.0118 | 3641 | 0.0136 | 3157 | 0.0118 | 3659 | 0.0136 | 3159 | 0.0118 | 3681 | 0.0137 | 3131 | 0.0117 | 3630 | 0.0135 |
| 3 | 3170 | 0.0118 | 3658 | 0.0136 | 3172 | 0.0118 | 3681 | 0.0137 | 3176 | 0.0118 | 3705 | 0.0138 | 3149 | 0.0117 | 3655 | 0.0136 |
| 4 | 3182 | 0.0118 | 3674 | 0.0137 | 3188 | 0.0119 | 3704 | 0.0138 | 3194 | 0.0119 | 3730 | 0.0139 | 3166 | 0.0118 | 3681 | 0.0137 |
| 5 | 3194 | 0.0119 | 3691 | 0.0137 | 3204 | 0.0119 | 3726 | 0.0139 | 3211 | 0.0120 | 3755 | 0.0140 | 3184 | 0.0119 | 3706 | 0.0138 |
| 6 | 3206 | 0.0119 | 3709 | 0.0138 | 3220 | 0.0120 | 3749 | 0.0140 | 3229 | 0.0120 | 3781 | 0.0141 | 3202 | 0.0119 | 3732 | 0.0139 |
| 7 | 3218 | 0.0120 | 3726 | 0.0139 | 3236 | 0.0120 | 3773 | 0.0140 | 3247 | 0.0121 | 3807 | 0.0142 | 3220 | 0.0120 | 3759 | 0.0140 |
| 8 | 3229 | 0.0120 | 3743 | 0.0139 | 3253 | 0.0121 | 3796 | 0.0141 | 3265 | 0.0122 | 3833 | 0.0143 | 3239 | 0.0121 | 3786 | 0.0141 |
| 9 | 3241 | 0.0121 | 3760 | 0.0140 | 3269 | 0.0122 | 3820 | 0.0142 | 3284 | 0.0122 | 3860 | 0.0144 | 3258 | 0.0121 | 3813 | 0.0142 |
| 10 | 3253 | 0.0121 | 3778 | 0.0141 | 3285 | 0.0122 | 3844 | 0.0143 | 3302 | 0.0123 | 3887 | 0.0145 | 3277 | 0.0122 | 3840 | 0.0143 |
| 11 | 3265 | 0.0122 | 3795 | 0.0141 | 3301 | 0.0123 | 3868 | 0.0144 | 3320 | 0.0124 | 3914 | 0.0146 | 3295 | 0.0123 | 3868 | 0.0144 |
| 12 | 3277 | 0.0122 | 3813 | 0.0142 | 3317 | 0.0124 | 3893 | 0.0145 | 3338 | 0.0124 | 3941 | 0.0147 | 3314 | 0.0123 | 3896 | 0.0145 |
| 13 | 3289 | 0.0122 | 3831 | 0.0143 | 3334 | 0.0124 | 3917 | 0.0146 | 3356 | 0.0125 | 3969 | 0.0148 | 3333 | 0.0124 | 3924 | 0.0146 |
| 14 | 3301 | 0.0123 | 3849 | 0.0143 | 3351 | 0.0125 | 3943 | 0.0147 | 3375 | 0.0126 | 3997 | 0.0149 | 3352 | 0.0125 | 3953 | 0.0147 |
| 15 | 3314 | 0.0123 | 3868 | 0.0144 | 3368 | 0.0125 | 3968 | 0.0148 | 3394 | 0.0126 | 4026 | 0.0150 | 3372 | 0.0126 | 3983 | 0.0148 |
| 16 | 3326 | 0.0124 | 3886 | 0.0145 | 3385 | 0.0126 | 3994 | 0.0149 | 3414 | 0.0127 | 4055 | 0.0151 | 3392 | 0.0126 | 4012 | 0.0149 |
| 17 | 3339 | 0.0124 | 3906 | 0.0145 | 3402 | 0.0127 | 4019 | 0.0150 | 3433 | 0.0128 | 4084 | 0.0152 | 3411 | 0.0127 | 4042 | 0.0150 |
| 18 | 3351 | 0.0125 | 3924 | 0.0146 | 3417 | 0.0127 | 4042 | 0.0151 | 3450 | 0.0128 | 4111 | 0.0153 | 3430 | 0.0128 | 4070 | 0.0152 |
| 19 | 3363 | 0.0125 | 3941 | 0.0147 | 3433 | 0.0128 | 4067 | 0.0151 | 3468 | 0.0129 | 4138 | 0.0154 | 3448 | 0.0128 | 4097 | 0.0153 |
| 20 | 3374 | 0.0126 | 3958 | 0.0147 | 3449 | 0.0128 | 4091 | 0.0152 | 3486 | 0.0130 | 4166 | 0.0155 | 3466 | 0.0129 | 4126 | 0.0154 |
| 21 | 3386 | 0.0126 | 3976 | 0.0148 | 3465 | 0.0129 | 4115 | 0.0153 | 3504 | 0.0130 | 4194 | 0.0156 | 3485 | 0.0130 | 4154 | 0.0155 |
| 22 | 3397 | 0.0126 | 3993 | 0.0149 | 3482 | 0.0130 | 4141 | 0.0154 | 3523 | 0.0131 | 4222 | 0.0157 | 3504 | 0.0130 | 4183 | 0.0156 |
| 23 | 3409 | 0.0127 | 4011 | 0.0149 | 3498 | 0.0130 | 4166 | 0.0155 | 3542 | 0.0132 | 4251 | 0.0158 | 3524 | 0.0131 | 4214 | 0.0157 |
| 24 | 3421 | 0.0127 | 4029 | 0.0150 | 3515 | 0.0131 | 4192 | 0.0156 | 3561 | 0.0133 | 4281 | 0.0159 | 3543 | 0.0132 | 4244 | 0.0158 |

**Table H13: Heat transfer coefficients and Biot number approximations for R4-36 at 14LPM**

| Coilset | 1 second | | | | 2 seconds | | | | 3 seconds | | | | 5 seconds | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $h_{lam}$ | $Bi_{lam}$ | $h_{turb}$ | $Bi_{turb}$ | $h_{lam}$ | $Bi_{lam}$ | $h_{turb}$ | $Bi_{turb}$ | $h_{lam}$ | $Bi_{lam}$ | $h_{turb}$ | $Bi_{turb}$ | $h_{lam}$ | $Bi_{lam}$ | $h_{turb}$ | $Bi_{turb}$ |
| 1 | 3798 | 0.0154 | 5354 | 0.0217 | 4296 | 0.0174 | 6588 | 0.0267 | 4560 | 0.0185 | 7283 | 0.0295 | 4553 | 0.0185 | 7290 | 0.0296 |
| 2 | 3798 | 0.0154 | 5355 | 0.0217 | 4296 | 0.0174 | 6588 | 0.0267 | 4560 | 0.0185 | 7283 | 0.0295 | 4556 | 0.0185 | 7296 | 0.0296 |
| 3 | 3798 | 0.0154 | 5355 | 0.0217 | 4296 | 0.0174 | 6588 | 0.0267 | 4560 | 0.0185 | 7283 | 0.0295 | 4559 | 0.0185 | 7302 | 0.0296 |
| 4 | 3798 | 0.0154 | 5355 | 0.0217 | 4297 | 0.0174 | 6589 | 0.0267 | 4561 | 0.0185 | 7284 | 0.0295 | 4562 | 0.0185 | 7309 | 0.0296 |
| 5 | 3798 | 0.0154 | 5355 | 0.0217 | 4297 | 0.0174 | 6589 | 0.0267 | 4561 | 0.0185 | 7284 | 0.0295 | 4566 | 0.0185 | 7315 | 0.0297 |
| 6 | 3798 | 0.0154 | 5355 | 0.0217 | 4297 | 0.0174 | 6589 | 0.0267 | 4561 | 0.0185 | 7284 | 0.0295 | 4569 | 0.0185 | 7322 | 0.0297 |
| 7 | 3798 | 0.0154 | 5356 | 0.0217 | 4297 | 0.0174 | 6589 | 0.0267 | 4561 | 0.0185 | 7284 | 0.0295 | 4572 | 0.0185 | 7328 | 0.0297 |
| 8 | 3798 | 0.0154 | 5356 | 0.0217 | 4297 | 0.0174 | 6589 | 0.0267 | 4561 | 0.0185 | 7284 | 0.0295 | 4575 | 0.0186 | 7334 | 0.0297 |
| 9 | 3799 | 0.0154 | 5356 | 0.0217 | 4297 | 0.0174 | 6589 | 0.0267 | 4561 | 0.0185 | 7284 | 0.0295 | 4578 | 0.0186 | 7341 | 0.0298 |
| 10 | 3799 | 0.0154 | 5356 | 0.0217 | 4297 | 0.0174 | 6589 | 0.0267 | 4561 | 0.0185 | 7284 | 0.0295 | 4581 | 0.0186 | 7347 | 0.0298 |
| 11 | 3799 | 0.0154 | 5356 | 0.0217 | 4297 | 0.0174 | 6589 | 0.0267 | 4561 | 0.0185 | 7284 | 0.0295 | 4584 | 0.0186 | 7353 | 0.0298 |
| 12 | 3799 | 0.0154 | 5357 | 0.0217 | 4297 | 0.0174 | 6589 | 0.0267 | 4561 | 0.0185 | 7284 | 0.0295 | 4587 | 0.0186 | 7359 | 0.0298 |
| 13 | 3799 | 0.0154 | 5357 | 0.0217 | 4297 | 0.0174 | 6589 | 0.0267 | 4561 | 0.0185 | 7284 | 0.0295 | 4589 | 0.0186 | 7364 | 0.0299 |
| 14 | 3799 | 0.0154 | 5357 | 0.0217 | 4297 | 0.0174 | 6589 | 0.0267 | 4561 | 0.0185 | 7284 | 0.0295 | 4592 | 0.0186 | 7370 | 0.0299 |

| Coilset | 8 seconds | | | | 10 seconds | | | | 15 seconds | | | | 20 seconds | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $h_{lam}$ | $Bi_{lam}$ | $h_{turb}$ | $Bi_{turb}$ | $h_{lam}$ | $Bi_{lam}$ | $h_{turb}$ | $Bi_{turb}$ | $h_{lam}$ | $Bi_{lam}$ | $h_{turb}$ | $Bi_{turb}$ | $h_{lam}$ | $Bi_{lam}$ | $h_{turb}$ | $Bi_{turb}$ |
| 1 | 4470 | 0.0181 | 7127 | 0.0289 | 4429 | 0.0180 | 7052 | 0.0286 | 4308 | 0.0175 | 6812 | 0.0276 | 4265 | 0.0173 | 6732 | 0.0273 |
| 2 | 4479 | 0.0182 | 7146 | 0.0290 | 4442 | 0.0180 | 7078 | 0.0287 | 4328 | 0.0176 | 6851 | 0.0278 | 4286 | 0.0174 | 6774 | 0.0275 |
| 3 | 4489 | 0.0182 | 7165 | 0.0291 | 4455 | 0.0181 | 7105 | 0.0288 | 4349 | 0.0176 | 6891 | 0.0279 | 4308 | 0.0175 | 6816 | 0.0276 |
| 4 | 4499 | 0.0182 | 7185 | 0.0291 | 4469 | 0.0181 | 7132 | 0.0289 | 4369 | 0.0177 | 6931 | 0.0281 | 4330 | 0.0176 | 6859 | 0.0278 |
| 5 | 4508 | 0.0183 | 7204 | 0.0292 | 4482 | 0.0182 | 7160 | 0.0290 | 4390 | 0.0178 | 6972 | 0.0283 | 4352 | 0.0176 | 6902 | 0.0280 |
| 6 | 4518 | 0.0183 | 7224 | 0.0293 | 4496 | 0.0182 | 7188 | 0.0291 | 4411 | 0.0179 | 7013 | 0.0284 | 4374 | 0.0177 | 6946 | 0.0282 |
| 7 | 4528 | 0.0184 | 7244 | 0.0294 | 4509 | 0.0183 | 7215 | 0.0293 | 4431 | 0.0180 | 7054 | 0.0286 | 4397 | 0.0178 | 6991 | 0.0283 |
| 8 | 4538 | 0.0184 | 7264 | 0.0295 | 4523 | 0.0183 | 7244 | 0.0294 | 4452 | 0.0181 | 7096 | 0.0288 | 4420 | 0.0179 | 7036 | 0.0285 |
| 9 | 4548 | 0.0184 | 7284 | 0.0295 | 4537 | 0.0184 | 7272 | 0.0295 | 4473 | 0.0181 | 7138 | 0.0289 | 4442 | 0.0180 | 7080 | 0.0287 |
| 10 | 4557 | 0.0185 | 7305 | 0.0296 | 4551 | 0.0185 | 7301 | 0.0296 | 4494 | 0.0182 | 7181 | 0.0291 | 4464 | 0.0181 | 7126 | 0.0289 |
| 11 | 4567 | 0.0185 | 7325 | 0.0297 | 4566 | 0.0185 | 7330 | 0.0297 | 4515 | 0.0183 | 7224 | 0.0293 | 4487 | 0.0182 | 7172 | 0.0291 |
| 12 | 4578 | 0.0186 | 7346 | 0.0298 | 4580 | 0.0186 | 7359 | 0.0298 | 4537 | 0.0184 | 7268 | 0.0295 | 4510 | 0.0183 | 7218 | 0.0293 |
| 13 | 4588 | 0.0186 | 7367 | 0.0299 | 4594 | 0.0186 | 7388 | 0.0300 | 4559 | 0.0185 | 7312 | 0.0297 | 4533 | 0.0184 | 7266 | 0.0295 |
| 14 | 4597 | 0.0186 | 7385 | 0.0299 | 4608 | 0.0187 | 7416 | 0.0301 | 4581 | 0.0186 | 7357 | 0.0298 | 4557 | 0.0185 | 7314 | 0.0297 |

| Coilset | 30 seconds | | | | 50 seconds | | | | 100 seconds | | | | 200 seconds | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $h_{lam}$ | $Bi_{lam}$ | $h_{turb}$ | $Bi_{turb}$ | $h_{lam}$ | $Bi_{lam}$ | $h_{turb}$ | $Bi_{turb}$ | $h_{lam}$ | $Bi_{lam}$ | $h_{turb}$ | $Bi_{turb}$ | $h_{lam}$ | $Bi_{lam}$ | $h_{turb}$ | $Bi_{turb}$ |
| 1 | 4260 | 0.0173 | 6750 | 0.0274 | 4238 | 0.0172 | 6715 | 0.0272 | 4173 | 0.0169 | 6552 | 0.0266 | 4162 | 0.0169 | 6524 | 0.0265 |
| 2 | 4284 | 0.0174 | 6800 | 0.0276 | 4266 | 0.0173 | 6774 | 0.0275 | 4201 | 0.0170 | 6611 | 0.0268 | 4190 | 0.0170 | 6583 | 0.0267 |
| 3 | 4305 | 0.0175 | 6841 | 0.0277 | 4294 | 0.0174 | 6833 | 0.0277 | 4230 | 0.0172 | 6672 | 0.0271 | 4219 | 0.0171 | 6644 | 0.0269 |
| 4 | 4327 | 0.0175 | 6885 | 0.0279 | 4315 | 0.0175 | 6874 | 0.0279 | 4254 | 0.0173 | 6721 | 0.0273 | 4244 | 0.0172 | 6696 | 0.0272 |
| 5 | 4350 | 0.0176 | 6928 | 0.0281 | 4336 | 0.0176 | 6915 | 0.0280 | 4276 | 0.0173 | 6762 | 0.0274 | 4266 | 0.0173 | 6738 | 0.0273 |
| 6 | 4372 | 0.0177 | 6973 | 0.0283 | 4357 | 0.0177 | 6958 | 0.0282 | 4297 | 0.0174 | 6804 | 0.0276 | 4288 | 0.0174 | 6781 | 0.0275 |
| 7 | 4395 | 0.0178 | 7017 | 0.0285 | 4379 | 0.0178 | 7001 | 0.0284 | 4319 | 0.0175 | 6847 | 0.0278 | 4310 | 0.0175 | 6824 | 0.0277 |
| 8 | 4418 | 0.0179 | 7062 | 0.0286 | 4401 | 0.0178 | 7043 | 0.0286 | 4341 | 0.0176 | 6891 | 0.0279 | 4332 | 0.0176 | 6866 | 0.0278 |
| 9 | 4441 | 0.0180 | 7108 | 0.0288 | 4423 | 0.0179 | 7087 | 0.0287 | 4363 | 0.0177 | 6934 | 0.0281 | 4354 | 0.0177 | 6911 | 0.0280 |
| 10 | 4464 | 0.0181 | 7155 | 0.0290 | 4445 | 0.0180 | 7132 | 0.0289 | 4386 | 0.0178 | 6978 | 0.0283 | 4377 | 0.0177 | 6955 | 0.0282 |
| 11 | 4487 | 0.0182 | 7201 | 0.0292 | 4468 | 0.0181 | 7177 | 0.0291 | 4409 | 0.0179 | 7023 | 0.0285 | 4400 | 0.0178 | 7001 | 0.0284 |
| 12 | 4510 | 0.0183 | 7248 | 0.0294 | 4491 | 0.0182 | 7222 | 0.0293 | 4432 | 0.0180 | 7068 | 0.0287 | 4423 | 0.0179 | 7047 | 0.0286 |
| 13 | 4533 | 0.0184 | 7295 | 0.0296 | 4513 | 0.0183 | 7267 | 0.0295 | 4454 | 0.0181 | 7114 | 0.0288 | 4446 | 0.0180 | 7092 | 0.0288 |
| 14 | 4557 | 0.0185 | 7344 | 0.0298 | 4535 | 0.0184 | 7313 | 0.0297 | 4477 | 0.0182 | 7160 | 0.0290 | 4469 | 0.0181 | 7138 | 0.0289 |

**Table H14: Heat transfer coefficients and Biot number approximations for R4-36 at 12LPM**

| Coilset | 1 second | | | | 2 seconds | | | | 3 seconds | | | | 5 seconds | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $h_{lam}$ | $Bi_{lam}$ | $h_{turb}$ | $Bi_{turb}$ | $h_{lam}$ | $Bi_{lam}$ | $h_{turb}$ | $Bi_{turb}$ | $h_{lam}$ | $Bi_{lam}$ | $h_{turb}$ | $Bi_{turb}$ | $h_{lam}$ | $Bi_{lam}$ | $h_{turb}$ | $Bi_{turb}$ |
| **1** | 4277 | 0.0173 | 6536 | 0.0265 | 4261 | 0.0173 | 6511 | 0.0264 | 4241 | 0.0172 | 6473 | 0.0262 | 4170 | 0.0169 | 6333 | 0.0257 |
| **2** | 4278 | 0.0173 | 6537 | 0.0265 | 4264 | 0.0173 | 6516 | 0.0264 | 4245 | 0.0172 | 6480 | 0.0263 | 4178 | 0.0169 | 6350 | 0.0257 |
| **3** | 4278 | 0.0173 | 6538 | 0.0265 | 4266 | 0.0173 | 6521 | 0.0264 | 4249 | 0.0172 | 6488 | 0.0263 | 4187 | 0.0170 | 6367 | 0.0258 |
| **4** | 4279 | 0.0173 | 6539 | 0.0265 | 4269 | 0.0173 | 6526 | 0.0265 | 4253 | 0.0172 | 6496 | 0.0263 | 4196 | 0.0170 | 6384 | 0.0259 |
| **5** | 4279 | 0.0174 | 6540 | 0.0265 | 4271 | 0.0173 | 6529 | 0.0265 | 4257 | 0.0173 | 6504 | 0.0264 | 4205 | 0.0171 | 6402 | 0.0260 |
| **6** | 4279 | 0.0174 | 6541 | 0.0265 | 4273 | 0.0173 | 6534 | 0.0265 | 4261 | 0.0173 | 6512 | 0.0264 | 4214 | 0.0171 | 6419 | 0.0260 |
| **7** | 4280 | 0.0174 | 6542 | 0.0265 | 4275 | 0.0173 | 6538 | 0.0265 | 4265 | 0.0173 | 6520 | 0.0264 | 4223 | 0.0171 | 6436 | 0.0261 |
| **8** | 4280 | 0.0174 | 6543 | 0.0265 | 4278 | 0.0173 | 6543 | 0.0265 | 4270 | 0.0173 | 6528 | 0.0265 | 4232 | 0.0172 | 6454 | 0.0262 |
| **9** | 4281 | 0.0174 | 6544 | 0.0265 | 4280 | 0.0174 | 6546 | 0.0265 | 4273 | 0.0173 | 6535 | 0.0265 | 4241 | 0.0172 | 6472 | 0.0262 |
| **10** | 4281 | 0.0174 | 6545 | 0.0265 | 4282 | 0.0174 | 6551 | 0.0266 | 4277 | 0.0173 | 6542 | 0.0265 | 4251 | 0.0172 | 6490 | 0.0263 |
| **11** | 4282 | 0.0174 | 6545 | 0.0265 | 4284 | 0.0174 | 6555 | 0.0266 | 4280 | 0.0174 | 6549 | 0.0266 | 4260 | 0.0173 | 6508 | 0.0264 |
| **12** | 4282 | 0.0174 | 6547 | 0.0265 | 4286 | 0.0174 | 6560 | 0.0266 | 4284 | 0.0174 | 6556 | 0.0266 | 4269 | 0.0173 | 6526 | 0.0265 |
| **13** | 4283 | 0.0174 | 6547 | 0.0265 | 4288 | 0.0174 | 6564 | 0.0266 | 4288 | 0.0174 | 6563 | 0.0266 | 4277 | 0.0173 | 6542 | 0.0265 |
| **14** | 4283 | 0.0174 | 6549 | 0.0266 | 4291 | 0.0174 | 6568 | 0.0266 | 4291 | 0.0174 | 6570 | 0.0266 | 4285 | 0.0174 | 6558 | 0.0266 |

| Coilset | 8 seconds | | | | 10 seconds | | | | 15 seconds | | | | 20 seconds | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $h_{lam}$ | $Bi_{lam}$ | $h_{turb}$ | $Bi_{turb}$ | $h_{lam}$ | $Bi_{lam}$ | $h_{turb}$ | $Bi_{turb}$ | $h_{lam}$ | $Bi_{lam}$ | $h_{turb}$ | $Bi_{turb}$ | $h_{lam}$ | $Bi_{lam}$ | $h_{turb}$ | $Bi_{turb}$ |
| **1** | 4096 | 0.0166 | 6193 | 0.0251 | 4086 | 0.0166 | 6188 | 0.0251 | 4034 | 0.0164 | 6092 | 0.0247 | 4002 | 0.0162 | 6042 | 0.0245 |
| **2** | 4110 | 0.0167 | 6220 | 0.0252 | 4103 | 0.0166 | 6219 | 0.0252 | 4054 | 0.0164 | 6129 | 0.0249 | 4023 | 0.0163 | 6082 | 0.0247 |
| **3** | 4124 | 0.0167 | 6247 | 0.0253 | 4120 | 0.0167 | 6251 | 0.0253 | 4074 | 0.0165 | 6166 | 0.0250 | 4045 | 0.0164 | 6122 | 0.0248 |
| **4** | 4139 | 0.0168 | 6275 | 0.0254 | 4136 | 0.0168 | 6283 | 0.0255 | 4094 | 0.0166 | 6205 | 0.0252 | 4067 | 0.0165 | 6163 | 0.0250 |
| **5** | 4153 | 0.0168 | 6303 | 0.0256 | 4153 | 0.0168 | 6314 | 0.0256 | 4115 | 0.0167 | 6243 | 0.0253 | 4089 | 0.0166 | 6204 | 0.0252 |
| **6** | 4168 | 0.0169 | 6331 | 0.0257 | 4170 | 0.0169 | 6347 | 0.0257 | 4134 | 0.0168 | 6280 | 0.0255 | 4111 | 0.0167 | 6246 | 0.0253 |
| **7** | 4183 | 0.0170 | 6359 | 0.0258 | 4187 | 0.0170 | 6380 | 0.0259 | 4154 | 0.0168 | 6319 | 0.0256 | 4133 | 0.0168 | 6288 | 0.0255 |
| **8** | 4197 | 0.0170 | 6388 | 0.0259 | 4203 | 0.0170 | 6412 | 0.0260 | 4174 | 0.0169 | 6358 | 0.0258 | 4155 | 0.0168 | 6330 | 0.0257 |
| **9** | 4212 | 0.0171 | 6417 | 0.0260 | 4221 | 0.0171 | 6446 | 0.0261 | 4195 | 0.0170 | 6398 | 0.0259 | 4177 | 0.0169 | 6373 | 0.0258 |
| **10** | 4227 | 0.0171 | 6446 | 0.0261 | 4238 | 0.0172 | 6480 | 0.0263 | 4216 | 0.0171 | 6438 | 0.0261 | 4200 | 0.0170 | 6416 | 0.0260 |
| **11** | 4243 | 0.0172 | 6475 | 0.0263 | 4256 | 0.0173 | 6514 | 0.0264 | 4236 | 0.0172 | 6478 | 0.0263 | 4222 | 0.0171 | 6460 | 0.0262 |
| **12** | 4258 | 0.0173 | 6506 | 0.0264 | 4274 | 0.0173 | 6549 | 0.0266 | 4258 | 0.0173 | 6520 | 0.0264 | 4246 | 0.0172 | 6506 | 0.0264 |
| **13** | 4273 | 0.0173 | 6535 | 0.0265 | 4292 | 0.0174 | 6584 | 0.0267 | 4279 | 0.0174 | 6562 | 0.0266 | 4269 | 0.0173 | 6551 | 0.0266 |
| **14** | 4287 | 0.0174 | 6562 | 0.0266 | 4308 | 0.0175 | 6615 | 0.0268 | 4300 | 0.0174 | 6603 | 0.0268 | 4293 | 0.0174 | 6597 | 0.0268 |

| Coilset | 30 seconds | | | | 50 seconds | | | | 100 seconds | | | | 200 seconds | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $h_{lam}$ | $Bi_{lam}$ | $h_{turb}$ | $Bi_{turb}$ | $h_{lam}$ | $Bi_{lam}$ | $h_{turb}$ | $Bi_{turb}$ | $h_{lam}$ | $Bi_{lam}$ | $h_{turb}$ | $Bi_{turb}$ | $h_{lam}$ | $Bi_{lam}$ | $h_{turb}$ | $Bi_{turb}$ |
| **1** | 3952 | 0.0160 | 5940 | 0.0241 | 3926 | 0.0159 | 5893 | 0.0239 | 3906 | 0.0158 | 5851 | 0.0237 | 3916 | 0.0159 | 5879 | 0.0238 |
| **2** | 3973 | 0.0161 | 5979 | 0.0242 | 3953 | 0.0160 | 5948 | 0.0241 | 3934 | 0.0160 | 5908 | 0.0240 | 3944 | 0.0160 | 5935 | 0.0241 |
| **3** | 3995 | 0.0162 | 6019 | 0.0244 | 3974 | 0.0161 | 5986 | 0.0243 | 3959 | 0.0161 | 5955 | 0.0241 | 3970 | 0.0161 | 5987 | 0.0243 |
| **4** | 4016 | 0.0163 | 6059 | 0.0246 | 3995 | 0.0162 | 6025 | 0.0244 | 3980 | 0.0161 | 5994 | 0.0243 | 3991 | 0.0162 | 6027 | 0.0244 |
| **5** | 4038 | 0.0164 | 6100 | 0.0247 | 4016 | 0.0163 | 6065 | 0.0246 | 4001 | 0.0162 | 6034 | 0.0245 | 4013 | 0.0163 | 6066 | 0.0246 |
| **6** | 4061 | 0.0165 | 6142 | 0.0249 | 4038 | 0.0164 | 6105 | 0.0248 | 4022 | 0.0163 | 6074 | 0.0246 | 4034 | 0.0164 | 6107 | 0.0248 |
| **7** | 4083 | 0.0166 | 6183 | 0.0251 | 4060 | 0.0165 | 6145 | 0.0249 | 4044 | 0.0164 | 6115 | 0.0248 | 4056 | 0.0164 | 6148 | 0.0249 |
| **8** | 4106 | 0.0166 | 6226 | 0.0252 | 4082 | 0.0166 | 6186 | 0.0251 | 4066 | 0.0165 | 6156 | 0.0250 | 4078 | 0.0165 | 6189 | 0.0251 |
| **9** | 4128 | 0.0167 | 6268 | 0.0254 | 4104 | 0.0166 | 6228 | 0.0253 | 4089 | 0.0166 | 6198 | 0.0251 | 4101 | 0.0166 | 6231 | 0.0253 |
| **10** | 4150 | 0.0168 | 6312 | 0.0256 | 4126 | 0.0167 | 6270 | 0.0254 | 4112 | 0.0167 | 6240 | 0.0253 | 4124 | 0.0167 | 6274 | 0.0254 |
| **11** | 4173 | 0.0169 | 6355 | 0.0258 | 4148 | 0.0168 | 6312 | 0.0256 | 4134 | 0.0168 | 6283 | 0.0255 | 4146 | 0.0168 | 6317 | 0.0256 |
| **12** | 4196 | 0.0170 | 6399 | 0.0259 | 4170 | 0.0169 | 6355 | 0.0258 | 4156 | 0.0169 | 6325 | 0.0256 | 4168 | 0.0169 | 6360 | 0.0258 |
| **13** | 4219 | 0.0171 | 6444 | 0.0261 | 4193 | 0.0170 | 6398 | 0.0259 | 4178 | 0.0169 | 6369 | 0.0258 | 4191 | 0.0170 | 6403 | 0.0260 |
| **14** | 4243 | 0.0172 | 6490 | 0.0263 | 4215 | 0.0171 | 6442 | 0.0261 | 4201 | 0.0170 | 6413 | 0.0260 | 4214 | 0.0171 | 6448 | 0.0261 |

**Table H15: Heat transfer coefficients and Biot number approximations for R4-36 at 10LPM**

| Coilset | 1 second | | | | 2 seconds | | | | 3 seconds | | | | 5 seconds | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $h_{lam}$ | $Bi_{lam}$ | $h_{turb}$ | $Bi_{turb}$ | $h_{lam}$ | $Bi_{lam}$ | $h_{turb}$ | $Bi_{turb}$ | $h_{lam}$ | $Bi_{lam}$ | $h_{turb}$ | $Bi_{turb}$ | $h_{lam}$ | $Bi_{lam}$ | $h_{turb}$ | $Bi_{turb}$ |
| **1** | 3880 | 0.0157 | 5549 | 0.0225 | 3887 | 0.0158 | 5566 | 0.0226 | 3898 | 0.0158 | 5593 | 0.0227 | 3884 | 0.0158 | 5577 | 0.0226 |
| **2** | 3880 | 0.0157 | 5549 | 0.0225 | 3887 | 0.0158 | 5566 | 0.0226 | 3898 | 0.0158 | 5593 | 0.0227 | 3887 | 0.0158 | 5582 | 0.0226 |
| **3** | 3880 | 0.0157 | 5549 | 0.0225 | 3887 | 0.0158 | 5566 | 0.0226 | 3898 | 0.0158 | 5593 | 0.0227 | 3890 | 0.0158 | 5587 | 0.0227 |
| **4** | 3880 | 0.0157 | 5549 | 0.0225 | 3887 | 0.0158 | 5567 | 0.0226 | 3898 | 0.0158 | 5593 | 0.0227 | 3892 | 0.0158 | 5592 | 0.0227 |
| **5** | 3880 | 0.0157 | 5549 | 0.0225 | 3887 | 0.0158 | 5567 | 0.0226 | 3898 | 0.0158 | 5593 | 0.0227 | 3895 | 0.0158 | 5596 | 0.0227 |
| **6** | 3880 | 0.0157 | 5549 | 0.0225 | 3887 | 0.0158 | 5567 | 0.0226 | 3899 | 0.0158 | 5594 | 0.0227 | 3897 | 0.0158 | 5601 | 0.0227 |
| **7** | 3880 | 0.0157 | 5549 | 0.0225 | 3887 | 0.0158 | 5567 | 0.0226 | 3899 | 0.0158 | 5594 | 0.0227 | 3900 | 0.0158 | 5606 | 0.0227 |
| **8** | 3880 | 0.0157 | 5549 | 0.0225 | 3887 | 0.0158 | 5567 | 0.0226 | 3899 | 0.0158 | 5594 | 0.0227 | 3902 | 0.0158 | 5610 | 0.0227 |
| **9** | 3880 | 0.0157 | 5549 | 0.0225 | 3887 | 0.0158 | 5567 | 0.0226 | 3899 | 0.0158 | 5594 | 0.0227 | 3904 | 0.0158 | 5614 | 0.0228 |
| **10** | 3880 | 0.0157 | 5549 | 0.0225 | 3887 | 0.0158 | 5567 | 0.0226 | 3899 | 0.0158 | 5594 | 0.0227 | 3906 | 0.0158 | 5618 | 0.0228 |
| **11** | 3880 | 0.0157 | 5549 | 0.0225 | 3887 | 0.0158 | 5567 | 0.0226 | 3899 | 0.0158 | 5594 | 0.0227 | 3909 | 0.0158 | 5622 | 0.0228 |
| **12** | 3880 | 0.0157 | 5549 | 0.0225 | 3888 | 0.0158 | 5567 | 0.0226 | 3899 | 0.0158 | 5594 | 0.0227 | 3911 | 0.0159 | 5626 | 0.0228 |
| **13** | 3880 | 0.0157 | 5549 | 0.0225 | 3888 | 0.0158 | 5567 | 0.0226 | 3899 | 0.0158 | 5594 | 0.0227 | 3913 | 0.0159 | 5630 | 0.0228 |
| **14** | 3880 | 0.0157 | 5549 | 0.0225 | 3888 | 0.0158 | 5567 | 0.0226 | 3899 | 0.0158 | 5595 | 0.0227 | 3916 | 0.0159 | 5635 | 0.0228 |
| **Coilset** | **8 seconds** | | | | **10 seconds** | | | | **15 seconds** | | | | **20 seconds** | | | |
| | $h_{lam}$ | $Bi_{lam}$ | $h_{turb}$ | $Bi_{turb}$ | $h_{lam}$ | $Bi_{lam}$ | $h_{turb}$ | $Bi_{turb}$ | $h_{lam}$ | $Bi_{lam}$ | $h_{turb}$ | $Bi_{turb}$ | $h_{lam}$ | $Bi_{lam}$ | $h_{turb}$ | $Bi_{turb}$ |
| **1** | 3826 | 0.0155 | 5478 | 0.0222 | 3797 | 0.0154 | 5427 | 0.0220 | 3748 | 0.0152 | 5355 | 0.0217 | 3710 | 0.0150 | 5294 | 0.0215 |
| **2** | 3834 | 0.0155 | 5493 | 0.0223 | 3807 | 0.0154 | 5445 | 0.0221 | 3764 | 0.0153 | 5383 | 0.0218 | 3729 | 0.0151 | 5328 | 0.0216 |
| **3** | 3841 | 0.0156 | 5507 | 0.0223 | 3817 | 0.0155 | 5463 | 0.0222 | 3780 | 0.0153 | 5411 | 0.0219 | 3748 | 0.0152 | 5361 | 0.0217 |
| **4** | 3849 | 0.0156 | 5520 | 0.0224 | 3827 | 0.0155 | 5481 | 0.0222 | 3795 | 0.0154 | 5439 | 0.0221 | 3767 | 0.0153 | 5395 | 0.0219 |
| **5** | 3857 | 0.0156 | 5534 | 0.0224 | 3837 | 0.0156 | 5499 | 0.0223 | 3810 | 0.0155 | 5466 | 0.0222 | 3787 | 0.0154 | 5430 | 0.0220 |
| **6** | 3865 | 0.0157 | 5549 | 0.0225 | 3847 | 0.0156 | 5518 | 0.0224 | 3826 | 0.0155 | 5495 | 0.0223 | 3806 | 0.0154 | 5464 | 0.0222 |
| **7** | 3872 | 0.0157 | 5563 | 0.0226 | 3857 | 0.0156 | 5536 | 0.0224 | 3842 | 0.0156 | 5524 | 0.0224 | 3824 | 0.0155 | 5498 | 0.0223 |
| **8** | 3880 | 0.0157 | 5577 | 0.0226 | 3867 | 0.0157 | 5555 | 0.0225 | 3857 | 0.0156 | 5552 | 0.0225 | 3844 | 0.0156 | 5534 | 0.0224 |
| **9** | 3888 | 0.0158 | 5592 | 0.0227 | 3877 | 0.0157 | 5573 | 0.0226 | 3873 | 0.0157 | 5582 | 0.0226 | 3863 | 0.0157 | 5569 | 0.0226 |
| **10** | 3896 | 0.0158 | 5607 | 0.0227 | 3888 | 0.0158 | 5593 | 0.0227 | 3890 | 0.0158 | 5612 | 0.0228 | 3883 | 0.0157 | 5606 | 0.0227 |
| **11** | 3904 | 0.0158 | 5621 | 0.0228 | 3898 | 0.0158 | 5611 | 0.0228 | 3906 | 0.0158 | 5642 | 0.0229 | 3903 | 0.0158 | 5642 | 0.0229 |
| **12** | 3912 | 0.0159 | 5636 | 0.0229 | 3909 | 0.0159 | 5631 | 0.0228 | 3923 | 0.0159 | 5672 | 0.0230 | 3924 | 0.0159 | 5680 | 0.0230 |
| **13** | 3919 | 0.0159 | 5649 | 0.0229 | 3919 | 0.0159 | 5649 | 0.0229 | 3939 | 0.0160 | 5703 | 0.0231 | 3944 | 0.0160 | 5718 | 0.0232 |
| **14** | 3927 | 0.0159 | 5663 | 0.0230 | 3928 | 0.0159 | 5667 | 0.0230 | 3955 | 0.0160 | 5731 | 0.0232 | 3963 | 0.0161 | 5754 | 0.0233 |
| **Coilset** | **30 seconds** | | | | **50 seconds** | | | | **100 seconds** | | | | **200 seconds** | | | |
| | $h_{lam}$ | $Bi_{lam}$ | $h_{turb}$ | $Bi_{turb}$ | $h_{lam}$ | $Bi_{lam}$ | $h_{turb}$ | $Bi_{turb}$ | $h_{lam}$ | $Bi_{lam}$ | $h_{turb}$ | $Bi_{turb}$ | $h_{lam}$ | $Bi_{lam}$ | $h_{turb}$ | $Bi_{turb}$ |
| **1** | 3658 | 0.0148 | 5200 | 0.0211 | 3611 | 0.0146 | 5111 | 0.0207 | 3591 | 0.0146 | 5076 | 0.0206 | 3586 | 0.0145 | 5068 | 0.0206 |
| **2** | 3679 | 0.0149 | 5236 | 0.0212 | 3633 | 0.0147 | 5150 | 0.0209 | 3619 | 0.0147 | 5130 | 0.0208 | 3615 | 0.0147 | 5122 | 0.0208 |
| **3** | 3700 | 0.0150 | 5273 | 0.0214 | 3653 | 0.0148 | 5186 | 0.0210 | 3640 | 0.0148 | 5167 | 0.0210 | 3638 | 0.0148 | 5164 | 0.0209 |
| **4** | 3721 | 0.0151 | 5310 | 0.0215 | 3675 | 0.0149 | 5223 | 0.0212 | 3661 | 0.0148 | 5203 | 0.0211 | 3659 | 0.0148 | 5200 | 0.0211 |
| **5** | 3743 | 0.0152 | 5349 | 0.0217 | 3696 | 0.0150 | 5260 | 0.0213 | 3683 | 0.0149 | 5241 | 0.0213 | 3680 | 0.0149 | 5238 | 0.0212 |
| **6** | 3765 | 0.0153 | 5388 | 0.0218 | 3718 | 0.0151 | 5299 | 0.0215 | 3704 | 0.0150 | 5279 | 0.0214 | 3702 | 0.0150 | 5276 | 0.0214 |
| **7** | 3787 | 0.0154 | 5426 | 0.0220 | 3739 | 0.0152 | 5337 | 0.0216 | 3726 | 0.0151 | 5317 | 0.0216 | 3724 | 0.0151 | 5315 | 0.0216 |
| **8** | 3808 | 0.0154 | 5465 | 0.0222 | 3762 | 0.0153 | 5376 | 0.0218 | 3749 | 0.0152 | 5357 | 0.0217 | 3747 | 0.0152 | 5355 | 0.0217 |
| **9** | 3830 | 0.0155 | 5505 | 0.0223 | 3784 | 0.0153 | 5415 | 0.0220 | 3771 | 0.0153 | 5396 | 0.0219 | 3770 | 0.0153 | 5395 | 0.0219 |
| **10** | 3852 | 0.0156 | 5545 | 0.0225 | 3805 | 0.0154 | 5455 | 0.0221 | 3793 | 0.0154 | 5436 | 0.0220 | 3792 | 0.0154 | 5435 | 0.0220 |
| **11** | 3874 | 0.0157 | 5586 | 0.0227 | 3827 | 0.0155 | 5495 | 0.0223 | 3815 | 0.0155 | 5476 | 0.0222 | 3814 | 0.0155 | 5476 | 0.0222 |
| **12** | 3897 | 0.0158 | 5628 | 0.0228 | 3850 | 0.0156 | 5536 | 0.0224 | 3837 | 0.0156 | 5517 | 0.0224 | 3837 | 0.0156 | 5516 | 0.0224 |
| **13** | 3920 | 0.0159 | 5670 | 0.0230 | 3872 | 0.0157 | 5578 | 0.0226 | 3860 | 0.0157 | 5558 | 0.0225 | 3860 | 0.0157 | 5558 | 0.0225 |
| **14** | 3943 | 0.0160 | 5713 | 0.0232 | 3896 | 0.0158 | 5620 | 0.0228 | 3883 | 0.0157 | 5600 | 0.0227 | 3883 | 0.0157 | 5601 | 0.0227 |

**Table H16: Heat transfer coefficients and Biot number approximations for R4-36 at 9LPM**

| Coilset | 1 second | | | | 2 seconds | | | | 3 seconds | | | | 5 seconds | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $h_{lam}$ | $Bi_{lam}$ | $h_{turb}$ | $Bi_{turb}$ | $h_{lam}$ | $Bi_{lam}$ | $h_{turb}$ | $Bi_{turb}$ | $h_{lam}$ | $Bi_{lam}$ | $h_{turb}$ | $Bi_{turb}$ | $h_{lam}$ | $Bi_{lam}$ | $h_{turb}$ | $Bi_{turb}$ |
| **1** | 3747 | 0.0152 | 5232 | 0.0212 | 3747 | 0.0152 | 5236 | 0.0212 | 3739 | 0.0152 | 5231 | 0.0212 | 3725 | 0.0151 | 5211 | 0.0211 |
| **2** | 3747 | 0.0152 | 5233 | 0.0212 | 3748 | 0.0152 | 5238 | 0.0212 | 3741 | 0.0152 | 5235 | 0.0212 | 3729 | 0.0151 | 5219 | 0.0212 |
| **3** | 3747 | 0.0152 | 5234 | 0.0212 | 3748 | 0.0152 | 5239 | 0.0212 | 3744 | 0.0152 | 5241 | 0.0213 | 3734 | 0.0151 | 5227 | 0.0212 |
| **4** | 3748 | 0.0152 | 5235 | 0.0212 | 3750 | 0.0152 | 5241 | 0.0213 | 3747 | 0.0152 | 5246 | 0.0213 | 3738 | 0.0152 | 5236 | 0.0212 |
| **5** | 3748 | 0.0152 | 5236 | 0.0212 | 3751 | 0.0152 | 5243 | 0.0213 | 3750 | 0.0152 | 5251 | 0.0213 | 3743 | 0.0152 | 5244 | 0.0213 |
| **6** | 3749 | 0.0152 | 5237 | 0.0212 | 3751 | 0.0152 | 5244 | 0.0213 | 3753 | 0.0152 | 5256 | 0.0213 | 3748 | 0.0152 | 5252 | 0.0213 |
| **7** | 3750 | 0.0152 | 5238 | 0.0212 | 3752 | 0.0152 | 5246 | 0.0213 | 3756 | 0.0152 | 5261 | 0.0213 | 3752 | 0.0152 | 5260 | 0.0213 |
| **8** | 3750 | 0.0152 | 5238 | 0.0212 | 3753 | 0.0152 | 5248 | 0.0213 | 3758 | 0.0152 | 5266 | 0.0214 | 3757 | 0.0152 | 5269 | 0.0214 |
| **9** | 3750 | 0.0152 | 5239 | 0.0212 | 3754 | 0.0152 | 5249 | 0.0213 | 3761 | 0.0153 | 5270 | 0.0214 | 3761 | 0.0153 | 5277 | 0.0214 |
| **10** | 3751 | 0.0152 | 5240 | 0.0212 | 3755 | 0.0152 | 5251 | 0.0213 | 3763 | 0.0153 | 5275 | 0.0214 | 3766 | 0.0153 | 5285 | 0.0214 |
| **11** | 3751 | 0.0152 | 5241 | 0.0213 | 3756 | 0.0152 | 5252 | 0.0213 | 3766 | 0.0153 | 5279 | 0.0214 | 3770 | 0.0153 | 5292 | 0.0215 |
| **12** | 3752 | 0.0152 | 5242 | 0.0213 | 3757 | 0.0152 | 5255 | 0.0213 | 3769 | 0.0153 | 5284 | 0.0214 | 3774 | 0.0153 | 5300 | 0.0215 |
| **13** | 3752 | 0.0152 | 5243 | 0.0213 | 3758 | 0.0152 | 5256 | 0.0213 | 3771 | 0.0153 | 5289 | 0.0214 | 3778 | 0.0153 | 5307 | 0.0215 |
| **14** | 3753 | 0.0152 | 5244 | 0.0213 | 3759 | 0.0152 | 5258 | 0.0213 | 3774 | 0.0153 | 5293 | 0.0215 | 3782 | 0.0153 | 5315 | 0.0216 |
| **Coilset** | **8 seconds** | | | | **10 seconds** | | | | **15 seconds** | | | | **20 seconds** | | | |
| | $h_{lam}$ | $Bi_{lam}$ | $h_{turb}$ | $Bi_{turb}$ | $h_{lam}$ | $Bi_{lam}$ | $h_{turb}$ | $Bi_{turb}$ | $h_{lam}$ | $Bi_{lam}$ | $h_{turb}$ | $Bi_{turb}$ | $h_{lam}$ | $Bi_{lam}$ | $h_{turb}$ | $Bi_{turb}$ |
| **1** | 3677 | 0.0149 | 5131 | 0.0208 | 3651 | 0.0148 | 5084 | 0.0206 | 3594 | 0.0146 | 4997 | 0.0203 | 3549 | 0.0144 | 4913 | 0.0199 |
| **2** | 3686 | 0.0149 | 5146 | 0.0209 | 3660 | 0.0148 | 5102 | 0.0207 | 3610 | 0.0146 | 5024 | 0.0204 | 3566 | 0.0145 | 4943 | 0.0200 |
| **3** | 3694 | 0.0150 | 5161 | 0.0209 | 3671 | 0.0149 | 5120 | 0.0208 | 3626 | 0.0147 | 5051 | 0.0205 | 3584 | 0.0145 | 4973 | 0.0202 |
| **4** | 3702 | 0.0150 | 5176 | 0.0210 | 3681 | 0.0149 | 5138 | 0.0208 | 3642 | 0.0148 | 5078 | 0.0206 | 3602 | 0.0146 | 5004 | 0.0203 |
| **5** | 3711 | 0.0150 | 5191 | 0.0210 | 3691 | 0.0150 | 5156 | 0.0209 | 3657 | 0.0148 | 5105 | 0.0207 | 3620 | 0.0147 | 5034 | 0.0204 |
| **6** | 3719 | 0.0151 | 5206 | 0.0211 | 3702 | 0.0150 | 5175 | 0.0210 | 3673 | 0.0149 | 5133 | 0.0208 | 3637 | 0.0147 | 5065 | 0.0205 |
| **7** | 3728 | 0.0151 | 5221 | 0.0212 | 3712 | 0.0151 | 5193 | 0.0211 | 3688 | 0.0150 | 5161 | 0.0209 | 3655 | 0.0148 | 5096 | 0.0207 |
| **8** | 3736 | 0.0152 | 5237 | 0.0212 | 3722 | 0.0151 | 5212 | 0.0211 | 3704 | 0.0150 | 5189 | 0.0210 | 3673 | 0.0149 | 5128 | 0.0208 |
| **9** | 3745 | 0.0152 | 5252 | 0.0213 | 3733 | 0.0151 | 5231 | 0.0212 | 3720 | 0.0151 | 5218 | 0.0212 | 3691 | 0.0150 | 5160 | 0.0209 |
| **10** | 3753 | 0.0152 | 5267 | 0.0214 | 3744 | 0.0152 | 5250 | 0.0213 | 3737 | 0.0152 | 5247 | 0.0213 | 3709 | 0.0150 | 5192 | 0.0211 |
| **11** | 3762 | 0.0153 | 5283 | 0.0214 | 3754 | 0.0152 | 5269 | 0.0214 | 3753 | 0.0152 | 5276 | 0.0214 | 3727 | 0.0151 | 5225 | 0.0212 |
| **12** | 3771 | 0.0153 | 5299 | 0.0215 | 3765 | 0.0153 | 5288 | 0.0214 | 3770 | 0.0153 | 5306 | 0.0215 | 3746 | 0.0152 | 5259 | 0.0213 |
| **13** | 3779 | 0.0153 | 5313 | 0.0215 | 3776 | 0.0153 | 5307 | 0.0215 | 3786 | 0.0154 | 5336 | 0.0216 | 3765 | 0.0153 | 5292 | 0.0215 |
| **14** | 3787 | 0.0154 | 5327 | 0.0216 | 3785 | 0.0153 | 5324 | 0.0216 | 3802 | 0.0154 | 5364 | 0.0218 | 3784 | 0.0153 | 5326 | 0.0216 |
| **Coilset** | **30 seconds** | | | | **50 seconds** | | | | **100 seconds** | | | | **200 seconds** | | | |
| | $h_{lam}$ | $Bi_{lam}$ | $h_{turb}$ | $Bi_{turb}$ | $h_{lam}$ | $Bi_{lam}$ | $h_{turb}$ | $Bi_{turb}$ | $h_{lam}$ | $Bi_{lam}$ | $h_{turb}$ | $Bi_{turb}$ | $h_{lam}$ | $Bi_{lam}$ | $h_{turb}$ | $Bi_{turb}$ |
| **1** | 3511 | 0.0142 | 4856 | 0.0197 | 3458 | 0.0140 | 4751 | 0.0193 | 3426 | 0.0139 | 4692 | 0.0190 | 3416 | 0.0139 | 4671 | 0.0189 |
| **2** | 3529 | 0.0143 | 4887 | 0.0198 | 3479 | 0.0141 | 4788 | 0.0194 | 3455 | 0.0140 | 4744 | 0.0192 | 3445 | 0.0140 | 4723 | 0.0192 |
| **3** | 3548 | 0.0144 | 4919 | 0.0199 | 3500 | 0.0142 | 4823 | 0.0196 | 3476 | 0.0141 | 4780 | 0.0194 | 3468 | 0.0141 | 4764 | 0.0193 |
| **4** | 3566 | 0.0145 | 4951 | 0.0201 | 3521 | 0.0143 | 4859 | 0.0197 | 3497 | 0.0142 | 4816 | 0.0195 | 3490 | 0.0142 | 4801 | 0.0195 |
| **5** | 3585 | 0.0145 | 4983 | 0.0202 | 3542 | 0.0144 | 4895 | 0.0198 | 3519 | 0.0143 | 4852 | 0.0197 | 3511 | 0.0142 | 4838 | 0.0196 |
| **6** | 3604 | 0.0146 | 5016 | 0.0203 | 3563 | 0.0144 | 4932 | 0.0200 | 3540 | 0.0144 | 4889 | 0.0198 | 3533 | 0.0143 | 4875 | 0.0198 |
| **7** | 3624 | 0.0147 | 5050 | 0.0205 | 3585 | 0.0145 | 4969 | 0.0201 | 3563 | 0.0144 | 4927 | 0.0200 | 3556 | 0.0144 | 4913 | 0.0199 |
| **8** | 3643 | 0.0148 | 5083 | 0.0206 | 3608 | 0.0146 | 5008 | 0.0203 | 3585 | 0.0145 | 4966 | 0.0201 | 3578 | 0.0145 | 4952 | 0.0201 |
| **9** | 3662 | 0.0148 | 5116 | 0.0207 | 3629 | 0.0147 | 5045 | 0.0205 | 3608 | 0.0146 | 5004 | 0.0203 | 3602 | 0.0146 | 4991 | 0.0202 |
| **10** | 3681 | 0.0149 | 5150 | 0.0209 | 3651 | 0.0148 | 5084 | 0.0206 | 3630 | 0.0147 | 5043 | 0.0205 | 3624 | 0.0147 | 5031 | 0.0204 |
| **11** | 3700 | 0.0150 | 5185 | 0.0210 | 3673 | 0.0149 | 5123 | 0.0208 | 3652 | 0.0148 | 5083 | 0.0206 | 3646 | 0.0148 | 5070 | 0.0206 |
| **12** | 3720 | 0.0151 | 5220 | 0.0212 | 3695 | 0.0150 | 5162 | 0.0209 | 3675 | 0.0149 | 5122 | 0.0208 | 3670 | 0.0149 | 5112 | 0.0207 |
| **13** | 3740 | 0.0152 | 5256 | 0.0213 | 3718 | 0.0151 | 5203 | 0.0211 | 3698 | 0.0150 | 5163 | 0.0209 | 3693 | 0.0150 | 5153 | 0.0209 |
| **14** | 3760 | 0.0152 | 5292 | 0.0215 | 3741 | 0.0152 | 5244 | 0.0213 | 3721 | 0.0151 | 5205 | 0.0211 | 3717 | 0.0151 | 5195 | 0.0211 |

**Table H17: Heat transfer coefficients and Biot number approximations for R4-36 at 7LPM**

| Coilset | 1 second | | | | 2 seconds | | | | 3 seconds | | | | 5 seconds | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $h_{lam}$ | $Bi_{lam}$ | $h_{turb}$ | $Bi_{turb}$ | $h_{lam}$ | $Bi_{lam}$ | $h_{turb}$ | $Bi_{turb}$ | $h_{lam}$ | $Bi_{lam}$ | $h_{turb}$ | $Bi_{turb}$ | $h_{lam}$ | $Bi_{lam}$ | $h_{turb}$ | $Bi_{turb}$ |
| **1** | 3233 | 0.0131 | 4084 | 0.0166 | 3235 | 0.0131 | 4089 | 0.0166 | 3252 | 0.0132 | 4124 | 0.0167 | 3244 | 0.0132 | 4116 | 0.0167 |
| **2** | 3233 | 0.0131 | 4084 | 0.0166 | 3235 | 0.0131 | 4089 | 0.0166 | 3252 | 0.0132 | 4124 | 0.0167 | 3245 | 0.0132 | 4118 | 0.0167 |
| **3** | 3233 | 0.0131 | 4084 | 0.0166 | 3235 | 0.0131 | 4089 | 0.0166 | 3252 | 0.0132 | 4124 | 0.0167 | 3247 | 0.0132 | 4121 | 0.0167 |
| **4** | 3233 | 0.0131 | 4084 | 0.0166 | 3236 | 0.0131 | 4090 | 0.0166 | 3252 | 0.0132 | 4124 | 0.0167 | 3248 | 0.0132 | 4123 | 0.0167 |
| **5** | 3233 | 0.0131 | 4084 | 0.0166 | 3236 | 0.0131 | 4090 | 0.0166 | 3252 | 0.0132 | 4124 | 0.0167 | 3250 | 0.0132 | 4125 | 0.0167 |
| **6** | 3233 | 0.0131 | 4084 | 0.0166 | 3236 | 0.0131 | 4090 | 0.0166 | 3252 | 0.0132 | 4124 | 0.0167 | 3251 | 0.0132 | 4127 | 0.0167 |
| **7** | 3233 | 0.0131 | 4084 | 0.0166 | 3236 | 0.0131 | 4090 | 0.0166 | 3252 | 0.0132 | 4124 | 0.0167 | 3252 | 0.0132 | 4129 | 0.0167 |
| **8** | 3233 | 0.0131 | 4085 | 0.0166 | 3236 | 0.0131 | 4090 | 0.0166 | 3252 | 0.0132 | 4125 | 0.0167 | 3254 | 0.0132 | 4132 | 0.0168 |
| **9** | 3233 | 0.0131 | 4085 | 0.0166 | 3236 | 0.0131 | 4090 | 0.0166 | 3252 | 0.0132 | 4125 | 0.0167 | 3255 | 0.0132 | 4134 | 0.0168 |
| **10** | 3233 | 0.0131 | 4085 | 0.0166 | 3236 | 0.0131 | 4090 | 0.0166 | 3252 | 0.0132 | 4125 | 0.0167 | 3256 | 0.0132 | 4136 | 0.0168 |
| **11** | 3233 | 0.0131 | 4085 | 0.0166 | 3236 | 0.0131 | 4090 | 0.0166 | 3252 | 0.0132 | 4125 | 0.0167 | 3257 | 0.0132 | 4138 | 0.0168 |
| **12** | 3233 | 0.0131 | 4085 | 0.0166 | 3236 | 0.0131 | 4090 | 0.0166 | 3252 | 0.0132 | 4125 | 0.0167 | 3259 | 0.0132 | 4140 | 0.0168 |
| **13** | 3233 | 0.0131 | 4085 | 0.0166 | 3236 | 0.0131 | 4090 | 0.0166 | 3252 | 0.0132 | 4125 | 0.0167 | 3260 | 0.0132 | 4143 | 0.0168 |
| **14** | 3233 | 0.0131 | 4085 | 0.0166 | 3236 | 0.0131 | 4090 | 0.0166 | 3252 | 0.0132 | 4125 | 0.0167 | 3262 | 0.0132 | 4145 | 0.0168 |

| Coilset | 8 seconds | | | | 10 seconds | | | | 15 seconds | | | | 20 seconds | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $h_{lam}$ | $Bi_{lam}$ | $h_{turb}$ | $Bi_{turb}$ | $h_{lam}$ | $Bi_{lam}$ | $h_{turb}$ | $Bi_{turb}$ | $h_{lam}$ | $Bi_{lam}$ | $h_{turb}$ | $Bi_{turb}$ | $h_{lam}$ | $Bi_{lam}$ | $h_{turb}$ | $Bi_{turb}$ |
| **1** | 3230 | 0.0131 | 4107 | 0.0167 | 3231 | 0.0131 | 4117 | 0.0167 | 3195 | 0.0130 | 4068 | 0.0165 | 3164 | 0.0128 | 4023 | 0.0163 |
| **2** | 3235 | 0.0131 | 4115 | 0.0167 | 3237 | 0.0131 | 4126 | 0.0167 | 3205 | 0.0130 | 4084 | 0.0166 | 3177 | 0.0129 | 4045 | 0.0164 |
| **3** | 3239 | 0.0131 | 4121 | 0.0167 | 3242 | 0.0131 | 4135 | 0.0168 | 3214 | 0.0130 | 4100 | 0.0166 | 3190 | 0.0129 | 4066 | 0.0165 |
| **4** | 3243 | 0.0132 | 4128 | 0.0167 | 3248 | 0.0132 | 4144 | 0.0168 | 3224 | 0.0131 | 4116 | 0.0167 | 3204 | 0.0130 | 4087 | 0.0166 |
| **5** | 3248 | 0.0132 | 4136 | 0.0168 | 3253 | 0.0132 | 4153 | 0.0168 | 3234 | 0.0131 | 4132 | 0.0168 | 3217 | 0.0130 | 4109 | 0.0167 |
| **6** | 3252 | 0.0132 | 4143 | 0.0168 | 3259 | 0.0132 | 4162 | 0.0169 | 3244 | 0.0132 | 4149 | 0.0168 | 3230 | 0.0131 | 4131 | 0.0167 |
| **7** | 3256 | 0.0132 | 4150 | 0.0168 | 3264 | 0.0132 | 4170 | 0.0169 | 3254 | 0.0132 | 4165 | 0.0169 | 3244 | 0.0132 | 4153 | 0.0168 |
| **8** | 3261 | 0.0132 | 4157 | 0.0169 | 3270 | 0.0133 | 4180 | 0.0169 | 3265 | 0.0132 | 4182 | 0.0170 | 3258 | 0.0132 | 4175 | 0.0169 |
| **9** | 3265 | 0.0132 | 4164 | 0.0169 | 3275 | 0.0133 | 4189 | 0.0170 | 3275 | 0.0133 | 4198 | 0.0170 | 3272 | 0.0133 | 4198 | 0.0170 |
| **10** | 3270 | 0.0133 | 4171 | 0.0169 | 3281 | 0.0133 | 4198 | 0.0170 | 3285 | 0.0133 | 4216 | 0.0171 | 3286 | 0.0133 | 4221 | 0.0171 |
| **11** | 3274 | 0.0133 | 4179 | 0.0169 | 3287 | 0.0133 | 4207 | 0.0171 | 3296 | 0.0134 | 4233 | 0.0172 | 3300 | 0.0134 | 4244 | 0.0172 |
| **12** | 3278 | 0.0133 | 4185 | 0.0170 | 3292 | 0.0133 | 4216 | 0.0171 | 3306 | 0.0134 | 4250 | 0.0172 | 3314 | 0.0134 | 4268 | 0.0173 |
| **13** | 3282 | 0.0133 | 4191 | 0.0170 | 3297 | 0.0134 | 4224 | 0.0171 | 3316 | 0.0134 | 4266 | 0.0173 | 3328 | 0.0135 | 4290 | 0.0174 |
| **14** | 3286 | 0.0133 | 4198 | 0.0170 | 3302 | 0.0134 | 4232 | 0.0172 | 3326 | 0.0135 | 4282 | 0.0174 | 3341 | 0.0135 | 4311 | 0.0175 |

| Coilset | 30 seconds | | | | 50 seconds | | | | 100 seconds | | | | 200 seconds | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $h_{lam}$ | $Bi_{lam}$ | $h_{turb}$ | $Bi_{turb}$ | $h_{lam}$ | $Bi_{lam}$ | $h_{turb}$ | $Bi_{turb}$ | $h_{lam}$ | $Bi_{lam}$ | $h_{turb}$ | $Bi_{turb}$ | $h_{lam}$ | $Bi_{lam}$ | $h_{turb}$ | $Bi_{turb}$ |
| **1** | 3134 | 0.0127 | 3987 | 0.0162 | 3082 | 0.0125 | 3905 | 0.0158 | 3064 | 0.0124 | 3880 | 0.0157 | 3054 | 0.0124 | 3862 | 0.0157 |
| **2** | 3150 | 0.0128 | 4013 | 0.0163 | 3098 | 0.0126 | 3929 | 0.0159 | 3084 | 0.0125 | 3913 | 0.0159 | 3078 | 0.0125 | 3903 | 0.0158 |
| **3** | 3166 | 0.0128 | 4039 | 0.0164 | 3114 | 0.0126 | 3954 | 0.0160 | 3102 | 0.0126 | 3941 | 0.0160 | 3099 | 0.0126 | 3935 | 0.0160 |
| **4** | 3183 | 0.0129 | 4064 | 0.0165 | 3130 | 0.0127 | 3979 | 0.0161 | 3120 | 0.0127 | 3969 | 0.0161 | 3119 | 0.0126 | 3967 | 0.0161 |
| **5** | 3200 | 0.0130 | 4091 | 0.0166 | 3146 | 0.0128 | 4005 | 0.0162 | 3138 | 0.0127 | 3998 | 0.0162 | 3140 | 0.0127 | 3999 | 0.0162 |
| **6** | 3216 | 0.0130 | 4118 | 0.0167 | 3163 | 0.0128 | 4031 | 0.0163 | 3156 | 0.0128 | 4027 | 0.0163 | 3161 | 0.0128 | 4033 | 0.0164 |
| **7** | 3232 | 0.0131 | 4144 | 0.0168 | 3179 | 0.0129 | 4057 | 0.0165 | 3175 | 0.0129 | 4056 | 0.0164 | 3182 | 0.0129 | 4066 | 0.0165 |
| **8** | 3249 | 0.0132 | 4171 | 0.0169 | 3196 | 0.0130 | 4083 | 0.0166 | 3194 | 0.0130 | 4086 | 0.0166 | 3204 | 0.0130 | 4101 | 0.0166 |
| **9** | 3265 | 0.0132 | 4198 | 0.0170 | 3212 | 0.0130 | 4109 | 0.0167 | 3213 | 0.0130 | 4116 | 0.0167 | 3225 | 0.0131 | 4135 | 0.0168 |
| **10** | 3283 | 0.0133 | 4226 | 0.0171 | 3229 | 0.0131 | 4136 | 0.0168 | 3232 | 0.0131 | 4146 | 0.0168 | 3247 | 0.0132 | 4170 | 0.0169 |
| **11** | 3300 | 0.0134 | 4255 | 0.0173 | 3245 | 0.0132 | 4163 | 0.0169 | 3250 | 0.0132 | 4177 | 0.0169 | 3268 | 0.0133 | 4205 | 0.0171 |
| **12** | 3317 | 0.0135 | 4283 | 0.0174 | 3262 | 0.0132 | 4191 | 0.0170 | 3269 | 0.0133 | 4208 | 0.0171 | 3290 | 0.0133 | 4241 | 0.0172 |
| **13** | 3335 | 0.0135 | 4313 | 0.0175 | 3280 | 0.0133 | 4219 | 0.0171 | 3289 | 0.0133 | 4240 | 0.0172 | 3313 | 0.0134 | 4279 | 0.0173 |
| **14** | 3351 | 0.0136 | 4340 | 0.0176 | 3297 | 0.0134 | 4247 | 0.0172 | 3309 | 0.0134 | 4273 | 0.0173 | 3336 | 0.0135 | 4316 | 0.0175 |

**Table H18: Heat transfer coefficients and Biot number approximations for R4-36 at 5.5LPM**

| Coilset | 1 second | | | | 2 seconds | | | | 3 seconds | | | | 5 seconds | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $h_{lam}$ | $Bi_{lam}$ | $h_{turb}$ | $Bi_{turb}$ | $h_{lam}$ | $Bi_{lam}$ | $h_{turb}$ | $Bi_{turb}$ | $h_{lam}$ | $Bi_{lam}$ | $h_{turb}$ | $Bi_{turb}$ | $h_{lam}$ | $Bi_{lam}$ | $h_{turb}$ | $Bi_{turb}$ |
| **1** | 2890 | 0.0117 | 3384 | 0.0137 | 2887 | 0.0117 | 3383 | 0.0137 | 2882 | 0.0117 | 3375 | 0.0137 | 2880 | 0.0117 | 3376 | 0.0137 |
| **2** | 2890 | 0.0117 | 3385 | 0.0137 | 2888 | 0.0117 | 3384 | 0.0137 | 2884 | 0.0117 | 3377 | 0.0137 | 2883 | 0.0117 | 3380 | 0.0137 |
| **3** | 2891 | 0.0117 | 3386 | 0.0137 | 2890 | 0.0117 | 3386 | 0.0137 | 2885 | 0.0117 | 3379 | 0.0137 | 2885 | 0.0117 | 3384 | 0.0137 |
| **4** | 2891 | 0.0117 | 3387 | 0.0137 | 2890 | 0.0117 | 3387 | 0.0137 | 2887 | 0.0117 | 3381 | 0.0137 | 2887 | 0.0117 | 3387 | 0.0137 |
| **5** | 2892 | 0.0117 | 3388 | 0.0137 | 2891 | 0.0117 | 3388 | 0.0137 | 2888 | 0.0117 | 3383 | 0.0137 | 2890 | 0.0117 | 3391 | 0.0137 |
| **6** | 2892 | 0.0117 | 3389 | 0.0137 | 2892 | 0.0117 | 3390 | 0.0137 | 2889 | 0.0117 | 3385 | 0.0137 | 2892 | 0.0117 | 3395 | 0.0138 |
| **7** | 2893 | 0.0117 | 3390 | 0.0137 | 2893 | 0.0117 | 3391 | 0.0138 | 2891 | 0.0117 | 3387 | 0.0137 | 2895 | 0.0117 | 3398 | 0.0138 |
| **8** | 2894 | 0.0117 | 3391 | 0.0137 | 2894 | 0.0117 | 3393 | 0.0138 | 2892 | 0.0117 | 3389 | 0.0137 | 2897 | 0.0117 | 3402 | 0.0138 |
| **9** | 2895 | 0.0117 | 3392 | 0.0138 | 2895 | 0.0117 | 3394 | 0.0138 | 2893 | 0.0117 | 3391 | 0.0138 | 2899 | 0.0118 | 3405 | 0.0138 |
| **10** | 2895 | 0.0117 | 3393 | 0.0138 | 2896 | 0.0117 | 3395 | 0.0138 | 2894 | 0.0117 | 3393 | 0.0138 | 2901 | 0.0118 | 3409 | 0.0138 |
| **11** | 2896 | 0.0117 | 3394 | 0.0138 | 2897 | 0.0117 | 3397 | 0.0138 | 2896 | 0.0117 | 3395 | 0.0138 | 2903 | 0.0118 | 3412 | 0.0138 |
| **12** | 2896 | 0.0117 | 3395 | 0.0138 | 2898 | 0.0118 | 3398 | 0.0138 | 2897 | 0.0117 | 3397 | 0.0138 | 2906 | 0.0118 | 3415 | 0.0138 |
| **13** | 2897 | 0.0117 | 3396 | 0.0138 | 2899 | 0.0118 | 3400 | 0.0138 | 2898 | 0.0118 | 3399 | 0.0138 | 2908 | 0.0118 | 3418 | 0.0139 |
| **14** | 2897 | 0.0117 | 3396 | 0.0138 | 2900 | 0.0118 | 3401 | 0.0138 | 2900 | 0.0118 | 3401 | 0.0138 | 2910 | 0.0118 | 3421 | 0.0139 |

| Coilset | 8 seconds | | | | 10 seconds | | | | 15 seconds | | | | 20 seconds | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $h_{lam}$ | $Bi_{lam}$ | $h_{turb}$ | $Bi_{turb}$ | $h_{lam}$ | $Bi_{lam}$ | $h_{turb}$ | $Bi_{turb}$ | $h_{lam}$ | $Bi_{lam}$ | $h_{turb}$ | $Bi_{turb}$ | $h_{lam}$ | $Bi_{lam}$ | $h_{turb}$ | $Bi_{turb}$ |
| **1** | 2875 | 0.0117 | 3376 | 0.0137 | 2855 | 0.0116 | 3348 | 0.0136 | 2849 | 0.0116 | 3353 | 0.0136 | 2825 | 0.0115 | 3319 | 0.0135 |
| **2** | 2879 | 0.0117 | 3382 | 0.0137 | 2861 | 0.0116 | 3357 | 0.0136 | 2857 | 0.0116 | 3366 | 0.0136 | 2836 | 0.0115 | 3335 | 0.0135 |
| **3** | 2883 | 0.0117 | 3388 | 0.0137 | 2866 | 0.0116 | 3365 | 0.0136 | 2866 | 0.0116 | 3379 | 0.0137 | 2847 | 0.0115 | 3351 | 0.0136 |
| **4** | 2887 | 0.0117 | 3394 | 0.0138 | 2872 | 0.0116 | 3373 | 0.0137 | 2874 | 0.0117 | 3392 | 0.0138 | 2857 | 0.0116 | 3367 | 0.0137 |
| **5** | 2891 | 0.0117 | 3400 | 0.0138 | 2878 | 0.0117 | 3382 | 0.0137 | 2883 | 0.0117 | 3404 | 0.0138 | 2869 | 0.0116 | 3384 | 0.0137 |
| **6** | 2895 | 0.0117 | 3406 | 0.0138 | 2883 | 0.0117 | 3390 | 0.0137 | 2892 | 0.0117 | 3417 | 0.0139 | 2880 | 0.0117 | 3401 | 0.0138 |
| **7** | 2898 | 0.0118 | 3412 | 0.0138 | 2889 | 0.0117 | 3398 | 0.0138 | 2900 | 0.0118 | 3431 | 0.0139 | 2891 | 0.0117 | 3418 | 0.0139 |
| **8** | 2903 | 0.0118 | 3418 | 0.0139 | 2894 | 0.0117 | 3407 | 0.0138 | 2909 | 0.0118 | 3444 | 0.0140 | 2902 | 0.0118 | 3435 | 0.0139 |
| **9** | 2906 | 0.0118 | 3423 | 0.0139 | 2900 | 0.0118 | 3416 | 0.0139 | 2918 | 0.0118 | 3458 | 0.0140 | 2914 | 0.0118 | 3452 | 0.0140 |
| **10** | 2911 | 0.0118 | 3430 | 0.0139 | 2906 | 0.0118 | 3424 | 0.0139 | 2927 | 0.0119 | 3471 | 0.0141 | 2925 | 0.0119 | 3470 | 0.0141 |
| **11** | 2915 | 0.0118 | 3436 | 0.0139 | 2912 | 0.0118 | 3433 | 0.0139 | 2936 | 0.0119 | 3485 | 0.0141 | 2937 | 0.0119 | 3488 | 0.0141 |
| **12** | 2918 | 0.0118 | 3441 | 0.0140 | 2917 | 0.0118 | 3441 | 0.0140 | 2945 | 0.0119 | 3499 | 0.0142 | 2949 | 0.0120 | 3505 | 0.0142 |
| **13** | 2922 | 0.0118 | 3446 | 0.0140 | 2922 | 0.0119 | 3449 | 0.0140 | 2954 | 0.0120 | 3511 | 0.0142 | 2960 | 0.0120 | 3522 | 0.0143 |
| **14** | 2925 | 0.0119 | 3451 | 0.0140 | 2928 | 0.0119 | 3457 | 0.0140 | 2962 | 0.0120 | 3524 | 0.0143 | 2970 | 0.0120 | 3537 | 0.0143 |

| Coilset | 30 seconds | | | | 50 seconds | | | | 100 seconds | | | | 200 seconds | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $h_{lam}$ | $Bi_{lam}$ | $h_{turb}$ | $Bi_{turb}$ | $h_{lam}$ | $Bi_{lam}$ | $h_{turb}$ | $Bi_{turb}$ | $h_{lam}$ | $Bi_{lam}$ | $h_{turb}$ | $Bi_{turb}$ | $h_{lam}$ | $Bi_{lam}$ | $h_{turb}$ | $Bi_{turb}$ |
| **1** | 2803 | 0.0114 | 3301 | 0.0134 | 2815 | 0.0114 | 3352 | 0.0136 | 2728 | 0.0111 | 3196 | 0.0130 | 2712 | 0.0110 | 3169 | 0.0129 |
| **2** | 2818 | 0.0114 | 3323 | 0.0135 | 2830 | 0.0115 | 3373 | 0.0137 | 2747 | 0.0111 | 3225 | 0.0131 | 2732 | 0.0111 | 3201 | 0.0130 |
| **3** | 2833 | 0.0115 | 3344 | 0.0136 | 2845 | 0.0115 | 3395 | 0.0138 | 2761 | 0.0112 | 3245 | 0.0132 | 2750 | 0.0112 | 3228 | 0.0131 |
| **4** | 2848 | 0.0115 | 3366 | 0.0136 | 2860 | 0.0116 | 3417 | 0.0139 | 2776 | 0.0113 | 3267 | 0.0132 | 2765 | 0.0112 | 3250 | 0.0132 |
| **5** | 2862 | 0.0116 | 3388 | 0.0137 | 2875 | 0.0117 | 3440 | 0.0139 | 2790 | 0.0113 | 3288 | 0.0133 | 2780 | 0.0113 | 3272 | 0.0133 |
| **6** | 2877 | 0.0117 | 3410 | 0.0138 | 2891 | 0.0117 | 3463 | 0.0140 | 2805 | 0.0114 | 3309 | 0.0134 | 2796 | 0.0113 | 3295 | 0.0134 |
| **7** | 2892 | 0.0117 | 3433 | 0.0139 | 2907 | 0.0118 | 3487 | 0.0141 | 2820 | 0.0114 | 3331 | 0.0135 | 2812 | 0.0114 | 3318 | 0.0135 |
| **8** | 2907 | 0.0118 | 3455 | 0.0140 | 2923 | 0.0119 | 3510 | 0.0142 | 2835 | 0.0115 | 3353 | 0.0136 | 2828 | 0.0115 | 3342 | 0.0135 |
| **9** | 2922 | 0.0118 | 3478 | 0.0141 | 2938 | 0.0119 | 3534 | 0.0143 | 2851 | 0.0116 | 3376 | 0.0137 | 2844 | 0.0115 | 3365 | 0.0136 |
| **10** | 2938 | 0.0119 | 3502 | 0.0142 | 2954 | 0.0120 | 3557 | 0.0144 | 2866 | 0.0116 | 3398 | 0.0138 | 2861 | 0.0116 | 3389 | 0.0137 |
| **11** | 2954 | 0.0120 | 3526 | 0.0143 | 2969 | 0.0120 | 3582 | 0.0145 | 2881 | 0.0117 | 3421 | 0.0139 | 2877 | 0.0117 | 3413 | 0.0138 |
| **12** | 2969 | 0.0120 | 3550 | 0.0144 | 2985 | 0.0121 | 3606 | 0.0146 | 2896 | 0.0117 | 3444 | 0.0140 | 2893 | 0.0117 | 3437 | 0.0139 |
| **13** | 2985 | 0.0121 | 3573 | 0.0145 | 3001 | 0.0122 | 3631 | 0.0147 | 2912 | 0.0118 | 3467 | 0.0141 | 2909 | 0.0118 | 3462 | 0.0140 |
| **14** | 2999 | 0.0122 | 3595 | 0.0146 | 3018 | 0.0122 | 3656 | 0.0148 | 2927 | 0.0119 | 3491 | 0.0142 | 2926 | 0.0119 | 3487 | 0.0141 |

# Appendix I: Surface and Water Temperature Profiles across Non-Dimensionalized DWHR System Length

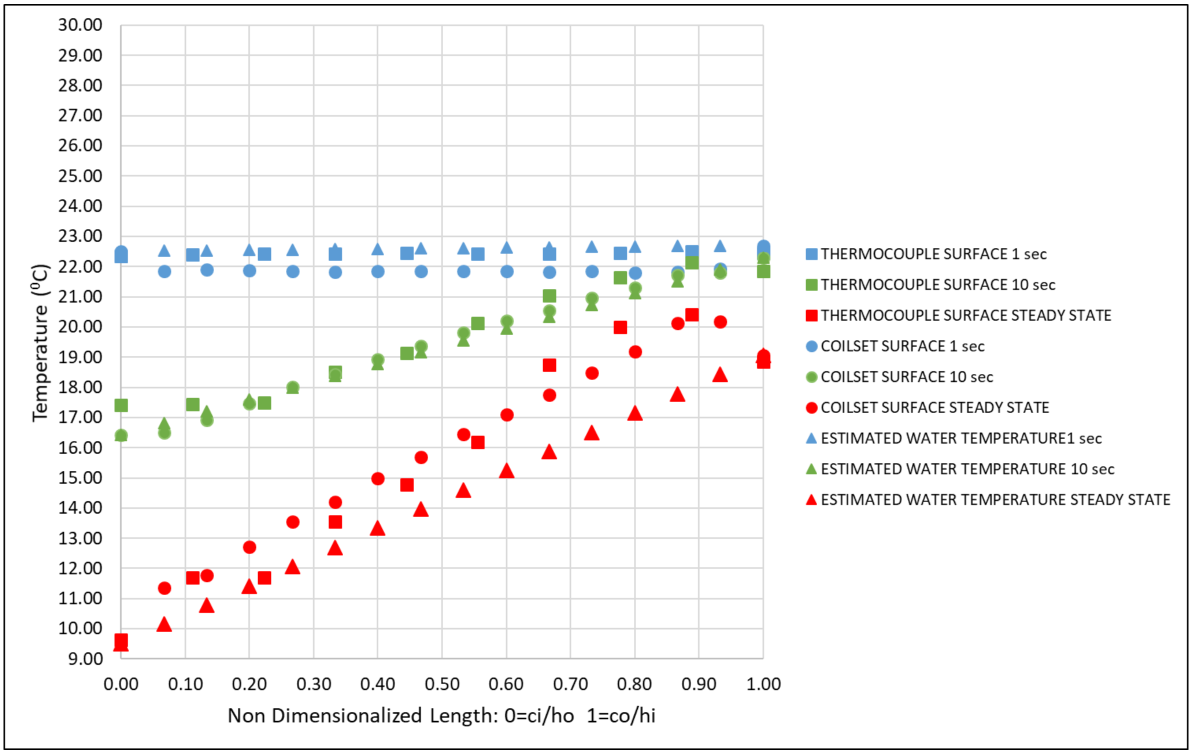


**Figure I1: Mains-side temperature profiles at different time instants for R3-36 at 14LPM**

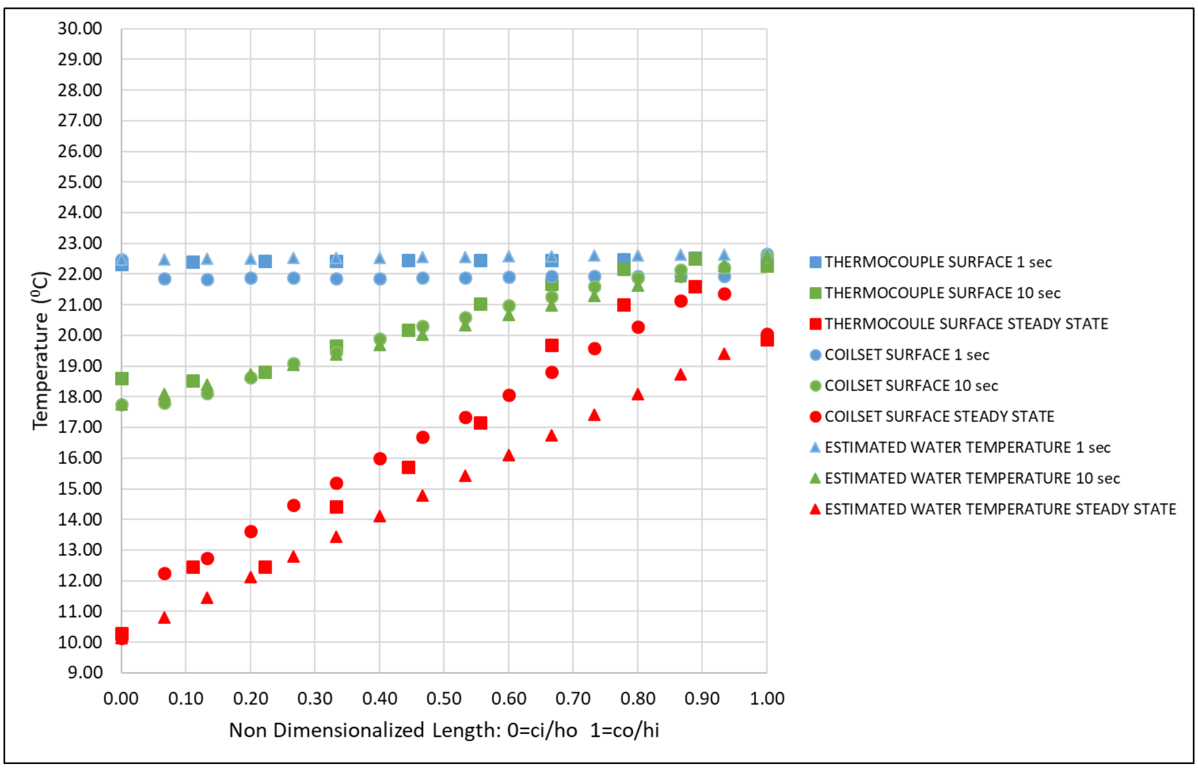


**Figure I2: Mains-side temperature profiles at different time instants for R3-36 at 12LPM**

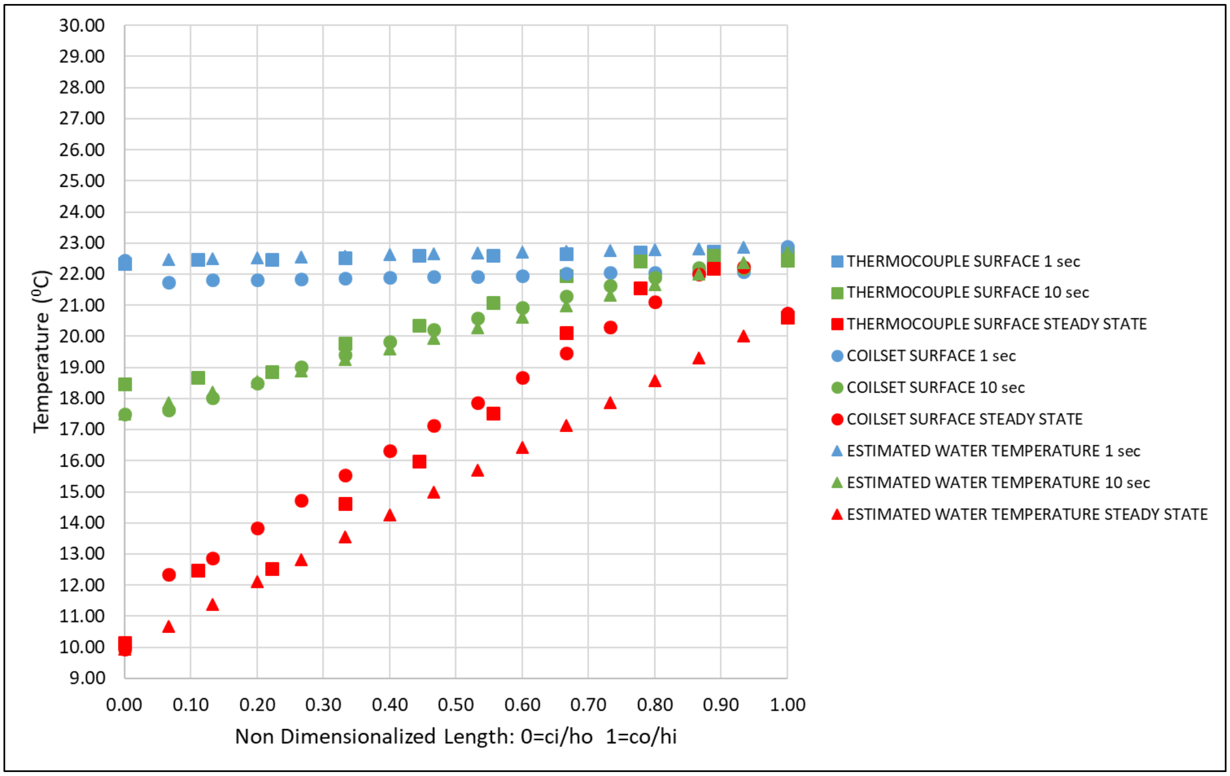


**Figure I3: Mains-side temperature profiles at different time instants for R3-36 at 10LPM**

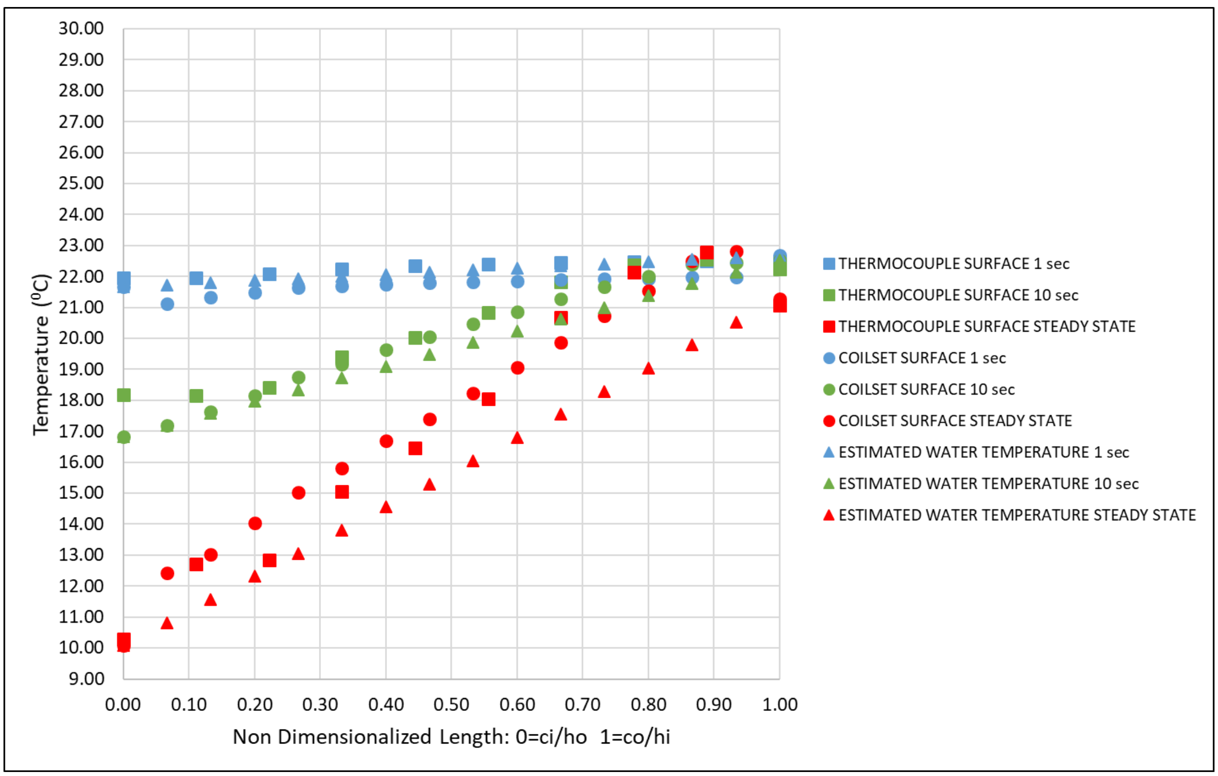


**Figure I4: Mains-side temperature profiles at different time instants for R3-36 at 9LPM**

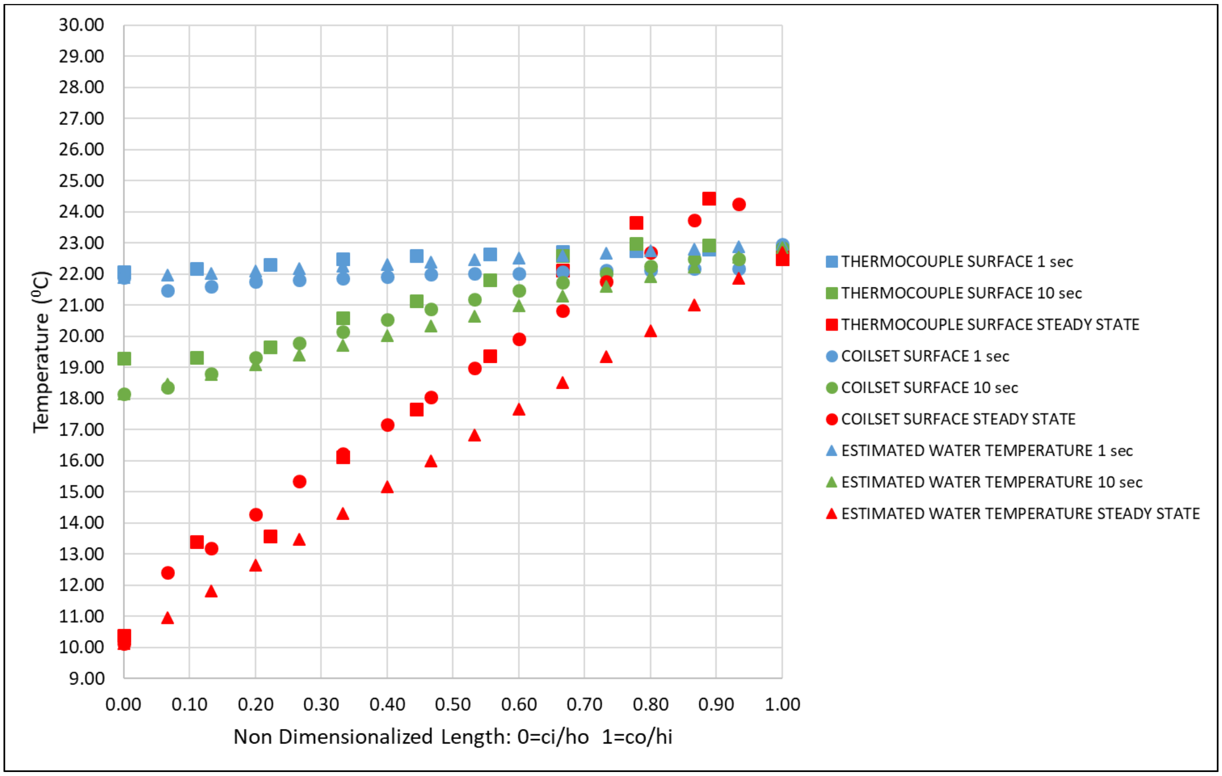


**Figure I5: Mains-side temperature profiles at different time instants for R3-36 at 7LPM**

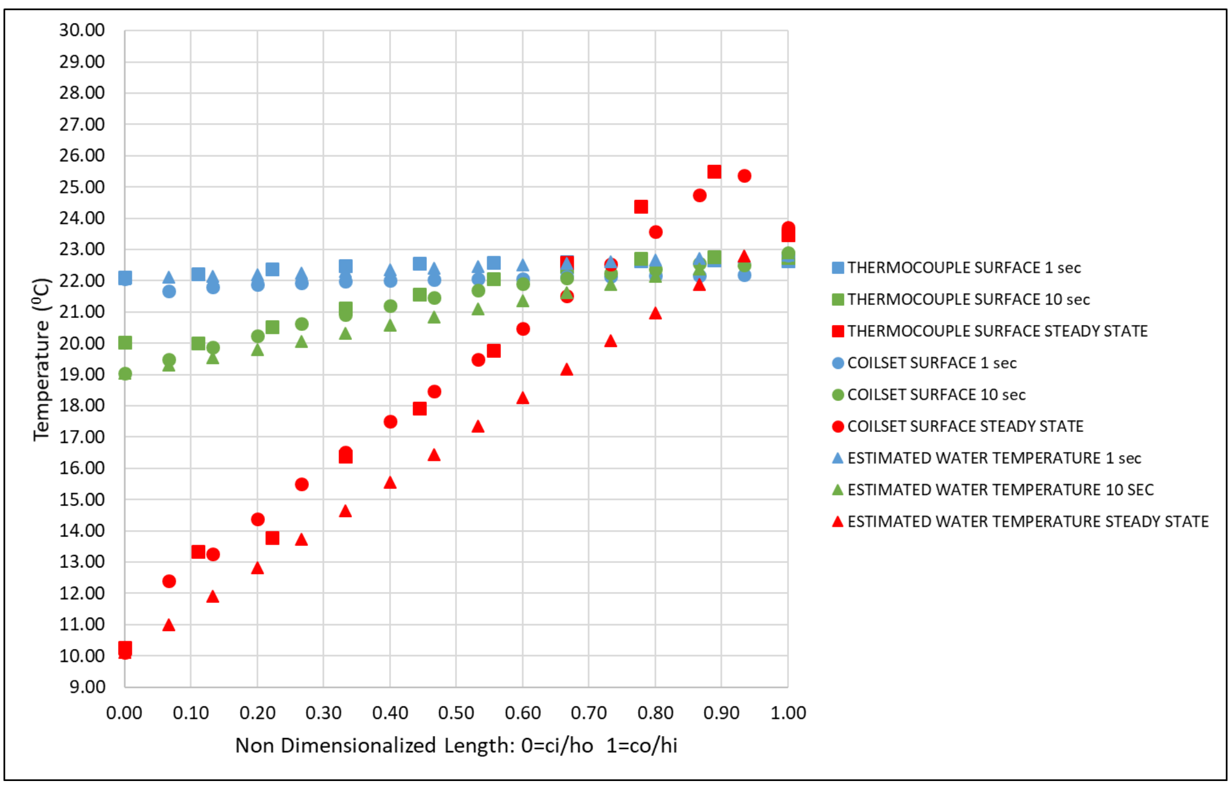


**Figure I6: Mains-side temperature profiles at different time instants for R3-36 at 5.5LPM**

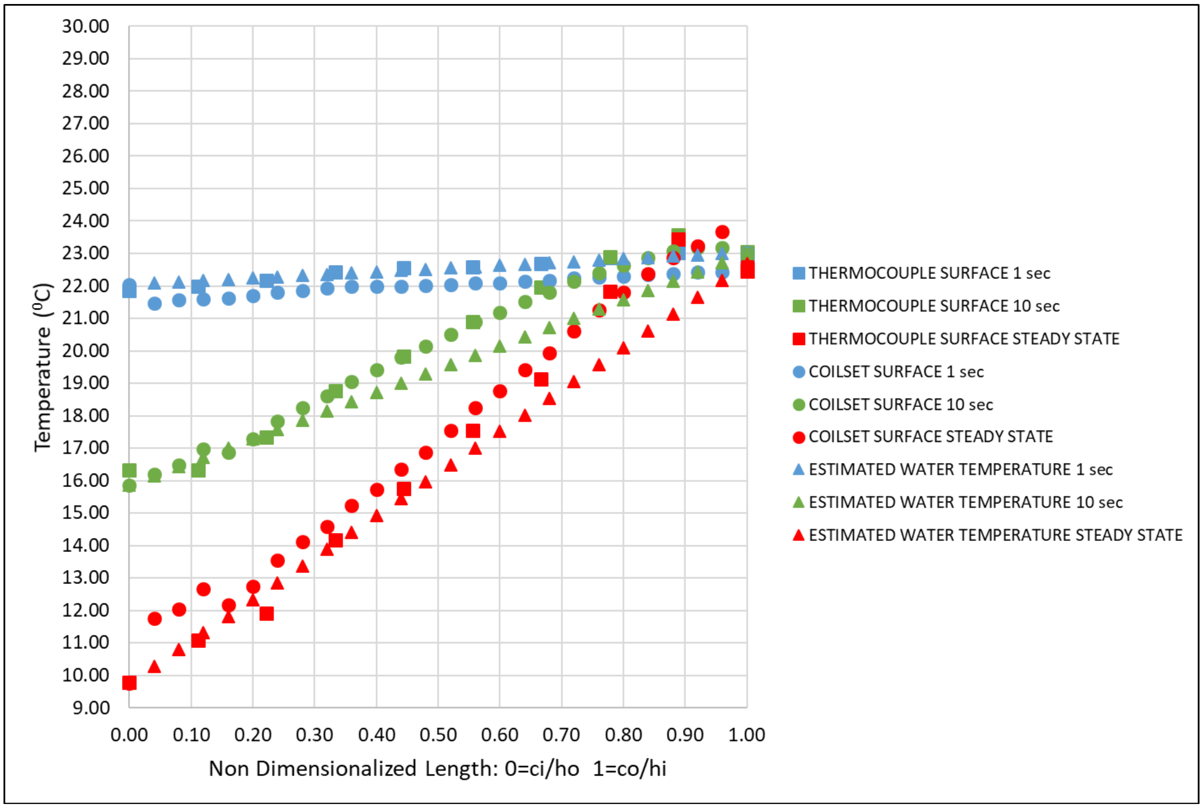


**Figure I7: Mains-side temperature profiles at different time instants for R3-60 at 14LPM**

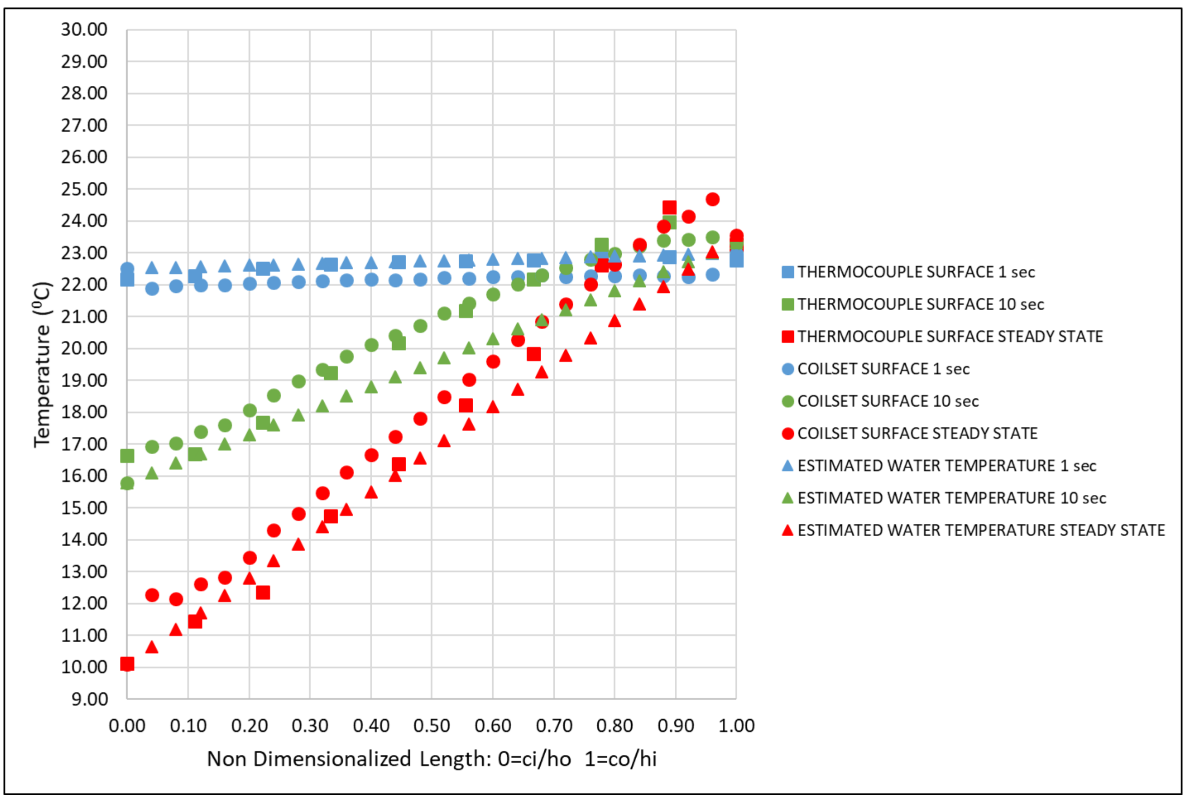


**Figure I8: Mains-side temperature profiles at different time instants for R3-60 at 12LPM**

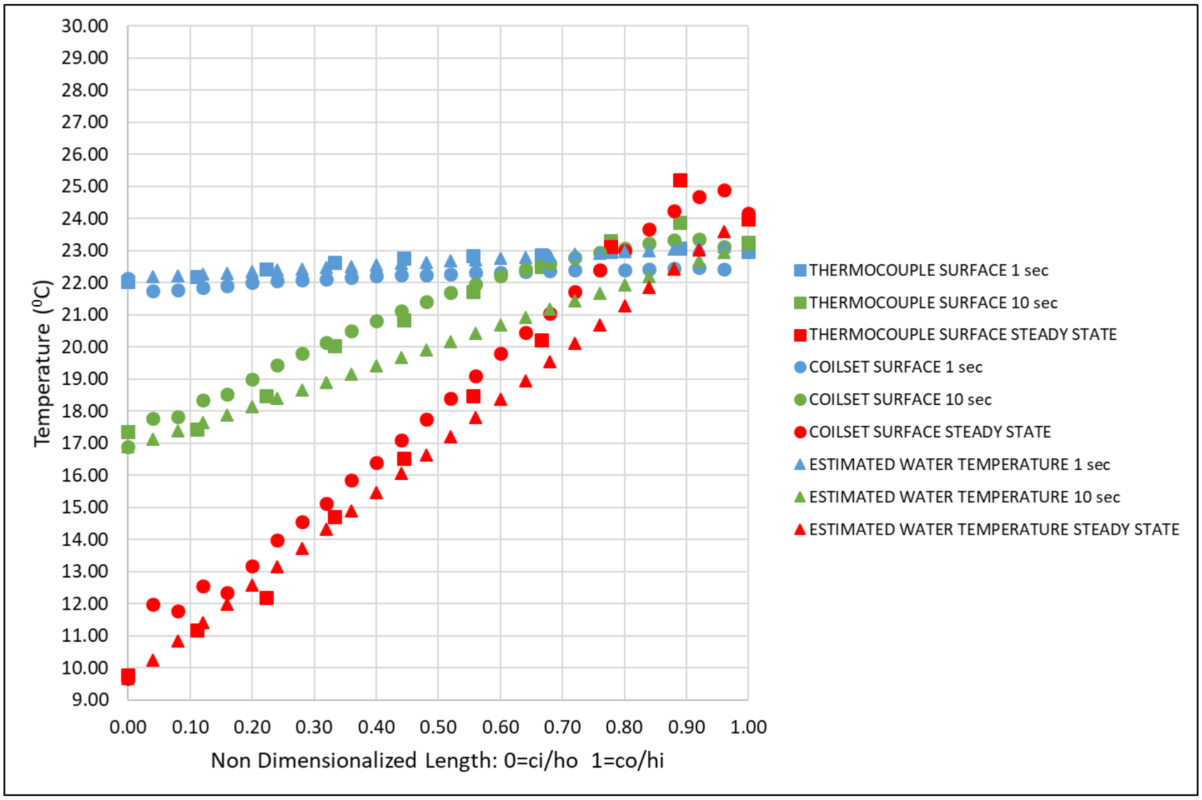


**Figure I9: Mains-side temperature profiles at different time instants for R3-60 at 10LPM**

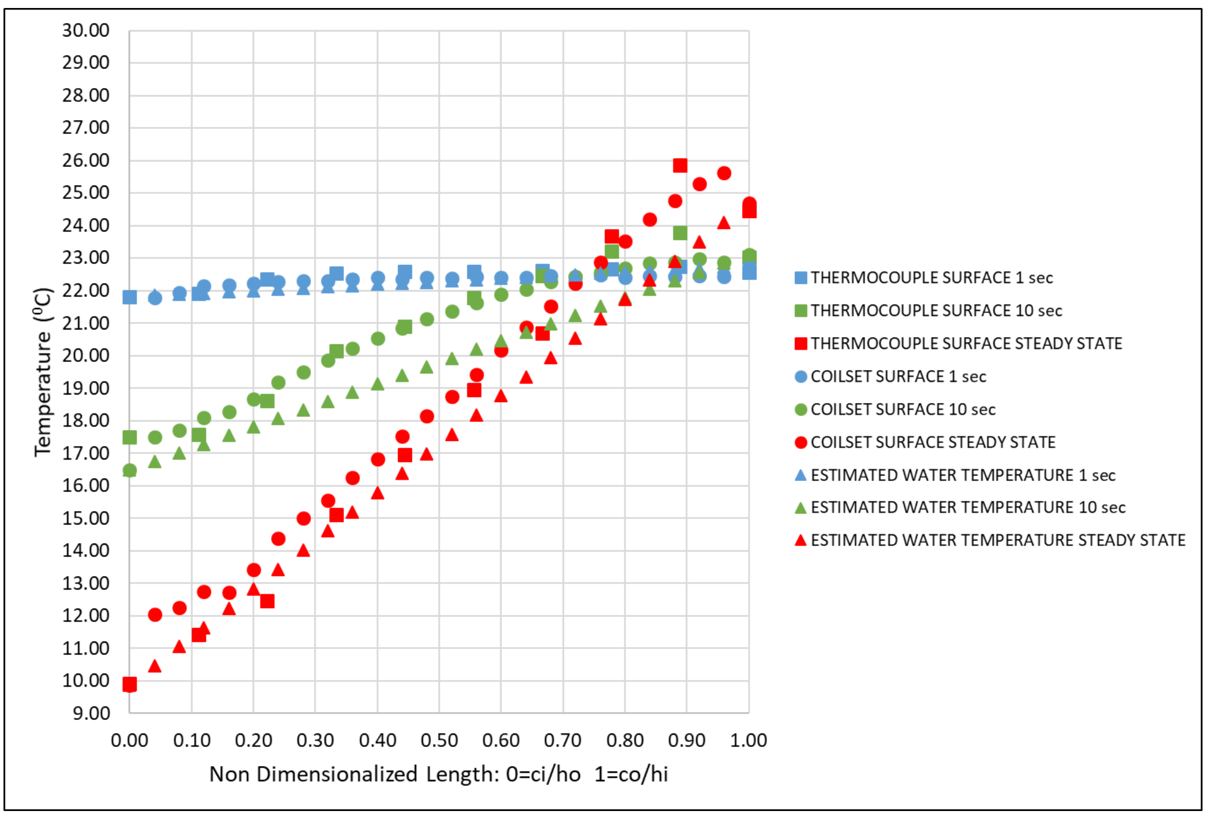


**Figure I10: Mains-side temperature profiles at different time instants for R3-60 at 9LPM**

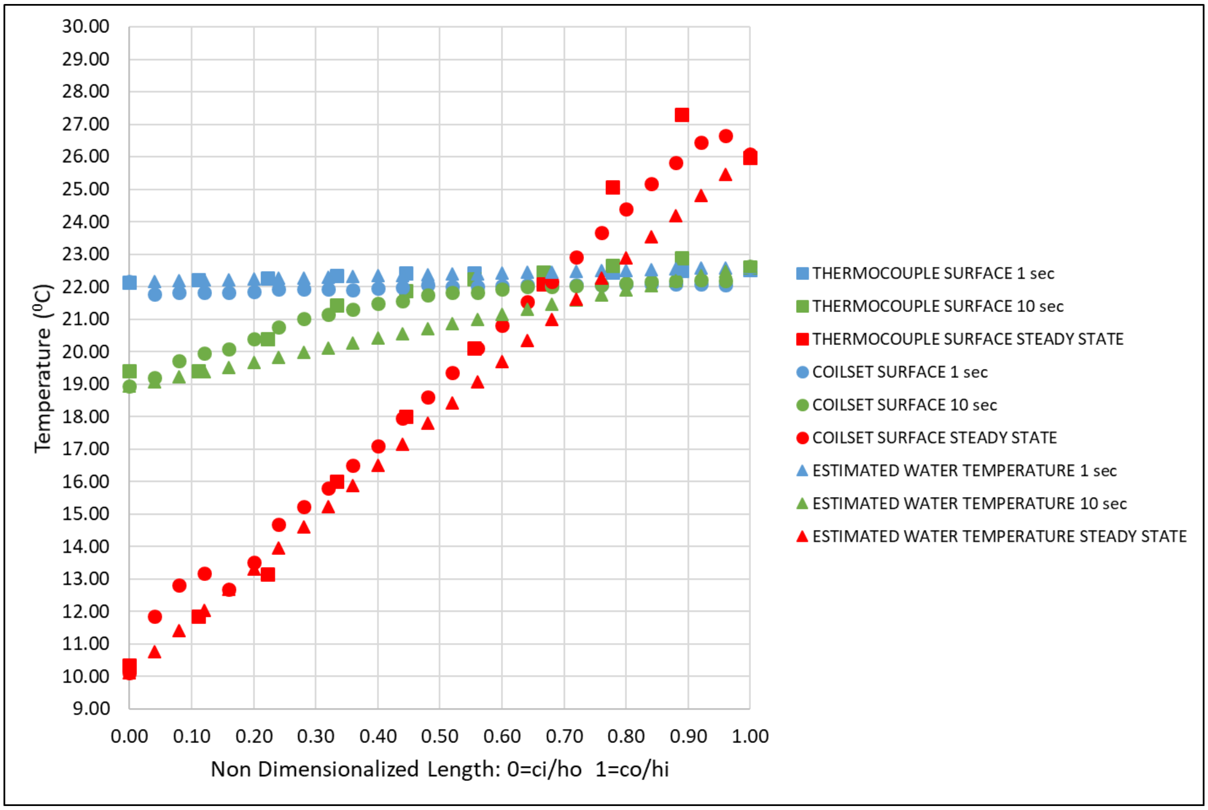


**Figure I11: Mains-side temperature profiles at different time instants for R3-60 at 7LPM**

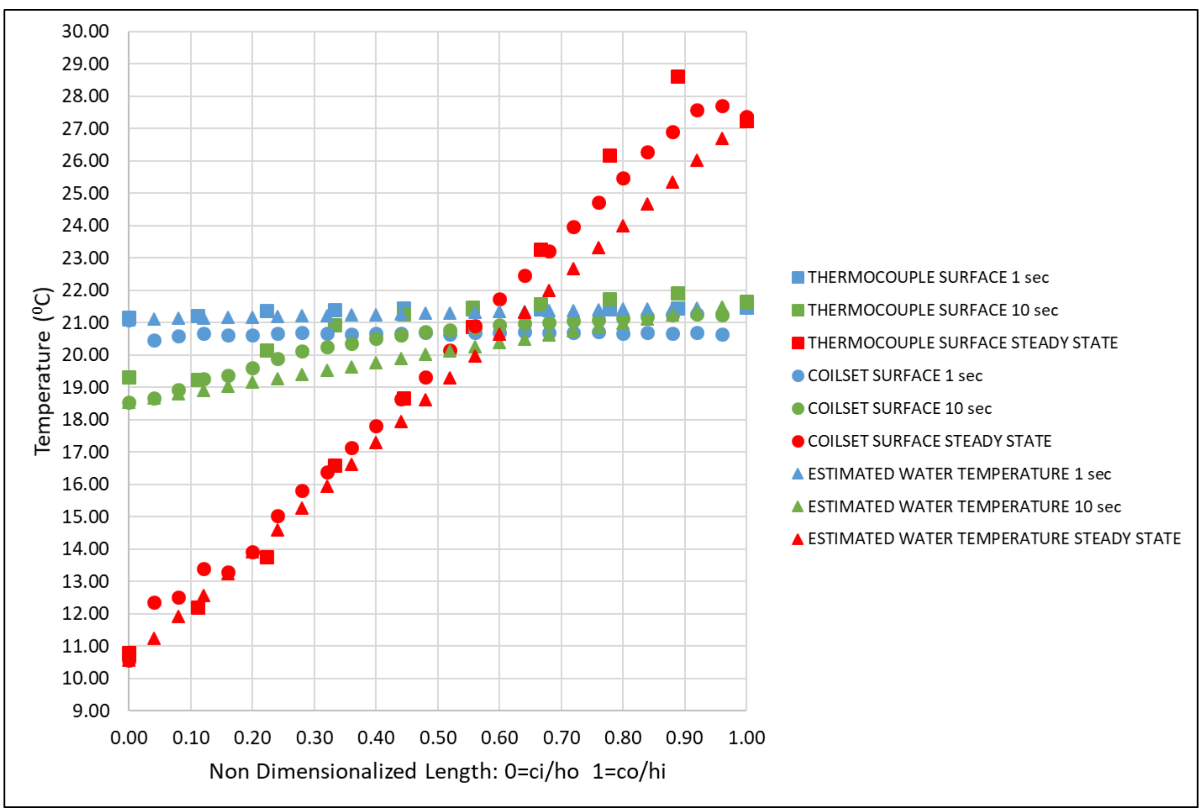


**Figure I12: Mains-side temperature profiles at different time instants for R3-60 at 5.5LPM**

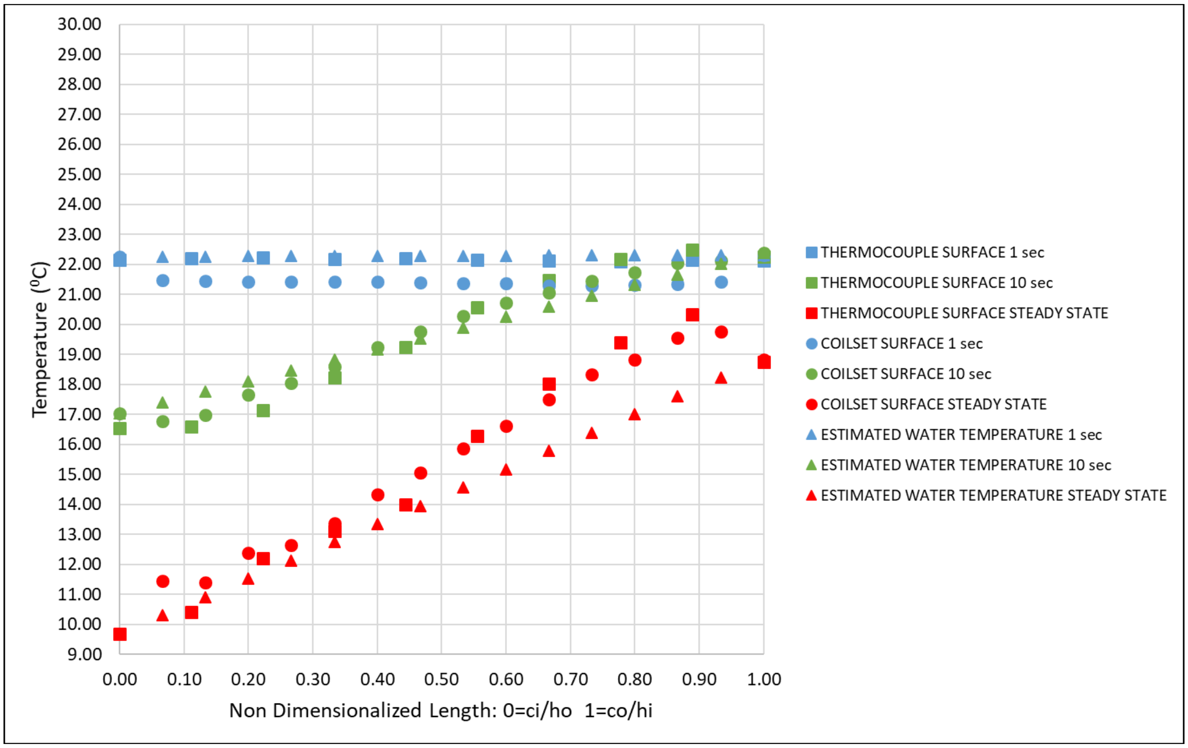


**Figure I13: Mains-side temperature profiles at different time instants for R4-36 at 14LPM**

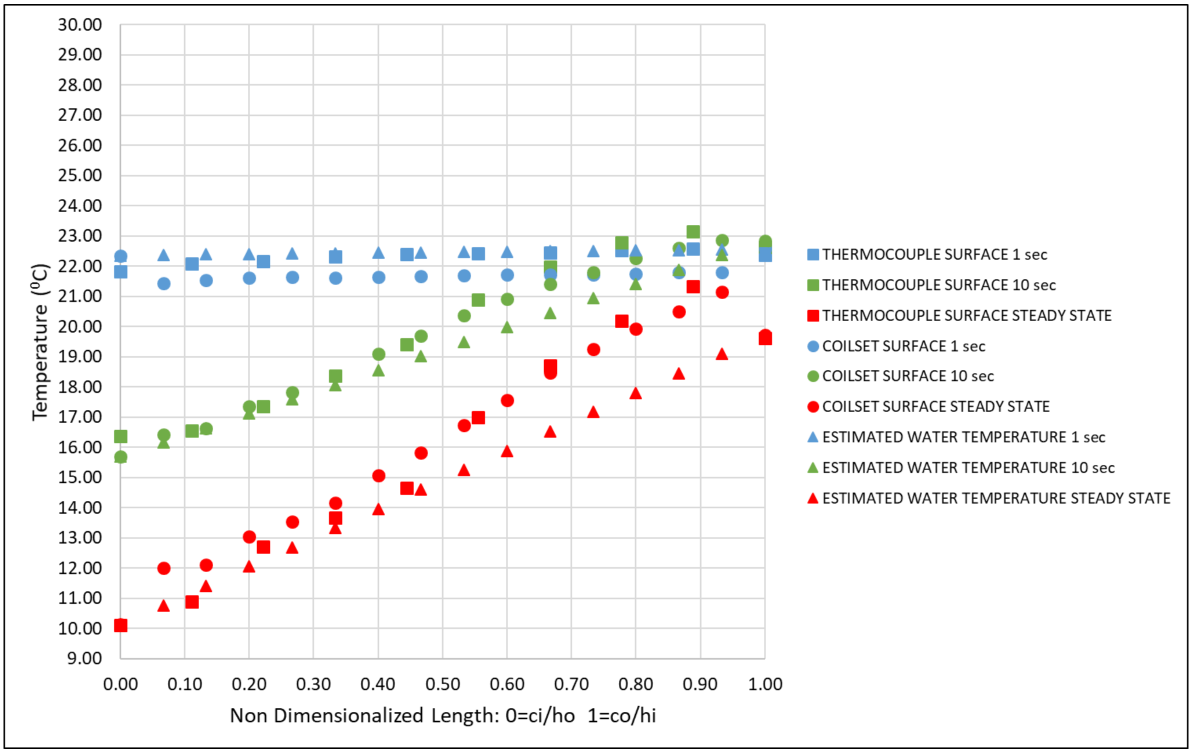


**Figure I14: Mains-side temperature profiles at different time instants for R4-36 at 12LPM**

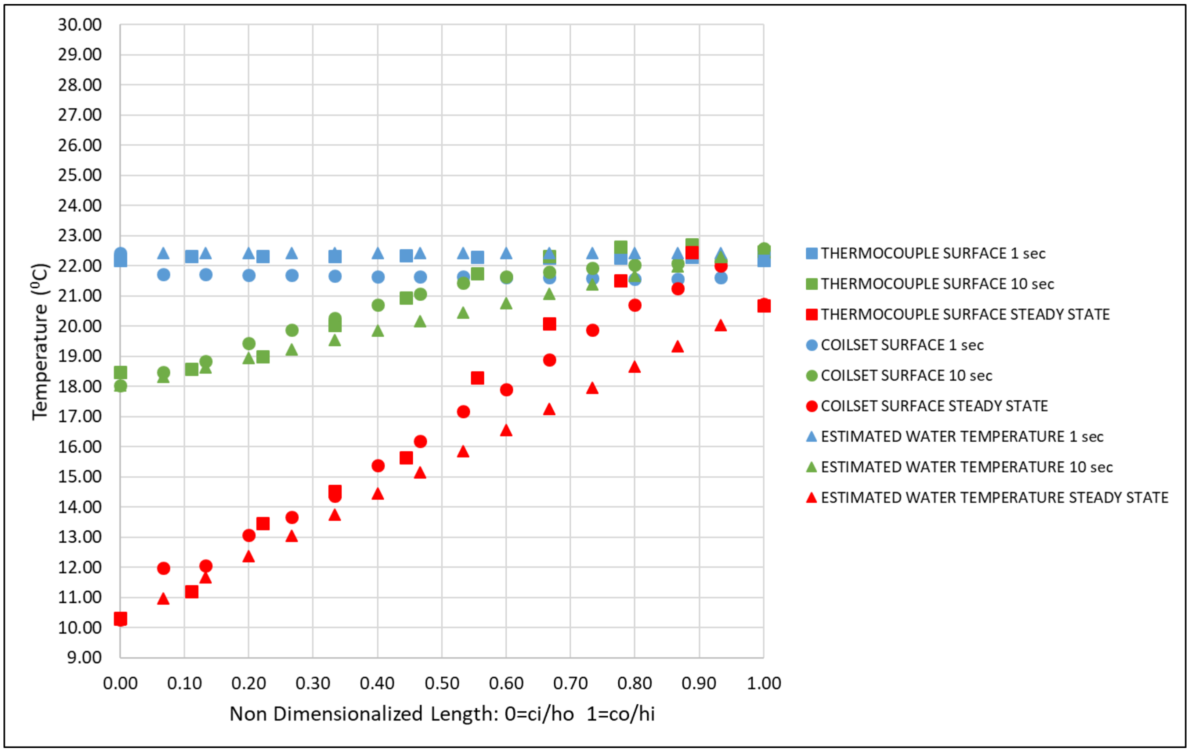


**Figure I15: Mains-side temperature profiles at different time instants for R4-36 at 10LPM**

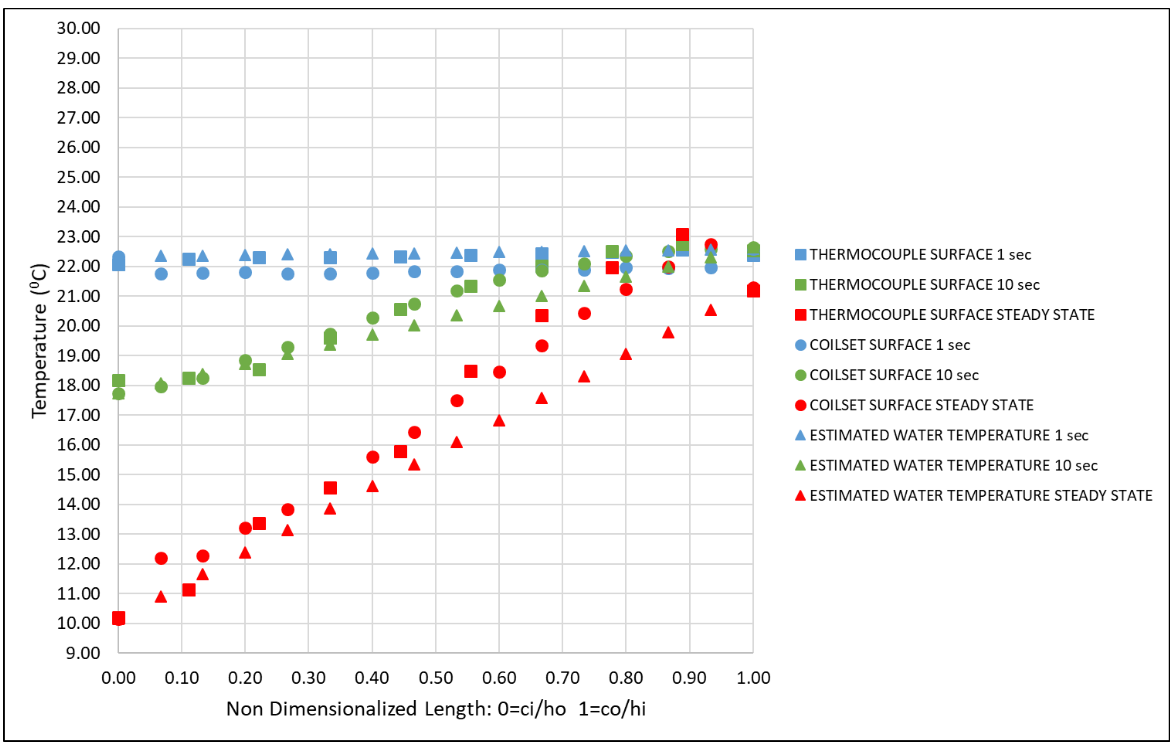


**Figure I16: Mains-side temperature profiles at different time instants for R4-36 at 9LPM**

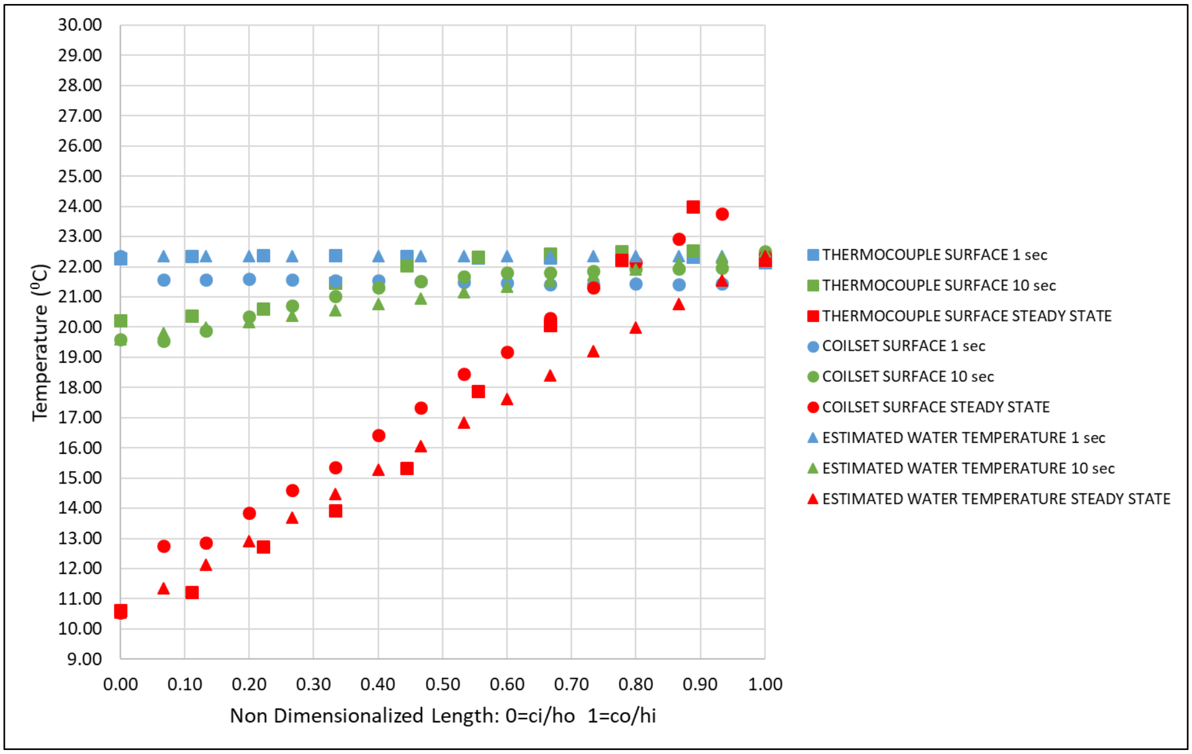


**Figure I17: Mains-side temperature profiles at different time instants for R4-36 at 7LPM**

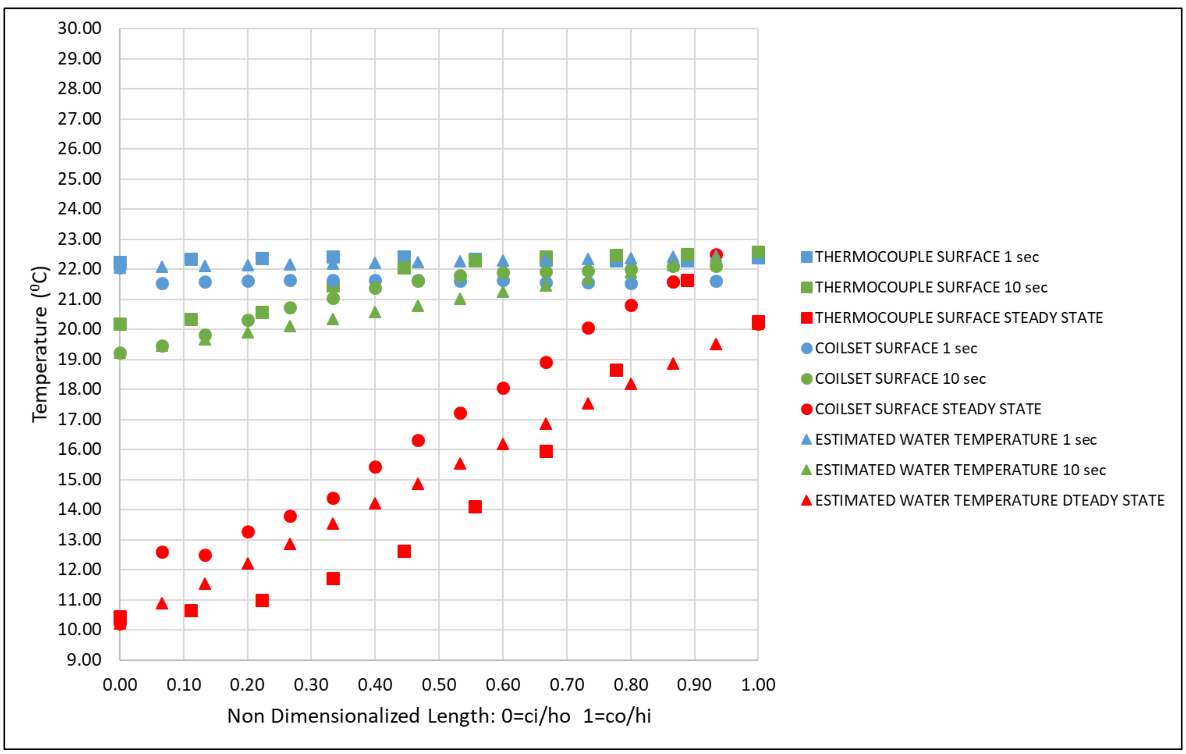


**Figure I18: Mains-side temperature profiles at different time instants for R4-36 at 5.5LPM**

# Appendix J: Surface and Water Temperature Profiles across Entire Test Duration

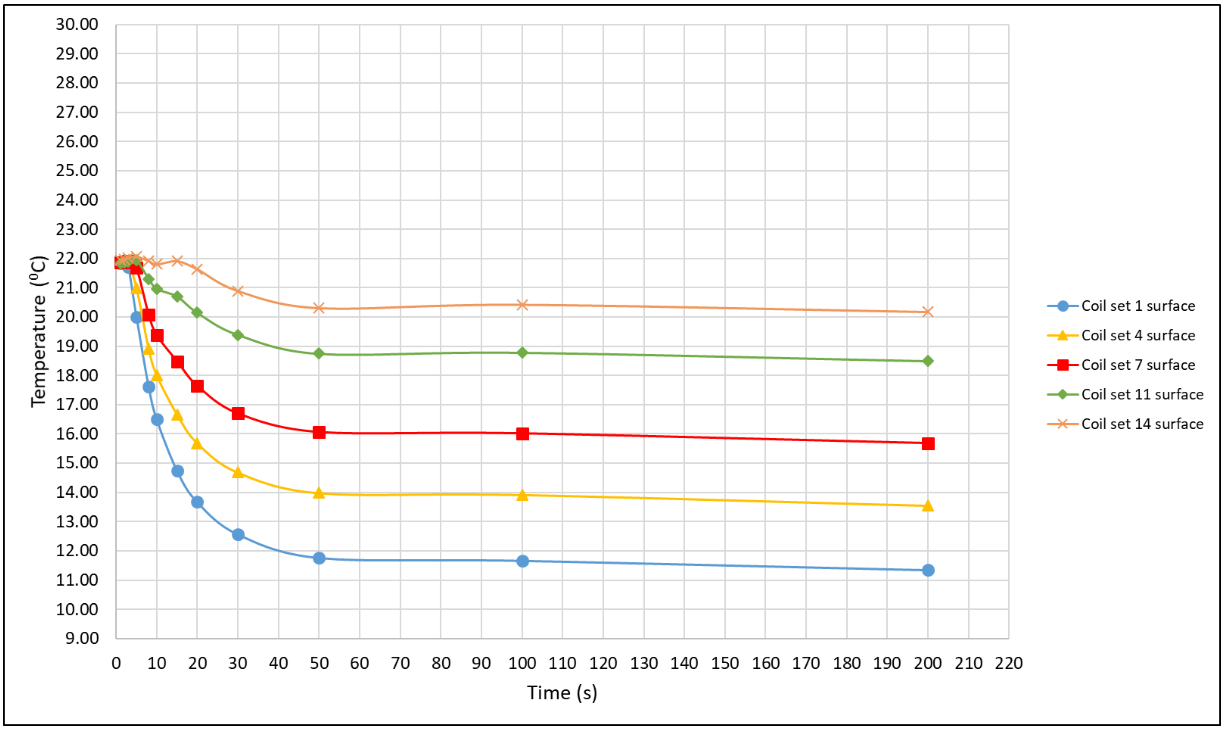


**Figure J1: Coil set surface temperature profiles at different time instants for R3-36 at 14LPM**

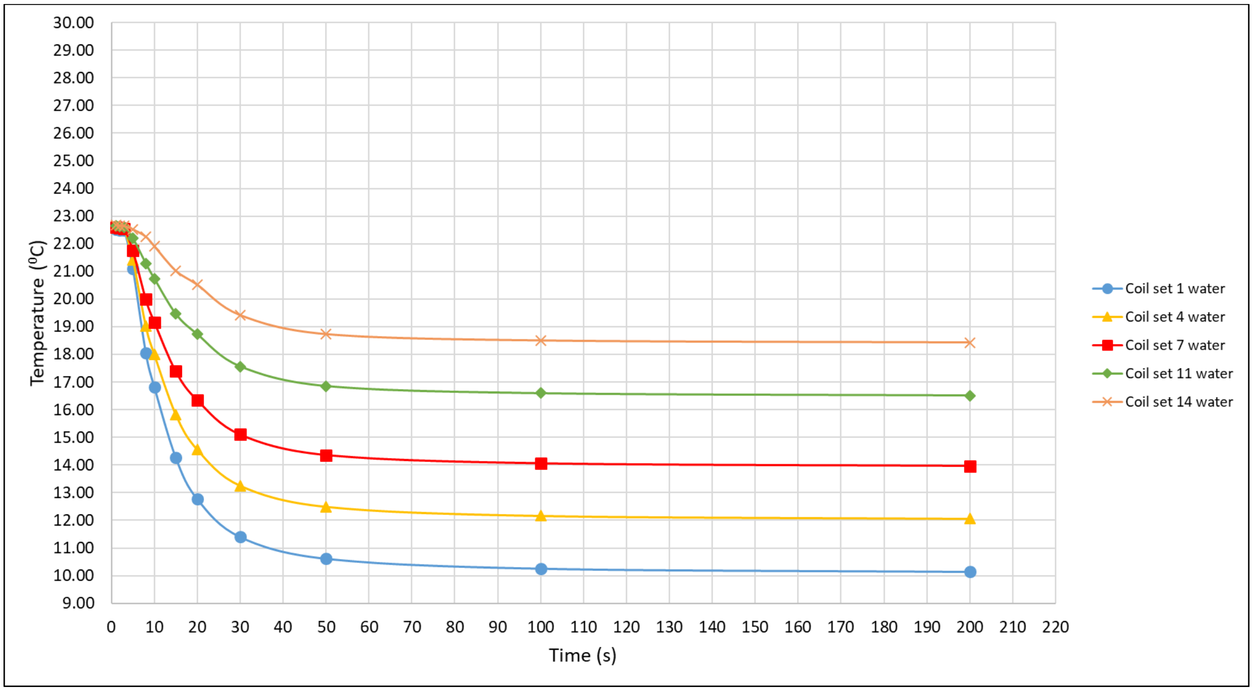


**Figure J2: Estimated coil set water temperature profiles at different time instants for R3-36 at 14LPM**

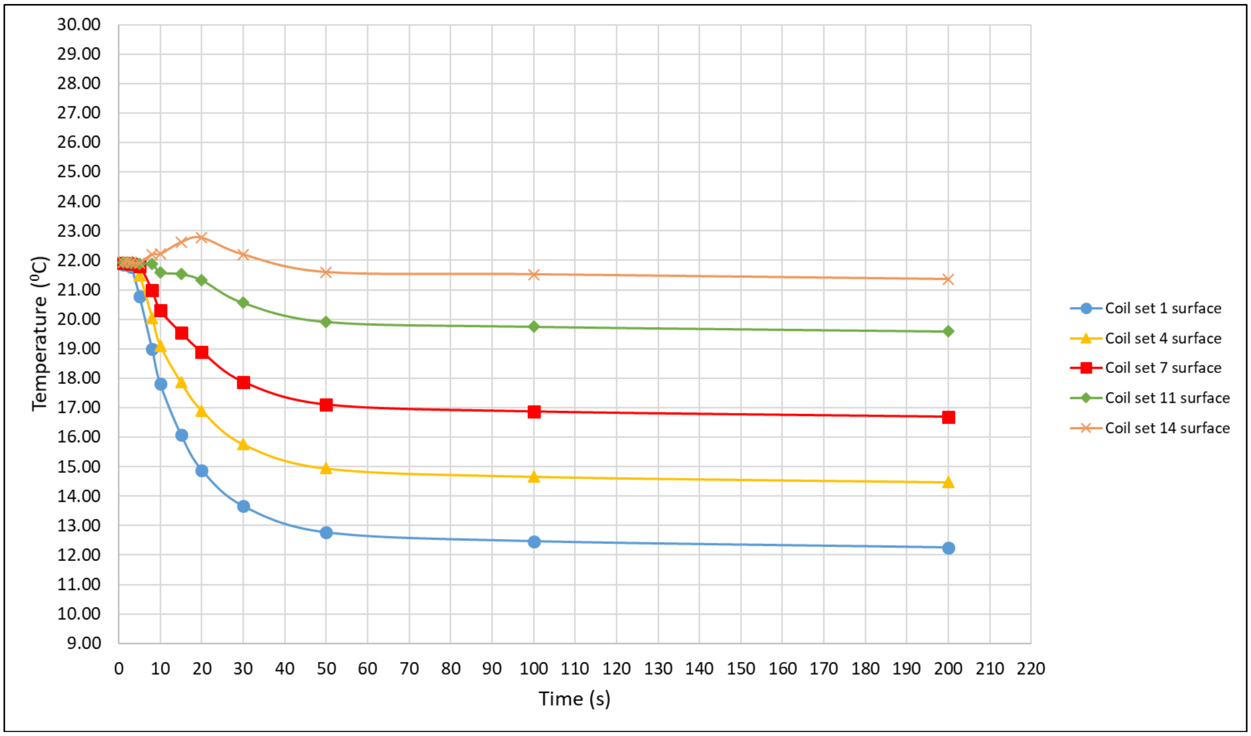


**Figure J3: Coil set surface temperature profiles at different time instants for R3-36 at 12LPM**

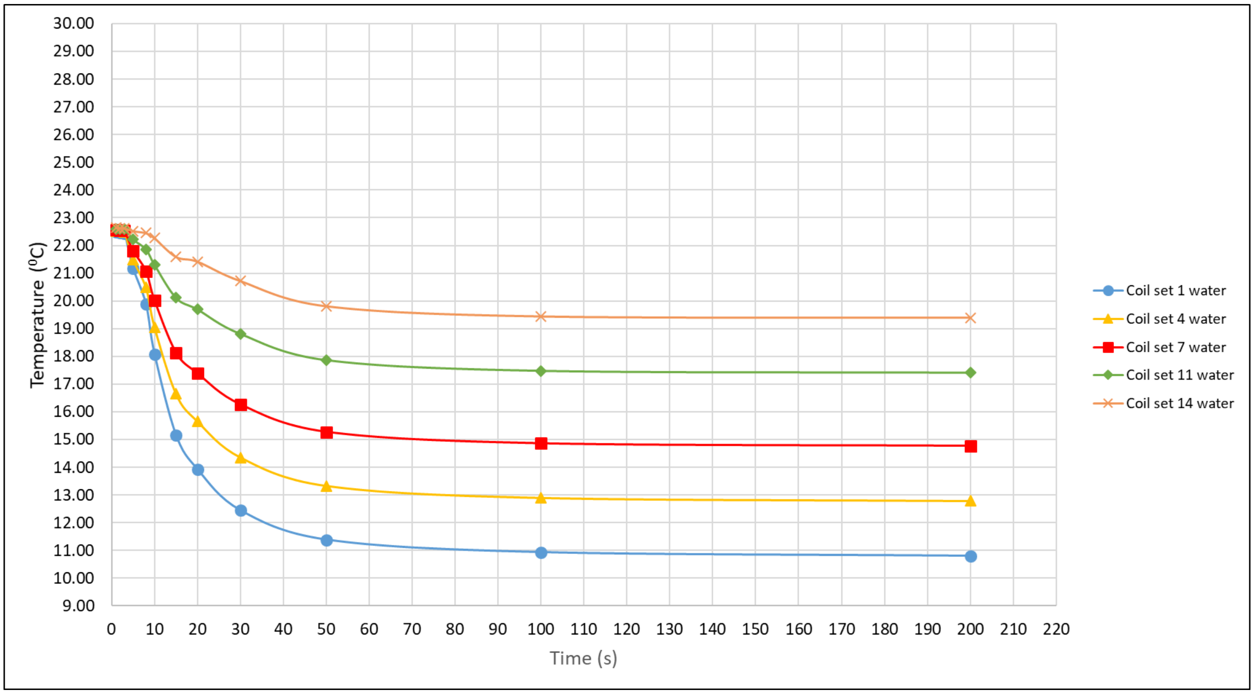


**Figure J4: Estimated coil set water temperature profiles at different time instants for R3-36 at 12LPM**

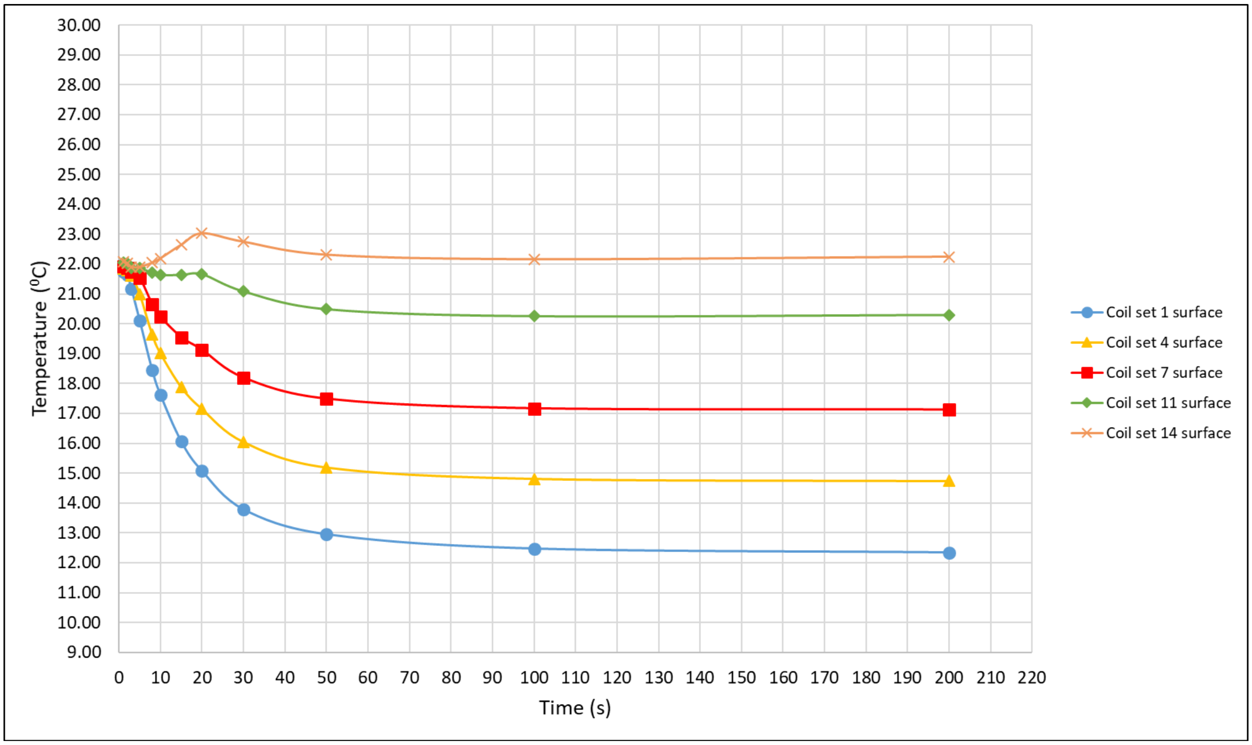


**Figure J5: Coil set surface temperature profiles at different time instants for R3-36 at 10LPM**

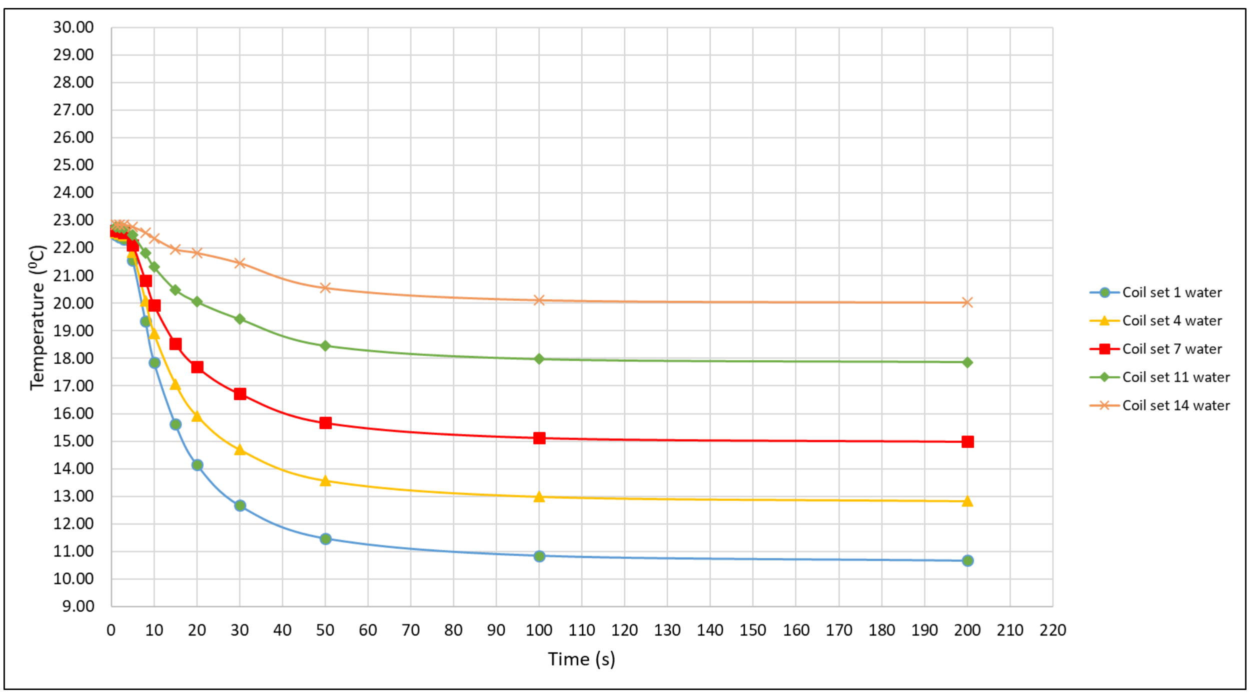


**Figure J6: Estimated coil set water temperature profiles at different time instants for R3-36 at 10LPM**

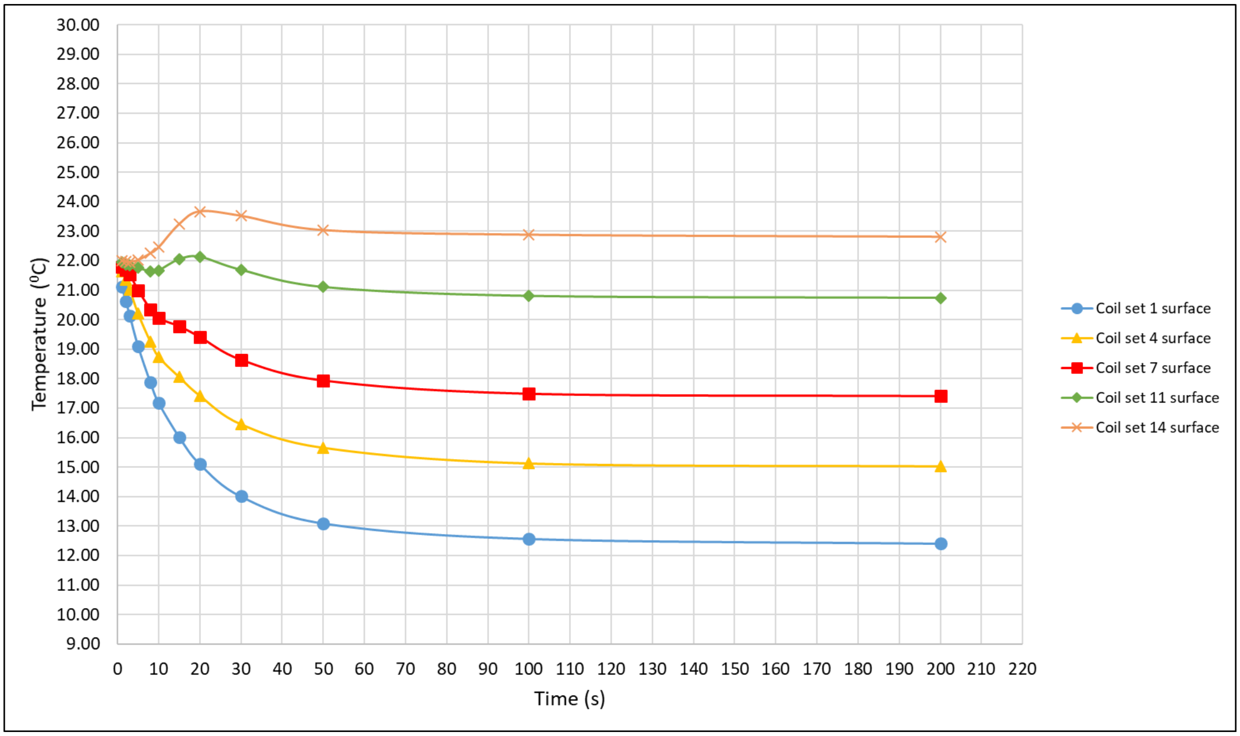


**Figure J7: Coil set surface temperature profiles at different time instants for R3-36 at 9LPM**

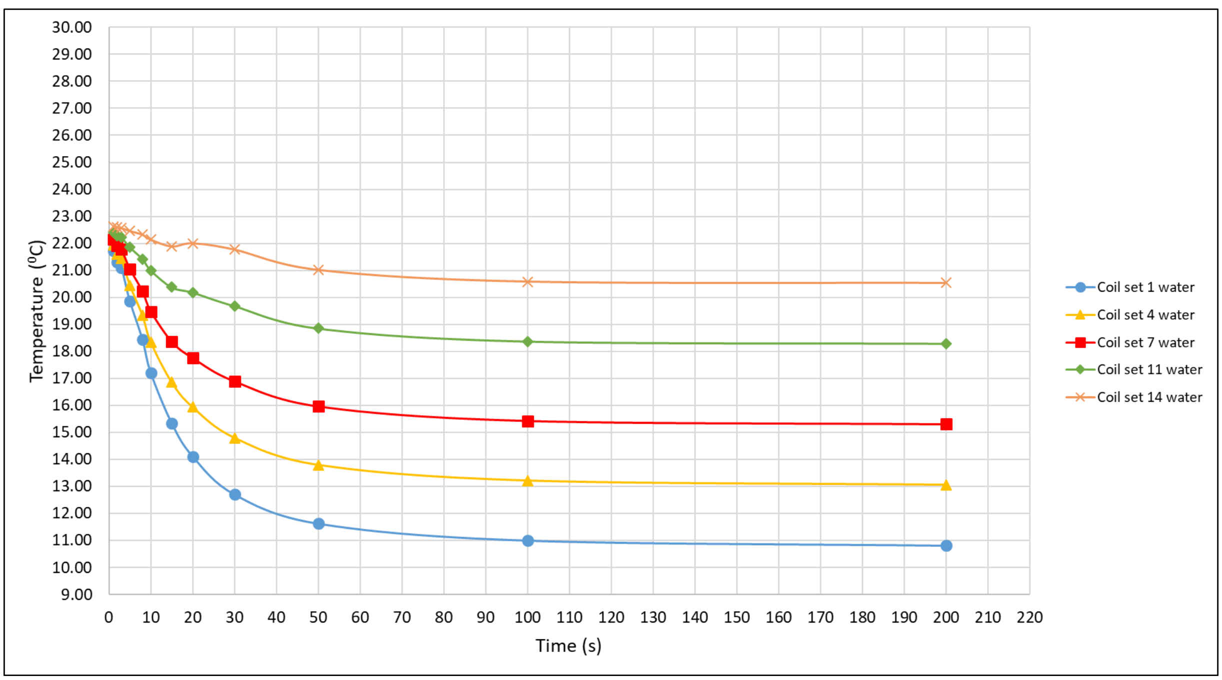


**Figure J8: Estimated coil set water temperature profiles at different time instants for R3-36 at 9LPM**

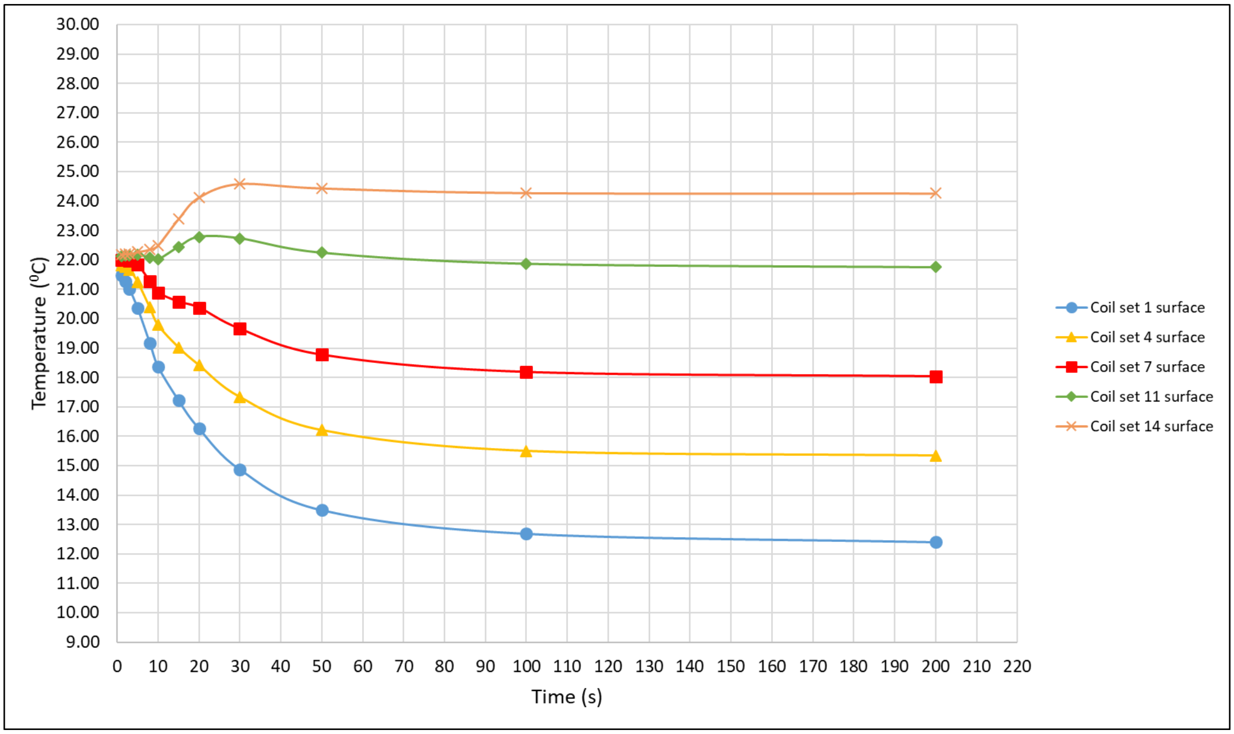


**Figure J9: Coil set surface temperature profiles at different time instants for R3-36 at 7LPM**

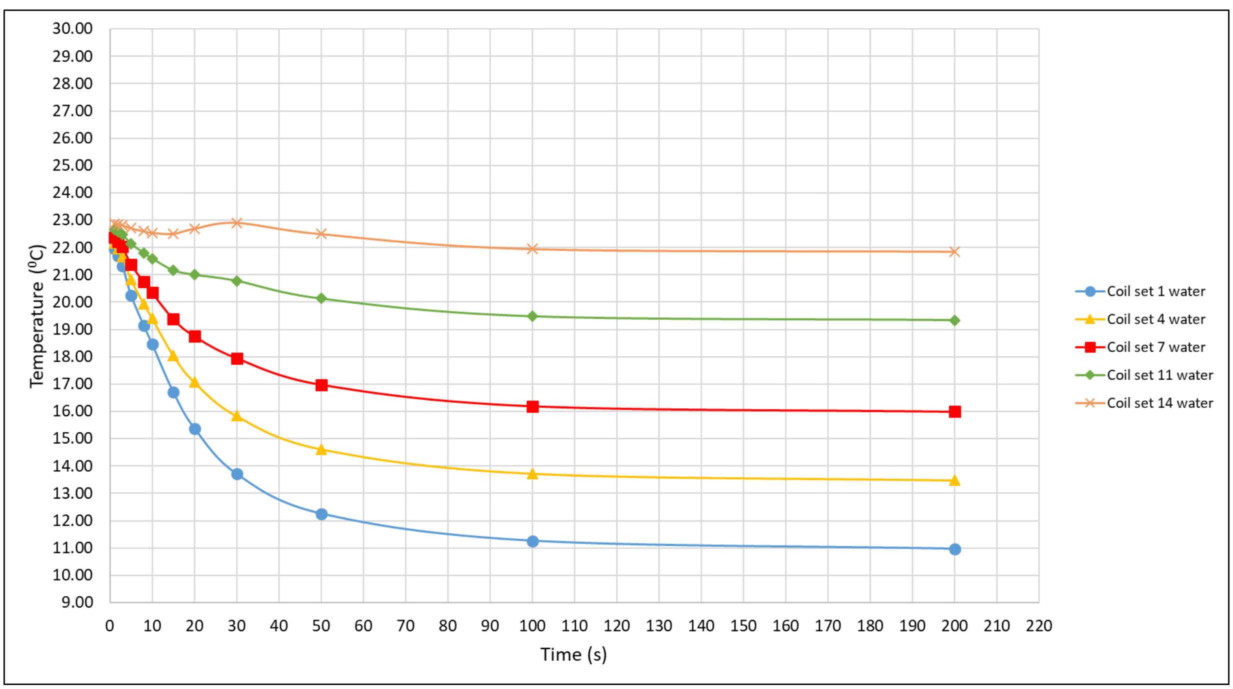


**Figure J10: Estimated coil set water temperature profiles at different time instants for R3-36 at 7LPM**

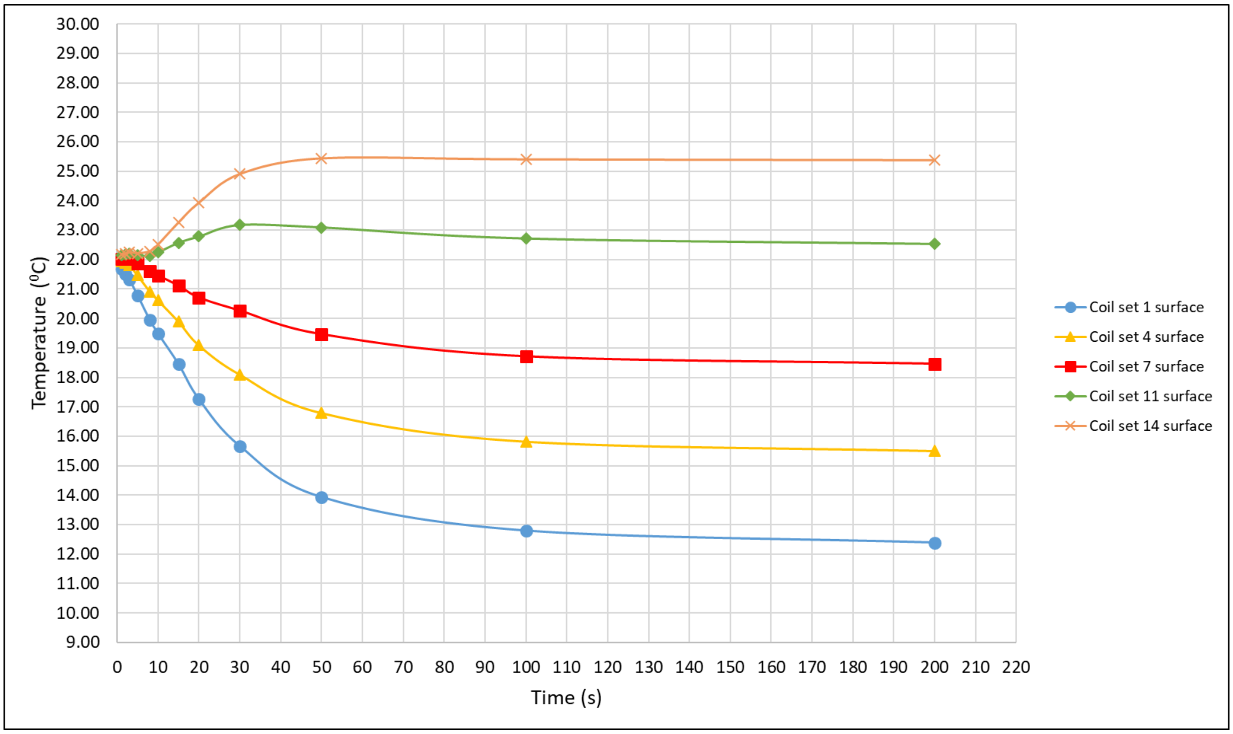


**Figure J11: Coil set surface temperature profiles at different time instants for R3-36 at 5.5LPM**

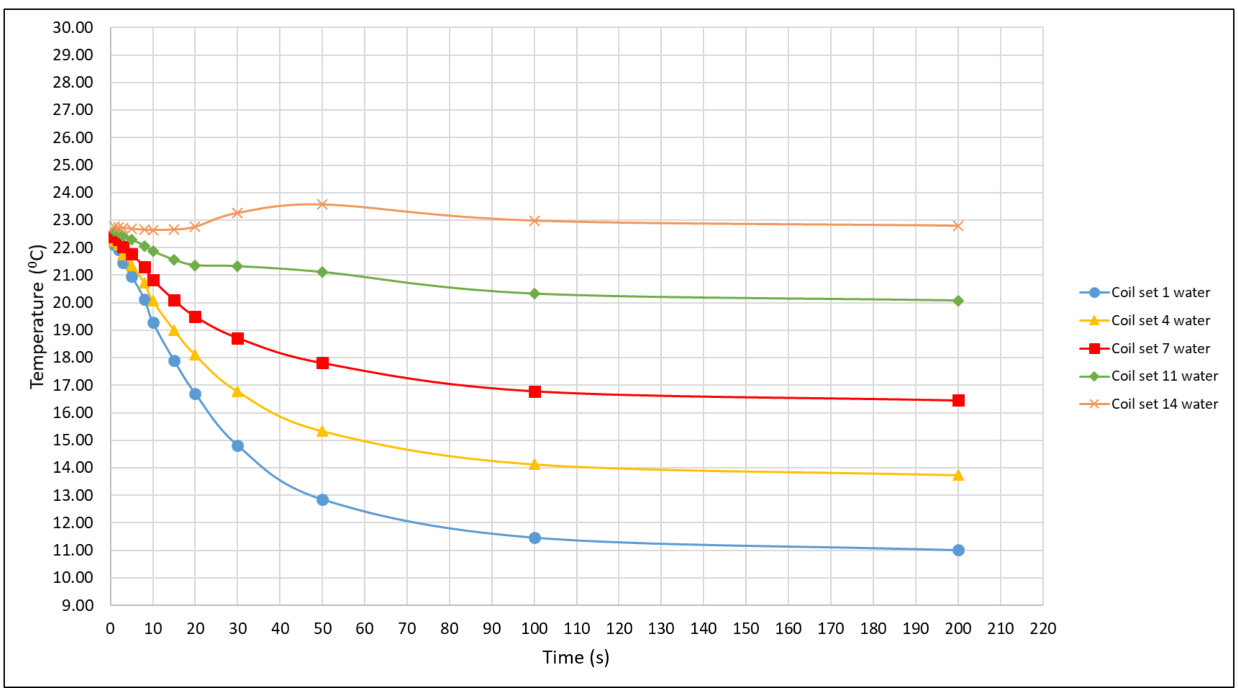


**Figure J12: Estimated coil set water temperature profiles at different time instants for R3-36 at 5.5LPM**

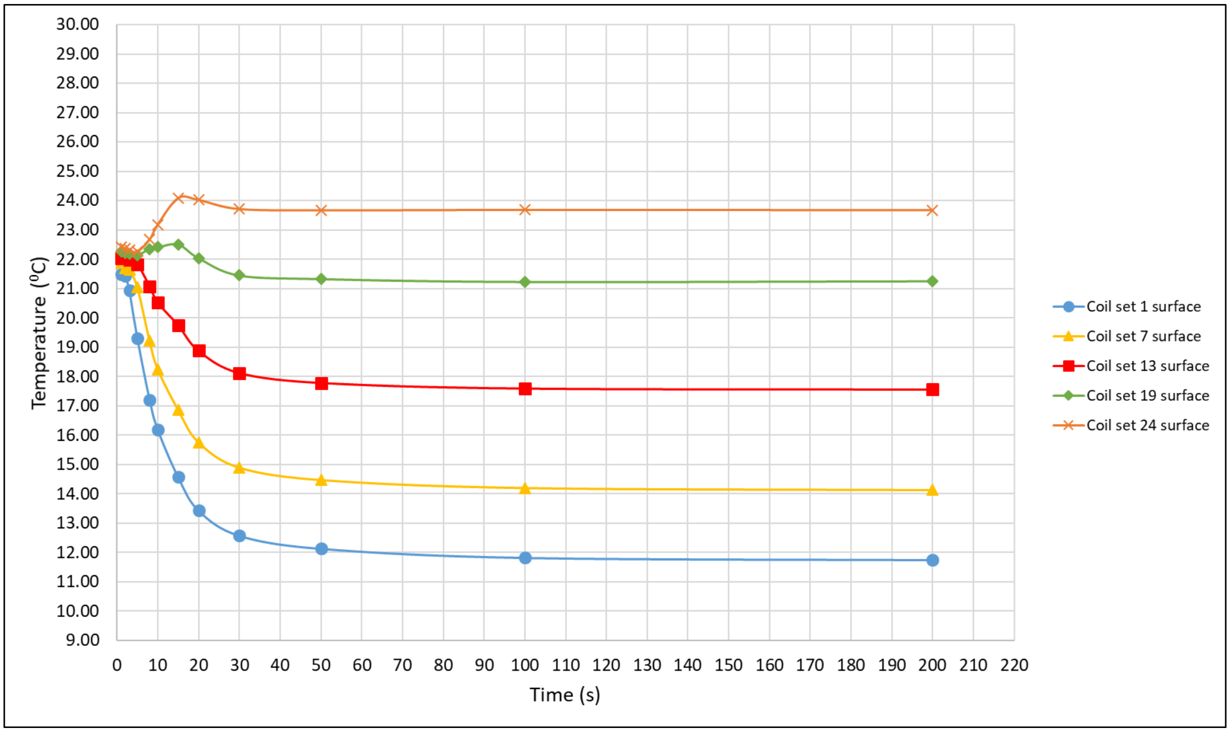


**Figure J13: Coil set surface temperature profiles at different time instants for R3-60 at 14LPM**

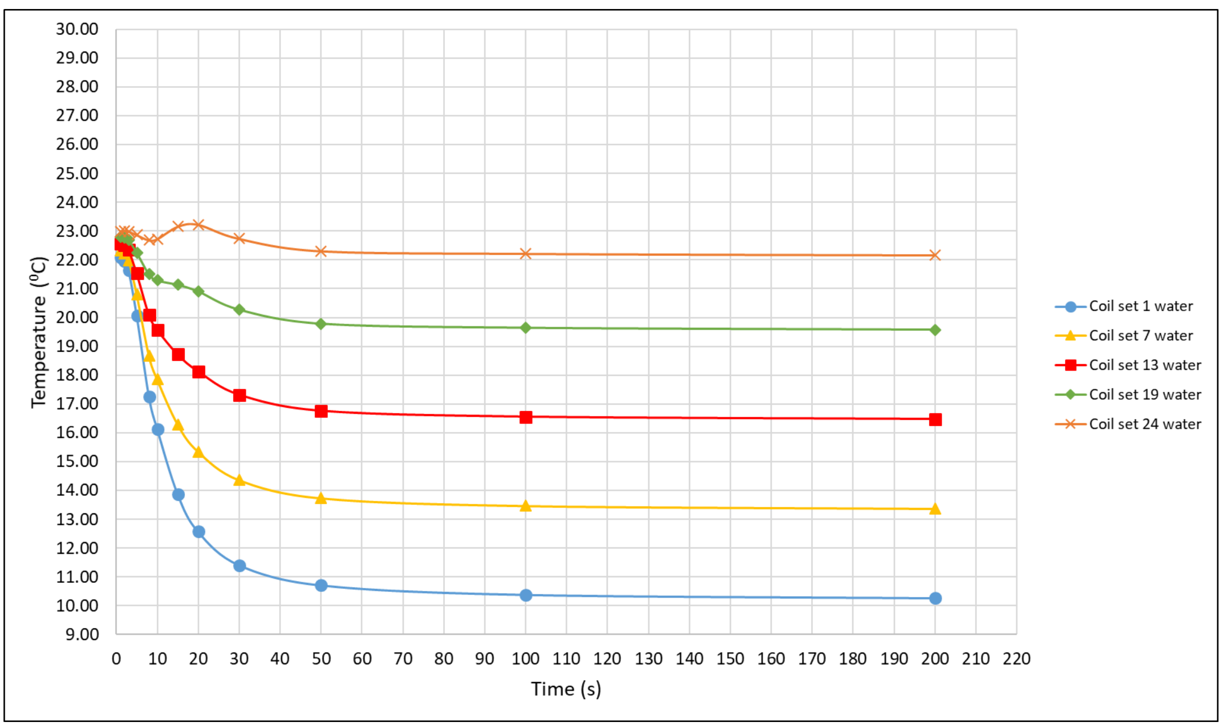


**Figure J14: Estimated coil set water temperature profiles at different time instants for R3-60 at 14LPM**

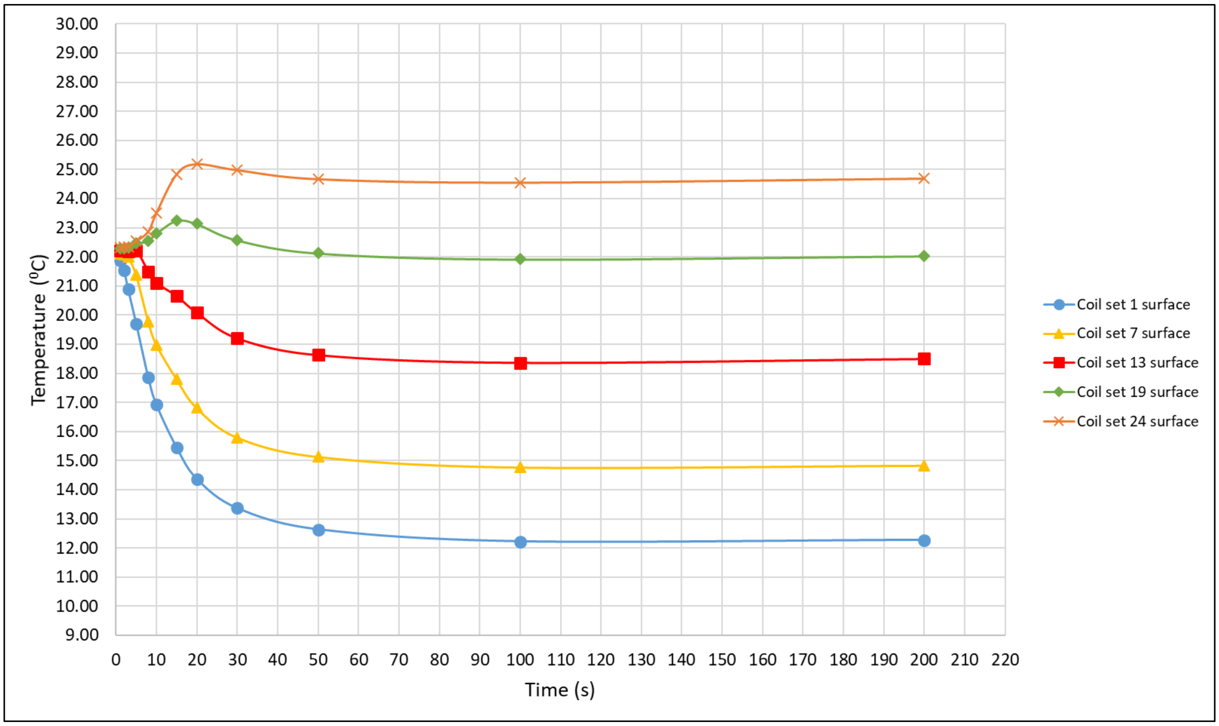


**Figure J15: Coil set surface temperature profiles at different time instants for R3-60 at 12LPM**

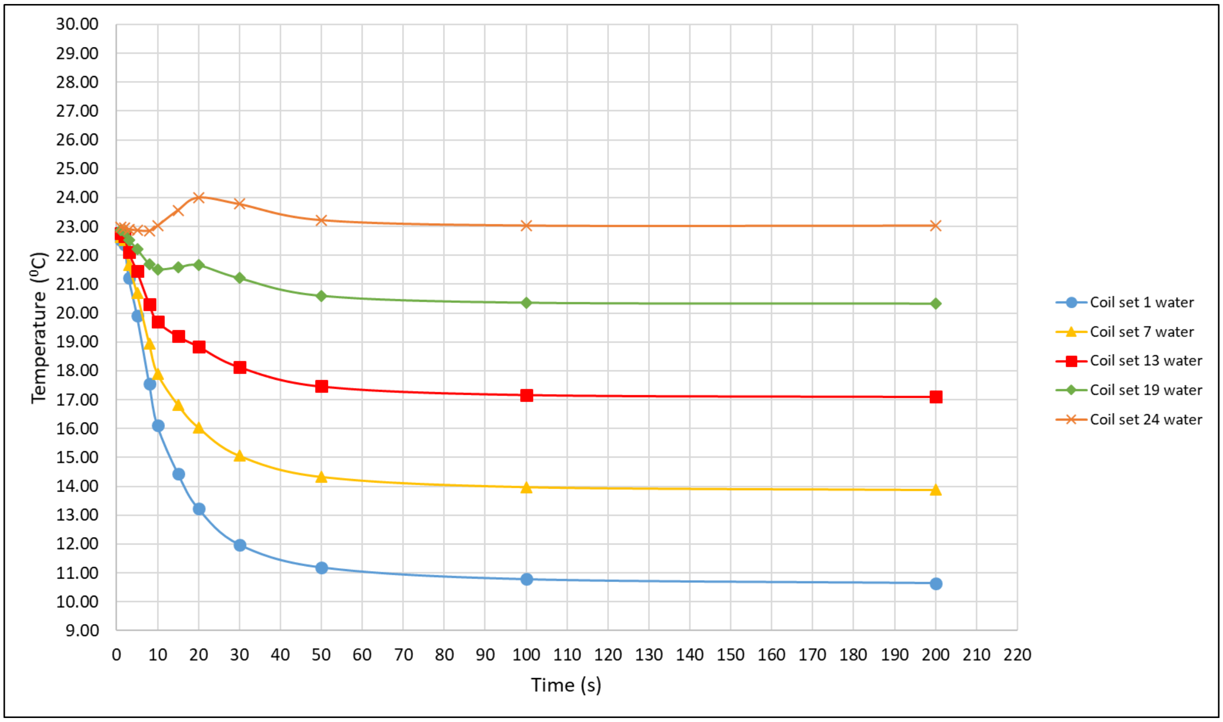


**Figure J16: Estimated coil set water temperature profiles at different time instants for R3-60 at 12LPM**

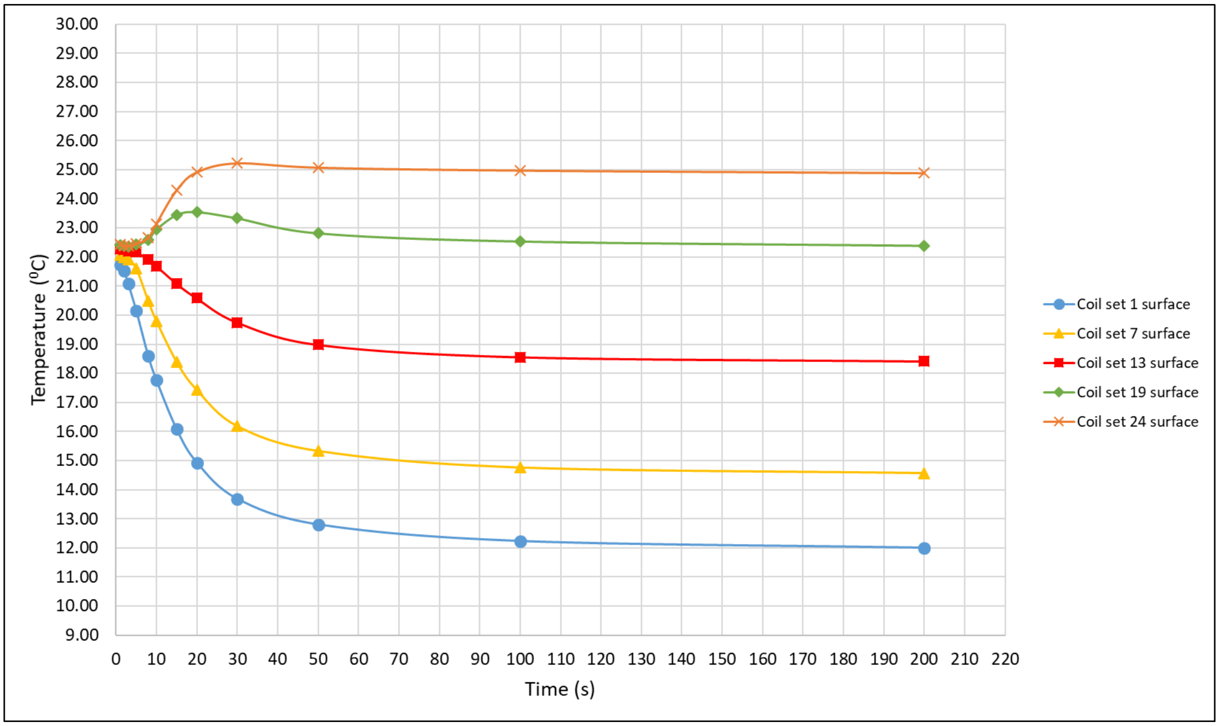


**Figure J17: Coil set surface temperature profiles at different time instants for R3-60 at 10LPM**

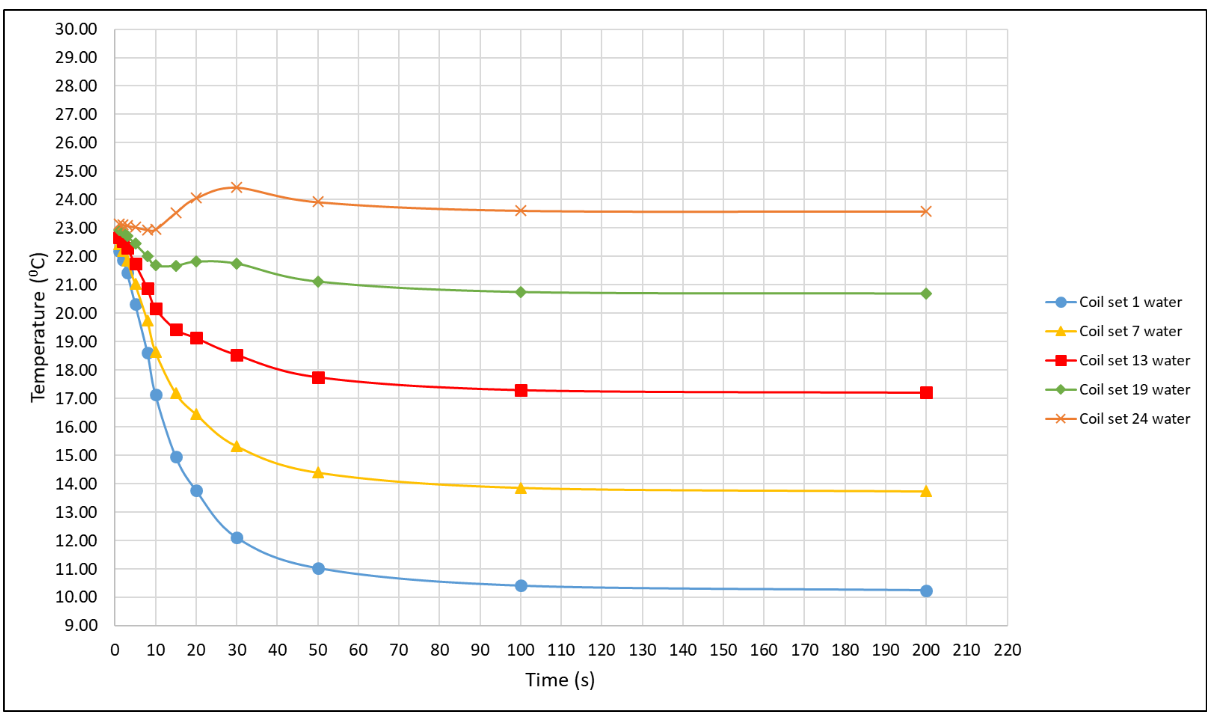


**Figure J18: Estimated coil set water temperature profiles at different time instants for R3-60 at 10LPM**

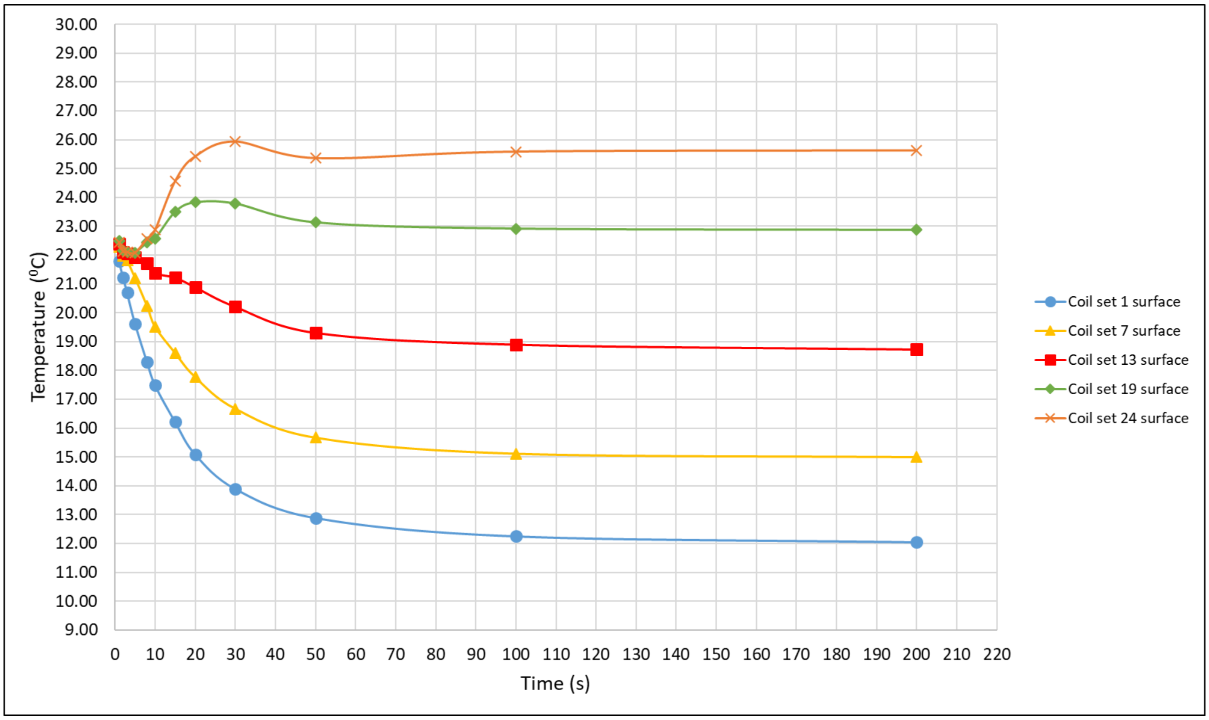


**Figure J19: Coil set surface temperature profiles at different time instants for R3-60 at 9LPM**

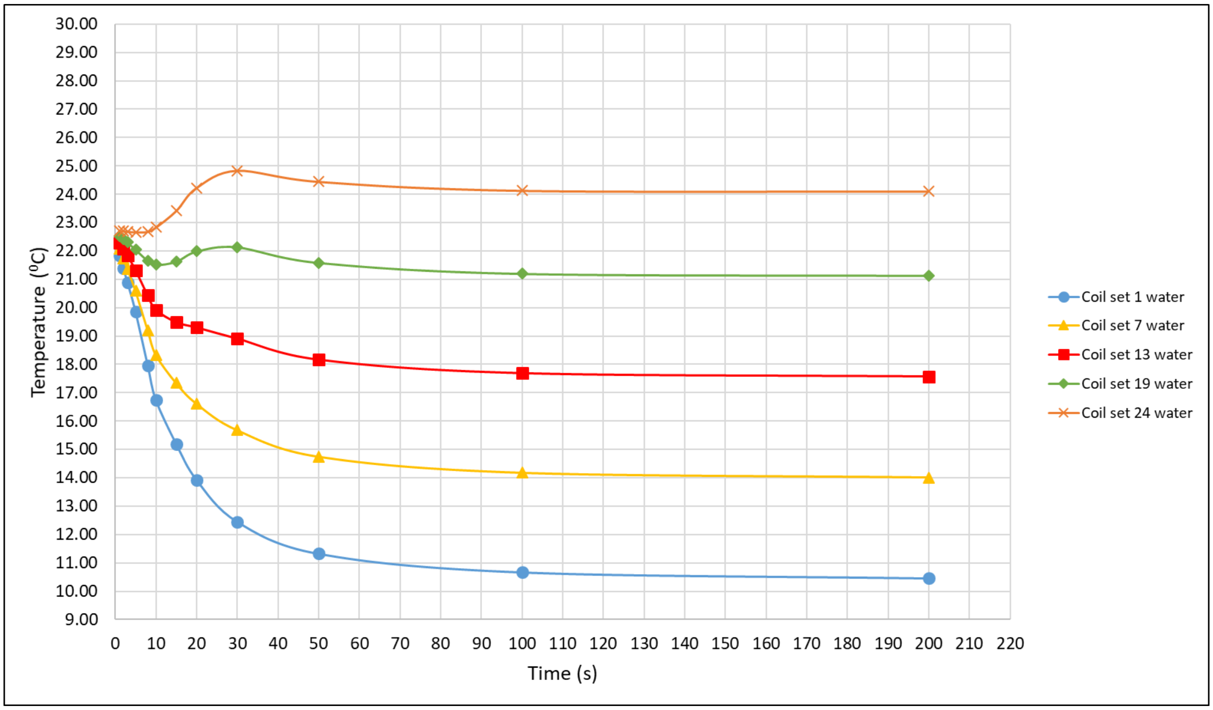


**Figure J20: Estimated coil set water temperature profiles at different time instants for R3-60 at 9LPM**

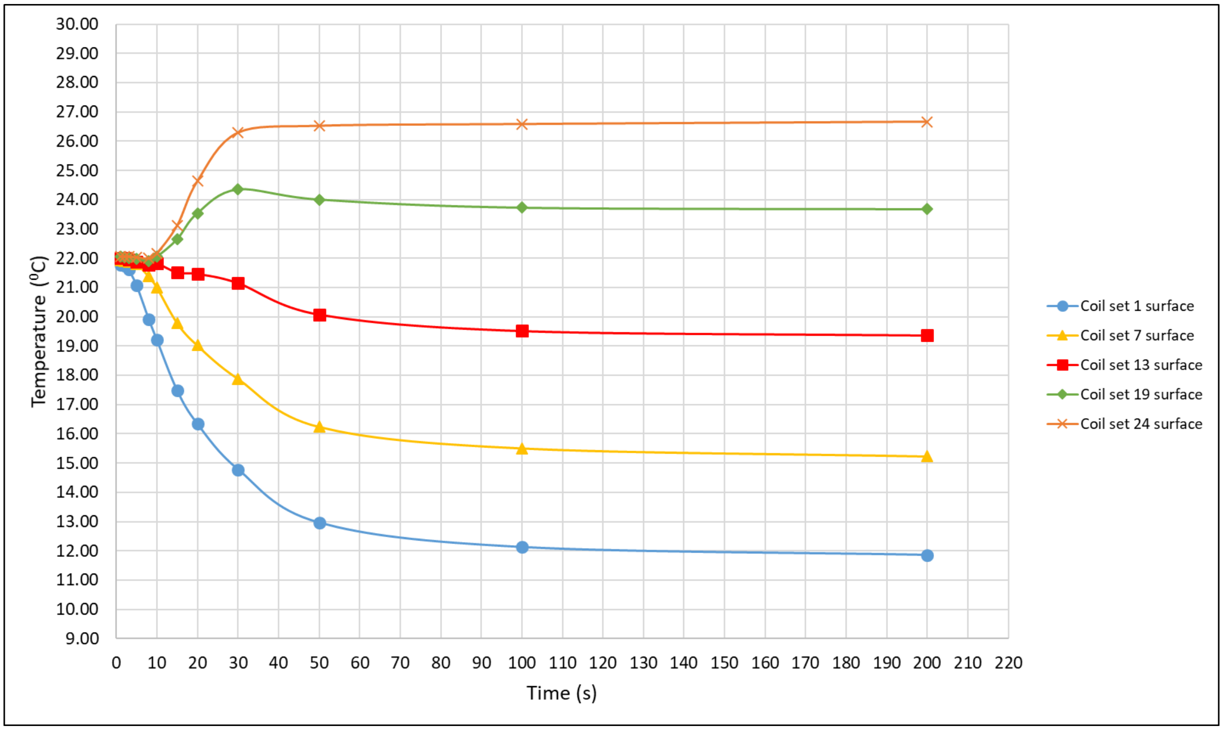


**Figure J21: Coil set surface temperature profiles at different time instants for R3-60 at 7LPM**

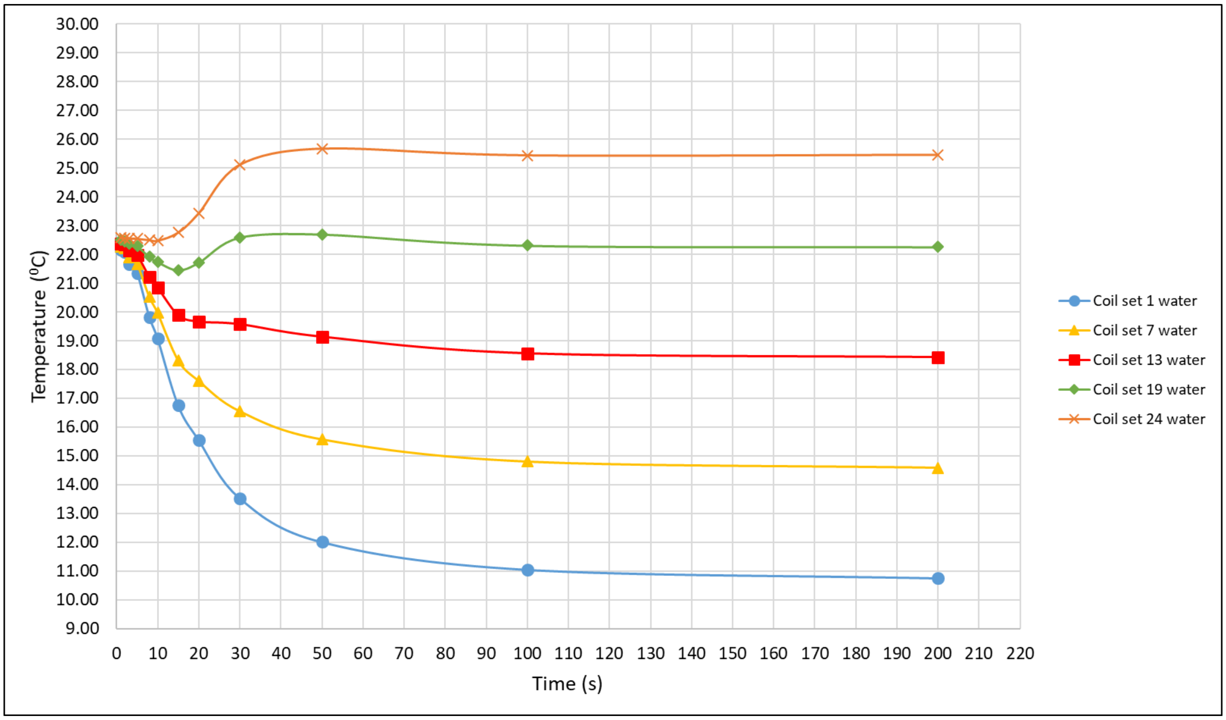


**Figure J22: Estimated coil set water temperature profiles at different time instants for R3-60 at 7LPM**

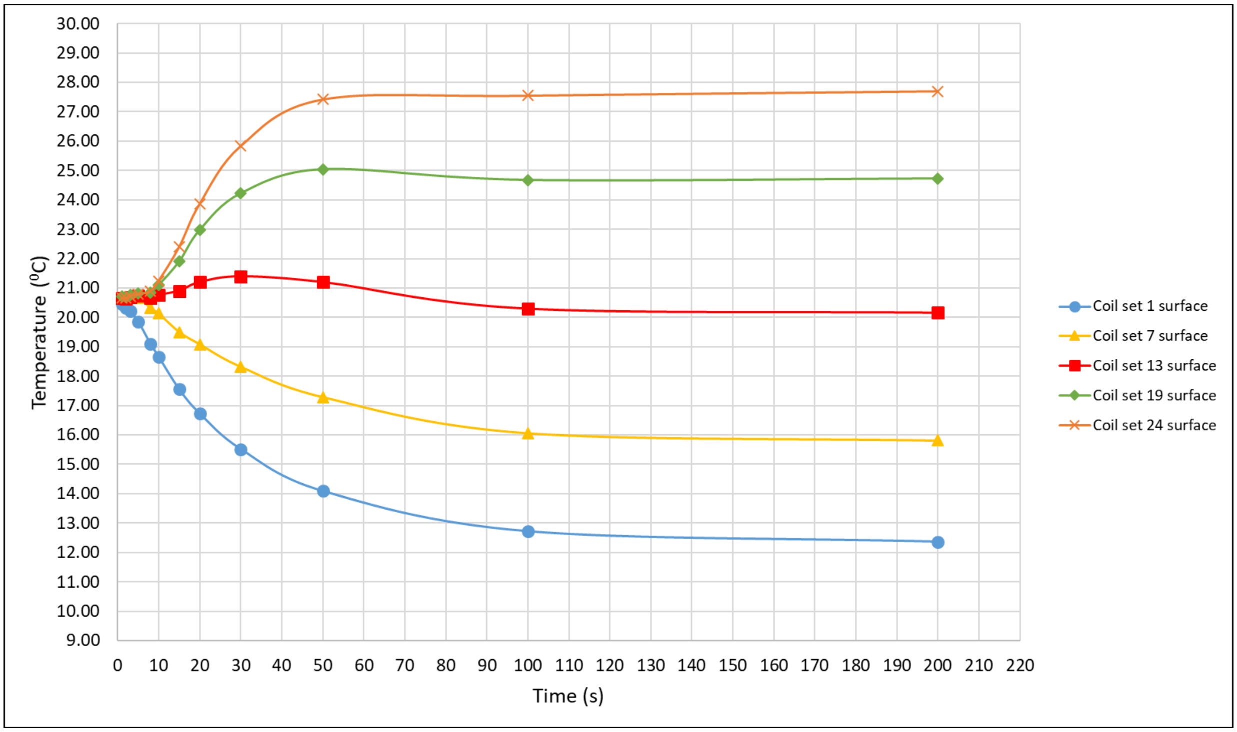


**Figure J23: Coil set surface temperature profiles at different time instants for R3-60 at 5.5LPM**

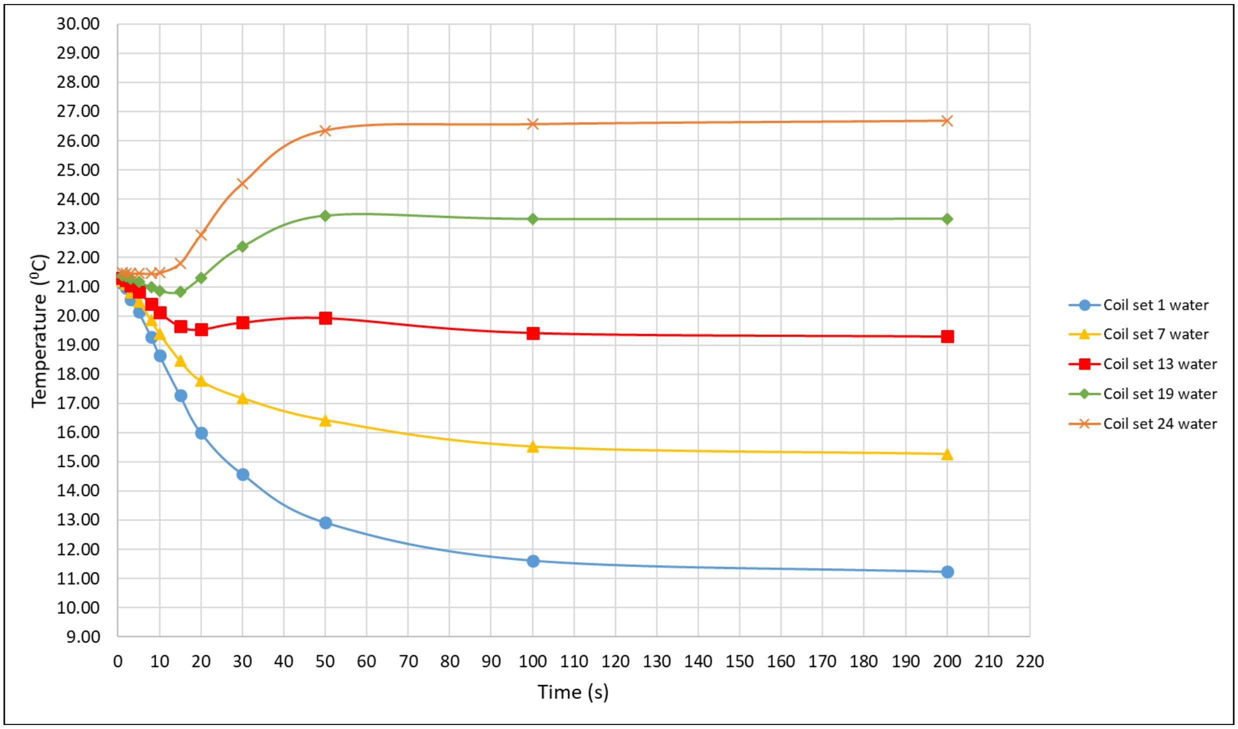


**Figure J24: Estimated coil set water temperature profiles at different time instants for R3-60 at 5.5LPM**

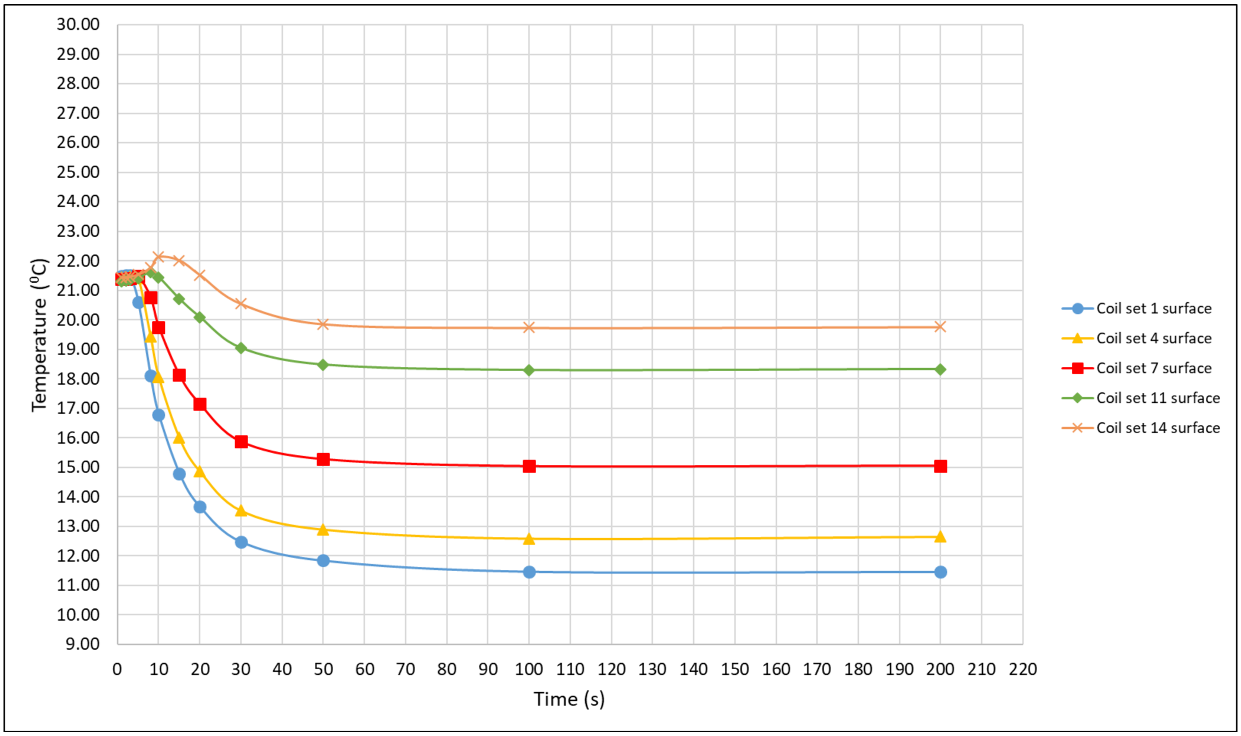


**Figure J25: Coil set surface temperature profiles at different time instants for R4-36 at 14LPM**

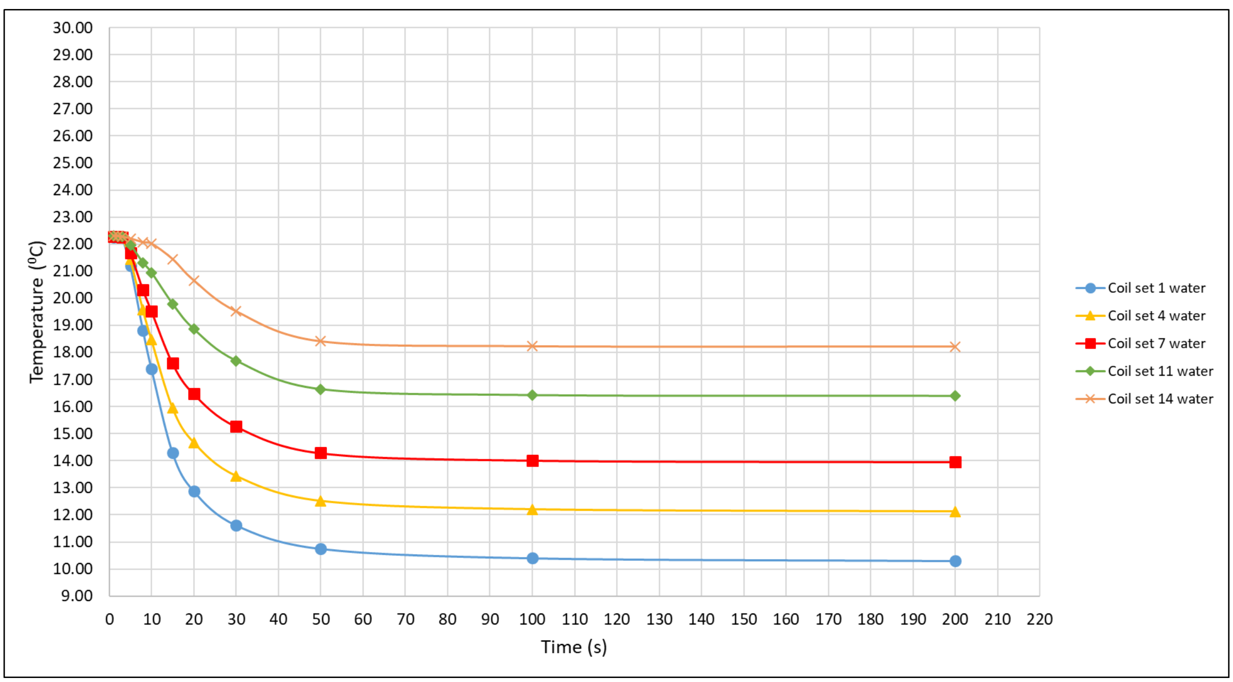


**Figure J26: Estimated coil set water temperature profiles at different time instants for R4-36 at 14LPM**

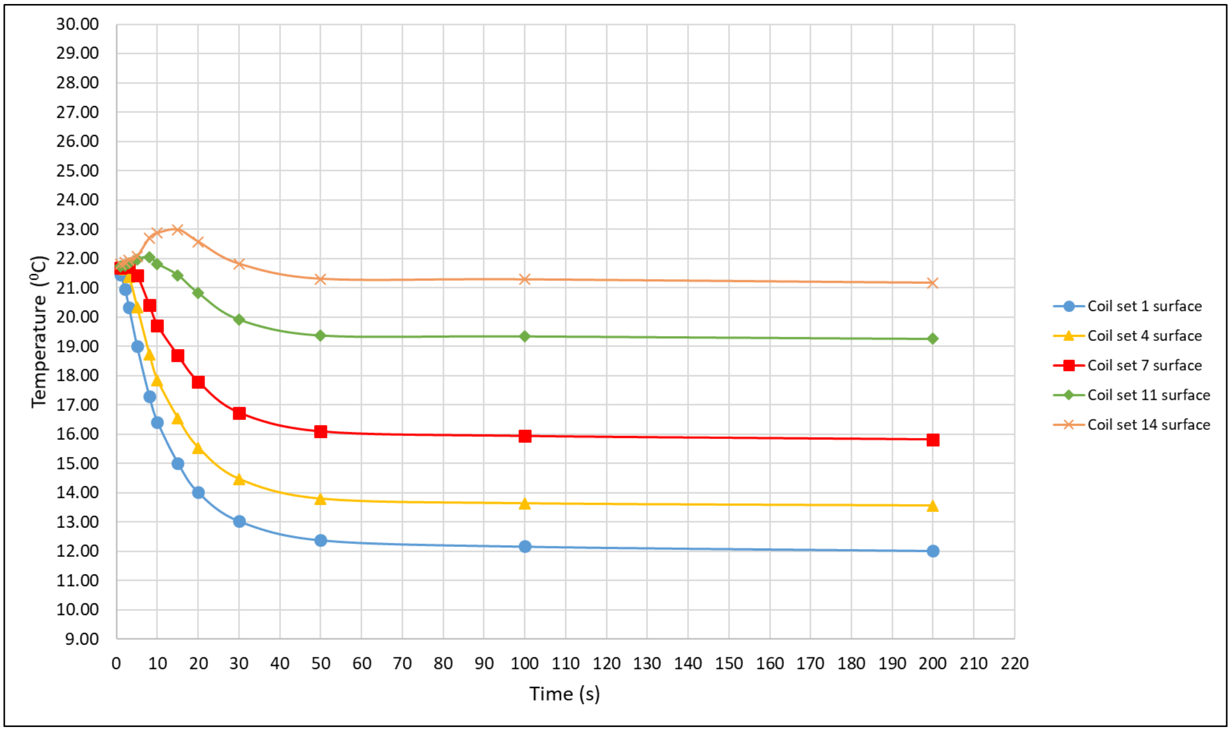


**Figure J27: Coil set surface temperature profiles at different time instants for R4-36 at 12LPM**

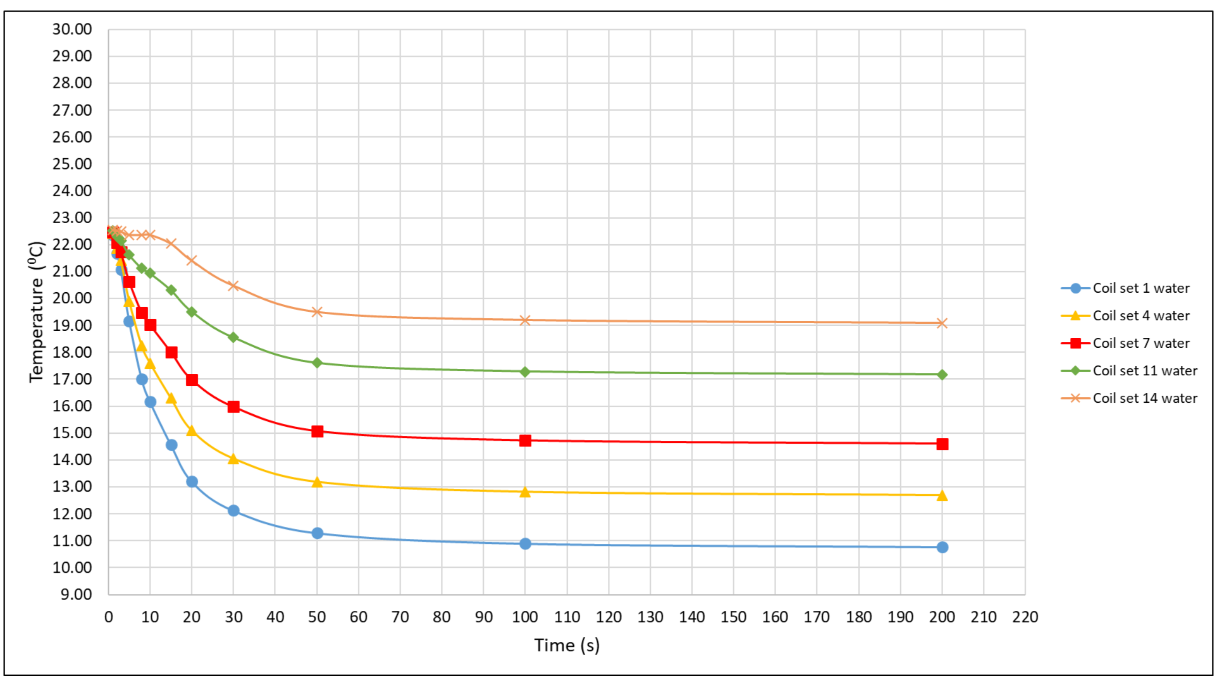


**Figure J28: Estimated coil set water temperature profiles at different time instants for R4-36 at 12LPM**

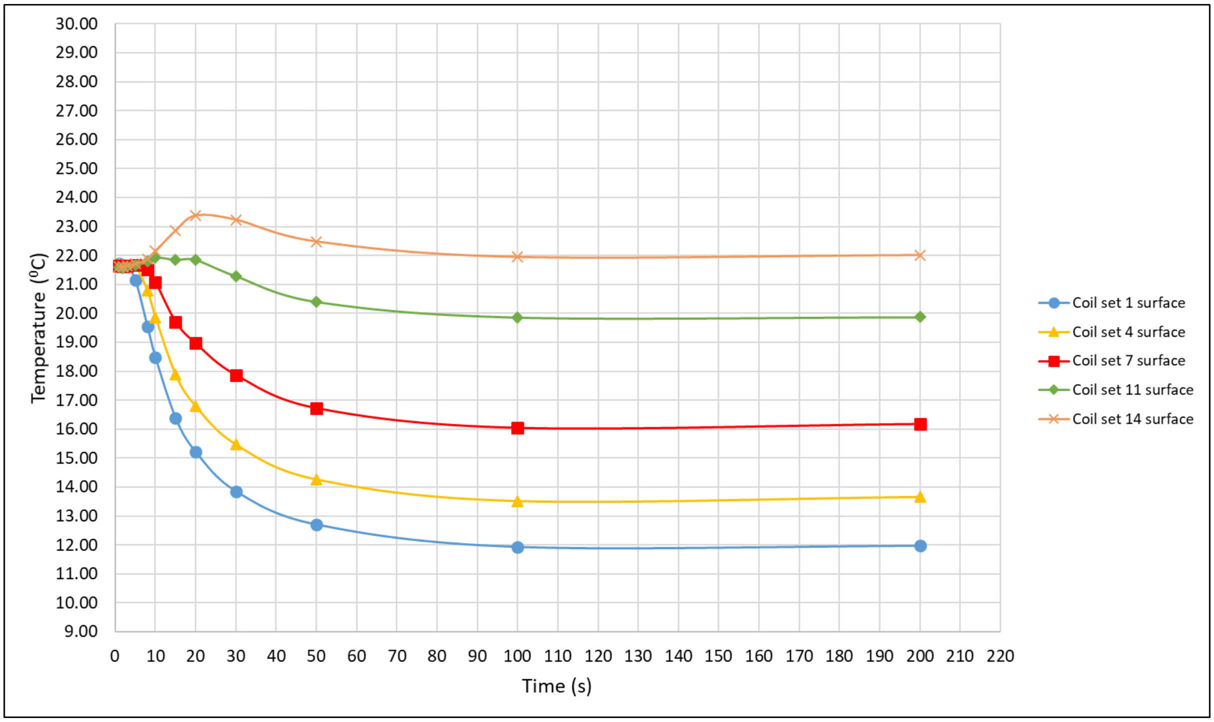


**Figure J29: Coil set surface temperature profiles at different time instants for R4-36 at 10LPM**

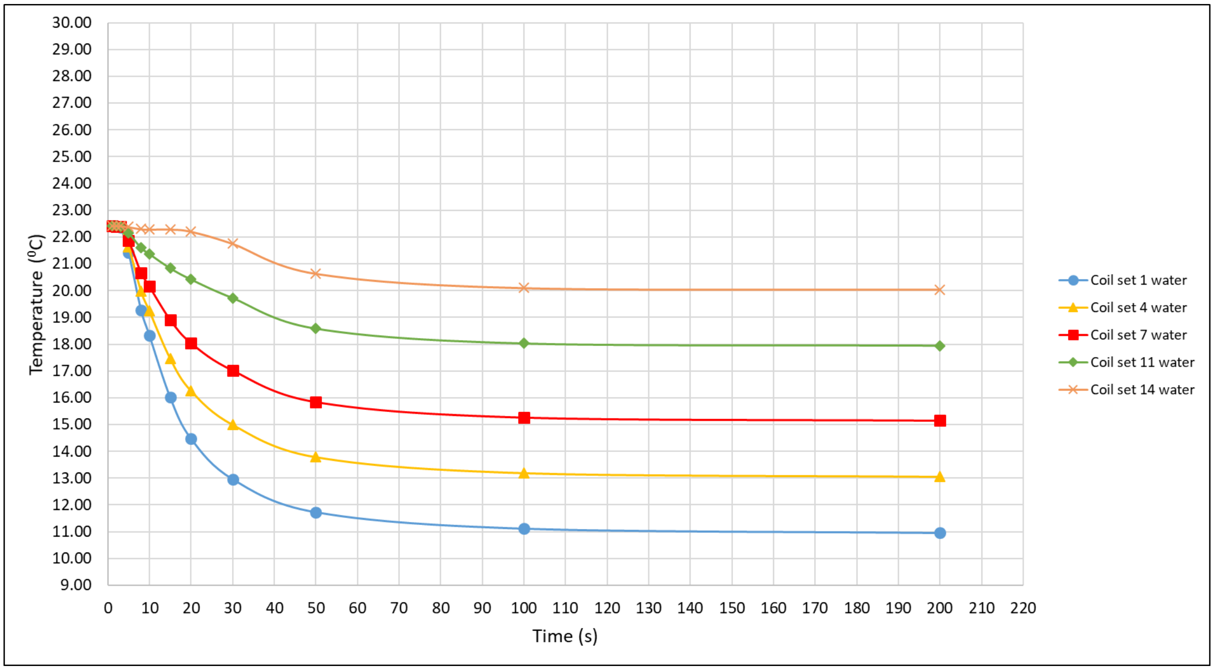


**Figure J30: Estimated coil set water temperature profiles at different time instants for R4-36 at 10LPM**

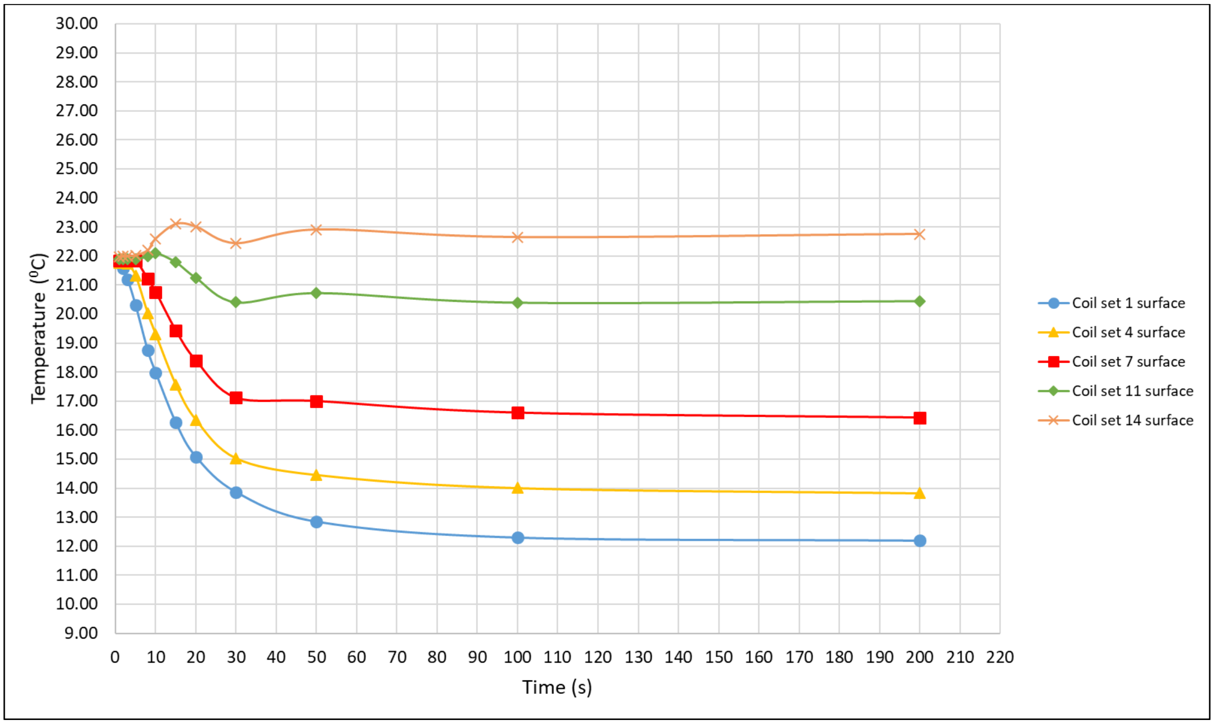


**Figure J31: Coil set surface temperature profiles at different time instants for R4-36 at 9LPM**

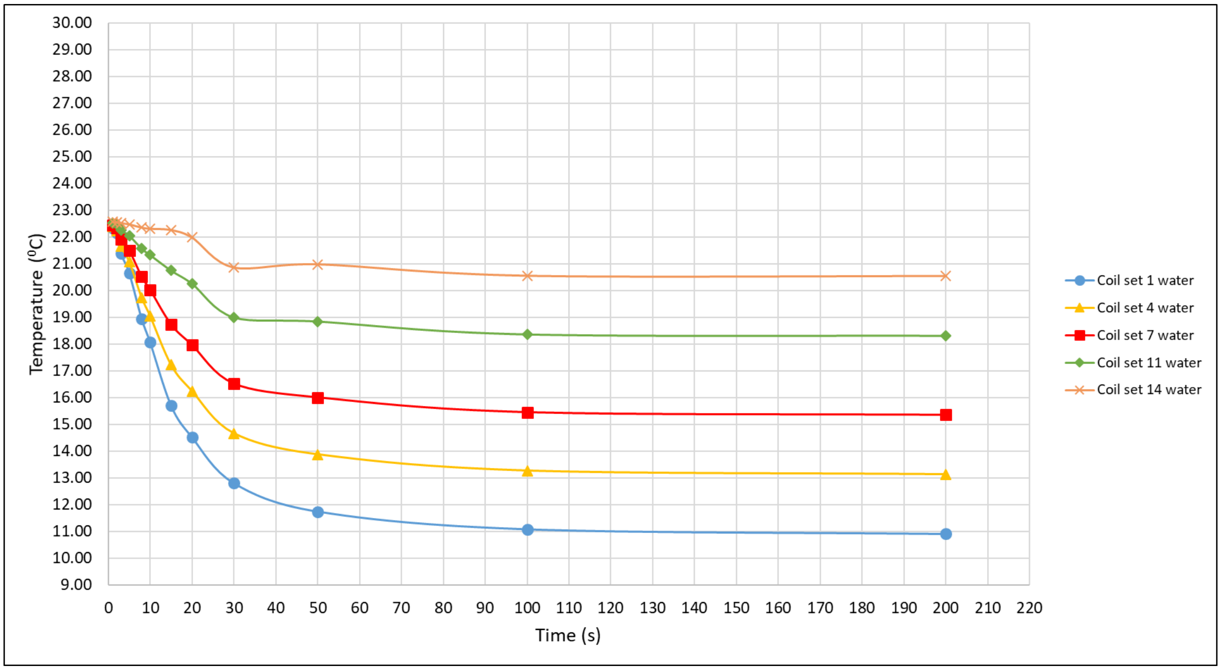


**Figure J32: Estimated coil set water temperature profiles at different time instants for R4-36 at 9LPM**

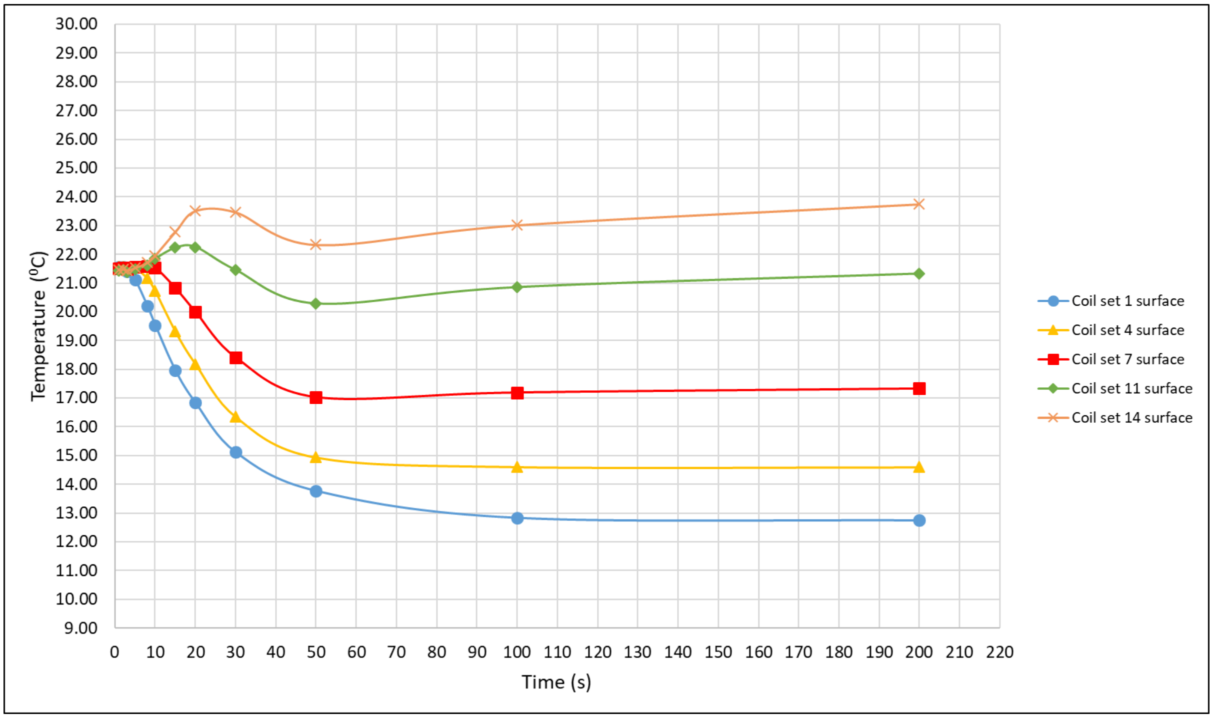


**Figure J33: Coil set surface temperature profiles at different time instants for R4-36 at 7LPM**

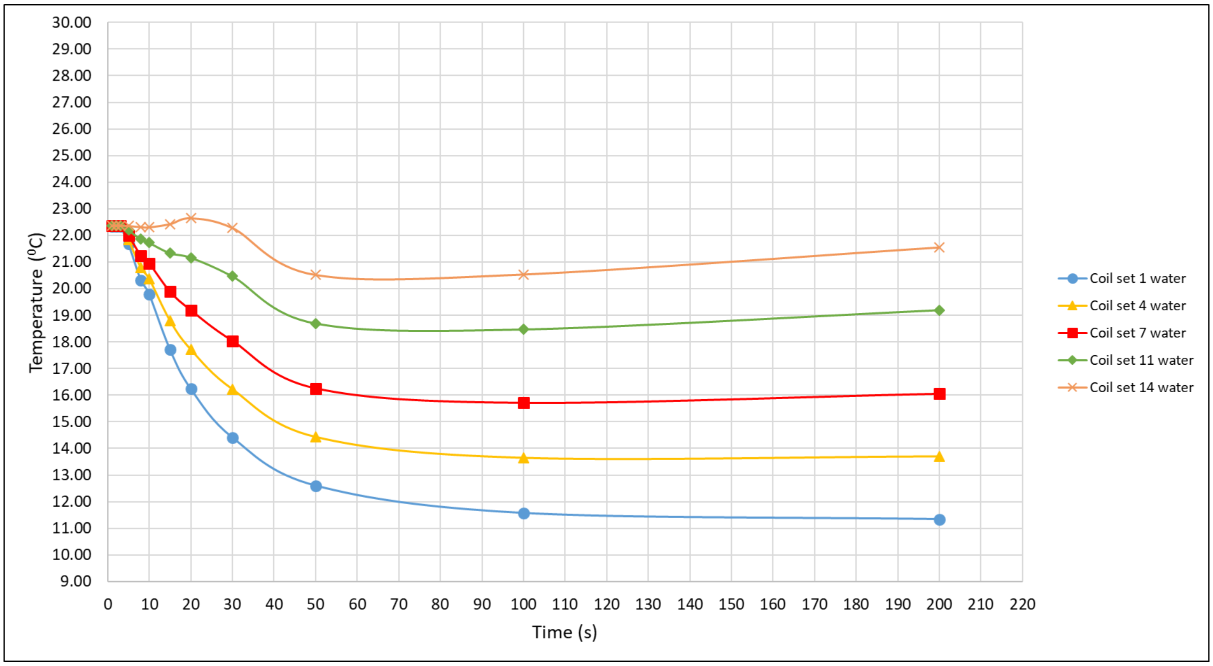


**Figure J34: Estimated coil set water temperature profiles at different time instants for R4-36 at 7LPM**

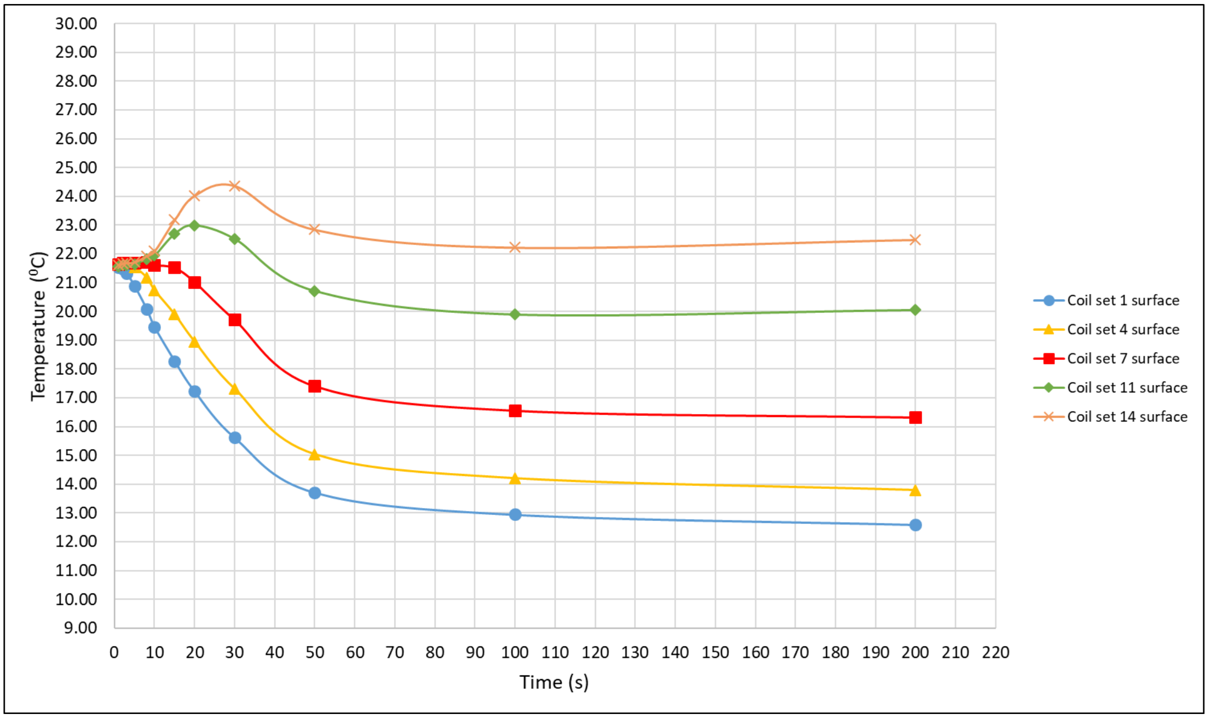


**Figure J35: Coil set surface temperature profiles at different time instants for R4-36 at 5.5LPM**

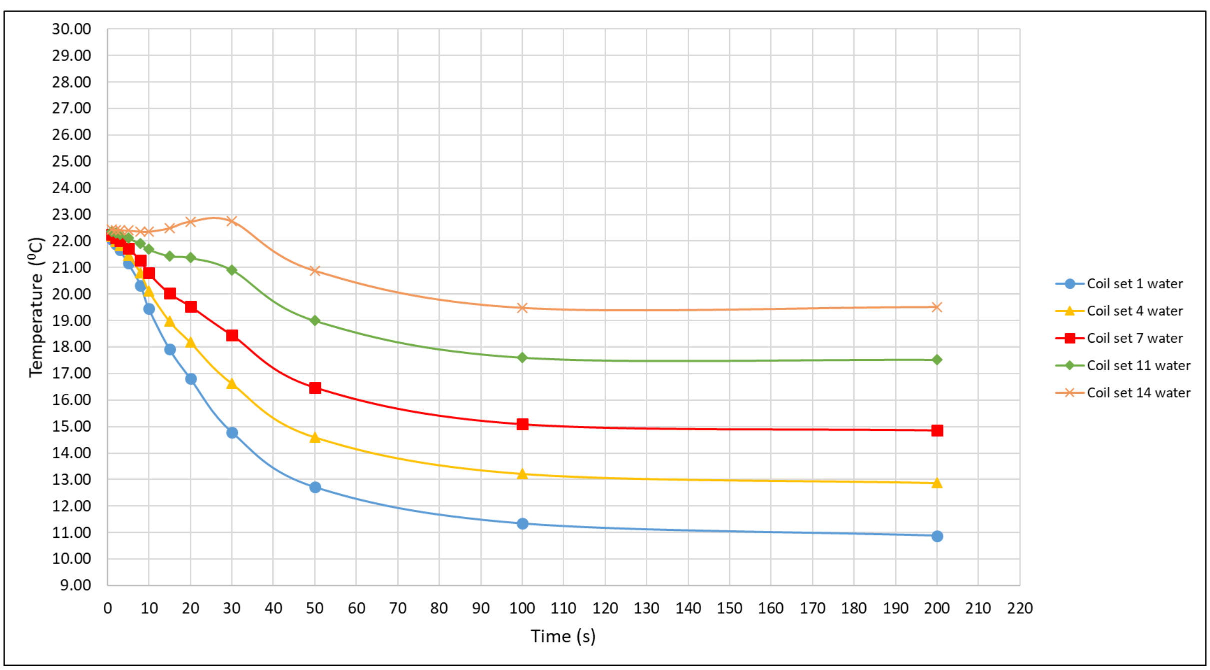


**Figure J36: Estimated coil set water temperature profiles at different time instants for R4-36 at 5.5LPM**

# Appendix K: MATLAB Script for Biot Number and Convection Coefficients Estimation

```
clear
density = 0;            % declaring density variable. FIXED VALUE
Cp = 0;                 % declaring specific heat variable. FIXED VALUE
mew = 0;                % declaring viscosity variable. FIXED VALUE
k = 0;                  % declaring fluid conductivity variable. FIXED VALUE
Pr = 0;                 % declaring Prandtl number variable. FIXED VALUE
coilVel = 0;            % declaring coil velocity. FIXED VALUE
REd = 0;                % declaring reynolds number variable. FIXED VALUE
De = 0;                 % declaring dean's number. FIXED VALUE
volume = 0;             % declaring volume for Biot Number. FIXED VALUE
sArea = 0;              % declaring surface area for Biot Number. FIXED VALUE

flowrateLPM = 5.57;     % LPM. USER INPUT REQUIRED
aOD = 0.00794;          % actual OD width of single coil(m). USER INPUT NEEDED WHEN PIPE CHANGED
bOD = 0.01271;          % actual OD length of single coil(m). USER INPUT NEEDED WHEN PIPE CHANGED
D6 = 0.12044;           % outermost diameter of pipe (m). USER INPUT NEEDED WHEN PIPE CHANGED
Lcircum = 0.344;        % circumference of pipe for convection HT. (m). USER INPUT NEEDED IF PIPE CHANGED
thickness = 0.00152;    % thickness of outer coil wall. FIXED AND WON'T CHANGE
a = aOD-(2*thickness);  % calculated ID width of single coil (m)
b = bOD-(2*thickness);  % calculated ID height of single coil (m)
dh = (2*a*b)/(a+b);     % calculated hydraulic diameter
D = D6-aOD;             % calculated Nominal OD of pipe
kCOPPER = 401;          % thermal conductivity of COPPER

% NOTES: A = Tfluid in CELSIUS
%        B = Tfluid in KELVIN
%        C = Tsurface in CELSIUS
%        E = Tsurface in KELVIN
%        h = CONVECTION COEFFICIENT

% FLUID TEMP in CELSIUS. CHANGE AS NEEDED
A = [10.21 10.87 11.54 12.20 12.87 13.53 14.20 14.86 15.53 16.19 16.86 17.52 18.19 18.85 19.52 20.18];
B = A + 273.15;                % FLUID TEMP IN KELVIN

% SURFACE TEMP IN CELSIUS. CHANGE AS NEEDED
C = [10.21 12.60 12.49 13.27 13.80 14.38 15.43 16.32 17.22 18.06 18.90 20.06 20.82 21.59 22.49 20.18];
E = C + 273.15;                % SURFACE TEMP IN KELVIN

countelements = numel(A);           % total elements in set
totalCount = countelements - 2;     % total energy readings needed

hLAM = zeros(countelements,1);      % Array of all LAMINAR convection coefficients
qLAM = zeros(countelements,1);      % Array of TOTAL LAMINAR convective heat transfer for ENTIRE COILSET
BiLAM = zeros(countelements,1);     % Array of all LAMINAR Biot Numbers

hTURB = zeros(countelements,1);     % Array of all TURBULENT convection coefficients
qTURB = zeros(countelements,1);     % Array of TOTAL TURBULENT convective heat transfer for ENTIRE COILSET
BiTURB = zeros(countelements,1);    % Array of all TURBULENT Biot Numbers

totalconvQ = zeros(countelements,1);  % Array of LAMINAR and TURBULENT qConv and Biot numbers

% INTERPOLATING DENSITY, Cp, VISCOSITY, CONDUCTIVITY and PRANDTL NUMBER
for i=2:(countelements-1)

    if  (B(i)>=275) && (B(i)<280)
      density = 1/(0.001+((0.001-0.001)*((B(i)-275)/(280-275))));          % kg/m3
      Cp = 4.211+((4.198-4.211)*((B(i)-275)/(280-275)));                   % kJ/kg.K
      mew = 0.001652+((0.001422-0.001652)*((B(i)-275)/(280-275)));         % N.s/m2
      k = 0.574+((0.582-0.574)*((B(i)-275)/(280-275)));                    % W/m.K
      Pr = 12.22+((10.26-12.22)*((B(i)-275)/(280-275)));                   % DimensionLess
      volume = a*b*Lcircum;                                                % Volume for Biot Number
      sArea = 2*Lcircum*(a+b);                                             % Surface Area for Biot Number
      coilVel = ((flowrateLPM/4)/60000)/(a*b);                             % calculating Velocity of each coil m/s
      REd = (density*coilVel*dh)/mew;                                      % calculating Reynolds number
      De = REd*(sqrt(dh/D));                                               % calculating Dean's number
      hLAM(i) = ((0.913*(power(De,0.476))*(power(Pr,0.2)))*k)/dh;          % calculating LAMINAR h (W/m2K)
      hTURB(i) = ((0.023*(power(REd,0.8))*(power(Pr,0.4))*(1+(3.4*(dh/D))))*k)/dh;
                                                                           % calculating turbulent h (w/m2K)
      qLAM(i) = (4 * hLAM(i) * sArea * (E(i) - B(i)))/1000;                % calculating LAMINAR Qconv for coilset (kW)
      qTURB(i) = (4 * hTURB(i) * sArea * (E(i) - B(i)))/1000;              % calculating TURBULENT Qconv for coilset (kW)
      BiLAM(i) = (hLAM(i)/kCOPPER)*(volume/sArea);                         % calculating LAMINAR Biot Number
      BiTURB(i) = (hTURB(i)/kCOPPER)*(volume/sArea);                       % calculating TURBULENT Biot Number
      totalconvQ = horzcat(qLAM,BiLAM,qTURB,BiTURB); % final array of calculated qCONV and Biot numbers both LAM and TURB
```

```
elseif (B(i)>=280) && (B(i)<285)
  density = 1/(0.001+((0.001-0.001)*((B(i)-280)/(285-280))));          % kg/m3
  Cp = 4.198+((4.189-4.198)*((B(i)-280)/(285-280)));                   % kJ/kg.K

  mew = 0.001422+((0.001225-0.001422)*((B(i)-280)/(285-280)));         % N.s/m2
  k = 0.582+((0.59-0.582)*((B(i)-280)/(285-280)));                     % W/m.K
  Pr = 10.26+((8.81-10.26)*((B(i)-280)/(285-280)));                    % DimensionLess
  volume = a*b*Lcircum;                                                % Volume for Biot Number
  sArea = 2*Lcircum*(a+b);                                             % Surface Area for Biot Number
  coilVel = ((flowrateLPM/4)/60000)/(a*b);                             % calculating Velocity of each coil m/s
  REd = (density*coilVel*dh)/mew;                                      % calculating Reynolds number
  De = REd*(sqrt(dh/D));                                               % calculating Dean's number
  hLAM(i) = ((0.913*(power(De,0.476))*(power(Pr,0.2)))*k)/dh;          % calculating LAMINAR h (W/m2K)
  hTURB(i) = ((0.023*(power(REd,0.8))*(power(Pr,0.4))*(1+(3.4*(dh/D))))*k)/dh;
                                                                       % calculating TURBULENT h (W/m2K)
  qLAM(i) = (4 * hLAM(i) * sArea * (E(i) - B(i)))/1000;                % calculating LAMINAR Qconv for coilset (kW)
  qTURB(i) = (4 * hTURB(i) * sArea * (E(i) - B(i)))/1000;              % calculating TURBULENT Qconv for coilset (kW)
  BiLAM(i) = (hLAM(i)/kCOPPER)*(volume/sArea);                         % calculating LAMINAR Biot Number
  BiTURB(i) = (hTURB(i)/kCOPPER)*(volume/sArea);                       % calculating TURBULENT Biot Number
  totalconvQ = horzcat(qLAM,BiLAM,qTURB,BiTURB); % final array of calculated qCONV and Biot numbers both LAM and TURB

elseif (B(i)>=285) && (B(i)<290)
  density = 1/(0.001+((0.001001-0.001)*((B(i)-285)/(290-285))));       % kg/m3
  Cp = 4.189+((4.184-4.189)*((B(i)-285)/(290-285)));                   % kJ/kg.K
  mew = 0.001225+((0.001080-0.001225)*((B(i)-285)/(290-285)));         % N.s/m2
  k = 0.59+((0.598-0.59)*((B(i)-285)/(290-285)));                      % W/m.K
  Pr = 8.81+((7.56-8.81)*((B(i)-285)/(290-285)));                      % DimensionLess
  volume = a*b*Lcircum;                                                % Volume for Biot Number
  sArea = 2*Lcircum*(a+b);                                             % Surface Area for Biot Number
  coilVel = ((flowrateLPM/4)/60000)/(a*b);                             % calculating Velocity of each coil m/s
  REd = (density*coilVel*dh)/mew;                                      % calculating Reynolds number
  De = REd*(sqrt(dh/D));                                               % calculating Dean's number
  hLAM(i) = ((0.913*(power(De,0.476))*(power(Pr,0.2)))*k)/dh;          % calculating LAMINAR h (W/m2K)
  hTURB(i) = ((0.023*(power(REd,0.8))*(power(Pr,0.4))*(1+(3.4*(dh/D))))*k)/dh;
                                                                       % calculating TURBULENT h (W/m2K)
  qLAM(i) = (4 * hLAM(i) * sArea * (E(i) - B(i)))/1000;                % calculating LAMINAR Qconv for coilset (kW)
  qTURB(i) = (4 * hTURB(i) * sArea * (E(i) - B(i)))/1000;              % calculating TURBULENT Qconv for coilset (kW)
  BiLAM(i) = (hLAM(i)/kCOPPER)*(volume/sArea);                         % calculating LAMINAR Biot Number
  BiTURB(i) = (hTURB(i)/kCOPPER)*(volume/sArea);                       % calculating TURBULENT Biot Number
  totalconvQ = horzcat(qLAM,BiLAM,qTURB,BiTURB); % final array of calculated qCONV and Biot numbers both LAM and TURB

elseif (B(i)>=290) && (B(i)<295)
  density = 1/(0.001001+((0.001002-0.001001)*((B(i)-290)/(295-290)))); % kg/m3
  Cp = 4.184+((4.181-4.184)*((B(i)-290)/(295-290)));                   % kJ/kg.K
  mew = 0.001080+((0.000959-0.001080)*((B(i)-290)/(295-290)));         % N.s/m2
  k = 0.598+((0.606-0.598)*((B(i)-290)/(295-290)));                    % W/m.K
  Pr = 7.56+((6.62-7.56)*((B(i)-290)/(295-290)));                      % DimensionLess
  volume = a*b*Lcircum;                                                % Volume for Biot Number
  sArea = 2*Lcircum*(a+b);                                             % Surface Area for Biot Number
  coilVel = ((flowrateLPM/4)/60000)/(a*b);                             % calculating Velocity of each coil m/s
  REd = (density*coilVel*dh)/mew;                                      % calculating Reynolds number
  De = REd*(sqrt(dh/D));                                               % calculating Dean's number
  hLAM(i) = ((0.913*(power(De,0.476))*(power(Pr,0.2)))*k)/dh;          %calculating LAMINAR h (W/m2K)
  hTURB(i) = ((0.023*(power(REd,0.8))*(power(Pr,0.4))*(1+(3.4*(dh/D))))*k)/dh;
                                                                       % calculating TURBULENT h (W/m2K)
  qLAM(i) = (4 * hLAM(i) * sArea * (E(i) - B(i)))/1000;                % calculating LAMINAR Qconv for coilset (kW)
  qTURB(i) = (4 * hTURB(i) * sArea * (E(i) - B(i)))/1000;              % calculating TURBULENT Qconv for coilset (kW)
  BiLAM(i) = (hLAM(i)/kCOPPER)*(volume/sArea);                         % calculating LAMINAR Biot Number
  BiTURB(i) = (hTURB(i)/kCOPPER)*(volume/sArea);                       % calculating TURBULENT Biot Number
  totalconvQ = horzcat(qLAM,BiLAM,qTURB,BiTURB); % final array of calculated qCONV and Biot numbers both LAM and TURB

elseif (B(i)>=295) && (B(i)<300)
  density = 1/(0.001002+((0.001003-0.001002)*((B(i)-295)/(300-295)))); % kg/m3
  Cp = 4.181+((4.179-4.181)*((B(i)-295)/(300-295)));                   % kJ/kg.K
  mew = 0.000959+((0.000855-0.000959)*((B(i)-295)/(300-295)));         % N.s/m2
  k = 0.606+((0.613-0.606)*((B(i)-295)/(300-295)));                    % W/m.K
  Pr = 6.62+((5.83-6.62)*((B(i)-295)/(300-295)));                      % DimensionLess
  volume = a*b*Lcircum;                                                % Volume for Biot Number
  sArea = 2*Lcircum*(a+b);                                             % Surface Area for Biot Number
  coilVel = ((flowrateLPM/4)/60000)/(a*b);                             % calculating Velocity of each coil m/s
  REd = (density*coilVel*dh)/mew;                                      % calculating Reynolds number
  De = REd*(sqrt(dh/D));                                               % calculating Dean's number
  hLAM(i) = ((0.913*(power(De,0.476))*(power(Pr,0.2)))*k)/dh;          % calculating LAMINAR h (W/m2K)
  hTURB(i) = ((0.023*(power(REd,0.8))*(power(Pr,0.4))*(1+(3.4*(dh/D))))*k)/dh;
                                                                       % calculating TURBULENT h (W/m2K)
  qLAM(i) = (4 * hLAM(i) * sArea * (E(i) - B(i)))/1000;                % calculating LAMINAR Qconv for coilset (kW)
  qTURB(i) = (4 * hTURB(i) * sArea * (E(i) - B(i)))/1000;              % calculating TURBULENT Qconv for coilset (kW)
  BiLAM(i) = (hLAM(i)/kCOPPER)*(volume/sArea);                         % calculating LAMINAR Biot Number
```

```
        BiTURB(i) = (hTURB(i)/kCOPPER)*(volume/sArea);                       % calculating TURBULENT Biot Number
        totalconvQ = horzcat(qLAM,BiLAM,qTURB,BiTURB); % final array of calculated qCONV and Biot numbers both LAM and TURB

       elseif (B(i)>=300) && (B(i)<305)
        density = 1/(0.001003+((0.001005-0.001003)*((B(i)-300)/(305-300)))); % kg/m3
        Cp = 4.179+((4.178-4.179)*((B(i)-300)/(305-300)));                   % kJ/kg.K
        mew = 0.000855+((0.000769-0.000855)*((B(i)-300)/(305-300)));         % N.s/m2
        k = 0.613+((0.620-0.613)*((B(i)-300)/(305-300)));                    % W/m.K
        Pr = 5.83+((5.20-5.83)*((B(i)-300)/(305-300)));                      % DimensionLess

        volume = a*b*Lcircum;                                                % Volume for Biot Number
        sArea = 2*Lcircum*(a+b);                                             % Surface Area for Biot Number
        coilVel = ((flowrateLPM/4)/60000)/(a*b);                             % calculating Velocity of each coil m/s
        REd = (density*coilVel*dh)/mew;                                      % calculating Reynolds number
        De = REd*(sqrt(dh/D));                                               % calculating Dean's number
        hLAM(i) = ((0.913*(power(De,0.476))*(power(Pr,0.2)))*k)/dh;          % calculating LAMINAR h (W/m2K)
        hTURB(i) = ((0.023*(power(REd,0.8))*(power(Pr,0.4))*(1+(3.4*(dh/D))))*k)/dh;
                                                                             % calculating TURBULENT h (W/m2K)
        qLAM(i) = (4 * hLAM(i) * sArea * (E(i) - B(i)))/1000;                % calculating LAMINAR Qconv for coilset (kW)
        qTURB(i) = (4 * hTURB(i) * sArea * (E(i) - B(i)))/1000;              % calculating TURBULENT Qconv for coilset (kW)
        BiLAM(i) = (hLAM(i)/kCOPPER)*(volume/sArea);                         % calculating LAMINAR Biot Number
        BiTURB(i) = (hTURB(i)/kCOPPER)*(volume/sArea);                       % calculating TURBULENT Biot Number
        totalconvQ = horzcat(qLAM,BiLAM,qTURB,BiTURB); % final array of calculated qCONV and Biot numbers both LAM and TURB
      end
  end
```

# Appendix L: MATLAB Script for Flow Energy Rate Calculations

```
clear
flowrateLPM = 5.57;  % LPM

% NOTES: A = Tfluid in CELSIUS
%        B = Tfluid in KELVIN

A = [10.21 10.87 11.54 12.20 12.87 13.53 14.20 14.86 15.53 16.19 16.86 17.52 18.19 18.85 19.52 20.18];
B = A + 273.15;                         % in Kelvin
countelements = numel(A);               % total elements in set
totalCount = countelements - 2;         % total energy readings needed
inputQ = zeros(countelements,1);        % storing computed heat input kW
outputQ = zeros(countelements,1);       % storing computed heat output kW
ioQ = zeros(countelements,1);           % concatenated final array
deltaQ = zeros(countelements,1);        % storing computed heat gain kW
Cp = 0;                                 % declaring specific heat variable
density = 0;                            % declaring density variable

for i=2:(countelements-1)
    if  (B(i)>=275) && (B(i)<280)
      Cp = 4.211+((4.198-4.211)*((B(i)-275)/(280-275)));                        % kJ/kg.K
      density = 1/(0.001+((0.001-0.001)*((B(i)-275)/(280-275))));              % kg/m3
      inputQ(i) = ((flowrateLPM/60000)*density)*Cp*B(i-1);
      outputQ(i) = ((flowrateLPM/60000)*density)*Cp*B(i);
      ioQ = horzcat(inputQ,outputQ);
      deltaQ(i) = outputQ(i) - inputQ(i);
    elseif (B(i)>=280) && (B(i)<285)
      Cp = 4.198+((4.189-4.198)*((B(i)-280)/(285-280)));                        % kJ/kg.K
      density = 1/(0.001+((0.001-0.001)*((B(i)-280)/(285-280))));              % kg/m3
      inputQ(i) = ((flowrateLPM/60000)*density)*Cp*B(i-1);
      outputQ(i) = ((flowrateLPM/60000)*density)*Cp*B(i);
      ioQ = horzcat(inputQ,outputQ);
      deltaQ(i) = outputQ(i) - inputQ(i);
    elseif (B(i)>=285) && (B(i)<290)
      Cp = 4.189+((4.184-4.189)*((B(i)-285)/(290-285)));                        % kJ/kg.K
      density = 1/(0.001+((0.001001-0.001)*((B(i)-285)/(290-285))));           % kg/m3
      inputQ(i) = ((flowrateLPM/60000)*density)*Cp*B(i-1);
      outputQ(i) = ((flowrateLPM/60000)*density)*Cp*B(i);
      ioQ = horzcat(inputQ,outputQ);
      deltaQ(i) = outputQ(i) - inputQ(i);
    elseif (B(i)>=290) && (B(i)<295)
      Cp = 4.184+((4.181-4.184)*((B(i)-290)/(295-290)));                        % kJ/kg.K
      density = 1/(0.001001+((0.001002-0.001001)*((B(i)-290)/(295-290))));     % kg/m3
      inputQ(i) = ((flowrateLPM/60000)*density)*Cp*B(i-1);
      outputQ(i) = ((flowrateLPM/60000)*density)*Cp*B(i);
      ioQ = horzcat(inputQ,outputQ);
      deltaQ(i) = outputQ(i) - inputQ(i);
    elseif (B(i)>=295) && (B(i)<300)
      Cp = 4.181+((4.179-4.181)*((B(i)-295)/(300-295)));                        % kJ/kg.K
      density = 1/(0.001002+((0.001003-0.001002)*((B(i)-295)/(300-295))));     % kg/m3
      inputQ(i) = ((flowrateLPM/60000)*density)*Cp*B(i-1);
      outputQ(i) = ((flowrateLPM/60000)*density)*Cp*B(i);
      ioQ = horzcat(inputQ,outputQ);
      deltaQ(i) = outputQ(i) - inputQ(i);
     elseif (B(i)>=300) && (B(i)<305)
      Cp = 4.179+((4.178-4.179)*((B(i)-300)/(305-300)));                        % kJ/kg.K
      density = 1/(0.001003+((0.001005-0.001003)*((B(i)-300)/(305-300))));     % kg/m3
      inputQ(i) = ((flowrateLPM/60000)*density)*Cp*B(i-1);
      outputQ(i) = ((flowrateLPM/60000)*density)*Cp*B(i);
      ioQ = horzcat(inputQ,outputQ);
      deltaQ(i) = outputQ(i) - inputQ(i);
    end
end
totaldeltaQ = sum(deltaQ);
```

# Appendix L: MATLAB Script for Storage Energy Rate Calculations

```
clear

volumeCoilset = 0.000058651;              % fluid volume in each coilset m3. CHANGE AS NEEDED

                                          % WaterTempC = Fluid temperature in coil sets measured in
Celsius
WaterTempC = [10.13 10.97 11.80 12.64 13.48 14.32 15.15 15.99 16.83 17.67 18.50 19.34 20.18 21.02 21.85
22.69];
WaterTempK = WaterTempC + 273.15;         % Fluid temperature in coil sets measured in Kelvin

                                          % dTdt = dT/dt
dTdt = [-0.003 -0.003 -0.003 -0.003 -0.002 -0.002 -0.002 -0.002 -0.002 -0.002 -0.002 -0.001 -0.001 -0.001
-0.001 -0.001];
                                          % K/s or C/s
countelements = numel(WaterTempC);        % total elements in set
totalCount = countelements - 2;           % total energy readings needed
storageQ = zeros(countelements,1);        % storage in kW


Cp = 0;                                   % declaring specific heat variable
density = 0;                              % declaring density variable

for i=2:(countelements-1)
    if  (WaterTempK(i)>=275) && (WaterTempK(i)<280)
      Cp = 4.211+((4.198-4.211)*((WaterTempK(i)-275)/(280-275)));                          % kJ/kg.K
      density = 1/(0.001+((0.001-0.001)*((WaterTempK(i)-275)/(280-275))));                 % kg/m3
      storageQ(i) = density*volumeCoilset*Cp*dTdt(i);                                      % kW
    elseif (WaterTempK(i)>=280) && (WaterTempK(i)<285)
      Cp = 4.198+((4.189-4.198)*((WaterTempK(i)-280)/(285-280)));                          % kJ/kg.K
      density = 1/(0.001+((0.001-0.001)*((WaterTempK(i)-280)/(285-280))));                 % kg/m3
      storageQ(i) = density*volumeCoilset*Cp*dTdt(i);                                      % kW
    elseif (WaterTempK(i)>=285) && (WaterTempK(i)<290)
      Cp = 4.189+((4.184-4.189)*((WaterTempK(i)-285)/(290-285)));                          % kJ/kg.K
      density = 1/(0.001+((0.001001-0.001)*((WaterTempK(i)-285)/(290-285))));              % kg/m3
      storageQ(i) = density*volumeCoilset*Cp*dTdt(i);                                      % kW
    elseif (WaterTempK(i)>=290) && (WaterTempK(i)<295)
      Cp = 4.184+((4.181-4.184)*((WaterTempK(i)-290)/(295-290)));                          % kJ/kg.K
      density = 1/(0.001001+((0.001002-0.001001)*((WaterTempK(i)-290)/(295-290))));        % kg/m3
      storageQ(i) = density*volumeCoilset*Cp*dTdt(i);                                      % kW
    elseif (WaterTempK(i)>=295) && (WaterTempK(i)<300)
      Cp = 4.181+((4.179-4.181)*((WaterTempK(i)-295)/(300-295)));                          % kJ/kg.K
      density = 1/(0.001002+((0.001003-0.001002)*((WaterTempK(i)-295)/(300-295))));        % kg/m3
      storageQ(i) = density*volumeCoilset*Cp*dTdt(i);                                      % kW
     elseif (WaterTempK(i)>=300) && (WaterTempK(i)<305)
      Cp = 4.179+((4.178-4.179)*((WaterTempK(i)-300)/(305-300)));                          % kJ/kg.K
      density = 1/(0.001003+((0.001005-0.001003)*((WaterTempK(i)-300)/(305-300))));        % kg/m3
      storageQ(i) = density*volumeCoilset*Cp*dTdt(i);                                      % kW
    end
end
```

# Appendix M: Energy Balance Tables at Coil Sets

**Table M1: Coil Set Energy Balance for R3-36 at 14LPM**

| Coilset | 1 second | | | 2 seconds | | | 3 seconds | | | 5 seconds | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Flow (kW) | Storage (kW) | Coil set $q_c$ (kW) | Flow (kW) | Storage (kW) | Coil set $q_c$ (kW) | Flow (kW) | Storage (kW) | Coil set $q_c$ (kW) | Flow (kW) | Storage (kW) | Coil set $q_c$ (kW) |
| **1** | 0.0064 | 0.0000 | 0.0064 | 0.0083 | -0.0051 | 0.0031 | 0.0096 | -0.0046 | 0.0049 | 0.1060 | -0.1692 | -0.0632 |
| **2** | 0.0128 | 0.0000 | 0.0128 | 0.0083 | -0.0056 | 0.0027 | 0.0096 | -0.0046 | 0.0049 | 0.1060 | -0.1574 | -0.0514 |
| **3** | 0.0064 | 0.0000 | 0.0064 | 0.0083 | -0.0059 | 0.0024 | 0.0192 | -0.0044 | 0.0148 | 0.1060 | -0.1454 | -0.0394 |
| **4** | 0.0064 | 0.0000 | 0.0064 | 0.0166 | -0.0061 | 0.0104 | 0.0096 | -0.0042 | 0.0054 | 0.1060 | -0.1334 | -0.0274 |
| **5** | 0.0064 | 0.0000 | 0.0064 | 0.0083 | -0.0066 | 0.0017 | 0.0096 | -0.0042 | 0.0054 | 0.1060 | -0.1216 | -0.0157 |
| **6** | 0.0128 | 0.0000 | 0.0128 | 0.0083 | -0.0069 | 0.0014 | 0.0096 | -0.0039 | 0.0057 | 0.1060 | -0.1096 | -0.0037 |
| **7** | 0.0064 | 0.0000 | 0.0064 | 0.0083 | -0.0071 | 0.0012 | 0.0096 | -0.0037 | 0.0059 | 0.1060 | -0.0977 | 0.0083 |
| **8** | 0.0064 | 0.0000 | 0.0064 | 0.0083 | -0.0076 | 0.0007 | 0.0192 | -0.0037 | 0.0155 | 0.0963 | -0.0859 | 0.0104 |
| **9** | 0.0064 | 0.0000 | 0.0064 | 0.0083 | -0.0078 | 0.0005 | 0.0096 | -0.0034 | 0.0062 | 0.1059 | -0.0739 | 0.0320 |
| **10** | 0.0128 | 0.0000 | 0.0128 | 0.0083 | -0.0081 | 0.0002 | 0.0096 | -0.0032 | 0.0064 | 0.1059 | -0.0619 | 0.0440 |
| **11** | 0.0064 | 0.0000 | 0.0064 | 0.0083 | -0.0086 | -0.0003 | 0.0096 | -0.0032 | 0.0064 | 0.1059 | -0.0502 | 0.0558 |
| **12** | 0.0064 | 0.0000 | 0.0064 | 0.0166 | -0.0088 | 0.0078 | 0.0096 | -0.0029 | 0.0067 | 0.1059 | -0.0382 | 0.0678 |
| **13** | 0.0064 | 0.0000 | 0.0064 | 0.0083 | -0.0091 | -0.0008 | 0.0192 | -0.0027 | 0.0165 | 0.1059 | -0.0262 | 0.0798 |
| **14** | 0.0128 | 0.0000 | 0.0128 | 0.0083 | -0.0095 | -0.0013 | 0.0096 | -0.0027 | 0.0069 | 0.1059 | -0.0144 | 0.0915 |
| **exit** | 0.0064 | 0.0000 | 0.0064 | 0.0083 | 0.0000 | 0.0083 | 0.0096 | 0.0000 | 0.0096 | 0.1059 | 0.0000 | 0.1059 |
| **TOTAL $q_c$** | **0.1213** | **0.0000** | **0.1213** | **0.1408** | **-0.1028** | **0.0380** | **0.1727** | **-0.0514** | **0.1213** | **1.5796** | **-1.2850** | **0.2947** |

| Coilset | 8 seconds | | | 10 seconds | | | 15 seconds | | | 20 seconds | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Flow (kW) | Storage (kW) | Coil set $q_c$ (kW) | Flow (kW) | Storage (kW) | Coil set $q_c$ (kW) | Flow (kW) | Storage (kW) | Coil set $q_c$ (kW) | Flow (kW) | Storage (kW) | Coil set $q_c$ (kW) |
| **1** | 0.3077 | -0.2480 | 0.0597 | 0.3766 | -0.1522 | 0.2243 | 0.4983 | -0.1252 | 0.3731 | 0.5929 | -0.0734 | 0.5195 |
| **2** | 0.3173 | -0.2306 | 0.0867 | 0.3765 | -0.1436 | 0.2329 | 0.4982 | -0.1190 | 0.3792 | 0.5829 | -0.0697 | 0.5132 |
| **3** | 0.3077 | -0.2131 | 0.0945 | 0.3765 | -0.1353 | 0.2412 | 0.4981 | -0.1126 | 0.3855 | 0.5926 | -0.0658 | 0.5268 |
| **4** | 0.3076 | -0.1957 | 0.1119 | 0.3861 | -0.1269 | 0.2591 | 0.4980 | -0.1064 | 0.3915 | 0.5826 | -0.0621 | 0.5205 |
| **5** | 0.3076 | -0.1783 | 0.1293 | 0.3764 | -0.1183 | 0.2580 | 0.4978 | -0.1000 | 0.3978 | 0.5923 | -0.0584 | 0.5339 |
| **6** | 0.3172 | -0.1609 | 0.1563 | 0.3763 | -0.1100 | 0.2663 | 0.4977 | -0.0936 | 0.4041 | 0.5823 | -0.0547 | 0.5276 |
| **7** | 0.3075 | -0.1435 | 0.1640 | 0.3763 | -0.1017 | 0.2746 | 0.4976 | -0.0875 | 0.4101 | 0.5920 | -0.0510 | 0.5410 |
| **8** | 0.3075 | -0.1259 | 0.1816 | 0.3762 | -0.0931 | 0.2831 | 0.4880 | -0.0811 | 0.4069 | 0.5820 | -0.0471 | 0.5349 |
| **9** | 0.3075 | -0.1085 | 0.1990 | 0.3762 | -0.0847 | 0.2914 | 0.4975 | -0.0750 | 0.4225 | 0.5917 | -0.0434 | 0.5483 |
| **10** | 0.3170 | -0.0911 | 0.2260 | 0.3761 | -0.0764 | 0.2997 | 0.4974 | -0.0686 | 0.4288 | 0.5817 | -0.0397 | 0.5420 |
| **11** | 0.3074 | -0.0737 | 0.2337 | 0.3761 | -0.0678 | 0.3082 | 0.4973 | -0.0622 | 0.4351 | 0.5915 | -0.0360 | 0.5555 |
| **12** | 0.3074 | -0.0563 | 0.2511 | 0.3856 | -0.0595 | 0.3262 | 0.4972 | -0.0561 | 0.4411 | 0.5815 | -0.0323 | 0.5492 |
| **13** | 0.3073 | -0.0389 | 0.2684 | 0.3760 | -0.0512 | 0.3248 | 0.4971 | -0.0497 | 0.4474 | 0.5912 | -0.0284 | 0.5628 |
| **14** | 0.3169 | -0.0215 | 0.2954 | 0.3759 | -0.0426 | 0.3333 | 0.4970 | -0.0436 | 0.4534 | 0.5813 | -0.0247 | 0.5565 |
| **exit** | 0.3073 | 0.0000 | 0.3073 | 0.3759 | 0.0000 | 0.3759 | 0.4969 | 0.0000 | 0.4969 | 0.5910 | 0.0000 | 0.5910 |
| **TOTAL $q_c$** | **4.6508** | **-1.8860** | **2.7649** | **5.6625** | **-1.3633** | **4.2991** | **7.4541** | **-1.1807** | **6.2734** | **8.8095** | **-0.6867** | **8.1228** |

| Coilset | 30 seconds | | | 50 seconds | | | 100 seconds | | | 200 seconds | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Flow (kW) | Storage (kW) | Coil set $q_c$ (kW) | Flow (kW) | Storage (kW) | Coil set $q_c$ (kW) | Flow (kW) | Storage (kW) | Coil set $q_c$ (kW) | Flow (kW) | Storage (kW) | Coil set $q_c$ (kW) |
| **1** | 0.6161 | -0.0337 | 0.5824 | 0.6098 | -0.0096 | 0.6002 | 0.6197 | -0.0017 | 0.6180 | 0.6283 | -0.0002 | 0.6280 |
| **2** | 0.6060 | -0.0332 | 0.5728 | 0.6195 | -0.0096 | 0.6099 | 0.6294 | -0.0017 | 0.6277 | 0.6183 | -0.0002 | 0.6180 |
| **3** | 0.6158 | -0.0327 | 0.5831 | 0.6095 | -0.0093 | 0.6001 | 0.6194 | -0.0017 | 0.6177 | 0.6279 | -0.0002 | 0.6277 |
| **4** | 0.6057 | -0.0322 | 0.5735 | 0.6093 | -0.0093 | 0.6000 | 0.6192 | -0.0017 | 0.6175 | 0.6277 | -0.0002 | 0.6275 |
| **5** | 0.6154 | -0.0317 | 0.5838 | 0.6190 | -0.0093 | 0.6096 | 0.6289 | -0.0015 | 0.6274 | 0.6178 | -0.0002 | 0.6175 |
| **6** | 0.6153 | -0.0312 | 0.5841 | 0.6090 | -0.0091 | 0.5999 | 0.6189 | -0.0015 | 0.6174 | 0.6274 | -0.0002 | 0.6271 |
| **7** | 0.6052 | -0.0307 | 0.5745 | 0.6088 | -0.0091 | 0.5997 | 0.6187 | -0.0015 | 0.6172 | 0.6272 | -0.0002 | 0.6270 |
| **8** | 0.6149 | -0.0299 | 0.5850 | 0.6184 | -0.0091 | 0.6094 | 0.6283 | -0.0015 | 0.6269 | 0.6172 | -0.0002 | 0.6170 |
| **9** | 0.6048 | -0.0294 | 0.5754 | 0.6085 | -0.0088 | 0.5996 | 0.6184 | -0.0015 | 0.6169 | 0.6269 | -0.0002 | 0.6266 |
| **10** | 0.6146 | -0.0289 | 0.5857 | 0.6083 | -0.0088 | 0.5995 | 0.6182 | -0.0012 | 0.6170 | 0.6267 | -0.0002 | 0.6264 |
| **11** | 0.6145 | -0.0284 | 0.5860 | 0.6179 | -0.0086 | 0.6094 | 0.6278 | -0.0012 | 0.6266 | 0.6167 | -0.0002 | 0.6165 |
| **12** | 0.6044 | -0.0279 | 0.5765 | 0.6080 | -0.0086 | 0.5994 | 0.6179 | -0.0012 | 0.6166 | 0.6264 | -0.0002 | 0.6261 |
| **13** | 0.6142 | -0.0274 | 0.5868 | 0.6079 | -0.0086 | 0.5993 | 0.6177 | -0.0012 | 0.6165 | 0.6262 | -0.0002 | 0.6260 |
| **14** | 0.6042 | -0.0269 | 0.5772 | 0.6175 | -0.0083 | 0.6092 | 0.6274 | -0.0012 | 0.6262 | 0.6163 | -0.0002 | 0.6161 |
| **exit** | 0.6139 | 0.0000 | 0.6139 | 0.6076 | 0.0000 | 0.6076 | 0.6175 | 0.0000 | 0.6175 | 0.6259 | 0.0000 | 0.6259 |
| **TOTAL $q_c$** | **9.1649** | **-0.4242** | **8.7407** | **9.1789** | **-0.1261** | **9.0528** | **9.3273** | **-0.0204** | **9.3070** | **9.3568** | **-0.0034** | **9.3534** |

## Table M2: Coil Set Energy Balance for R3-36 at 12LPM

| Coilset | 1 second | | | 2 seconds | | | 3 seconds | | | 5 seconds | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Flow (kW) | Storage (kW) | Coil set $q_c$ (kW) | Flow (kW) | Storage (kW) | Coil set $q_c$ (kW) | Flow (kW) | Storage (kW) | Coil set $q_c$ (kW) | Flow (kW) | Storage (kW) | Coil set $q_c$ (kW) |
| **1** | 0.0067 | 0.0000 | 0.0067 | 0.0081 | -0.0024 | 0.0057 | 0.0082 | -0.0069 | 0.0013 | 0.0822 | -0.1542 | -0.0720 |
| **2** | 0.0067 | 0.0000 | 0.0067 | 0.0081 | -0.0024 | 0.0057 | 0.0164 | -0.0064 | 0.0100 | 0.0904 | -0.1434 | -0.0530 |
| **3** | 0.0134 | 0.0000 | 0.0134 | 0.0162 | -0.0024 | 0.0138 | 0.0082 | -0.0059 | 0.0023 | 0.0822 | -0.1324 | -0.0502 |
| **4** | 0.0067 | 0.0000 | 0.0067 | 0.0081 | -0.0024 | 0.0057 | 0.0164 | -0.0054 | 0.0110 | 0.0822 | -0.1214 | -0.0392 |
| **5** | 0.0067 | 0.0000 | 0.0067 | 0.0081 | -0.0024 | 0.0057 | 0.0082 | -0.0049 | 0.0033 | 0.0904 | -0.1106 | -0.0202 |
| **6** | 0.0067 | 0.0000 | 0.0067 | 0.0081 | -0.0024 | 0.0057 | 0.0082 | -0.0044 | 0.0038 | 0.0822 | -0.0996 | -0.0174 |
| **7** | 0.0067 | 0.0000 | 0.0067 | 0.0081 | -0.0024 | 0.0057 | 0.0164 | -0.0039 | 0.0125 | 0.0822 | -0.0886 | -0.0064 |
| **8** | 0.0134 | 0.0000 | 0.0134 | 0.0162 | -0.0024 | 0.0138 | 0.0082 | -0.0034 | 0.0048 | 0.0904 | -0.0778 | 0.0126 |
| **9** | 0.0067 | 0.0000 | 0.0067 | 0.0081 | -0.0024 | 0.0057 | 0.0164 | -0.0029 | 0.0135 | 0.0822 | -0.0668 | 0.0154 |
| **10** | 0.0067 | 0.0000 | 0.0067 | 0.0081 | -0.0024 | 0.0057 | 0.0082 | -0.0024 | 0.0058 | 0.0822 | -0.0558 | 0.0264 |
| **11** | 0.0067 | 0.0000 | 0.0067 | 0.0081 | -0.0024 | 0.0057 | 0.0082 | -0.0020 | 0.0062 | 0.0904 | -0.0450 | 0.0454 |
| **12** | 0.0067 | 0.0000 | 0.0067 | 0.0081 | -0.0024 | 0.0057 | 0.0164 | -0.0015 | 0.0149 | 0.0822 | -0.0340 | 0.0482 |
| **13** | 0.0134 | 0.0000 | 0.0134 | 0.0162 | -0.0024 | 0.0138 | 0.0082 | -0.0010 | 0.0072 | 0.0822 | -0.0230 | 0.0592 |
| **14** | 0.0067 | 0.0000 | 0.0067 | 0.0081 | -0.0024 | 0.0057 | 0.0164 | -0.0005 | 0.0159 | 0.0904 | -0.0122 | 0.0782 |
| **exit** | 0.0067 | 0.0000 | 0.0067 | 0.0081 | 0.0000 | 0.0081 | 0.0082 | 0.0000 | 0.0082 | 0.0822 | 0.0000 | 0.0822 |
| **TOTAL $q_c$** | **0.1208** | **0.0000** | **0.1208** | **0.1459** | **-0.0343** | **0.1117** | **0.1721** | **-0.0514** | **0.1208** | **1.2741** | **-1.1650** | **0.1091** |

| Coilset | 8 seconds | | | 10 seconds | | | 15 seconds | | | 20 seconds | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Flow (kW) | Storage (kW) | Coil set $q_c$ (kW) | Flow (kW) | Storage (kW) | Coil set $q_c$ (kW) | Flow (kW) | Storage (kW) | Coil set $q_c$ (kW) | Flow (kW) | Storage (kW) | Coil set $q_c$ (kW) |
| **1** | 0.1653 | -0.1058 | 0.0596 | 0.2652 | -0.2213 | 0.0439 | 0.4089 | -0.1430 | 0.2659 | 0.4855 | -0.0609 | 0.4246 |
| **2** | 0.1571 | -0.0982 | 0.0589 | 0.2651 | -0.2058 | 0.0593 | 0.4172 | -0.1347 | 0.2825 | 0.4770 | -0.0567 | 0.4203 |
| **3** | 0.1653 | -0.0904 | 0.0750 | 0.2734 | -0.1906 | 0.0828 | 0.4087 | -0.1260 | 0.2827 | 0.4852 | -0.0527 | 0.4325 |
| **4** | 0.1653 | -0.0828 | 0.0826 | 0.2651 | -0.1754 | 0.0897 | 0.4170 | -0.1177 | 0.2993 | 0.4851 | -0.0486 | 0.4365 |
| **5** | 0.1653 | -0.0752 | 0.0901 | 0.2650 | -0.1599 | 0.1051 | 0.4086 | -0.1091 | 0.2995 | 0.4766 | -0.0446 | 0.4320 |
| **6** | 0.1570 | -0.0673 | 0.0897 | 0.2650 | -0.1447 | 0.1203 | 0.4168 | -0.1007 | 0.3161 | 0.4849 | -0.0407 | 0.4442 |
| **7** | 0.1653 | -0.0597 | 0.1056 | 0.2650 | -0.1295 | 0.1354 | 0.4084 | -0.0921 | 0.3163 | 0.4848 | -0.0365 | 0.4482 |
| **8** | 0.1653 | -0.0521 | 0.1131 | 0.2732 | -0.1141 | 0.1591 | 0.4167 | -0.0838 | 0.3329 | 0.4763 | -0.0326 | 0.4437 |
| **9** | 0.1653 | -0.0443 | 0.1210 | 0.2649 | -0.0989 | 0.1660 | 0.4083 | -0.0752 | 0.3331 | 0.4846 | -0.0284 | 0.4562 |
| **10** | 0.1570 | -0.0367 | 0.1203 | 0.2649 | -0.0837 | 0.1812 | 0.4165 | -0.0669 | 0.3497 | 0.4845 | -0.0245 | 0.4600 |
| **11** | 0.1652 | -0.0291 | 0.1361 | 0.2649 | -0.0683 | 0.1966 | 0.4081 | -0.0583 | 0.3499 | 0.4760 | -0.0206 | 0.4555 |
| **12** | 0.1652 | -0.0213 | 0.1439 | 0.2648 | -0.0531 | 0.2117 | 0.4164 | -0.0499 | 0.3665 | 0.4843 | -0.0164 | 0.4679 |
| **13** | 0.1652 | -0.0137 | 0.1515 | 0.2731 | -0.0379 | 0.2352 | 0.4080 | -0.0414 | 0.3666 | 0.4842 | -0.0125 | 0.4717 |
| **14** | 0.1569 | -0.0061 | 0.1508 | 0.2648 | -0.0225 | 0.2423 | 0.4163 | -0.0330 | 0.3832 | 0.4758 | -0.0083 | 0.4674 |
| **exit** | 0.1652 | 0.0000 | 0.1652 | 0.2648 | 0.0000 | 0.2648 | 0.4079 | 0.0000 | 0.4079 | 0.4840 | 0.0000 | 0.4840 |
| **TOTAL $q_c$** | **2.4460** | **-0.7827** | **1.6633** | **3.9993** | **-1.7059** | **2.2934** | **6.1837** | **-1.2319** | **4.9519** | **7.2287** | **-0.4840** | **6.7447** |

| Coilset | 30 seconds | | | 50 seconds | | | 100 seconds | | | 200 seconds | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Flow (kW) | Storage (kW) | Coil set $q_c$ (kW) | Flow (kW) | Storage (kW) | Coil set $q_c$ (kW) | Flow (kW) | Storage (kW) | Coil set $q_c$ (kW) | Flow (kW) | Storage (kW) | Coil set $q_c$ (kW) |
| **1** | 0.5361 | -0.0364 | 0.4997 | 0.5460 | -0.0130 | 0.5330 | 0.5489 | -0.0022 | 0.5467 | 0.5573 | -0.0002 | 0.5571 |
| **2** | 0.5275 | -0.0349 | 0.4927 | 0.5459 | -0.0128 | 0.5331 | 0.5572 | -0.0022 | 0.5549 | 0.5572 | -0.0002 | 0.5569 |
| **3** | 0.5358 | -0.0334 | 0.5024 | 0.5373 | -0.0128 | 0.5246 | 0.5486 | -0.0022 | 0.5463 | 0.5570 | -0.0002 | 0.5568 |
| **4** | 0.5356 | -0.0319 | 0.5037 | 0.5456 | -0.0125 | 0.5331 | 0.5568 | -0.0022 | 0.5546 | 0.5653 | -0.0002 | 0.5651 |
| **5** | 0.5271 | -0.0304 | 0.4967 | 0.5454 | -0.0125 | 0.5329 | 0.5482 | -0.0022 | 0.5460 | 0.5567 | -0.0002 | 0.5565 |
| **6** | 0.5353 | -0.0289 | 0.5064 | 0.5453 | -0.0123 | 0.5330 | 0.5565 | -0.0020 | 0.5546 | 0.5565 | -0.0002 | 0.5563 |
| **7** | 0.5352 | -0.0275 | 0.5077 | 0.5451 | -0.0123 | 0.5328 | 0.5479 | -0.0020 | 0.5460 | 0.5564 | -0.0002 | 0.5561 |
| **8** | 0.5266 | -0.0260 | 0.5007 | 0.5366 | -0.0120 | 0.5246 | 0.5562 | -0.0020 | 0.5542 | 0.5562 | -0.0002 | 0.5560 |
| **9** | 0.5349 | -0.0245 | 0.5104 | 0.5448 | -0.0118 | 0.5330 | 0.5476 | -0.0020 | 0.5457 | 0.5561 | -0.0002 | 0.5558 |
| **10** | 0.5348 | -0.0230 | 0.5117 | 0.5447 | -0.0118 | 0.5329 | 0.5559 | -0.0020 | 0.5539 | 0.5559 | -0.0002 | 0.5557 |
| **11** | 0.5263 | -0.0216 | 0.5047 | 0.5445 | -0.0115 | 0.5330 | 0.5473 | -0.0020 | 0.5454 | 0.5558 | -0.0002 | 0.5555 |
| **12** | 0.5345 | -0.0201 | 0.5145 | 0.5444 | -0.0115 | 0.5329 | 0.5556 | -0.0020 | 0.5537 | 0.5641 | -0.0002 | 0.5638 |
| **13** | 0.5344 | -0.0186 | 0.5158 | 0.5359 | -0.0113 | 0.5247 | 0.5471 | -0.0017 | 0.5454 | 0.5555 | -0.0002 | 0.5553 |
| **14** | 0.5260 | -0.0171 | 0.5088 | 0.5442 | -0.0113 | 0.5329 | 0.5554 | -0.0017 | 0.5537 | 0.5554 | 0.0000 | 0.5554 |
| **exit** | 0.5342 | 0.0000 | 0.5342 | 0.5441 | 0.0000 | 0.5441 | 0.5468 | 0.0000 | 0.5468 | 0.5553 | 0.0000 | 0.5553 |
| **TOTAL $q_c$** | **7.9842** | **-0.3743** | **7.6099** | **8.1498** | **-0.1693** | **7.9806** | **8.2761** | **-0.0282** | **8.2479** | **8.3607** | **-0.0032** | **8.3575** |

## Table M3: Coil Set Energy Balance for R3-36 at 10LPM

| Coilset | 1 second | | | 2 seconds | | | 3 seconds | | | 5 seconds | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Flow (kW) | Storage (kW) | Coil set $q_c$ (kW) | Flow (kW) | Storage (kW) | Coil set $q_c$ (kW) | Flow (kW) | Storage (kW) | Coil set $q_c$ (kW) | Flow (kW) | Storage (kW) | Coil set $q_c$ (kW) |
| **1** | 0.0205 | 0.0000 | 0.0205 | 0.0206 | -0.0159 | 0.0047 | 0.0275 | -0.0184 | 0.0091 | 0.0618 | -0.0950 | -0.0332 |
| **2** | 0.0205 | 0.0000 | 0.0205 | 0.0274 | -0.0149 | 0.0125 | 0.0275 | -0.0169 | 0.0106 | 0.0686 | -0.0884 | -0.0197 |
| **3** | 0.0205 | 0.0000 | 0.0205 | 0.0206 | -0.0137 | 0.0069 | 0.0275 | -0.0157 | 0.0118 | 0.0618 | -0.0817 | -0.0200 |
| **4** | 0.0205 | 0.0000 | 0.0205 | 0.0274 | -0.0125 | 0.0149 | 0.0275 | -0.0144 | 0.0130 | 0.0618 | -0.0751 | -0.0134 |
| **5** | 0.0205 | 0.0000 | 0.0205 | 0.0206 | -0.0115 | 0.0091 | 0.0275 | -0.0130 | 0.0145 | 0.0686 | -0.0685 | 0.0001 |
| **6** | 0.0205 | 0.0000 | 0.0205 | 0.0206 | -0.0103 | 0.0103 | 0.0275 | -0.0117 | 0.0157 | 0.0618 | -0.0619 | -0.0001 |
| **7** | 0.0205 | 0.0000 | 0.0205 | 0.0274 | -0.0091 | 0.0184 | 0.0275 | -0.0105 | 0.0170 | 0.0618 | -0.0553 | 0.0065 |
| **8** | 0.0137 | 0.0000 | 0.0137 | 0.0206 | -0.0081 | 0.0125 | 0.0206 | -0.0091 | 0.0116 | 0.0686 | -0.0487 | 0.0199 |
| **9** | 0.0205 | 0.0000 | 0.0205 | 0.0274 | -0.0069 | 0.0206 | 0.0275 | -0.0078 | 0.0196 | 0.0618 | -0.0421 | 0.0197 |
| **10** | 0.0205 | 0.0000 | 0.0205 | 0.0206 | -0.0056 | 0.0149 | 0.0275 | -0.0066 | 0.0209 | 0.0618 | -0.0355 | 0.0263 |
| **11** | 0.0205 | 0.0000 | 0.0205 | 0.0206 | -0.0046 | 0.0159 | 0.0275 | -0.0051 | 0.0223 | 0.0686 | -0.0289 | 0.0398 |
| **12** | 0.0205 | 0.0000 | 0.0205 | 0.0274 | -0.0034 | 0.0240 | 0.0275 | -0.0039 | 0.0236 | 0.0618 | -0.0223 | 0.0395 |
| **13** | 0.0205 | 0.0000 | 0.0205 | 0.0206 | -0.0022 | 0.0184 | 0.0275 | -0.0027 | 0.0248 | 0.0618 | -0.0157 | 0.0461 |
| **14** | 0.0205 | 0.0000 | 0.0205 | 0.0274 | -0.0012 | 0.0262 | 0.0275 | -0.0012 | 0.0263 | 0.0686 | -0.0091 | 0.0596 |
| **exit** | 0.0205 | 0.0000 | 0.0205 | 0.0206 | 0.0000 | 0.0206 | 0.0275 | 0.0000 | 0.0275 | 0.0618 | 0.0000 | 0.0618 |
| **TOTAL $q_c$** | **0.3010** | **0.0000** | **0.3010** | **0.3496** | **-0.1199** | **0.2297** | **0.4053** | **-0.1370** | **0.2683** | **0.9609** | **-0.7281** | **0.2328** |

| Coilset | 8 seconds | | | 10 seconds | | | 15 seconds | | | 20 seconds | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Flow (kW) | Storage (kW) | Coil set $q_c$ (kW) | Flow (kW) | Storage (kW) | Coil set $q_c$ (kW) | Flow (kW) | Storage (kW) | Coil set $q_c$ (kW) | Flow (kW) | Storage (kW) | Coil set $q_c$ (kW) |
| **1** | 0.1737 | -0.1810 | -0.0073 | 0.2430 | -0.1816 | 0.0614 | 0.3398 | -0.1104 | 0.2295 | 0.4107 | -0.0717 | 0.3390 |
| **2** | 0.1667 | -0.1683 | -0.0016 | 0.2360 | -0.1693 | 0.0667 | 0.3398 | -0.1032 | 0.2365 | 0.4106 | -0.0665 | 0.3441 |
| **3** | 0.1736 | -0.1558 | 0.0179 | 0.2429 | -0.1573 | 0.0857 | 0.3328 | -0.0964 | 0.2364 | 0.4105 | -0.0616 | 0.3489 |
| **4** | 0.1736 | -0.1433 | 0.0304 | 0.2360 | -0.1453 | 0.0907 | 0.3396 | -0.0892 | 0.2504 | 0.4104 | -0.0564 | 0.3540 |
| **5** | 0.1736 | -0.1305 | 0.0431 | 0.2429 | -0.1330 | 0.1099 | 0.3396 | -0.0824 | 0.2572 | 0.4103 | -0.0515 | 0.3588 |
| **6** | 0.1666 | -0.1180 | 0.0486 | 0.2429 | -0.1210 | 0.1219 | 0.3395 | -0.0755 | 0.2640 | 0.4102 | -0.0466 | 0.3636 |
| **7** | 0.1736 | -0.1055 | 0.0681 | 0.2359 | -0.1090 | 0.1269 | 0.3394 | -0.0684 | 0.2711 | 0.4101 | -0.0414 | 0.3687 |
| **8** | 0.1736 | -0.0928 | 0.0808 | 0.2428 | -0.0967 | 0.1461 | 0.3325 | -0.0615 | 0.2710 | 0.4100 | -0.0365 | 0.3735 |
| **9** | 0.1735 | -0.0803 | 0.0933 | 0.2358 | -0.0847 | 0.1511 | 0.3393 | -0.0544 | 0.2850 | 0.4099 | -0.0314 | 0.3786 |
| **10** | 0.1666 | -0.0678 | 0.0988 | 0.2427 | -0.0727 | 0.1700 | 0.3393 | -0.0475 | 0.2918 | 0.4098 | -0.0265 | 0.3834 |
| **11** | 0.1735 | -0.0551 | 0.1185 | 0.2427 | -0.0605 | 0.1823 | 0.3392 | -0.0406 | 0.2986 | 0.4097 | -0.0215 | 0.3882 |
| **12** | 0.1735 | -0.0426 | 0.1309 | 0.2358 | -0.0485 | 0.1873 | 0.3392 | -0.0335 | 0.3056 | 0.4097 | -0.0164 | 0.3933 |
| **13** | 0.1735 | -0.0301 | 0.1434 | 0.2427 | -0.0365 | 0.2062 | 0.3322 | -0.0267 | 0.3055 | 0.4096 | -0.0115 | 0.3981 |
| **14** | 0.1665 | -0.0174 | 0.1492 | 0.2357 | -0.0242 | 0.2115 | 0.3391 | -0.0196 | 0.3195 | 0.4095 | -0.0064 | 0.4031 |
| **exit** | 0.1735 | 0.0000 | 0.1735 | 0.2426 | 0.0000 | 0.2426 | 0.3390 | 0.0000 | 0.3390 | 0.4094 | 0.0000 | 0.4094 |
| **TOTAL $q_c$** | **2.5756** | **-1.3883** | **1.1873** | **3.6005** | **-1.4402** | **2.1603** | **5.0702** | **-0.9092** | **4.1610** | **6.1502** | **-0.5458** | **5.6044** |

| Coilset | 30 seconds | | | 50 seconds | | | 100 seconds | | | 200 seconds | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Flow (kW) | Storage (kW) | Coil set $q_c$ (kW) | Flow (kW) | Storage (kW) | Coil set $q_c$ (kW) | Flow (kW) | Storage (kW) | Coil set $q_c$ (kW) | Flow (kW) | Storage (kW) | Coil set $q_c$ (kW) |
| **1** | 0.4755 | -0.0363 | 0.4392 | 0.4878 | -0.0145 | 0.4733 | 0.4964 | -0.0032 | 0.4932 | 0.5049 | -0.0005 | 0.5045 |
| **2** | 0.4684 | -0.0344 | 0.4340 | 0.4877 | -0.0142 | 0.4734 | 0.4963 | -0.0029 | 0.4933 | 0.5048 | -0.0005 | 0.5043 |
| **3** | 0.4753 | -0.0322 | 0.4431 | 0.4806 | -0.0140 | 0.4666 | 0.5031 | -0.0029 | 0.5001 | 0.5046 | -0.0005 | 0.5041 |
| **4** | 0.4681 | -0.0302 | 0.4379 | 0.4874 | -0.0137 | 0.4736 | 0.4959 | -0.0029 | 0.4930 | 0.5045 | -0.0005 | 0.5040 |
| **5** | 0.4750 | -0.0280 | 0.4470 | 0.4872 | -0.0135 | 0.4737 | 0.4958 | -0.0027 | 0.4931 | 0.5043 | -0.0005 | 0.5038 |
| **6** | 0.4748 | -0.0257 | 0.4491 | 0.4871 | -0.0132 | 0.4738 | 0.4956 | -0.0027 | 0.4929 | 0.5042 | -0.0002 | 0.5039 |
| **7** | 0.4677 | -0.0238 | 0.4439 | 0.4869 | -0.0130 | 0.4739 | 0.4955 | -0.0027 | 0.4928 | 0.5040 | -0.0002 | 0.5038 |
| **8** | 0.4746 | -0.0216 | 0.4530 | 0.4798 | -0.0128 | 0.4671 | 0.5023 | -0.0027 | 0.4996 | 0.4968 | -0.0002 | 0.4966 |
| **9** | 0.4675 | -0.0196 | 0.4479 | 0.4866 | -0.0125 | 0.4741 | 0.4952 | -0.0025 | 0.4927 | 0.5037 | -0.0002 | 0.5034 |
| **10** | 0.4744 | -0.0174 | 0.4570 | 0.4865 | -0.0123 | 0.4743 | 0.4950 | -0.0025 | 0.4926 | 0.5035 | -0.0002 | 0.5033 |
| **11** | 0.4742 | -0.0152 | 0.4591 | 0.4864 | -0.0118 | 0.4746 | 0.4949 | -0.0025 | 0.4925 | 0.5034 | -0.0002 | 0.5032 |
| **12** | 0.4672 | -0.0132 | 0.4539 | 0.4863 | -0.0115 | 0.4748 | 0.4948 | -0.0022 | 0.4926 | 0.5033 | -0.0002 | 0.5030 |
| **13** | 0.4740 | -0.0110 | 0.4630 | 0.4792 | -0.0113 | 0.4680 | 0.5016 | -0.0022 | 0.4994 | 0.5032 | -0.0002 | 0.5029 |
| **14** | 0.4669 | -0.0091 | 0.4579 | 0.4861 | -0.0110 | 0.4750 | 0.4946 | -0.0022 | 0.4923 | 0.5030 | -0.0002 | 0.5028 |
| **exit** | 0.4738 | 0.0000 | 0.4738 | 0.4859 | 0.0000 | 0.4859 | 0.4944 | 0.0000 | 0.4944 | 0.5029 | 0.0000 | 0.5029 |
| **TOTAL $q_c$** | **7.0774** | **-0.3176** | **6.7598** | **7.2815** | **-0.1793** | **7.1022** | **7.4515** | **-0.0368** | **7.4147** | **7.5512** | **-0.0047** | **7.5465** |

## Table M4: Coil Set Energy Balance for R3-36 at 9LPM

| Coilset | 1 second | | | 2 seconds | | | 3 seconds | | | 5 seconds | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Flow (kW) | Storage (kW) | Coil set $q_c$ (kW) | Flow (kW) | Storage (kW) | Coil set $q_c$ (kW) | Flow (kW) | Storage (kW) | Coil set $q_c$ (kW) | Flow (kW) | Storage (kW) | Coil set $q_c$ (kW) |
| **1** | 0.0430 | 0.0000 | 0.0430 | 0.0617 | -0.1006 | -0.0389 | 0.0681 | -0.0570 | 0.0111 | 0.1247 | -0.1511 | -0.0264 |
| **2** | 0.0430 | 0.0000 | 0.0430 | 0.0555 | -0.0933 | -0.0377 | 0.0743 | -0.0531 | 0.0212 | 0.1247 | -0.1403 | -0.0156 |
| **3** | 0.0368 | 0.0000 | 0.0368 | 0.0617 | -0.0862 | -0.0245 | 0.0681 | -0.0490 | 0.0191 | 0.1247 | -0.1298 | -0.0051 |
| **4** | 0.0430 | 0.0000 | 0.0430 | 0.0617 | -0.0791 | -0.0174 | 0.0743 | -0.0448 | 0.0295 | 0.1247 | -0.1192 | 0.0054 |
| **5** | 0.0430 | 0.0000 | 0.0430 | 0.0617 | -0.0717 | -0.0100 | 0.0681 | -0.0409 | 0.0272 | 0.1247 | -0.1085 | 0.0162 |
| **6** | 0.0430 | 0.0000 | 0.0430 | 0.0555 | -0.0646 | -0.0091 | 0.0681 | -0.0367 | 0.0314 | 0.1247 | -0.0979 | 0.0267 |
| **7** | 0.0430 | 0.0000 | 0.0430 | 0.0617 | -0.0575 | 0.0042 | 0.0743 | -0.0326 | 0.0417 | 0.1247 | -0.0874 | 0.0373 |
| **8** | 0.0368 | 0.0000 | 0.0368 | 0.0617 | -0.0502 | 0.0115 | 0.0681 | -0.0286 | 0.0395 | 0.1309 | -0.0766 | 0.0543 |
| **9** | 0.0430 | 0.0000 | 0.0430 | 0.0617 | -0.0431 | 0.0186 | 0.0743 | -0.0245 | 0.0498 | 0.1246 | -0.0661 | 0.0586 |
| **10** | 0.0430 | 0.0000 | 0.0430 | 0.0555 | -0.0360 | 0.0195 | 0.0681 | -0.0203 | 0.0478 | 0.1246 | -0.0556 | 0.0691 |
| **11** | 0.0430 | 0.0000 | 0.0430 | 0.0617 | -0.0286 | 0.0330 | 0.0681 | -0.0164 | 0.0517 | 0.1246 | -0.0448 | 0.0798 |
| **12** | 0.0430 | 0.0000 | 0.0430 | 0.0617 | -0.0215 | 0.0401 | 0.0743 | -0.0122 | 0.0620 | 0.1246 | -0.0343 | 0.0904 |
| **13** | 0.0368 | 0.0000 | 0.0368 | 0.0617 | -0.0144 | 0.0472 | 0.0681 | -0.0081 | 0.0600 | 0.1246 | -0.0237 | 0.1009 |
| **14** | 0.0430 | 0.0000 | 0.0430 | 0.0555 | -0.0071 | 0.0484 | 0.0743 | -0.0042 | 0.0701 | 0.1246 | -0.0130 | 0.1116 |
| **exit** | 0.0430 | 0.0000 | 0.0430 | 0.0617 | 0.0000 | 0.0617 | 0.0681 | 0.0000 | 0.0681 | 0.1246 | 0.0000 | 0.1246 |
| **TOTAL $q_c$** | **0.6263** | **0.0000** | **0.6263** | **0.9006** | **-0.7538** | **0.1468** | **1.0584** | **-0.4283** | **0.6301** | **1.8760** | **-1.1482** | **0.7277** |

| Coilset | 8 seconds | | | 10 seconds | | | 15 seconds | | | 20 seconds | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Flow (kW) | Storage (kW) | Coil set $q_c$ (kW) | Flow (kW) | Storage (kW) | Coil set $q_c$ (kW) | Flow (kW) | Storage (kW) | Coil set $q_c$ (kW) | Flow (kW) | Storage (kW) | Coil set $q_c$ (kW) |
| **1** | 0.1888 | -0.1154 | 0.0734 | 0.2398 | -0.1517 | 0.0881 | 0.3158 | -0.0910 | 0.2248 | 0.3833 | -0.0601 | 0.3232 |
| **2** | 0.1888 | -0.1073 | 0.0815 | 0.2398 | -0.1419 | 0.0979 | 0.3220 | -0.0851 | 0.2369 | 0.3770 | -0.0552 | 0.3217 |
| **3** | 0.1888 | -0.0992 | 0.0896 | 0.2397 | -0.1318 | 0.1079 | 0.3156 | -0.0790 | 0.2367 | 0.3831 | -0.0500 | 0.3331 |
| **4** | 0.1825 | -0.0914 | 0.0911 | 0.2397 | -0.1218 | 0.1179 | 0.3156 | -0.0728 | 0.2428 | 0.3830 | -0.0449 | 0.3382 |
| **5** | 0.1887 | -0.0833 | 0.1055 | 0.2397 | -0.1120 | 0.1277 | 0.3218 | -0.0669 | 0.2549 | 0.3767 | -0.0400 | 0.3367 |
| **6** | 0.1887 | -0.0752 | 0.1135 | 0.2397 | -0.1019 | 0.1377 | 0.3155 | -0.0608 | 0.2547 | 0.3828 | -0.0348 | 0.3480 |
| **7** | 0.1887 | -0.0673 | 0.1214 | 0.2396 | -0.0918 | 0.1478 | 0.3154 | -0.0546 | 0.2608 | 0.3828 | -0.0297 | 0.3531 |
| **8** | 0.1887 | -0.0593 | 0.1294 | 0.2396 | -0.0820 | 0.1575 | 0.3217 | -0.0488 | 0.2729 | 0.3764 | -0.0247 | 0.3517 |
| **9** | 0.1887 | -0.0512 | 0.1375 | 0.2396 | -0.0720 | 0.1676 | 0.3153 | -0.0426 | 0.2727 | 0.3826 | -0.0196 | 0.3630 |
| **10** | 0.1887 | -0.0433 | 0.1453 | 0.2395 | -0.0619 | 0.1776 | 0.3152 | -0.0365 | 0.2788 | 0.3825 | -0.0145 | 0.3681 |
| **11** | 0.1886 | -0.0352 | 0.1534 | 0.2395 | -0.0521 | 0.1874 | 0.3215 | -0.0306 | 0.2909 | 0.3762 | -0.0095 | 0.3666 |
| **12** | 0.1823 | -0.0272 | 0.1552 | 0.2395 | -0.0421 | 0.1974 | 0.3151 | -0.0245 | 0.2907 | 0.3824 | -0.0044 | 0.3780 |
| **13** | 0.1886 | -0.0193 | 0.1693 | 0.2394 | -0.0321 | 0.2074 | 0.3151 | -0.0184 | 0.2967 | 0.3823 | 0.0007 | 0.3830 |
| **14** | 0.1886 | -0.0113 | 0.1773 | 0.2394 | -0.0223 | 0.2171 | 0.3213 | -0.0125 | 0.3089 | 0.3759 | 0.0056 | 0.3816 |
| **exit** | 0.1886 | 0.0000 | 0.1886 | 0.2394 | 0.0000 | 0.2394 | 0.3150 | 0.0000 | 0.3150 | 0.3821 | 0.0000 | 0.3821 |
| **TOTAL $q_c$** | **2.8178** | **-0.8858** | **1.9320** | **3.5939** | **-1.2175** | **2.3764** | **4.7620** | **-0.7240** | **4.0380** | **5.7091** | **-0.3811** | **5.3280** |

| Coilset | 30 seconds | | | 50 seconds | | | 100 seconds | | | 200 seconds | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Flow (kW) | Storage (kW) | Coil set $q_c$ (kW) | Flow (kW) | Storage (kW) | Coil set $q_c$ (kW) | Flow (kW) | Storage (kW) | Coil set $q_c$ (kW) | Flow (kW) | Storage (kW) | Coil set $q_c$ (kW) |
| **1** | 0.4411 | -0.0346 | 0.4065 | 0.4580 | -0.0133 | 0.4447 | 0.4703 | -0.0032 | 0.4671 | 0.4751 | -0.0005 | 0.4746 |
| **2** | 0.4347 | -0.0324 | 0.4023 | 0.4578 | -0.0130 | 0.4448 | 0.4638 | -0.0029 | 0.4609 | 0.4687 | -0.0005 | 0.4682 |
| **3** | 0.4409 | -0.0302 | 0.4107 | 0.4641 | -0.0125 | 0.4515 | 0.4700 | -0.0029 | 0.4671 | 0.4748 | -0.0005 | 0.4743 |
| **4** | 0.4407 | -0.0280 | 0.4128 | 0.4575 | -0.0123 | 0.4453 | 0.4699 | -0.0029 | 0.4669 | 0.4747 | -0.0005 | 0.4742 |
| **5** | 0.4406 | -0.0258 | 0.4148 | 0.4574 | -0.0120 | 0.4454 | 0.4634 | -0.0027 | 0.4607 | 0.4745 | -0.0002 | 0.4743 |
| **6** | 0.4342 | -0.0235 | 0.4106 | 0.4573 | -0.0118 | 0.4455 | 0.4696 | -0.0027 | 0.4669 | 0.4680 | -0.0002 | 0.4678 |
| **7** | 0.4403 | -0.0213 | 0.4190 | 0.4571 | -0.0113 | 0.4458 | 0.4694 | -0.0027 | 0.4667 | 0.4742 | -0.0002 | 0.4740 |
| **8** | 0.4402 | -0.0189 | 0.4214 | 0.4633 | -0.0110 | 0.4523 | 0.4629 | -0.0025 | 0.4605 | 0.4741 | -0.0002 | 0.4738 |
| **9** | 0.4401 | -0.0167 | 0.4235 | 0.4569 | -0.0108 | 0.4461 | 0.4691 | -0.0025 | 0.4667 | 0.4739 | -0.0002 | 0.4737 |
| **10** | 0.4337 | -0.0145 | 0.4193 | 0.4567 | -0.0105 | 0.4462 | 0.4690 | -0.0025 | 0.4665 | 0.4675 | -0.0002 | 0.4672 |
| **11** | 0.4399 | -0.0122 | 0.4277 | 0.4566 | -0.0100 | 0.4466 | 0.4625 | -0.0025 | 0.4601 | 0.4737 | -0.0002 | 0.4734 |
| **12** | 0.4398 | -0.0100 | 0.4298 | 0.4565 | -0.0098 | 0.4467 | 0.4688 | -0.0022 | 0.4665 | 0.4735 | -0.0002 | 0.4733 |
| **13** | 0.4397 | -0.0078 | 0.4319 | 0.4627 | -0.0095 | 0.4532 | 0.4686 | -0.0022 | 0.4664 | 0.4734 | -0.0002 | 0.4732 |
| **14** | 0.4333 | -0.0056 | 0.4277 | 0.4563 | -0.0093 | 0.4470 | 0.4622 | -0.0022 | 0.4600 | 0.4670 | -0.0002 | 0.4667 |
| **exit** | 0.4395 | 0.0000 | 0.4395 | 0.4562 | 0.0000 | 0.4562 | 0.4684 | 0.0000 | 0.4684 | 0.4732 | 0.0000 | 0.4732 |
| **TOTAL $q_c$** | **6.5790** | **-0.2816** | **6.2974** | **6.8744** | **-0.1572** | **6.7172** | **7.0078** | **-0.0366** | **6.9713** | **7.0862** | **-0.0044** | **7.0818** |

## Table M5: Coil Set Energy Balance for R3-36 at 7LPM

| Coilset | 1 second | | | 2 seconds | | | 3 seconds | | | 5 seconds | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Flow (kW) | Storage (kW) | Coil set $q_c$ (kW) | Flow (kW) | Storage (kW) | Coil set $q_c$ (kW) | Flow (kW) | Storage (kW) | Coil set $q_c$ (kW) | Flow (kW) | Storage (kW) | Coil set $q_c$ (kW) |
| **1** | 0.0329 | 0.0000 | 0.0329 | 0.0421 | -0.0688 | -0.0266 | 0.0517 | -0.0847 | -0.0330 | 0.0898 | -0.1330 | -0.0432 |
| **2** | 0.0329 | 0.0000 | 0.0329 | 0.0421 | -0.0639 | -0.0218 | 0.0564 | -0.0788 | -0.0224 | 0.0898 | -0.1236 | -0.0339 |
| **3** | 0.0329 | 0.0000 | 0.0329 | 0.0421 | -0.0592 | -0.0171 | 0.0517 | -0.0729 | -0.0212 | 0.0898 | -0.1146 | -0.0248 |
| **4** | 0.0329 | 0.0000 | 0.0329 | 0.0421 | -0.0546 | -0.0125 | 0.0564 | -0.0671 | -0.0106 | 0.0850 | -0.1055 | -0.0205 |
| **5** | 0.0329 | 0.0000 | 0.0329 | 0.0421 | -0.0497 | -0.0076 | 0.0517 | -0.0612 | -0.0095 | 0.0897 | -0.0962 | -0.0065 |
| **6** | 0.0329 | 0.0000 | 0.0329 | 0.0421 | -0.0450 | -0.0029 | 0.0517 | -0.0553 | -0.0036 | 0.0897 | -0.0871 | 0.0026 |
| **7** | 0.0329 | 0.0000 | 0.0329 | 0.0421 | -0.0404 | 0.0017 | 0.0564 | -0.0494 | 0.0070 | 0.0897 | -0.0781 | 0.0117 |
| **8** | 0.0376 | 0.0000 | 0.0376 | 0.0421 | -0.0355 | 0.0066 | 0.0517 | -0.0436 | 0.0082 | 0.0897 | -0.0688 | 0.0210 |
| **9** | 0.0329 | 0.0000 | 0.0329 | 0.0421 | -0.0308 | 0.0113 | 0.0564 | -0.0377 | 0.0187 | 0.0897 | -0.0597 | 0.0300 |
| **10** | 0.0329 | 0.0000 | 0.0329 | 0.0421 | -0.0262 | 0.0159 | 0.0517 | -0.0318 | 0.0199 | 0.0897 | -0.0507 | 0.0391 |
| **11** | 0.0329 | 0.0000 | 0.0329 | 0.0421 | -0.0213 | 0.0208 | 0.0517 | -0.0259 | 0.0258 | 0.0897 | -0.0414 | 0.0484 |
| **12** | 0.0329 | 0.0000 | 0.0329 | 0.0421 | -0.0166 | 0.0255 | 0.0564 | -0.0201 | 0.0363 | 0.0850 | -0.0323 | 0.0527 |
| **13** | 0.0329 | 0.0000 | 0.0329 | 0.0421 | -0.0120 | 0.0301 | 0.0517 | -0.0142 | 0.0375 | 0.0897 | -0.0232 | 0.0665 |
| **14** | 0.0329 | 0.0000 | 0.0329 | 0.0421 | -0.0071 | 0.0350 | 0.0564 | -0.0083 | 0.0481 | 0.0897 | -0.0139 | 0.0758 |
| **exit** | 0.0329 | 0.0000 | 0.0329 | 0.0421 | 0.0000 | 0.0421 | 0.0517 | 0.0000 | 0.0517 | 0.0897 | 0.0000 | 0.0897 |
| **TOTAL $q_c$** | **0.4982** | **0.0000** | **0.4982** | **0.6318** | **-0.5310** | **0.1007** | **0.8038** | **-0.6510** | **0.1529** | **1.3365** | **-1.0281** | **0.3083** |

| Coilset | 8 seconds | | | 10 seconds | | | 15 seconds | | | 20 seconds | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Flow (kW) | Storage (kW) | Coil set $q_c$ (kW) | Flow (kW) | Storage (kW) | Coil set $q_c$ (kW) | Flow (kW) | Storage (kW) | Coil set $q_c$ (kW) | Flow (kW) | Storage (kW) | Coil set $q_c$ (kW) |
| **1** | 0.1286 | -0.0901 | 0.0384 | 0.1476 | -0.0836 | 0.0641 | 0.2185 | -0.0861 | 0.1325 | 0.2733 | -0.0650 | 0.2083 |
| **2** | 0.1238 | -0.0838 | 0.0400 | 0.1524 | -0.0777 | 0.0747 | 0.2136 | -0.0797 | 0.1340 | 0.2732 | -0.0594 | 0.2138 |
| **3** | 0.1285 | -0.0776 | 0.0509 | 0.1476 | -0.0718 | 0.0758 | 0.2184 | -0.0730 | 0.1454 | 0.2780 | -0.0535 | 0.2245 |
| **4** | 0.1238 | -0.0713 | 0.0525 | 0.1476 | -0.0659 | 0.0817 | 0.2136 | -0.0667 | 0.1469 | 0.2731 | -0.0478 | 0.2253 |
| **5** | 0.1285 | -0.0651 | 0.0634 | 0.1523 | -0.0600 | 0.0923 | 0.2184 | -0.0600 | 0.1583 | 0.2730 | -0.0422 | 0.2309 |
| **6** | 0.1237 | -0.0588 | 0.0650 | 0.1476 | -0.0541 | 0.0934 | 0.2183 | -0.0536 | 0.1647 | 0.2730 | -0.0365 | 0.2364 |
| **7** | 0.1285 | -0.0524 | 0.0761 | 0.1475 | -0.0482 | 0.0993 | 0.2135 | -0.0470 | 0.1664 | 0.2729 | -0.0309 | 0.2420 |
| **8** | 0.1237 | -0.0463 | 0.0774 | 0.1523 | -0.0424 | 0.1099 | 0.2183 | -0.0407 | 0.1776 | 0.2777 | -0.0250 | 0.2527 |
| **9** | 0.1285 | -0.0399 | 0.0886 | 0.1475 | -0.0365 | 0.1110 | 0.2134 | -0.0340 | 0.1794 | 0.2728 | -0.0193 | 0.2535 |
| **10** | 0.1237 | -0.0338 | 0.0899 | 0.1475 | -0.0306 | 0.1169 | 0.2182 | -0.0277 | 0.1905 | 0.2727 | -0.0137 | 0.2590 |
| **11** | 0.1284 | -0.0274 | 0.1010 | 0.1522 | -0.0247 | 0.1275 | 0.2182 | -0.0211 | 0.1971 | 0.2727 | -0.0081 | 0.2646 |
| **12** | 0.1237 | -0.0213 | 0.1024 | 0.1475 | -0.0188 | 0.1286 | 0.2133 | -0.0147 | 0.1986 | 0.2726 | -0.0024 | 0.2702 |
| **13** | 0.1284 | -0.0149 | 0.1135 | 0.1474 | -0.0130 | 0.1345 | 0.2181 | -0.0081 | 0.2100 | 0.2775 | 0.0034 | 0.2809 |
| **14** | 0.1237 | -0.0088 | 0.1148 | 0.1522 | -0.0071 | 0.1451 | 0.2132 | -0.0017 | 0.2115 | 0.2725 | 0.0091 | 0.2816 |
| **exit** | 0.1284 | 0.0000 | 0.1284 | 0.1474 | 0.0000 | 0.1474 | 0.2181 | 0.0000 | 0.2181 | 0.2725 | 0.0000 | 0.2725 |
| **TOTAL $q_c$** | **1.8938** | **-0.6915** | **1.2023** | **2.2366** | **-0.6343** | **1.6023** | **3.2451** | **-0.6140** | **2.6311** | **4.1075** | **-0.3912** | **3.7162** |

| Coilset | 30 seconds | | | 50 seconds | | | 100 seconds | | | 200 seconds | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Flow (kW) | Storage (kW) | Coil set $q_c$ (kW) | Flow (kW) | Storage (kW) | Coil set $q_c$ (kW) | Flow (kW) | Storage (kW) | Coil set $q_c$ (kW) | Flow (kW) | Storage (kW) | Coil set $q_c$ (kW) |
| **1** | 0.3477 | -0.0410 | 0.3067 | 0.3899 | -0.0179 | 0.3719 | 0.4008 | -0.0049 | 0.3959 | 0.4113 | -0.0007 | 0.4105 |
| **2** | 0.3427 | -0.0375 | 0.3051 | 0.3848 | -0.0169 | 0.3679 | 0.4007 | -0.0047 | 0.3960 | 0.4062 | -0.0007 | 0.4055 |
| **3** | 0.3475 | -0.0339 | 0.3136 | 0.3896 | -0.0160 | 0.3737 | 0.4054 | -0.0047 | 0.4008 | 0.4110 | -0.0007 | 0.4102 |
| **4** | 0.3474 | -0.0304 | 0.3170 | 0.3895 | -0.0150 | 0.3745 | 0.4004 | -0.0044 | 0.3960 | 0.4108 | -0.0005 | 0.4103 |
| **5** | 0.3473 | -0.0267 | 0.3205 | 0.3893 | -0.0140 | 0.3754 | 0.4003 | -0.0042 | 0.3961 | 0.4107 | -0.0005 | 0.4102 |
| **6** | 0.3423 | -0.0233 | 0.3190 | 0.3843 | -0.0128 | 0.3715 | 0.4001 | -0.0039 | 0.3962 | 0.4056 | -0.0005 | 0.4051 |
| **7** | 0.3471 | -0.0196 | 0.3275 | 0.3891 | -0.0118 | 0.3773 | 0.4000 | -0.0039 | 0.3961 | 0.4104 | -0.0005 | 0.4099 |
| **8** | 0.3470 | -0.0162 | 0.3308 | 0.3890 | -0.0108 | 0.3782 | 0.4047 | -0.0037 | 0.4010 | 0.4102 | -0.0005 | 0.4097 |
| **9** | 0.3469 | -0.0125 | 0.3344 | 0.3889 | -0.0098 | 0.3791 | 0.3997 | -0.0034 | 0.3963 | 0.4101 | -0.0005 | 0.4096 |
| **10** | 0.3419 | -0.0091 | 0.3329 | 0.3838 | -0.0088 | 0.3750 | 0.3996 | -0.0034 | 0.3962 | 0.4051 | -0.0005 | 0.4046 |
| **11** | 0.3467 | -0.0054 | 0.3414 | 0.3887 | -0.0078 | 0.3808 | 0.3995 | -0.0032 | 0.3963 | 0.4099 | -0.0002 | 0.4096 |
| **12** | 0.3467 | -0.0020 | 0.3447 | 0.3885 | -0.0071 | 0.3814 | 0.3994 | -0.0029 | 0.3965 | 0.4097 | -0.0002 | 0.4095 |
| **13** | 0.3466 | 0.0017 | 0.3483 | 0.3884 | -0.0059 | 0.3826 | 0.4042 | -0.0029 | 0.4012 | 0.4096 | -0.0002 | 0.4094 |
| **14** | 0.3416 | 0.0051 | 0.3468 | 0.3834 | -0.0051 | 0.3783 | 0.3992 | -0.0027 | 0.3965 | 0.4046 | -0.0002 | 0.4044 |
| **exit** | 0.3464 | 0.0000 | 0.3464 | 0.3883 | 0.0000 | 0.3883 | 0.3991 | 0.0000 | 0.3991 | 0.4094 | 0.0000 | 0.4094 |
| **TOTAL $q_c$** | **5.1858** | **-0.2506** | **4.9352** | **5.8155** | **-0.1597** | **5.6558** | **6.0132** | **-0.0530** | **5.9602** | **6.1346** | **-0.0066** | **6.1279** |

## Table M6: Coil Set Energy Balance for R3-36 at 5.5LPM

| Coilset | 1 second | | | 2 seconds | | | 3 seconds | | | 5 seconds | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Flow (kW) | Storage (kW) | Coil set $q_c$ (kW) | Flow (kW) | Storage (kW) | Coil set $q_c$ (kW) | Flow (kW) | Storage (kW) | Coil set $q_c$ (kW) | Flow (kW) | Storage (kW) | Coil set $q_c$ (kW) |
| **1** | 0.0174 | 0.0000 | 0.0174 | 0.0209 | -0.0458 | -0.0249 | 0.0350 | -0.1119 | -0.0769 | 0.0456 | -0.0605 | -0.0149 |
| **2** | 0.0173 | 0.0000 | 0.0173 | 0.0244 | -0.0423 | -0.0179 | 0.0315 | -0.1035 | -0.0720 | 0.0491 | -0.0563 | -0.0072 |
| **3** | 0.0173 | 0.0000 | 0.0173 | 0.0209 | -0.0392 | -0.0183 | 0.0350 | -0.0955 | -0.0605 | 0.0456 | -0.0519 | -0.0063 |
| **4** | 0.0173 | 0.0000 | 0.0173 | 0.0244 | -0.0360 | -0.0116 | 0.0350 | -0.0874 | -0.0524 | 0.0456 | -0.0475 | -0.0019 |
| **5** | 0.0173 | 0.0000 | 0.0173 | 0.0209 | -0.0325 | -0.0116 | 0.0350 | -0.0790 | -0.0441 | 0.0456 | -0.0433 | 0.0022 |
| **6** | 0.0173 | 0.0000 | 0.0173 | 0.0209 | -0.0294 | -0.0085 | 0.0315 | -0.0710 | -0.0395 | 0.0491 | -0.0389 | 0.0102 |
| **7** | 0.0173 | 0.0000 | 0.0173 | 0.0244 | -0.0262 | -0.0018 | 0.0350 | -0.0629 | -0.0279 | 0.0456 | -0.0345 | 0.0111 |
| **8** | 0.0208 | 0.0000 | 0.0208 | 0.0209 | -0.0228 | -0.0019 | 0.0350 | -0.0546 | -0.0196 | 0.0456 | -0.0303 | 0.0152 |
| **9** | 0.0173 | 0.0000 | 0.0173 | 0.0244 | -0.0196 | 0.0048 | 0.0350 | -0.0465 | -0.0115 | 0.0456 | -0.0259 | 0.0196 |
| **10** | 0.0173 | 0.0000 | 0.0173 | 0.0209 | -0.0164 | 0.0045 | 0.0315 | -0.0384 | -0.0069 | 0.0491 | -0.0215 | 0.0275 |
| **11** | 0.0173 | 0.0000 | 0.0173 | 0.0209 | -0.0130 | 0.0079 | 0.0350 | -0.0301 | 0.0049 | 0.0456 | -0.0174 | 0.0282 |
| **12** | 0.0173 | 0.0000 | 0.0173 | 0.0244 | -0.0098 | 0.0146 | 0.0350 | -0.0220 | 0.0130 | 0.0456 | -0.0130 | 0.0326 |
| **13** | 0.0173 | 0.0000 | 0.0173 | 0.0209 | -0.0066 | 0.0143 | 0.0350 | -0.0139 | 0.0210 | 0.0456 | -0.0086 | 0.0370 |
| **14** | 0.0173 | 0.0000 | 0.0173 | 0.0244 | -0.0032 | 0.0212 | 0.0315 | -0.0056 | 0.0258 | 0.0491 | -0.0044 | 0.0447 |
| **exit** | 0.0173 | 0.0000 | 0.0173 | 0.0209 | 0.0000 | 0.0209 | 0.0350 | 0.0000 | 0.0350 | 0.0456 | 0.0000 | 0.0456 |
| **TOTAL $q_c$** | **0.2637** | **0.0000** | **0.2637** | **0.3344** | **-0.3426** | **-0.0082** | **0.5107** | **-0.8223** | **-0.3116** | **0.6975** | **-0.4540** | **0.2435** |

| Coilset | 8 seconds | | | 10 seconds | | | 15 seconds | | | 20 seconds | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Flow (kW) | Storage (kW) | Coil set $q_c$ (kW) | Flow (kW) | Storage (kW) | Coil set $q_c$ (kW) | Flow (kW) | Storage (kW) | Coil set $q_c$ (kW) | Flow (kW) | Storage (kW) | Coil set $q_c$ (kW) |
| **1** | 0.0673 | -0.0676 | -0.0003 | 0.0934 | -0.1036 | -0.0102 | 0.1389 | -0.0679 | 0.0710 | 0.1794 | -0.0588 | 0.1206 |
| **2** | 0.0708 | -0.0627 | 0.0081 | 0.0934 | -0.0955 | -0.0021 | 0.1351 | -0.0625 | 0.0726 | 0.1756 | -0.0539 | 0.1217 |
| **3** | 0.0673 | -0.0578 | 0.0095 | 0.0898 | -0.0877 | 0.0021 | 0.1388 | -0.0573 | 0.0815 | 0.1794 | -0.0490 | 0.1304 |
| **4** | 0.0673 | -0.0529 | 0.0144 | 0.0934 | -0.0798 | 0.0135 | 0.1351 | -0.0519 | 0.0831 | 0.1755 | -0.0441 | 0.1314 |
| **5** | 0.0708 | -0.0480 | 0.0228 | 0.0933 | -0.0717 | 0.0216 | 0.1388 | -0.0468 | 0.0920 | 0.1793 | -0.0392 | 0.1401 |
| **6** | 0.0673 | -0.0428 | 0.0244 | 0.0933 | -0.0639 | 0.0294 | 0.1350 | -0.0414 | 0.0937 | 0.1755 | -0.0343 | 0.1412 |
| **7** | 0.0673 | -0.0379 | 0.0293 | 0.0933 | -0.0561 | 0.0373 | 0.1388 | -0.0362 | 0.1025 | 0.1793 | -0.0294 | 0.1499 |
| **8** | 0.0708 | -0.0330 | 0.0378 | 0.0897 | -0.0480 | 0.0418 | 0.1350 | -0.0309 | 0.1042 | 0.1754 | -0.0245 | 0.1509 |
| **9** | 0.0673 | -0.0281 | 0.0391 | 0.0933 | -0.0401 | 0.0532 | 0.1387 | -0.0257 | 0.1130 | 0.1792 | -0.0196 | 0.1596 |
| **10** | 0.0673 | -0.0230 | 0.0443 | 0.0933 | -0.0323 | 0.0610 | 0.1350 | -0.0203 | 0.1147 | 0.1754 | -0.0147 | 0.1607 |
| **11** | 0.0708 | -0.0181 | 0.0527 | 0.0933 | -0.0242 | 0.0691 | 0.1387 | -0.0152 | 0.1235 | 0.1791 | -0.0098 | 0.1694 |
| **12** | 0.0672 | -0.0132 | 0.0540 | 0.0933 | -0.0164 | 0.0769 | 0.1349 | -0.0098 | 0.1252 | 0.1753 | -0.0049 | 0.1704 |
| **13** | 0.0672 | -0.0083 | 0.0589 | 0.0897 | -0.0086 | 0.0811 | 0.1387 | -0.0046 | 0.1340 | 0.1791 | 0.0000 | 0.1791 |
| **14** | 0.0708 | -0.0034 | 0.0674 | 0.0933 | -0.0005 | 0.0928 | 0.1349 | 0.0007 | 0.1356 | 0.1753 | 0.0049 | 0.1802 |
| **exit** | 0.0672 | 0.0000 | 0.0672 | 0.0933 | 0.0000 | 0.0933 | 0.1386 | 0.0000 | 0.1386 | 0.1790 | 0.0000 | 0.1790 |
| **TOTAL $q_c$** | **1.0267** | **-0.4970** | **0.5297** | **1.3891** | **-0.7285** | **0.6607** | **2.0551** | **-0.4698** | **1.5853** | **2.6618** | **-0.3773** | **2.2845** |

| Coilset | 30 seconds | | | 50 seconds | | | 100 seconds | | | 200 seconds | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Flow (kW) | Storage (kW) | Coil set $q_c$ (kW) | Flow (kW) | Storage (kW) | Coil set $q_c$ (kW) | Flow (kW) | Storage (kW) | Coil set $q_c$ (kW) | Flow (kW) | Storage (kW) | Coil set $q_c$ (kW) |
| **1** | 0.2561 | -0.0464 | 0.2097 | 0.3232 | -0.0241 | 0.2991 | 0.3443 | -0.0069 | 0.3374 | 0.3559 | -0.0012 | 0.3547 |
| **2** | 0.2560 | -0.0417 | 0.2143 | 0.3192 | -0.0218 | 0.2973 | 0.3403 | -0.0066 | 0.3337 | 0.3519 | -0.0010 | 0.3509 |
| **3** | 0.2559 | -0.0373 | 0.2186 | 0.3230 | -0.0199 | 0.3031 | 0.3440 | -0.0061 | 0.3379 | 0.3556 | -0.0010 | 0.3547 |
| **4** | 0.2558 | -0.0326 | 0.2232 | 0.3190 | -0.0177 | 0.3013 | 0.3400 | -0.0059 | 0.3341 | 0.3555 | -0.0010 | 0.3545 |
| **5** | 0.2558 | -0.0282 | 0.2276 | 0.3227 | -0.0154 | 0.3073 | 0.3438 | -0.0056 | 0.3381 | 0.3514 | -0.0010 | 0.3505 |
| **6** | 0.2557 | -0.0235 | 0.2322 | 0.3187 | -0.0132 | 0.3055 | 0.3436 | -0.0054 | 0.3382 | 0.3552 | -0.0010 | 0.3542 |
| **7** | 0.2557 | -0.0191 | 0.2366 | 0.3225 | -0.0113 | 0.3113 | 0.3396 | -0.0051 | 0.3345 | 0.3551 | -0.0007 | 0.3543 |
| **8** | 0.2556 | -0.0145 | 0.2412 | 0.3186 | -0.0091 | 0.3095 | 0.3434 | -0.0047 | 0.3387 | 0.3510 | -0.0007 | 0.3503 |
| **9** | 0.2556 | -0.0100 | 0.2455 | 0.3224 | -0.0069 | 0.3155 | 0.3394 | -0.0044 | 0.3350 | 0.3548 | -0.0007 | 0.3541 |
| **10** | 0.2555 | -0.0054 | 0.2501 | 0.3184 | -0.0047 | 0.3137 | 0.3432 | -0.0042 | 0.3390 | 0.3547 | -0.0007 | 0.3540 |
| **11** | 0.2554 | -0.0010 | 0.2545 | 0.3222 | -0.0027 | 0.3195 | 0.3431 | -0.0039 | 0.3392 | 0.3507 | -0.0007 | 0.3500 |
| **12** | 0.2554 | 0.0037 | 0.2591 | 0.3182 | -0.0005 | 0.3177 | 0.3391 | -0.0034 | 0.3357 | 0.3545 | -0.0005 | 0.3540 |
| **13** | 0.2553 | 0.0081 | 0.2634 | 0.3220 | 0.0017 | 0.3237 | 0.3429 | -0.0032 | 0.3397 | 0.3544 | -0.0005 | 0.3539 |
| **14** | 0.2553 | 0.0127 | 0.2680 | 0.3180 | 0.0039 | 0.3220 | 0.3389 | -0.0029 | 0.3360 | 0.3504 | -0.0005 | 0.3499 |
| **exit** | 0.2552 | 0.0000 | 0.2552 | 0.3218 | 0.0000 | 0.3218 | 0.3427 | 0.0000 | 0.3427 | 0.3542 | 0.0000 | 0.3542 |
| **TOTAL $q_c$** | **3.8344** | **-0.2352** | **3.5993** | **4.8099** | **-0.1415** | **4.6683** | **5.1283** | **-0.0684** | **5.0599** | **5.3055** | **-0.0113** | **5.2942** |

# Table M7: Coil Set Energy Balance for R3-60 at 14LPM

| Coilset | 1 second | | | 2 seconds | | | 3 seconds | | | 5 seconds | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Flow (kW) | Storage (kW) | Coil set $q_c$ (kW) | Flow (kW) | Storage (kW) | Coil set $q_c$ (kW) | Flow (kW) | Storage (kW) | Coil set $q_c$ (kW) | Flow (kW) | Storage (kW) | Coil set $q_c$ (kW) |
| **1** | 0.0331 | 0.0000 | 0.0331 | 0.0451 | -0.0309 | 0.0141 | 0.0570 | -0.0717 | -0.0147 | 0.1143 | -0.1834 | -0.0691 |
| **2** | 0.0331 | 0.0000 | 0.0331 | 0.0361 | -0.0293 | 0.0067 | 0.0570 | -0.0686 | -0.0117 | 0.1143 | -0.1762 | -0.0619 |
| **3** | 0.0331 | 0.0000 | 0.0331 | 0.0451 | -0.0279 | 0.0171 | 0.0570 | -0.0658 | -0.0089 | 0.1238 | -0.1687 | -0.0449 |
| **4** | 0.0331 | 0.0000 | 0.0331 | 0.0451 | -0.0263 | 0.0188 | 0.0570 | -0.0628 | -0.0059 | 0.1143 | -0.1615 | -0.0472 |
| **5** | 0.0331 | 0.0000 | 0.0331 | 0.0360 | -0.0247 | 0.0114 | 0.0475 | -0.0600 | -0.0126 | 0.1143 | -0.1541 | -0.0398 |
| **6** | 0.0331 | 0.0000 | 0.0331 | 0.0451 | -0.0230 | 0.0220 | 0.0570 | -0.0572 | -0.0003 | 0.1143 | -0.1466 | -0.0323 |
| **7** | 0.0331 | 0.0000 | 0.0331 | 0.0360 | -0.0214 | 0.0146 | 0.0570 | -0.0542 | 0.0028 | 0.1143 | -0.1394 | -0.0251 |
| **8** | 0.0331 | 0.0000 | 0.0331 | 0.0451 | -0.0200 | 0.0251 | 0.0570 | -0.0514 | 0.0055 | 0.1238 | -0.1319 | -0.0081 |
| **9** | 0.0331 | 0.0000 | 0.0331 | 0.0451 | -0.0184 | 0.0267 | 0.0570 | -0.0484 | 0.0086 | 0.1143 | -0.1247 | -0.0104 |
| **10** | 0.0331 | 0.0000 | 0.0331 | 0.0360 | -0.0167 | 0.0193 | 0.0570 | -0.0456 | 0.0114 | 0.1143 | -0.1173 | -0.0030 |
| **11** | 0.0331 | 0.0000 | 0.0331 | 0.0451 | -0.0151 | 0.0299 | 0.0570 | -0.0428 | 0.0142 | 0.1143 | -0.1098 | 0.0045 |
| **12** | 0.0331 | 0.0000 | 0.0331 | 0.0451 | -0.0135 | 0.0316 | 0.0569 | -0.0398 | 0.0172 | 0.1143 | -0.1026 | 0.0117 |
| **13** | 0.0248 | 0.0000 | 0.0248 | 0.0360 | -0.0121 | 0.0240 | 0.0475 | -0.0370 | 0.0105 | 0.1238 | -0.0952 | 0.0286 |
| **14** | 0.0331 | 0.0000 | 0.0331 | 0.0451 | -0.0105 | 0.0346 | 0.0569 | -0.0340 | 0.0230 | 0.1143 | -0.0879 | 0.0263 |
| **15** | 0.0331 | 0.0000 | 0.0331 | 0.0451 | -0.0088 | 0.0362 | 0.0569 | -0.0312 | 0.0258 | 0.1143 | -0.0805 | 0.0338 |
| **16** | 0.0331 | 0.0000 | 0.0331 | 0.0360 | -0.0072 | 0.0288 | 0.0569 | -0.0284 | 0.0286 | 0.1142 | -0.0730 | 0.0412 |
| **17** | 0.0331 | 0.0000 | 0.0331 | 0.0451 | -0.0056 | 0.0395 | 0.0569 | -0.0253 | 0.0316 | 0.1142 | -0.0658 | 0.0484 |
| **18** | 0.0331 | 0.0000 | 0.0331 | 0.0451 | -0.0042 | 0.0409 | 0.0569 | -0.0226 | 0.0344 | 0.1238 | -0.0584 | 0.0654 |
| **19** | 0.0331 | 0.0000 | 0.0331 | 0.0360 | -0.0026 | 0.0335 | 0.0569 | -0.0195 | 0.0374 | 0.1142 | -0.0512 | 0.0631 |
| **20** | 0.0331 | 0.0000 | 0.0331 | 0.0451 | -0.0009 | 0.0441 | 0.0569 | -0.0167 | 0.0402 | 0.1142 | -0.0437 | 0.0705 |
| **21** | 0.0331 | 0.0000 | 0.0331 | 0.0360 | 0.0007 | 0.0367 | 0.0475 | -0.0140 | 0.0335 | 0.1142 | -0.0363 | 0.0779 |
| **22** | 0.0331 | 0.0000 | 0.0331 | 0.0451 | 0.0023 | 0.0474 | 0.0569 | -0.0109 | 0.0460 | 0.1142 | -0.0291 | 0.0852 |
| **23** | 0.0331 | 0.0000 | 0.0331 | 0.0450 | 0.0037 | 0.0488 | 0.0569 | -0.0081 | 0.0488 | 0.1237 | -0.0216 | 0.1021 |
| **24** | 0.0331 | 0.0000 | 0.0331 | 0.0360 | 0.0053 | 0.0414 | 0.0569 | -0.0051 | 0.0518 | 0.1142 | -0.0144 | 0.0998 |
| **exit** | 0.0331 | 0.0000 | 0.0331 | 0.0450 | 0.0000 | 0.0450 | 0.0569 | 0.0000 | 0.0569 | 0.1142 | 0.0000 | 0.1142 |
| **TOTAL $q_c$** | **0.8198** | **0.0000** | **0.8198** | **1.0453** | **-0.3070** | **0.7383** | **1.3952** | **-0.9211** | **0.4741** | **2.9041** | **-2.3734** | **0.5308** |

| Coilset | 8 seconds | | | 10 seconds | | | 15 seconds | | | 20 seconds | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Flow (kW) | Storage (kW) | Coil set $q_c$ (kW) | Flow (kW) | Storage (kW) | Coil set $q_c$ (kW) | Flow (kW) | Storage (kW) | Coil set $q_c$ (kW) | Flow (kW) | Storage (kW) | Coil set $q_c$ (kW) |
| **1** | 0.2287 | -0.2188 | 0.0099 | 0.2758 | -0.1294 | 0.1465 | 0.3781 | -0.1057 | 0.2724 | 0.4652 | -0.0607 | 0.4045 |
| **2** | 0.2191 | -0.2097 | 0.0095 | 0.2663 | -0.1235 | 0.1428 | 0.3875 | -0.1001 | 0.2874 | 0.4752 | -0.0579 | 0.4173 |
| **3** | 0.2287 | -0.2008 | 0.0278 | 0.2758 | -0.1177 | 0.1581 | 0.3779 | -0.0947 | 0.2832 | 0.4650 | -0.0551 | 0.4099 |
| **4** | 0.2286 | -0.1919 | 0.0367 | 0.2757 | -0.1118 | 0.1639 | 0.3779 | -0.0891 | 0.2888 | 0.4649 | -0.0523 | 0.4127 |
| **5** | 0.2191 | -0.1831 | 0.0360 | 0.2662 | -0.1060 | 0.1602 | 0.3872 | -0.0837 | 0.3035 | 0.4749 | -0.0495 | 0.4255 |
| **6** | 0.2286 | -0.1742 | 0.0544 | 0.2757 | -0.1002 | 0.1755 | 0.3777 | -0.0781 | 0.2996 | 0.4647 | -0.0466 | 0.4181 |
| **7** | 0.2191 | -0.1653 | 0.0537 | 0.2662 | -0.0943 | 0.1718 | 0.3871 | -0.0727 | 0.3144 | 0.4646 | -0.0441 | 0.4206 |
| **8** | 0.2286 | -0.1565 | 0.0721 | 0.2756 | -0.0885 | 0.1871 | 0.3776 | -0.0671 | 0.3105 | 0.4746 | -0.0413 | 0.4334 |
| **9** | 0.2285 | -0.1474 | 0.0812 | 0.2756 | -0.0827 | 0.1929 | 0.3775 | -0.0617 | 0.3158 | 0.4645 | -0.0385 | 0.4260 |
| **10** | 0.2190 | -0.1385 | 0.0805 | 0.2661 | -0.0768 | 0.1892 | 0.3869 | -0.0564 | 0.3306 | 0.4644 | -0.0357 | 0.4287 |
| **11** | 0.2285 | -0.1297 | 0.0988 | 0.2756 | -0.0710 | 0.2045 | 0.3774 | -0.0508 | 0.3267 | 0.4744 | -0.0329 | 0.4415 |
| **12** | 0.2285 | -0.1208 | 0.1077 | 0.2755 | -0.0652 | 0.2103 | 0.3774 | -0.0454 | 0.3320 | 0.4642 | -0.0301 | 0.4342 |
| **13** | 0.2189 | -0.1120 | 0.1070 | 0.2660 | -0.0594 | 0.2066 | 0.3868 | -0.0398 | 0.3469 | 0.4641 | -0.0273 | 0.4369 |
| **14** | 0.2284 | -0.1031 | 0.1253 | 0.2755 | -0.0535 | 0.2219 | 0.3773 | -0.0345 | 0.3428 | 0.4641 | -0.0245 | 0.4396 |
| **15** | 0.2284 | -0.0943 | 0.1342 | 0.2755 | -0.0477 | 0.2277 | 0.3772 | -0.0289 | 0.3484 | 0.4741 | -0.0217 | 0.4524 |
| **16** | 0.2189 | -0.0854 | 0.1335 | 0.2659 | -0.0419 | 0.2240 | 0.3866 | -0.0235 | 0.3631 | 0.4639 | -0.0189 | 0.4451 |
| **17** | 0.2284 | -0.0763 | 0.1521 | 0.2754 | -0.0361 | 0.2393 | 0.3771 | -0.0182 | 0.3590 | 0.4638 | -0.0161 | 0.4478 |
| **18** | 0.2284 | -0.0675 | 0.1609 | 0.2754 | -0.0302 | 0.2451 | 0.3771 | -0.0126 | 0.3645 | 0.4738 | -0.0133 | 0.4606 |
| **19** | 0.2188 | -0.0586 | 0.1602 | 0.2658 | -0.0244 | 0.2414 | 0.3864 | -0.0072 | 0.3792 | 0.4637 | -0.0107 | 0.4530 |
| **20** | 0.2283 | -0.0498 | 0.1786 | 0.2753 | -0.0186 | 0.2567 | 0.3770 | -0.0016 | 0.3753 | 0.4636 | -0.0079 | 0.4557 |
| **21** | 0.2188 | -0.0409 | 0.1779 | 0.2658 | -0.0128 | 0.2530 | 0.3863 | 0.0037 | 0.3901 | 0.4736 | -0.0051 | 0.4685 |
| **22** | 0.2283 | -0.0321 | 0.1962 | 0.2753 | -0.0070 | 0.2683 | 0.3769 | 0.0093 | 0.3862 | 0.4635 | -0.0023 | 0.4612 |
| **23** | 0.2283 | -0.0233 | 0.2050 | 0.2752 | -0.0012 | 0.2741 | 0.3768 | 0.0147 | 0.3915 | 0.4634 | 0.0005 | 0.4639 |
| **24** | 0.2188 | -0.0142 | 0.2046 | 0.2657 | 0.0047 | 0.2704 | 0.3862 | 0.0202 | 0.4064 | 0.4734 | 0.0033 | 0.4767 |
| **exit** | 0.2283 | 0.0000 | 0.2283 | 0.2752 | 0.0000 | 0.2752 | 0.3767 | 0.0000 | 0.3767 | 0.4633 | 0.0000 | 0.4633 |
| **TOTAL $q_c$** | **5.6260** | **-2.7941** | **2.8320** | **6.8022** | **-1.4953** | **5.3069** | **9.5188** | **-1.0238** | **8.4950** | **11.6851** | **-0.6882** | **10.9969** |

| Coilset | 30 seconds | | | 50 seconds | | | 100 seconds | | | 200 seconds | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Flow (kW) | Storage (kW) | Coil set $q_c$ (kW) | Flow (kW) | Storage (kW) | Coil set $q_c$ (kW) | Flow (kW) | Storage (kW) | Coil set $q_c$ (kW) | Flow (kW) | Storage (kW) | Coil set $q_c$ (kW) |
| **1** | 0.4910 | -0.0271 | 0.4639 | 0.4855 | -0.0082 | 0.4773 | 0.4931 | -0.0016 | 0.4915 | 0.5061 | -0.0002 | 0.5058 |
| **2** | 0.4909 | -0.0264 | 0.4645 | 0.4951 | -0.0079 | 0.4871 | 0.5027 | -0.0014 | 0.5013 | 0.4962 | -0.0002 | 0.4960 |
| **3** | 0.5008 | -0.0257 | 0.4751 | 0.4853 | -0.0079 | 0.4773 | 0.4929 | -0.0014 | 0.4915 | 0.5058 | -0.0002 | 0.5056 |
| **4** | 0.4907 | -0.0250 | 0.4657 | 0.4948 | -0.0077 | 0.4871 | 0.5024 | -0.0014 | 0.5010 | 0.5057 | -0.0002 | 0.5055 |
| **5** | 0.4906 | -0.0243 | 0.4663 | 0.4850 | -0.0077 | 0.4773 | 0.4927 | -0.0014 | 0.4913 | 0.5056 | -0.0002 | 0.5054 |
| **6** | 0.4905 | -0.0236 | 0.4669 | 0.4849 | -0.0075 | 0.4775 | 0.5022 | -0.0014 | 0.5008 | 0.4958 | -0.0002 | 0.4955 |
| **7** | 0.5004 | -0.0231 | 0.4773 | 0.4945 | -0.0072 | 0.4873 | 0.4924 | -0.0012 | 0.4913 | 0.5054 | -0.0002 | 0.5052 |
| **8** | 0.4903 | -0.0224 | 0.4679 | 0.4847 | -0.0072 | 0.4775 | 0.5020 | -0.0012 | 0.5008 | 0.5053 | -0.0002 | 0.5050 |
| **9** | 0.4902 | -0.0217 | 0.4685 | 0.4943 | -0.0070 | 0.4873 | 0.4922 | -0.0012 | 0.4911 | 0.4954 | -0.0002 | 0.4952 |
| **10** | 0.4901 | -0.0210 | 0.4691 | 0.4845 | -0.0070 | 0.4775 | 0.4921 | -0.0012 | 0.4909 | 0.5050 | -0.0002 | 0.5048 |
| **11** | 0.4999 | -0.0203 | 0.4797 | 0.4844 | -0.0068 | 0.4776 | 0.5016 | -0.0012 | 0.5005 | 0.5049 | -0.0002 | 0.5047 |
| **12** | 0.4898 | -0.0196 | 0.4703 | 0.4940 | -0.0068 | 0.4872 | 0.4919 | -0.0009 | 0.4910 | 0.5048 | -0.0002 | 0.5046 |
| **13** | 0.4898 | -0.0189 | 0.4709 | 0.4842 | -0.0065 | 0.4777 | 0.5014 | -0.0009 | 0.5005 | 0.4950 | -0.0002 | 0.4948 |
| **14** | 0.4897 | -0.0182 | 0.4715 | 0.4938 | -0.0063 | 0.4875 | 0.4917 | -0.0009 | 0.4907 | 0.5046 | -0.0002 | 0.5044 |
| **15** | 0.4996 | -0.0175 | 0.4821 | 0.4840 | -0.0063 | 0.4777 | 0.5012 | -0.0009 | 0.5003 | 0.5045 | -0.0002 | 0.5043 |
| **16** | 0.4895 | -0.0168 | 0.4727 | 0.4839 | -0.0061 | 0.4779 | 0.4915 | -0.0007 | 0.4908 | 0.5044 | -0.0002 | 0.5042 |
| **17** | 0.4894 | -0.0161 | 0.4734 | 0.4935 | -0.0061 | 0.4875 | 0.4914 | -0.0007 | 0.4907 | 0.4946 | -0.0002 | 0.4944 |
| **18** | 0.4893 | -0.0154 | 0.4740 | 0.4838 | -0.0058 | 0.4779 | 0.5010 | -0.0007 | 0.5003 | 0.5042 | -0.0002 | 0.5040 |
| **19** | 0.4992 | -0.0149 | 0.4844 | 0.4933 | -0.0056 | 0.4878 | 0.4912 | -0.0007 | 0.4905 | 0.5041 | -0.0002 | 0.5039 |
| **20** | 0.4892 | -0.0142 | 0.4750 | 0.4836 | -0.0056 | 0.4780 | 0.5008 | -0.0007 | 0.5001 | 0.4944 | -0.0002 | 0.4941 |
| **21** | 0.4891 | -0.0135 | 0.4756 | 0.4835 | -0.0054 | 0.4782 | 0.4911 | -0.0005 | 0.4906 | 0.5040 | -0.0002 | 0.5037 |
| **22** | 0.4890 | -0.0128 | 0.4762 | 0.4931 | -0.0054 | 0.4877 | 0.5006 | -0.0005 | 0.5001 | 0.5039 | -0.0002 | 0.5036 |
| **23** | 0.4989 | -0.0121 | 0.4868 | 0.4833 | -0.0051 | 0.4782 | 0.4909 | -0.0005 | 0.4904 | 0.5038 | -0.0002 | 0.5036 |
| **24** | 0.4889 | -0.0114 | 0.4775 | 0.4929 | -0.0051 | 0.4878 | 0.5004 | -0.0005 | 0.5000 | 0.4940 | -0.0002 | 0.4938 |
| **exit** | 0.4888 | 0.0000 | 0.4888 | 0.4832 | 0.0000 | 0.4832 | 0.4907 | 0.0000 | 0.4907 | 0.5036 | 0.0000 | 0.5036 |
| **TOTAL $q_c$** | **12.3056** | **-0.4616** | **11.8441** | **12.2032** | **-0.1581** | **12.0451** | **12.4023** | **-0.0236** | **12.3787** | **12.5513** | **-0.0056** | **12.5457** |

## Table M8: Coil Set Energy Balance for R3-60 at 12LPM

| Coilset | 1 second | | | 2 seconds | | | 3 seconds | | | 5 seconds | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Flow (kW) | Storage (kW) | Coil set $q_c$ (kW) | Flow (kW) | Storage (kW) | Coil set $q_c$ (kW) | Flow (kW) | Storage (kW) | Coil set $q_c$ (kW) | Flow (kW) | Storage (kW) | Coil set $q_c$ (kW) |
| **1** | 0.0160 | 0.0000 | 0.0160 | 0.0244 | -0.0381 | -0.0137 | 0.0568 | -0.2657 | -0.2089 | 0.1065 | -0.1520 | -0.0455 |
| **2** | 0.0160 | 0.0000 | 0.0160 | 0.0163 | -0.0365 | -0.0202 | 0.0649 | -0.2548 | -0.1898 | 0.1065 | -0.1455 | -0.0390 |
| **3** | 0.0160 | 0.0000 | 0.0160 | 0.0244 | -0.0351 | -0.0107 | 0.0568 | -0.2436 | -0.1868 | 0.0983 | -0.1392 | -0.0409 |
| **4** | 0.0160 | 0.0000 | 0.0160 | 0.0163 | -0.0335 | -0.0172 | 0.0568 | -0.2327 | -0.1758 | 0.1065 | -0.1327 | -0.0262 |
| **5** | 0.0160 | 0.0000 | 0.0160 | 0.0244 | -0.0321 | -0.0077 | 0.0649 | -0.2215 | -0.1565 | 0.1065 | -0.1264 | -0.0199 |
| **6** | 0.0160 | 0.0000 | 0.0160 | 0.0163 | -0.0307 | -0.0144 | 0.0568 | -0.2103 | -0.1535 | 0.1065 | -0.1201 | -0.0136 |
| **7** | 0.0080 | 0.0000 | 0.0080 | 0.0244 | -0.0291 | -0.0047 | 0.0568 | -0.1994 | -0.1426 | 0.1065 | -0.1136 | -0.0071 |
| **8** | 0.0160 | 0.0000 | 0.0160 | 0.0163 | -0.0277 | -0.0114 | 0.0649 | -0.1882 | -0.1233 | 0.0983 | -0.1073 | -0.0090 |
| **9** | 0.0160 | 0.0000 | 0.0160 | 0.0244 | -0.0260 | -0.0016 | 0.0568 | -0.1773 | -0.1204 | 0.1064 | -0.1008 | 0.0057 |
| **10** | 0.0160 | 0.0000 | 0.0160 | 0.0244 | -0.0247 | -0.0002 | 0.0568 | -0.1661 | -0.1093 | 0.1064 | -0.0945 | 0.0120 |
| **11** | 0.0160 | 0.0000 | 0.0160 | 0.0163 | -0.0233 | -0.0070 | 0.0649 | -0.1549 | -0.0900 | 0.1064 | -0.0882 | 0.0183 |
| **12** | 0.0160 | 0.0000 | 0.0160 | 0.0244 | -0.0216 | 0.0028 | 0.0568 | -0.1440 | -0.0872 | 0.1064 | -0.0817 | 0.0248 |
| **13** | 0.0160 | 0.0000 | 0.0160 | 0.0163 | -0.0202 | -0.0040 | 0.0568 | -0.1328 | -0.0760 | 0.0982 | -0.0754 | 0.0229 |
| **14** | 0.0160 | 0.0000 | 0.0160 | 0.0244 | -0.0186 | 0.0058 | 0.0568 | -0.1219 | -0.0651 | 0.1064 | -0.0689 | 0.0376 |
| **15** | 0.0160 | 0.0000 | 0.0160 | 0.0163 | -0.0172 | -0.0009 | 0.0649 | -0.1107 | -0.0458 | 0.1064 | -0.0626 | 0.0438 |
| **16** | 0.0160 | 0.0000 | 0.0160 | 0.0244 | -0.0158 | 0.0086 | 0.0568 | -0.0995 | -0.0427 | 0.1064 | -0.0563 | 0.0501 |
| **17** | 0.0160 | 0.0000 | 0.0160 | 0.0244 | -0.0142 | 0.0102 | 0.0568 | -0.0886 | -0.0318 | 0.1064 | -0.0498 | 0.0566 |
| **18** | 0.0160 | 0.0000 | 0.0160 | 0.0163 | -0.0128 | 0.0035 | 0.0649 | -0.0774 | -0.0125 | 0.0982 | -0.0435 | 0.0547 |
| **19** | 0.0080 | 0.0000 | 0.0080 | 0.0244 | -0.0112 | 0.0132 | 0.0568 | -0.0665 | -0.0097 | 0.1064 | -0.0370 | 0.0694 |
| **20** | 0.0160 | 0.0000 | 0.0160 | 0.0163 | -0.0098 | 0.0065 | 0.0568 | -0.0554 | 0.0014 | 0.1064 | -0.0307 | 0.0757 |
| **21** | 0.0160 | 0.0000 | 0.0160 | 0.0244 | -0.0084 | 0.0160 | 0.0649 | -0.0442 | 0.0207 | 0.1064 | -0.0244 | 0.0820 |
| **22** | 0.0160 | 0.0000 | 0.0160 | 0.0163 | -0.0067 | 0.0095 | 0.0568 | -0.0333 | 0.0235 | 0.1064 | -0.0179 | 0.0885 |
| **23** | 0.0160 | 0.0000 | 0.0160 | 0.0244 | -0.0053 | 0.0191 | 0.0568 | -0.0221 | 0.0347 | 0.0982 | -0.0116 | 0.0866 |
| **24** | 0.0160 | 0.0000 | 0.0160 | 0.0163 | -0.0037 | 0.0125 | 0.0649 | -0.0112 | 0.0537 | 0.1064 | -0.0051 | 0.1013 |
| **exit** | 0.0160 | 0.0000 | 0.0160 | 0.0244 | 0.0000 | 0.0244 | 0.0568 | 0.0000 | 0.0568 | 0.1064 | 0.0000 | 0.1064 |
| **TOTAL $q_c$** | **0.3844** | **0.0000** | **0.3844** | **0.5206** | **-0.5023** | **0.0183** | **1.4851** | **-3.3219** | **-1.8368** | **2.6197** | **-1.8848** | **0.7349** |

| Coilset | 8 seconds | | | 10 seconds | | | 15 seconds | | | 20 seconds | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Flow (kW) | Storage (kW) | Coil set $q_c$ (kW) | Flow (kW) | Storage (kW) | Coil set $q_c$ (kW) | Flow (kW) | Storage (kW) | Coil set $q_c$ (kW) | Flow (kW) | Storage (kW) | Coil set $q_c$ (kW) |
| **1** | 0.1897 | -0.1838 | 0.0059 | 0.2494 | -0.1690 | 0.0804 | 0.3350 | -0.0772 | 0.2578 | 0.3948 | -0.0569 | 0.3379 |
| **2** | 0.1896 | -0.1759 | 0.0138 | 0.2494 | -0.1608 | 0.0886 | 0.3266 | -0.0728 | 0.2538 | 0.3948 | -0.0534 | 0.3413 |
| **3** | 0.1896 | -0.1679 | 0.0217 | 0.2493 | -0.1524 | 0.0969 | 0.3349 | -0.0683 | 0.2666 | 0.3947 | -0.0502 | 0.3445 |
| **4** | 0.1896 | -0.1600 | 0.0296 | 0.2493 | -0.1442 | 0.1051 | 0.3348 | -0.0639 | 0.2710 | 0.3862 | -0.0466 | 0.3396 |
| **5** | 0.1896 | -0.1521 | 0.0375 | 0.2493 | -0.1361 | 0.1132 | 0.3264 | -0.0592 | 0.2672 | 0.3945 | -0.0434 | 0.3511 |
| **6** | 0.1896 | -0.1441 | 0.0454 | 0.2493 | -0.1279 | 0.1214 | 0.3347 | -0.0548 | 0.2800 | 0.3944 | -0.0401 | 0.3543 |
| **7** | 0.1896 | -0.1360 | 0.0536 | 0.2575 | -0.1197 | 0.1378 | 0.3263 | -0.0503 | 0.2760 | 0.3944 | -0.0366 | 0.3578 |
| **8** | 0.1896 | -0.1281 | 0.0615 | 0.2492 | -0.1113 | 0.1379 | 0.3346 | -0.0459 | 0.2887 | 0.3943 | -0.0333 | 0.3609 |
| **9** | 0.1895 | -0.1201 | 0.0694 | 0.2492 | -0.1032 | 0.1460 | 0.3346 | -0.0415 | 0.2931 | 0.3942 | -0.0298 | 0.3644 |
| **10** | 0.1895 | -0.1122 | 0.0773 | 0.2492 | -0.0950 | 0.1542 | 0.3262 | -0.0370 | 0.2891 | 0.3857 | -0.0266 | 0.3592 |
| **11** | 0.1895 | -0.1043 | 0.0852 | 0.2491 | -0.0868 | 0.1623 | 0.3345 | -0.0326 | 0.3019 | 0.3941 | -0.0233 | 0.3708 |
| **12** | 0.1895 | -0.0964 | 0.0931 | 0.2491 | -0.0787 | 0.1704 | 0.3344 | -0.0282 | 0.3063 | 0.3940 | -0.0198 | 0.3742 |
| **13** | 0.1977 | -0.0884 | 0.1093 | 0.2491 | -0.0703 | 0.1788 | 0.3260 | -0.0235 | 0.3025 | 0.3939 | -0.0165 | 0.3774 |
| **14** | 0.1895 | -0.0803 | 0.1092 | 0.2491 | -0.0621 | 0.1869 | 0.3343 | -0.0191 | 0.3153 | 0.3939 | -0.0130 | 0.3808 |
| **15** | 0.1895 | -0.0724 | 0.1171 | 0.2490 | -0.0540 | 0.1950 | 0.3343 | -0.0147 | 0.3196 | 0.3938 | -0.0098 | 0.3840 |
| **16** | 0.1894 | -0.0645 | 0.1250 | 0.2490 | -0.0458 | 0.2032 | 0.3259 | -0.0102 | 0.3157 | 0.3854 | -0.0065 | 0.3789 |
| **17** | 0.1894 | -0.0565 | 0.1329 | 0.2490 | -0.0377 | 0.2113 | 0.3342 | -0.0058 | 0.3284 | 0.3937 | -0.0030 | 0.3907 |
| **18** | 0.1894 | -0.0486 | 0.1408 | 0.2490 | -0.0293 | 0.2196 | 0.3342 | -0.0014 | 0.3328 | 0.3936 | 0.0002 | 0.3939 |
| **19** | 0.1894 | -0.0407 | 0.1487 | 0.2572 | -0.0212 | 0.2361 | 0.3258 | 0.0030 | 0.3288 | 0.3936 | 0.0037 | 0.3973 |
| **20** | 0.1894 | -0.0328 | 0.1566 | 0.2489 | -0.0130 | 0.2359 | 0.3341 | 0.0074 | 0.3415 | 0.3935 | 0.0070 | 0.4005 |
| **21** | 0.1894 | -0.0249 | 0.1645 | 0.2489 | -0.0049 | 0.2440 | 0.3257 | 0.0121 | 0.3378 | 0.3934 | 0.0102 | 0.4037 |
| **22** | 0.1894 | -0.0167 | 0.1726 | 0.2489 | 0.0033 | 0.2521 | 0.3340 | 0.0165 | 0.3505 | 0.3850 | 0.0137 | 0.3987 |
| **23** | 0.1893 | -0.0088 | 0.1805 | 0.2488 | 0.0116 | 0.2605 | 0.3340 | 0.0209 | 0.3549 | 0.3933 | 0.0170 | 0.4103 |
| **24** | 0.1893 | -0.0009 | 0.1884 | 0.2488 | 0.0198 | 0.2686 | 0.3256 | 0.0253 | 0.3509 | 0.3933 | 0.0205 | 0.4137 |
| **exit** | 0.1893 | 0.0000 | 0.1893 | 0.2488 | 0.0000 | 0.2488 | 0.3339 | 0.0000 | 0.3339 | 0.3932 | 0.0000 | 0.3932 |
| **TOTAL $q_c$** | **4.7453** | **-2.2165** | **2.5288** | **6.2437** | **-1.7889** | **4.4548** | **8.2850** | **-0.6211** | **7.6639** | **9.8158** | **-0.4366** | **9.3792** |

| Coilset | 30 seconds | | | 50 seconds | | | 100 seconds | | | 200 seconds | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Flow (kW) | Storage (kW) | Coil set $q_c$ (kW) | Flow (kW) | Storage (kW) | Coil set $q_c$ (kW) | Flow (kW) | Storage (kW) | Coil set $q_c$ (kW) | Flow (kW) | Storage (kW) | Coil set $q_c$ (kW) |
| **1** | 0.4337 | -0.0292 | 0.4045 | 0.4351 | -0.0093 | 0.4257 | 0.4457 | -0.0019 | 0.4438 | 0.4564 | -0.0002 | 0.4562 |
| **2** | 0.4421 | -0.0280 | 0.4140 | 0.4433 | -0.0091 | 0.4342 | 0.4456 | -0.0019 | 0.4437 | 0.4563 | -0.0002 | 0.4561 |
| **3** | 0.4335 | -0.0271 | 0.4064 | 0.4349 | -0.0091 | 0.4257 | 0.4539 | -0.0019 | 0.4521 | 0.4478 | -0.0002 | 0.4475 |
| **4** | 0.4334 | -0.0259 | 0.4075 | 0.4348 | -0.0089 | 0.4259 | 0.4454 | -0.0019 | 0.4435 | 0.4561 | -0.0002 | 0.4559 |
| **5** | 0.4333 | -0.0250 | 0.4083 | 0.4347 | -0.0089 | 0.4258 | 0.4453 | -0.0016 | 0.4437 | 0.4560 | -0.0002 | 0.4558 |
| **6** | 0.4417 | -0.0238 | 0.4179 | 0.4429 | -0.0086 | 0.4343 | 0.4452 | -0.0016 | 0.4436 | 0.4559 | -0.0002 | 0.4557 |
| **7** | 0.4331 | -0.0229 | 0.4102 | 0.4345 | -0.0086 | 0.4258 | 0.4535 | -0.0016 | 0.4519 | 0.4558 | -0.0002 | 0.4555 |
| **8** | 0.4330 | -0.0217 | 0.4113 | 0.4344 | -0.0084 | 0.4260 | 0.4450 | -0.0016 | 0.4434 | 0.4472 | -0.0002 | 0.4470 |
| **9** | 0.4414 | -0.0207 | 0.4206 | 0.4426 | -0.0084 | 0.4342 | 0.4449 | -0.0016 | 0.4433 | 0.4556 | -0.0002 | 0.4553 |
| **10** | 0.4328 | -0.0198 | 0.4130 | 0.4342 | -0.0082 | 0.4260 | 0.4448 | -0.0014 | 0.4434 | 0.4555 | -0.0002 | 0.4552 |
| **11** | 0.4327 | -0.0186 | 0.4141 | 0.4341 | -0.0082 | 0.4259 | 0.4531 | -0.0014 | 0.4517 | 0.4553 | -0.0002 | 0.4551 |
| **12** | 0.4326 | -0.0177 | 0.4149 | 0.4340 | -0.0079 | 0.4260 | 0.4446 | -0.0014 | 0.4432 | 0.4552 | -0.0002 | 0.4550 |
| **13** | 0.4410 | -0.0165 | 0.4245 | 0.4422 | -0.0079 | 0.4343 | 0.4445 | -0.0014 | 0.4431 | 0.4467 | -0.0002 | 0.4465 |
| **14** | 0.4325 | -0.0156 | 0.4169 | 0.4338 | -0.0077 | 0.4261 | 0.4444 | -0.0014 | 0.4430 | 0.4551 | -0.0002 | 0.4548 |
| **15** | 0.4324 | -0.0144 | 0.4180 | 0.4337 | -0.0075 | 0.4263 | 0.4527 | -0.0014 | 0.4513 | 0.4550 | -0.0002 | 0.4547 |
| **16** | 0.4323 | -0.0135 | 0.4188 | 0.4337 | -0.0075 | 0.4262 | 0.4442 | -0.0012 | 0.4431 | 0.4549 | -0.0002 | 0.4547 |
| **17** | 0.4407 | -0.0126 | 0.4281 | 0.4419 | -0.0074 | 0.4345 | 0.4442 | -0.0012 | 0.4430 | 0.4548 | 0.0000 | 0.4548 |
| **18** | 0.4322 | -0.0114 | 0.4208 | 0.4335 | -0.0072 | 0.4263 | 0.4441 | -0.0012 | 0.4429 | 0.4463 | 0.0000 | 0.4463 |
| **19** | 0.4321 | -0.0105 | 0.4216 | 0.4334 | -0.0072 | 0.4262 | 0.4524 | -0.0012 | 0.4512 | 0.4546 | 0.0000 | 0.4546 |
| **20** | 0.4405 | -0.0093 | 0.4312 | 0.4417 | -0.0070 | 0.4347 | 0.4439 | -0.0012 | 0.4428 | 0.4546 | 0.0000 | 0.4546 |
| **21** | 0.4319 | -0.0084 | 0.4236 | 0.4333 | -0.0070 | 0.4263 | 0.4438 | -0.0009 | 0.4429 | 0.4545 | 0.0000 | 0.4545 |
| **22** | 0.4319 | -0.0072 | 0.4247 | 0.4332 | -0.0067 | 0.4264 | 0.4438 | -0.0009 | 0.4428 | 0.4544 | 0.0000 | 0.4544 |
| **23** | 0.4318 | -0.0063 | 0.4255 | 0.4331 | -0.0067 | 0.4264 | 0.4521 | -0.0009 | 0.4511 | 0.4459 | 0.0000 | 0.4459 |
| **24** | 0.4402 | -0.0051 | 0.4351 | 0.4414 | -0.0065 | 0.4349 | 0.4436 | -0.0009 | 0.4427 | 0.4542 | 0.0000 | 0.4542 |
| **exit** | 0.4317 | 0.0000 | 0.4317 | 0.4330 | 0.0000 | 0.4330 | 0.4436 | 0.0000 | 0.4436 | 0.4542 | 0.0000 | 0.4542 |
| **TOTAL $q_c$** | **10.8742** | **-0.4112** | **10.4631** | **10.9070** | **-0.1899** | **10.7171** | **11.1642** | **-0.0336** | **11.1307** | **11.3382** | **-0.0037** | **11.3345** |

# Table M9: Coil Set Energy Balance for R3-60 at 10LPM

| Coilset | 1 second | | | 2 seconds | | | 3 seconds | | | 5 seconds | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Flow (kW) | Storage (kW) | Coil set $q_c$ (kW) | Flow (kW) | Storage (kW) | Coil set $q_c$ (kW) | Flow (kW) | Storage (kW) | Coil set $q_c$ (kW) | Flow (kW) | Storage (kW) | Coil set $q_c$ (kW) |
| **1** | 0.0274 | 0.0000 | 0.0274 | 0.0345 | -0.0693 | -0.0349 | 0.0483 | -0.1052 | -0.0569 | 0.0830 | -0.1285 | -0.0455 |
| **2** | 0.0274 | 0.0000 | 0.0274 | 0.0413 | -0.0663 | -0.0249 | 0.0483 | -0.1007 | -0.0524 | 0.0830 | -0.1231 | -0.0401 |
| **3** | 0.0274 | 0.0000 | 0.0274 | 0.0345 | -0.0635 | -0.0290 | 0.0552 | -0.0965 | -0.0414 | 0.0761 | -0.1180 | -0.0419 |
| **4** | 0.0274 | 0.0000 | 0.0274 | 0.0345 | -0.0605 | -0.0260 | 0.0483 | -0.0921 | -0.0438 | 0.0830 | -0.1126 | -0.0296 |
| **5** | 0.0342 | 0.0000 | 0.0342 | 0.0413 | -0.0577 | -0.0163 | 0.0483 | -0.0879 | -0.0396 | 0.0830 | -0.1073 | -0.0243 |
| **6** | 0.0274 | 0.0000 | 0.0274 | 0.0345 | -0.0549 | -0.0204 | 0.0483 | -0.0837 | -0.0355 | 0.0830 | -0.1019 | -0.0189 |
| **7** | 0.0274 | 0.0000 | 0.0274 | 0.0413 | -0.0519 | -0.0105 | 0.0483 | -0.0793 | -0.0310 | 0.0761 | -0.0966 | -0.0205 |
| **8** | 0.0274 | 0.0000 | 0.0274 | 0.0345 | -0.0491 | -0.0146 | 0.0552 | -0.0751 | -0.0199 | 0.0830 | -0.0914 | -0.0085 |
| **9** | 0.0274 | 0.0000 | 0.0274 | 0.0345 | -0.0461 | -0.0116 | 0.0483 | -0.0707 | -0.0224 | 0.0830 | -0.0861 | -0.0031 |
| **10** | 0.0274 | 0.0000 | 0.0274 | 0.0413 | -0.0433 | -0.0019 | 0.0483 | -0.0665 | -0.0182 | 0.0830 | -0.0807 | 0.0022 |
| **11** | 0.0274 | 0.0000 | 0.0274 | 0.0345 | -0.0405 | -0.0060 | 0.0483 | -0.0623 | -0.0140 | 0.0760 | -0.0754 | 0.0007 |
| **12** | 0.0274 | 0.0000 | 0.0274 | 0.0345 | -0.0374 | -0.0030 | 0.0483 | -0.0579 | -0.0096 | 0.0830 | -0.0700 | 0.0129 |
| **13** | 0.0342 | 0.0000 | 0.0342 | 0.0413 | -0.0347 | 0.0067 | 0.0552 | -0.0537 | 0.0015 | 0.0830 | -0.0649 | 0.0181 |
| **14** | 0.0274 | 0.0000 | 0.0274 | 0.0345 | -0.0316 | 0.0028 | 0.0483 | -0.0493 | -0.0010 | 0.0830 | -0.0596 | 0.0234 |
| **15** | 0.0274 | 0.0000 | 0.0274 | 0.0345 | -0.0288 | 0.0056 | 0.0483 | -0.0451 | 0.0032 | 0.0760 | -0.0542 | 0.0218 |
| **16** | 0.0274 | 0.0000 | 0.0274 | 0.0413 | -0.0260 | 0.0153 | 0.0483 | -0.0409 | 0.0073 | 0.0829 | -0.0488 | 0.0341 |
| **17** | 0.0274 | 0.0000 | 0.0274 | 0.0345 | -0.0230 | 0.0114 | 0.0483 | -0.0365 | 0.0118 | 0.0829 | -0.0435 | 0.0394 |
| **18** | 0.0274 | 0.0000 | 0.0274 | 0.0344 | -0.0202 | 0.0142 | 0.0552 | -0.0323 | 0.0229 | 0.0829 | -0.0384 | 0.0446 |
| **19** | 0.0274 | 0.0000 | 0.0274 | 0.0413 | -0.0172 | 0.0241 | 0.0483 | -0.0279 | 0.0204 | 0.0760 | -0.0330 | 0.0430 |
| **20** | 0.0274 | 0.0000 | 0.0274 | 0.0344 | -0.0144 | 0.0200 | 0.0483 | -0.0237 | 0.0246 | 0.0829 | -0.0277 | 0.0553 |
| **21** | 0.0342 | 0.0000 | 0.0342 | 0.0413 | -0.0116 | 0.0297 | 0.0483 | -0.0195 | 0.0287 | 0.0829 | -0.0223 | 0.0606 |
| **22** | 0.0274 | 0.0000 | 0.0274 | 0.0344 | -0.0086 | 0.0258 | 0.0483 | -0.0151 | 0.0332 | 0.0829 | -0.0170 | 0.0660 |
| **23** | 0.0274 | 0.0000 | 0.0274 | 0.0344 | -0.0058 | 0.0286 | 0.0552 | -0.0109 | 0.0442 | 0.0760 | -0.0119 | 0.0642 |
| **24** | 0.0274 | 0.0000 | 0.0274 | 0.0413 | -0.0028 | 0.0385 | 0.0483 | -0.0065 | 0.0418 | 0.0829 | -0.0065 | 0.0764 |
| **exit** | 0.0274 | 0.0000 | 0.0274 | 0.0344 | 0.0000 | 0.0344 | 0.0483 | 0.0000 | 0.0483 | 0.0829 | 0.0000 | 0.0829 |
| **TOTAL $q_c$** | **0.7054** | **0.0000** | **0.7054** | **0.9233** | **-0.8652** | **0.0581** | **1.2416** | **-1.3398** | **-0.0982** | **2.0324** | **-1.6194** | **0.4131** |

| Coilset | 8 seconds | | | 10 seconds | | | 15 seconds | | | 20 seconds | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Flow (kW) | Storage (kW) | Coil set $q_c$ (kW) | Flow (kW) | Storage (kW) | Coil set $q_c$ (kW) | Flow (kW) | Storage (kW) | Coil set $q_c$ (kW) | Flow (kW) | Storage (kW) | Coil set $q_c$ (kW) |
| **1** | 0.1310 | -0.1327 | -0.0018 | 0.1726 | -0.1731 | -0.0005 | 0.2577 | -0.1017 | 0.1560 | 0.3117 | -0.0553 | 0.2564 |
| **2** | 0.1309 | -0.1271 | 0.0038 | 0.1795 | -0.1654 | 0.0140 | 0.2646 | -0.0961 | 0.1686 | 0.3047 | -0.0518 | 0.2529 |
| **3** | 0.1240 | -0.1218 | 0.0023 | 0.1725 | -0.1579 | 0.0146 | 0.2576 | -0.0905 | 0.1672 | 0.3116 | -0.0485 | 0.2631 |
| **4** | 0.1309 | -0.1162 | 0.0147 | 0.1725 | -0.1502 | 0.0223 | 0.2576 | -0.0848 | 0.1727 | 0.3115 | -0.0450 | 0.2665 |
| **5** | 0.1309 | -0.1108 | 0.0201 | 0.1725 | -0.1428 | 0.0297 | 0.2645 | -0.0792 | 0.1853 | 0.3115 | -0.0415 | 0.2700 |
| **6** | 0.1309 | -0.1055 | 0.0255 | 0.1794 | -0.1353 | 0.0441 | 0.2575 | -0.0736 | 0.1839 | 0.3045 | -0.0380 | 0.2665 |
| **7** | 0.1309 | -0.0999 | 0.0310 | 0.1725 | -0.1276 | 0.0449 | 0.2575 | -0.0678 | 0.1897 | 0.3113 | -0.0345 | 0.2769 |
| **8** | 0.1240 | -0.0945 | 0.0295 | 0.1725 | -0.1202 | 0.0523 | 0.2644 | -0.0622 | 0.2022 | 0.3113 | -0.0312 | 0.2801 |
| **9** | 0.1309 | -0.0889 | 0.0420 | 0.1794 | -0.1125 | 0.0669 | 0.2574 | -0.0566 | 0.2008 | 0.3043 | -0.0277 | 0.2766 |
| **10** | 0.1309 | -0.0836 | 0.0473 | 0.1724 | -0.1050 | 0.0674 | 0.2574 | -0.0510 | 0.2064 | 0.3112 | -0.0242 | 0.2870 |
| **11** | 0.1309 | -0.0780 | 0.0529 | 0.1724 | -0.0975 | 0.0749 | 0.2643 | -0.0454 | 0.2189 | 0.3111 | -0.0207 | 0.2904 |
| **12** | 0.1309 | -0.0726 | 0.0583 | 0.1724 | -0.0899 | 0.0826 | 0.2573 | -0.0398 | 0.2175 | 0.3111 | -0.0172 | 0.2939 |
| **13** | 0.1240 | -0.0670 | 0.0570 | 0.1793 | -0.0824 | 0.0969 | 0.2573 | -0.0342 | 0.2230 | 0.3041 | -0.0140 | 0.2902 |
| **14** | 0.1308 | -0.0617 | 0.0692 | 0.1724 | -0.0747 | 0.0977 | 0.2572 | -0.0286 | 0.2286 | 0.3110 | -0.0105 | 0.3005 |
| **15** | 0.1308 | -0.0561 | 0.0748 | 0.1724 | -0.0673 | 0.1051 | 0.2642 | -0.0230 | 0.2411 | 0.3110 | -0.0070 | 0.3040 |
| **16** | 0.1308 | -0.0507 | 0.0801 | 0.1724 | -0.0598 | 0.1125 | 0.2572 | -0.0175 | 0.2397 | 0.3109 | -0.0035 | 0.3074 |
| **17** | 0.1308 | -0.0451 | 0.0857 | 0.1792 | -0.0521 | 0.1271 | 0.2571 | -0.0119 | 0.2453 | 0.3039 | 0.0000 | 0.3039 |
| **18** | 0.1239 | -0.0398 | 0.0842 | 0.1723 | -0.0447 | 0.1277 | 0.2641 | -0.0063 | 0.2578 | 0.3108 | 0.0033 | 0.3141 |
| **19** | 0.1308 | -0.0342 | 0.0966 | 0.1723 | -0.0370 | 0.1353 | 0.2571 | -0.0005 | 0.2566 | 0.3108 | 0.0067 | 0.3175 |
| **20** | 0.1308 | -0.0288 | 0.1020 | 0.1792 | -0.0295 | 0.1496 | 0.2570 | 0.0051 | 0.2622 | 0.3038 | 0.0102 | 0.3140 |
| **21** | 0.1308 | -0.0235 | 0.1073 | 0.1723 | -0.0221 | 0.1502 | 0.2640 | 0.0107 | 0.2747 | 0.3107 | 0.0137 | 0.3244 |
| **22** | 0.1308 | -0.0179 | 0.1129 | 0.1723 | -0.0144 | 0.1578 | 0.2570 | 0.0163 | 0.2733 | 0.3106 | 0.0172 | 0.3278 |
| **23** | 0.1239 | -0.0126 | 0.1113 | 0.1723 | -0.0070 | 0.1653 | 0.2570 | 0.0219 | 0.2788 | 0.3106 | 0.0205 | 0.3311 |
| **24** | 0.1308 | -0.0070 | 0.1238 | 0.1791 | 0.0007 | 0.1798 | 0.2639 | 0.0274 | 0.2913 | 0.3037 | 0.0239 | 0.3276 |
| **exit** | 0.1308 | 0.0000 | 0.1308 | 0.1722 | 0.0000 | 0.1722 | 0.2569 | 0.0000 | 0.2569 | 0.3105 | 0.0000 | 0.3105 |
| **TOTAL $q_c$** | **3.2370** | **-1.6759** | **1.5611** | **4.3582** | **-2.0677** | **2.2905** | **6.4876** | **-0.8893** | **5.5983** | **7.7283** | **-0.3751** | **7.3532** |

| Coilset | 30 seconds | | | 50 seconds | | | 100 seconds | | | 200 seconds | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Flow (kW) | Storage (kW) | Coil set $q_c$ (kW) | Flow (kW) | Storage (kW) | Coil set $q_c$ (kW) | Flow (kW) | Storage (kW) | Coil set $q_c$ (kW) | Flow (kW) | Storage (kW) | Coil set $q_c$ (kW) |
| **1** | 0.3758 | -0.0388 | 0.3371 | 0.3880 | -0.0126 | 0.3754 | 0.3950 | -0.0028 | 0.3922 | 0.4044 | -0.0005 | 0.4039 |
| **2** | 0.3688 | -0.0367 | 0.3321 | 0.3879 | -0.0124 | 0.3755 | 0.4018 | -0.0028 | 0.3990 | 0.4043 | -0.0005 | 0.4038 |
| **3** | 0.3757 | -0.0345 | 0.3411 | 0.3878 | -0.0119 | 0.3759 | 0.3948 | -0.0028 | 0.3920 | 0.4042 | -0.0005 | 0.4037 |
| **4** | 0.3686 | -0.0324 | 0.3362 | 0.3877 | -0.0117 | 0.3760 | 0.4016 | -0.0028 | 0.3988 | 0.4041 | -0.0002 | 0.4039 |
| **5** | 0.3755 | -0.0306 | 0.3449 | 0.3876 | -0.0114 | 0.3762 | 0.3946 | -0.0026 | 0.3921 | 0.4040 | -0.0002 | 0.4038 |
| **6** | 0.3754 | -0.0285 | 0.3469 | 0.3875 | -0.0112 | 0.3763 | 0.3945 | -0.0026 | 0.3920 | 0.4039 | -0.0002 | 0.4037 |
| **7** | 0.3684 | -0.0263 | 0.3420 | 0.3874 | -0.0107 | 0.3767 | 0.4013 | -0.0026 | 0.3988 | 0.4038 | -0.0002 | 0.4036 |
| **8** | 0.3752 | -0.0242 | 0.3510 | 0.3873 | -0.0105 | 0.3768 | 0.3943 | -0.0023 | 0.3920 | 0.4037 | -0.0002 | 0.4035 |
| **9** | 0.3682 | -0.0221 | 0.3460 | 0.3872 | -0.0103 | 0.3770 | 0.4011 | -0.0023 | 0.3988 | 0.4036 | -0.0002 | 0.4034 |
| **10** | 0.3750 | -0.0200 | 0.3550 | 0.3871 | -0.0100 | 0.3771 | 0.3941 | -0.0023 | 0.3918 | 0.4035 | -0.0002 | 0.4033 |
| **11** | 0.3750 | -0.0179 | 0.3570 | 0.3870 | -0.0098 | 0.3772 | 0.3940 | -0.0023 | 0.3917 | 0.4034 | -0.0002 | 0.4031 |
| **12** | 0.3680 | -0.0158 | 0.3521 | 0.3870 | -0.0093 | 0.3776 | 0.4008 | -0.0021 | 0.3987 | 0.4033 | -0.0002 | 0.4030 |
| **13** | 0.3748 | -0.0140 | 0.3609 | 0.3938 | -0.0091 | 0.3847 | 0.3938 | -0.0021 | 0.3917 | 0.4032 | -0.0002 | 0.4030 |
| **14** | 0.3678 | -0.0119 | 0.3560 | 0.3868 | -0.0089 | 0.3780 | 0.4007 | -0.0021 | 0.3986 | 0.4031 | -0.0002 | 0.4029 |
| **15** | 0.3747 | -0.0098 | 0.3649 | 0.3867 | -0.0086 | 0.3781 | 0.3937 | -0.0021 | 0.3916 | 0.4030 | -0.0002 | 0.4028 |
| **16** | 0.3746 | -0.0077 | 0.3669 | 0.3867 | -0.0081 | 0.3785 | 0.3936 | -0.0019 | 0.3918 | 0.4030 | -0.0002 | 0.4027 |
| **17** | 0.3676 | -0.0056 | 0.3620 | 0.3866 | -0.0079 | 0.3787 | 0.4004 | -0.0019 | 0.3986 | 0.4029 | -0.0002 | 0.4026 |
| **18** | 0.3745 | -0.0035 | 0.3710 | 0.3865 | -0.0077 | 0.3788 | 0.3935 | -0.0019 | 0.3916 | 0.4028 | -0.0002 | 0.4026 |
| **19** | 0.3675 | -0.0014 | 0.3661 | 0.3864 | -0.0074 | 0.3790 | 0.4003 | -0.0016 | 0.3987 | 0.4027 | -0.0002 | 0.4025 |
| **20** | 0.3744 | 0.0007 | 0.3751 | 0.3864 | -0.0072 | 0.3791 | 0.3933 | -0.0016 | 0.3917 | 0.4026 | 0.0000 | 0.4026 |
| **21** | 0.3743 | 0.0026 | 0.3769 | 0.3863 | -0.0067 | 0.3795 | 0.3932 | -0.0016 | 0.3916 | 0.4025 | 0.0000 | 0.4025 |
| **22** | 0.3673 | 0.0047 | 0.3720 | 0.3862 | -0.0065 | 0.3797 | 0.4001 | -0.0016 | 0.3984 | 0.4025 | 0.0000 | 0.4025 |
| **23** | 0.3742 | 0.0067 | 0.3809 | 0.3862 | -0.0063 | 0.3799 | 0.3931 | -0.0014 | 0.3917 | 0.4024 | 0.0000 | 0.4024 |
| **24** | 0.3672 | 0.0088 | 0.3760 | 0.3861 | -0.0060 | 0.3801 | 0.3999 | -0.0014 | 0.3985 | 0.4023 | 0.0000 | 0.4023 |
| **exit** | 0.3741 | 0.0000 | 0.3741 | 0.3860 | 0.0000 | 0.3860 | 0.3930 | 0.0000 | 0.3930 | 0.4023 | 0.0000 | 0.4023 |
| **TOTAL $q_c$** | **9.3026** | **-0.3583** | **8.9443** | **9.6802** | **-0.2224** | **9.4578** | **9.9168** | **-0.0515** | **9.8653** | **10.0815** | **-0.0051** | **10.0763** |

# Table M10: Coil Set Energy Balance for R3-60 at 9LPM

| Coilset | 1 second | | | 2 seconds | | | 3 seconds | | | 5 seconds | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Flow (kW) | Storage (kW) | Coil set $q_c$ (kW) | Flow (kW) | Storage (kW) | Coil set $q_c$ (kW) | Flow (kW) | Storage (kW) | Coil set $q_c$ (kW) | Flow (kW) | Storage (kW) | Coil set $q_c$ (kW) |
| **1** | 0.0245 | 0.0000 | 0.0245 | 0.0369 | -0.1093 | -0.0725 | 0.0493 | -0.1117 | -0.0624 | 0.0746 | -0.1217 | -0.0472 |
| **2** | 0.0245 | 0.0000 | 0.0245 | 0.0368 | -0.1047 | -0.0678 | 0.0493 | -0.1068 | -0.0576 | 0.0746 | -0.1166 | -0.0420 |
| **3** | 0.0184 | 0.0000 | 0.0184 | 0.0307 | -0.1000 | -0.0693 | 0.0431 | -0.1021 | -0.0591 | 0.0808 | -0.1113 | -0.0305 |
| **4** | 0.0245 | 0.0000 | 0.0245 | 0.0368 | -0.0954 | -0.0585 | 0.0492 | -0.0973 | -0.0480 | 0.0746 | -0.1061 | -0.0316 |
| **5** | 0.0245 | 0.0000 | 0.0245 | 0.0368 | -0.0907 | -0.0539 | 0.0492 | -0.0926 | -0.0434 | 0.0746 | -0.1010 | -0.0264 |
| **6** | 0.0245 | 0.0000 | 0.0245 | 0.0368 | -0.0861 | -0.0492 | 0.0492 | -0.0879 | -0.0387 | 0.0746 | -0.0959 | -0.0213 |
| **7** | 0.0184 | 0.0000 | 0.0184 | 0.0307 | -0.0814 | -0.0507 | 0.0492 | -0.0831 | -0.0338 | 0.0808 | -0.0908 | -0.0100 |
| **8** | 0.0245 | 0.0000 | 0.0245 | 0.0368 | -0.0768 | -0.0399 | 0.0431 | -0.0784 | -0.0353 | 0.0746 | -0.0854 | -0.0109 |
| **9** | 0.0245 | 0.0000 | 0.0245 | 0.0368 | -0.0721 | -0.0353 | 0.0492 | -0.0735 | -0.0243 | 0.0745 | -0.0803 | -0.0057 |
| **10** | 0.0245 | 0.0000 | 0.0245 | 0.0368 | -0.0675 | -0.0306 | 0.0492 | -0.0689 | -0.0196 | 0.0745 | -0.0752 | -0.0006 |
| **11** | 0.0184 | 0.0000 | 0.0184 | 0.0307 | -0.0628 | -0.0321 | 0.0492 | -0.0642 | -0.0150 | 0.0808 | -0.0700 | 0.0107 |
| **12** | 0.0245 | 0.0000 | 0.0245 | 0.0368 | -0.0582 | -0.0213 | 0.0492 | -0.0593 | -0.0101 | 0.0745 | -0.0649 | 0.0096 |
| **13** | 0.0245 | 0.0000 | 0.0245 | 0.0368 | -0.0535 | -0.0167 | 0.0431 | -0.0547 | -0.0116 | 0.0745 | -0.0596 | 0.0150 |
| **14** | 0.0245 | 0.0000 | 0.0245 | 0.0368 | -0.0488 | -0.0120 | 0.0492 | -0.0498 | -0.0005 | 0.0745 | -0.0544 | 0.0201 |
| **15** | 0.0184 | 0.0000 | 0.0184 | 0.0307 | -0.0442 | -0.0135 | 0.0492 | -0.0451 | 0.0041 | 0.0807 | -0.0493 | 0.0314 |
| **16** | 0.0245 | 0.0000 | 0.0245 | 0.0368 | -0.0395 | -0.0027 | 0.0492 | -0.0405 | 0.0088 | 0.0745 | -0.0442 | 0.0303 |
| **17** | 0.0245 | 0.0000 | 0.0245 | 0.0368 | -0.0349 | 0.0020 | 0.0492 | -0.0356 | 0.0136 | 0.0745 | -0.0391 | 0.0354 |
| **18** | 0.0245 | 0.0000 | 0.0245 | 0.0368 | -0.0302 | 0.0066 | 0.0431 | -0.0309 | 0.0121 | 0.0745 | -0.0337 | 0.0408 |
| **19** | 0.0184 | 0.0000 | 0.0184 | 0.0307 | -0.0256 | 0.0051 | 0.0492 | -0.0260 | 0.0232 | 0.0807 | -0.0286 | 0.0521 |
| **20** | 0.0245 | 0.0000 | 0.0245 | 0.0368 | -0.0209 | 0.0159 | 0.0492 | -0.0214 | 0.0278 | 0.0745 | -0.0235 | 0.0510 |
| **21** | 0.0245 | 0.0000 | 0.0245 | 0.0368 | -0.0163 | 0.0206 | 0.0492 | -0.0167 | 0.0325 | 0.0745 | -0.0184 | 0.0561 |
| **22** | 0.0245 | 0.0000 | 0.0245 | 0.0368 | -0.0116 | 0.0252 | 0.0492 | -0.0119 | 0.0374 | 0.0745 | -0.0133 | 0.0613 |
| **23** | 0.0184 | 0.0000 | 0.0184 | 0.0307 | -0.0070 | 0.0237 | 0.0431 | -0.0072 | 0.0359 | 0.0807 | -0.0079 | 0.0728 |
| **24** | 0.0245 | 0.0000 | 0.0245 | 0.0368 | -0.0023 | 0.0345 | 0.0492 | -0.0023 | 0.0469 | 0.0745 | -0.0028 | 0.0717 |
| **exit** | 0.0245 | 0.0000 | 0.0245 | 0.0368 | 0.0000 | 0.0368 | 0.0492 | 0.0000 | 0.0492 | 0.0745 | 0.0000 | 0.0745 |
| **TOTAL $q_c$** | **0.5758** | **0.0000** | **0.5758** | **0.8842** | **-1.3399** | **-0.4557** | **1.2002** | **-1.3680** | **-0.1678** | **1.9007** | **-1.4940** | **0.4067** |

| Coilset | 8 seconds | | | 10 seconds | | | 15 seconds | | | 20 seconds | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Flow (kW) | Storage (kW) | Coil set $q_c$ (kW) | Flow (kW) | Storage (kW) | Coil set $q_c$ (kW) | Flow (kW) | Storage (kW) | Coil set $q_c$ (kW) | Flow (kW) | Storage (kW) | Coil set $q_c$ (kW) |
| **1** | 0.1304 | -0.1465 | -0.0161 | 0.1612 | -0.1421 | 0.0191 | 0.2244 | -0.0723 | 0.1521 | 0.2822 | -0.0593 | 0.2229 |
| **2** | 0.1242 | -0.1400 | -0.0158 | 0.1674 | -0.1351 | 0.0322 | 0.2181 | -0.0678 | 0.1503 | 0.2821 | -0.0551 | 0.2271 |
| **3** | 0.1304 | -0.1337 | -0.0033 | 0.1612 | -0.1284 | 0.0328 | 0.2243 | -0.0636 | 0.1607 | 0.2758 | -0.0508 | 0.2250 |
| **4** | 0.1242 | -0.1272 | -0.0029 | 0.1674 | -0.1214 | 0.0460 | 0.2243 | -0.0592 | 0.1651 | 0.2820 | -0.0466 | 0.2354 |
| **5** | 0.1304 | -0.1209 | 0.0096 | 0.1611 | -0.1144 | 0.0468 | 0.2242 | -0.0550 | 0.1692 | 0.2820 | -0.0424 | 0.2395 |
| **6** | 0.1242 | -0.1143 | 0.0099 | 0.1673 | -0.1074 | 0.0600 | 0.2180 | -0.0506 | 0.1674 | 0.2819 | -0.0382 | 0.2437 |
| **7** | 0.1304 | -0.1078 | 0.0226 | 0.1611 | -0.1004 | 0.0607 | 0.2242 | -0.0464 | 0.1778 | 0.2756 | -0.0338 | 0.2418 |
| **8** | 0.1242 | -0.1015 | 0.0227 | 0.1673 | -0.0936 | 0.0737 | 0.2241 | -0.0419 | 0.1822 | 0.2818 | -0.0296 | 0.2522 |
| **9** | 0.1304 | -0.0950 | 0.0354 | 0.1611 | -0.0866 | 0.0745 | 0.2179 | -0.0377 | 0.1802 | 0.2818 | -0.0254 | 0.2564 |
| **10** | 0.1242 | -0.0887 | 0.0355 | 0.1673 | -0.0796 | 0.0876 | 0.2241 | -0.0333 | 0.1908 | 0.2817 | -0.0212 | 0.2605 |
| **11** | 0.1304 | -0.0822 | 0.0482 | 0.1611 | -0.0726 | 0.0884 | 0.2241 | -0.0291 | 0.1949 | 0.2754 | -0.0170 | 0.2584 |
| **12** | 0.1241 | -0.0756 | 0.0485 | 0.1672 | -0.0656 | 0.1016 | 0.2240 | -0.0247 | 0.1993 | 0.2816 | -0.0128 | 0.2688 |
| **13** | 0.1303 | -0.0694 | 0.0610 | 0.1610 | -0.0589 | 0.1021 | 0.2178 | -0.0205 | 0.1973 | 0.2816 | -0.0086 | 0.2730 |
| **14** | 0.1241 | -0.0628 | 0.0613 | 0.1672 | -0.0519 | 0.1153 | 0.2240 | -0.0161 | 0.2079 | 0.2815 | -0.0044 | 0.2771 |
| **15** | 0.1303 | -0.0565 | 0.0738 | 0.1610 | -0.0449 | 0.1161 | 0.2239 | -0.0119 | 0.2121 | 0.2752 | -0.0002 | 0.2750 |
| **16** | 0.1241 | -0.0500 | 0.0741 | 0.1672 | -0.0379 | 0.1292 | 0.2239 | -0.0074 | 0.2165 | 0.2815 | 0.0040 | 0.2854 |
| **17** | 0.1303 | -0.0435 | 0.0868 | 0.1610 | -0.0309 | 0.1300 | 0.2177 | -0.0033 | 0.2144 | 0.2814 | 0.0081 | 0.2896 |
| **18** | 0.1241 | -0.0372 | 0.0869 | 0.1671 | -0.0242 | 0.1430 | 0.2239 | 0.0012 | 0.2250 | 0.2814 | 0.0123 | 0.2937 |
| **19** | 0.1303 | -0.0307 | 0.0996 | 0.1609 | -0.0172 | 0.1437 | 0.2238 | 0.0054 | 0.2292 | 0.2751 | 0.0167 | 0.2918 |
| **20** | 0.1241 | -0.0244 | 0.0996 | 0.1671 | -0.0102 | 0.1569 | 0.2176 | 0.0098 | 0.2274 | 0.2813 | 0.0209 | 0.3022 |
| **21** | 0.1303 | -0.0179 | 0.1124 | 0.1609 | -0.0033 | 0.1577 | 0.2238 | 0.0140 | 0.2377 | 0.2813 | 0.0251 | 0.3064 |
| **22** | 0.1241 | -0.0114 | 0.1127 | 0.1671 | 0.0037 | 0.1708 | 0.2238 | 0.0184 | 0.2421 | 0.2812 | 0.0293 | 0.3105 |
| **23** | 0.1302 | -0.0051 | 0.1251 | 0.1609 | 0.0105 | 0.1714 | 0.2237 | 0.0226 | 0.2463 | 0.2749 | 0.0335 | 0.3084 |
| **24** | 0.1240 | 0.0014 | 0.1254 | 0.1671 | 0.0174 | 0.1845 | 0.2175 | 0.0270 | 0.2445 | 0.2811 | 0.0377 | 0.3188 |
| **exit** | 0.1302 | 0.0000 | 0.1302 | 0.1609 | 0.0000 | 0.1609 | 0.2237 | 0.0000 | 0.2237 | 0.2811 | 0.0000 | 0.2811 |
| **TOTAL $q_c$** | **3.1839** | **-1.7410** | **1.4429** | **4.1001** | **-1.4952** | **2.6050** | **5.5567** | **-0.5426** | **5.0140** | **7.0026** | **-0.2578** | **6.7447** |

| Coilset | 30 seconds | | | 50 seconds | | | 100 seconds | | | 200 seconds | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Flow (kW) | Storage (kW) | Coil set $q_c$ (kW) | Flow (kW) | Storage (kW) | Coil set $q_c$ (kW) | Flow (kW) | Storage (kW) | Coil set $q_c$ (kW) | Flow (kW) | Storage (kW) | Coil set $q_c$ (kW) |
| **1** | 0.3404 | -0.0346 | 0.3058 | 0.3578 | -0.0131 | 0.3448 | 0.3717 | -0.0030 | 0.3687 | 0.3689 | -0.0005 | 0.3684 |
| **2** | 0.3403 | -0.0324 | 0.3078 | 0.3578 | -0.0128 | 0.3449 | 0.3653 | -0.0030 | 0.3623 | 0.3750 | -0.0005 | 0.3746 |
| **3** | 0.3402 | -0.0303 | 0.3099 | 0.3577 | -0.0124 | 0.3453 | 0.3716 | -0.0030 | 0.3685 | 0.3687 | -0.0005 | 0.3682 |
| **4** | 0.3338 | -0.0282 | 0.3056 | 0.3576 | -0.0121 | 0.3454 | 0.3652 | -0.0028 | 0.3624 | 0.3686 | -0.0005 | 0.3681 |
| **5** | 0.3400 | -0.0261 | 0.3139 | 0.3575 | -0.0117 | 0.3458 | 0.3714 | -0.0028 | 0.3686 | 0.3748 | -0.0005 | 0.3743 |
| **6** | 0.3399 | -0.0240 | 0.3159 | 0.3574 | -0.0112 | 0.3462 | 0.3650 | -0.0028 | 0.3622 | 0.3684 | -0.0005 | 0.3679 |
| **7** | 0.3399 | -0.0217 | 0.3182 | 0.3573 | -0.0110 | 0.3463 | 0.3712 | -0.0026 | 0.3686 | 0.3683 | -0.0005 | 0.3679 |
| **8** | 0.3398 | -0.0196 | 0.3202 | 0.3572 | -0.0105 | 0.3467 | 0.3648 | -0.0026 | 0.3622 | 0.3745 | -0.0005 | 0.3740 |
| **9** | 0.3397 | -0.0175 | 0.3222 | 0.3571 | -0.0103 | 0.3469 | 0.3710 | -0.0026 | 0.3684 | 0.3681 | -0.0002 | 0.3679 |
| **10** | 0.3334 | -0.0154 | 0.3180 | 0.3570 | -0.0098 | 0.3473 | 0.3646 | -0.0023 | 0.3623 | 0.3680 | -0.0002 | 0.3678 |
| **11** | 0.3396 | -0.0133 | 0.3263 | 0.3570 | -0.0093 | 0.3476 | 0.3708 | -0.0023 | 0.3685 | 0.3742 | -0.0002 | 0.3739 |
| **12** | 0.3395 | -0.0112 | 0.3283 | 0.3569 | -0.0091 | 0.3478 | 0.3644 | -0.0023 | 0.3621 | 0.3678 | -0.0002 | 0.3676 |
| **13** | 0.3395 | -0.0091 | 0.3304 | 0.3631 | -0.0086 | 0.3545 | 0.3706 | -0.0023 | 0.3683 | 0.3678 | -0.0002 | 0.3675 |
| **14** | 0.3394 | -0.0070 | 0.3324 | 0.3567 | -0.0084 | 0.3484 | 0.3643 | -0.0021 | 0.3622 | 0.3677 | -0.0002 | 0.3675 |
| **15** | 0.3393 | -0.0049 | 0.3344 | 0.3567 | -0.0079 | 0.3488 | 0.3705 | -0.0021 | 0.3684 | 0.3738 | -0.0002 | 0.3736 |
| **16** | 0.3330 | -0.0028 | 0.3302 | 0.3566 | -0.0074 | 0.3492 | 0.3641 | -0.0021 | 0.3620 | 0.3675 | -0.0002 | 0.3673 |
| **17** | 0.3392 | -0.0007 | 0.3385 | 0.3565 | -0.0072 | 0.3493 | 0.3703 | -0.0019 | 0.3685 | 0.3675 | -0.0002 | 0.3672 |
| **18** | 0.3391 | 0.0014 | 0.3405 | 0.3565 | -0.0067 | 0.3497 | 0.3640 | -0.0019 | 0.3621 | 0.3736 | -0.0002 | 0.3734 |
| **19** | 0.3391 | 0.0037 | 0.3428 | 0.3564 | -0.0065 | 0.3499 | 0.3702 | -0.0019 | 0.3683 | 0.3673 | -0.0002 | 0.3671 |
| **20** | 0.3390 | 0.0058 | 0.3448 | 0.3563 | -0.0060 | 0.3503 | 0.3638 | -0.0016 | 0.3622 | 0.3672 | -0.0002 | 0.3670 |
| **21** | 0.3390 | 0.0079 | 0.3469 | 0.3563 | -0.0056 | 0.3507 | 0.3700 | -0.0016 | 0.3684 | 0.3734 | -0.0002 | 0.3732 |
| **22** | 0.3326 | 0.0100 | 0.3426 | 0.3562 | -0.0053 | 0.3509 | 0.3637 | -0.0016 | 0.3621 | 0.3671 | 0.0000 | 0.3671 |
| **23** | 0.3389 | 0.0121 | 0.3510 | 0.3562 | -0.0049 | 0.3513 | 0.3699 | -0.0016 | 0.3683 | 0.3670 | 0.0000 | 0.3670 |
| **24** | 0.3388 | 0.0142 | 0.3530 | 0.3561 | -0.0046 | 0.3514 | 0.3636 | -0.0014 | 0.3622 | 0.3732 | 0.0000 | 0.3732 |
| **exit** | 0.3388 | 0.0000 | 0.3388 | 0.3560 | 0.0000 | 0.3560 | 0.3698 | 0.0000 | 0.3698 | 0.3669 | 0.0000 | 0.3669 |
| **TOTAL $q_c$** | **8.4621** | **-0.2436** | **8.2185** | **8.9279** | **-0.2126** | **8.7153** | **9.1918** | **-0.0543** | **9.1375** | **9.2455** | **-0.0068** | **9.2388** |

# Table M11: Coil Set Energy Balance for R3-60 at 7LPM

| Coilset | 1 second | | | 2 seconds | | | 3 seconds | | | 5 seconds | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Flow (kW) | Storage (kW) | Coil set $q_c$ (kW) | Flow (kW) | Storage (kW) | Coil set $q_c$ (kW) | Flow (kW) | Storage (kW) | Coil set $q_c$ (kW) | Flow (kW) | Storage (kW) | Coil set $q_c$ (kW) |
| **1** | 0.0096 | 0.0000 | 0.0096 | 0.0097 | -0.0202 | -0.0106 | 0.0195 | -0.0982 | -0.0787 | 0.0244 | -0.0358 | -0.0114 |
| **2** | 0.0096 | 0.0000 | 0.0096 | 0.0097 | -0.0195 | -0.0099 | 0.0195 | -0.0940 | -0.0745 | 0.0244 | -0.0342 | -0.0098 |
| **3** | 0.0048 | 0.0000 | 0.0048 | 0.0097 | -0.0186 | -0.0089 | 0.0195 | -0.0898 | -0.0703 | 0.0293 | -0.0328 | -0.0035 |
| **4** | 0.0096 | 0.0000 | 0.0096 | 0.0097 | -0.0179 | -0.0082 | 0.0195 | -0.0856 | -0.0661 | 0.0244 | -0.0312 | -0.0068 |
| **5** | 0.0096 | 0.0000 | 0.0096 | 0.0145 | -0.0172 | -0.0027 | 0.0195 | -0.0814 | -0.0619 | 0.0244 | -0.0298 | -0.0054 |
| **6** | 0.0096 | 0.0000 | 0.0096 | 0.0097 | -0.0165 | -0.0068 | 0.0195 | -0.0772 | -0.0578 | 0.0244 | -0.0284 | -0.0040 |
| **7** | 0.0096 | 0.0000 | 0.0096 | 0.0097 | -0.0158 | -0.0062 | 0.0146 | -0.0730 | -0.0584 | 0.0244 | -0.0268 | -0.0023 |
| **8** | 0.0048 | 0.0000 | 0.0048 | 0.0097 | -0.0149 | -0.0052 | 0.0195 | -0.0689 | -0.0494 | 0.0293 | -0.0254 | 0.0039 |
| **9** | 0.0096 | 0.0000 | 0.0096 | 0.0097 | -0.0142 | -0.0045 | 0.0195 | -0.0647 | -0.0452 | 0.0244 | -0.0237 | 0.0007 |
| **10** | 0.0096 | 0.0000 | 0.0096 | 0.0097 | -0.0135 | -0.0038 | 0.0195 | -0.0605 | -0.0410 | 0.0244 | -0.0223 | 0.0021 |
| **11** | 0.0096 | 0.0000 | 0.0096 | 0.0097 | -0.0128 | -0.0031 | 0.0195 | -0.0563 | -0.0368 | 0.0244 | -0.0209 | 0.0035 |
| **12** | 0.0096 | 0.0000 | 0.0096 | 0.0097 | -0.0121 | -0.0024 | 0.0195 | -0.0521 | -0.0326 | 0.0244 | -0.0193 | 0.0051 |
| **13** | 0.0048 | 0.0000 | 0.0048 | 0.0145 | -0.0112 | 0.0033 | 0.0195 | -0.0479 | -0.0284 | 0.0293 | -0.0179 | 0.0114 |
| **14** | 0.0096 | 0.0000 | 0.0096 | 0.0097 | -0.0105 | -0.0008 | 0.0195 | -0.0437 | -0.0243 | 0.0244 | -0.0163 | 0.0081 |
| **15** | 0.0096 | 0.0000 | 0.0096 | 0.0097 | -0.0098 | -0.0001 | 0.0195 | -0.0395 | -0.0201 | 0.0244 | -0.0149 | 0.0095 |
| **16** | 0.0096 | 0.0000 | 0.0096 | 0.0097 | -0.0091 | 0.0006 | 0.0195 | -0.0354 | -0.0159 | 0.0244 | -0.0135 | 0.0109 |
| **17** | 0.0096 | 0.0000 | 0.0096 | 0.0097 | -0.0084 | 0.0013 | 0.0195 | -0.0312 | -0.0117 | 0.0244 | -0.0119 | 0.0125 |
| **18** | 0.0048 | 0.0000 | 0.0048 | 0.0097 | -0.0074 | 0.0022 | 0.0195 | -0.0270 | -0.0075 | 0.0293 | -0.0105 | 0.0188 |
| **19** | 0.0096 | 0.0000 | 0.0096 | 0.0097 | -0.0067 | 0.0029 | 0.0146 | -0.0228 | -0.0082 | 0.0244 | -0.0088 | 0.0156 |
| **20** | 0.0096 | 0.0000 | 0.0096 | 0.0097 | -0.0060 | 0.0036 | 0.0195 | -0.0186 | 0.0009 | 0.0244 | -0.0074 | 0.0170 |
| **21** | 0.0096 | 0.0000 | 0.0096 | 0.0145 | -0.0053 | 0.0091 | 0.0195 | -0.0144 | 0.0050 | 0.0244 | -0.0060 | 0.0184 |
| **22** | 0.0096 | 0.0000 | 0.0096 | 0.0097 | -0.0047 | 0.0050 | 0.0195 | -0.0102 | 0.0092 | 0.0244 | -0.0044 | 0.0200 |
| **23** | 0.0048 | 0.0000 | 0.0048 | 0.0097 | -0.0037 | 0.0059 | 0.0195 | -0.0060 | 0.0134 | 0.0293 | -0.0030 | 0.0263 |
| **24** | 0.0096 | 0.0000 | 0.0096 | 0.0097 | -0.0030 | 0.0066 | 0.0195 | -0.0019 | 0.0176 | 0.0244 | -0.0014 | 0.0230 |
| **exit** | 0.0096 | 0.0000 | 0.0096 | 0.0097 | 0.0000 | 0.0097 | 0.0195 | 0.0000 | 0.0195 | 0.0244 | 0.0000 | 0.0244 |
| **TOTAL $q_c$** | **0.2168** | **0.0000** | **0.2168** | **0.2561** | **-0.2791** | **-0.0230** | **0.4770** | **-1.2003** | **-0.7232** | **0.6346** | **-0.4466** | **0.1880** |

| Coilset | 8 seconds | | | 10 seconds | | | 15 seconds | | | 20 seconds | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Flow (kW) | Storage (kW) | Coil set $q_c$ (kW) | Flow (kW) | Storage (kW) | Coil set $q_c$ (kW) | Flow (kW) | Storage (kW) | Coil set $q_c$ (kW) | Flow (kW) | Storage (kW) | Coil set $q_c$ (kW) |
| **1** | 0.0595 | -0.1429 | -0.0834 | 0.0746 | -0.0859 | -0.0114 | 0.1277 | -0.1079 | 0.0198 | 0.1680 | -0.0564 | 0.1116 |
| **2** | 0.0546 | -0.1369 | -0.0823 | 0.0745 | -0.0824 | -0.0079 | 0.1277 | -0.1028 | 0.0249 | 0.1680 | -0.0525 | 0.1156 |
| **3** | 0.0595 | -0.1308 | -0.0713 | 0.0696 | -0.0787 | -0.0091 | 0.1277 | -0.0974 | 0.0303 | 0.1729 | -0.0487 | 0.1242 |
| **4** | 0.0595 | -0.1250 | -0.0655 | 0.0745 | -0.0752 | -0.0007 | 0.1277 | -0.0923 | 0.0354 | 0.1680 | -0.0450 | 0.1230 |
| **5** | 0.0546 | -0.1189 | -0.0644 | 0.0745 | -0.0715 | 0.0031 | 0.1277 | -0.0869 | 0.0408 | 0.1679 | -0.0410 | 0.1269 |
| **6** | 0.0595 | -0.1129 | -0.0533 | 0.0745 | -0.0677 | 0.0068 | 0.1276 | -0.0818 | 0.0459 | 0.1679 | -0.0373 | 0.1306 |
| **7** | 0.0595 | -0.1068 | -0.0473 | 0.0745 | -0.0642 | 0.0103 | 0.1325 | -0.0764 | 0.0561 | 0.1728 | -0.0335 | 0.1393 |
| **8** | 0.0546 | -0.1008 | -0.0462 | 0.0696 | -0.0605 | 0.0090 | 0.1276 | -0.0713 | 0.0564 | 0.1679 | -0.0296 | 0.1383 |
| **9** | 0.0595 | -0.0947 | -0.0352 | 0.0745 | -0.0570 | 0.0175 | 0.1276 | -0.0659 | 0.0617 | 0.1678 | -0.0259 | 0.1420 |
| **10** | 0.0595 | -0.0887 | -0.0291 | 0.0745 | -0.0533 | 0.0212 | 0.1276 | -0.0605 | 0.0671 | 0.1678 | -0.0221 | 0.1457 |
| **11** | 0.0546 | -0.0826 | -0.0280 | 0.0745 | -0.0496 | 0.0249 | 0.1276 | -0.0554 | 0.0722 | 0.1727 | -0.0182 | 0.1546 |
| **12** | 0.0595 | -0.0768 | -0.0173 | 0.0745 | -0.0461 | 0.0284 | 0.1276 | -0.0501 | 0.0775 | 0.1678 | -0.0144 | 0.1534 |
| **13** | 0.0595 | -0.0707 | -0.0112 | 0.0695 | -0.0424 | 0.0272 | 0.1276 | -0.0449 | 0.0826 | 0.1678 | -0.0107 | 0.1571 |
| **14** | 0.0595 | -0.0647 | -0.0052 | 0.0745 | -0.0389 | 0.0356 | 0.1275 | -0.0396 | 0.0880 | 0.1677 | -0.0070 | 0.1608 |
| **15** | 0.0546 | -0.0586 | -0.0041 | 0.0745 | -0.0351 | 0.0394 | 0.1275 | -0.0344 | 0.0931 | 0.1727 | -0.0030 | 0.1696 |
| **16** | 0.0595 | -0.0526 | 0.0069 | 0.0745 | -0.0314 | 0.0431 | 0.1275 | -0.0291 | 0.0984 | 0.1677 | 0.0007 | 0.1684 |
| **17** | 0.0595 | -0.0465 | 0.0130 | 0.0745 | -0.0279 | 0.0466 | 0.1275 | -0.0237 | 0.1038 | 0.1677 | 0.0044 | 0.1721 |
| **18** | 0.0545 | -0.0405 | 0.0141 | 0.0695 | -0.0242 | 0.0453 | 0.1275 | -0.0186 | 0.1089 | 0.1677 | 0.0084 | 0.1760 |
| **19** | 0.0595 | -0.0347 | 0.0248 | 0.0745 | -0.0207 | 0.0538 | 0.1324 | -0.0133 | 0.1191 | 0.1726 | 0.0121 | 0.1847 |
| **20** | 0.0595 | -0.0286 | 0.0309 | 0.0745 | -0.0170 | 0.0575 | 0.1275 | -0.0081 | 0.1193 | 0.1676 | 0.0158 | 0.1835 |
| **21** | 0.0545 | -0.0226 | 0.0320 | 0.0745 | -0.0133 | 0.0612 | 0.1275 | -0.0028 | 0.1247 | 0.1676 | 0.0198 | 0.1874 |
| **22** | 0.0595 | -0.0165 | 0.0430 | 0.0745 | -0.0098 | 0.0647 | 0.1275 | 0.0023 | 0.1298 | 0.1676 | 0.0235 | 0.1911 |
| **23** | 0.0595 | -0.0105 | 0.0490 | 0.0695 | -0.0060 | 0.0635 | 0.1275 | 0.0077 | 0.1351 | 0.1725 | 0.0272 | 0.1997 |
| **24** | 0.0545 | -0.0044 | 0.0501 | 0.0745 | -0.0026 | 0.0719 | 0.1274 | 0.0128 | 0.1402 | 0.1676 | 0.0312 | 0.1987 |
| **exit** | 0.0595 | 0.0000 | 0.0595 | 0.0745 | 0.0000 | 0.0745 | 0.1274 | 0.0000 | 0.1274 | 0.1675 | 0.0000 | 0.1675 |
| **TOTAL $q_c$** | **1.4482** | **-1.7686** | **-0.3204** | **1.8379** | **-1.0613** | **0.7765** | **3.1988** | **-1.1403** | **2.0586** | **4.2239** | **-0.3022** | **3.9217** |

| Coilset | 30 seconds | | | 50 seconds | | | 100 seconds | | | 200 seconds | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Flow (kW) | Storage (kW) | Coil set $q_c$ (kW) | Flow (kW) | Storage (kW) | Coil set $q_c$ (kW) | Flow (kW) | Storage (kW) | Coil set $q_c$ (kW) | Flow (kW) | Storage (kW) | Coil set $q_c$ (kW) |
| **1** | 0.2508 | -0.0471 | 0.2037 | 0.2941 | -0.0177 | 0.2763 | 0.3137 | -0.0044 | 0.3093 | 0.3183 | -0.0007 | 0.3176 |
| **2** | 0.2558 | -0.0434 | 0.2124 | 0.2990 | -0.0166 | 0.2824 | 0.3087 | -0.0044 | 0.3042 | 0.3182 | -0.0007 | 0.3175 |
| **3** | 0.2507 | -0.0397 | 0.2110 | 0.2939 | -0.0156 | 0.2783 | 0.3135 | -0.0042 | 0.3093 | 0.3181 | -0.0007 | 0.3174 |
| **4** | 0.2506 | -0.0359 | 0.2147 | 0.2939 | -0.0145 | 0.2794 | 0.3085 | -0.0040 | 0.3045 | 0.3180 | -0.0007 | 0.3173 |
| **5** | 0.2556 | -0.0322 | 0.2234 | 0.2988 | -0.0135 | 0.2852 | 0.3134 | -0.0040 | 0.3094 | 0.3130 | -0.0005 | 0.3125 |
| **6** | 0.2505 | -0.0284 | 0.2221 | 0.2937 | -0.0124 | 0.2813 | 0.3083 | -0.0037 | 0.3046 | 0.3178 | -0.0005 | 0.3174 |
| **7** | 0.2505 | -0.0245 | 0.2260 | 0.2986 | -0.0114 | 0.2872 | 0.3132 | -0.0035 | 0.3097 | 0.3178 | -0.0005 | 0.3173 |
| **8** | 0.2554 | -0.0207 | 0.2347 | 0.2936 | -0.0103 | 0.2833 | 0.3081 | -0.0035 | 0.3046 | 0.3177 | -0.0005 | 0.3172 |
| **9** | 0.2504 | -0.0170 | 0.2334 | 0.2935 | -0.0093 | 0.2842 | 0.3130 | -0.0033 | 0.3098 | 0.3176 | -0.0005 | 0.3171 |
| **10** | 0.2503 | -0.0133 | 0.2371 | 0.2984 | -0.0082 | 0.2902 | 0.3080 | -0.0030 | 0.3049 | 0.3175 | -0.0005 | 0.3170 |
| **11** | 0.2553 | -0.0095 | 0.2458 | 0.2934 | -0.0072 | 0.2861 | 0.3129 | -0.0030 | 0.3098 | 0.3174 | -0.0005 | 0.3169 |
| **12** | 0.2503 | -0.0058 | 0.2444 | 0.2933 | -0.0061 | 0.2872 | 0.3078 | -0.0028 | 0.3050 | 0.3173 | -0.0002 | 0.3171 |
| **13** | 0.2502 | -0.0021 | 0.2481 | 0.2982 | -0.0051 | 0.2931 | 0.3127 | -0.0028 | 0.3099 | 0.3123 | -0.0002 | 0.3121 |
| **14** | 0.2502 | 0.0016 | 0.2518 | 0.2932 | -0.0040 | 0.2892 | 0.3077 | -0.0026 | 0.3051 | 0.3172 | -0.0002 | 0.3170 |
| **15** | 0.2551 | 0.0054 | 0.2605 | 0.2931 | -0.0030 | 0.2901 | 0.3126 | -0.0023 | 0.3103 | 0.3171 | -0.0002 | 0.3169 |
| **16** | 0.2501 | 0.0091 | 0.2592 | 0.2980 | -0.0019 | 0.2962 | 0.3076 | -0.0023 | 0.3052 | 0.3171 | -0.0002 | 0.3168 |
| **17** | 0.2500 | 0.0128 | 0.2628 | 0.2930 | -0.0009 | 0.2921 | 0.3125 | -0.0021 | 0.3104 | 0.3170 | -0.0002 | 0.3168 |
| **18** | 0.2550 | 0.0165 | 0.2715 | 0.2929 | 0.0002 | 0.2932 | 0.3074 | -0.0019 | 0.3056 | 0.3169 | -0.0002 | 0.3167 |
| **19** | 0.2500 | 0.0205 | 0.2704 | 0.2979 | 0.0012 | 0.2990 | 0.3123 | -0.0019 | 0.3105 | 0.3169 | -0.0002 | 0.3166 |
| **20** | 0.2499 | 0.0242 | 0.2741 | 0.2928 | 0.0023 | 0.2952 | 0.3073 | -0.0016 | 0.3057 | 0.3168 | 0.0000 | 0.3168 |
| **21** | 0.2549 | 0.0279 | 0.2828 | 0.2977 | 0.0033 | 0.3010 | 0.3122 | -0.0016 | 0.3106 | 0.3118 | 0.0000 | 0.3118 |
| **22** | 0.2498 | 0.0316 | 0.2815 | 0.2927 | 0.0044 | 0.2972 | 0.3072 | -0.0014 | 0.3058 | 0.3167 | 0.0000 | 0.3167 |
| **23** | 0.2498 | 0.0353 | 0.2851 | 0.2927 | 0.0053 | 0.2980 | 0.3121 | -0.0012 | 0.3110 | 0.3166 | 0.0000 | 0.3166 |
| **24** | 0.2548 | 0.0390 | 0.2938 | 0.2976 | 0.0065 | 0.3041 | 0.3071 | -0.0012 | 0.3059 | 0.3166 | 0.0000 | 0.3166 |
| **exit** | 0.2497 | 0.0000 | 0.2497 | 0.2926 | 0.0000 | 0.2926 | 0.3120 | 0.0000 | 0.3120 | 0.3165 | 0.0000 | 0.3165 |
| **TOTAL $q_c$** | **6.2957** | **-0.0958** | **6.1999** | **7.3765** | **-0.1344** | **7.2421** | **7.7600** | **-0.0667** | **7.6934** | **7.9182** | **-0.0079** | **7.9102** |

# Table M12: Coil Set Energy Balance for R3-60 at 5.5LPM

| Coilset | 1 second | | | 2 seconds | | | 3 seconds | | | 5 seconds | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Flow (kW) | Storage (kW) | Coil set $q_c$ (kW) | Flow (kW) | Storage (kW) | Coil set $q_c$ (kW) | Flow (kW) | Storage (kW) | Coil set $q_c$ (kW) | Flow (kW) | Storage (kW) | Coil set $q_c$ (kW) |
| **1** | 0.0073 | 0.0000 | 0.0073 | 0.0072 | -0.0358 | -0.0286 | 0.0146 | -0.0870 | -0.0725 | 0.0218 | -0.0512 | -0.0295 |
| **2** | 0.0036 | 0.0000 | 0.0036 | 0.0072 | -0.0342 | -0.0270 | 0.0146 | -0.0833 | -0.0688 | 0.0218 | -0.0491 | -0.0274 |
| **3** | 0.0073 | 0.0000 | 0.0073 | 0.0109 | -0.0328 | -0.0219 | 0.0146 | -0.0796 | -0.0650 | 0.0181 | -0.0468 | -0.0287 |
| **4** | 0.0036 | 0.0000 | 0.0036 | 0.0072 | -0.0312 | -0.0239 | 0.0109 | -0.0759 | -0.0649 | 0.0218 | -0.0447 | -0.0229 |
| **5** | 0.0073 | 0.0000 | 0.0073 | 0.0072 | -0.0298 | -0.0225 | 0.0146 | -0.0721 | -0.0576 | 0.0218 | -0.0424 | -0.0206 |
| **6** | 0.0073 | 0.0000 | 0.0073 | 0.0072 | -0.0284 | -0.0211 | 0.0146 | -0.0684 | -0.0539 | 0.0218 | -0.0400 | -0.0183 |
| **7** | 0.0036 | 0.0000 | 0.0036 | 0.0109 | -0.0268 | -0.0159 | 0.0146 | -0.0647 | -0.0501 | 0.0181 | -0.0379 | -0.0198 |
| **8** | 0.0073 | 0.0000 | 0.0073 | 0.0072 | -0.0254 | -0.0181 | 0.0146 | -0.0610 | -0.0464 | 0.0217 | -0.0356 | -0.0139 |
| **9** | 0.0036 | 0.0000 | 0.0036 | 0.0072 | -0.0237 | -0.0165 | 0.0146 | -0.0572 | -0.0427 | 0.0217 | -0.0335 | -0.0118 |
| **10** | 0.0073 | 0.0000 | 0.0073 | 0.0072 | -0.0223 | -0.0151 | 0.0109 | -0.0535 | -0.0426 | 0.0217 | -0.0312 | -0.0094 |
| **11** | 0.0073 | 0.0000 | 0.0073 | 0.0109 | -0.0209 | -0.0101 | 0.0146 | -0.0498 | -0.0352 | 0.0181 | -0.0289 | -0.0107 |
| **12** | 0.0036 | 0.0000 | 0.0036 | 0.0072 | -0.0193 | -0.0121 | 0.0146 | -0.0461 | -0.0315 | 0.0217 | -0.0268 | -0.0050 |
| **13** | 0.0073 | 0.0000 | 0.0073 | 0.0072 | -0.0179 | -0.0107 | 0.0146 | -0.0423 | -0.0278 | 0.0217 | -0.0244 | -0.0027 |
| **14** | 0.0036 | 0.0000 | 0.0036 | 0.0072 | -0.0163 | -0.0090 | 0.0146 | -0.0386 | -0.0241 | 0.0217 | -0.0223 | -0.0006 |
| **15** | 0.0073 | 0.0000 | 0.0073 | 0.0109 | -0.0149 | -0.0040 | 0.0146 | -0.0349 | -0.0203 | 0.0181 | -0.0200 | -0.0019 |
| **16** | 0.0073 | 0.0000 | 0.0073 | 0.0072 | -0.0135 | -0.0062 | 0.0109 | -0.0312 | -0.0203 | 0.0217 | -0.0177 | 0.0041 |
| **17** | 0.0036 | 0.0000 | 0.0036 | 0.0072 | -0.0119 | -0.0046 | 0.0146 | -0.0275 | -0.0129 | 0.0217 | -0.0156 | 0.0062 |
| **18** | 0.0073 | 0.0000 | 0.0073 | 0.0072 | -0.0105 | -0.0032 | 0.0146 | -0.0237 | -0.0092 | 0.0217 | -0.0133 | 0.0085 |
| **19** | 0.0036 | 0.0000 | 0.0036 | 0.0109 | -0.0088 | 0.0020 | 0.0146 | -0.0200 | -0.0055 | 0.0181 | -0.0112 | 0.0070 |
| **20** | 0.0073 | 0.0000 | 0.0073 | 0.0072 | -0.0074 | -0.0002 | 0.0146 | -0.0163 | -0.0017 | 0.0217 | -0.0088 | 0.0129 |
| **21** | 0.0073 | 0.0000 | 0.0073 | 0.0072 | -0.0060 | 0.0012 | 0.0146 | -0.0126 | 0.0020 | 0.0217 | -0.0065 | 0.0152 |
| **22** | 0.0036 | 0.0000 | 0.0036 | 0.0072 | -0.0044 | 0.0028 | 0.0109 | -0.0088 | 0.0021 | 0.0217 | -0.0044 | 0.0173 |
| **23** | 0.0073 | 0.0000 | 0.0073 | 0.0109 | -0.0030 | 0.0078 | 0.0146 | -0.0051 | 0.0094 | 0.0181 | -0.0021 | 0.0160 |
| **24** | 0.0036 | 0.0000 | 0.0036 | 0.0072 | -0.0014 | 0.0059 | 0.0146 | -0.0014 | 0.0132 | 0.0217 | 0.0000 | 0.0217 |
| **exit** | 0.0073 | 0.0000 | 0.0073 | 0.0072 | 0.0000 | 0.0072 | 0.0146 | 0.0000 | 0.0146 | 0.0217 | 0.0000 | 0.0217 |
| **TOTAL $q_c$** | **0.1452** | **0.0000** | **0.1452** | **0.2029** | **-0.4467** | **-0.2438** | **0.3493** | **-1.0611** | **-0.7118** | **0.5219** | **-0.6144** | **-0.0925** |

| Coilset | 8 seconds | | | 10 seconds | | | 15 seconds | | | 20 seconds | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Flow (kW) | Storage (kW) | Coil set $q_c$ (kW) | Flow (kW) | Storage (kW) | Coil set $q_c$ (kW) | Flow (kW) | Storage (kW) | Coil set $q_c$ (kW) | Flow (kW) | Storage (kW) | Coil set $q_c$ (kW) |
| **1** | 0.0329 | -0.0661 | -0.0332 | 0.0439 | -0.0724 | -0.0286 | 0.0744 | -0.0645 | 0.0099 | 0.1085 | -0.0592 | 0.0493 |
| **2** | 0.0365 | -0.0633 | -0.0268 | 0.0439 | -0.0692 | -0.0253 | 0.0707 | -0.0610 | 0.0096 | 0.1123 | -0.0548 | 0.0575 |
| **3** | 0.0329 | -0.0605 | -0.0276 | 0.0475 | -0.0659 | -0.0184 | 0.0744 | -0.0575 | 0.0168 | 0.1085 | -0.0501 | 0.0584 |
| **4** | 0.0365 | -0.0577 | -0.0212 | 0.0439 | -0.0626 | -0.0188 | 0.0744 | -0.0540 | 0.0203 | 0.1122 | -0.0457 | 0.0666 |
| **5** | 0.0329 | -0.0547 | -0.0218 | 0.0439 | -0.0594 | -0.0155 | 0.0707 | -0.0508 | 0.0199 | 0.1085 | -0.0410 | 0.0675 |
| **6** | 0.0365 | -0.0519 | -0.0154 | 0.0439 | -0.0561 | -0.0123 | 0.0744 | -0.0473 | 0.0271 | 0.1122 | -0.0366 | 0.0756 |
| **7** | 0.0329 | -0.0491 | -0.0162 | 0.0475 | -0.0528 | -0.0053 | 0.0744 | -0.0438 | 0.0306 | 0.1085 | -0.0319 | 0.0765 |
| **8** | 0.0365 | -0.0463 | -0.0098 | 0.0438 | -0.0496 | -0.0057 | 0.0706 | -0.0403 | 0.0303 | 0.1122 | -0.0275 | 0.0847 |
| **9** | 0.0329 | -0.0433 | -0.0104 | 0.0438 | -0.0463 | -0.0025 | 0.0743 | -0.0368 | 0.0376 | 0.1084 | -0.0228 | 0.0856 |
| **10** | 0.0329 | -0.0405 | -0.0076 | 0.0438 | -0.0431 | 0.0008 | 0.0743 | -0.0333 | 0.0410 | 0.1084 | -0.0184 | 0.0900 |
| **11** | 0.0365 | -0.0377 | -0.0012 | 0.0475 | -0.0398 | 0.0077 | 0.0706 | -0.0298 | 0.0408 | 0.1121 | -0.0137 | 0.0984 |
| **12** | 0.0329 | -0.0347 | -0.0018 | 0.0438 | -0.0365 | 0.0073 | 0.0743 | -0.0263 | 0.0480 | 0.1084 | -0.0093 | 0.0991 |
| **13** | 0.0365 | -0.0319 | 0.0046 | 0.0438 | -0.0333 | 0.0106 | 0.0743 | -0.0230 | 0.0513 | 0.1121 | -0.0047 | 0.1075 |
| **14** | 0.0329 | -0.0291 | 0.0038 | 0.0438 | -0.0300 | 0.0138 | 0.0743 | -0.0196 | 0.0548 | 0.1084 | -0.0002 | 0.1081 |
| **15** | 0.0365 | -0.0263 | 0.0102 | 0.0475 | -0.0268 | 0.0207 | 0.0706 | -0.0161 | 0.0545 | 0.1121 | 0.0044 | 0.1165 |
| **16** | 0.0329 | -0.0233 | 0.0096 | 0.0438 | -0.0235 | 0.0203 | 0.0743 | -0.0126 | 0.0617 | 0.1084 | 0.0088 | 0.1172 |
| **17** | 0.0329 | -0.0205 | 0.0124 | 0.0438 | -0.0202 | 0.0236 | 0.0743 | -0.0091 | 0.0652 | 0.1083 | 0.0135 | 0.1218 |
| **18** | 0.0365 | -0.0177 | 0.0188 | 0.0438 | -0.0170 | 0.0268 | 0.0706 | -0.0056 | 0.0650 | 0.1121 | 0.0179 | 0.1300 |
| **19** | 0.0329 | -0.0149 | 0.0180 | 0.0475 | -0.0137 | 0.0338 | 0.0743 | -0.0021 | 0.0722 | 0.1083 | 0.0226 | 0.1309 |
| **20** | 0.0365 | -0.0119 | 0.0247 | 0.0438 | -0.0105 | 0.0334 | 0.0743 | 0.0014 | 0.0757 | 0.1120 | 0.0270 | 0.1390 |
| **21** | 0.0329 | -0.0091 | 0.0238 | 0.0438 | -0.0072 | 0.0366 | 0.0706 | 0.0047 | 0.0752 | 0.1083 | 0.0316 | 0.1399 |
| **22** | 0.0365 | -0.0063 | 0.0302 | 0.0438 | -0.0040 | 0.0399 | 0.0743 | 0.0081 | 0.0824 | 0.1120 | 0.0361 | 0.1481 |
| **23** | 0.0329 | -0.0035 | 0.0294 | 0.0475 | -0.0007 | 0.0468 | 0.0743 | 0.0116 | 0.0859 | 0.1083 | 0.0407 | 0.1490 |
| **24** | 0.0365 | -0.0005 | 0.0361 | 0.0438 | 0.0026 | 0.0464 | 0.0706 | 0.0151 | 0.0857 | 0.1120 | 0.0451 | 0.1571 |
| **exit** | 0.0329 | 0.0000 | 0.0329 | 0.0438 | 0.0000 | 0.0438 | 0.0743 | 0.0000 | 0.0743 | 0.1083 | 0.0000 | 0.1083 |
| **TOTAL $q_c$** | **0.8621** | **-0.8007** | **0.0614** | **1.1179** | **-0.8381** | **0.2798** | **1.8285** | **-0.5925** | **1.2360** | **2.7508** | **-0.1682** | **2.5827** |

| Coilset | 30 seconds | | | 50 seconds | | | 100 seconds | | | 200 seconds | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Flow (kW) | Storage (kW) | Coil set $q_c$ (kW) | Flow (kW) | Storage (kW) | Coil set $q_c$ (kW) | Flow (kW) | Storage (kW) | Coil set $q_c$ (kW) | Flow (kW) | Storage (kW) | Coil set $q_c$ (kW) |
| **1** | 0.1610 | -0.0331 | 0.1279 | 0.2230 | -0.0194 | 0.2036 | 0.2560 | -0.0061 | 0.2499 | 0.2606 | -0.0009 | 0.2597 |
| **2** | 0.1647 | -0.0299 | 0.1349 | 0.2268 | -0.0175 | 0.2093 | 0.2559 | -0.0058 | 0.2501 | 0.2605 | -0.0009 | 0.2596 |
| **3** | 0.1610 | -0.0266 | 0.1344 | 0.2229 | -0.0159 | 0.2070 | 0.2558 | -0.0054 | 0.2505 | 0.2644 | -0.0007 | 0.2637 |
| **4** | 0.1609 | -0.0235 | 0.1374 | 0.2267 | -0.0140 | 0.2127 | 0.2558 | -0.0051 | 0.2506 | 0.2604 | -0.0007 | 0.2597 |
| **5** | 0.1609 | -0.0203 | 0.1406 | 0.2228 | -0.0124 | 0.2104 | 0.2557 | -0.0049 | 0.2508 | 0.2603 | -0.0007 | 0.2596 |
| **6** | 0.1646 | -0.0170 | 0.1476 | 0.2227 | -0.0105 | 0.2122 | 0.2556 | -0.0044 | 0.2512 | 0.2602 | -0.0007 | 0.2595 |
| **7** | 0.1608 | -0.0137 | 0.1471 | 0.2265 | -0.0089 | 0.2177 | 0.2555 | -0.0042 | 0.2513 | 0.2602 | -0.0007 | 0.2595 |
| **8** | 0.1608 | -0.0105 | 0.1503 | 0.2226 | -0.0070 | 0.2156 | 0.2555 | -0.0040 | 0.2515 | 0.2640 | -0.0005 | 0.2635 |
| **9** | 0.1645 | -0.0072 | 0.1573 | 0.2264 | -0.0051 | 0.2213 | 0.2554 | -0.0037 | 0.2517 | 0.2600 | -0.0005 | 0.2595 |
| **10** | 0.1608 | -0.0042 | 0.1566 | 0.2225 | -0.0035 | 0.2190 | 0.2553 | -0.0033 | 0.2521 | 0.2599 | -0.0005 | 0.2595 |
| **11** | 0.1607 | -0.0009 | 0.1598 | 0.2225 | -0.0016 | 0.2209 | 0.2553 | -0.0030 | 0.2522 | 0.2599 | -0.0005 | 0.2594 |
| **12** | 0.1607 | 0.0023 | 0.1631 | 0.2263 | 0.0000 | 0.2263 | 0.2552 | -0.0028 | 0.2524 | 0.2598 | -0.0002 | 0.2596 |
| **13** | 0.1644 | 0.0056 | 0.1700 | 0.2224 | 0.0019 | 0.2243 | 0.2552 | -0.0023 | 0.2528 | 0.2636 | -0.0002 | 0.2634 |
| **14** | 0.1607 | 0.0088 | 0.1695 | 0.2262 | 0.0035 | 0.2297 | 0.2551 | -0.0021 | 0.2530 | 0.2597 | -0.0002 | 0.2595 |
| **15** | 0.1607 | 0.0121 | 0.1728 | 0.2223 | 0.0054 | 0.2277 | 0.2550 | -0.0019 | 0.2532 | 0.2596 | -0.0002 | 0.2594 |
| **16** | 0.1606 | 0.0151 | 0.1758 | 0.2223 | 0.0070 | 0.2292 | 0.2550 | -0.0014 | 0.2536 | 0.2596 | -0.0002 | 0.2593 |
| **17** | 0.1643 | 0.0184 | 0.1827 | 0.2261 | 0.0088 | 0.2349 | 0.2549 | -0.0012 | 0.2538 | 0.2595 | 0.0000 | 0.2595 |
| **18** | 0.1606 | 0.0216 | 0.1822 | 0.2222 | 0.0107 | 0.2329 | 0.2549 | -0.0009 | 0.2540 | 0.2633 | 0.0000 | 0.2633 |
| **19** | 0.1606 | 0.0249 | 0.1854 | 0.2260 | 0.0123 | 0.2383 | 0.2548 | -0.0005 | 0.2544 | 0.2594 | 0.0000 | 0.2594 |
| **20** | 0.1643 | 0.0281 | 0.1924 | 0.2221 | 0.0142 | 0.2363 | 0.2548 | -0.0002 | 0.2546 | 0.2594 | 0.0000 | 0.2594 |
| **21** | 0.1605 | 0.0314 | 0.1919 | 0.2221 | 0.0158 | 0.2379 | 0.2547 | 0.0000 | 0.2547 | 0.2593 | 0.0002 | 0.2595 |
| **22** | 0.1605 | 0.0344 | 0.1949 | 0.2259 | 0.0177 | 0.2435 | 0.2547 | 0.0005 | 0.2552 | 0.2593 | 0.0002 | 0.2595 |
| **23** | 0.1605 | 0.0377 | 0.1981 | 0.2220 | 0.0193 | 0.2413 | 0.2546 | 0.0007 | 0.2553 | 0.2631 | 0.0002 | 0.2633 |
| **24** | 0.1642 | 0.0409 | 0.2051 | 0.2258 | 0.0211 | 0.2469 | 0.2546 | 0.0009 | 0.2555 | 0.2592 | 0.0002 | 0.2594 |
| **exit** | 0.1604 | 0.0000 | 0.1604 | 0.2219 | 0.0000 | 0.2219 | 0.2545 | 0.0000 | 0.2545 | 0.2591 | 0.0000 | 0.2591 |
| **TOTAL $q_c$** | **4.0438** | **0.0944** | **4.1383** | **5.5988** | **0.0219** | **5.6208** | **6.3799** | **-0.0611** | **6.3188** | **6.5143** | **-0.0075** | **6.5069** |

## Table M13: Coil Set Energy Balance for R4-36 at 14LPM

| Coilset | 1 second | | | 2 seconds | | | 3 seconds | | | 5 seconds | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Flow (kW) | Storage (kW) | Coil set $q_c$ (kW) | Flow (kW) | Storage (kW) | Coil set $q_c$ (kW) | Flow (kW) | Storage (kW) | Coil set $q_c$ (kW) | Flow (kW) | Storage (kW) | Coil set $q_c$ (kW) |
| **1** | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0067 | 0.0067 | 0.0000 | -0.0079 | -0.0079 | 0.0761 | -0.2093 | -0.1332 |
| **2** | 0.0064 | 0.0000 | 0.0064 | 0.0000 | 0.0059 | 0.0059 | 0.0000 | -0.0079 | -0.0079 | 0.0761 | -0.1940 | -0.1179 |
| **3** | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0047 | 0.0047 | 0.0000 | -0.0079 | -0.0079 | 0.0666 | -0.1790 | -0.1124 |
| **4** | 0.0064 | 0.0000 | 0.0064 | 0.0083 | 0.0035 | 0.0118 | 0.0094 | -0.0079 | 0.0015 | 0.0761 | -0.1641 | -0.0880 |
| **5** | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0028 | 0.0028 | 0.0000 | -0.0079 | -0.0079 | 0.0761 | -0.1487 | -0.0726 |
| **6** | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0016 | 0.0016 | 0.0000 | -0.0079 | -0.0079 | 0.0761 | -0.1338 | -0.0577 |
| **7** | 0.0064 | 0.0000 | 0.0064 | 0.0000 | 0.0004 | 0.0004 | 0.0000 | -0.0079 | -0.0079 | 0.0761 | -0.1188 | -0.0427 |
| **8** | 0.0000 | 0.0000 | 0.0000 | 0.0000 | -0.0004 | -0.0004 | 0.0000 | -0.0079 | -0.0079 | 0.0666 | -0.1035 | -0.0369 |
| **9** | 0.0064 | 0.0000 | 0.0064 | 0.0000 | -0.0016 | -0.0016 | 0.0000 | -0.0079 | -0.0079 | 0.0761 | -0.0885 | -0.0124 |
| **10** | 0.0000 | 0.0000 | 0.0000 | 0.0000 | -0.0028 | -0.0028 | 0.0000 | -0.0079 | -0.0079 | 0.0761 | -0.0736 | 0.0025 |
| **11** | 0.0000 | 0.0000 | 0.0000 | 0.0000 | -0.0035 | -0.0035 | 0.0000 | -0.0079 | -0.0079 | 0.0761 | -0.0582 | 0.0179 |
| **12** | 0.0064 | 0.0000 | 0.0064 | 0.0083 | -0.0047 | 0.0035 | 0.0094 | -0.0079 | 0.0015 | 0.0761 | -0.0433 | 0.0328 |
| **13** | 0.0000 | 0.0000 | 0.0000 | 0.0000 | -0.0059 | -0.0059 | 0.0000 | -0.0079 | -0.0079 | 0.0666 | -0.0283 | 0.0383 |
| **14** | 0.0064 | 0.0000 | 0.0064 | 0.0000 | -0.0067 | -0.0067 | 0.0000 | -0.0079 | -0.0079 | 0.0761 | -0.0130 | 0.0631 |
| **exit** | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0761 | 0.0000 | 0.0761 |
| **TOTAL $q_c$** | **0.0383** | **0.0000** | **0.0383** | **0.0165** | **0.0000** | **0.0165** | **0.0187** | **-0.1101** | **-0.0914** | **1.1131** | **-1.5561** | **-0.4429** |

| Coilset | 8 seconds | | | 10 seconds | | | 15 seconds | | | 20 seconds | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Flow (kW) | Storage (kW) | Coil set $q_c$ (kW) | Flow (kW) | Storage (kW) | Coil set $q_c$ (kW) | Flow (kW) | Storage (kW) | Coil set $q_c$ (kW) | Flow (kW) | Storage (kW) | Coil set $q_c$ (kW) |
| **1** | 0.2391 | -0.3123 | -0.0732 | 0.3465 | -0.2805 | 0.0660 | 0.5290 | -0.2450 | 0.2840 | 0.5795 | -0.1113 | 0.4682 |
| **2** | 0.2391 | -0.2894 | -0.0503 | 0.3369 | -0.2596 | 0.0772 | 0.5288 | -0.2296 | 0.2993 | 0.5793 | -0.1077 | 0.4716 |
| **3** | 0.2391 | -0.2670 | -0.0279 | 0.3464 | -0.2387 | 0.1077 | 0.5287 | -0.2141 | 0.3146 | 0.5792 | -0.1038 | 0.4754 |
| **4** | 0.2391 | -0.2445 | -0.0054 | 0.3368 | -0.2178 | 0.1190 | 0.5286 | -0.1987 | 0.3299 | 0.5694 | -0.1002 | 0.4692 |
| **5** | 0.2391 | -0.2216 | 0.0174 | 0.3464 | -0.1969 | 0.1495 | 0.5284 | -0.1833 | 0.3452 | 0.5789 | -0.0962 | 0.4827 |
| **6** | 0.2390 | -0.1992 | 0.0398 | 0.3463 | -0.1760 | 0.1703 | 0.5283 | -0.1679 | 0.3605 | 0.5787 | -0.0923 | 0.4865 |
| **7** | 0.2390 | -0.1767 | 0.0623 | 0.3367 | -0.1551 | 0.1815 | 0.5282 | -0.1525 | 0.3758 | 0.5786 | -0.0887 | 0.4899 |
| **8** | 0.2390 | -0.1539 | 0.0851 | 0.3462 | -0.1342 | 0.2120 | 0.5377 | -0.1375 | 0.4003 | 0.5784 | -0.0847 | 0.4937 |
| **9** | 0.2390 | -0.1314 | 0.1075 | 0.3366 | -0.1134 | 0.2232 | 0.5280 | -0.1221 | 0.4059 | 0.5783 | -0.0812 | 0.4972 |
| **10** | 0.2389 | -0.1090 | 0.1299 | 0.3461 | -0.0925 | 0.2537 | 0.5279 | -0.1067 | 0.4212 | 0.5782 | -0.0772 | 0.5010 |
| **11** | 0.2389 | -0.0862 | 0.1528 | 0.3461 | -0.0716 | 0.2745 | 0.5278 | -0.0913 | 0.4365 | 0.5781 | -0.0732 | 0.5048 |
| **12** | 0.2389 | -0.0637 | 0.1752 | 0.3364 | -0.0508 | 0.2857 | 0.5277 | -0.0760 | 0.4518 | 0.5683 | -0.0697 | 0.4986 |
| **13** | 0.2389 | -0.0413 | 0.1976 | 0.3460 | -0.0299 | 0.3161 | 0.5276 | -0.0606 | 0.4670 | 0.5779 | -0.0657 | 0.5121 |
| **14** | 0.2389 | -0.0185 | 0.2204 | 0.3364 | -0.0090 | 0.3273 | 0.5275 | -0.0452 | 0.4823 | 0.5777 | -0.0622 | 0.5155 |
| **exit** | 0.2389 | 0.0000 | 0.2389 | 0.3459 | 0.0000 | 0.3459 | 0.5274 | 0.0000 | 0.5274 | 0.5776 | 0.0000 | 0.5776 |
| **TOTAL $q_c$** | **3.5848** | **-2.3147** | **1.2701** | **5.1358** | **-2.0261** | **3.1097** | **7.9319** | **-2.0304** | **5.9015** | **8.6582** | **-1.2141** | **7.4441** |

| Coilset | 30 seconds | | | 50 seconds | | | 100 seconds | | | 200 seconds | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Flow (kW) | Storage (kW) | Coil set $q_c$ (kW) | Flow (kW) | Storage (kW) | Coil set $q_c$ (kW) | Flow (kW) | Storage (kW) | Coil set $q_c$ (kW) | Flow (kW) | Storage (kW) | Coil set $q_c$ (kW) |
| **1** | 0.6018 | -0.0498 | 0.5521 | 0.5881 | -0.0170 | 0.5711 | 0.5839 | -0.0028 | 0.5811 | 0.5915 | -0.0004 | 0.5911 |
| **2** | 0.6017 | -0.0494 | 0.5523 | 0.5879 | -0.0174 | 0.5706 | 0.5837 | -0.0028 | 0.5810 | 0.5914 | -0.0004 | 0.5910 |
| **3** | 0.5917 | -0.0490 | 0.5427 | 0.5878 | -0.0178 | 0.5700 | 0.5933 | -0.0024 | 0.5909 | 0.5912 | -0.0004 | 0.5908 |
| **4** | 0.6014 | -0.0485 | 0.5528 | 0.5876 | -0.0182 | 0.5695 | 0.5834 | -0.0024 | 0.5811 | 0.5911 | -0.0004 | 0.5907 |
| **5** | 0.6012 | -0.0481 | 0.5531 | 0.5875 | -0.0186 | 0.5689 | 0.5833 | -0.0024 | 0.5809 | 0.5909 | -0.0004 | 0.5905 |
| **6** | 0.6010 | -0.0477 | 0.5533 | 0.5873 | -0.0189 | 0.5684 | 0.5831 | -0.0024 | 0.5808 | 0.5907 | -0.0004 | 0.5903 |
| **7** | 0.6009 | -0.0473 | 0.5535 | 0.5872 | -0.0193 | 0.5678 | 0.5830 | -0.0020 | 0.5810 | 0.5906 | -0.0004 | 0.5902 |
| **8** | 0.5909 | -0.0473 | 0.5436 | 0.5771 | -0.0197 | 0.5574 | 0.5925 | -0.0020 | 0.5906 | 0.5807 | -0.0004 | 0.5803 |
| **9** | 0.6005 | -0.0469 | 0.5536 | 0.5869 | -0.0201 | 0.5668 | 0.5827 | -0.0020 | 0.5807 | 0.5903 | 0.0000 | 0.5903 |
| **10** | 0.6004 | -0.0465 | 0.5539 | 0.5867 | -0.0205 | 0.5662 | 0.5825 | -0.0020 | 0.5805 | 0.5901 | 0.0000 | 0.5901 |
| **11** | 0.6003 | -0.0461 | 0.5542 | 0.5866 | -0.0209 | 0.5657 | 0.5824 | -0.0016 | 0.5808 | 0.5899 | 0.0000 | 0.5899 |
| **12** | 0.6002 | -0.0457 | 0.5545 | 0.5864 | -0.0213 | 0.5652 | 0.5822 | -0.0016 | 0.5806 | 0.5898 | 0.0000 | 0.5898 |
| **13** | 0.5902 | -0.0453 | 0.5449 | 0.5863 | -0.0217 | 0.5647 | 0.5918 | -0.0016 | 0.5902 | 0.5897 | 0.0000 | 0.5897 |
| **14** | 0.5999 | -0.0449 | 0.5550 | 0.5862 | -0.0221 | 0.5641 | 0.5820 | -0.0016 | 0.5804 | 0.5896 | 0.0000 | 0.5896 |
| **exit** | 0.5998 | 0.0000 | 0.5998 | 0.5861 | 0.0000 | 0.5861 | 0.5819 | 0.0000 | 0.5819 | 0.5894 | 0.0000 | 0.5894 |
| **TOTAL $q_c$** | **8.9817** | **-0.6625** | **8.3192** | **8.7957** | **-0.2733** | **8.5224** | **8.7717** | **-0.0292** | **8.7425** | **8.8469** | **-0.0032** | **8.8437** |

## Table M14: Coil Set Energy Balance for R4-36 at 12LPM

| Coilset | 1 second | | | 2 seconds | | | 3 seconds | | | 5 seconds | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Flow (kW) | Storage (kW) | Coil set $q_c$ (kW) | Flow (kW) | Storage (kW) | Coil set $q_c$ (kW) | Flow (kW) | Storage (kW) | Coil set $q_c$ (kW) | Flow (kW) | Storage (kW) | Coil set $q_c$ (kW) |
| **1** | 0.0082 | 0.0000 | 0.0082 | 0.0492 | -0.2750 | -0.2258 | 0.0904 | -0.2310 | -0.1406 | 0.2053 | -0.3784 | -0.1731 |
| **2** | 0.0163 | 0.0000 | 0.0163 | 0.0574 | -0.2553 | -0.1979 | 0.0822 | -0.2145 | -0.1323 | 0.1971 | -0.3508 | -0.1537 |
| **3** | 0.0082 | 0.0000 | 0.0082 | 0.0492 | -0.2353 | -0.1860 | 0.0904 | -0.1975 | -0.1072 | 0.2053 | -0.3236 | -0.1183 |
| **4** | 0.0163 | 0.0000 | 0.0163 | 0.0574 | -0.2152 | -0.1577 | 0.0904 | -0.1806 | -0.0902 | 0.1971 | -0.2964 | -0.0993 |
| **5** | 0.0082 | 0.0000 | 0.0082 | 0.0492 | -0.1955 | -0.1463 | 0.0904 | -0.1641 | -0.0737 | 0.2053 | -0.2688 | -0.0636 |
| **6** | 0.0082 | 0.0000 | 0.0082 | 0.0574 | -0.1754 | -0.1180 | 0.0821 | -0.1471 | -0.0650 | 0.2053 | -0.2417 | -0.0364 |
| **7** | 0.0163 | 0.0000 | 0.0163 | 0.0492 | -0.1554 | -0.1061 | 0.0903 | -0.1302 | -0.0399 | 0.1970 | -0.2145 | -0.0175 |
| **8** | 0.0082 | 0.0000 | 0.0082 | 0.0574 | -0.1357 | -0.0783 | 0.0903 | -0.1137 | -0.0233 | 0.2052 | -0.1869 | 0.0183 |
| **9** | 0.0163 | 0.0000 | 0.0163 | 0.0492 | -0.1156 | -0.0664 | 0.0903 | -0.0968 | -0.0064 | 0.1970 | -0.1598 | 0.0372 |
| **10** | 0.0082 | 0.0000 | 0.0082 | 0.0574 | -0.0956 | -0.0381 | 0.0821 | -0.0799 | 0.0023 | 0.2052 | -0.1326 | 0.0726 |
| **11** | 0.0082 | 0.0000 | 0.0082 | 0.0492 | -0.0759 | -0.0267 | 0.0903 | -0.0633 | 0.0270 | 0.2052 | -0.1050 | 0.1001 |
| **12** | 0.0163 | 0.0000 | 0.0163 | 0.0574 | -0.0559 | 0.0016 | 0.0903 | -0.0464 | 0.0439 | 0.1969 | -0.0779 | 0.1191 |
| **13** | 0.0082 | 0.0000 | 0.0082 | 0.0492 | -0.0358 | 0.0134 | 0.0903 | -0.0295 | 0.0608 | 0.2051 | -0.0507 | 0.1544 |
| **14** | 0.0163 | 0.0000 | 0.0163 | 0.0574 | -0.0161 | 0.0413 | 0.0821 | -0.0130 | 0.0691 | 0.1969 | -0.0232 | 0.1737 |
| **exit** | 0.0082 | 0.0000 | 0.0082 | 0.0492 | 0.0000 | 0.0492 | 0.0903 | 0.0000 | 0.0903 | 0.2051 | 0.0000 | 0.2051 |
| **TOTAL $q_c$** | **0.1716** | **0.0000** | **0.1716** | **0.7959** | **-2.0377** | **-1.2418** | **1.3223** | **-1.7075** | **-0.3852** | **3.0291** | **-2.8104** | **0.2187** |

| Coilset | 8 seconds | | | 10 seconds | | | 15 seconds | | | 20 seconds | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Flow (kW) | Storage (kW) | Coil set $q_c$ (kW) | Flow (kW) | Storage (kW) | Coil set $q_c$ (kW) | Flow (kW) | Storage (kW) | Coil set $q_c$ (kW) | Flow (kW) | Storage (kW) | Coil set $q_c$ (kW) |
| **1** | 0.3373 | -0.2829 | 0.0544 | 0.3990 | -0.1663 | 0.2327 | 0.4750 | -0.1258 | 0.3492 | 0.5293 | -0.1085 | 0.4207 |
| **2** | 0.3373 | -0.2612 | 0.0760 | 0.3906 | -0.1537 | 0.2369 | 0.4832 | -0.1179 | 0.3653 | 0.5291 | -0.1038 | 0.4253 |
| **3** | 0.3372 | -0.2395 | 0.0977 | 0.3989 | -0.1407 | 0.2582 | 0.4747 | -0.1104 | 0.3644 | 0.5290 | -0.0994 | 0.4296 |
| **4** | 0.3454 | -0.2178 | 0.1276 | 0.3988 | -0.1276 | 0.2712 | 0.4830 | -0.1025 | 0.3805 | 0.5372 | -0.0947 | 0.4426 |
| **5** | 0.3371 | -0.1961 | 0.1410 | 0.3904 | -0.1150 | 0.2754 | 0.4745 | -0.0950 | 0.3795 | 0.5287 | -0.0903 | 0.4384 |
| **6** | 0.3371 | -0.1744 | 0.1626 | 0.3987 | -0.1020 | 0.2967 | 0.4744 | -0.0871 | 0.3873 | 0.5285 | -0.0855 | 0.4430 |
| **7** | 0.3370 | -0.1528 | 0.1843 | 0.3986 | -0.0890 | 0.3096 | 0.4826 | -0.0796 | 0.4031 | 0.5284 | -0.0812 | 0.4472 |
| **8** | 0.3370 | -0.1307 | 0.2063 | 0.3903 | -0.0764 | 0.3139 | 0.4742 | -0.0717 | 0.4026 | 0.5283 | -0.0764 | 0.4518 |
| **9** | 0.3369 | -0.1090 | 0.2279 | 0.3985 | -0.0634 | 0.3351 | 0.4825 | -0.0642 | 0.4183 | 0.5282 | -0.0721 | 0.4561 |
| **10** | 0.3369 | -0.0874 | 0.2495 | 0.3984 | -0.0504 | 0.3480 | 0.4740 | -0.0563 | 0.4177 | 0.5280 | -0.0673 | 0.4607 |
| **11** | 0.3368 | -0.0657 | 0.2711 | 0.3901 | -0.0378 | 0.3523 | 0.4740 | -0.0488 | 0.4251 | 0.5279 | -0.0630 | 0.4649 |
| **12** | 0.3450 | -0.0441 | 0.3009 | 0.3983 | -0.0248 | 0.3735 | 0.4822 | -0.0409 | 0.4412 | 0.5362 | -0.0583 | 0.4779 |
| **13** | 0.3367 | -0.0224 | 0.3143 | 0.3982 | -0.0118 | 0.3864 | 0.4738 | -0.0334 | 0.4403 | 0.5277 | -0.0539 | 0.4738 |
| **14** | 0.3367 | -0.0008 | 0.3359 | 0.3899 | 0.0008 | 0.3907 | 0.4820 | -0.0256 | 0.4564 | 0.5276 | -0.0492 | 0.4784 |
| **exit** | 0.3366 | 0.0000 | 0.3366 | 0.3981 | 0.0000 | 0.3981 | 0.4736 | 0.0000 | 0.4736 | 0.5275 | 0.0000 | 0.5275 |
| **TOTAL $q_c$** | **5.0710** | **-1.9849** | **3.0861** | **5.9369** | **-1.1581** | **4.7788** | **7.1637** | **-1.0591** | **6.1045** | **7.9415** | **-1.1036** | **6.8379** |

| Coilset | 30 seconds | | | 50 seconds | | | 100 seconds | | | 200 seconds | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Flow (kW) | Storage (kW) | Coil set $q_c$ (kW) | Flow (kW) | Storage (kW) | Coil set $q_c$ (kW) | Flow (kW) | Storage (kW) | Coil set $q_c$ (kW) | Flow (kW) | Storage (kW) | Coil set $q_c$ (kW) |
| **1** | 0.5339 | -0.0426 | 0.4912 | 0.5279 | -0.0166 | 0.5113 | 0.5355 | -0.0032 | 0.5324 | 0.5400 | -0.0004 | 0.5396 |
| **2** | 0.5421 | -0.0422 | 0.4998 | 0.5278 | -0.0166 | 0.5112 | 0.5354 | -0.0032 | 0.5322 | 0.5399 | -0.0004 | 0.5395 |
| **3** | 0.5336 | -0.0418 | 0.4918 | 0.5277 | -0.0170 | 0.5107 | 0.5352 | -0.0032 | 0.5321 | 0.5397 | -0.0004 | 0.5393 |
| **4** | 0.5334 | -0.0410 | 0.4924 | 0.5359 | -0.0170 | 0.5189 | 0.5267 | -0.0028 | 0.5239 | 0.5396 | -0.0004 | 0.5392 |
| **5** | 0.5333 | -0.0406 | 0.4927 | 0.5274 | -0.0174 | 0.5100 | 0.5349 | -0.0028 | 0.5322 | 0.5394 | -0.0004 | 0.5390 |
| **6** | 0.5415 | -0.0402 | 0.5012 | 0.5272 | -0.0174 | 0.5099 | 0.5348 | -0.0028 | 0.5320 | 0.5393 | -0.0004 | 0.5389 |
| **7** | 0.5330 | -0.0398 | 0.4932 | 0.5271 | -0.0177 | 0.5093 | 0.5346 | -0.0028 | 0.5319 | 0.5391 | -0.0004 | 0.5387 |
| **8** | 0.5328 | -0.0394 | 0.4934 | 0.5269 | -0.0181 | 0.5088 | 0.5345 | -0.0028 | 0.5317 | 0.5390 | -0.0004 | 0.5386 |
| **9** | 0.5327 | -0.0390 | 0.4937 | 0.5268 | -0.0181 | 0.5086 | 0.5343 | -0.0028 | 0.5316 | 0.5388 | -0.0004 | 0.5384 |
| **10** | 0.5409 | -0.0386 | 0.5023 | 0.5266 | -0.0185 | 0.5081 | 0.5342 | -0.0028 | 0.5314 | 0.5387 | -0.0004 | 0.5383 |
| **11** | 0.5325 | -0.0382 | 0.4943 | 0.5265 | -0.0185 | 0.5080 | 0.5340 | -0.0024 | 0.5317 | 0.5385 | -0.0004 | 0.5381 |
| **12** | 0.5324 | -0.0374 | 0.4950 | 0.5348 | -0.0189 | 0.5159 | 0.5256 | -0.0024 | 0.5232 | 0.5384 | -0.0004 | 0.5380 |
| **13** | 0.5322 | -0.0370 | 0.4952 | 0.5263 | -0.0189 | 0.5074 | 0.5338 | -0.0024 | 0.5314 | 0.5383 | -0.0004 | 0.5379 |
| **14** | 0.5404 | -0.0366 | 0.5038 | 0.5262 | -0.0193 | 0.5069 | 0.5337 | -0.0024 | 0.5313 | 0.5382 | -0.0004 | 0.5378 |
| **exit** | 0.5320 | 0.0000 | 0.5320 | 0.5261 | 0.0000 | 0.5261 | 0.5336 | 0.0000 | 0.5336 | 0.5381 | 0.0000 | 0.5381 |
| **TOTAL $q_c$** | **8.0268** | **-0.5547** | **7.4721** | **7.9211** | **-0.2500** | **7.6711** | **8.0008** | **-0.0383** | **7.9626** | **8.0848** | **-0.0055** | **8.0793** |

## Table M15: Coil Set Energy Balance for R4-36 at 10LPM

| Coilset | 1 second | | | 2 seconds | | | 3 seconds | | | 5 seconds | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Flow (kW) | Storage (kW) | Coil set $q_c$ (kW) | Flow (kW) | Storage (kW) | Coil set $q_c$ (kW) | Flow (kW) | Storage (kW) | Coil set $q_c$ (kW) | Flow (kW) | Storage (kW) | Coil set $q_c$ (kW) |
| **1** | 0.0000 | 0.0000 | 0.0000 | 0.0000 | -0.0075 | -0.0075 | 0.0000 | -0.0075 | -0.0075 | 0.0475 | -0.1885 | -0.1409 |
| **2** | 0.0000 | 0.0000 | 0.0000 | 0.0000 | -0.0067 | -0.0067 | 0.0067 | -0.0067 | 0.0000 | 0.0543 | -0.1747 | -0.1204 |
| **3** | 0.0000 | 0.0000 | 0.0000 | 0.0000 | -0.0063 | -0.0063 | 0.0000 | -0.0063 | -0.0063 | 0.0475 | -0.1605 | -0.1130 |
| **4** | 0.0000 | 0.0000 | 0.0000 | 0.0067 | -0.0059 | 0.0008 | 0.0000 | -0.0059 | -0.0059 | 0.0543 | -0.1464 | -0.0921 |
| **5** | 0.0000 | 0.0000 | 0.0000 | 0.0000 | -0.0051 | -0.0051 | 0.0000 | -0.0051 | -0.0051 | 0.0475 | -0.1326 | -0.0851 |
| **6** | 0.0000 | 0.0000 | 0.0000 | 0.0000 | -0.0047 | -0.0047 | 0.0067 | -0.0047 | 0.0020 | 0.0475 | -0.1184 | -0.0709 |
| **7** | 0.0000 | 0.0000 | 0.0000 | 0.0000 | -0.0043 | -0.0043 | 0.0000 | -0.0043 | -0.0043 | 0.0543 | -0.1042 | -0.0499 |
| **8** | 0.0000 | 0.0000 | 0.0000 | 0.0000 | -0.0035 | -0.0035 | 0.0000 | -0.0035 | -0.0035 | 0.0475 | -0.0905 | -0.0430 |
| **9** | 0.0000 | 0.0000 | 0.0000 | 0.0000 | -0.0031 | -0.0031 | 0.0000 | -0.0031 | -0.0031 | 0.0543 | -0.0763 | -0.0220 |
| **10** | 0.0000 | 0.0000 | 0.0000 | 0.0000 | -0.0028 | -0.0028 | 0.0067 | -0.0028 | 0.0040 | 0.0475 | -0.0622 | -0.0146 |
| **11** | 0.0000 | 0.0000 | 0.0000 | 0.0000 | -0.0020 | -0.0020 | 0.0000 | -0.0020 | -0.0020 | 0.0475 | -0.0484 | -0.0009 |
| **12** | 0.0000 | 0.0000 | 0.0000 | 0.0067 | -0.0016 | 0.0051 | 0.0000 | -0.0016 | -0.0016 | 0.0543 | -0.0342 | 0.0201 |
| **13** | 0.0000 | 0.0000 | 0.0000 | 0.0000 | -0.0012 | -0.0012 | 0.0000 | -0.0012 | -0.0012 | 0.0475 | -0.0201 | 0.0274 |
| **14** | 0.0000 | 0.0000 | 0.0000 | 0.0000 | -0.0004 | -0.0004 | 0.0067 | -0.0004 | 0.0063 | 0.0543 | -0.0063 | 0.0480 |
| **exit** | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0475 | 0.0000 | 0.0475 |
| **TOTAL $q_c$** | **0.0000** | **0.0000** | **0.0000** | **0.0134** | **-0.0551** | **-0.0417** | **0.0269** | **-0.0551** | **-0.0282** | **0.7534** | **-1.3632** | **-0.6098** |

| Coilset | 8 seconds | | | 10 seconds | | | 15 seconds | | | 20 seconds | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Flow (kW) | Storage (kW) | Coil set $q_c$ (kW) | Flow (kW) | Storage (kW) | Coil set $q_c$ (kW) | Flow (kW) | Storage (kW) | Coil set $q_c$ (kW) | Flow (kW) | Storage (kW) | Coil set $q_c$ (kW) |
| **1** | 0.1574 | -0.2811 | -0.1238 | 0.2055 | -0.1867 | 0.0188 | 0.3338 | -0.1821 | 0.1517 | 0.4131 | -0.1215 | 0.2916 |
| **2** | 0.1642 | -0.2602 | -0.0960 | 0.2124 | -0.1725 | 0.0399 | 0.3407 | -0.1683 | 0.1724 | 0.4200 | -0.1124 | 0.3076 |
| **3** | 0.1573 | -0.2394 | -0.0820 | 0.2055 | -0.1583 | 0.0472 | 0.3337 | -0.1541 | 0.1796 | 0.4129 | -0.1037 | 0.3092 |
| **4** | 0.1573 | -0.2185 | -0.0611 | 0.2123 | -0.1441 | 0.0682 | 0.3336 | -0.1403 | 0.1934 | 0.4198 | -0.0946 | 0.3252 |
| **5** | 0.1573 | -0.1976 | -0.0403 | 0.2055 | -0.1299 | 0.0755 | 0.3336 | -0.1261 | 0.2075 | 0.4127 | -0.0859 | 0.3268 |
| **6** | 0.1641 | -0.1767 | -0.0126 | 0.2123 | -0.1157 | 0.0965 | 0.3405 | -0.1119 | 0.2286 | 0.4196 | -0.0772 | 0.3423 |
| **7** | 0.1573 | -0.1558 | 0.0014 | 0.2054 | -0.1016 | 0.1039 | 0.3335 | -0.0981 | 0.2354 | 0.4125 | -0.0681 | 0.3443 |
| **8** | 0.1573 | -0.1354 | 0.0219 | 0.2122 | -0.0874 | 0.1249 | 0.3334 | -0.0839 | 0.2496 | 0.4194 | -0.0595 | 0.3599 |
| **9** | 0.1573 | -0.1145 | 0.0428 | 0.2054 | -0.0732 | 0.1322 | 0.3334 | -0.0701 | 0.2633 | 0.4123 | -0.0504 | 0.3619 |
| **10** | 0.1641 | -0.0936 | 0.0705 | 0.2122 | -0.0590 | 0.1532 | 0.3403 | -0.0559 | 0.2844 | 0.4192 | -0.0417 | 0.3775 |
| **11** | 0.1572 | -0.0728 | 0.0845 | 0.2053 | -0.0449 | 0.1605 | 0.3333 | -0.0417 | 0.2915 | 0.4122 | -0.0331 | 0.3791 |
| **12** | 0.1572 | -0.0519 | 0.1053 | 0.2122 | -0.0307 | 0.1815 | 0.3332 | -0.0279 | 0.3053 | 0.4191 | -0.0240 | 0.3950 |
| **13** | 0.1572 | -0.0311 | 0.1261 | 0.2053 | -0.0165 | 0.1888 | 0.3332 | -0.0138 | 0.3194 | 0.4120 | -0.0153 | 0.3966 |
| **14** | 0.1640 | -0.0102 | 0.1538 | 0.2121 | -0.0024 | 0.2098 | 0.3400 | 0.0000 | 0.3400 | 0.4189 | -0.0063 | 0.4126 |
| **exit** | 0.1572 | 0.0000 | 0.1572 | 0.2052 | 0.0000 | 0.2052 | 0.3331 | 0.0000 | 0.3331 | 0.4118 | 0.0000 | 0.4118 |
| **TOTAL $q_c$** | **2.3866** | **-2.0389** | **0.3477** | **3.1288** | **-1.3229** | **1.8060** | **5.0292** | **-1.2740** | **3.7553** | **6.2353** | **-0.8938** | **5.3415** |

| Coilset | 30 seconds | | | 50 seconds | | | 100 seconds | | | 200 seconds | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Flow (kW) | Storage (kW) | Coil set $q_c$ (kW) | Flow (kW) | Storage (kW) | Coil set $q_c$ (kW) | Flow (kW) | Storage (kW) | Coil set $q_c$ (kW) | Flow (kW) | Storage (kW) | Coil set $q_c$ (kW) |
| **1** | 0.4750 | -0.0596 | 0.4154 | 0.4729 | -0.0245 | 0.4484 | 0.4814 | -0.0047 | 0.4767 | 0.4889 | -0.0008 | 0.4881 |
| **2** | 0.4679 | -0.0564 | 0.4114 | 0.4797 | -0.0241 | 0.4556 | 0.4813 | -0.0047 | 0.4765 | 0.4888 | -0.0008 | 0.4880 |
| **3** | 0.4747 | -0.0533 | 0.4215 | 0.4726 | -0.0241 | 0.4485 | 0.4811 | -0.0047 | 0.4764 | 0.4886 | -0.0004 | 0.4882 |
| **4** | 0.4676 | -0.0497 | 0.4179 | 0.4794 | -0.0237 | 0.4557 | 0.4810 | -0.0047 | 0.4762 | 0.4815 | -0.0004 | 0.4811 |
| **5** | 0.4744 | -0.0465 | 0.4279 | 0.4723 | -0.0237 | 0.4486 | 0.4808 | -0.0047 | 0.4761 | 0.4883 | -0.0004 | 0.4879 |
| **6** | 0.4743 | -0.0434 | 0.4309 | 0.4791 | -0.0233 | 0.4558 | 0.4807 | -0.0047 | 0.4759 | 0.4882 | -0.0004 | 0.4878 |
| **7** | 0.4672 | -0.0402 | 0.4270 | 0.4720 | -0.0233 | 0.4488 | 0.4805 | -0.0047 | 0.4758 | 0.4880 | -0.0004 | 0.4876 |
| **8** | 0.4740 | -0.0370 | 0.4370 | 0.4788 | -0.0233 | 0.4556 | 0.4873 | -0.0043 | 0.4830 | 0.4879 | -0.0004 | 0.4875 |
| **9** | 0.4670 | -0.0339 | 0.4331 | 0.4718 | -0.0229 | 0.4489 | 0.4802 | -0.0043 | 0.4759 | 0.4877 | -0.0004 | 0.4873 |
| **10** | 0.4738 | -0.0307 | 0.4431 | 0.4786 | -0.0228 | 0.4557 | 0.4801 | -0.0043 | 0.4758 | 0.4876 | -0.0004 | 0.4872 |
| **11** | 0.4737 | -0.0276 | 0.4462 | 0.4715 | -0.0224 | 0.4491 | 0.4800 | -0.0043 | 0.4757 | 0.4875 | -0.0004 | 0.4871 |
| **12** | 0.4666 | -0.0240 | 0.4426 | 0.4784 | -0.0224 | 0.4559 | 0.4799 | -0.0043 | 0.4756 | 0.4804 | -0.0004 | 0.4800 |
| **13** | 0.4735 | -0.0209 | 0.4526 | 0.4713 | -0.0220 | 0.4493 | 0.4798 | -0.0043 | 0.4754 | 0.4872 | -0.0004 | 0.4868 |
| **14** | 0.4664 | -0.0177 | 0.4487 | 0.4781 | -0.0220 | 0.4561 | 0.4797 | -0.0043 | 0.4753 | 0.4871 | -0.0004 | 0.4867 |
| **exit** | 0.4733 | 0.0000 | 0.4733 | 0.4711 | 0.0000 | 0.4711 | 0.4795 | 0.0000 | 0.4795 | 0.4870 | 0.0000 | 0.4870 |
| **TOTAL $q_c$** | **7.0695** | **-0.5408** | **6.5287** | **7.1276** | **-0.3245** | **6.8032** | **7.2134** | **-0.0635** | **7.1499** | **7.3046** | **-0.0063** | **7.2982** |

## Table M16: Coil Set Energy Balance for R4-36 at 9LPM

| Coilset | 1 second | | | 2 seconds | | | 3 seconds | | | 5 seconds | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Flow (kW) | Storage (kW) | Coil set $q_c$ (kW) | Flow (kW) | Storage (kW) | Coil set $q_c$ (kW) | Flow (kW) | Storage (kW) | Coil set $q_c$ (kW) | Flow (kW) | Storage (kW) | Coil set $q_c$ (kW) |
| **1** | 0.0124 | 0.0000 | 0.0124 | 0.0186 | -0.0767 | -0.0581 | 0.0564 | -0.3006 | -0.2442 | 0.0882 | -0.1433 | -0.0550 |
| **2** | 0.0062 | 0.0000 | 0.0062 | 0.0186 | -0.0712 | -0.0526 | 0.0501 | -0.2786 | -0.2284 | 0.0882 | -0.1326 | -0.0444 |
| **3** | 0.0124 | 0.0000 | 0.0124 | 0.0186 | -0.0653 | -0.0467 | 0.0564 | -0.2565 | -0.2001 | 0.0882 | -0.1224 | -0.0341 |
| **4** | 0.0124 | 0.0000 | 0.0124 | 0.0248 | -0.0594 | -0.0346 | 0.0564 | -0.2345 | -0.1781 | 0.0882 | -0.1121 | -0.0239 |
| **5** | 0.0062 | 0.0000 | 0.0062 | 0.0186 | -0.0539 | -0.0353 | 0.0564 | -0.2124 | -0.1560 | 0.0882 | -0.1015 | -0.0133 |
| **6** | 0.0124 | 0.0000 | 0.0124 | 0.0186 | -0.0480 | -0.0294 | 0.0501 | -0.1904 | -0.1403 | 0.0882 | -0.0913 | -0.0031 |
| **7** | 0.0124 | 0.0000 | 0.0124 | 0.0186 | -0.0421 | -0.0235 | 0.0564 | -0.1684 | -0.1120 | 0.0882 | -0.0810 | 0.0072 |
| **8** | 0.0062 | 0.0000 | 0.0062 | 0.0186 | -0.0366 | -0.0180 | 0.0564 | -0.1463 | -0.0899 | 0.0882 | -0.0704 | 0.0178 |
| **9** | 0.0124 | 0.0000 | 0.0124 | 0.0186 | -0.0307 | -0.0121 | 0.0564 | -0.1243 | -0.0679 | 0.0882 | -0.0602 | 0.0280 |
| **10** | 0.0124 | 0.0000 | 0.0124 | 0.0186 | -0.0248 | -0.0062 | 0.0501 | -0.1023 | -0.0522 | 0.0882 | -0.0500 | 0.0382 |
| **11** | 0.0062 | 0.0000 | 0.0062 | 0.0186 | -0.0193 | -0.0006 | 0.0564 | -0.0802 | -0.0239 | 0.0882 | -0.0393 | 0.0489 |
| **12** | 0.0124 | 0.0000 | 0.0124 | 0.0248 | -0.0134 | 0.0115 | 0.0564 | -0.0582 | -0.0018 | 0.0882 | -0.0291 | 0.0591 |
| **13** | 0.0124 | 0.0000 | 0.0124 | 0.0186 | -0.0075 | 0.0112 | 0.0564 | -0.0362 | 0.0202 | 0.0882 | -0.0189 | 0.0693 |
| **14** | 0.0062 | 0.0000 | 0.0062 | 0.0186 | -0.0020 | 0.0167 | 0.0501 | -0.0142 | 0.0360 | 0.0882 | -0.0083 | 0.0799 |
| **exit** | 0.0124 | 0.0000 | 0.0124 | 0.0186 | 0.0000 | 0.0186 | 0.0564 | 0.0000 | 0.0564 | 0.0882 | 0.0000 | 0.0882 |
| **TOTAL $q_c$** | **0.1547** | **0.0000** | **0.1547** | **0.2918** | **-0.5507** | **-0.2588** | **0.8208** | **-2.2031** | **-1.3823** | **1.3233** | **-1.0604** | **0.2628** |

| Coilset | 8 seconds | | | 10 seconds | | | 15 seconds | | | 20 seconds | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Flow (kW) | Storage (kW) | Coil set $q_c$ (kW) | Flow (kW) | Storage (kW) | Coil set $q_c$ (kW) | Flow (kW) | Storage (kW) | Coil set $q_c$ (kW) | Flow (kW) | Storage (kW) | Coil set $q_c$ (kW) |
| **1** | 0.1647 | -0.2268 | -0.0621 | 0.2091 | -0.1706 | 0.0386 | 0.3203 | -0.1861 | 0.1342 | 0.3633 | -0.0939 | 0.2694 |
| **2** | 0.1710 | -0.2103 | -0.0392 | 0.2028 | -0.1583 | 0.0444 | 0.3266 | -0.1723 | 0.1543 | 0.3696 | -0.0883 | 0.2812 |
| **3** | 0.1647 | -0.1941 | -0.0294 | 0.2091 | -0.1457 | 0.0634 | 0.3201 | -0.1580 | 0.1621 | 0.3631 | -0.0828 | 0.2803 |
| **4** | 0.1647 | -0.1779 | -0.0133 | 0.2090 | -0.1331 | 0.0759 | 0.3265 | -0.1442 | 0.1823 | 0.3694 | -0.0773 | 0.2921 |
| **5** | 0.1710 | -0.1618 | 0.0092 | 0.2027 | -0.1209 | 0.0818 | 0.3200 | -0.1300 | 0.1900 | 0.3629 | -0.0717 | 0.2912 |
| **6** | 0.1646 | -0.1456 | 0.0190 | 0.2090 | -0.1083 | 0.1007 | 0.3264 | -0.1158 | 0.2105 | 0.3692 | -0.0662 | 0.3030 |
| **7** | 0.1646 | -0.1295 | 0.0351 | 0.2090 | -0.0957 | 0.1133 | 0.3199 | -0.1020 | 0.2179 | 0.3628 | -0.0607 | 0.3021 |
| **8** | 0.1709 | -0.1133 | 0.0576 | 0.2026 | -0.0834 | 0.1192 | 0.3262 | -0.0878 | 0.2384 | 0.3691 | -0.0551 | 0.3139 |
| **9** | 0.1646 | -0.0972 | 0.0674 | 0.2089 | -0.0708 | 0.1381 | 0.3198 | -0.0740 | 0.2458 | 0.3627 | -0.0496 | 0.3130 |
| **10** | 0.1646 | -0.0811 | 0.0835 | 0.2089 | -0.0582 | 0.1507 | 0.3261 | -0.0598 | 0.2663 | 0.3689 | -0.0441 | 0.3248 |
| **11** | 0.1709 | -0.0645 | 0.1064 | 0.2025 | -0.0460 | 0.1565 | 0.3197 | -0.0457 | 0.2740 | 0.3625 | -0.0386 | 0.3239 |
| **12** | 0.1645 | -0.0484 | 0.1162 | 0.2089 | -0.0334 | 0.1754 | 0.3260 | -0.0319 | 0.2941 | 0.3688 | -0.0331 | 0.3357 |
| **13** | 0.1645 | -0.0323 | 0.1323 | 0.2088 | -0.0208 | 0.1880 | 0.3196 | -0.0177 | 0.3019 | 0.3624 | -0.0275 | 0.3348 |
| **14** | 0.1708 | -0.0161 | 0.1547 | 0.2025 | -0.0087 | 0.1938 | 0.3259 | -0.0039 | 0.3220 | 0.3687 | -0.0220 | 0.3466 |
| **exit** | 0.1645 | 0.0000 | 0.1645 | 0.2088 | 0.0000 | 0.2088 | 0.3195 | 0.0000 | 0.3195 | 0.3622 | 0.0000 | 0.3622 |
| **TOTAL $q_c$** | **2.5007** | **-1.6989** | **0.8018** | **3.1026** | **-1.2540** | **1.8486** | **4.8425** | **-1.3292** | **3.5133** | **5.4856** | **-0.8109** | **4.6747** |

| Coilset | 30 seconds | | | 50 seconds | | | 100 seconds | | | 200 seconds | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Flow (kW) | Storage (kW) | Coil set $q_c$ (kW) | Flow (kW) | Storage (kW) | Coil set $q_c$ (kW) | Flow (kW) | Storage (kW) | Coil set $q_c$ (kW) | Flow (kW) | Storage (kW) | Coil set $q_c$ (kW) |
| **1** | 0.3985 | -0.0675 | 0.3310 | 0.4506 | -0.0209 | 0.4297 | 0.4619 | -0.0051 | 0.4568 | 0.4672 | -0.0008 | 0.4664 |
| **2** | 0.3984 | -0.0659 | 0.3325 | 0.4505 | -0.0190 | 0.4315 | 0.4618 | -0.0051 | 0.4566 | 0.4671 | -0.0008 | 0.4663 |
| **3** | 0.3983 | -0.0639 | 0.3344 | 0.4503 | -0.0174 | 0.4330 | 0.4616 | -0.0051 | 0.4565 | 0.4669 | -0.0008 | 0.4661 |
| **4** | 0.3982 | -0.0623 | 0.3359 | 0.4502 | -0.0154 | 0.4348 | 0.4551 | -0.0047 | 0.4504 | 0.4731 | -0.0004 | 0.4727 |
| **5** | 0.3981 | -0.0603 | 0.3377 | 0.4501 | -0.0138 | 0.4362 | 0.4613 | -0.0047 | 0.4566 | 0.4666 | -0.0004 | 0.4662 |
| **6** | 0.3980 | -0.0587 | 0.3392 | 0.4499 | -0.0118 | 0.4381 | 0.4612 | -0.0043 | 0.4568 | 0.4665 | -0.0004 | 0.4661 |
| **7** | 0.3979 | -0.0568 | 0.3411 | 0.4498 | -0.0102 | 0.4395 | 0.4610 | -0.0043 | 0.4567 | 0.4663 | -0.0004 | 0.4659 |
| **8** | 0.3978 | -0.0552 | 0.3426 | 0.4560 | -0.0083 | 0.4477 | 0.4609 | -0.0043 | 0.4565 | 0.4662 | -0.0004 | 0.4658 |
| **9** | 0.3977 | -0.0532 | 0.3445 | 0.4495 | -0.0067 | 0.4428 | 0.4607 | -0.0039 | 0.4568 | 0.4660 | -0.0004 | 0.4656 |
| **10** | 0.3976 | -0.0516 | 0.3460 | 0.4494 | -0.0047 | 0.4447 | 0.4606 | -0.0039 | 0.4567 | 0.4659 | -0.0004 | 0.4655 |
| **11** | 0.3975 | -0.0496 | 0.3479 | 0.4493 | -0.0032 | 0.4461 | 0.4605 | -0.0039 | 0.4566 | 0.4658 | -0.0004 | 0.4654 |
| **12** | 0.3974 | -0.0480 | 0.3494 | 0.4492 | -0.0012 | 0.4480 | 0.4541 | -0.0035 | 0.4505 | 0.4720 | 0.0000 | 0.4720 |
| **13** | 0.3973 | -0.0461 | 0.3513 | 0.4491 | 0.0004 | 0.4495 | 0.4603 | -0.0035 | 0.4567 | 0.4656 | 0.0000 | 0.4656 |
| **14** | 0.3972 | -0.0445 | 0.3528 | 0.4490 | 0.0024 | 0.4513 | 0.4602 | -0.0035 | 0.4566 | 0.4654 | 0.0000 | 0.4654 |
| **exit** | 0.3972 | 0.0000 | 0.3972 | 0.4489 | 0.0000 | 0.4489 | 0.4600 | 0.0000 | 0.4600 | 0.4653 | 0.0000 | 0.4653 |
| **TOTAL $q_c$** | **5.9669** | **-0.7836** | **5.1833** | **6.7516** | **-0.1298** | **6.6218** | **6.9012** | **-0.0603** | **6.8409** | **7.0060** | **-0.0055** | **7.0004** |

## Table M17: Coil Set Energy Balance for R4-36 at 7LPM

| Coilset | 1 second | | | 2 seconds | | | 3 seconds | | | 5 seconds | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Flow (kW) | Storage (kW) | Coil set $q_c$ (kW) | Flow (kW) | Storage (kW) | Coil set $q_c$ (kW) | Flow (kW) | Storage (kW) | Coil set $q_c$ (kW) | Flow (kW) | Storage (kW) | Coil set $q_c$ (kW) |
| **1** | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0004 | 0.0004 | 0.0000 | -0.0035 | -0.0035 | 0.0231 | -0.1298 | -0.1067 |
| **2** | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0004 | 0.0004 | 0.0000 | -0.0035 | -0.0035 | 0.0231 | -0.1200 | -0.0969 |
| **3** | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0008 | 0.0008 | 0.0046 | -0.0031 | 0.0014 | 0.0277 | -0.1102 | -0.0824 |
| **4** | 0.0000 | 0.0000 | 0.0000 | 0.0045 | 0.0012 | 0.0057 | 0.0000 | -0.0028 | -0.0028 | 0.0231 | -0.1003 | -0.0772 |
| **5** | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0012 | 0.0012 | 0.0000 | -0.0028 | -0.0028 | 0.0231 | -0.0905 | -0.0674 |
| **6** | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0016 | 0.0016 | 0.0000 | -0.0024 | -0.0024 | 0.0231 | -0.0806 | -0.0575 |
| **7** | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0020 | 0.0020 | 0.0000 | -0.0020 | -0.0020 | 0.0231 | -0.0708 | -0.0477 |
| **8** | 0.0045 | 0.0000 | 0.0045 | 0.0000 | 0.0020 | 0.0020 | 0.0046 | -0.0020 | 0.0026 | 0.0277 | -0.0610 | -0.0332 |
| **9** | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0024 | 0.0024 | 0.0000 | -0.0016 | -0.0016 | 0.0231 | -0.0511 | -0.0280 |
| **10** | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0028 | 0.0028 | 0.0000 | -0.0012 | -0.0012 | 0.0231 | -0.0413 | -0.0182 |
| **11** | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0028 | 0.0028 | 0.0000 | -0.0012 | -0.0012 | 0.0231 | -0.0315 | -0.0083 |
| **12** | 0.0000 | 0.0000 | 0.0000 | 0.0045 | 0.0031 | 0.0077 | 0.0000 | -0.0008 | -0.0008 | 0.0231 | -0.0216 | 0.0015 |
| **13** | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0035 | 0.0035 | 0.0046 | -0.0004 | 0.0042 | 0.0277 | -0.0118 | 0.0159 |
| **14** | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0035 | 0.0035 | 0.0000 | -0.0004 | -0.0004 | 0.0231 | -0.0020 | 0.0212 |
| **exit** | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0231 | 0.0000 | 0.0231 |
| **TOTAL $q_c$** | **0.0045** | **0.0000** | **0.0045** | **0.0091** | **0.0275** | **0.0366** | **0.0138** | **-0.0275** | **-0.0137** | **0.3607** | **-0.9225** | **-0.5618** |

| Coilset | 8 seconds | | | 10 seconds | | | 15 seconds | | | 20 seconds | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Flow (kW) | Storage (kW) | Coil set $q_c$ (kW) | Flow (kW) | Storage (kW) | Coil set $q_c$ (kW) | Flow (kW) | Storage (kW) | Coil set $q_c$ (kW) | Flow (kW) | Storage (kW) | Coil set $q_c$ (kW) |
| **1** | 0.0706 | -0.1783 | -0.1077 | 0.0903 | -0.1043 | -0.0140 | 0.1735 | -0.1639 | 0.0096 | 0.2376 | -0.1167 | 0.1210 |
| **2** | 0.0753 | -0.1649 | -0.0897 | 0.0951 | -0.0964 | -0.0014 | 0.1783 | -0.1505 | 0.0278 | 0.2424 | -0.1064 | 0.1360 |
| **3** | 0.0705 | -0.1515 | -0.0810 | 0.0903 | -0.0886 | 0.0017 | 0.1735 | -0.1371 | 0.0364 | 0.2376 | -0.0961 | 0.1414 |
| **4** | 0.0705 | -0.1385 | -0.0680 | 0.0903 | -0.0807 | 0.0096 | 0.1734 | -0.1240 | 0.0494 | 0.2375 | -0.0855 | 0.1520 |
| **5** | 0.0752 | -0.1251 | -0.0499 | 0.0950 | -0.0728 | 0.0222 | 0.1734 | -0.1106 | 0.0628 | 0.2423 | -0.0752 | 0.1671 |
| **6** | 0.0705 | -0.1118 | -0.0412 | 0.0903 | -0.0649 | 0.0253 | 0.1782 | -0.0972 | 0.0810 | 0.2374 | -0.0650 | 0.1724 |
| **7** | 0.0705 | -0.0984 | -0.0278 | 0.0903 | -0.0571 | 0.0332 | 0.1734 | -0.0838 | 0.0895 | 0.2374 | -0.0547 | 0.1827 |
| **8** | 0.0752 | -0.0850 | -0.0098 | 0.0950 | -0.0492 | 0.0458 | 0.1733 | -0.0705 | 0.1029 | 0.2422 | -0.0445 | 0.1977 |
| **9** | 0.0705 | -0.0720 | -0.0015 | 0.0903 | -0.0413 | 0.0489 | 0.1733 | -0.0571 | 0.1163 | 0.2373 | -0.0342 | 0.2031 |
| **10** | 0.0705 | -0.0586 | 0.0119 | 0.0903 | -0.0334 | 0.0568 | 0.1781 | -0.0437 | 0.1344 | 0.2373 | -0.0240 | 0.2133 |
| **11** | 0.0752 | -0.0452 | 0.0300 | 0.0950 | -0.0256 | 0.0694 | 0.1733 | -0.0303 | 0.1430 | 0.2421 | -0.0138 | 0.2283 |
| **12** | 0.0705 | -0.0319 | 0.0387 | 0.0902 | -0.0177 | 0.0725 | 0.1733 | -0.0173 | 0.1559 | 0.2372 | -0.0031 | 0.2340 |
| **13** | 0.0705 | -0.0189 | 0.0516 | 0.0902 | -0.0098 | 0.0804 | 0.1732 | -0.0039 | 0.1693 | 0.2372 | 0.0071 | 0.2442 |
| **14** | 0.0752 | -0.0055 | 0.0697 | 0.0950 | -0.0020 | 0.0930 | 0.1780 | 0.0094 | 0.1875 | 0.2420 | 0.0173 | 0.2593 |
| **exit** | 0.0705 | 0.0000 | 0.0705 | 0.0902 | 0.0000 | 0.0902 | 0.1732 | 0.0000 | 0.1732 | 0.2371 | 0.0000 | 0.2371 |
| **TOTAL $q_c$** | **1.0814** | **-1.2856** | **-0.2042** | **1.3778** | **-0.7438** | **0.6340** | **2.6194** | **-1.0805** | **1.5389** | **3.5845** | **-0.6949** | **2.8896** |

| Coilset | 30 seconds | | | 50 seconds | | | 100 seconds | | | 200 seconds | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Flow (kW) | Storage (kW) | Coil set $q_c$ (kW) | Flow (kW) | Storage (kW) | Coil set $q_c$ (kW) | Flow (kW) | Storage (kW) | Coil set $q_c$ (kW) | Flow (kW) | Storage (kW) | Coil set $q_c$ (kW) |
| **1** | 0.2999 | -0.0722 | 0.2277 | 0.2993 | -0.0355 | 0.2638 | 0.3411 | -0.0083 | 0.3328 | 0.3900 | -0.0008 | 0.3892 |
| **2** | 0.2949 | -0.0674 | 0.2275 | 0.2992 | -0.0355 | 0.2637 | 0.3410 | -0.0075 | 0.3335 | 0.3850 | -0.0004 | 0.3846 |
| **3** | 0.2998 | -0.0631 | 0.2367 | 0.2991 | -0.0355 | 0.2636 | 0.3409 | -0.0067 | 0.3342 | 0.3898 | 0.0000 | 0.3898 |
| **4** | 0.2948 | -0.0587 | 0.2360 | 0.2991 | -0.0355 | 0.2636 | 0.3408 | -0.0063 | 0.3345 | 0.3847 | 0.0004 | 0.3851 |
| **5** | 0.2996 | -0.0544 | 0.2452 | 0.2990 | -0.0355 | 0.2635 | 0.3407 | -0.0055 | 0.3352 | 0.3895 | 0.0008 | 0.3903 |
| **6** | 0.2995 | -0.0496 | 0.2499 | 0.2989 | -0.0355 | 0.2634 | 0.3406 | -0.0051 | 0.3355 | 0.3894 | 0.0008 | 0.3902 |
| **7** | 0.2946 | -0.0453 | 0.2493 | 0.2988 | -0.0351 | 0.2637 | 0.3405 | -0.0043 | 0.3362 | 0.3843 | 0.0012 | 0.3855 |
| **8** | 0.2994 | -0.0410 | 0.2584 | 0.2938 | -0.0351 | 0.2588 | 0.3404 | -0.0035 | 0.3368 | 0.3891 | 0.0016 | 0.3907 |
| **9** | 0.2944 | -0.0366 | 0.2578 | 0.2987 | -0.0351 | 0.2636 | 0.3403 | -0.0032 | 0.3371 | 0.3841 | 0.0020 | 0.3860 |
| **10** | 0.2993 | -0.0319 | 0.2674 | 0.2986 | -0.0351 | 0.2636 | 0.3402 | -0.0024 | 0.3378 | 0.3889 | 0.0024 | 0.3912 |
| **11** | 0.2992 | -0.0276 | 0.2717 | 0.2986 | -0.0351 | 0.2635 | 0.3401 | -0.0016 | 0.3386 | 0.3888 | 0.0028 | 0.3915 |
| **12** | 0.2943 | -0.0232 | 0.2710 | 0.2985 | -0.0350 | 0.2634 | 0.3401 | -0.0012 | 0.3389 | 0.3838 | 0.0031 | 0.3869 |
| **13** | 0.2991 | -0.0189 | 0.2802 | 0.2984 | -0.0346 | 0.2638 | 0.3400 | -0.0004 | 0.3396 | 0.3886 | 0.0035 | 0.3921 |
| **14** | 0.2941 | -0.0142 | 0.2800 | 0.2984 | -0.0346 | 0.2637 | 0.3399 | 0.0000 | 0.3399 | 0.3835 | 0.0039 | 0.3875 |
| **exit** | 0.2990 | 0.0000 | 0.2990 | 0.2983 | 0.0000 | 0.2983 | 0.3398 | 0.0000 | 0.3398 | 0.3884 | 0.0000 | 0.3884 |
| **TOTAL $q_c$** | **4.4618** | **-0.6041** | **3.8578** | **4.4766** | **-0.4927** | **3.9839** | **5.1064** | **-0.0560** | **5.0503** | **5.8077** | **0.0213** | **5.8290** |

## Table M18: Coil Set Energy Balance for R4-36 at 5.5LPM

| Coilset | 1 second | | | 2 seconds | | | 3 seconds | | | 5 seconds | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Flow (kW) | Storage (kW) | Coil set $q_c$ (kW) | Flow (kW) | Storage (kW) | Coil set $q_c$ (kW) | Flow (kW) | Storage (kW) | Coil set $q_c$ (kW) | Flow (kW) | Storage (kW) | Coil set $q_c$ (kW) |
| **1** | 0.0108 | 0.0000 | 0.0108 | 0.0144 | -0.0806 | -0.0662 | 0.0217 | -0.0842 | -0.0625 | 0.0327 | -0.0972 | -0.0644 |
| **2** | 0.0072 | 0.0000 | 0.0072 | 0.0144 | -0.0751 | -0.0607 | 0.0217 | -0.0779 | -0.0562 | 0.0364 | -0.0897 | -0.0533 |
| **3** | 0.0108 | 0.0000 | 0.0108 | 0.0180 | -0.0692 | -0.0512 | 0.0180 | -0.0716 | -0.0536 | 0.0327 | -0.0826 | -0.0499 |
| **4** | 0.0108 | 0.0000 | 0.0108 | 0.0144 | -0.0633 | -0.0489 | 0.0217 | -0.0653 | -0.0436 | 0.0364 | -0.0755 | -0.0392 |
| **5** | 0.0108 | 0.0000 | 0.0108 | 0.0144 | -0.0578 | -0.0434 | 0.0217 | -0.0590 | -0.0374 | 0.0327 | -0.0681 | -0.0353 |
| **6** | 0.0072 | 0.0000 | 0.0072 | 0.0144 | -0.0519 | -0.0375 | 0.0217 | -0.0527 | -0.0311 | 0.0364 | -0.0610 | -0.0246 |
| **7** | 0.0108 | 0.0000 | 0.0108 | 0.0144 | -0.0460 | -0.0316 | 0.0217 | -0.0464 | -0.0248 | 0.0327 | -0.0539 | -0.0212 |
| **8** | 0.0108 | 0.0000 | 0.0108 | 0.0180 | -0.0405 | -0.0225 | 0.0180 | -0.0401 | -0.0221 | 0.0364 | -0.0464 | -0.0100 |
| **9** | 0.0108 | 0.0000 | 0.0108 | 0.0144 | -0.0346 | -0.0202 | 0.0217 | -0.0338 | -0.0122 | 0.0327 | -0.0393 | -0.0066 |
| **10** | 0.0072 | 0.0000 | 0.0072 | 0.0144 | -0.0287 | -0.0143 | 0.0217 | -0.0275 | -0.0059 | 0.0364 | -0.0323 | 0.0041 |
| **11** | 0.0108 | 0.0000 | 0.0108 | 0.0144 | -0.0232 | -0.0088 | 0.0217 | -0.0212 | 0.0004 | 0.0327 | -0.0248 | 0.0079 |
| **12** | 0.0108 | 0.0000 | 0.0108 | 0.0144 | -0.0173 | -0.0029 | 0.0217 | -0.0149 | 0.0067 | 0.0364 | -0.0177 | 0.0187 |
| **13** | 0.0108 | 0.0000 | 0.0108 | 0.0180 | -0.0114 | 0.0066 | 0.0180 | -0.0087 | 0.0094 | 0.0327 | -0.0106 | 0.0221 |
| **14** | 0.0072 | 0.0000 | 0.0072 | 0.0144 | -0.0059 | 0.0085 | 0.0217 | -0.0024 | 0.0193 | 0.0364 | -0.0031 | 0.0332 |
| **exit** | 0.0108 | 0.0000 | 0.0108 | 0.0144 | 0.0000 | 0.0144 | 0.0217 | 0.0000 | 0.0217 | 0.0327 | 0.0000 | 0.0327 |
| **TOTAL $q_c$** | **0.1477** | **0.0000** | **0.1477** | **0.2274** | **-0.6058** | **-0.3784** | **0.3140** | **-0.6058** | **-0.2918** | **0.5165** | **-0.7023** | **-0.1858** |
| **Coilset** | **8 seconds** | | | **10 seconds** | | | **15 seconds** | | | **20 seconds** | | |
| | **Flow (kW)** | **Storage (kW)** | **Coil set $q_c$ (kW)** | **Flow (kW)** | **Storage (kW)** | **Coil set $q_c$ (kW)** | **Flow (kW)** | **Storage (kW)** | **Coil set $q_c$ (kW)** | **Flow (kW)** | **Storage (kW)** | **Coil set $q_c$ (kW)** |
| **1** | 0.0589 | -0.1086 | -0.0497 | 0.0812 | -0.1756 | -0.0944 | 0.1321 | -0.1205 | 0.0116 | 0.1740 | -0.0871 | 0.0869 |
| **2** | 0.0552 | -0.1008 | -0.0455 | 0.0848 | -0.1622 | -0.0774 | 0.1321 | -0.1107 | 0.0214 | 0.1702 | -0.0788 | 0.0914 |
| **3** | 0.0589 | -0.0925 | -0.0336 | 0.0811 | -0.1488 | -0.0677 | 0.1358 | -0.1004 | 0.0354 | 0.1740 | -0.0709 | 0.1030 |
| **4** | 0.0552 | -0.0846 | -0.0294 | 0.0848 | -0.1354 | -0.0506 | 0.1321 | -0.0906 | 0.0415 | 0.1701 | -0.0626 | 0.1075 |
| **5** | 0.0589 | -0.0763 | -0.0175 | 0.0811 | -0.1220 | -0.0409 | 0.1320 | -0.0803 | 0.0517 | 0.1739 | -0.0543 | 0.1196 |
| **6** | 0.0589 | -0.0685 | -0.0096 | 0.0811 | -0.1086 | -0.0275 | 0.1320 | -0.0701 | 0.0619 | 0.1739 | -0.0461 | 0.1278 |
| **7** | 0.0552 | -0.0606 | -0.0054 | 0.0848 | -0.0952 | -0.0104 | 0.1320 | -0.0602 | 0.0718 | 0.1701 | -0.0378 | 0.1323 |
| **8** | 0.0589 | -0.0523 | 0.0065 | 0.0811 | -0.0819 | -0.0007 | 0.1358 | -0.0500 | 0.0858 | 0.1738 | -0.0299 | 0.1439 |
| **9** | 0.0552 | -0.0445 | 0.0107 | 0.0848 | -0.0685 | 0.0163 | 0.1320 | -0.0401 | 0.0918 | 0.1700 | -0.0216 | 0.1484 |
| **10** | 0.0589 | -0.0362 | 0.0227 | 0.0811 | -0.0551 | 0.0260 | 0.1320 | -0.0299 | 0.1021 | 0.1738 | -0.0134 | 0.1604 |
| **11** | 0.0589 | -0.0283 | 0.0305 | 0.0811 | -0.0417 | 0.0394 | 0.1319 | -0.0197 | 0.1123 | 0.1737 | -0.0051 | 0.1686 |
| **12** | 0.0552 | -0.0201 | 0.0351 | 0.0848 | -0.0283 | 0.0564 | 0.1319 | -0.0098 | 0.1221 | 0.1699 | 0.0031 | 0.1731 |
| **13** | 0.0589 | -0.0122 | 0.0467 | 0.0811 | -0.0149 | 0.0661 | 0.1357 | 0.0004 | 0.1361 | 0.1737 | 0.0110 | 0.1847 |
| **14** | 0.0552 | -0.0039 | 0.0512 | 0.0848 | -0.0016 | 0.0832 | 0.1319 | 0.0102 | 0.1421 | 0.1699 | 0.0193 | 0.1892 |
| **exit** | 0.0589 | 0.0000 | 0.0589 | 0.0811 | 0.0000 | 0.0811 | 0.1319 | 0.0000 | 0.1319 | 0.1736 | 0.0000 | 0.1736 |
| **TOTAL $q_c$** | **0.8610** | **-0.7894** | **0.0716** | **1.2388** | **-1.2398** | **-0.0010** | **1.9912** | **-0.7718** | **1.2194** | **2.5846** | **-0.4743** | **2.1103** |
| **Coilset** | **30 seconds** | | | **50 seconds** | | | **100 seconds** | | | **200 seconds** | | |
| | **Flow (kW)** | **Storage (kW)** | **Coil set $q_c$ (kW)** | **Flow (kW)** | **Storage (kW)** | **Coil set $q_c$ (kW)** | **Flow (kW)** | **Storage (kW)** | **Coil set $q_c$ (kW)** | **Flow (kW)** | **Storage (kW)** | **Coil set $q_c$ (kW)** |
| **1** | 0.2356 | -0.0797 | 0.1560 | 0.2550 | -0.0411 | 0.2140 | 0.2455 | -0.0107 | 0.2348 | 0.2568 | -0.0020 | 0.2548 |
| **2** | 0.2394 | -0.0737 | 0.1657 | 0.2549 | -0.0407 | 0.2143 | 0.2415 | -0.0107 | 0.2309 | 0.2606 | -0.0016 | 0.2590 |
| **3** | 0.2355 | -0.0674 | 0.1681 | 0.2549 | -0.0402 | 0.2146 | 0.2454 | -0.0111 | 0.2343 | 0.2566 | -0.0016 | 0.2550 |
| **4** | 0.2354 | -0.0611 | 0.1744 | 0.2508 | -0.0398 | 0.2109 | 0.2453 | -0.0111 | 0.2342 | 0.2604 | -0.0012 | 0.2592 |
| **5** | 0.2354 | -0.0552 | 0.1802 | 0.2547 | -0.0398 | 0.2149 | 0.2413 | -0.0110 | 0.2303 | 0.2565 | -0.0012 | 0.2553 |
| **6** | 0.2392 | -0.0488 | 0.1904 | 0.2547 | -0.0394 | 0.2152 | 0.2452 | -0.0110 | 0.2341 | 0.2603 | -0.0012 | 0.2591 |
| **7** | 0.2353 | -0.0425 | 0.1928 | 0.2546 | -0.0390 | 0.2156 | 0.2451 | -0.0110 | 0.2340 | 0.2563 | -0.0008 | 0.2555 |
| **8** | 0.2352 | -0.0366 | 0.1986 | 0.2545 | -0.0386 | 0.2159 | 0.2411 | -0.0110 | 0.2301 | 0.2601 | -0.0008 | 0.2593 |
| **9** | 0.2352 | -0.0303 | 0.2049 | 0.2545 | -0.0382 | 0.2163 | 0.2449 | -0.0110 | 0.2339 | 0.2562 | -0.0008 | 0.2554 |
| **10** | 0.2390 | -0.0240 | 0.2150 | 0.2544 | -0.0382 | 0.2162 | 0.2449 | -0.0110 | 0.2339 | 0.2600 | -0.0004 | 0.2596 |
| **11** | 0.2351 | -0.0181 | 0.2170 | 0.2544 | -0.0378 | 0.2166 | 0.2409 | -0.0110 | 0.2299 | 0.2560 | -0.0004 | 0.2556 |
| **12** | 0.2350 | -0.0118 | 0.2232 | 0.2503 | -0.0374 | 0.2129 | 0.2448 | -0.0110 | 0.2338 | 0.2599 | 0.0000 | 0.2599 |
| **13** | 0.2350 | -0.0055 | 0.2295 | 0.2543 | -0.0370 | 0.2173 | 0.2447 | -0.0110 | 0.2337 | 0.2559 | 0.0000 | 0.2559 |
| **14** | 0.2388 | 0.0004 | 0.2392 | 0.2542 | -0.0366 | 0.2176 | 0.2408 | -0.0110 | 0.2298 | 0.2597 | 0.0000 | 0.2597 |
| **exit** | 0.2349 | 0.0000 | 0.2349 | 0.2541 | 0.0000 | 0.2541 | 0.2446 | 0.0000 | 0.2446 | 0.2558 | 0.0000 | 0.2558 |
| **TOTAL $q_c$** | **3.5442** | **-0.5544** | **2.9898** | **3.8102** | **-0.5439** | **3.2663** | **3.6560** | **-0.1538** | **3.5023** | **3.8711** | **-0.0118** | **3.8593** |

# Appendix N: Summarized Energy Balance Data Tables

**Table N1: Energy Balance Data at 14 LPM**

| Time (s) | R3-36 | | | R3-60 | | | R4-36 | | |
|---|---|---|---|---|---|---|---|---|---|
| | Flow (kW) | Storage (kW) | Overall $q_c$ (kW) | Flow (kW) | Storage (kW) | Overall $q_c$ (kW) | Flow (kW) | Storage (kW) | Overall $q_c$ (kW) |
| 1 | 0.1213 | 0.0000 | 0.1213 | 0.8198 | 0.0000 | 0.8198 | 0.0383 | 0.0000 | 0.0383 |
| 2 | 0.1408 | -0.1028 | 0.0380 | 1.0453 | -0.3070 | 0.7383 | 0.0165 | 0.0000 | 0.0165 |
| 3 | 0.1727 | -0.0514 | 0.1213 | 1.3952 | -0.9211 | 0.4741 | 0.0187 | -0.1101 | -0.0914 |
| 5 | 1.5796 | -1.2850 | 0.2947 | 2.9041 | -2.3734 | 0.5308 | 1.1131 | -1.5561 | -0.4429 |
| 8 | 4.6508 | -1.8860 | 2.7649 | 5.6260 | -2.7941 | 2.8320 | 3.5848 | -2.3147 | 1.2701 |
| 10 | 5.6625 | -1.3633 | 4.2991 | 6.8022 | -1.4953 | 5.3069 | 5.1358 | -2.0261 | 3.1097 |
| 15 | 7.4541 | -1.1807 | 6.2734 | 9.5188 | -1.0238 | 8.4950 | 7.9319 | -2.0304 | 5.9015 |
| 20 | 8.8095 | -0.6867 | 8.1228 | 11.6851 | -0.6882 | 10.9969 | 8.6582 | -1.2141 | 7.4441 |
| 30 | 9.1649 | -0.4242 | 8.7407 | 12.3056 | -0.4616 | 11.8441 | 8.9817 | -0.6625 | 8.3192 |
| 50 | 9.1789 | -0.1261 | 9.0528 | 12.2032 | -0.1581 | 12.0451 | 8.7957 | -0.2733 | 8.5224 |
| 100 | 9.3273 | -0.0204 | 9.3070 | 12.4023 | -0.0236 | 12.3787 | 8.7717 | -0.0292 | 8.7425 |
| 200 | 9.3568 | -0.0034 | 9.3534 | 12.5513 | -0.0056 | 12.5457 | 8.8469 | -0.0032 | 8.8437 |

**Table N2: Energy Balance Data at 12 LPM**

| Time (s) | R3-36 | | | R3-60 | | | R4-36 | | |
|---|---|---|---|---|---|---|---|---|---|
| | Flow (kW) | Storage (kW) | Overall $q_c$ (kW) | Flow (kW) | Storage (kW) | Overall $q_c$ (kW) | Flow (kW) | Storage (kW) | Overall $q_c$ (kW) |
| 1 | 0.1208 | 0.0000 | 0.1208 | 0.3844 | 0.0000 | 0.3844 | 0.1716 | 0.0000 | 0.1716 |
| 2 | 0.1459 | -0.0343 | 0.1117 | 0.5206 | -0.5023 | 0.0183 | 0.7959 | -2.0377 | -1.2418 |
| 3 | 0.1721 | -0.0514 | 0.1208 | 1.4851 | -3.3219 | -1.8368 | 1.3223 | -1.7075 | -0.3852 |
| 5 | 1.2741 | -1.1650 | 0.1091 | 2.6197 | -1.8848 | 0.7349 | 3.0291 | -2.8104 | 0.2187 |
| 8 | 2.4460 | -0.7827 | 1.6633 | 4.7453 | -2.2165 | 2.5288 | 5.0710 | -1.9849 | 3.0861 |
| 10 | 3.9993 | -1.7059 | 2.2934 | 6.2437 | -1.7889 | 4.4548 | 5.9369 | -1.1581 | 4.7788 |
| 15 | 6.1837 | -1.2319 | 4.9519 | 8.2850 | -0.6211 | 7.6639 | 7.1637 | -1.0591 | 6.1045 |
| 20 | 7.2287 | -0.4840 | 6.7447 | 9.8158 | -0.4366 | 9.3792 | 7.9415 | -1.1036 | 6.8379 |
| 30 | 7.9842 | -0.3743 | 7.6099 | 10.8742 | -0.4112 | 10.4631 | 8.0268 | -0.5547 | 7.4721 |
| 50 | 8.1498 | -0.1693 | 7.9806 | 10.9070 | -0.1899 | 10.7171 | 7.9211 | -0.2500 | 7.6711 |
| 100 | 8.2761 | -0.0282 | 8.2479 | 11.1642 | -0.0336 | 11.1307 | 8.0008 | -0.0383 | 7.9626 |
| 200 | 8.3607 | -0.0032 | 8.3575 | 11.3382 | -0.0037 | 11.3345 | 8.0848 | -0.0055 | 8.0793 |

Table N3: Energy Balance Data at 10 LPM

| Time (s) | R3-36 | | | R3-60 | | | R4-36 | | |
|---|---|---|---|---|---|---|---|---|---|
| | Flow (kW) | Storage (kW) | Overall $q_c$ (kW) | Flow (kW) | Storage (kW) | Overall $q_c$ (kW) | Flow (kW) | Storage (kW) | Overall $q_c$ (kW) |
| **1** | 0.3010 | 0.0000 | 0.3010 | 0.7054 | 0.0000 | 0.7054 | 0.0000 | 0.0000 | 0.0000 |
| **2** | 0.3496 | -0.1199 | 0.2297 | 0.9233 | -0.8652 | 0.0581 | 0.0134 | -0.0551 | -0.0417 |
| **3** | 0.4053 | -0.1370 | 0.2683 | 1.2416 | -1.3398 | -0.0982 | 0.0269 | -0.0551 | -0.0282 |
| **5** | 0.9609 | -0.7281 | 0.2328 | 2.0324 | -1.6194 | 0.4131 | 0.7534 | -1.3632 | -0.6098 |
| **8** | 2.5756 | -1.3883 | 1.1873 | 3.2370 | -1.6759 | 1.5611 | 2.3866 | -2.0389 | 0.3477 |
| **10** | 3.6005 | -1.4402 | 2.1603 | 4.3582 | -2.0677 | 2.2905 | 3.1288 | -1.3229 | 1.8060 |
| **15** | 5.0702 | -0.9092 | 4.1610 | 6.4876 | -0.8893 | 5.5983 | 5.0292 | -1.2740 | 3.7553 |
| **20** | 6.1502 | -0.5458 | 5.6044 | 7.7283 | -0.3751 | 7.3532 | 6.2353 | -0.8938 | 5.3415 |
| **30** | 7.0774 | -0.3176 | 6.7598 | 9.3026 | -0.3583 | 8.9443 | 7.0695 | -0.5408 | 6.5287 |
| **50** | 7.2815 | -0.1793 | 7.1022 | 9.6802 | -0.2224 | 9.4578 | 7.1276 | -0.3245 | 6.8032 |
| **100** | 7.4515 | -0.0368 | 7.4147 | 9.9168 | -0.0515 | 9.8653 | 7.2134 | -0.0635 | 7.1499 |
| **200** | 7.5512 | -0.0047 | 7.5465 | 10.0815 | -0.0051 | 10.0763 | 7.3046 | -0.0063 | 7.2982 |

Table N4: Energy Balance Data at 9 LPM

| Time (s) | R3-36 | | | R3-60 | | | R4-36 | | |
|---|---|---|---|---|---|---|---|---|---|
| | Flow (kW) | Storage (kW) | Overall $q_c$ (kW) | Flow (kW) | Storage (kW) | Overall $q_c$ (kW) | Flow (kW) | Storage (kW) | Overall $q_c$ (kW) |
| **1** | 0.6263 | 0.0000 | 0.6263 | 0.5758 | 0.0000 | 0.5758 | 0.1547 | 0.0000 | 0.1547 |
| **2** | 0.9006 | -0.7538 | 0.1468 | 0.8842 | -1.3399 | -0.4557 | 0.2918 | -0.5507 | -0.2588 |
| **3** | 1.0584 | -0.4283 | 0.6301 | 1.2002 | -1.3680 | -0.1678 | 0.8208 | -2.2031 | -1.3823 |
| **5** | 1.8760 | -1.1482 | 0.7277 | 1.9007 | -1.4940 | 0.4067 | 1.3233 | -1.0604 | 0.2628 |
| **8** | 2.8178 | -0.8858 | 1.9320 | 3.1839 | -1.7410 | 1.4429 | 2.5007 | -1.6989 | 0.8018 |
| **10** | 3.5939 | -1.2175 | 2.3764 | 4.1001 | -1.4952 | 2.6050 | 3.1026 | -1.2540 | 1.8486 |
| **15** | 4.7620 | -0.7240 | 4.0380 | 5.5567 | -0.5426 | 5.0140 | 4.8425 | -1.3292 | 3.5133 |
| **20** | 5.7091 | -0.3811 | 5.3280 | 7.0026 | -0.2578 | 6.7447 | 5.4856 | -0.8109 | 4.6747 |
| **30** | 6.5790 | -0.2816 | 6.2974 | 8.4621 | -0.2436 | 8.2185 | 5.9669 | -0.7836 | 5.1833 |
| **50** | 6.8744 | -0.1572 | 6.7172 | 8.9279 | -0.2126 | 8.7153 | 6.7516 | -0.1298 | 6.6218 |
| **100** | 7.0078 | -0.0366 | 6.9713 | 9.1918 | -0.0543 | 9.1375 | 6.9012 | -0.0603 | 6.8409 |
| **200** | 7.0862 | -0.0044 | 7.0818 | 9.2455 | -0.0068 | 9.2388 | 7.0060 | -0.0055 | 7.0004 |

Table N5: Energy Balance Data at 7 LPM

| Time (s) | R3-36 | | | R3-60 | | | R4-36 | | |
|---|---|---|---|---|---|---|---|---|---|
| | Flow (kW) | Storage (kW) | Overall $q_c$ (kW) | Flow (kW) | Storage (kW) | Overall $q_c$ (kW) | Flow (kW) | Storage (kW) | Overall $q_c$ (kW) |
| **1** | 0.4982 | 0.0000 | 0.4982 | 0.2168 | 0.0000 | 0.2168 | 0.0045 | 0.0000 | 0.0045 |
| **2** | 0.6318 | -0.5310 | 0.1007 | 0.2561 | -0.2791 | -0.0230 | 0.0091 | 0.0275 | 0.0366 |
| **3** | 0.8038 | -0.6510 | 0.1529 | 0.4770 | -1.2003 | -0.7232 | 0.0138 | -0.0275 | -0.0137 |
| **5** | 1.3365 | -1.0281 | 0.3083 | 0.6346 | -0.4466 | 0.1880 | 0.3607 | -0.9225 | -0.5618 |
| **8** | 1.8938 | -0.6915 | 1.2023 | 1.4482 | -1.7686 | -0.3204 | 1.0814 | -1.2856 | -0.2042 |
| **10** | 2.2366 | -0.6343 | 1.6023 | 1.8379 | -1.0613 | 0.7765 | 1.3778 | -0.7438 | 0.6340 |
| **15** | 3.2451 | -0.6140 | 2.6311 | 3.1988 | -1.1403 | 2.0586 | 2.6194 | -1.0805 | 1.5389 |
| **20** | 4.1075 | -0.3912 | 3.7162 | 4.2239 | -0.3022 | 3.9217 | 3.5845 | -0.6949 | 2.8896 |
| **30** | 5.1858 | -0.2506 | 4.9352 | 6.2957 | -0.0958 | 6.1999 | 4.4618 | -0.6041 | 3.8578 |
| **50** | 5.8155 | -0.1597 | 5.6558 | 7.3765 | -0.1344 | 7.2421 | 4.4766 | -0.4927 | 3.9839 |
| **100** | 6.0132 | -0.0530 | 5.9602 | 7.7600 | -0.0667 | 7.6934 | 5.1064 | -0.0560 | 5.0503 |
| **200** | 6.1346 | -0.0066 | 6.1279 | 7.9182 | -0.0079 | 7.9102 | 5.8077 | 0.0213 | 5.8290 |

Table N6: Energy Balance Data at 5.5 LPM

| Time (s) | R3-36 | | | R3-60 | | | R4-36 | | |
|---|---|---|---|---|---|---|---|---|---|
| | Flow (kW) | Storage (kW) | Overall $q_c$ (kW) | Flow (kW) | Storage (kW) | Overall $q_c$ (kW) | Flow (kW) | Storage (kW) | Overall $q_c$ (kW) |
| **1** | 0.2637 | 0.0000 | 0.2637 | 0.1452 | 0.0000 | 0.1452 | 0.1477 | 0.0000 | 0.1477 |
| **2** | 0.3344 | -0.3426 | -0.0082 | 0.2029 | -0.4467 | -0.2438 | 0.2274 | -0.6058 | -0.3784 |
| **3** | 0.5107 | -0.8223 | -0.3116 | 0.3493 | -1.0611 | -0.7118 | 0.3140 | -0.6058 | -0.2918 |
| **5** | 0.6975 | -0.4540 | 0.2435 | 0.5219 | -0.6144 | -0.0925 | 0.5165 | -0.7023 | -0.1858 |
| **8** | 1.0267 | -0.4970 | 0.5297 | 0.8621 | -0.8007 | 0.0614 | 0.8610 | -0.7894 | 0.0716 |
| **10** | 1.3891 | -0.7285 | 0.6607 | 1.1179 | -0.8381 | 0.2798 | 1.2388 | -1.2398 | -0.0010 |
| **15** | 2.0551 | -0.4698 | 1.5853 | 1.8285 | -0.5925 | 1.2360 | 1.9912 | -0.7718 | 1.2194 |
| **20** | 2.6618 | -0.3773 | 2.2845 | 2.7508 | -0.1682 | 2.5827 | 2.5846 | -0.4743 | 2.1103 |
| **30** | 3.8344 | -0.2352 | 3.5993 | 4.0438 | 0.0944 | 4.1383 | 3.5442 | -0.5544 | 2.9898 |
| **50** | 4.8099 | -0.1415 | 4.6683 | 5.5988 | 0.0219 | 5.6208 | 3.8102 | -0.5439 | 3.2663 |
| **100** | 5.1283 | -0.0684 | 5.0599 | 6.3799 | -0.0611 | 6.3188 | 3.6560 | -0.1538 | 3.5023 |
| **200** | 5.3055 | -0.0113 | 5.2942 | 6.5143 | -0.0075 | 6.5069 | 3.8711 | -0.0118 | 3.8593 |

# Appendix O: Energy Balance Plots

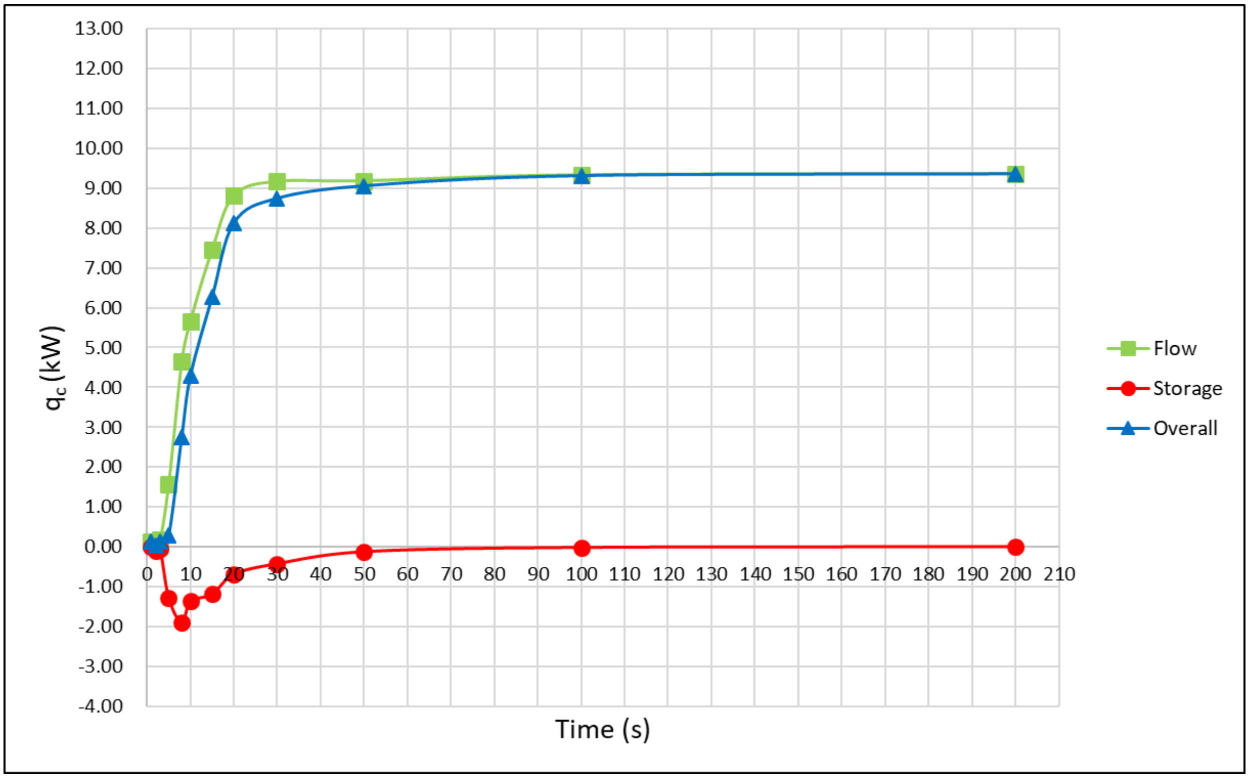


**Figure O1: Mains-side energy balance plot for R3-36 at 14LPM**

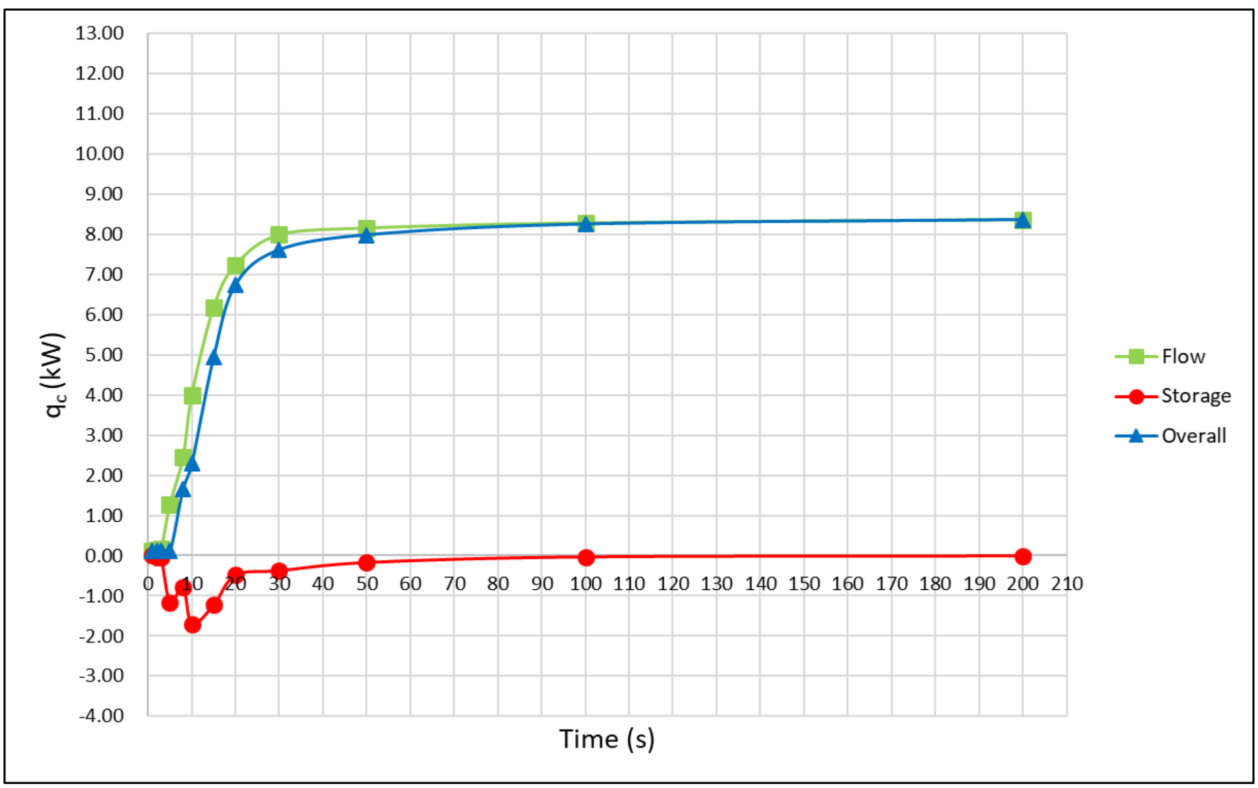


**Figure O2: Mains-side energy balance plot for R3-36 at 12LPM**

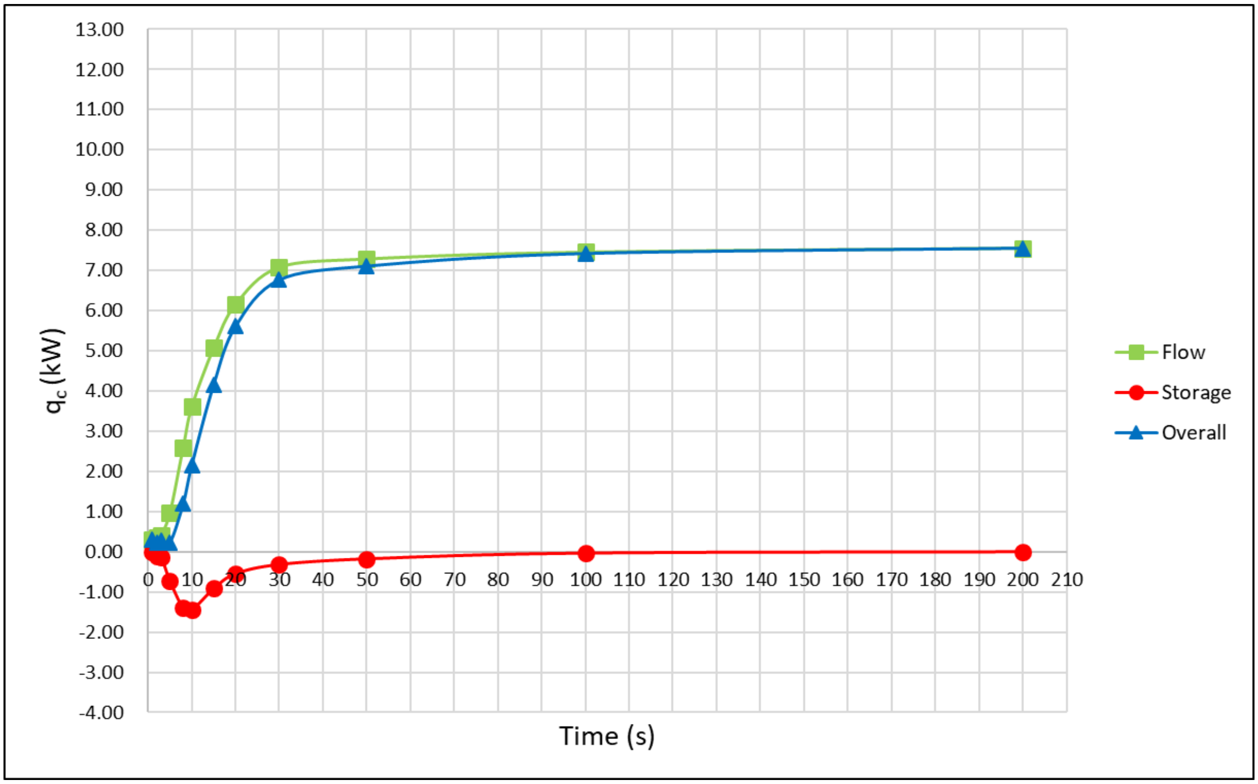


**Figure O3: Mains-side energy balance plot for R3-36 at 10LPM**

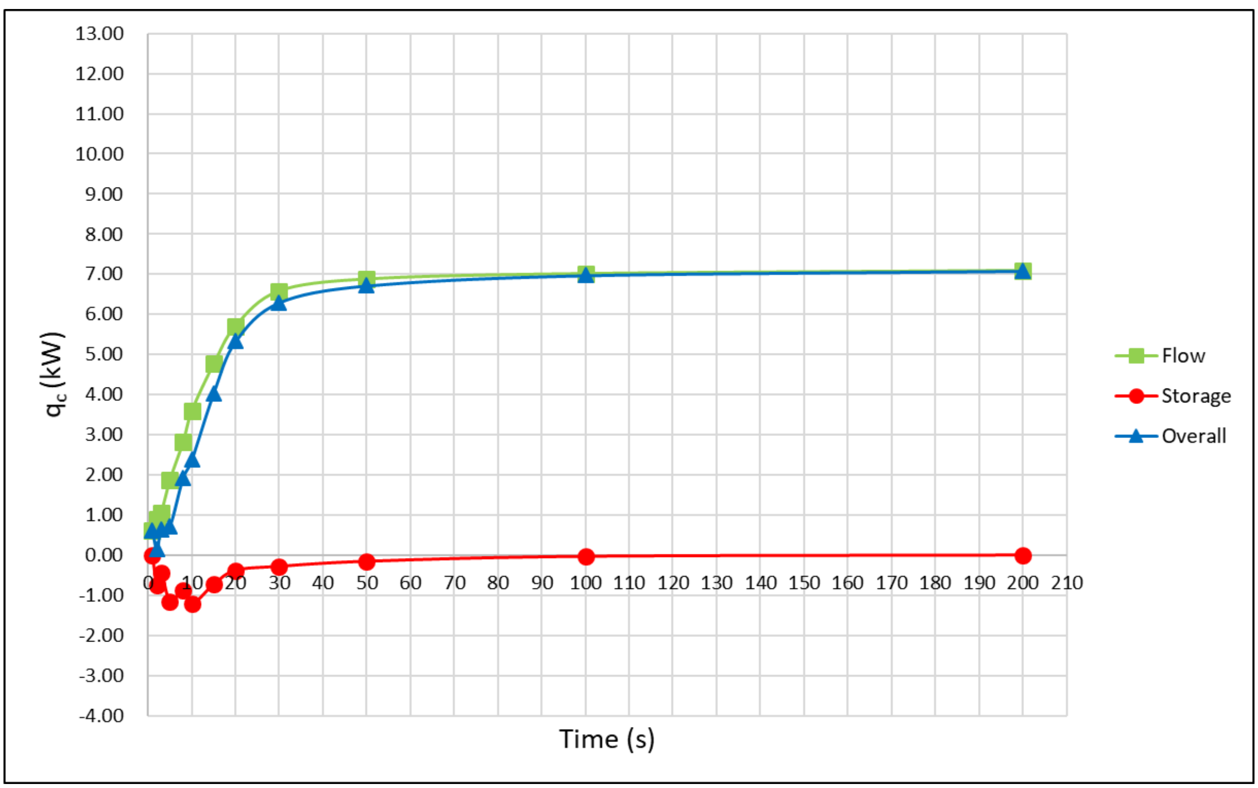


**Figure O4: Mains-side energy balance plot for R3-36 at 9LPM**

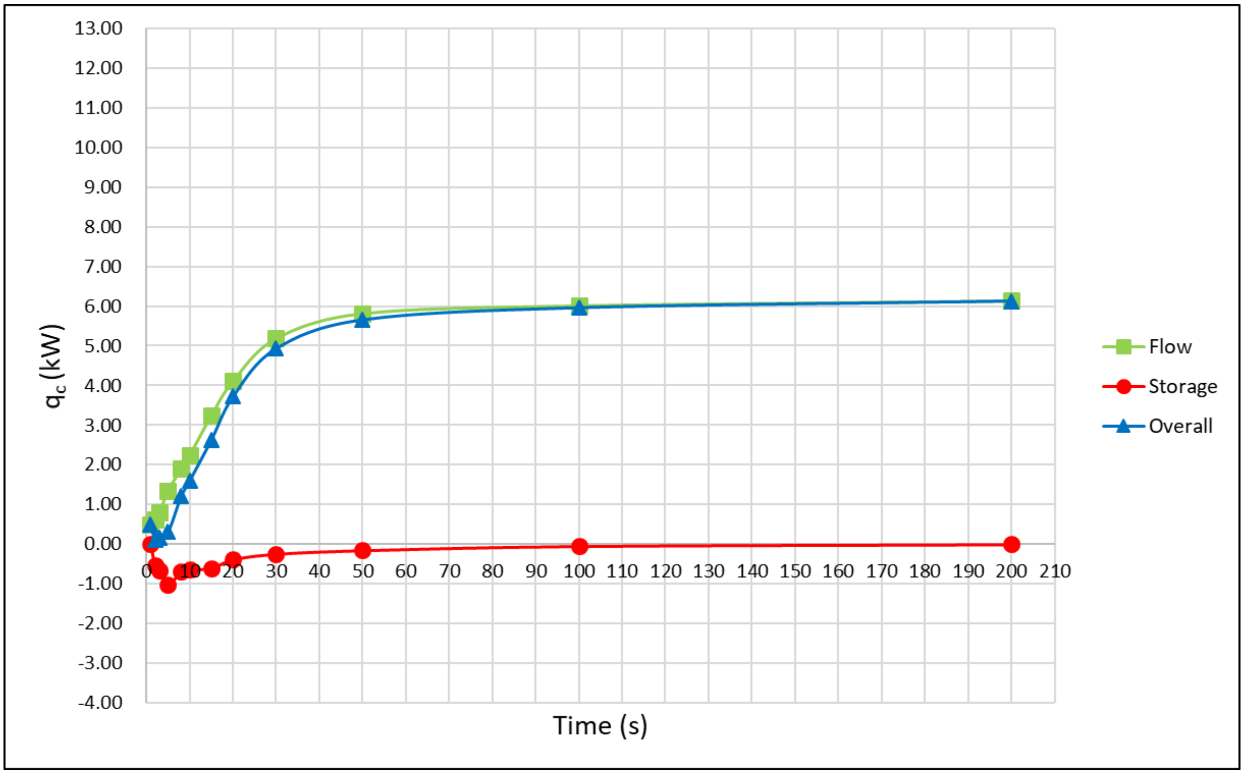


**Figure O5: Mains-side energy balance plot for R3-36 at 7LPM**

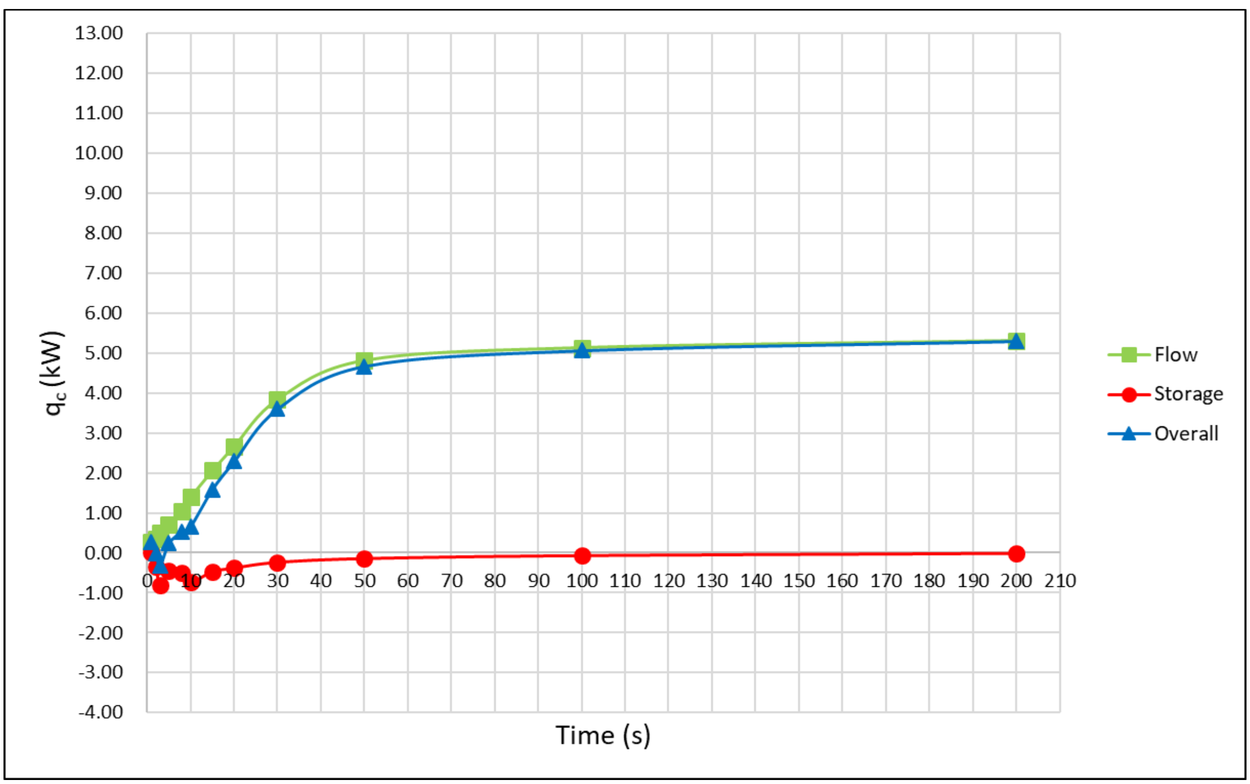


**Figure O6: Mains-side energy balance plot for R3-36 at 5.5LPM**

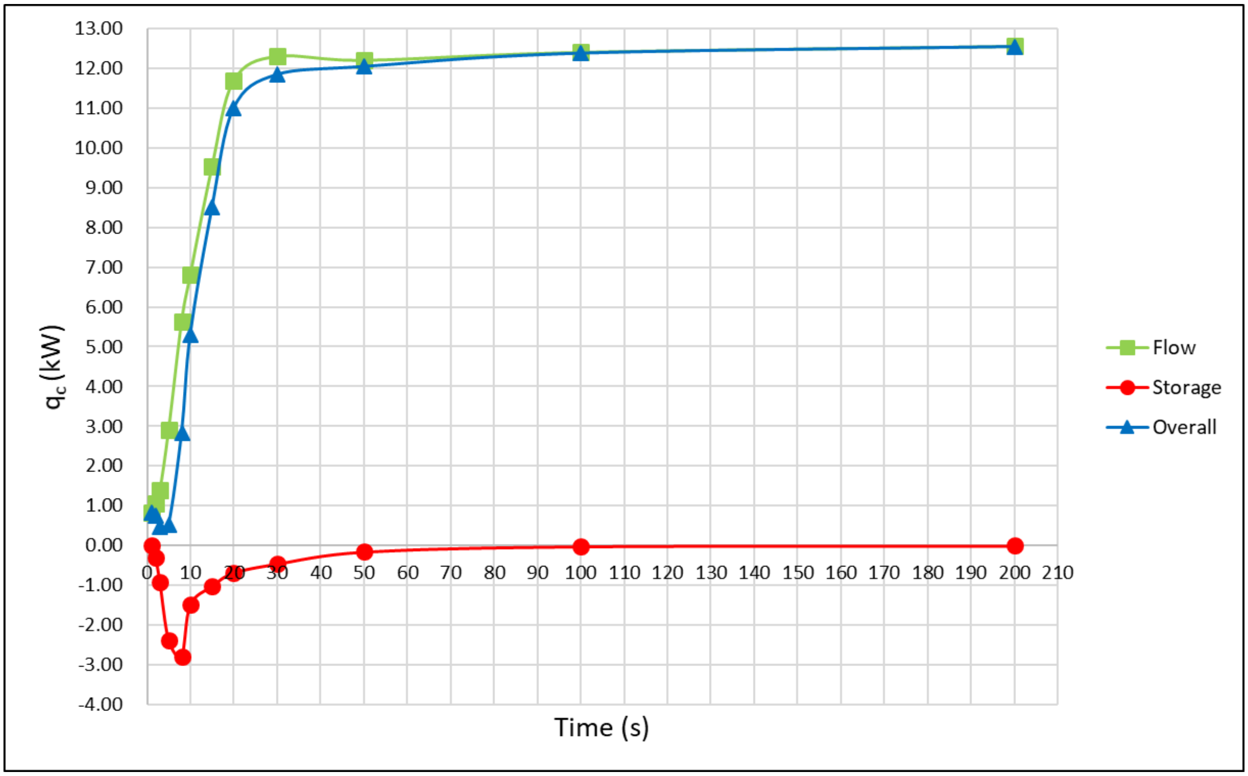


**Figure O7: Mains-side energy balance plot for R3-60 at 14LPM**

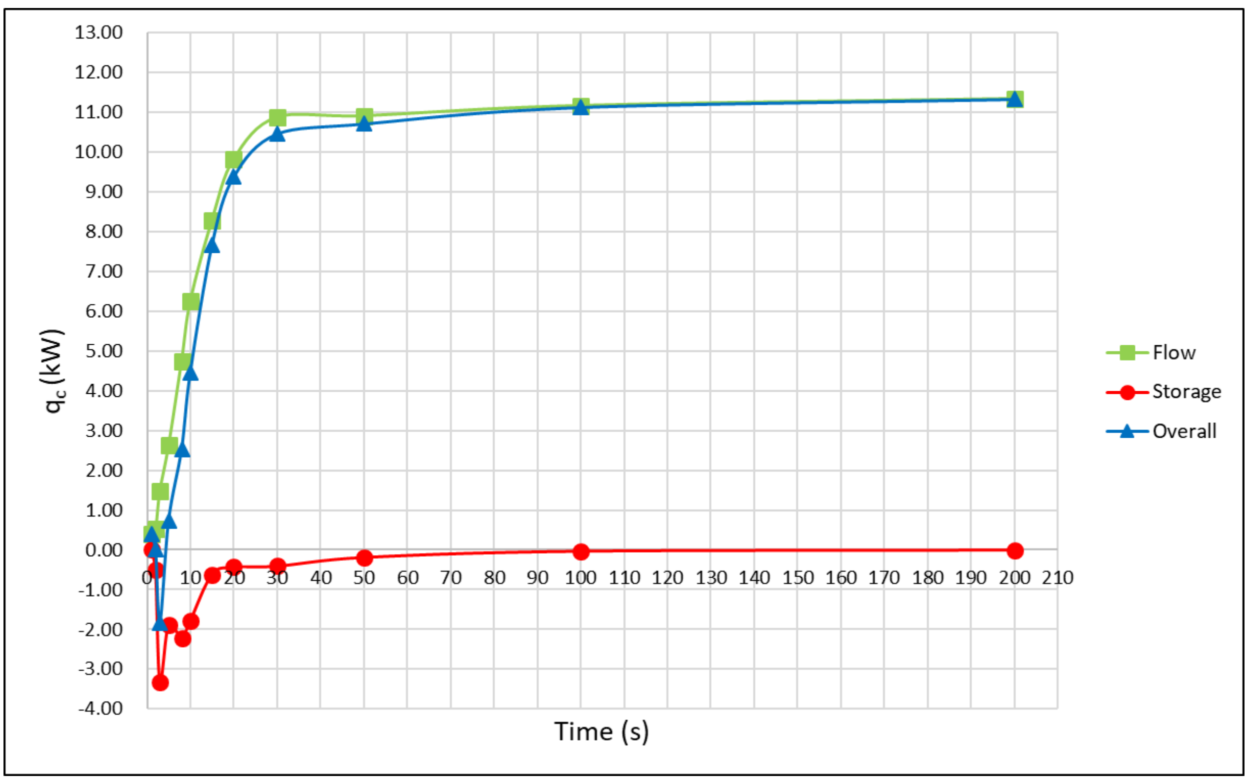


**Figure O8: Mains-side energy balance plot for R3-60 at 12LPM**

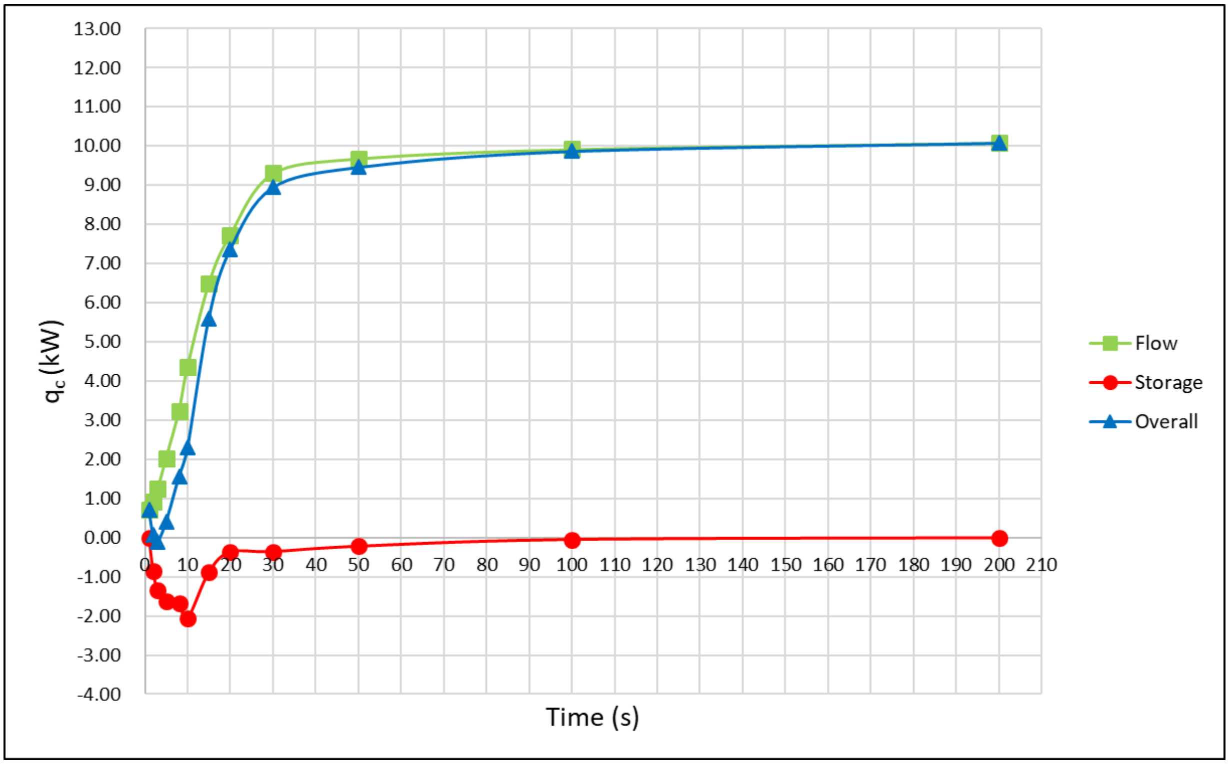


**Figure O9: Mains-side energy balance plot for R3-60 at 10LPM**

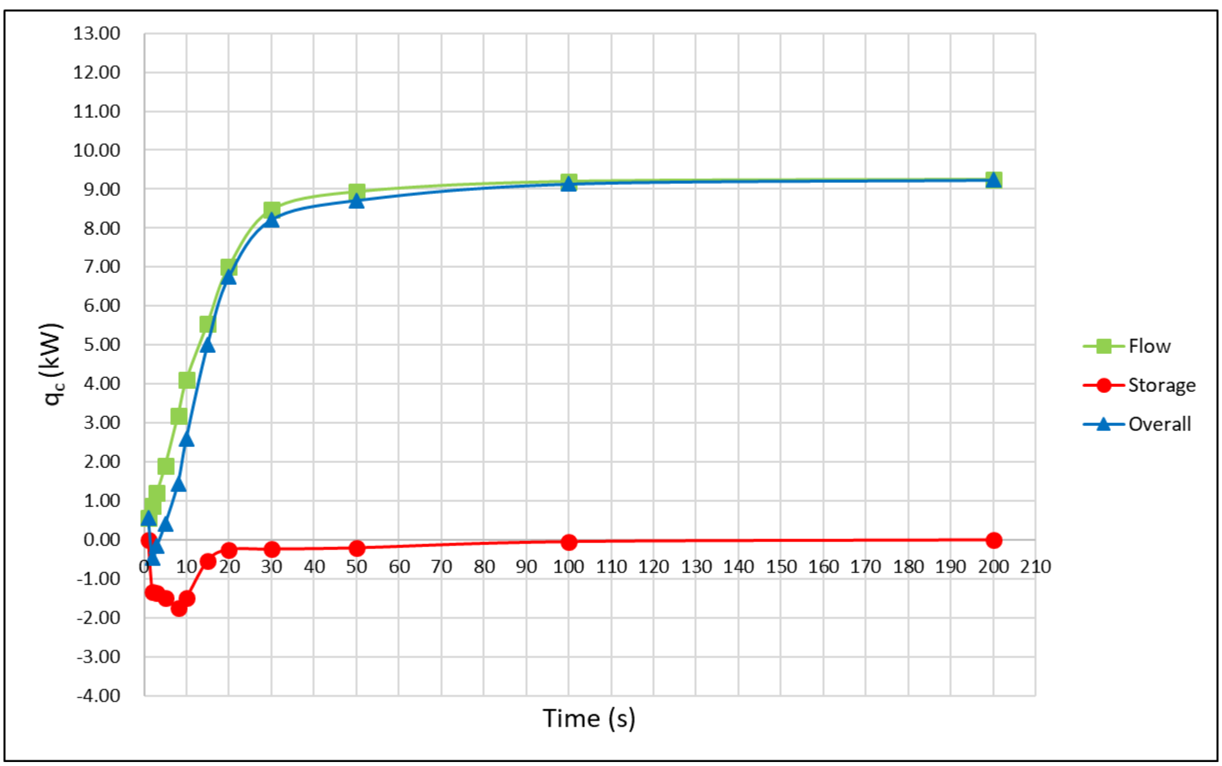


**Figure O10: Mains-side energy balance plot for R3-60 at 9LPM**

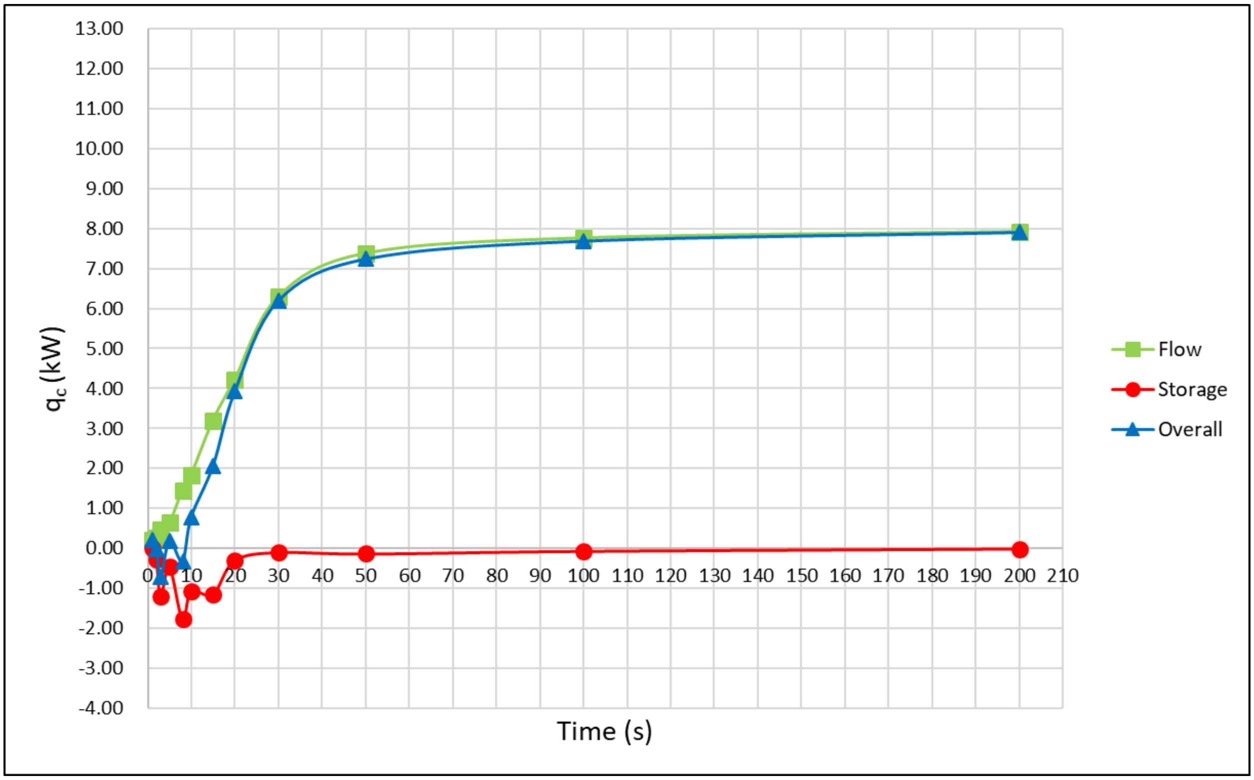


**Figure O11: Mains-side energy balance plot for R3-60 at 7LPM**

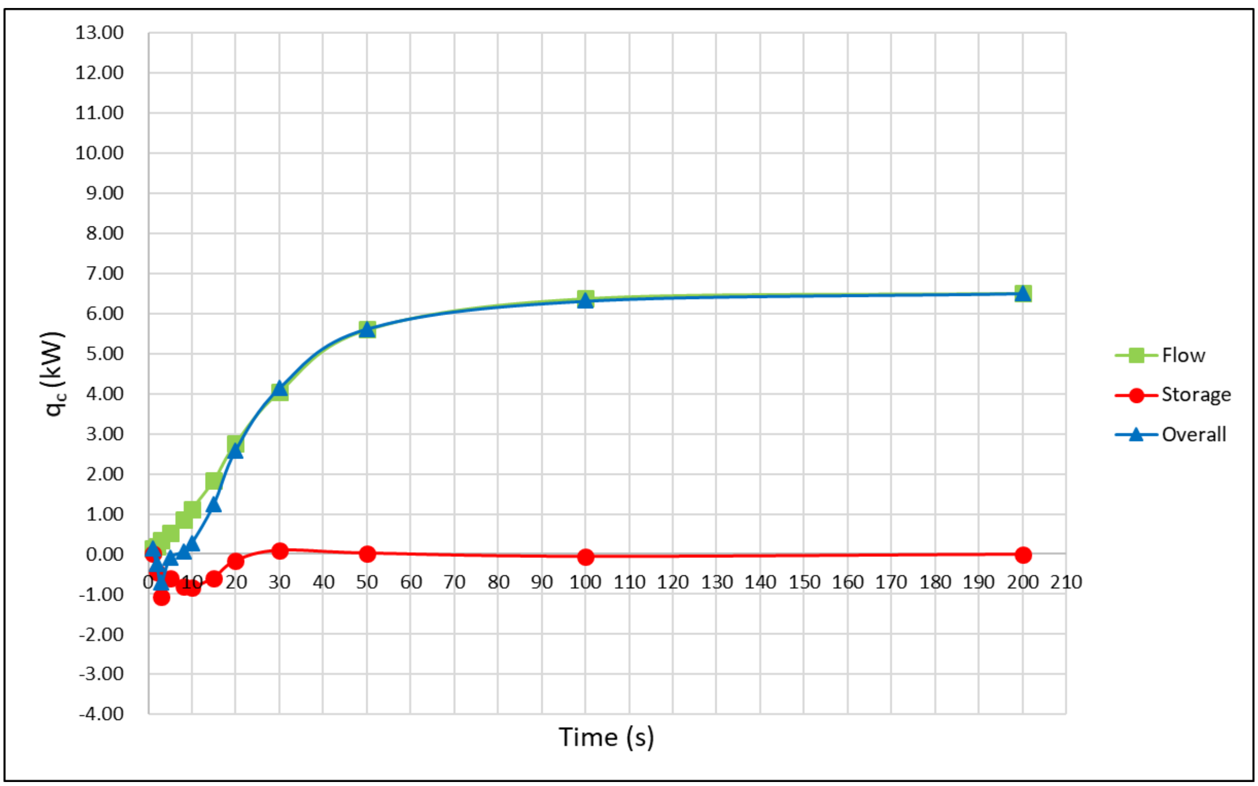


**Figure O12: Mains-side energy balance plot for R3-60 at 5.5LPM**

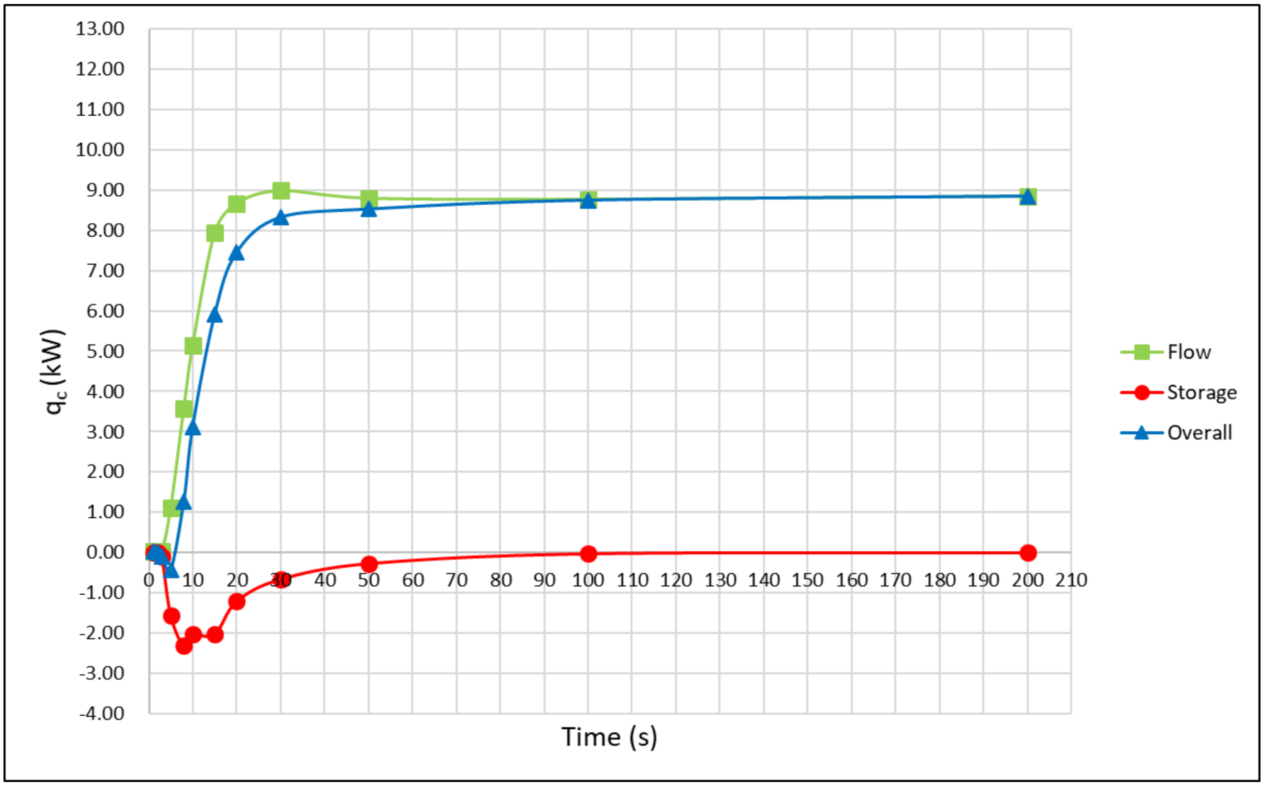


**Figure O13: Mains-side energy balance plot for R4-36 at 14LPM**

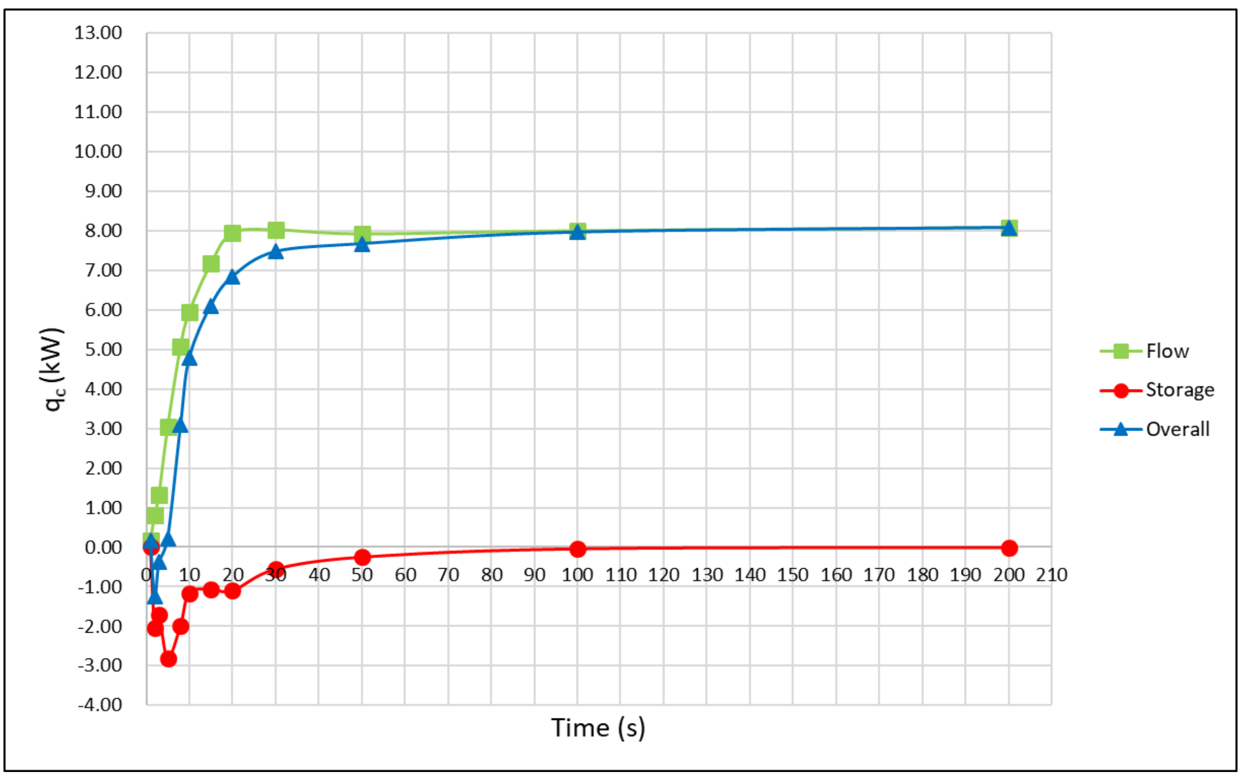


**Figure O14: Mains-side energy balance plot for R4-36 at 12LPM**

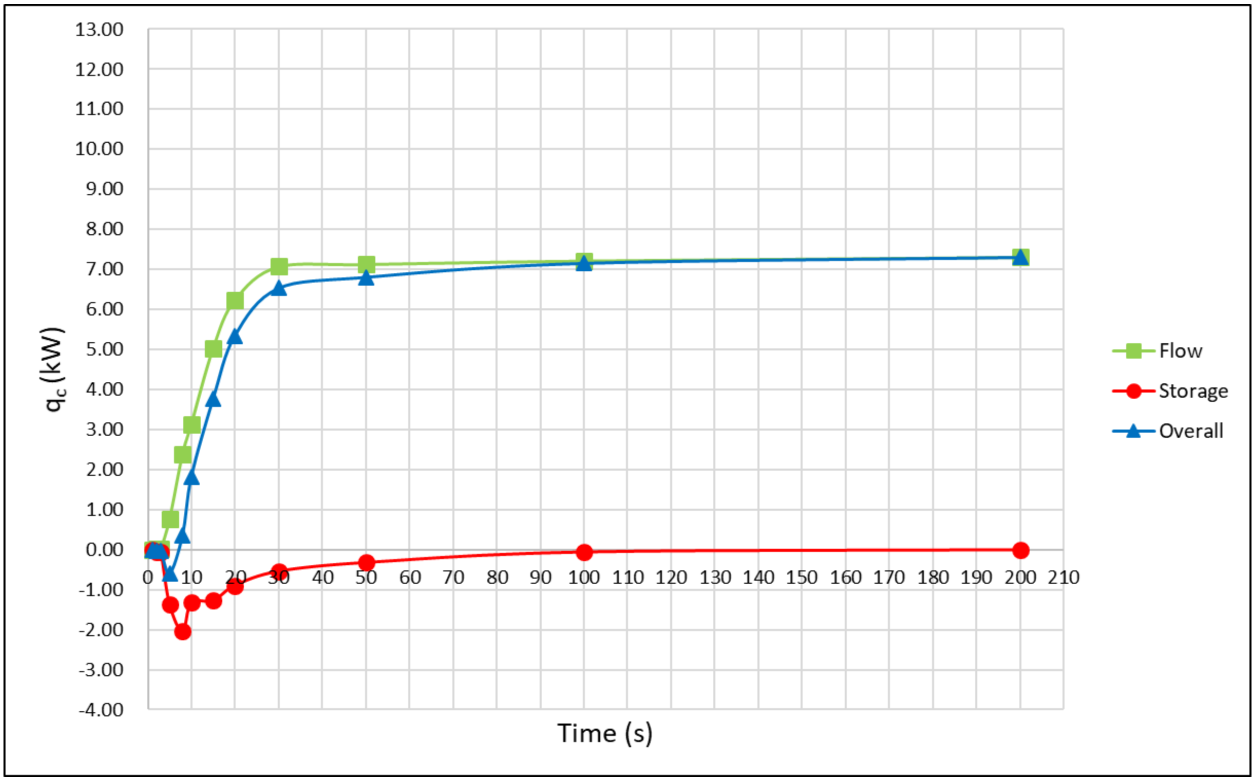


**Figure O15: Mains-side energy balance plot for R4-36 at 10LPM**

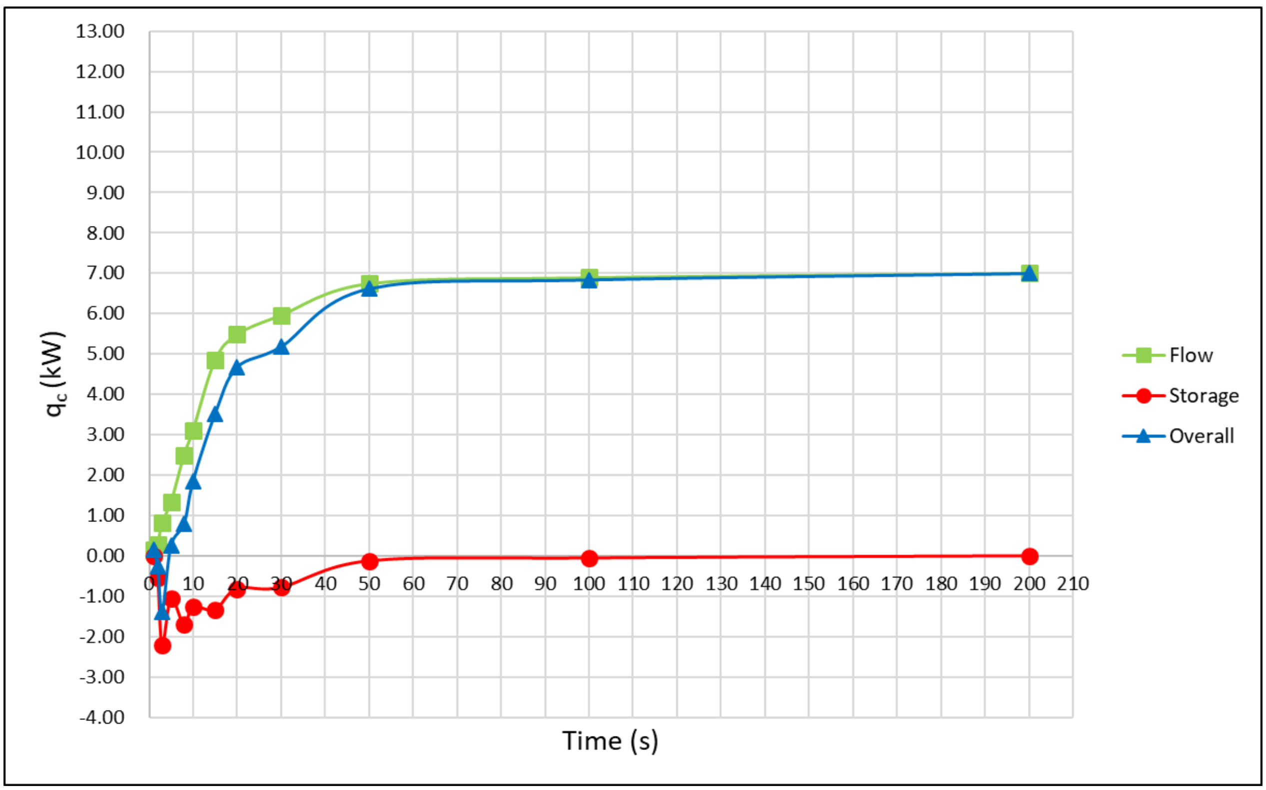


**Figure O16: Mains-side energy balance plot for R4-36 at 9LPM**

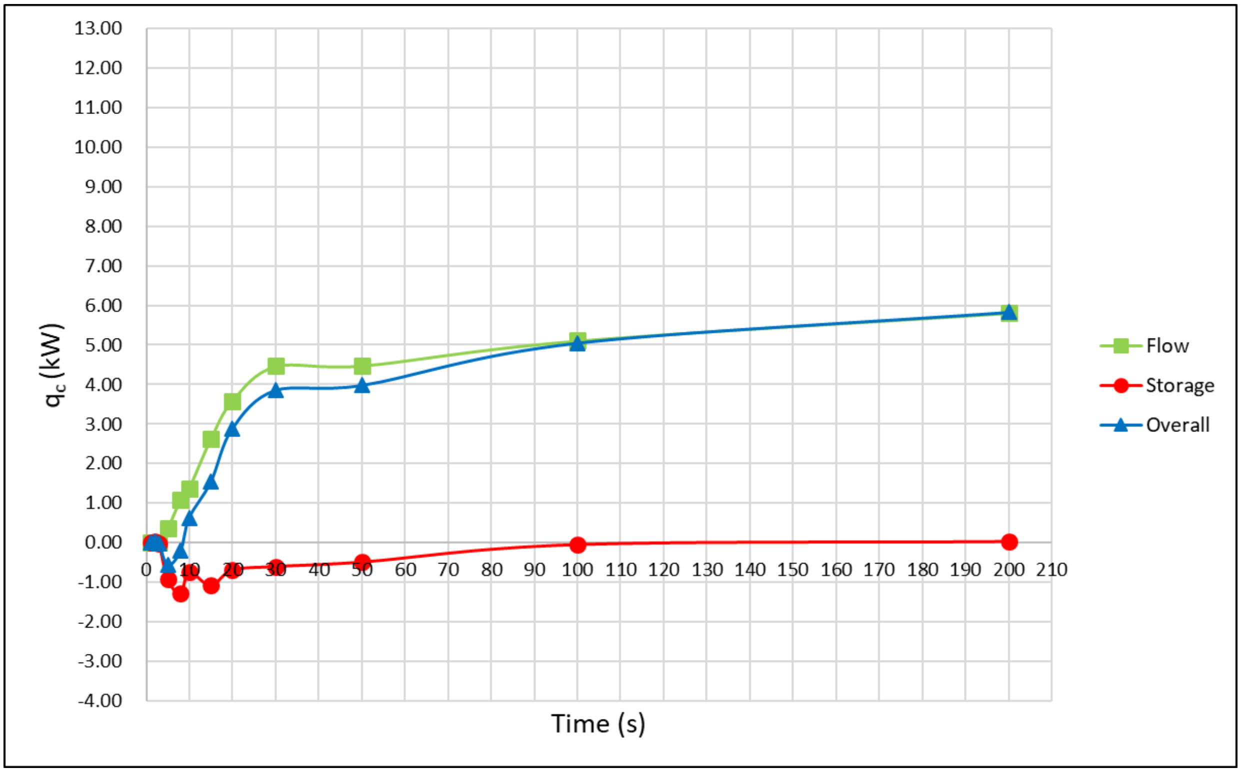


**Figure O17: Mains-side energy balance plot for R4-36 at 7LPM**

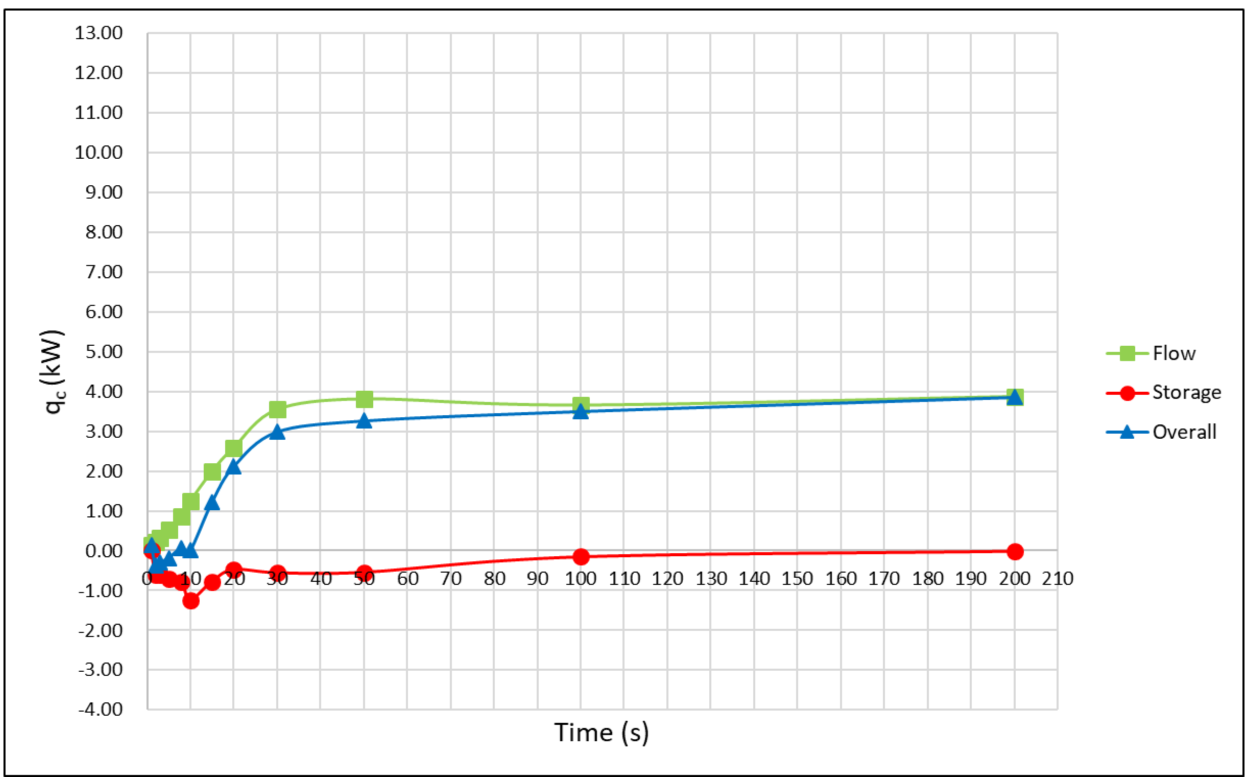


**Figure O18: Mains-side energy balance plot for R4-36 at 5.5LPM**

# Appendix P: First Order Time Response Plots for $q_c$

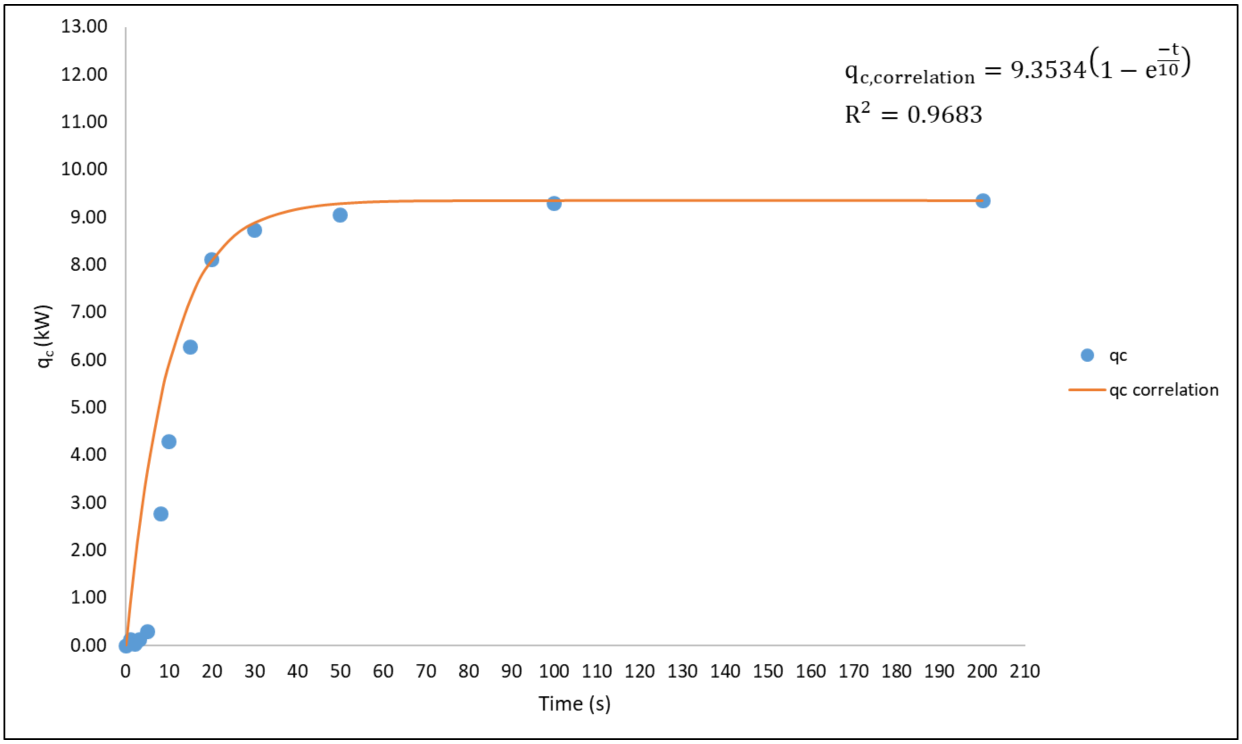


**Figure P1: First order time response for R3-36 at 14LPM**

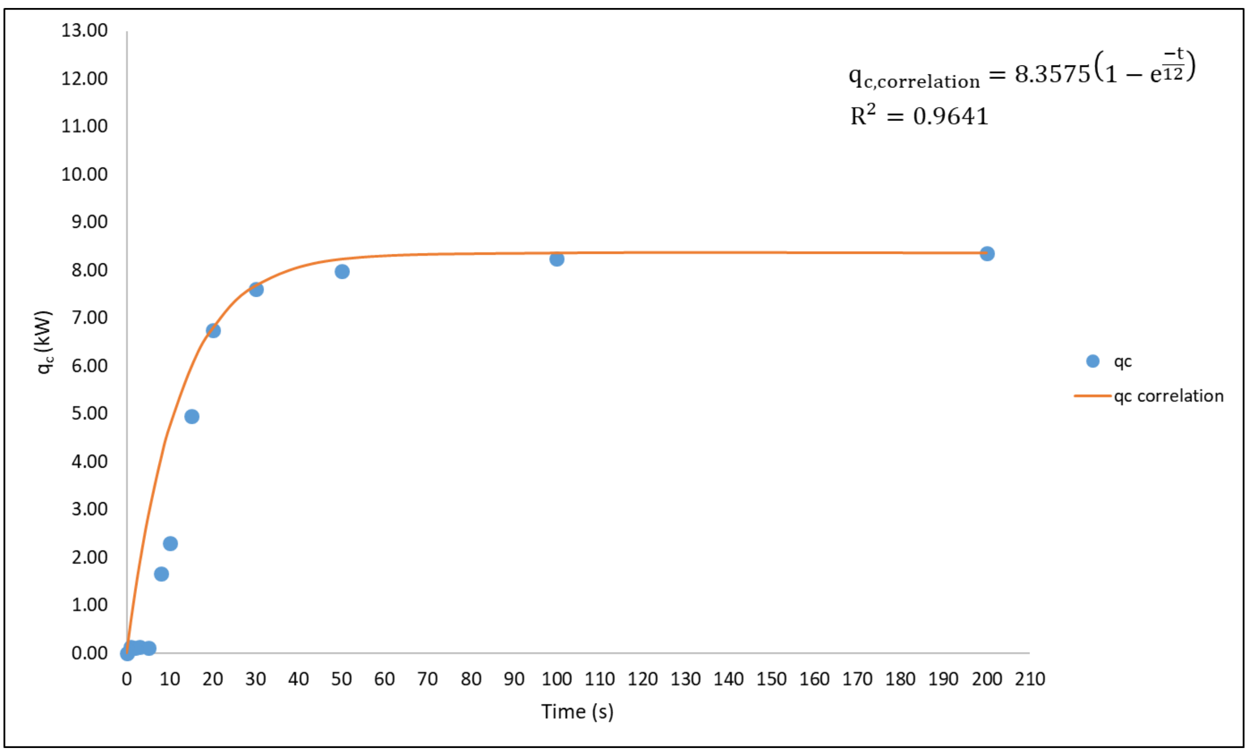


**Figure P2: First order time response for R3-36 at 12LPM**

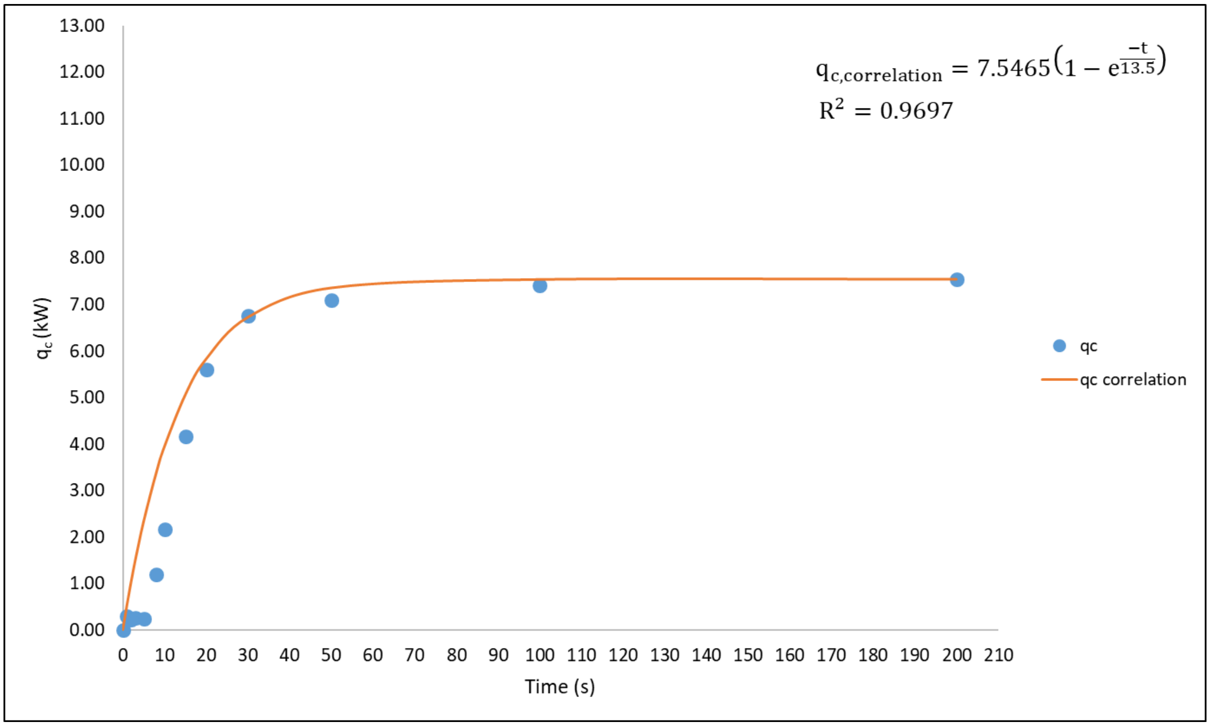


**Figure P3: First order time response for R3-36 at 10LPM**

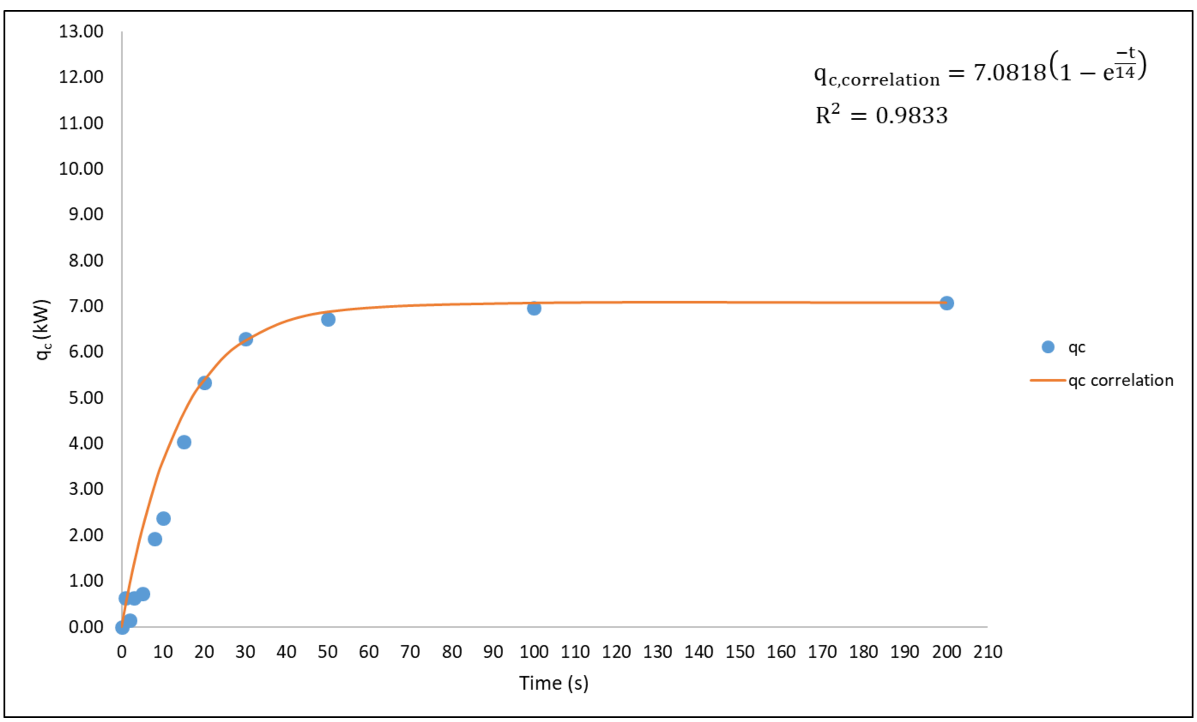


**Figure P4: First order time response for R3-36 at 9LPM**

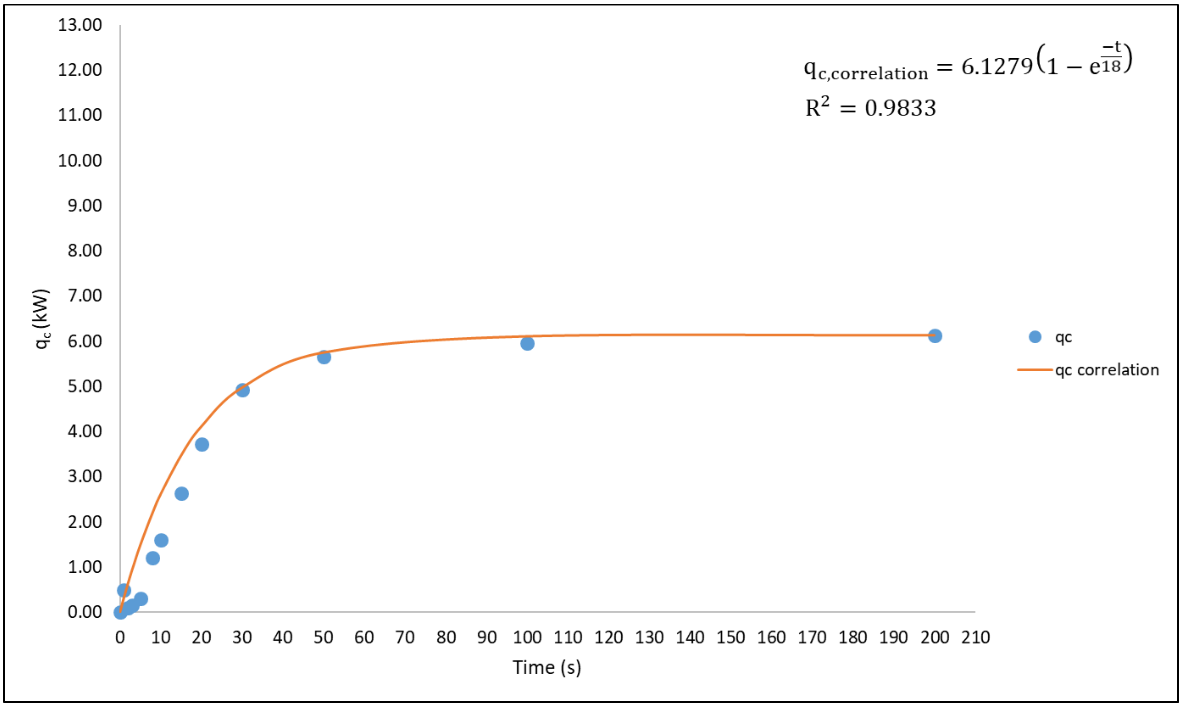


**Figure P5: First order time response for R3-36 at 7LPM**

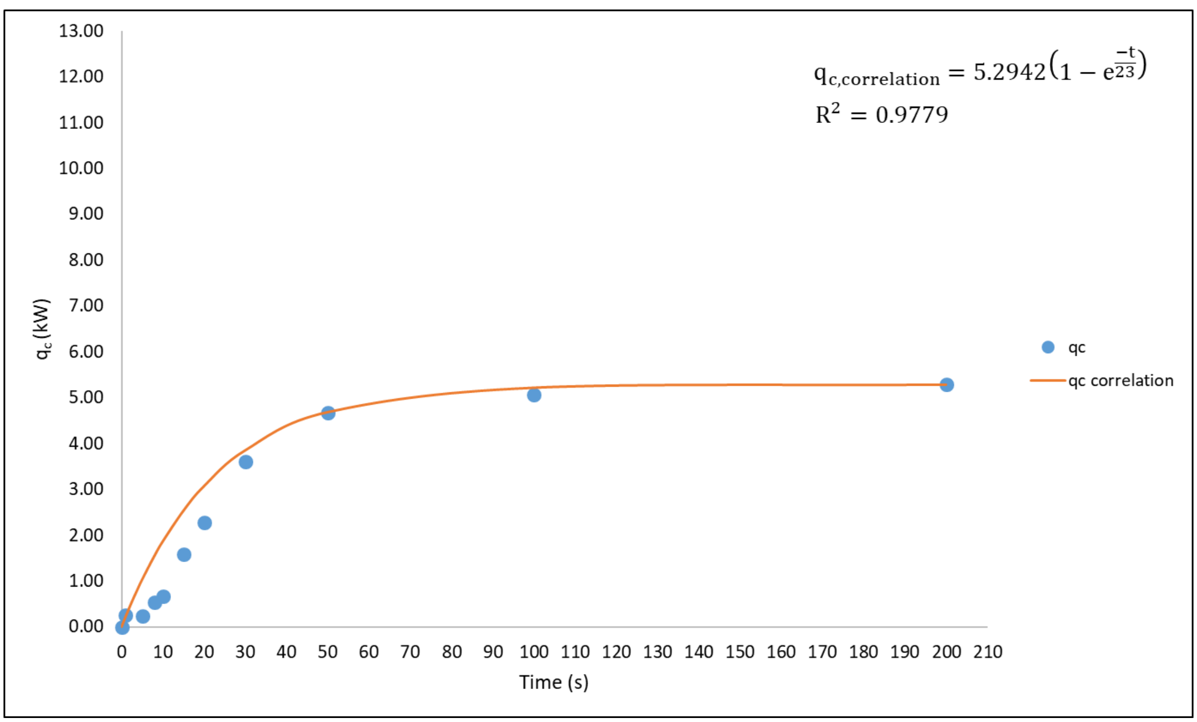


**Figure P6: First order time response for R3-36 at 5.5LPM**

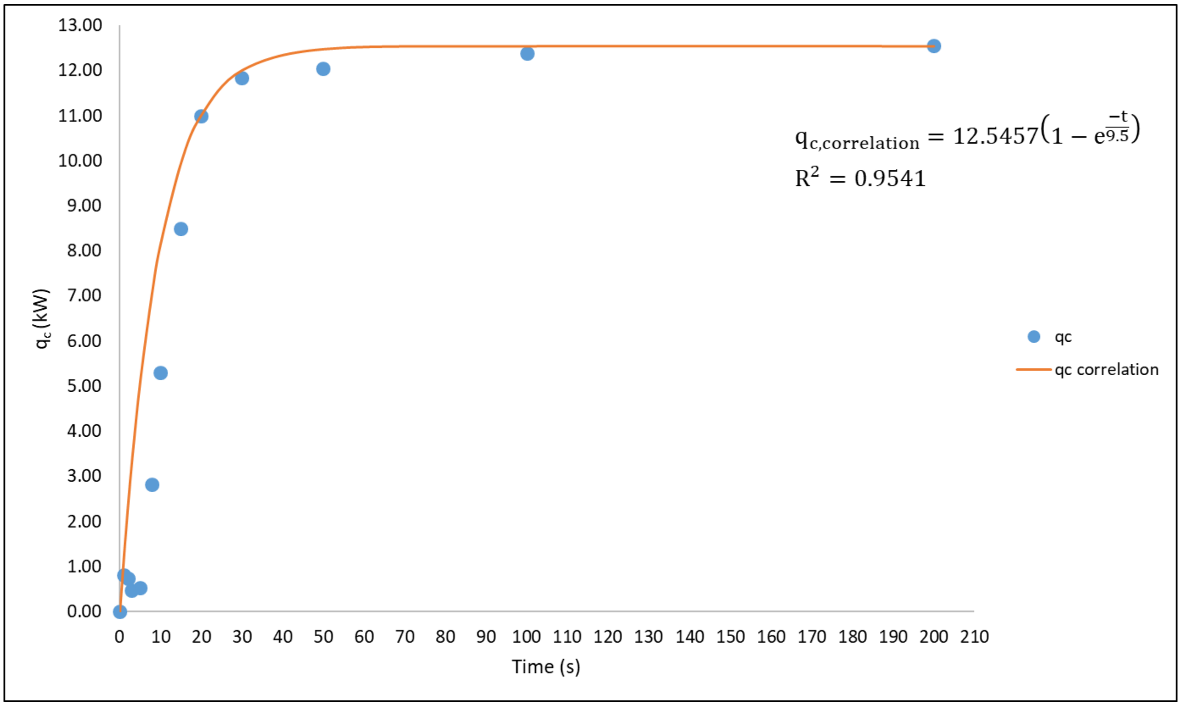


**Figure P7: First order time response for R3-60 at 14LPM**

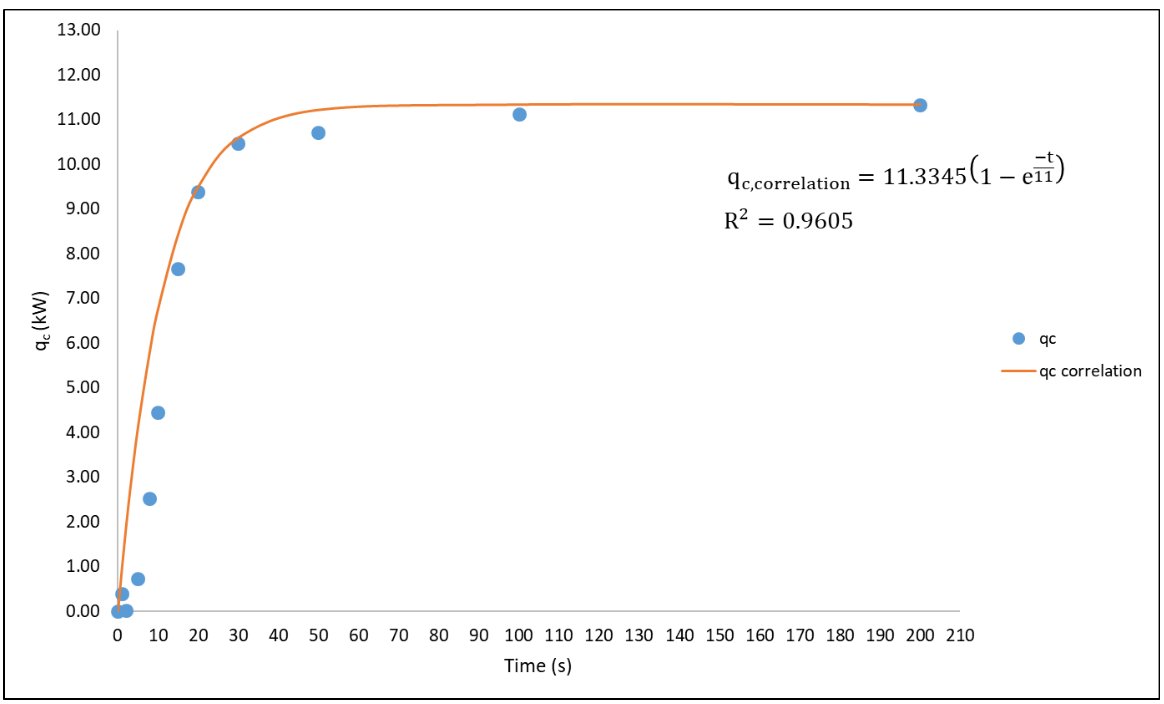


**Figure P8: First order time response for R3-60 at 12LPM**

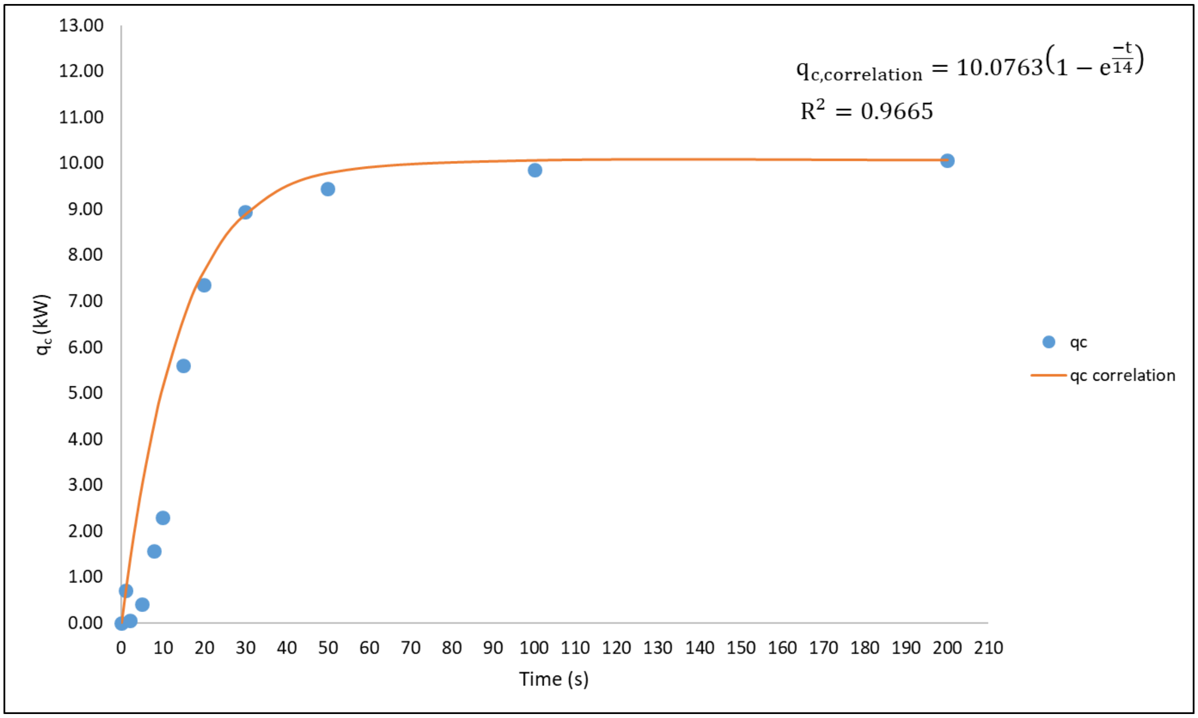


**Figure P9: First order time response for R3-60 at 10LPM**

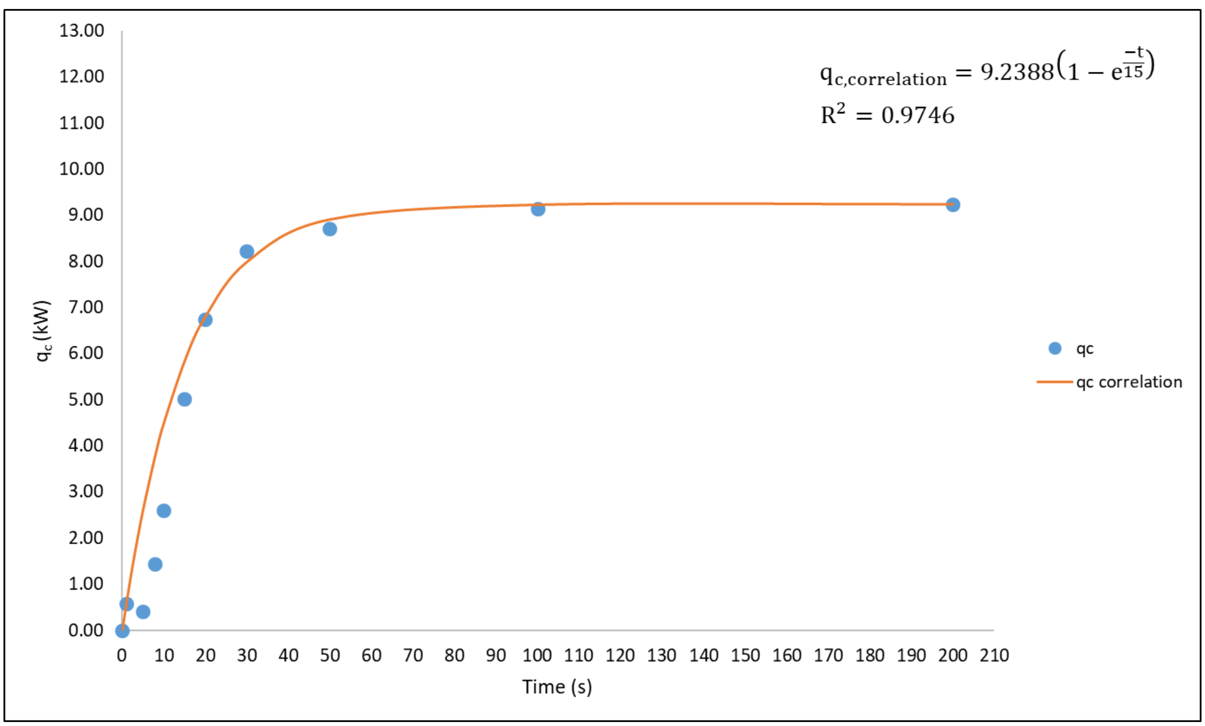


**Figure P10: First order time response for R3-60 at 9LPM**

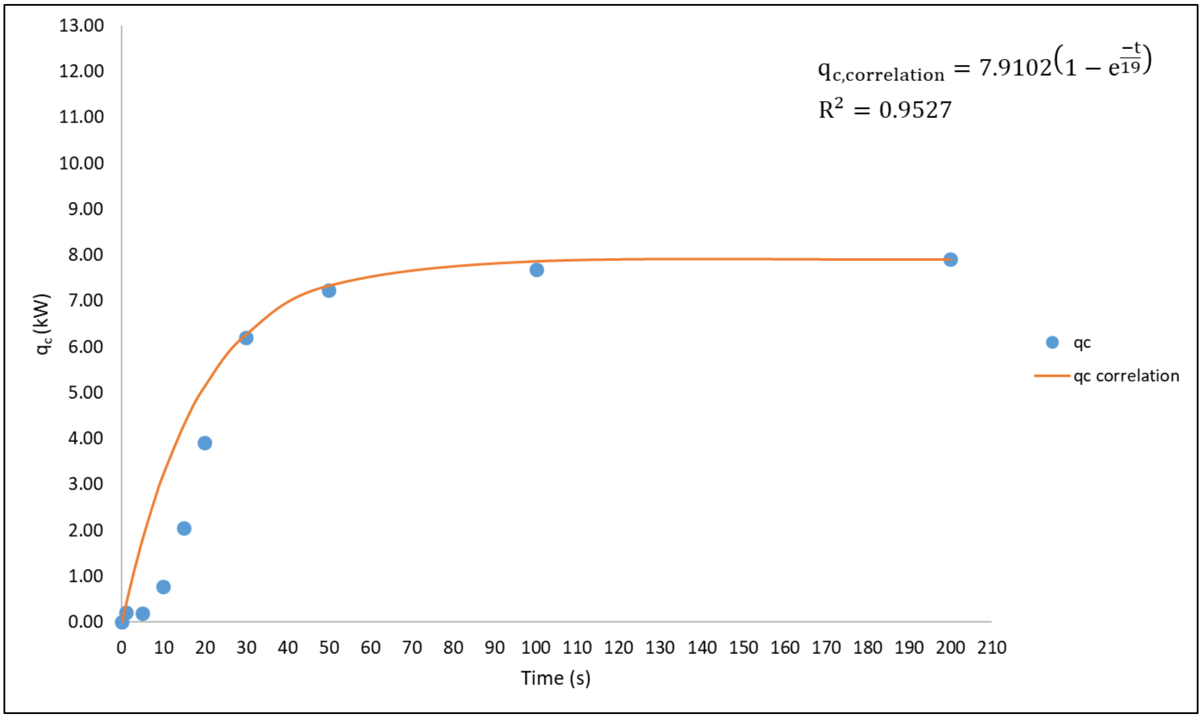


**Figure P11: First order time response for R3-60 at 7LPM**

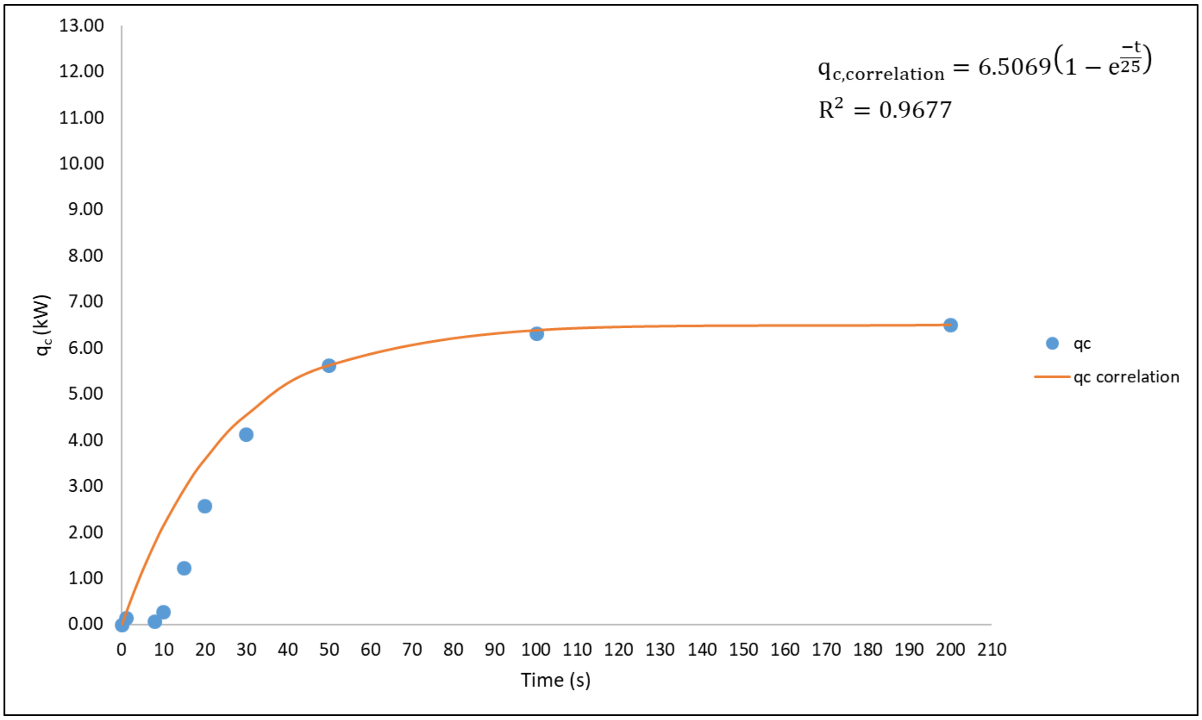


**Figure P12: First order time response for R3-60 at 5.5LPM**

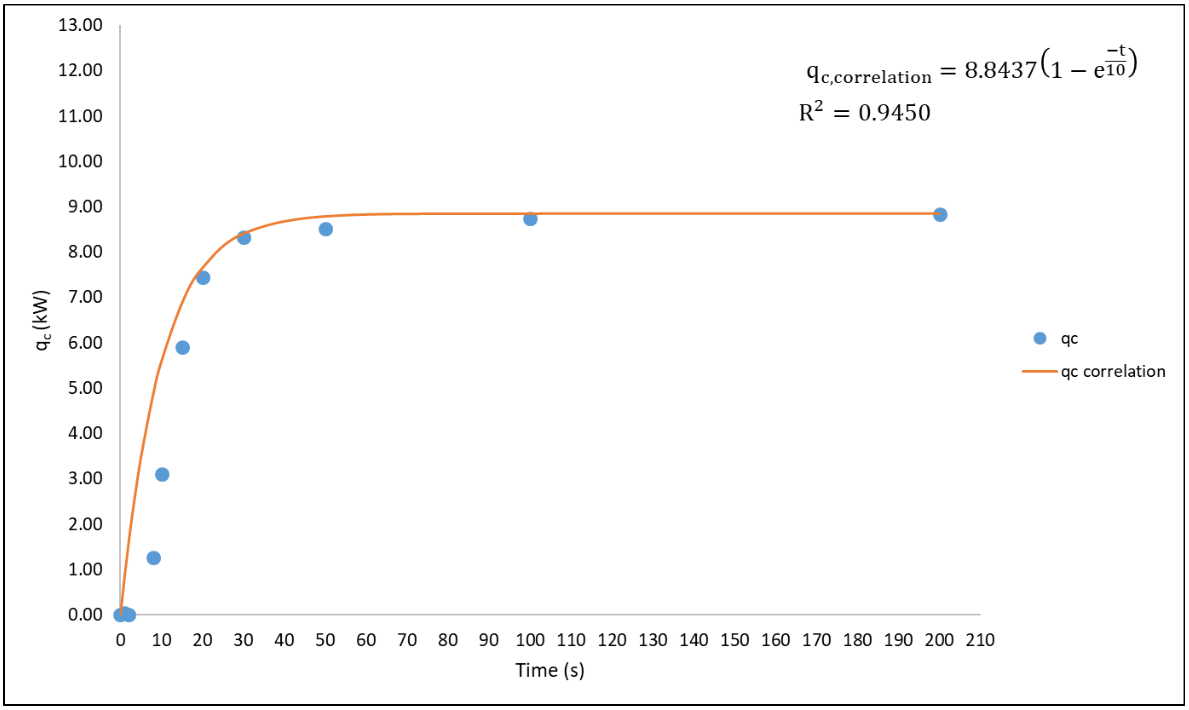


**Figure P13: First order time response for R4-36 at 14LPM**

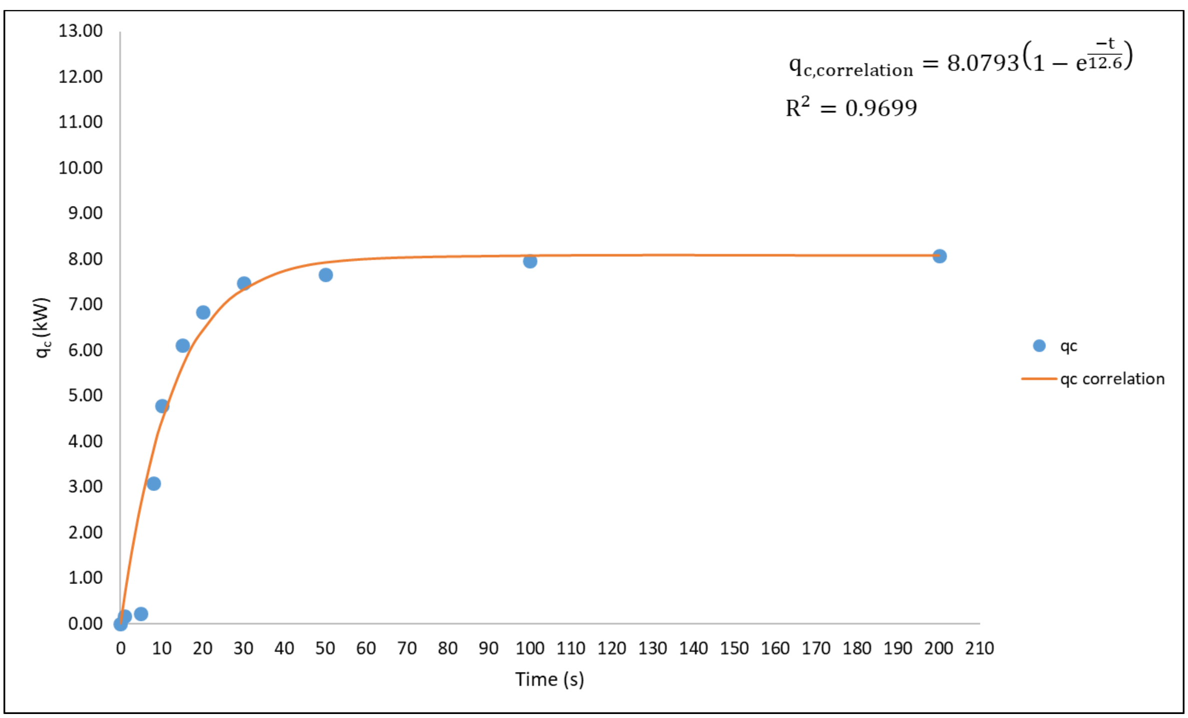


**Figure P14: First order time response for R4-36 at 12LPM**

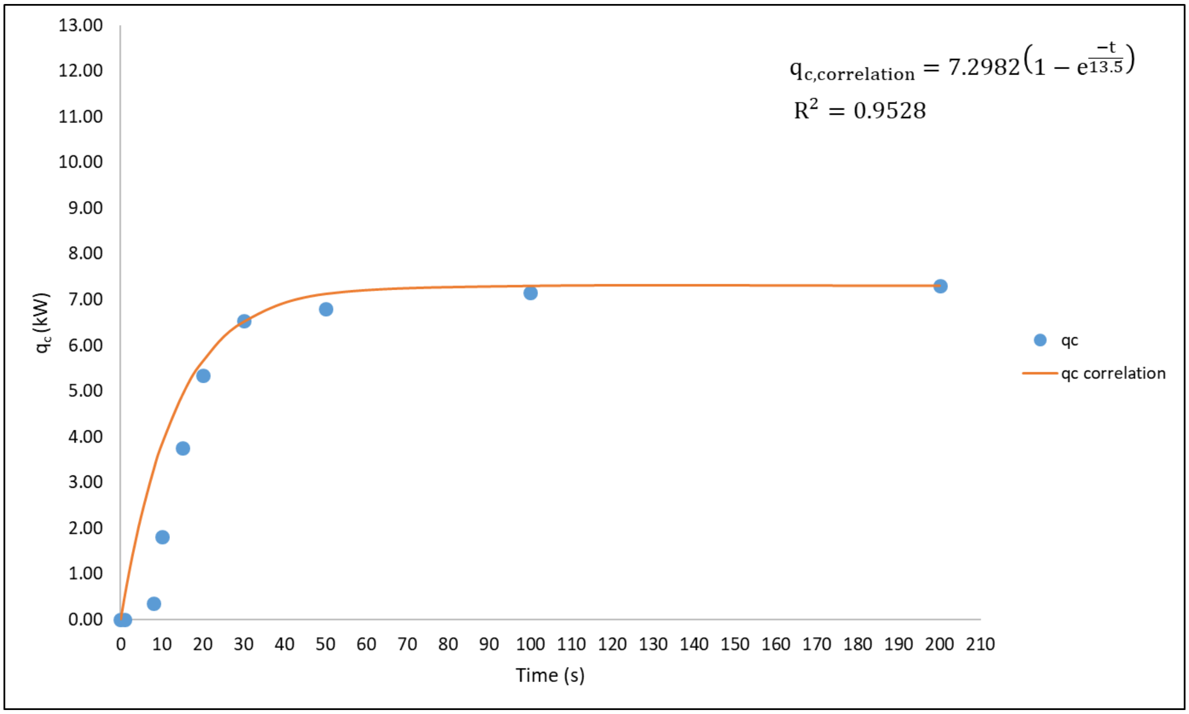


**Figure P15: First order time response for R4-36 at 10LPM**

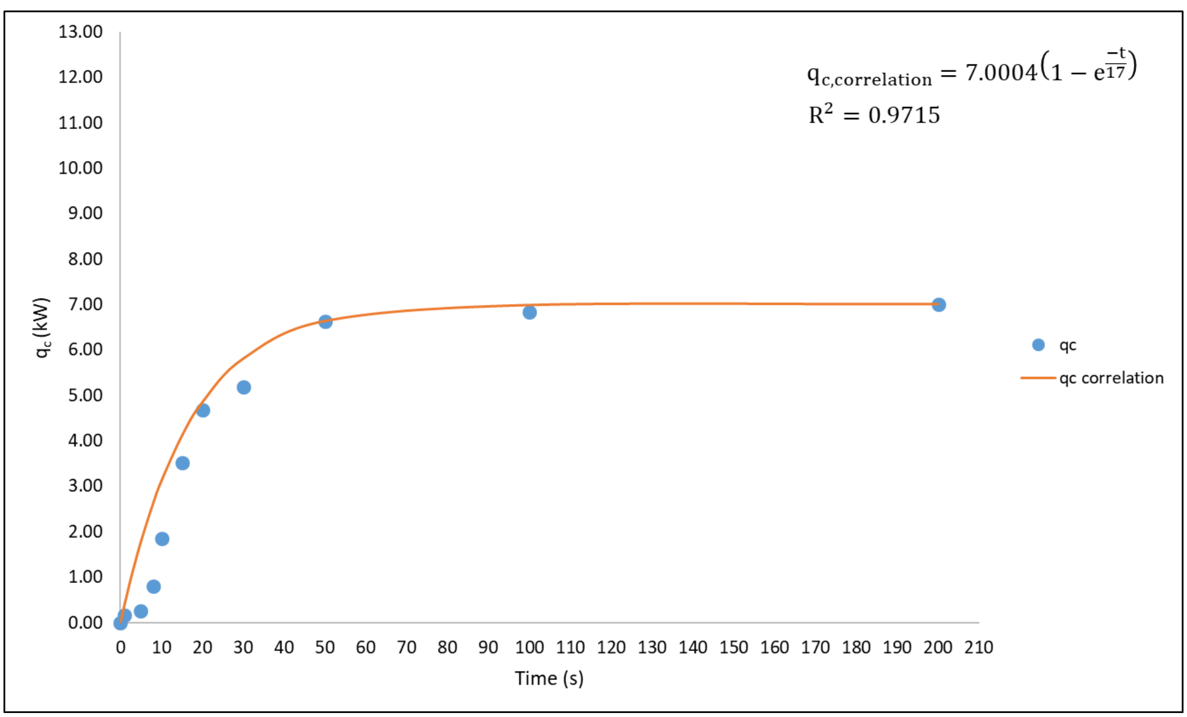


**Figure P16: First order time response for R4-36 at 9LPM**

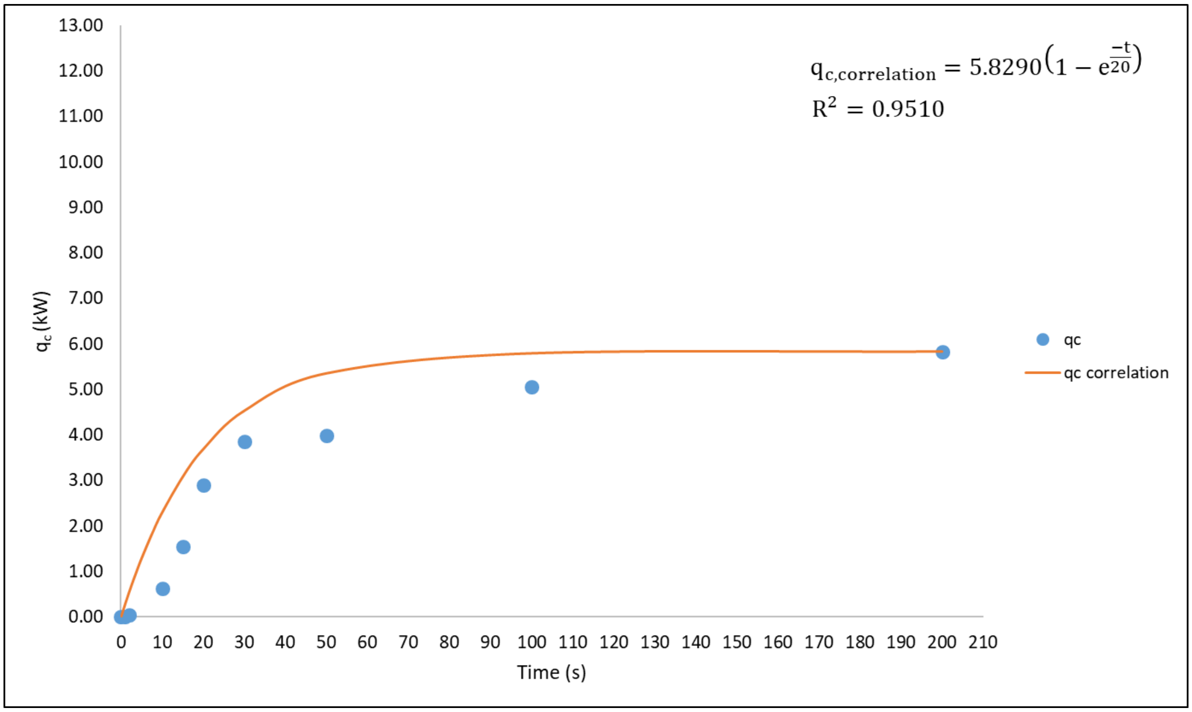


**Figure P17: First order time response for R4-36 at 7LPM**

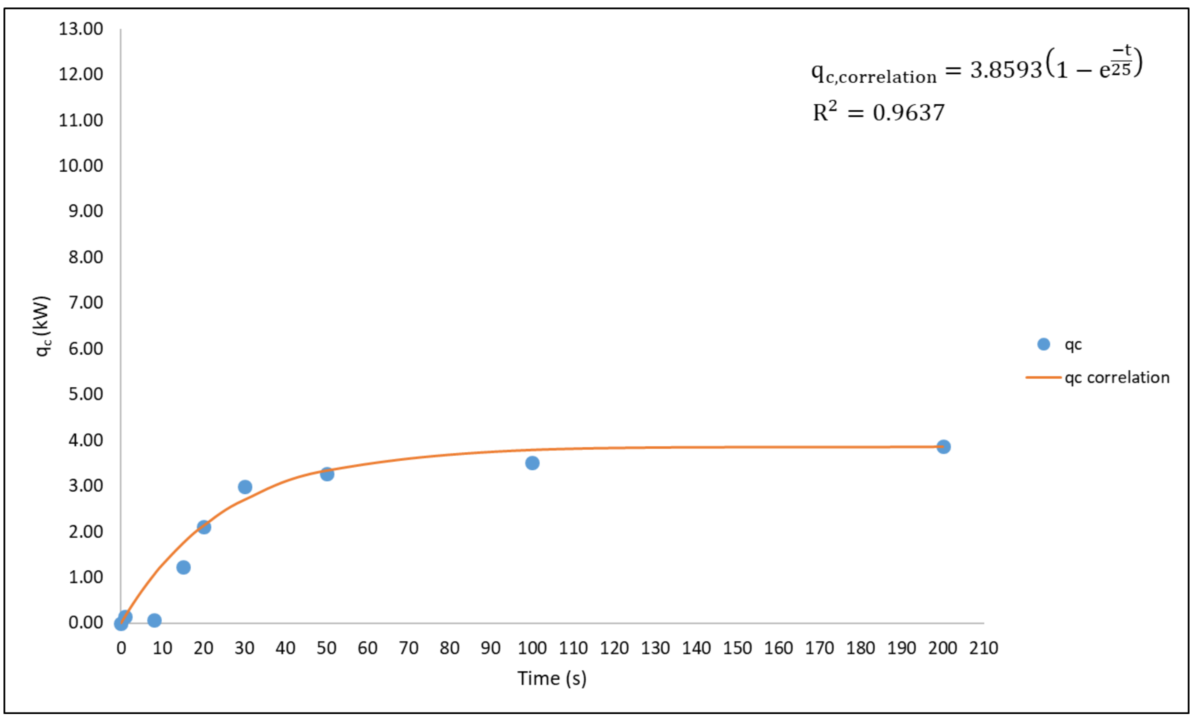


**Figure P18: First order time response for R4-36 at 5.5LPM**