WEB VERSION

PROJECT REPORT 2:

TRNSYS Modelling of Centralised Water Heating System and Point of Use of MicroHeat Continuous Flow Electric Water Heating System

Dr Biddyut Paul and Associate Prof. John Andrews

School of Aerospace Mechanical and Manufacturing Engineering, RMIT University

for

MicroHeat Technologies Pty Ltd

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EXECUTIVE SUMMARY

This is the second report by the School of Aerospace Mechanical and Manufacturing Engineering (SAMME) in the joint research project involving the Centre for Design and SAMME at RMIT University in collaboration with industry partner, MicroHeat Pty Ltd, to test and evaluate the performance of the Continuous Flow Electric Water Heater (CFEWH) developed by MicroHeat.

The first SAMME report (completed in September 2012) covered the experimental performance analysis and validation of the MicroHeat CFEWH system. This second report presents the results of energy modelling of the system in two types of multistorey residential building in Melbourne using the TRNSYS energy system simulation software package.

The two buildings used as case studies of potential applications of the MicroHeat CFEWH units, and the competing water heating systems examined, were the following;

- An existing high-density apartment complex, La Banque building, located in the Melbourne CBD at 380 Little Lonsdale Street and consisting of 257 apartments on 35 levels. Here two alternatives were investigated:
  - Hot water via a centralised gas-boosted plant (as currently installed)
  - Hot water via individual continuous flow electric hot water heaters (CFEWH) in each apartment

- A proposed medium-density apartment complex, the Brahe Place building located in East Melbourne at 18 Brahe Place, and consisting of eight apartments on three levels. Here three alternative water heating systems were investigated:
  - A centralised gas-boosted plant
  - A solar-boosted centralised gas plant
  - Individual MicroHeat continuous flow electric hot water heaters (CFEWH) in each apartment.

Hot water demand in the low, average and high occupancy scenarios for the LaBanque building were 5,159 kL, 6,847 kL and 10,699 kL respectively. For Brahe Place building the hot water demand was 161 kL and 269 kL respectively for the two occupancy levels considered. These values matches those used in the LCA study component of the present project (Lockrey 2012).

In the case of the centralised gas heating system for the La Banque building, it was found that the annual total gas and electricity consumption was 1,876.1 GJ gas and 4,481 kWh electricity; 2,198.1 GJ gas and 4,699 kWh electricity; and 2,931.9 GJ gas and 5,312 kWh electricity for the low, average and high occupancy scenarios respectively. The average apartment's annual water heating energy consumption was 7.3 GJ gas and 17 kWh electricity; 8.6 GJ gas and 18 kWh electricity; and 11.4 GJ gas; and 21 kWh electricity for low, average and high occupancy levels respectively. Around 712.3 GJ (38%), 716.2 GJ (33%) and 723 GJ (25%) of the heating energy was lost from the pipe works and storage tanks for the low, average and high occupancy levels respectively.

The electrical energy required by the CFEWH heating systems in all 257 apartments in the La Banque building for low, average and high occupancy scenarios was 220.1 MWh, 292.2 MWh and 456.6 MWh respectively. For individual apartment annual water heating electricity consumption was 864 kWh, 1,145 kWh and 1,784 kWh for low, average and high occupancy level respectively.

The total annual secondary energy use by each of the water heating system options for the three occupancy scenarios is presented in Table A. It should be noted here that gas and electrical energy are simply added on a direct energy content basis without considering the primary energy inputs to deliver to the consumer this secondary energy. The latter and the associate overall greenhouse gas impacts are analysed separately in the complementary report by the RMIT Centre for Design within this overall study. In all three occupancy scenarios the centralised gas water heating system for the La Banque building used more secondary energy (in the form of gas plus some electricity for pumping) than the point-of-use CFEWH system (all in the form of electricity). For example, for low occupancy level, centralised gas heating system annually consumed 1,876.1 GJ (521,139 kWh) gas and 4,481 kWh of electricity, that is, a total equivalent secondary energy of 525,620 kWh; whereas the CFEWH system potentially consumed 222,087 kWh of delivered electricity (Table A).

	Type of hot water systems for La Banque building					
	Bosch gas ring main			MicroHeat CFEWH		
Hot water use profile	Low	Average	High	Low	Average	High
Water use (kL/y)	5,159	6,847	10,699	5,159	6,847	10,699
Gas use (GJ/y)	1,876.1 (521,139 kWh)	2,198.1 (610,583 kWh)	2,931.9 (814,417 kWh)	0	0	0
Eletricity use (kWh/y)	4,481	4,699	5,312	222,087	294,138	458,516
Total energy use (kWh equivalent/y)	525,620	615,282	819,729	222,087	294,138	458,516

Table A: La Banque building total annual water and secondary energy use for the different water heating options and occupancy levels

The annual total gas and electricity consumption for the Brahe Place building for the centralised gas heating system was 92.7 GJ gas and 1,152 kWh electricity; and 113 GJ gas and 1,162 kWh electricity for the average and high occupancy levels respectively. The average apartment's annual water heating energy consumption was 11.6 GJ gas and 144 kWh electricity, and 14.1 GJ gas and 145 kWh electricity respectively. Around 39.7 GJ (43%) and 39.8 GJ (35%) of the heating energy was lost from the pipe works and storage tanks for the average and high occupancy levels respectively.

It is observed that in the case of the centralised gas heating system for this medium-density apartment complex, the average apartment's annual water heating energy consumption is estimated to be higher than that for the high-density high-rise apartment complex.

For the solar-boosted centralised gas heating option for Brahe Place building, the annual total gas consumption was 74.6 GJ and 93.9 GJ for the average and high occupancy levels respectively. The solar contributions to the total water heating energy requirements were 14.8 GJ (20%) and 15.5 GJ (17%) for the average and high occupancy situations respectively. However, it needs to be noted here that we have not investigated whether the solar system is optimised in terms of collector area and solar fraction within the present study; we have simply assumed the specifications of the solar system for this building provided by the building designers, Wood and Grieve. However, in the TRNSYS model the collectors are assumed to be installed facing North, tilted at the Melbourne latitude angle (38°) to receive optimum solar radiation for the year round application. For average and high occupancy levels the average apartment's annual water heating energy consumption was 9.3 GJ gas and 157 kWh electricity, and 11.7 GJ gas and 161 kWh electricity respectively. In this case around 40 GJ (45%) and 39.9 GJ (36%) of the heating energy was lost from the pipe works and storage tanks for the average and high occupancy levels respectively.

It is found that the addition of a solar preheating system contributes to an increase in the total electricity consumption for pumping. In the centralised gas heating system, total pumping energy consumptions were 980 kWh and 988 kWh for the average and high occupancy levels respectively. For the solar-boosted centralised-gas heating system total pumping energy consumptions were 1,085 kWh and 1,112 kWh for the average and high occupancy levels respectively, which is around 11% and 12.5% increment for the average and high occupancy scenarios.

The annual total electrical energy required in the Brahe Place building by the CFEWH heating system in all eight apartments was 6.9 MWh and 11.5 MWh for average and high occupancy scenarios respectively. For each individual apartment the annual water heating electricity consumption was 864 kWh and 1,440 kWh for average and high occupancy level respectively.

For both occupancy levels in the Brahe Place building the centralised gas water heating system used more secondary energy (in the form of gas plus some electricity for pumping) than the solar-gas ring-main (in the form of gas plus some electricity for pumping) and the point-of-use CFEWH system (all in the form of electricity). For example, for average occupancy, the centralised gas heating system annually consumed 92.7 (25,750 kWh) gas and 1,152 kWh of electricity, that is, a total equivalent secondary energy of 26,902 kWh; centralised solar-gas heating system annually consumed 74.6 (20,722 kWh) gas and 1,256 kWh of electricity, that is, a total equivalent secondary energy of 21,978 kWh; whereas the CFEWH system potentially consumed 6,913 kWh of delivered electricity (Table B).

	Type of hot water systems for Brahe Place building					
	Rheem gas ring-main		Rheem solar gas ring-main		MicroHeat CFEWH	
Hot water use profile	Average	High	Average	High	Average	High
Water use (kL/y)	161	269	161	269	161	269
Gas use (GJ/y)	92.7 (25,750 kWh)	113.0 (31,389 kWh)	74.6 (20,722 kWh)	93.9 (26,083 kWh)	0	0
Eletricity use (kWh/y)	1,152	1,162	1,256	1,289	6,913	11,523
Total energy use (kWh equivalent/y)	26,902	32,551	21,978	27,372	6,913	11,523

Table B: Brahe Place building total annual water and secondary energy use for the different water heating options and occupancy levels

It is important to note, however, that the TRNSYS analysis conducted in both these case studies covered only secondary energy consumption, rather than the full primary energy and greenhouse gas emission impacts of the various water heating system options.

1 INTRODUCTION

1.1 Background

MicroHeat Technologies Pty Ltd is an Australian private company focusing on research and development of applications using advanced fluid heating technology. In this context, MicroHeat has developed a Continuous Flow Electric Water Heater (CFEWH) using the MicroHeat PCT patent-protected technology. This development, which has now been commercialised, seeks to achieve energy optimisation and thereby reduce significantly both energy and water consumption in the supply of hot water.

This joint research project has involved the Centre for Design and School of Aerospace Mechanical and Manufacturing Engineering (SAMME) at RMIT University working in collaboration with industry partner MicroHeat Pty Ltd. SAMME has been responsible for experimental performance analysis and validation of the system, and energy modelling of the system using TRNSYS energy system simulation software package, incorporating performance characteristics from the validation stage, using a 'whole systems' approach. The RMIT Centre for Design has been responsible for Life Cycle Analysis (LCA) and looking at complete life cycle impacts of the MicroHeat system in the modelled scenarios from the validation stage. The first SAMME report (completed in September 2012) covered the experimental performance analysis and validation of the MicroHeat CFEWH system. This energy modelling part of the project reported in this document has been conducted by Dr Biddyut Paul, under supervision of Associate Prof. John Andrews.

1.2 Objective of this project

The objectives of this energy modelling component of the project conducted by RMIT SAMME have been to:

- Develop an overall energy model of the water heating system in TRNSYS software for a high-rise high-density apartment complex for case studies of potential applications of the MicroHeat CFEWH units

- Use the performance data of CFEWH units obtained in part 1 for energy modelling in TRNSYS
- Develop an overall energy model for a high-rise high-density apartment complex for case studies of centralised gas system
- Develop an overall energy model for a medium-density apartment complex for case studies of the MicroHeat CFEWH units
- Develop an overall energy model for a medium-density apartment complex for case studies of centralised gas and solar- boosted gas systems
- Provide a TRNSYS modelling summary report to MicroHeat and Centre for Design.

1.3 Method

The method that has been followed throughout to achieve the modelling objectives has involved the following main activities:

- Understanding the overall system of the water heating system operation and systems components
- Collecting detailed information of all the system components required for modeling
- Developing the models in TRNSYS for the different cases
- Running the simulation for different scenarios
- Analysing the results of simulations and report writing.

1.4 Scope of this project

This component of the overall research project has focused on energy modeling of the hot water supply options to two types of multistorey residential building in Melbourne using the TRNSYS energy system simulation software package. The hot water supply options examined were a centralised gas water heater, a solar-boosted centralised gas heater, and the MicroHeat CFEWH units.

1.5 Outcomes

The following outcomes were expected from the energy modeling:

- Overall annual energy consumption of by different types of water heating system considered for this study
- Comparative study of all the systems considered
- A TRNSYS model that can be used to insert MicroHeat and other technologies into various scenarios, for systems analysis and policy advice.

2 TRNSYS MODELLING OF HOT WATER SYSTEMS

2.1 Introduction

A Transient Systems Simulation (TRNSYS) program is widely used to simulate the performance of a wide range of energy systems by breaking it down into individual black box components. A TRNSYS project is typically setup by connecting components graphically in the Simulation Studio. Each type of component is described by a mathematical model in the TRNSYS simulation engine and has a set of matching Proforma's in the Simulation Studio. The proforma has a black-box description of a component: inputs, outputs and parameters (TRNSYS17 2012).

2.2 Assembling a system

The main visual interface is the TRNSYS Simulation Studio (Figure 1). From there, a project can be created by drag-and-dropping components to the workspace, connecting them together and setting the global simulation parameters. The Simulation Studio saves the project information in a TRNSYS Project File (*.tpf). When a simulation is run, the Studio also creates a TRNSYS input file (text file that contains all the information on the simulation but no graphical information). The simulation Studio also includes an output manager from where it can be controlled which variables are integrated, printed and/or plotted, and a log/error manager that allow to study in detail what happened during a simulation.

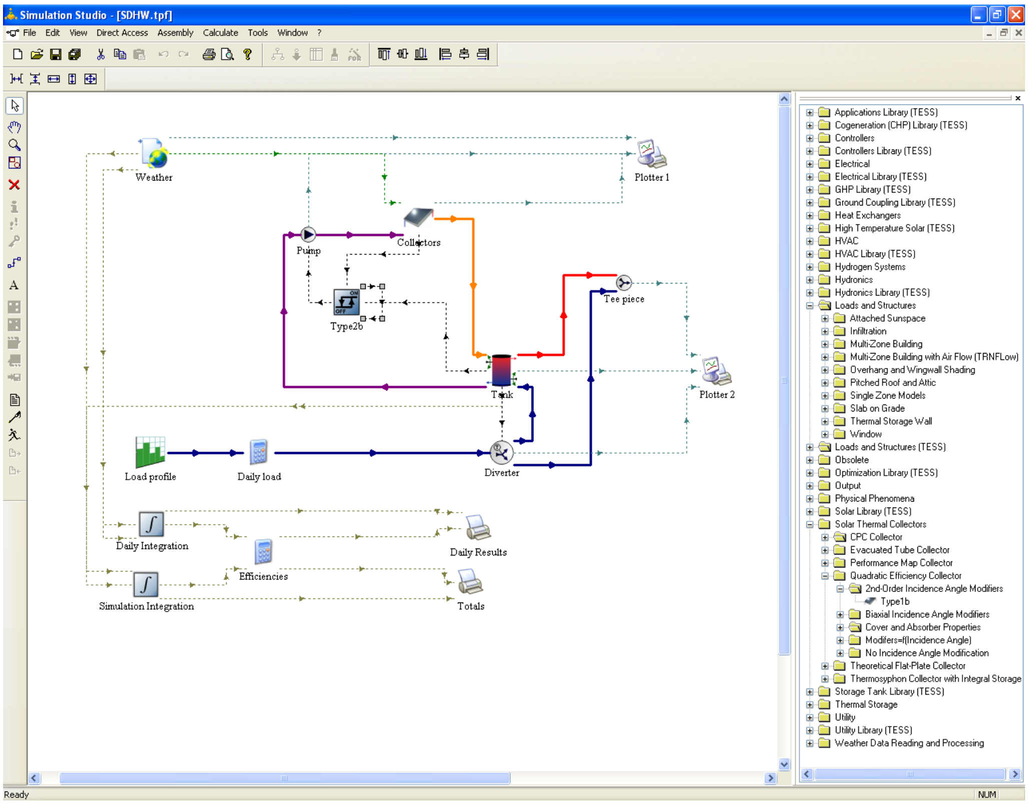

Figure 1: TRNSYS simulation Studio (TRNSYS17 2012)

2.3 Standard components for modelling a simple hot water system

TRNSYS components are often referred to as Types. All the components necessary for modelling a hot water system are available in TRNSYS standard library. In general, the following components are necessary to develop a simple hot water system in TRNSYS:

- Water Draw off (Type14b)
- Auxiliary heater (Type6)
- Storage tanks (Type534)
- Pump (Type3b)
- Pipe (Type31)
- Tempering valve controller (Type953)
- Flow diverters (Type11f)
- Tee-Piece (Type11h)
- Temperature controller (Type1502)
- Online Plotter (Type65)
- Output printer (Type25)

2.4 Inputs and outputs

An important step in the creation of an assembly in Simulation Studio is the specification of the required variables for each component model. With the graphical interface, outputs from one component can be connected to the inputs to another. The specific variable (input, output, parameter, and derivative) window can be accessed in the assembly panel by double-clicking the desired model icon. The Simulation Studio generates a text input file for the TRNSYS simulation engine (TRNSYS17 2012). That input file is referred to as the **deck file.** During simulation output from a component is fed to the other components according to the order of the components set up in the model.

2.5 Running a simulation

After setting up all the components in the Simulation Studio with all the system parameters and inputs, the simulation start time, stop time, simulation time step can be given in the 'Global Infos' control card window (Figure 2).

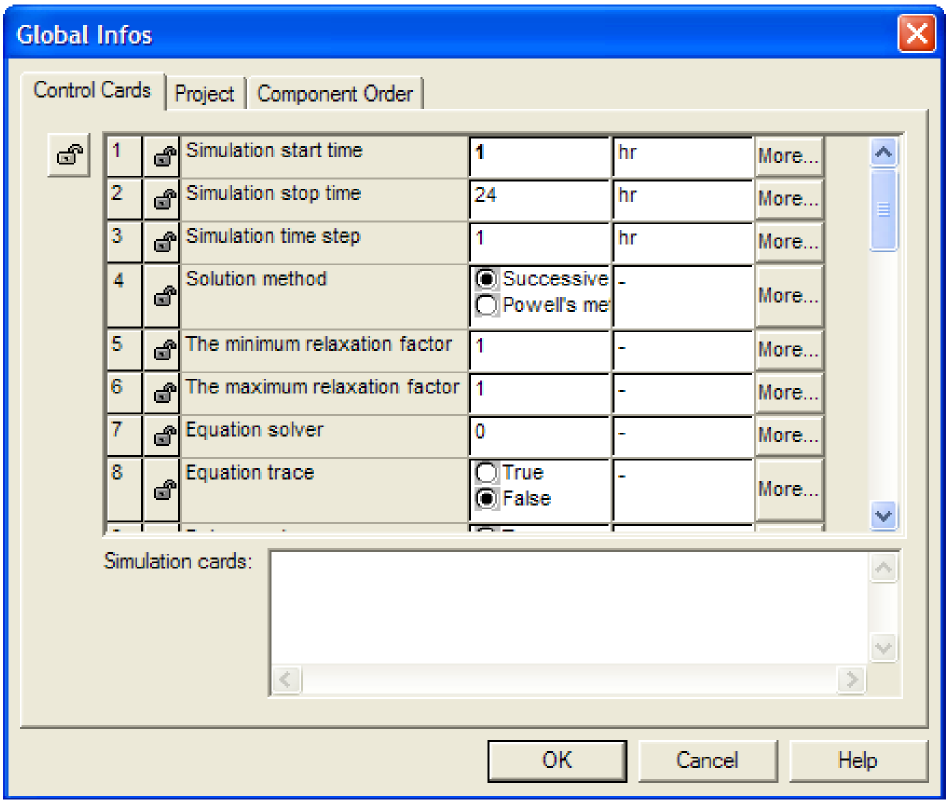

Figure 2: Control card Window (TRNSYS17 2012)

2.6 Displaying simulation results

The simulation engine is called by an executable program, TRNExe.exe, which also implements the online plotter, a very useful tool that allows viewing several output variables during a simulation (Figure 3). Detail information about TRNSYS can be easily accessible from the manuals.

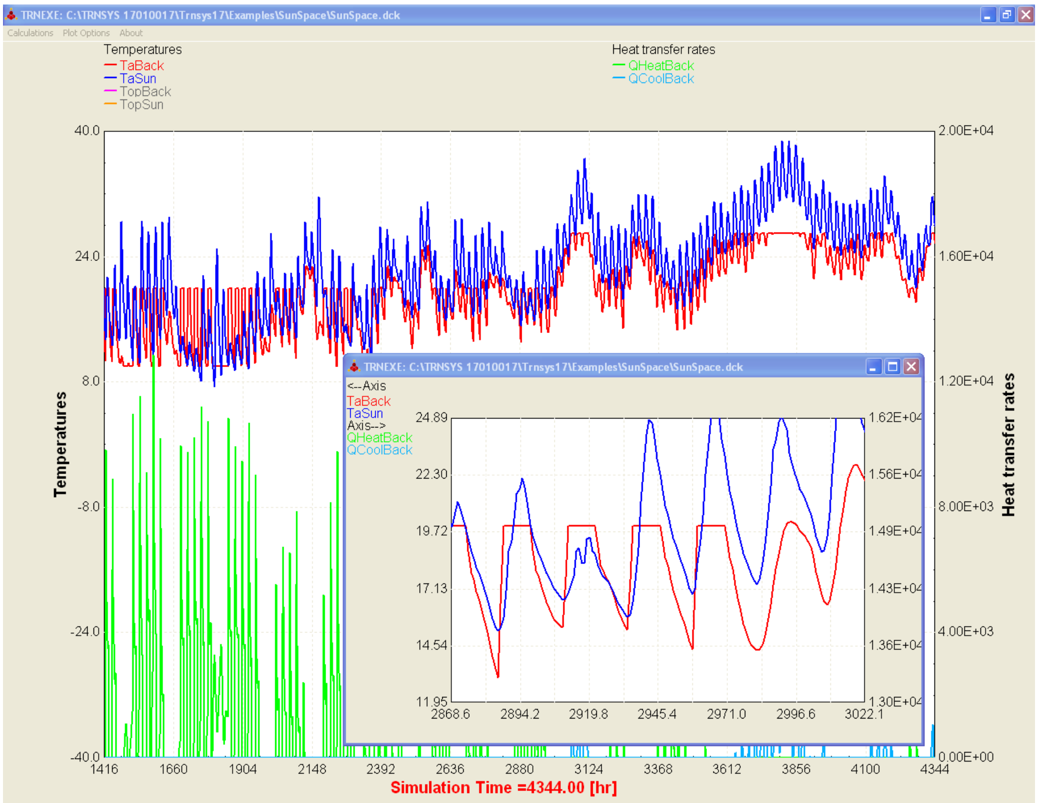

Figure 3: Online Plotter TRNexe (TRNSYS17 2012)

3 LA BANQUE BUILDING CASE STUDY – HIGH-RISE RESIDENTIAL TOWER

3.1 Building description

The first building selected by Wood and Grieve consulting company for energy modeling of hot water system in TRNSYS is a high-density apartment complex, La Banque building, (Figure 4), located in the Melbourne CBD at 380 Little Lonsdale Street and consisting of 257 apartments on 35 levels.

Figure 4: La Banque building, Melbourne CBD (Lockrey 2012)

Two potential types of hot water system are considered for comparison in this case study using TRNSYS modeling:

- Hot water via a centralised gas-boosted plant
- Hot water via individual continuous flow electric hot water heaters (CFEWH) in each apartment

Currently, centralised gas-boosted water heating system supplies the total hot water demand in the building.

3.2 Building hot water demand

Annual hot water demand data was not available for La Banque due to building management not having access to this data, and the inability to get a response from the body corporate accounts staff. A comprehensive literature review on Australian hot water demand has been conducted by Lockrey (2012) as a part of the LCA study in the present project. Table 1 shows the hot water demand of the La Banque building that he assumed for three different occupancy levels: low, average and high.

Scenario	Residents	Residents per residence	Hot water demand per apartment per day (L)	Annual hot water demand per apartment (kL)	Annual building hot water demand (kL)
Low occupancy	257	1.0	55	20	5,159
Average occupancy	370	1.5	73	27	6,848
High occupancy	670	2.6	114	42	10,694

Table 1: Hot water use scenarios for La Banque building (257 apartments) (Lockrey 2012)

Hot water demand also varies throughout the year depending on the seasons. The seasonal hot water load profile as a fraction of the maximum total daily demand is shown in Table 2 (Standards Australia 2008).

Seasonal load profile for Australia	
Month	**Load multiplier Zones 1 to 4**
Jan	0.7
Feb	0.8
Mar	0.85
Apr	0.9
May	0.95
Jun	1
Jul	1
Aug	1
Sep	1
Oct	0.95
Nov	0.9
Dec	0.8

Table 2: Seasonal hot water load profile (Standards Australia 2008)

To match the total annual hot water demand for all the scenarios that was used by Lockrey (2012), maximum daily hot water demand (Table 3) for input to the TRNSYS model was estimated by back calculation and using the seasonal load fraction of Table 2.

Scenario	Maximum hot water demand per apartment per day (L)	Annual building hot water demand (kL)
Low occupancy	60.8	5,159
Average occupancy	80.7	6,847
High occupancy	126.1	10,699

Table 3: Maximum daily hot water demand for Labanque building (257 apartments)

Maximum daily hot water demand along with seasonal load multipliers were applied to give the variation in total daily hot water demand over a year. Hot water demand also varies hour by hour through each day. The hourly variation assumed in the TRNSYS modelling is provided in Table 4 (Standards Australia 2008).

Hourly load profile for Australia	
Time	**Load Multiplier Zones 1 to 4**
07:00	0.15
08:00	0.15
11:00	0.1
13:00	0.1
15:00	0.125
16:00	0.125
17:00	0.125
18:00	0.125

Table 4: Hourly hot water load profile (Standards Australia 2008)

The hourly hot water demand in any given hour can then be found as follows:

Hourly load = maximum daily hot water demand × hourly load multiplier for that hour × seasonal load multiplier

3.3 Ambient cold water temperature

In addition, the mains tap water temperature in Australia varies throughout the year depending on the season and climatic zone. Figure 4 shows all four climatic zones, and the corresponding average monthly cold water temperatures for these zones are shown in Table 5

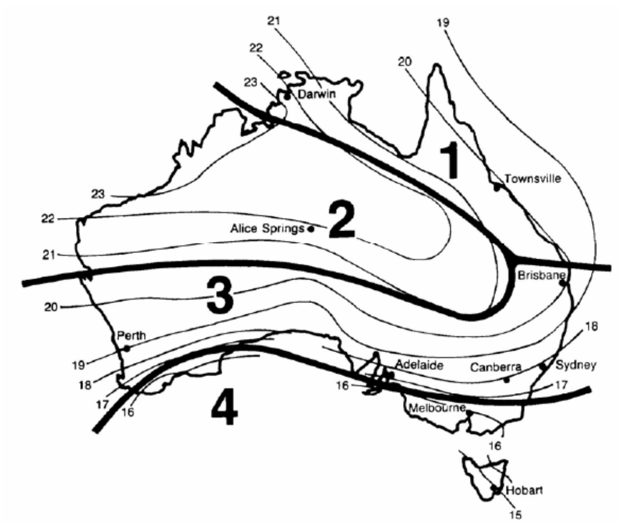

Figure 4: Australian climatic zones (Standards Australia 2008)

COLD WATER TEMPERATURE (°C)

Month	Zone 1	Zone 2	Zone 3	Zone 4
January	28	29	23	20
February	28	27	23	20
March	27	24	21	18
April	25	20	18	15
May	23	14	15	11
June	20	11	12	9
July	20	9	11	8
August	21	12	12	10
September	24	18	15	12
October	26	23	19	15
November	28	26	21	17
December	28	28	22	19

Table 5: Monthly cold water temperature for Australian climatic zones (°C) (Standards Australia 2008)

The La Banque building is located in Melbourne, which is in zone 4. So column 4 temperatures in Table 5 were used for the cold water temperature profile in each month.

3.4 Centralised-gas ring-main water heating system

3.4.1 System components, layout and operation

As mentioned before, currently a centralised gas-boosted ring-main hot water system supplies all the hot water demand for the 257 apartments on the 35 levels of the building. The overall system consists of two loops: a heating cycle loop and a water draw off loop (Figure 5). In the water heating loop, the main water heating source is 10 instantaneous gas heater units on a manifold on the roof. These units are Bosch series-32 gas heaters (KM3211WHQ), and they are connected to 2 x 315 L storage tanks. The average efficiency of the Bosch series-32 heaters is specified as 80% (Bosch 2011). Water is heated up to the specified 70°C through the heaters and transferred to the storage tanks via hot water heater cycle pumps (CHI 4-20 with 0.59 kW input power, flow rate 4.5 m^3/h, 1 for each tank and bank of 5 heaters). A thermostat is located at the base of the tanks to turn on the pump and heaters when bottom of the tank temperature fall below 50°C.

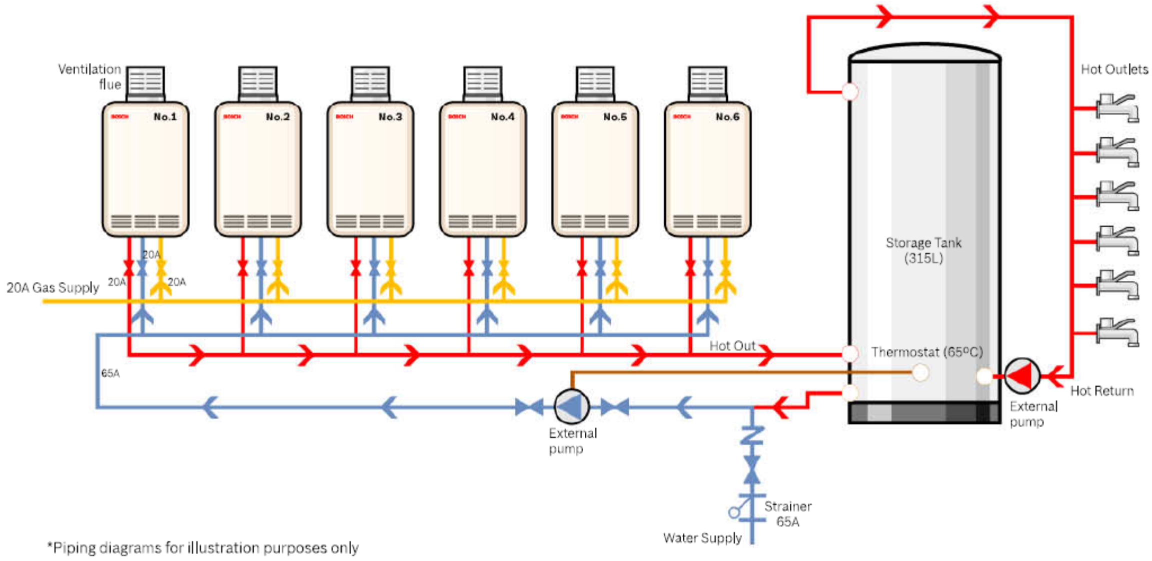

Figure 5: Typical Bosch ring-main gas heating system (Bosch 2011)

In the water draw off loop (demand side) the tanks are connected to the main hot water flow pipes (75 mm dia, 150 m long and 40 mm dia, 1375 m long) and return pipes (40 mm dia, 150 m long) throughout all the floors of the building. Water is circulated through this ring main constantly (24 hours a day, 7 days a week), using a hot water flow and return pump (UPS 32-80 N 180 with 0.2 kW input power, flow rate 4.2 m^3/h, and two identical pumps alternately in use periodically). The hot water flow and return pipes are interconnected at each level to minimise the pressure drop when there is draw off (Figure 6). When hot water is drawn off by residents, cold water is mixed with the hot water within each apartment to yield a delivery temperature of 50°C.

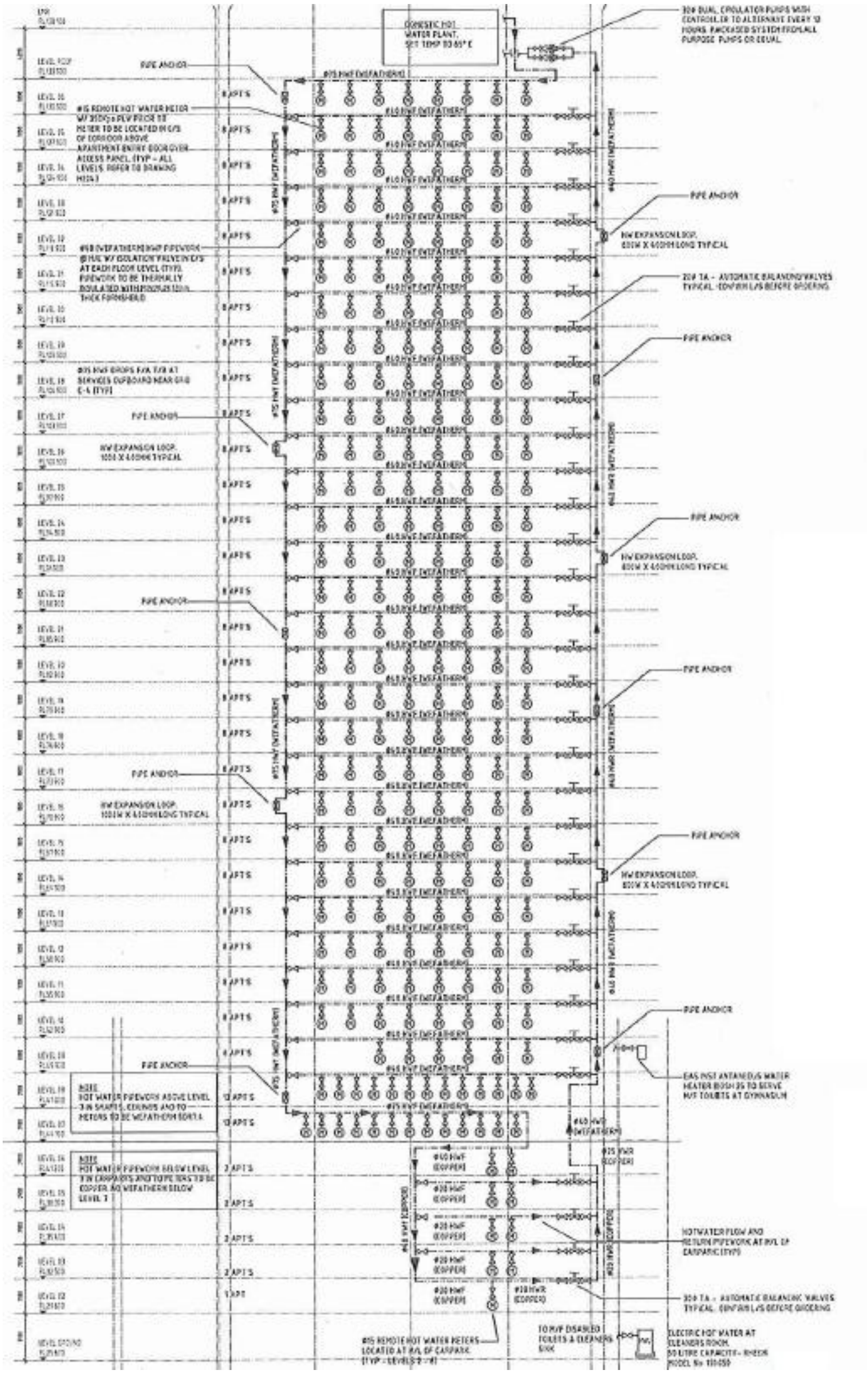

Figure 6: La Banque building hot water flow and return schematic (Wood and Grieve Engineers 2011a)

A top-up cold water line is connected to the hot water return pipe just before the latter enters the storage tank (Figure 7).

Figure 7: Storage tank water flow and return pipe connections in La Banque gas heating system (Photo from Simon Lockrey 2012)

Table 6 lists of all the components and their detailed specifications in the overall gas-boosted ring-main water heating system. These specification values were input to the TRNSYS model.

Sl. No.	System component	Specifications
1	Storage tank	Bosch (315C232LR), volume 315 L, height 1.97 m, 2 units
2	Cycle pump	Grundfos CHI 4-20, input power 0.59 kW, flow rate 4.5 m^3/h, 2 units
3	Gas heater	Bosch series-32 (KM3211WHQ), gas input 350 MJ/h, efficiency 80%, 10 units
4	Hot water flow pipe	Wefatherm polymer pipe, 1375 m long – 40 mm dia. (29 mm inner dia.), 150 m long – 75 mm dia. (55 mm inner dia.)
5	Hot water return pipe	Wefatherm polymer pipe, 150 m long – 40 mm dia. (29 mm inner dia.)
6	Pipe Insulation	Armaflex insulation, thickness 25 mm, loss coefficient 8.8 kJ/hm^2K for 75 mm pipe, and 11.2 kJ/hm^2K for 40 mm pipe (based on inner surface area of the pipe)
7	Flow/return pump	Grundfos UPS 32-80 N 180, input power 0.2 kW, flow rate 4.2 m^3/h, 1 unit operating

Table 6: Gas heating system components for La Banque building

Overall pipe heat loss coefficient (kJ/hm^2K) in the above Table 6 was calculated using Thermotec the heat loss values (Table 7), and using following equations (Holman 1990).

$$q = UA\Delta T_{overall} \tag{1}$$

$$U = \frac{(q/L)}{\pi D \Delta T_{overall}} \tag{2}$$

In these above equations U is the overall pipe heat loss coefficient (kJ/hm^2K), q/L is the heat loss per unit length of pipe (kJ/h/m), D is the diameter of the pipe (m) and $\Delta T_{overall}$ is the temperature difference between hot water in the pipe and ambient air (°C).

In Table 7 the heat loss per meter, q/L (kJ/h/m) is detailed for a similar insulation type to Armaflex foil covered insulation. In this calculation overall temperature difference 50°C was considered with ambient temperature 20°C and hot water flowing through the pipe was around 70°C. The overall pipe heat loss coefficient was estimated based on inner surface are of the pipe to comply with TRNSYS pipe input parameters.

WATER TEMP °C		55				60				65			
AMBIENT TEMP °C		10	12	15	20	10	12	15	20	10	12	15	20
PIPE O.D. (mm)	INSULATION THICKNESS												
39	Nil	251.3	239.4	221.4	191.2	288.7	276.5	258.1	227.5	326.2	313.6	294.8	263.8
	15	49.0	47.5	45.4	42.1	60.8	58.7	55.1	49.0	83.5	76.3	65.9	55.8
	20	46.4	44.3	41.4	36.0	52.6	50.4	47.5	42.1	58.7	58.3	58.0	48.2
	25	42.5	40.7	38.2	33.5	47.9	46.1	43.2	38.5	53.3	52.2	50.8	43.6
	30	37.8	36.4	33.8	29.9	42.8	41.4	38.9	34.6	47.9	47.5	46.8	39.2
51	Nil	315.3	300.6	278.3	240.8	362.5	347.4	324.7	287.3	409.7	394.2	370.8	332.3
	15	65.1	62.3	57.6	50.0	73.8	70.9	66.2	58.7	82.4	77.4	70.2	67.3
	20	55.8	53.6	49.7	43.2	63.0	60.5	56.5	50.4	70.2	67.7	64.1	57.6
	25	50.4	48.2	54.0	39.2	56.9	54.7	51.5	45.7	63.4	61.2	58.0	52.2
	30	45.0	42.6	39.6	34.9	50.8	48.6	43.4	40.7	56.5	54.4	51.5	46.4
60	Nil	362.5	345.2	319.7	276.8	416.5	399.2	372.9	329.4	470.5	452.9	426.4	382.0
	15	73.4	70.2	65.2	56.8	83.1	79.9	75.2	66.2	92.9	87.1	78.5	75.6
	20	54.0	52.9	51.5	48.6	70.6	67.7	63.7	56.5	78.8	76.0	71.6	64.4
	25	52.9	51.8	50.4	43.9	61.6	60.1	57.6	51.1	70.9	68.4	64.4	58.3
	30	50.0	47.9	44.6	38.9	56.5	54.3	51.1	45.3	63.0	60.5	56.9	51.8
76	Nil	444.2	423.4	392.0	339.8	510.5	482.1	439.6	404.3	576.7	555.1	522.7	468.7
	15	87.8	83.2	76.3	64.8	99.4	95.4	89.3	79.2	110.9	106.9	100.8	90.7
	20	73.8	70.6	65.9	57.6	84.2	81.0	76.0	67.3	94.0	90.4	85.3	77.0
	25	66.6	63.7	59.4	52.2	75.2	72.4	68.0	60.5	83.9	81.0	76.3	68.8
	30	58.7	56.2	52.9	45.7	66.2	63.7	59.8	53.3	73.8	71.3	67.3	60.8
102	Nil	572.4	545.8	505.8	439.2	657.7	630.7	590.1	522.0	743.1	715.3	673.9	604.8
	15	110.5	97.6	77.8	71.2	125.3	115.2	99.7	74.1	140.1	135.0	127.1	114.1
	20	93.2	80.6	61.6	51.2	105.5	96.8	84.2	63.0	117.2	113.1	106.2	94.7
	25	87.1	74.9	56.9	30.6	94.0	86.4	75.2	56.5	95.4	92.9	88.9	82.4
	30	76.7	67.0	52.2	27.6	82.1	75.6	65.8	49.7	87.5	84.6	79.9	72.0

Table 7: Thermotec heat loss table 4-Zero/Quickseal/sealed tube in kJ/h/m (Thermotec 2007)

3.4.2 TRNSYS model of centralised-gas water heating system

The overall gas heating system has been modelled in TRNSYS software to calculate total gas consumption by heaters, electricity use by heaters and pumps, and thermal losses from the piping and tanks. All the necessary components were imported into the TRNSYS Simulation Studio and connected in correct order to replicate the actual system (Figure 8). Necessary input data for all the components in the model are taken from the Table 6 in section 3.4.1. Water draw-off profiles for the different occupancy scenarios and the cold water temperature profile as in section 3.2 were input into the model, and remained the same in all scenarios investigated for this building.

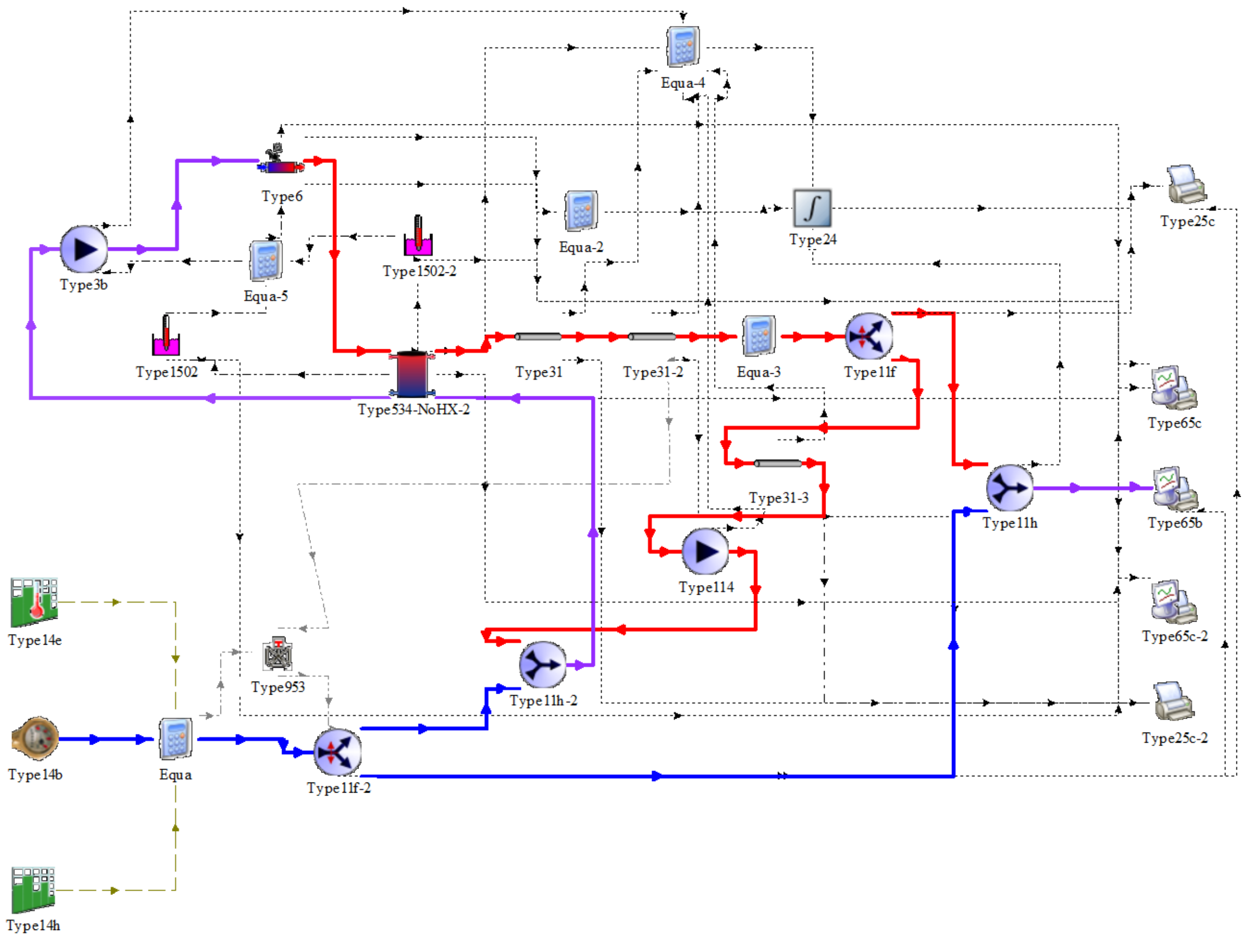

Figure 8: TRNSYS model of the centralised gas-boosted water heating system in the La Banque building

In Figure 8, thick lines represent the main water circulation loops for heating, and the water draw off/return. Blue lines signify cold water, red lines high-temperature hot water (that is, around 70°C), and purple lines low temperature (that is, around 50°C - 55°C) hot water. At the beginning of the simulation, the model read the daily hot water demand profile (Type14b), seasonal load profile (Type14h) and cold water temperature profile (Type14e), and then all this information is used to compute the hourly hot water demand in an equation box (Equa) during each day for all the apartments. The tempering valve controller (Type953) sends a signal to the diverting valve (Type11f-2) to split the cold water in the right fractions: that is, how much water is sent to the storage tank for heating, and how much is mixed with the hot water to get the desired 50°C set temperature at the draw-off in the apartments. This decision is made based on the incoming cold water temperature and outlet hot water temperature after passing through the hot water flow pipes (Type 31-2) before mixing with cold water.

The storage tank (Type534-NoHX) is considered as a stratified tank with 10 nodes, i.e. the height of the tank is divided into 10 equal segments, and with two inlet and two outlet ports. In the heating cycle loop there are two temperature controllers (Type1052 and Type1052-2) to monitor temperature of the bottom and top nodes of the storage tank, and decide when to turn on the pump (Type3b) and heaters (Type6) through an equation box (Equa-5) logic. The temperature controller for bottom node is set to 53°C with a dead band of 6°C, and for top node it is set to 67°C with a dead band of 4°C (TRNSYS17 2012). The equation box logics are set in such a way that the cycle pumps and heaters are turned on when the temperature of either the bottom or top of the tank falls below 50°C or 65°C respectively, and turned off when the temperature of either the bottom or top of the tank is above 56°C or 69°C respectively. The heating cycle pump draws off the water from bottom of the tank (node 10) and delivers it back at the top of the tank (node 1) after heating it up in the heaters to 70°C.

In the hot water flow and return loop for the hot water demand side, hot water is drawn off from top of the storage tank (node 1) by a hot water flow and return pump (Type114) and then passes through the equivalent length of hot water flow pipes (Type31 and Type 31-2) (main hot water flow pipe and adding all other hot water flow pipes in all levels of the building). The hot water is then split into the right fractions in a diverting valve (Type11f) by an equation box (Equa-3). One fraction of the hot water flow is sent to the Tee-piece (Type11h) to mix up with the cold water at the apartments, and other fraction is return back to bottom of the storage tank (node 10) after passing through the equivalent length of the return flow pipe (Type 31-3). The returned flow is also mixed with the cold water flow through another Tee-piece (Type11h-2) before entering the storage tank which was diverted at the beginning to be heated up. Online plotters (Type65b, Type65c and Type65c-2) plot all the necessary graphs during the simulation; integrator (Type24) integrates all the output results, and output printers (Type25c and Type25c-2) stores all the results in an output txt file.

The number of apartment served by the gas water heaters is specified in the equation box (Equa) linked to the input temperature profile (Type14e), daily hot water demand profile (Type14b), and the profile of the seasonal variation of this demand (Type14h). The gas input of a single Bosch heater (250 MJ/h) is also multiplied by the number of heaters within the Type6 heater specifications in the TRNSYS model. Similarly the power consumption of a single cycle pump (0.59 kW) and volume of a single storage tank (315 L) is also multiplied by the number of units of these components in the model.

3.4.3 TRNSYS simulation of annual operation and results

The TRNSYS model simulations for the La Banque building centralised-gas heating system was run for three occupancy levels: low, average and high. The model was set up for yearly simulation on an hour by hour basis and each simulation time step was 0.001 h (3.6 sec). Figure 9 shows the TRNSYS-generated cold-water temperature profile which was used for all the cases. From this graph it can be seen that there is a significant variation of cold water temperature throughout the year ranging from 9°C to 20°C.

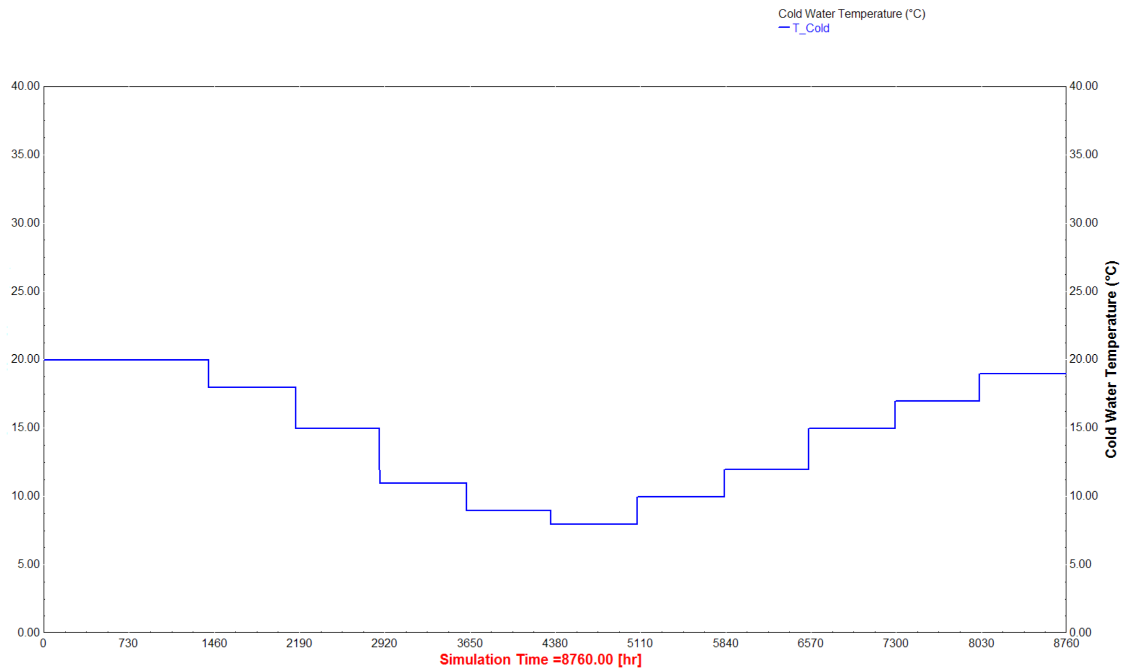

Figure 9: TRNSYS-generated annual cold water temperature profile

Daily (for January) and yearly hot water demand profiles for the low occupancy scenario for 257 apartments at La Banque building are shown in Figure 10 and Figure 11 respectively. From Figure 10 it can be seen that in the morning 7 am to 9 am high hot water demand, low demand between 11 am and 12 noon, and 1 pm and 2 pm, then moderately high demand between 3 pm and 7 pm.

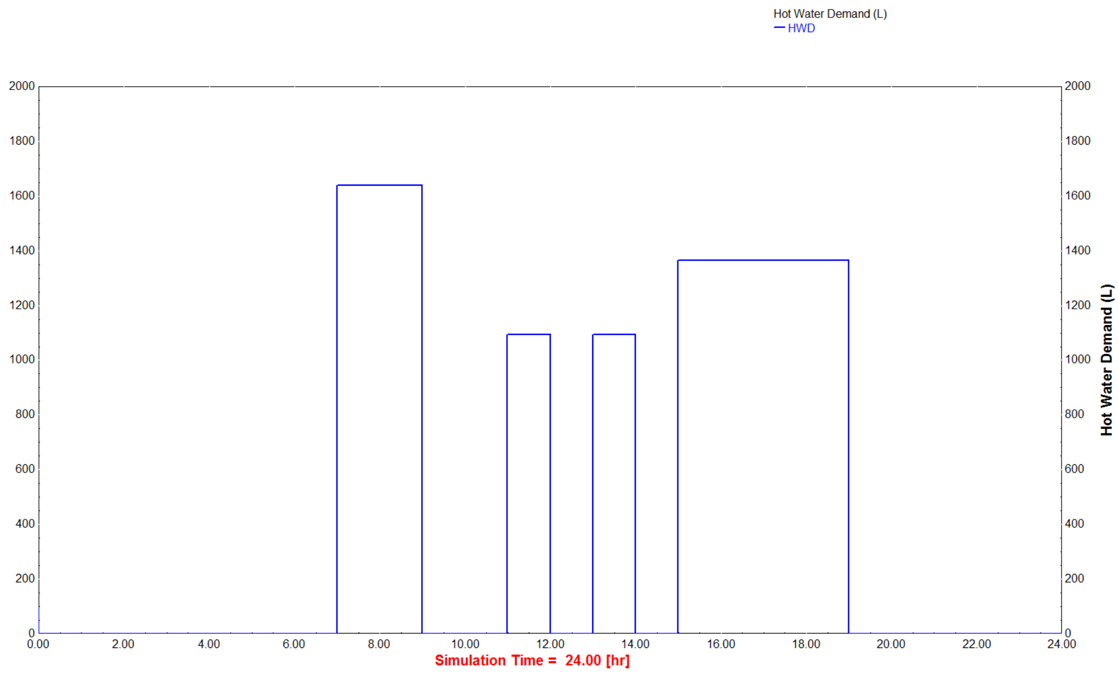

Figure 10: TRNSYS-generated daily (for January) hot water demand profile for 257 apartments in La Banque building (low occupancy level)

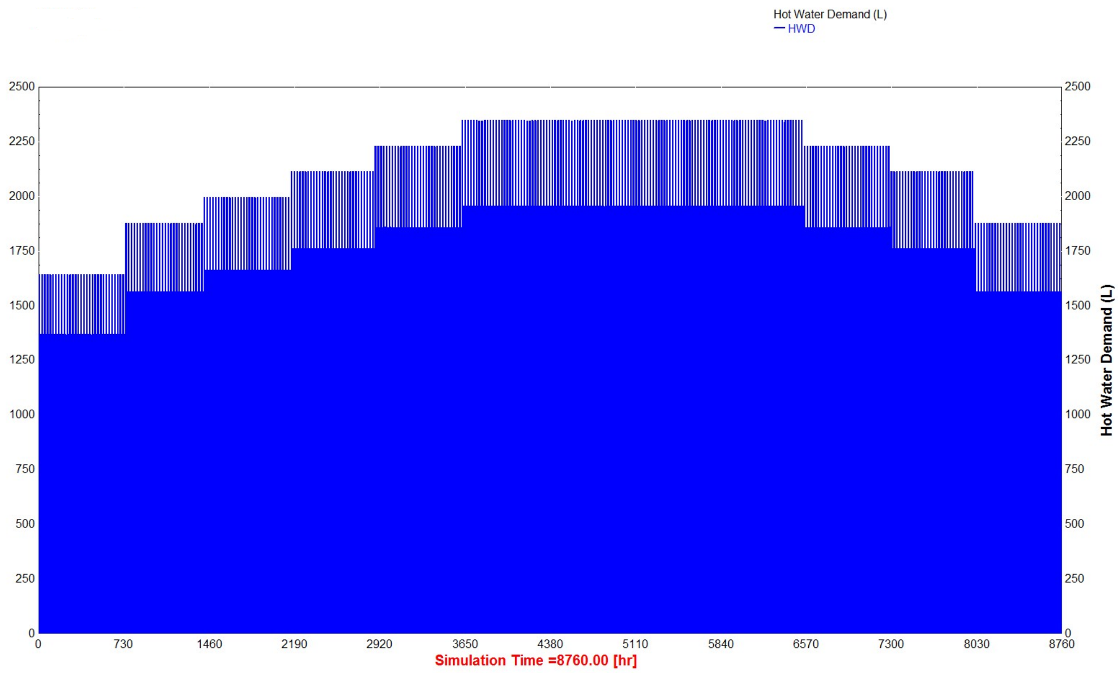

Figure 11: Annual hot water demand profile for 257 apartments in the La Banque building (low occupancy level)

Figure 12 and Figure 13 respectively show the daily (for January) and yearly cold water and delivered tempered hot water temperature profiles by gas heating system for 257 apartments in La Banque building for low occupancy scenario. This is conforming that the model is working right and always delivering desired tempered hot water temperature at 50°C. Same tempered delivery temperature profiles were found for average and high occupancy scenarios as well.

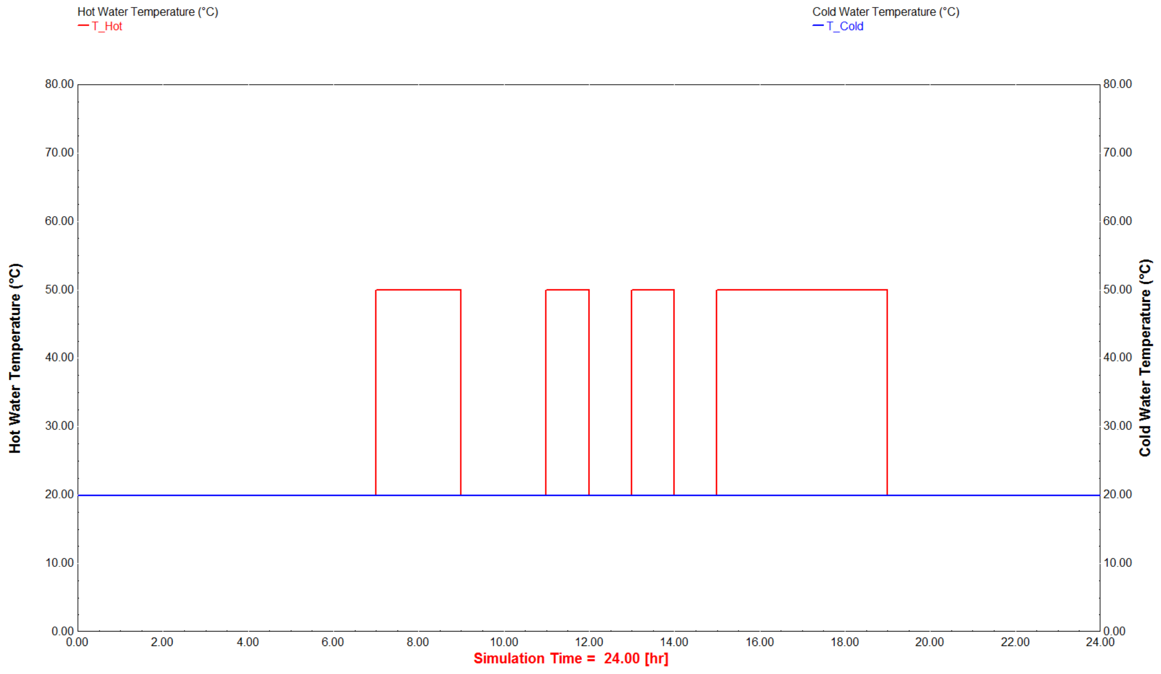

Figure 12: Daily (for January) cold water and delivered tempered hot water temperature by gas heating system for 257 apartments in La Banque building (low occupancy scenario)

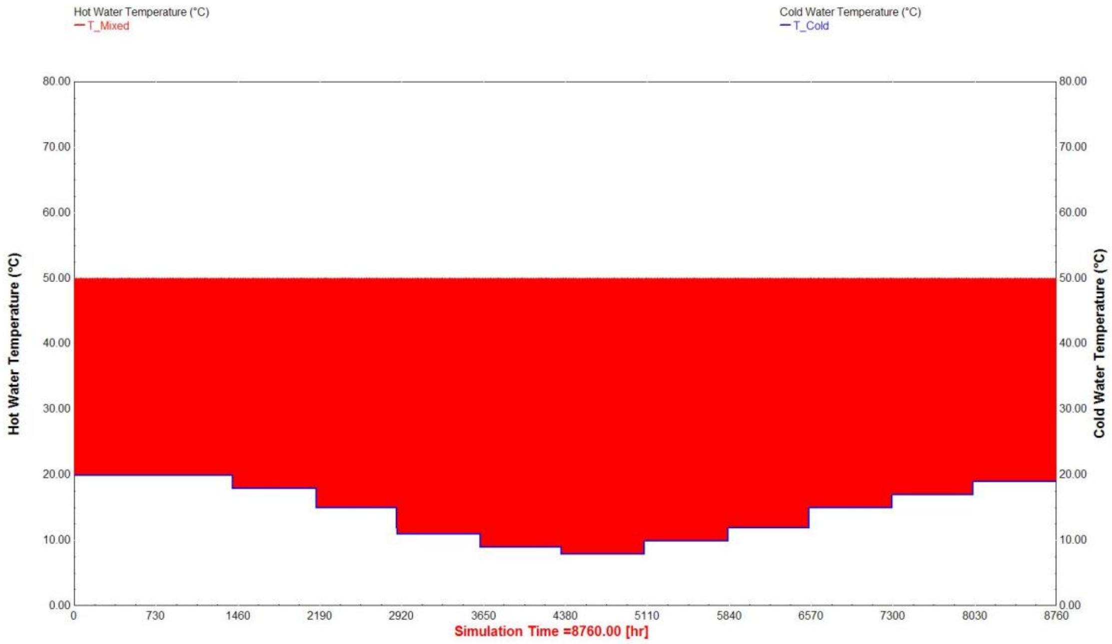

Figure 13: Annual cold water and delivered tempered hot water temperature profile by gas heating system for 257 apartments in La Banque building (low occupancy scenario)

Daily (for January) and yearly required heat supply rate by the gas heating system to meet the hot water demand in La Banque building for low occupancy level can be seen from Figure 14 and Figure 15 respectively. More frequent heating is required during the hot water draw off than other time of the day and in winter time more heating energy is required than summer time.

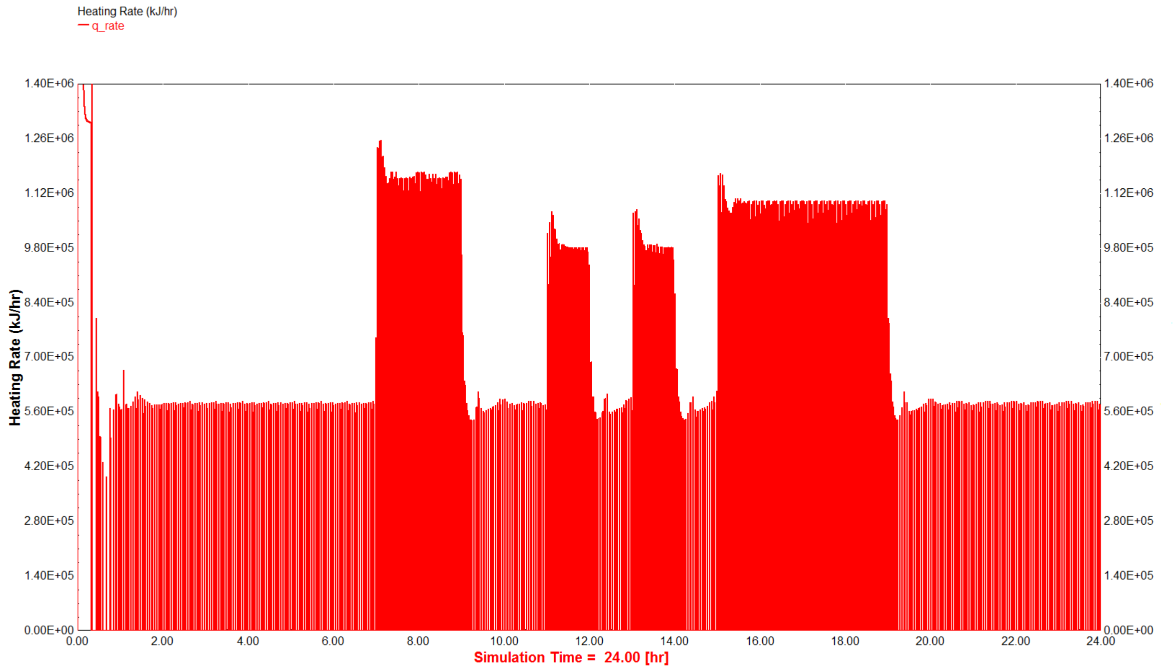

Figure 14: Daily (for January) heating rate profile by gas ring-main system for 257 apartments in La Banque building (low occupancy level)

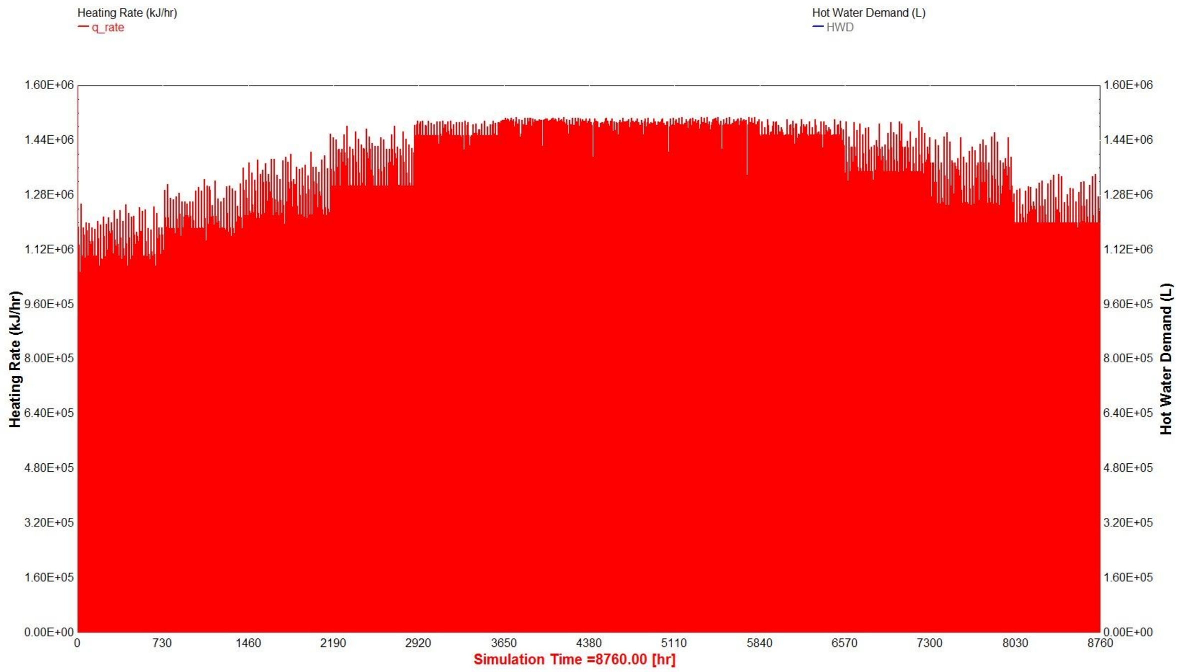

Figure 15: Annual heating rate profile by gas plant ring-main system for 257 apartments in La Banque building (low occupancy level)

A significant temperature difference of around 15°C was found between the top and bottom of the storage tank (Figure 16). This represents effective stratification in the storage tank. In a real case scenario there is also a 15 to 20°C temperature difference between the top and bottom of the tank. The yearly temperature profile in the storage tank for the low occupancy level for 257 apartments in La Banque building is shown in Figure 17.

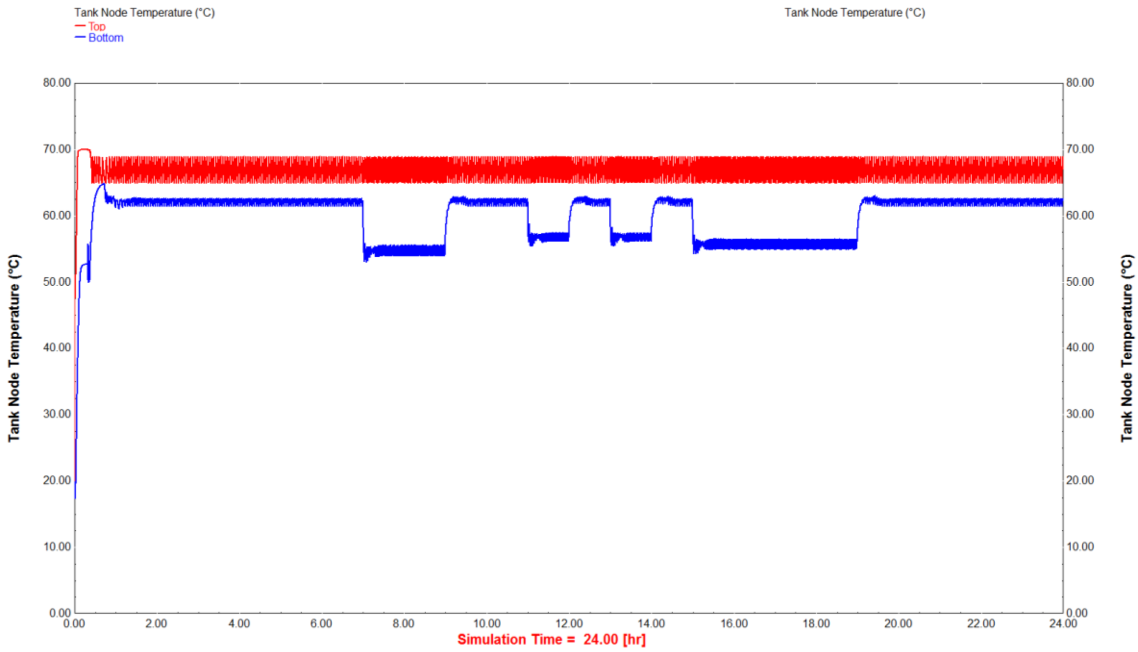

Figure 16: Daily (for January) storage tank top and bottom temperature profile by gas plant ring-main system for 257 apartments in the La Banque building (low occupancy level)

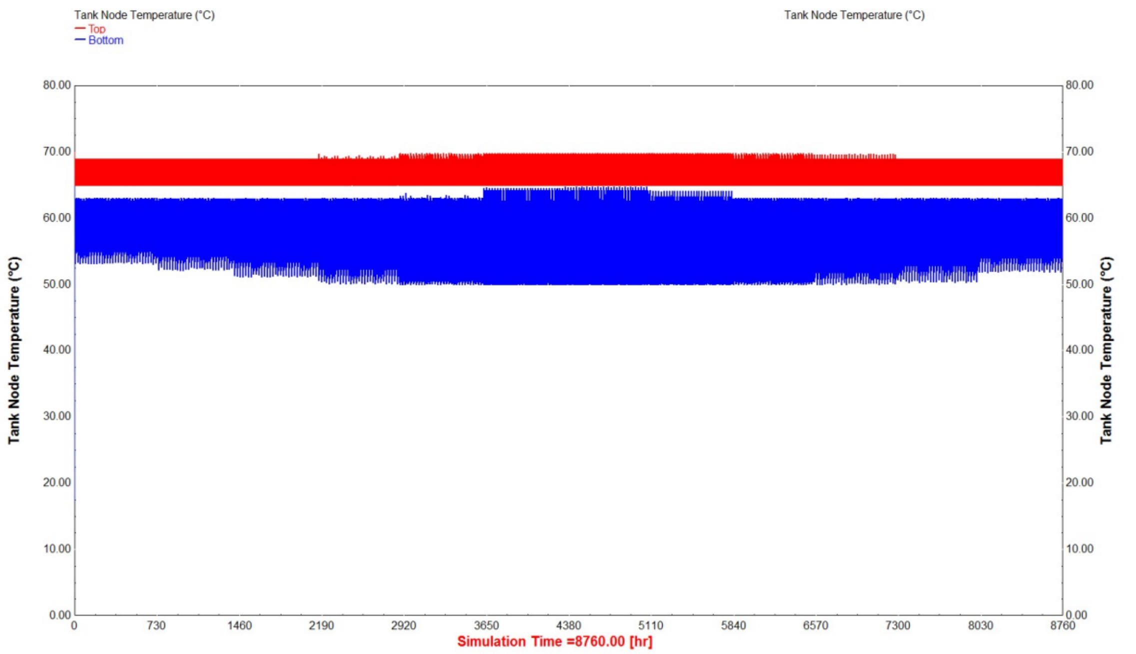

Figure 17: Annual storage tank top and bottom temperature profile by gas plant ring-main system for 257 apartments in La Banque building (low occupancy level)

Results obtained from the simulation of La Banque building centralised gas ring-main water heating system for low, average and high occupancy scenarios are tabulated in Table 8.

Occupancy	**Annual hot water demand (kL)**	**Annual gas consumption (GJ)**	**Piping annual heat loss (GJ)**	**Storage tank annual heat loss (GJ)**	**Cycle pump annual electricity consumption (kWh)**	**Flow/return pump annual electricity consumption (kWh)**	**Cycle and flow/return pump combined annual electricity consumption (kWh)**
Low	5,159	1,876.1	703.8	8.5	1,227	1,752	2,979
Average	6,847	2,198.1	707.6	8.6	1,359	1,752	3,111
High	10,699	2,931.9	714.2	8.8	1,730	1,752	3,482

Table 8: TRNSYS simulation results for the gas ring-main water heating system in the La Banque Building.

From the above results table it can be seen that the actual hot water demand of low, average and high occupancy scenarios were 5,159 kL, 6,847 kL and 10,699 kL respectively, which matches the values in Table 1 (section 3.2) obtained by Lockrey (2012). The annual total gas consumption was 1,876.1 GJ, 2,198.1 GJ and 2,931.9 GJ for the low, average and high occupancy scenarios respectively. This total gas energy consumption includes piping and storage tank heat losses, which account for 712.3 GJ (703.8+8.5), 716.2 GJ (707.6+8.6) and 723 GJ (714.2+8.8) of gas consumption in the low, average and high occupancy levels respectively. So, around 38%, 33% and 25% of the heating energy was lost from the pipe works and storage tanks for the low, average and high occupancy levels respectively. The flow and return pumps run 24/7 throughout the year consuming annually 1,752 kWh of electricity for all three scenarios. But the heating cycle pump consumes 1,227 kWh, 1,359 kWh and 1,730 kWh for low, average and high occupancy scenarios respectively. These results were expected as the heating cycle pump needs to run more in the higher occupancy scenarios.

Occupancy	Cycle pump annual electricity consumption (kWh)	Two cycle pumps combined rated power consumption (kW)	Heating mode annual operation of cycle pump and gas heater (hrs)	No. of Bosch gas heater units	Yearly total heating operation hours (hrs)	Yearly total standby operation hours (hrs)	Annual total electricity consumption by heaters in heating and standby mode (kWh)
Low	1,227	1.18	1,040	10	10,400	77,200	1,502
Average	1,359	1.18	1,152	10	11,520	76,080	1,588
High	1,730	1.18	1,466	10	14,663	72,937	1,830

Table 9: Gas heating system heating and standby mode electricity consumption for La Banque building

The Bosch 32 series gas heater unit runs a fan and electronics when heating at 85 W per unit, and standby electricity consumption is 8 W per unit (as advised by Bosch). The standby and heating mode operation electricity consumption by the 10 Bosch 32 series heater units was estimated by back calculating using the information on the electricity consumption by heating cycle pump (Table 9). It is found that the annual total electricity consumption by the gas heaters in the heating and standby mode are 1,502 kWh, 1,588 kWh and 1,830 kWh for the low, average and high occupancy levels respectively.

Occupancy	Annual total water heating gas consumption including losses (GJ)	Hot water system annual total electricity consumption by all pumps and heaters (kWh)	Annual gas consumption per apartment (GJ)	Hot water system annual total electricity consumption per apartment (kWh)
Low	1,876.1	4,481	7.3	17
Average	2,198.1	4,699	8.6	18
High	2,931.9	5,312	11.4	21

Table 10: La Banque building ring-main gas heating system annual total energy inputs

Table 10 shows annual total gas and electrical energy required by the gas-boosted ring-main water heating system in the 257 apartments as well the average consumption per apartment in La Banque building. For low, average and high occupancy levels the average apartment's annual water heating energy consumption was 7.3 GJ gas and 17 kWh electricity; 8.6 GJ gas and 18 kWh electricity; and 11.4 GJ gas; and 21 kWh electricity respectively.

3.5 Continuous-flow MicroHeat electric water heaters in each apartment

3.5.1 System components, layout and operation

The second water heating option for the La Banque building investigated using TRNSYS modelling is a point-of-use electric hot water system in each apartment. It has been assumed that 257 MicroHeat continuous flow electric water heaters (CFEWH) with cold water inlets (Figure 18) are installed at the entry of each apartment, and set to deliver hot water at 50°C. Water is supplied cold to the apartments, and heated up to the specified 50°C with modulating electrical power based on inlet temperature and flow rate.

Figure 18: MicroHeat Series 2 three phase continuous flow electric water heater

The average efficiency of the MicroHeat Series 2 three phase heaters is 98%, confirmed through testing at the RMIT School of Aerospace, Mechanical and Manufacturing Engineering (SAMME) as reported in our first report in this project (Paul and Andrews 2012). This efficiency value is at the lower end of error range, and for this present energy modelling study we have assumed the conservative value. The MicroHeat Series 2 three-phase heaters run at a standby electricity consumption of 1.3 W per unit (as advised by MicroHeat) when no water is being drawn. For this system no piping losses are considered, as inside the apartment from the door the pipe length is same for all system options studied.

3.5.2 TRNSYS model of MicroHeat CFEWH system

The TRNSYS model of the CFEWH system for La Banque building is much simpler than the centralised gas-boosted ring-main system. All these components are imported into a TRNSYS simulation studio and connected in the correct order to replicate the actual system (Figure 18). The number of apartment served by the separate electric water heaters is specified in the equation box linked to the input temperature profile (Type14e), daily hot water demand profile (Type14b), and the profile of the seasonal variation of this demand (Type14h). The capacity of a single heater (27 kW) is also multiplied by the number of apartments within the Type 6 heater specifications in the TRNSYS model.

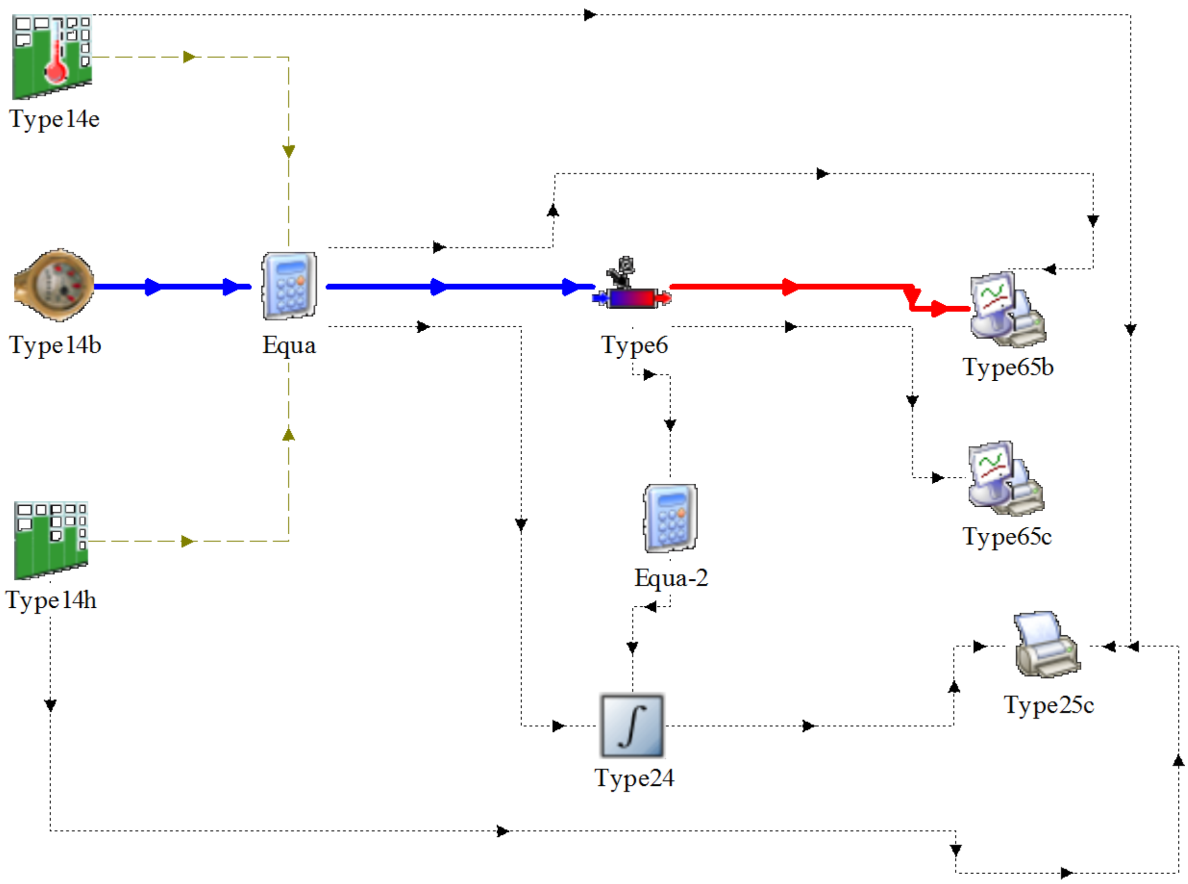

Figure 18: TRNSYS model of La Banque building using individual CFEWH water heater in each apartment

In Figure 18 the blue lines represents cold water and the red line represents hot water. As before in the gas heating model, at the beginning of the simulation, the model first reads the daily hot water demand profile (Type14b), the seasonal load profile (Type14h) and the cold water temperature profile (Type14e). Then all these data are used in an equation box to compute the hourly hot water demand over each day for all the apartments. Cold water passes through the heater (Type6), which delivers the desired outlet temperature of 50°C. Online plotters (Type65b and Type65c) plot all the necessary graphs during the simulation; the integrator (Type24) integrates all the output results, and output printer (Type25c) stores all the results in an output txt file.

3.5.3 TRNSYS simulation of annual operation and results

The TRNSYS model simulation for the La Banque building CFEWH system was run for the same three occupancy levels as for the gas system on an hourly basis over a year using a simulation time step of 0.001 h (3.66 sec). All graphs of result obtained from this simulation are shown in Appendix A. Results obtained from this simulation are presented in Table 11.

Occupancy	Annual hot water demand (kL)	Annual electricity consumption (MWh)
Low	5,159	220.1
Average	6,847	292.2
High	10,699	456.6

Table 11: TRNSYS simulation results for CFEWH system for La Banque Building

It can be seen that annual electricity consumption for water heating was 220.1 MWh, 292.2 MWh and 456.6 MWh for the low, average and high occupancy scenarios respectively.

Heating mode (hrs/day)	Standby mode (hrs/day)	No. of CFEWH units	Yearly total standby operation (hrs)	CFEWH standby power consumption (W)	Yearly total standby electrical energy consumption (kWh)
8	16	257	1,500,880	1.3	1,951

Table 12: CFEWH system standby mode total electricity consumption for La Banque building

Each MicroHeat Series 2 three-phase CFEWH unit consumes 1.3 W in standby mode. Total electricity consumption by the 257 CFEWH units in standby mode was estimated by assuming that each heater will be in heating mode 8 hrs/day consistent with the daily water draw off profile (Table 4 and Figure A-1); hence it will be in standby mode operation 16 hrs/day. It is found that annual total electricity consumption by heaters in standby mode is 1,951 kWh (Table 12). This value is same for all three occupancy scenarios.

Occupancy	**Annual water heating electricity consumption (MWh)**	**Annual standby electricity consumption by heater units (kWh)**	**Building hot water system total annual electricity consumption (MWh)**	**Hot water system annual total electricity consumption per apartment (kWh)**
Low	220.1	1,951	222.1	864
Average	292.2	1,951	294.1	1,145
High	456.6	1,951	458.5	1,784

Table 13: La Banque building CFEWH system annual total energy inputs

Table 13 shows annual total electrical energy required by the CFEWH heating system in all 257 apartments as well in individual apartment in La Banque building. For low, average and high occupancy scenarios, the total building annual water heating electricity consumption was 220.1 MWh, 292.2 MWh and 456.6 MWh respectively. For individual apartment annual water heating electricity consumption was 864 kWh, 1,145 kWh and 1,784 kWh for low, average and high occupancy level respectively.

3.6 Comparison of water heating system options

Table 14 compares all the results found for both the centralised Bosch gas main-ring water heating system and the point-of-use MicroHeat CFEWH system for the three occupancy levels in the La Banque building. It should be noted that energy usage is given solely in terms of secondary energy, that is, the energy content of the natural gas consumed, and the energy content of the delivered electricity without considering the primary energy inputs to deliver to the consumer this secondary energy.

From this table it can be seen that in all three occupancy scenarios the centralised gas water heating system used more secondary energy (in the form of gas plus some electricity for pumping) than the point-of-use CFEWH system (all in the form of electricity). For example, for low occupancy level, centralised gas heating system annually consumed 1,876.1 GJ (521,139 kWh) gas and 4,481 kWh of electricity, that is, a total equivalent secondary energy of 525,620 kWh; whereas the CFEWH system potentially consumed 222,087 kWh of delivered electricity.

	Type of hot water systems for La Banque building					
	Bosch gas ring main			MicroHeat CFEWH		
Hot water use profile	Low	Average	High	Low	Average	High
Water use (kL/y)	5,159	6,847	10,699	5,159	6,847	10,699
Gas use (GJ/y)	1,876.1 (521,139 kWh)	2,198.1 (610,583 kWh)	2,931.9 (814,417 kWh)	0	0	0
Eletricity use (kWh/y)	4,481	4,699	5,312	222,087	294,138	458,516
Total energy use (kWh equivalent/y)	525,620	615,282	819,729	222,087	294,138	458,516

Table 14: La Banque building total annual water and secondary energy use for the different water heating options and occupancy levels

4 BRAHE PLACE BUILDING CASE STUDY – LOW-RISE RESIDENTIAL APARTMENTS

4.1 Building description

The second building selected by Wood and Grieve for energy modeling of hot water systems in TRNSYS is a proposed medium-density apartment complex, the Brahe Place building (Figure 19), located in East Melbourne at 18 Brahe Place, and consisting of eight apartments on three levels.

Figure 19: Brahe Place building, Melbourne CBD (Lockrey 2012)

The proposed building is still at a planning stage and Wood and Grieve specified three potential types of hot water system for comparison in this case study using TRNSYS modeling:

- Hot water via a centralised gas-boosted plant.
- Hot water via a solar-boosted centralised gas plant.
- Hot water via individual continuous flow electric hot water heaters (CFEWH) in each apartment.

4.2 Building hot water demand and ambient cold water temperature

Building hot water demand data for Brahe Place building were taken from the LCA study report by Lockrey (2012). Table 15 shows the hot water demand assumed for this building at two different occupancy levels: average and high.

Scenario	Residents	Residents per residence	Hot water demand per apartment per day (L)	Annual hot water demand per apartment (kL)	Annual building hot water demand (kL)
Average occupancy	8	1.0	55	20	161
High occupancy	16	2.0	92	34	269

Table 15: Hot water use scenarios for Brahe Place building (8 apartments) (Lockrey 2012)

Maximum daily hot water demand (Table 16) was estimated for input to the TRNSYS model by back calculation and using the seasonal load fraction of Table 2, since the hot water demand varies throughout the year depending on the seasons.

Scenario	Maximum hot water demand per apartment per day (L)	Annual building hot water demand (kL)
Average occupancy	60.8	161
High occupancy	101.7	269

Table 16: Maximum daily hot water demand for Brahe Place building (8 apartments)

In the TRNSYS model these daily maximum hot water demand per apartment data were used along with seasonal hot water load profile and hourly load profile to get hourly hot water demand. The detailed methodology for calculating hourly hot water demand in any given hour is described earlier in section 3.2. The same cold water temperature profile in each month used for the La Banque building described in section 3.3 was also used for the Brahe place building, since both buildings are located in Melbourne.

4.3 Centralised gas-boosted water heating system

4.3.1 System components, layout and operation

The first of the three potential hot water systems considered for modeling in TRNSYS for Brahe Place is a centralised gas-boosted ring-main hot water system to meet all the hot water demand for the 8 apartments of the building. The overall system consists of two loops: a heating cycle loop and water draw off loop, as in the gas heating system for the La Banque building. The main water heating source is two instantaneous Rheem Multipak (MPE02K) gas heater units (Figure 20), and they are connected to 2×410 L storage tanks. The average efficiency of the Rheem Muiltipak series heaters is 80%.

Figure 20: Typical Rheem Multipak setup (Rheem 2007)

Water is heated up to the specified 70°C through the heaters and transferred to the storage tanks via Lowara hot water heater cycle pumps (4HMS3 with 0.51 kW input power, flow rate 4.0 m^3/h, 1 operates for both tanks). A thermostat controls the startup of the pump and heaters when the water temperature at the bottom of the tank falls below 50°C (as in the La Banque system).

The tanks are connected to a ring-main throughout the building, through which water is circulated through pipes (32 mm dia, 25 m long and 25 mm dia, 50 m long) and return pipes (25 mm dia, 25 m long) constantly (24 hours a day, 7 days a week), using a Grundfos hot water flow and return pump (UPS 25-60 130) with 100 W input power, flow rate 0.2 m^3/h. Two identical pumps are alternately in use). When hot water is drawn off by residents, cold water is mixed with the hot water being circulated through the ring-main with tempering valves to yield a delivery temperature of 50°C. A top-up cold water line is connected to the hot water return pipe just entering the storage tank. Table 17 lists of all the components and their detailed specifications in the overall gas-boosted ring-main water heating system. These specification values were input to the TRNSYS model.

Sl. No.	System component	Specifications
1	Storage tank	Rheem (610 430), volume 410 L, height 1.64 m, 2 units
2	Cycle pump	Lowara (4HMS3), input power 0.51 kW, flow rate 4.0 m^3/h, 1 unit
3	Gas heater	Rheem Multipak (MPE02K), gas input 410 MJ/h, efficiency 80%, 2 units
4	Hot water flow pipe	Copper pipe, 50 m long – 25 mm dia. (22.2 mm inner dia.), 25 m long – 32 mm dia. (28.6 mm inner dia.) (Standard Australia 2004)
5	Hot water return pipe	Copper pipe, 25 m long – 25 mm dia. (22.2 mm inner dia.)
6	Pipe Insulation	Armaflex insulation, thickness 25 mm, loss coefficient 9.3 kJ/hm^2K for 32 mm pipe, and 10.7 kJ/hm^2K for 25 mm pipe (based on inner surface area of the pipe)
7	Flow/return pump	Grundfos (UPS 25-60 130), input power 0.1 kW, flow rate 0.2 m^3/h, 1 unit operating

Table 17: Gas heating system components for Brahe Place building

Overall pipe heat loss coefficient (kJ/hm^2K) in the above Table 17 is calculated using Thermotec the heat loss values (Table 18), where the heat loss per meter (kJ/h/m) is detailed for a similar insulation type to Armaflex foil covered insulation. The detailed methodology for calculating overall pipe heat loss coefficient is described earlier in section 3.4.1.

WATER TEMP °C		55				60				65			
AMBIENT TEMP °C		10	12	15	20	10	12	15	20	10	12	15	20
PIPE O.D. (mm)	INSULATION THICKNESS												
13	Nil	99.7	93.2	87.5	75.2	114.5	109.4	102.2	89.6	129.2	124.2	116.6	104.1
	15	27.7	26.6	24.8	21.9	31.3	31.0	30.2	25.2	34.9	33.8	31.7	28.4
	20	23.8	23.1	21.6	19.4	28.1	27.0	25.5	22.7	32.4	31.0	29.1	25.9
	25	22.0	21.2	20.5	19.1	25.9	25.2	23.8	21.2	29.9	27.7	24.5	23.1
	30	20.5	20.2	19.4	18.4	24.1	23.4	22.0	19.8	27.7	25.6	22.3	20.5
15	Nil	113.4	108.0	99.4	85.7	130.3	122.8	112.3	101.9	147.2	141.5	132.5	118.1
	15	30.6	28.4	25.2	23.1	34.6	33.5	31.0	27.7	38.5	37.8	36.7	35.3
	20	24.1	23.8	23.1	22.0	30.6	29.2	27.0	24.1	36.7	34.9	31.7	27.4
	25	23.8	23.1	22.3	21.2	28.1	26.6	25.6	22.3	34.6	30.6	25.2	24.1
	30	20.9	20.2	19.8	18.7	25.9	25.2	23.4	20.9	31.0	28.1	23.8	21.6
20	Nil	142.9	136.1	125.6	108.4	164.2	156.2	144.7	128.9	185.4	178.2	167.4	149.4
	15	33.1	33.8	31.7	27.7	40.1	38.5	36.0	32.0	44.6	42.8	40.3	36.4
	20	29.9	28.8	27.3	24.5	35.2	33.8	31.7	28.1	40.7	38.9	36.6	31.7
	25	28.4	27.7	26.3	23.4	32.4	31.0	29.2	25.9	36.4	34.2	31.3	27.0
	30	25.9	25.2	24.5	22.3	29.5	28.4	26.6	23.8	33.1	31.3	28.6	24.6
25	Nil	172.4	164.1	151.9	131.0	198.0	189.7	177.1	155.9	223.6	214.9	202.3	180.7
	15	40.0	39.2	38.2	36.0	45.4	43.6	41.0	36.4	50.8	47.9	43.9	36.7
	20	35.6	33.8	31.3	27.0	40.0	38.5	36.4	32.0	44.6	42.8	40.3	36.0
	25	33.1	32.4	28.8	24.5	36.7	35.2	32.8	29.5	38.2	37.8	37.4	35.3
	30	27.5	28.1	24.1	22.7	33.1	31.7	29.9	26.6	35.3	34.6	33.8	32.4
32	Nil	212.4	202.3	187.2	161.6	244.1	223.6	218.2	192.2	275.8	265.3	249.4	222.8
	15	47.2	45.0	41.8	36.4	53.3	51.1	47.9	42.5	59.4	55.8	50.8	48.6
	20	41.0	40.0	38.5	35.6	46.4	45.0	42.8	38.9	51.8	50.1	47.5	42.1
	25	37.1	36.0	34.6	32.0	42.1	40.7	38.5	35.0	47.9	45.0	41.8	37.8
	30	33.8	33.1	32.0	28.1	38.2	36.7	34.6	30.6	42.5	40.7	37.8	33.1

Table 18: Thermotec heat loss table 4-Zero/Quickseal/sealed tube in kJ/h/m (Thermotec 2007)

4.3.2 TRNSYS model of centralised-gas water heating system

The same TRNSYS model developed for the La Banque building gas heating system was also used for Brahe Place system to calculate total gas consumption by heaters, electricity use by heaters and pumps, and thermal losses from the piping and tanks, since the operation of both heating systems is identical. The necessary input data for all the components in the model are taken from Table 17 in section 4.3.1. Water draw-off profiles for the different occupancy levels and the cold water temperature profile as in section 4.2 were input into the model, and remained the same in all scenarios investigated for this building.

4.3.3 TRNSYS simulation of annual operation and results

The TRNSYS model simulations for the Brahe Place building centralised-gas heating system was run for two occupancy levels: average and high. The model was set up for yearly simulation on an hour by hour basis and each simulation time step was 0.001 h (3.6 sec). Daily (for January) and yearly hot water demand profiles for the low occupancy level for eight apartments at Brahe Place building are shown in Figure 21 and Figure 22 respectively. All other graphs of results obtained from this simulation are shown in the Appendix B. It was found that the model always delivered the desired tempered hot water temperature at 50°C (Figure B-1 in Appendix B) for both average and high occupancy.

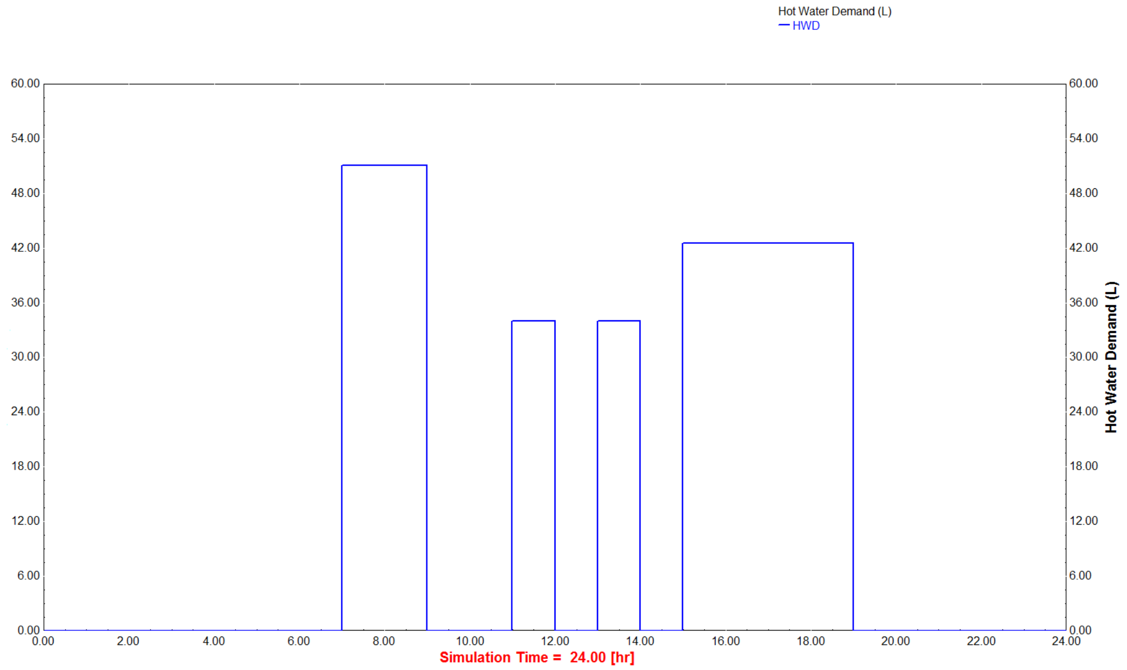

Figure 21: TRNSYS-generated daily (for January) hot water demand profile for eight apartments in Brahe Place building (average occupancy level)

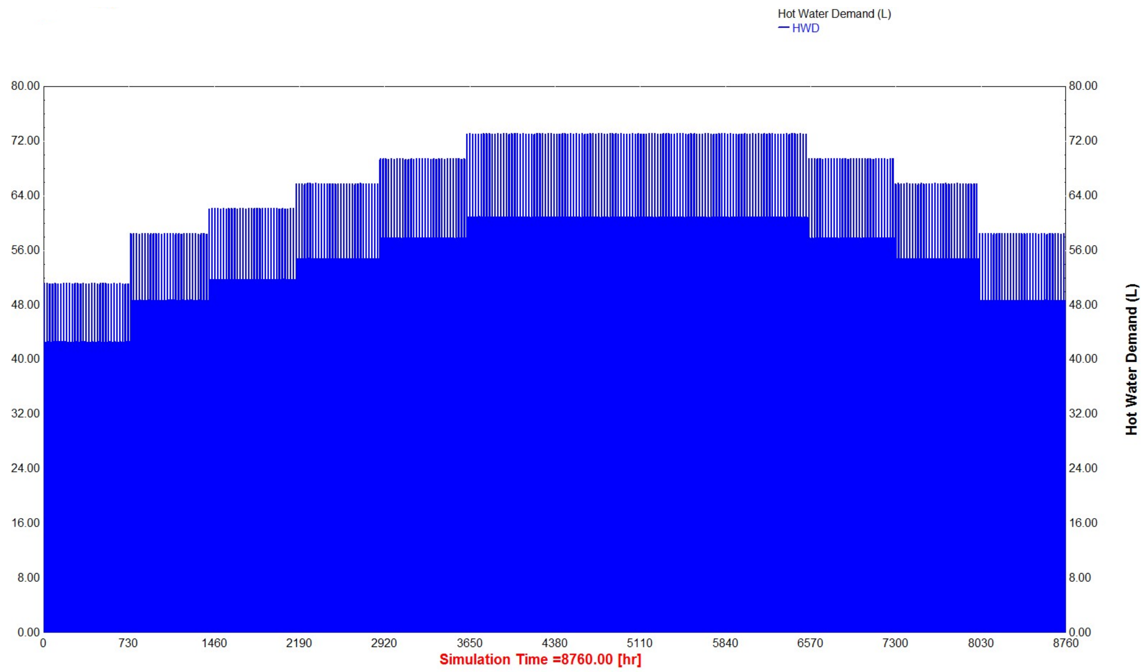

Figure 22: Annual hot water demand profile for eight apartments in the Brahe Place building (average occupancy level)

Results obtained from the simulation of the centralised-gas ring-main water heating system for average and high occupancy levels in the Brahe Place building are presented in Table 19.

Occupancy	Annual hot water demand (kL)	Annual gas consumption (GJ)	Piping annual heat loss (GJ)	Storage tank annual heat loss (GJ)	Cycle pump annual electricity consumption (kWh)	Flow/return pump annual electricity consumption (kWh)	Cycle and flow/return pump combined annual electricity consumption (kWh)
Average	161	92.7	30.3	9.4	104	876	980
High	269	113.0	30.4	9.4	112	876	988

Table 19: TRNSYS simulation results for the gas ring-main water heating system in the Brahe Place building.

From the above results table it can be seen that the annual hot water demand at average and high occupancy were 161 kL and 269 kL respectively, which matches the values in Table 15 (section 4.2) obtained by Lockrey (2012). The annual total gas consumption was 92.7 GJ and 113 GJ for the average and high occupancy levels respectively. This total gas energy consumption includes piping and storage tank heat losses, which account for 39.7 GJ (30.3+9.4) and 39.8 GJ (30.4+9.4) of gas consumption in the average and high occupancy situations respectively. Hence around 43% and 35% of the heating energy was lost from the pipe works and storage tanks for the average and high occupancy levels respectively. The flow and return pumps run continuously throughout the year, consuming annually 876 kWh of electricity for both cases. But the heating cycle pump consumed 104 kWh and 112 kWh at average and high occupancy respectively.

Occupancy	Cycle pump annual electricity consumption (kWh)	Cycle pump rated power consumption (kW)	Heating mode annual operation of cycle pump and gas heater (hrs)	No. of Rheem gas heater units	Yearly total heating operation hours (hrs)	Yearly total standby operation hours (hrs)	Annual total electricity consumption by heaters in heating and standby mode (kWh)
Average	104	0.51	205	2	409	17,111	172
High	112	0.51	220	2	441	17,079	174

Table 20: Gas heating system heating and standby mode electricity consumption for the Brahe Place building

It is assumed that, like the Bosch 32 series gas heater, the Rheem Multipak (MPE02K) series gas heater unit also runs a fan and electronics when heating at 85 W per unit, and standby electricity consumption is 8 W per unit. The standby and heating mode operation electricity consumption by the two Rheem Multipak (MPE02K) series heater units is estimated as 172 kWh and 174 kWh for the average and high occupancy cases respectively (Table 20).

Occupancy	Annual total water heating gas consumption including losses (GJ)	Hot water system annual total electricity consumption by all pumps and heaters (kWh)	Annual gas consumption per apartment (GJ)	Hot water system annual total electricity consumption per apartment (kWh)
Average	92.7	1,152	11.6	144
High	113	1,162	14.1	145

Table 21: Brahe Place building ring-main gas heating system annual total energy inputs

Table 21 shows annual total gas and electrical energy required by the gas-boosted ring-main water heating system in the eight apartments as well the average consumption per apartment in Brahe Place building. For average and high occupancy levels the average apartment's annual water heating energy consumption was 11.6 GJ gas and 144 kWh electricity, and 14.1 GJ gas and 145 kWh electricity respectively. So, in case of the centralised gas heating system for medium density apartment complex, average apartment's annual water heating energy consumption is higher than the high density high rise apartment complex. For example, in case of La Banque building for low occupancy level (where the water hot water demand was the same as for average occupancy demand in the Brahe Place building) the average apartment's annual water heating energy consumption was 7.3 GJ gas and 17 kWh electricity (Table 10).

4.4 Solar-boosted centralised gas water heating system

4.4.1 System components, layout and operation

The second of the three potential hot water systems considered for modeling in TRNSYS for Brahe Place is a centralised solar-boosted gas ring-main hot water system to meet the hot water demand of the building. In this case, the overall system consists of three loops: a solar preheating loop, heating cycle loop, and water draw off loop. The main water heating source is two instantaneous Rheem Multipak (MPE02K) gas heater units and they are connected to 2×410 L storage tanks. There are four Rheem solar collectors (NPT200) on a frame, with a solar controller (052104) and a pump (Grundfos UPS 25-60 130 with 100 W input power, flow rate 0.2 m^3/h) connected to the storage tanks in a separate loop. The solar controller will turn on the solar pump and draw water from bottom of the tanks and will pass through the collectors to preheat the water, if the output temperature of the collectors is above 50°C. This will supplement the gas required by the gas heater to meet the hot water demand of the building. Then water is heated up to the specified 70°C through the heaters and transferred to the storage tanks via Lowara hot water heater cycle pumps (4HMS3 with 0.51 kW input power, flow rate 4.0 m^3/h, 1 operates for both tanks).

It needs to be noted here that we have not investigated whether the solar system is optimised in terms of collector area and solar fraction within the present study; we have simply assumed the specifications of the solar system for this building provided by the building designers, Wood and Grieve. However, in the TRNSYS model the collectors are assumed to be installed facing North, tilted at the Melbourne latitude angle (38°) to receive optimum solar radiation for the year round application.

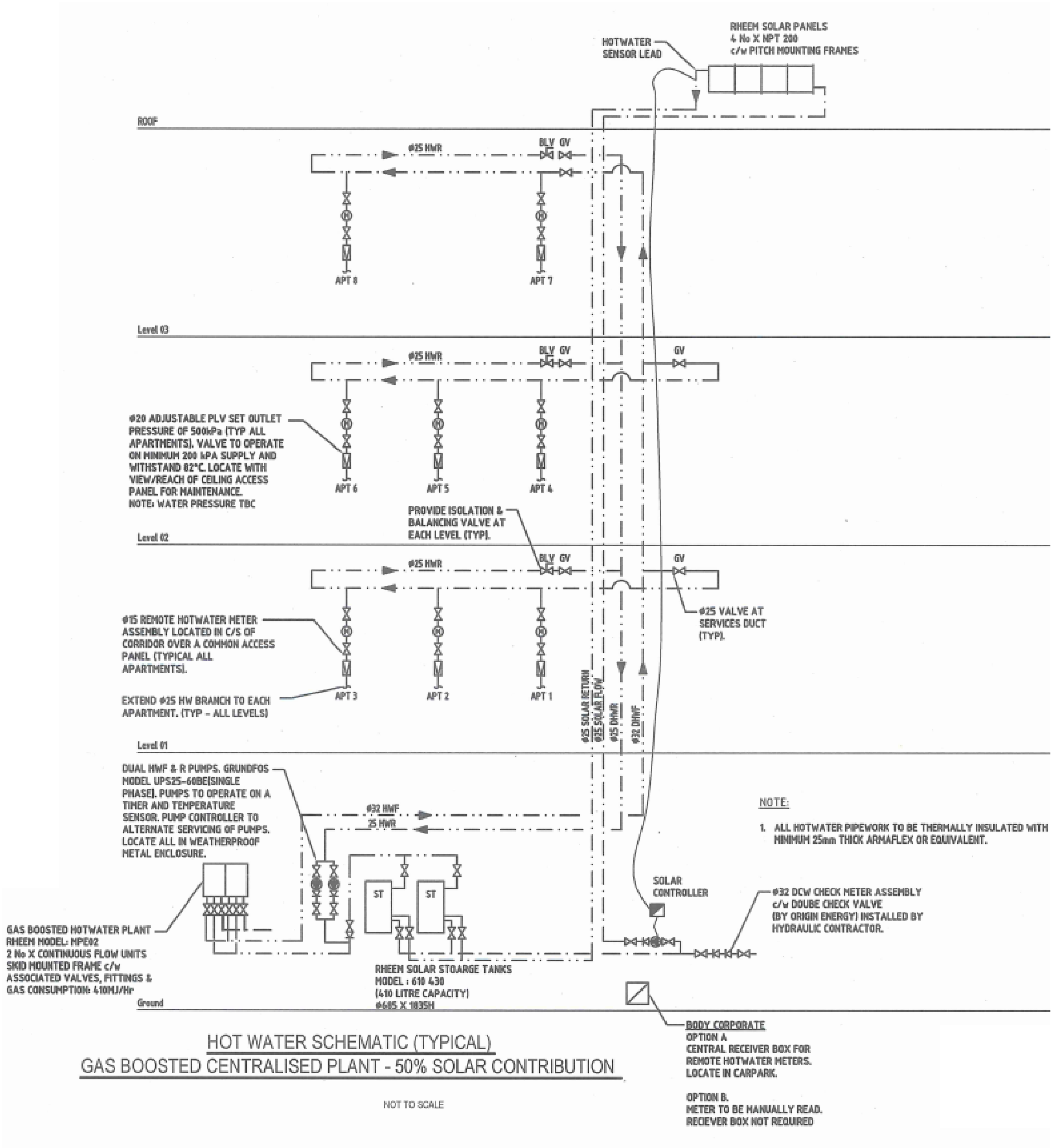

Figure 23: Brahe Place building solar-gas hot water flow and return schematic (Wood and Grieve Engineers 2011b)

In the water draw-off loop (demand side) the tanks are connected to the main hot water flow pipes (32 mm and 25 mm dia.) and return pipes (25 mm dia.) throughout all the floors of the building. Water is circulated through this ring main constantly (24 hours a day, 7 days a week), using a Grundfos hot water flow and return pump (UPS 25-60 130 with 100 W input power, flow rate 0.2 m^3/h, and two identical pumps alternately in use periodically). The hot water flow and return pipes are interconnected at each level to minimise the pressure drop when there is draw off (Figure 23). When hot water is drawn off by residents, cold water is mixed with the hot water within each apartment to yield a delivery temperature of 50°C. Table 22 lists of all the components and their detailed specifications in the overall solar-boosted gas ring-main water heating system. These specification values were input to the TRNSYS model.

Sl. No.	System component	Specifications
1	Storage tank	Rheem (610 430), volume 410 L, height 1.64 m, 2 units
2	Cycle pump	Lowara (4HMS3), input power 0.51 kW, flow rate 4.0 m^3/h, 1 unit
3	Gas heater	Rheem Multipak (MPE02K), gas input 410 MJ/h, efficiency 80%, 2 units
4	Hot water flow pipe	Copper pipe, 50 m long – 25 mm dia. (22.2 mm inner dia.), 25 m long – 32 mm dia. (28.6 mm inner dia.) (Standard Australia 2004)
5	Hot water return pipe	Copper pipe, 25 m long – 25 mm dia. (22.2 mm inner dia.)
6	Pipe Insulation	Armaflex insulation, thickness 25 mm, loss coefficient 9.3 kJ/hm^2K for 32 mm pipe, and 10.7 kJ/hm^2K for 25 mm pipe (based on inner surface area of the pipe)
7	Flow/return pump	Grundfos (UPS 25-60 130), input power 0.1 kW, flow rate 0.2 m^3/h, 1 unit operating
8	Solar collector	Rheem (NPT200), aperture area 1.86 m^2, black polyester absorber (0.92 absorptance coefficient), 4 units
9.	Solar pump	Grundfos (UPS 25-60 130), input power 0.1 kW, flow rate 0.2 m^3/h, 1 unit

Table 22: Solar-boosted gas heating system components for Brahe Place building

4.4.2 TRNSYS model of centralised solar-gas system

For modeling the solar-boosted centralised gas water heating system for Brahe Place in TRNSYS, a solar heating loop is added to the existing model which was used for the gas heating system in section 4.3.2. This model is more complicated than the gas-only heating system model. The necessary input data for all the components in the model are taken from Table 22 in section 4.4.1. Water draw-off profiles for the different occupancy levels and the cold water temperature profile remained the same as for the gas heating system.

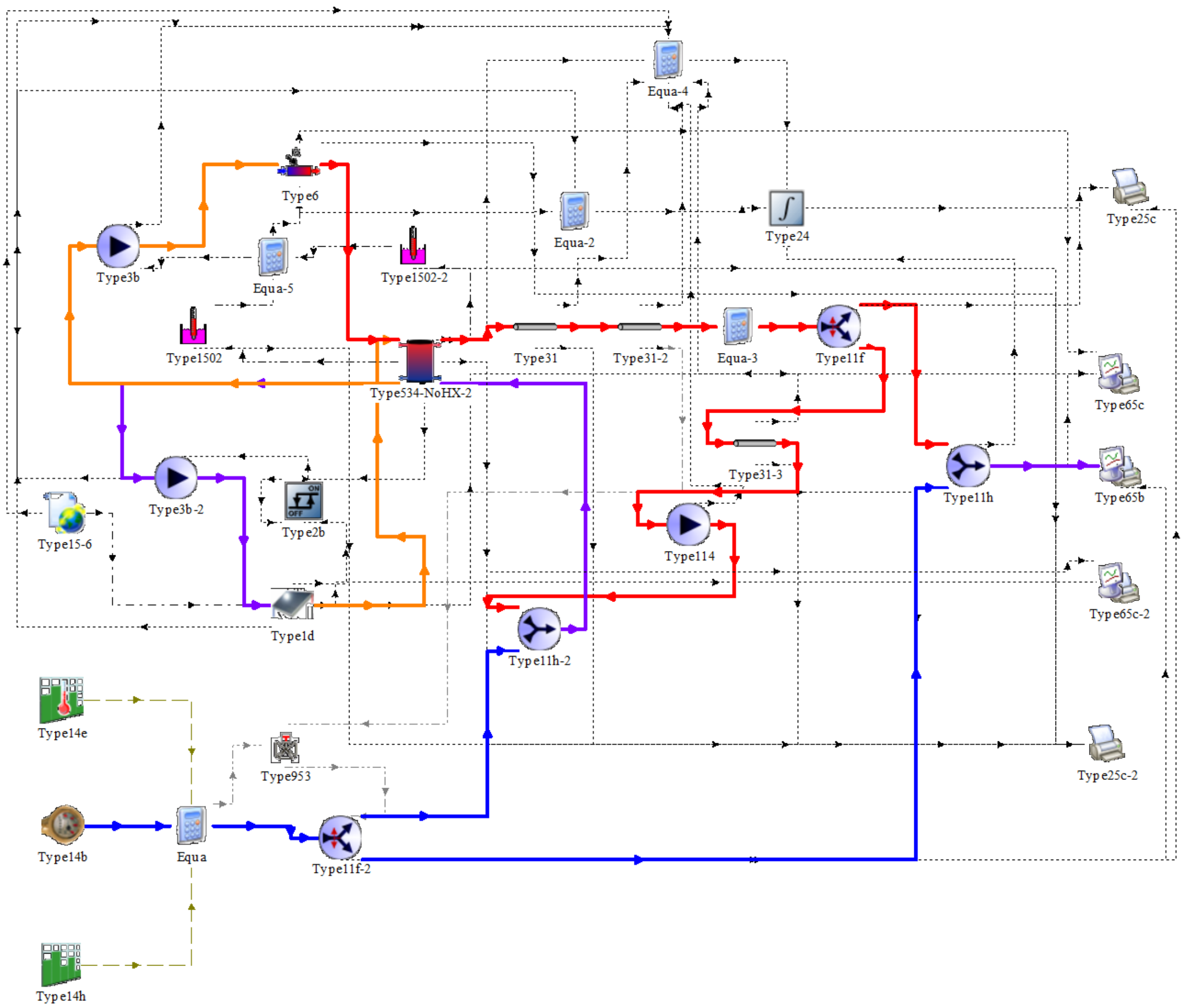

Figure 24: TRNSYS model of the solar-boosted centralised gas water heating system in the Brahe Place building

In Figure 24, thick lines represent the main water circulation loops for gas and solar heating, and the water draw off/return. Blue lines signify cold water, red lines high-temperature hot water (that is, around 70°C), orange lines moderately high temperature (that is, around 60°C) and purple lines low temperature (that is, around 50°C) hot water. At the beginning of the simulation, the model read the daily hot water demand profile (Type14b), seasonal load profile (Type14h) and cold water temperature profile (Type14e), and then all this information is used to compute the hourly hot water demand during each day for all the apartments. The tempering valve controller (Type953) sends a signal to the diverting valve (Type11f-2) to split the cold water in the right fractions: that is, how much water is sent to the storage tank for heating, and how much is mixed with the hot water to get the desired 50°C set temperature at the draw-off in the apartments. This decision is made based on the incoming cold water temperature and outlet hot water temperature after passing through the hot water flow pipes (Type 31-2) before mixing with cold water.

The storage tank (Type534-NoHX-2) is considered as a stratified tank with 10 nodes, i.e. the height of the tank is divided into 10 equal segments, and with three inlet and three outlet ports. Firstly, in the solar preheating loop the model read the Melbourne weather data file (Type15-6) and input to the solar collector (Type1d). After that the differential controller (Type2b) which acts as a solar controller reads outlet temperature of the solar collectors and the temperature of the bottom of the storage tank (node 10), and decides when to turn on the solar pump (Type3b-2). The differential controller is set to 10°C upper dead band and 2°C lower dead band, so that the solar pump turned on when the outlet temperature of solar collectors is 10°C above the bottom of the tank, and turned off when the outlet temperature of solar collectors is 2°C above the bottom of the tank. The solar pump draws off the water from bottom of the tank (node 10) and delivers it back at the middle of the tank (node 5) after heating up in the solar collectors.

In the heating cycle loop there are two temperature controllers (Type1052 and Type1052-2) to monitor temperature of the middle (node 5) and top (node 1) of the storage tank, and decides when to turn on the pump (Type3b) and heaters (Type6) through an equation box (Equa-5) logic. The temperature controller for middle node is set to 60°C with a dead band of 4°C, and for top node is set to 67°C with a dead band of 4°C (TRNSYS17 2012). The equation box logics are set in such a way that the cycle pumps and heaters turned on when the temperature either middle or top of the tank falls below 58°C or 65°C respectively, and turned off when the temperature either middle or top of the tank is above 62°C or 69°C respectively. The heating cycle pump draws off the water from middle of the tank (node 5) and delivers it back at the top of the tank (node 1) after heating up in the heaters to 70°C.

In the hot water flow and return loop for the hot water demand side, hot water is drawn off from top of the storage tank (node 1) by a hot water flow and return pump (Type114) and then passes through the equivalent length of hot water flow pipes (Type31 and Type 31-2) (main hot water flow pipe and adding all other hot water flow pipes in all levels of the building). The hot water is then split into the right fractions in a diverting valve (Type11f) by an equation box. One fraction of the hot water flow is sent to the Tee-piece (Type11h) to mix up with the cold water at the apartments, and other refraction is return back to bottom of the storage tank (node 10) after passing through the equivalent length of the return flow pipe (Type 31-3). The returned flow is also mixed with the cold water flow through another Tee-piece (Type11h-2) before entering the storage tank which was diverted at the beginning to be heated up. Online plotters (Type65b and Type65c) plot all the necessary graphs during the simulation; integrator (Type24) integrates all the output results, and output printer (Type25c) stores all the results in an output txt file.

4.4.3 TRNSYS simulation of annual operation and results

The TRNSYS model simulation for the Brahe Place building solar-boosted gas heating system was run for the same two occupancy levels as for the gas system on an hourly basis over a year using a simulation time step of 0.001 hr (3.66 sec). All graphs of results obtained from this simulation are shown in the Appendix C. In this case also for all occupancy levels, the model always delivered the desired tempered hot water temperature of 50°C (Figure C-2 in Appendix C).

Table 23 shows results obtained from the simulation of the Brahe Place building centralised solar-gas ring-main water heating system for average and high occupancy levels. From this Table it can be seen that the annual total gas consumption was 74.6 GJ and 93.9 GJ for the average and high occupancy levels respectively. The annual total heat energy supplied by the solar collectors is 14.8 GJ and 15.5 GJ, which was 20% and 17% of the overall heat energy requirement to meet the hot water demand for Brahe Place building for the average and high occupancy situations respectively. For this solar-boosting option collector area optimisation has not been done as it was not in the scope of this current project. The average solar radiation values on the collector surface tilted at the angle of 38° (Melbourne latitude) and facing north found from the simulation was 16.6 MJ/m^2/day. This value is consistent with daily average solar radiation data on an inclined surface in Melbourne, which is 17.1 MJ/m^2/day (BOM 2008).

Occupancy	Annual hot water demand (kL)	Annual gas consumption (GJ)	Annual energy supplied by solar collectors (GJ)	Piping annual heat loss (GJ)	Storage tank annual heat loss (GJ)	Cycle pump annual electricity consumption (kWh)	Flow/return pump annual electricity consumption (kWh)	Solar pump annual electricity consumption (kWh)	Cycle, flow/return and solar pump combined annual electricity consumption (kWh)	Average solar radiation on collector surface tilted at the angle of Melbourne latitude and facing North ($MJ/m^2/day$)
Average	161	74.6	14.8	30.5	9.5	102	876	107	1,085	16.6
High	269	93.9	15.5	30.6	9.3	125	876	111	1,112	16.6

Table 23: TRNSYS simulation results for the solar-gas ring-main water heating system in the Brahe Place building.

The total gas energy consumption includes piping and storage tank heat losses, which account for 40 GJ (30.5+9.5) and 39.9 GJ (30.6+9.3) of gas consumption in the average and high occupancy situations respectively. So, around 45% and 36% of the heating energy was lost from the pipe works and storage tanks for the average and high occupancy levels respectively.

The flow and return pumps run continuously throughout the year consuming annually 876 kWh of electricity for both cases. But the solar pump and heating cycle pump consume 107 kWh and 102 kWh for average scenario, and high scenario 111 kWh and 125 kWh respectively. From this result it is observed that the addition of a solar preheating system contributes to an increase in the total electricity consumption for pumping. In the centralised gas heating system, total pumping energy consumptions were 980 kWh and 988 kWh for the average and high occupancy levels respectively (Table 19). Now for the present solar-boosted centralised-gas heating system total pumping energy consumptions are 1,085 kWh and 1,112 kWh for the average and high occupancy levels respectively, which is around a 11% and 12.5% increment for the average and high occupancy scenarios.

The standby and heating mode operation electricity consumption by the two Rheem Multipak (MPE02K) series heater units is estimated as 171 kWh and 178 kWh for the average and high occupancy cases respectively (Table 24).

Occupancy	Cycle pump annual electricity consumption (kWh)	Cycle pump rated power consumption (kW)	Heating mode annual operation of cycle pump and gas heater (hrs)	No. of Rheem gas heater units	Yearly total heating operation hours (hrs)	Yearly total standby operation hours (hrs)	Annual total electricity consumption by heaters in heating and standby mode (kWh)
Average	102	0.51	199	2	398	17,122	171
High	125	0.51	245	2	489	17,031	178

Table 24: Solar-gas heating system heating and standby mode electricity consumption for Brahe Place building

Table 25 shows the annual total gas and electrical energy required by the solar-boosted gas ring-main water heating system in the eight apartments as well the average consumption per apartment in Brahe Place building.

Occupancy	Annual total water heating gas consumption including losses (GJ)	Hot water system annual total electricity consumption by all pumps and heaters (kWh)	Annual gas consumption per apartment (GJ)	Hot water system annual total electricity consumption per apartment (kWh)
Average	74.6	1,256	9.3	157
High	93.9	1,289	11.7	161

Table 25: Brahe Place building solar-boosted ring-main gas heating system annual total energy inputs

For average and high occupancy levels the average apartment's annual water heating energy consumptions were 9.3 GJ gas and 157 kWh electricity, and 11.7 GJ gas and 161 kWh electricity respectively. From this result it is observed that the addition of a solar preheating system contributes to a decrease in the total gas energy consumption in the overall water heating system but increased the electricity consumption for pumping the water. In the centralised gas heating system, the average apartment's annual water heating energy consumption was 11.6 GJ gas and 144 kWh electricity, and 14.1 GJ gas and 145 kWh electricity for the average and high occupancy levels respectively (Table 21). So, for the present solar-boosted centralised-gas heating system the annual gas consumption is around 20% and 17% less for the average and high occupancy scenarios but contributes to a 11% and 12.5% increment in the pumping energy consumptions for the average and high occupancy scenarios respectively as discussed earlier.

4.5 Continuous-flow MicroHeat electric water heaters in each apartment

4.5.1 System components, layout and operation

The third alternative water heating option for the Brahe Place building investigated using TRNSYS modelling is a point-of-use electric hot water system in each apartment. It has been assumed that eight MicroHeat Series 2 three-phase CFEWH units are installed at the entry of each apartment, and set to deliver hot water at 50°C (similar to the La Banque building). Detailed information of this unit was given earlier in section 3.5.1.

4.5.2 TRNSYS model of MicroHeat CFEWH system

The same TRNSYS model of the CFEWH system developed for the La Banque building is also used for Brahe Place system, simply by changing the number of apartments served by the separate electric water heaters as specified in the equation box (Figure 18) linked to the input temperature profile (Type14e), daily hot water demand profile (Type14b), and the profile of the seasonal variation of this demand (Type14h). The capacity of a single heater (27 kW) is also multiplied by the number of apartments within the Type 6 heater specifications in the TRNSYS model.

4.5.3 TRNSYS simulation of annual operation and results

The TRNSYS model simulation for the Brahe Place building CFEWH system was run for the same two occupancy levels as for the gas system on an hourly basis over a year using a simulation time step of 0.001 hr (3.6 sec).

Occupancy	Annual hot water demand (kL)	Annual electricity consumption (MWh)
Average	161	6.9
High	269	11.5

Table 26: TRNSYS simulation results for CFEWH system for Brahe Place building

All the result's graphs obtained from this simulation are shown in the Appendix D. Results obtained from this simulation are presented in Table 26. It can be seen that annual electricity consumption for water heating was 6.9 MWh and 11.5 MWh for the average and high occupancy cases respectively (Table 26).

Heating mode (hrs/day)	Standby mode (hrs/day)	No. of CFEWH units	Yearly total standby operation (hrs)	CFEWH standby power consumption (W)	Yearly total standby electrical energy consumption (kWh)
8	16	8	46,720	1.3	61

Table 27: CFEWH system standby mode total electricity consumption for Brahe Place building

It is found that annual total electricity consumption by CFEWH units in standby mode is 61 kWh. This value is the same for both occupancy levels (Table 27).

Occupancy	Annual water heating electricity consumption (MWh)	Annual standby electricity consumption by heater units (kWh)	Building hot water system total annual electricity consumption (MWh)	Hot water system annual total electricity consumption per apartment (kWh)
Average	6.9	61	6.9	864
High	11.5	61	11.5	1,440

Table 28: Brahe Place building CFEWH system annual total energy inputs

Table 28 shows the annual total electrical energy required by the CFEWH heating system in all eight apartments as well as in an individual apartment in the Brahe Place building. For average and high occupancy scenarios, the total building annual water heating electricity consumption was 6.9 MWh and 11.5 MWh respectively. For each individual apartment the annual water heating electricity consumption was 864 kWh and 1,440 kWh for average and high occupancy level respectively.

4.6 Comparison of water heating system options

Table 29 compares all the results found for both the centralised Rheem gas main-ring water heating system and the point-of-use MicroHeat CFEWH system for the two occupancy levels in the Brahe Place building. As with the La Banque building analysis, energy usage is given solely in terms of secondary energy, that is, the energy content of the natural gas consumed, and the energy content of the delivered electricity, rather than converting to full primary energy inputs.

From this table it can be seen that at both occupancy levels the centralised gas water heating system used more secondary energy (in the form of gas plus some electricity for pumping) than the solar-gas ring-main (in the form of gas plus some electricity for pumping) and the point-of-use CFEWH system (all in the form of electricity). For example, for average occupancy, the centralised gas heating system annually consumed 92.7 (25,750 kWh) gas and 1,152 kWh of electricity, that is, a total equivalent secondary energy of 26,902 kWh; centralised solar-gas heating system annually consumed 74.6 (20,722 kWh) gas and 1,256 kWh of electricity, that is, a total equivalent secondary energy of 21,978 kWh; whereas the CFEWH system potentially consumed 6,913 kWh of delivered electricity.

	Type of hot water systems for Brahe Place building					
	Rheem gas ring-main		**Rheem solar gas ring-main**		**MicroHeat CFEWH**	
Hot water use profile	Average	High	Average	High	Average	High
Water use (kL/y)	161	269	161	269	161	269
Gas use (GJ/y)	92.7 (25,750 kWh)	113.0 (31,389 kWh)	74.6 (20,722 kWh)	93.9 (26,083 kWh)	0	0
Eletricity use (kWh/y)	1,152	1,162	1,256	1,289	6,913	11,523
Total energy use (kWh equivalent/y)	26,902	32,551	21,978	27,372	6,913	11,523

Table 29: Brahe Place building total annual water and secondary energy use for the different water heating options and occupancy levels

5 CONCLUSIONS

In this report, we have presented the results of the energy modelling of the CFEWH system in two types of multistorey residential building in Melbourne using the TRNSYS energy system simulation software package.

The two buildings used as case studies of potential applications of the MicroHeat CFEWH units, and the competing water heating systems examined, were the following;

- An existing high-density apartment complex, La Banque building, located in the Melbourne CBD at 380 Little Lonsdale Street and consisting of 257 apartments on 35 levels. Here two alternatives were investigated at three different occupancy levels:
  - Hot water via a centralised gas-boosted plant (as currently installed)
  - Hot water via individual continuous flow electric hot water heaters (CFEWH) in each apartment

- A proposed medium-density apartment complex, the Brahe Place building located in East Melbourne at 18 Brahe Place, and consisting of eight apartments on three levels. Here three alternative water heating systems were investigated at two occupancy levels:
  - A centralised gas-boosted plant
  - A solar-boosted centralised gas plant
  - Individual MicroHeat continuous flow electric hot water heaters (CFEWH) in each apartment.

For all the cases and for each run of the simulation the models delivered the desired output hot water temperature at 50°C. A significant water temperature difference of around 15°C was found between the top and bottom of the storage tank in the case of the centralised gas water heating system and the solar-boosted gas heating system, indicating that effective stratification was occurring in the storage tank.

Hot water demand in the low, average and high occupancy scenarios for the LaBanque building were 5,159 kL, 6,847 kL and 10,699 kL respectively. For Brahe Place building the hot water demand was 161 kL and 269 kL respectively for the two occupancy levels considered. These values matches those used in the LCA study component of the present project (Lockrey 2012).

In the case of the centralised gas heating system for the La Banque building, it was found that the annual total gas and electricity consumption was 1,876.1 GJ gas and 4,481 kWh electricity; 2,198.1 GJ gas and 4,699 kWh electricity; and 2,931.9 GJ gas and 5,312 kWh electricity for the low, average and high occupancy scenarios respectively. The average apartment's annual water heating energy consumption was 7.3 GJ gas and 17 kWh electricity; 8.6 GJ gas and 18 kWh electricity; and 11.4 GJ gas; and 21 kWh electricity for low, average and high occupancy levels respectively. Around 712.3 GJ (38%), 716.2 GJ (33%) and 723 GJ (25%) of the heating energy was lost from the pipe works and storage tanks for the low, average and high occupancy levels respectively.

The electrical energy required by the CFEWH heating systems in all 257 apartments in the La Banque building for low, average and high occupancy scenarios was 220.1 MWh, 292.2 MWh and 456.6 MWh respectively. For individual apartment annual water heating electricity consumption was 864 kWh, 1,145 kWh and 1,784 kWh for low, average and high occupancy level respectively.

The total annual secondary energy use by each of the water heating system options for the three occupancy scenarios has also been calculated. It should be noted here that gas and electrical energy have simply been added on a direct energy content basis without considering the primary energy inputs to deliver to the consumer this secondary energy. The latter and the associate overall greenhouse gas impacts are analysed separately in the complementary report by the RMIT Centre for Design within this overall study. In all three occupancy scenarios the centralised gas water heating system for the La Banque building used more secondary energy (in the form of gas plus some electricity for pumping) than the point-of-use CFEWH system (all in the form of electricity). For example, for low occupancy level, centralised gas heating system annually consumed 1,876.1 GJ (521,139 kWh) gas and 4,481 kWh of electricity, that is, a total equivalent secondary energy of 525,620 kWh; whereas the CFEWH system potentially consumed 222,087 kWh of delivered electricity.

The annual total gas and electricity consumption for the Brahe Place building for the centralised gas heating system was 92.7 GJ gas and 1,152 kWh electricity; and 113 GJ gas and 1,162 kWh electricity for the average and high occupancy levels respectively. The average apartment's annual water heating energy consumption was 11.6 GJ gas and 144 kWh electricity, and 14.1 GJ gas and 145 kWh electricity respectively. Around 39.7 GJ (43%) and 39.8 GJ (35%) of the heating energy was lost from the pipe works and storage tanks for the average and high occupancy levels respectively.

It is observed that in the case of the centralised gas heating system for this medium-density apartment complex, the average apartment's annual water heating energy consumption is estimated to be higher than that for the high-density high-rise apartment complex.

For the solar-boosted centralised gas heating option for Brahe Place building, the annual total gas consumption was 74.6 GJ and 93.9 GJ for the average and high occupancy levels respectively. The solar contributions to the total water heating energy requirements were 14.8 GJ (20%) and 15.5 GJ (17%) for the average and high occupancy situations respectively. It needs to be noted here that we have not investigated whether the solar system is optimised in terms of collector area and solar fraction within the present study; we have simply assumed the specifications of the solar system for this building provided by the building designers, Wood and Grieve. For average and high occupancy levels the average apartment's annual water heating energy consumption was 9.3 GJ gas and 157 kWh electricity, and 11.7 GJ gas and 161 kWh electricity respectively. In this case around 40 GJ (45%) and 39.9 GJ (36%) of the heating energy was lost from the pipe works and storage tanks for the average and high occupancy levels respectively.

It is found that the addition of a solar preheating system contributes to an increase in the total electricity consumption for pumping. In the centralised gas heating system, total pumping energy consumptions were 980 kWh and 988 kWh for the average and high occupancy levels respectively. For the solar-boosted centralised-gas heating system total pumping energy consumptions were 1,085 kWh and 1,112 kWh for the average and high occupancy levels respectively, which is around a 11% and 12.5% increment for the average and high occupancy scenarios.

The annual total electrical energy required in the Brahe Place building by the CFEWH heating system in all eight apartments was 6.9 MWh and 11.5 MWh for average and high occupancy scenarios respectively. For each individual apartment the annual water heating electricity consumption was 864 kWh and 1,440 kWh for average and high occupancy level respectively.

For both occupancy levels in the Brahe Place building the centralised gas water heating system used more secondary energy (in the form of gas plus some electricity for pumping) than the solar-gas ring-main (in the form of gas plus some electricity for pumping) and the point-of-use CFEWH system (all in the form of electricity). For example, for average occupancy, the centralised gas heating system annually consumed 92.7 (25,750 kWh) gas and 1,152 kWh of electricity, that is, a total equivalent secondary energy of 26,902 kWh; centralised solar-gas heating system annually consumed 74.6 (20,722 kWh) gas and 1,256 kWh of electricity, that is, a total equivalent secondary energy of 21,978 kWh; whereas the CFEWH system potentially consumed 6,913 kWh of delivered electricity.

It is important to note, however, that the TRNSYS analysis conducted in both these case studies covered only secondary energy consumption, rather than the primary energy and greenhouse gas emission impacts of the various water heating system options.

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APPENDICES

Appendix A: Results graphs of CFEWH system for the La Banque building

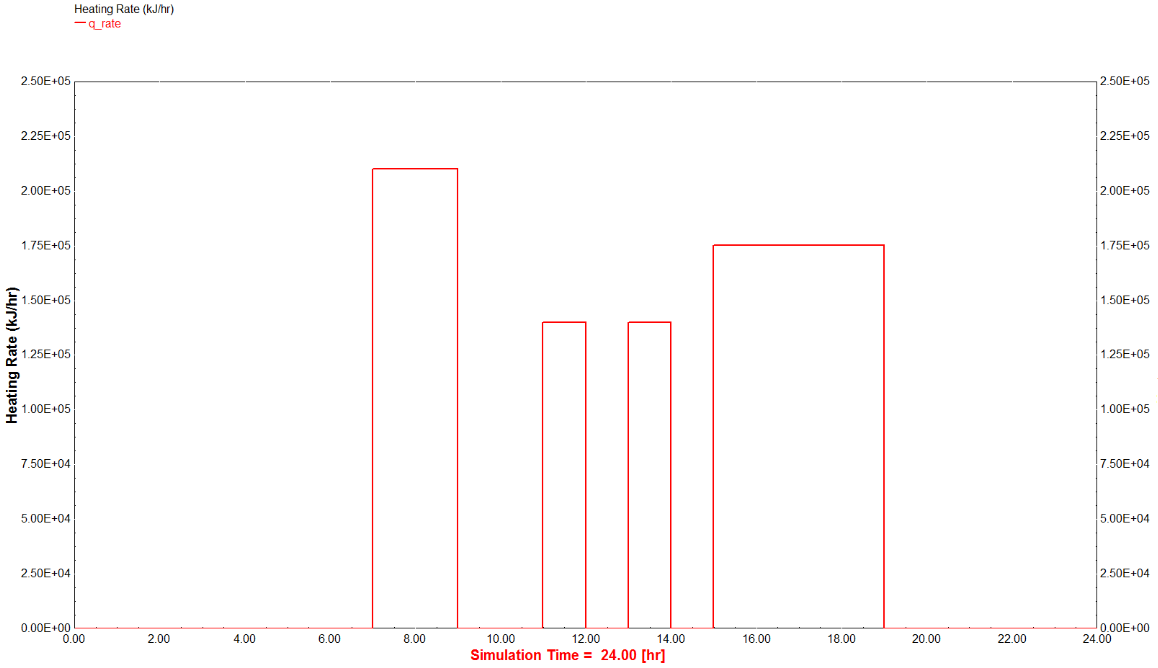

Figure A-1: Daily (for January) heating rate profile by CFEWH system for 257 apartments in La Banque building (low occupancy level)

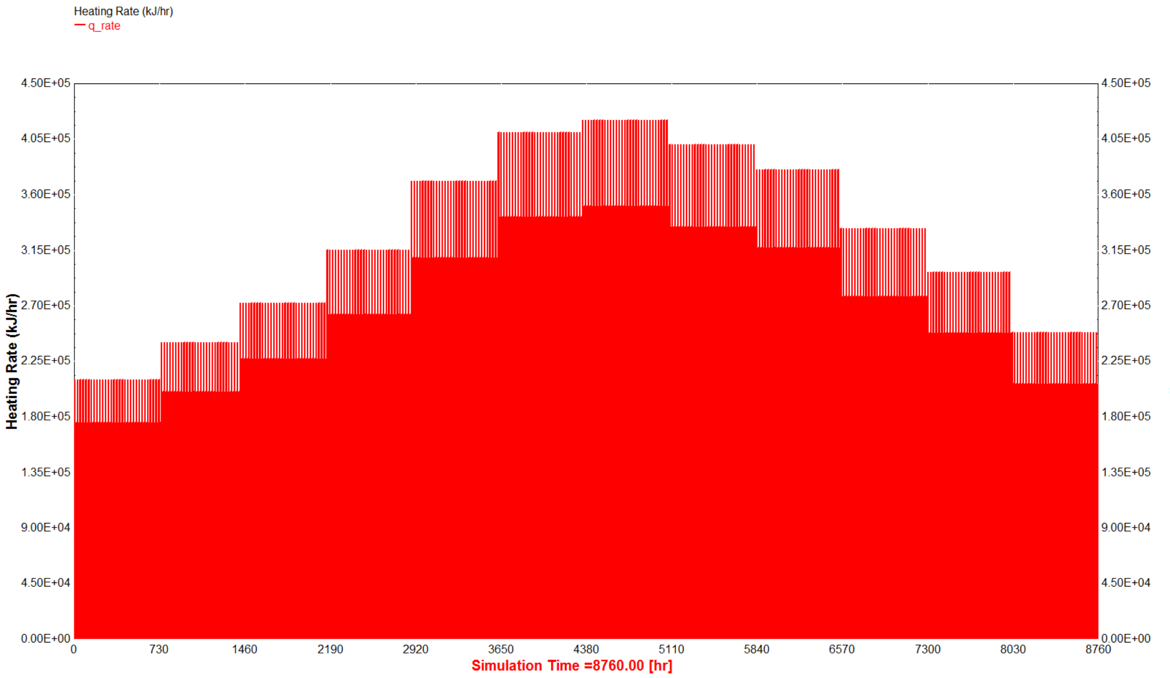

Figure A-2: Annual heating rate profile by CFEWH system for 257 apartments in La Banque building (low occupancy level)

Appendix B: Results graphs of centralised gas heating system Brahe Place building

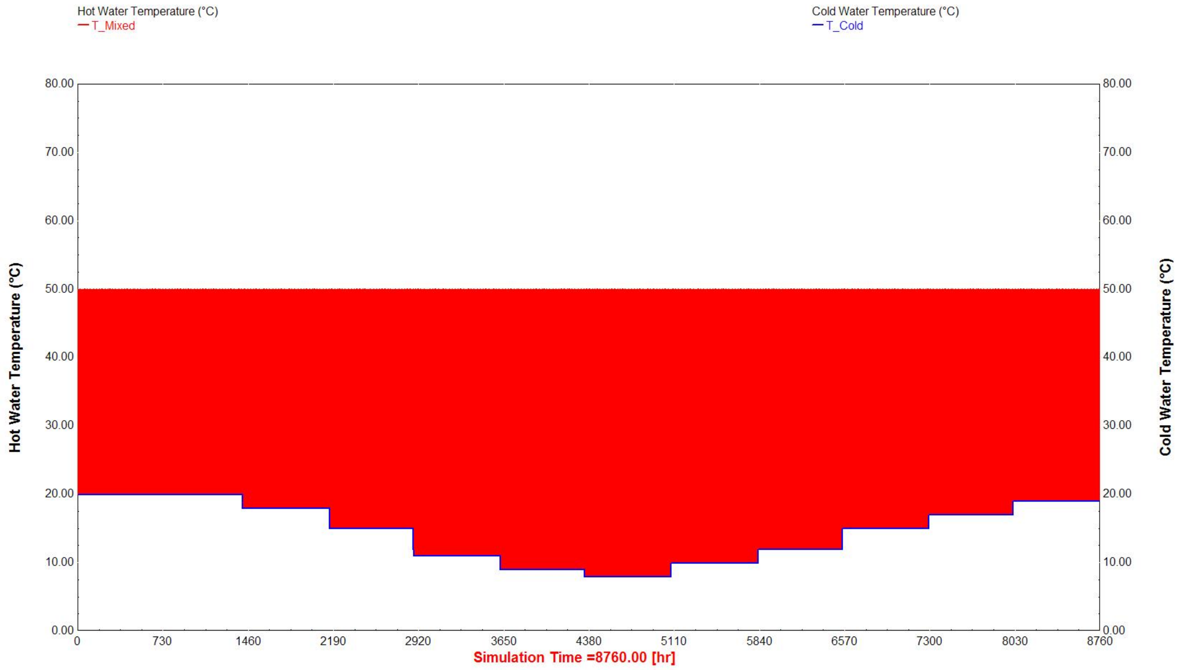

Figure B-1: Annual cold water and delivered tempered hot water temperature profile by gas heating system for eight apartments in Brahe Place building (average occupancy scenario)

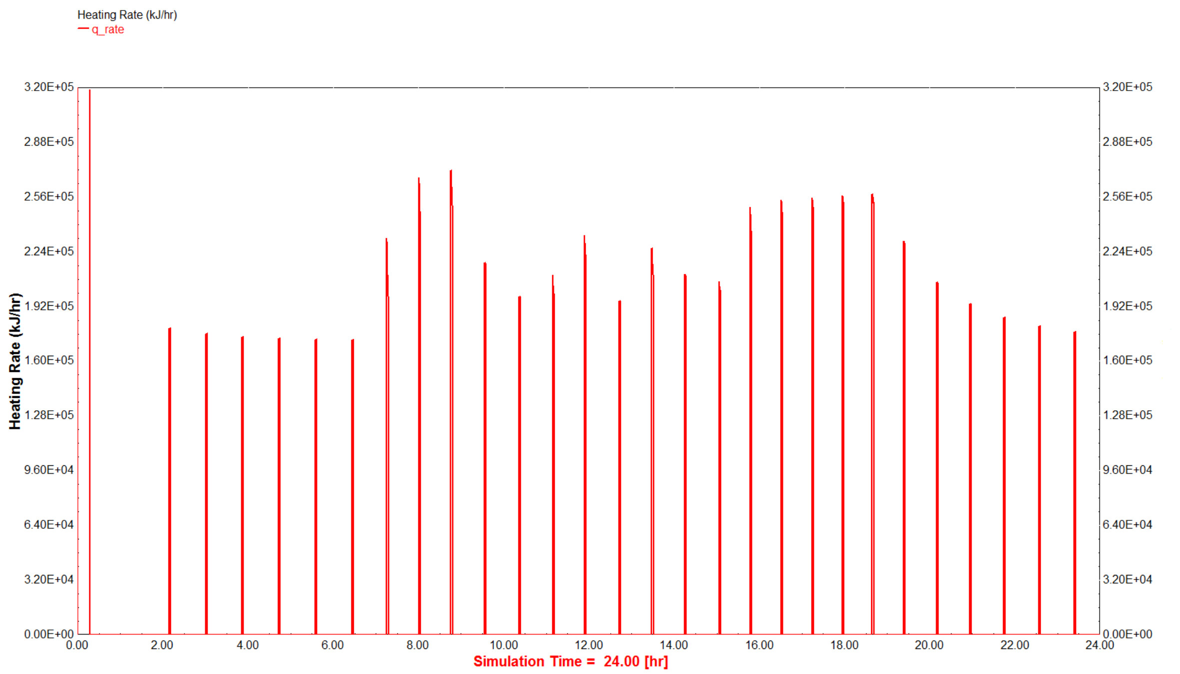

Figure B-2: Daily (for January) heating rate profile by gas ring-main system for eight apartments in Brahe Place building (average occupancy level)

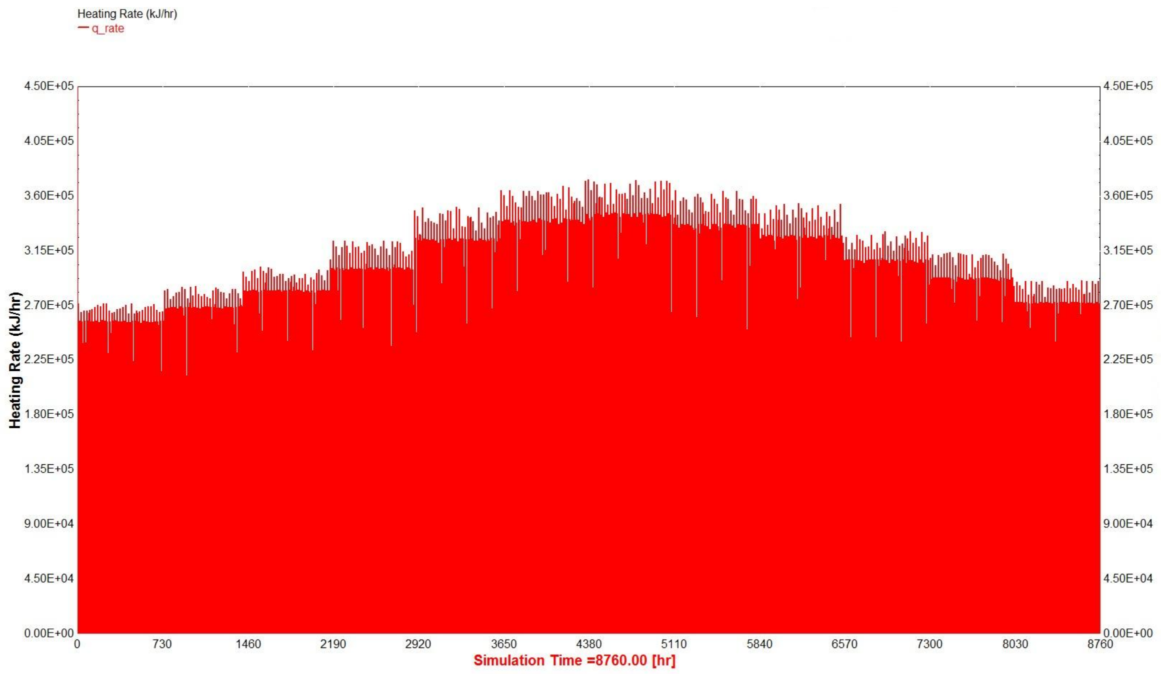

Figure B-3: Annual heating rate profile by gas ring-main system for eight apartments in Brahe Place building (average occupancy level)

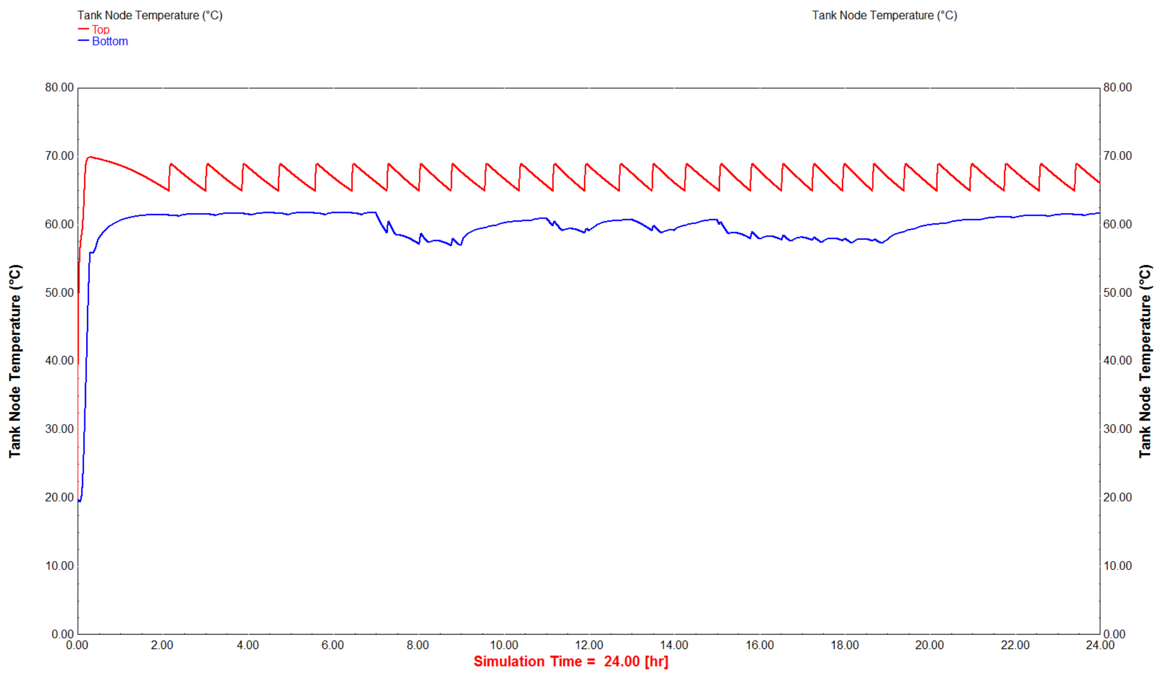

Figure B-4: Daily (for January) storage tank top and bottom temperature profile by gas heating system for eight apartments in the Brahe Place building (average occupancy level)

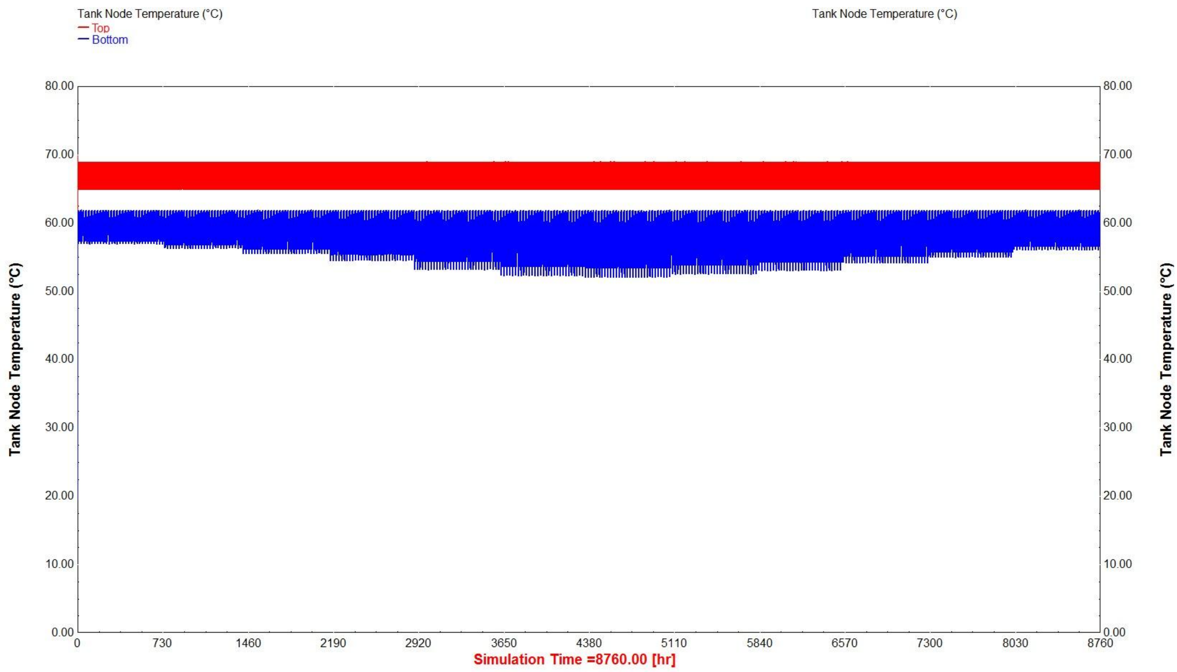

Figure B-5: Annual storage tank top and bottom temperature profile by gas heating system for eight apartments in Brahe Place building (average occupancy level)

Appendix C: Results graphs of solar-boosted centralised gas heating system for the Brahe Place building

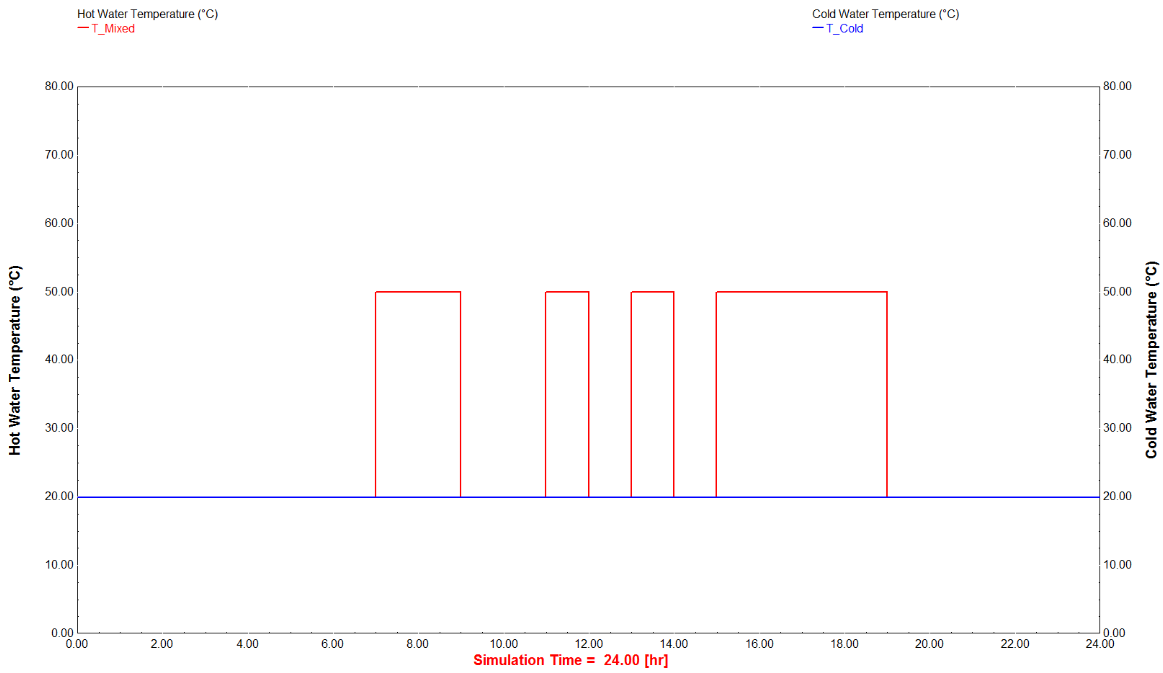

Figure C-1: Daily (for January) cold water and delivered tempered hot water temperature by solar-boosted gas heating system for eight apartments in Brahe Place building (average occupancy scenario)

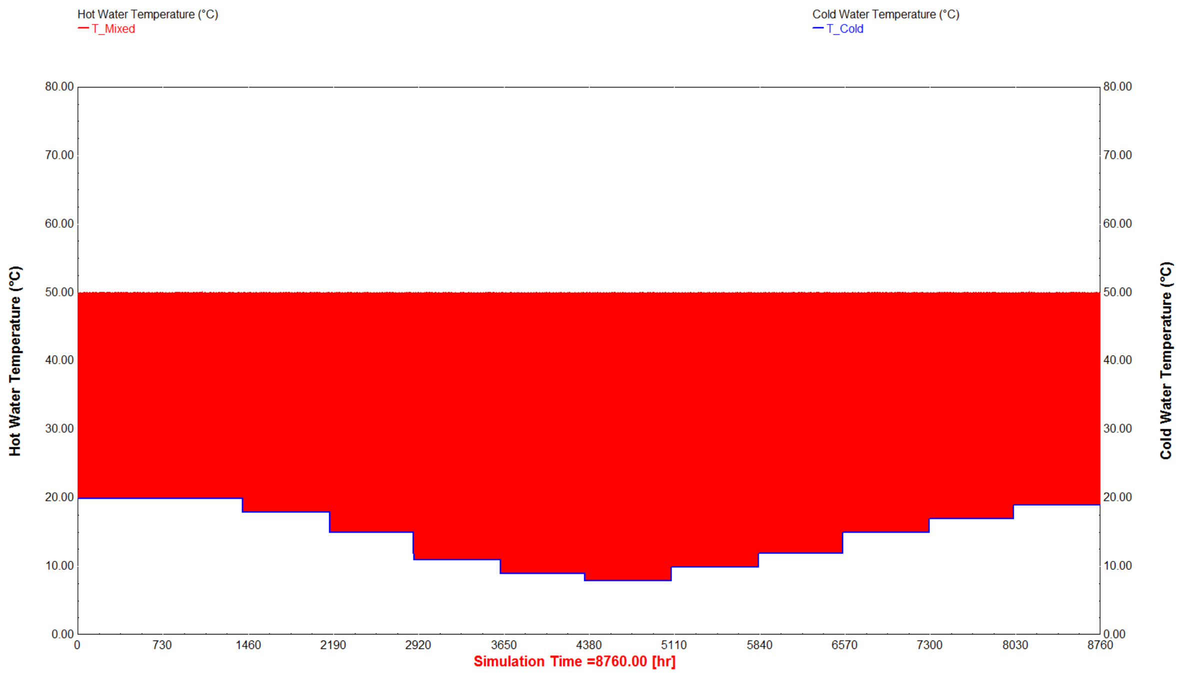

Figure C-2: Annual cold water and delivered tempered hot water temperature profile by solar-boosted gas heating system for eight apartments in Brahe Place building (average occupancy scenario)

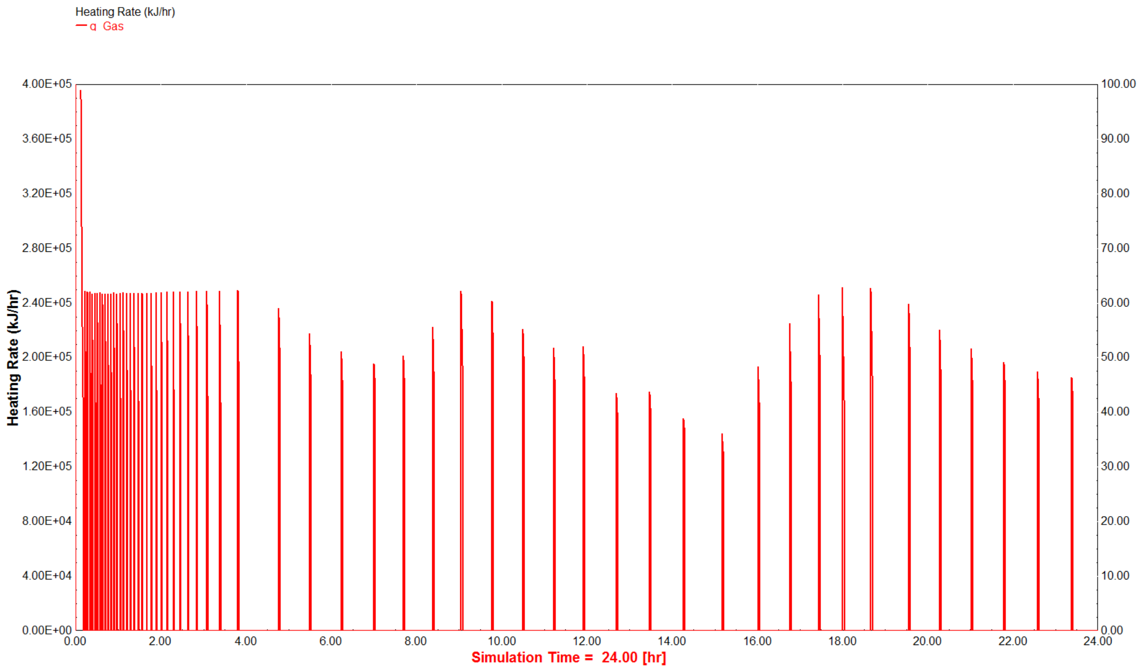

Figure C-3: Daily (for January) gas heating rate profile by solar-boosted gas ring-main system for eight apartments in Brahe Place building (average occupancy level)

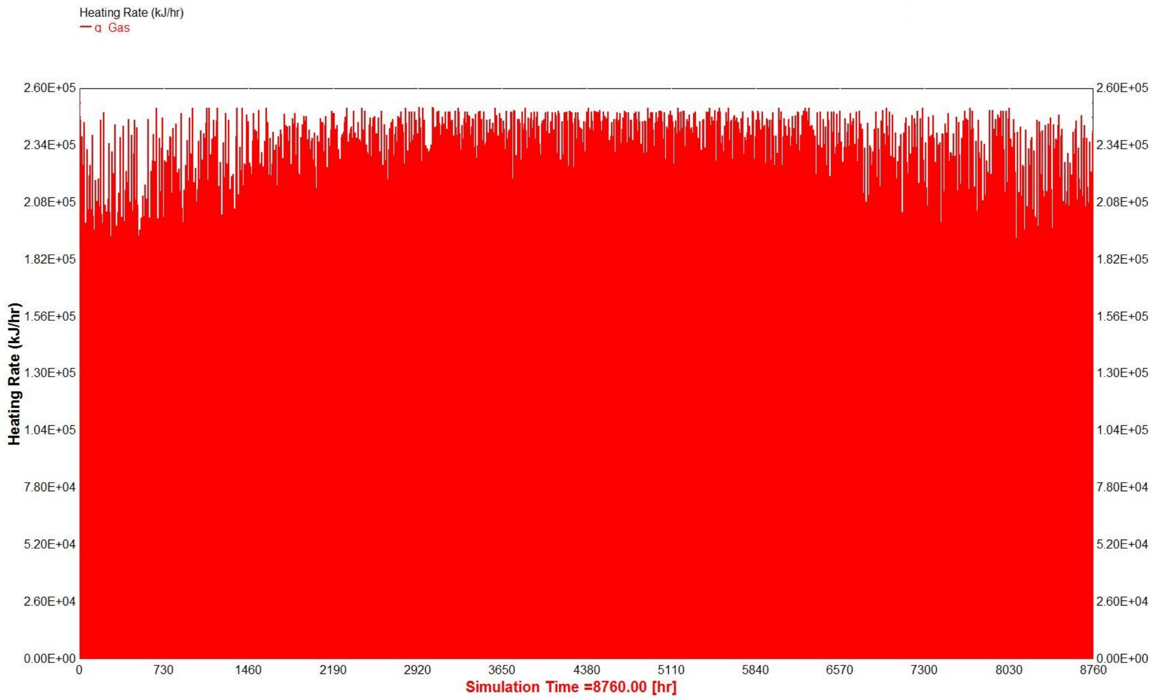

Figure C-4: Annual gas heating rate profile by solar-boosted gas ring-main system for eight apartments in Brahe Place building (average occupancy level)

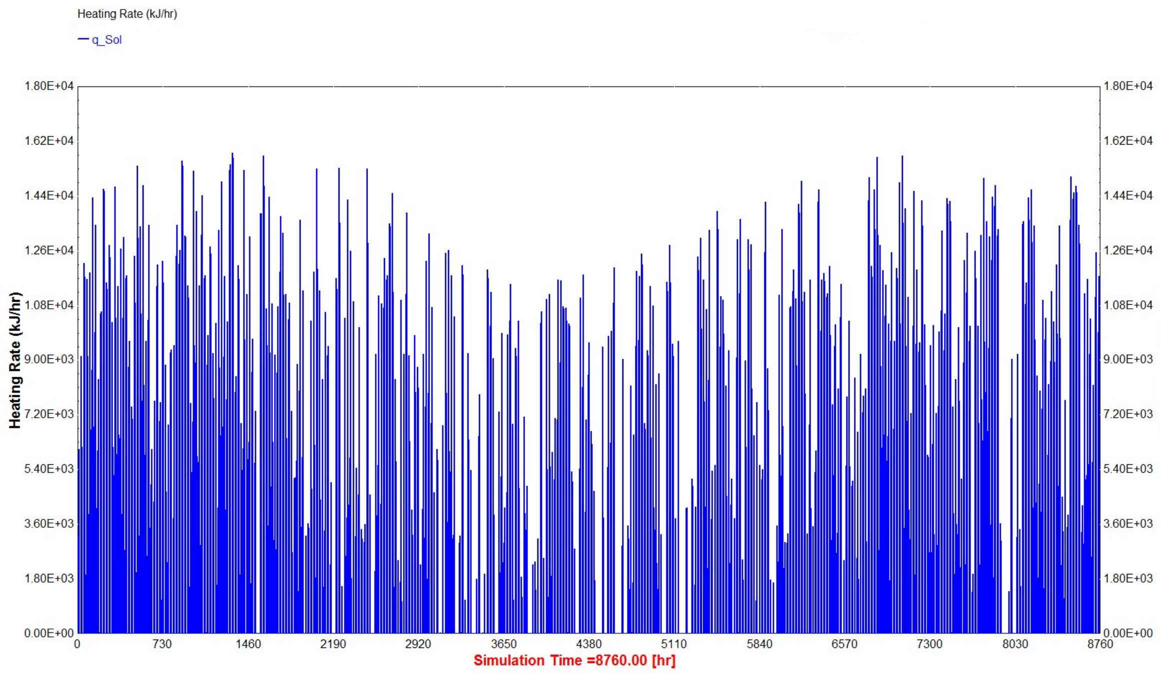

Figure C-5: Annual solar collector heat supply rate profile by solar-boosted gas ring-main system for eight apartments in Brahe Place building (average occupancy level)

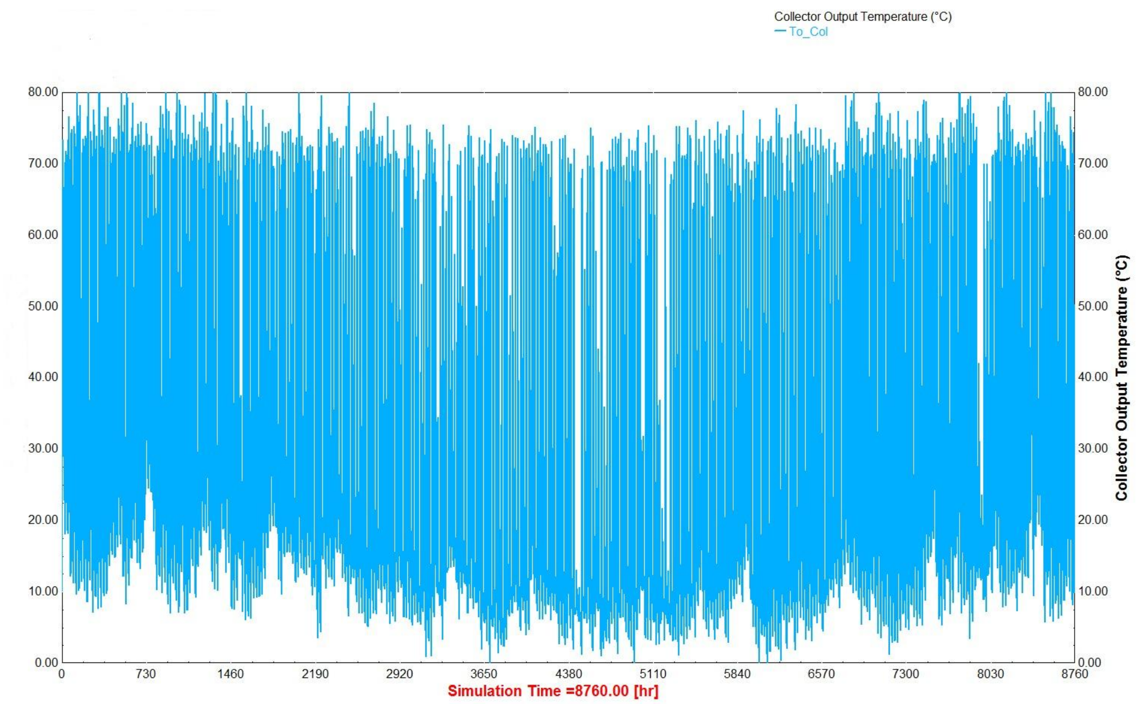

Figure C-6: Solar collector annual temperature profile by solar-boosted gas ring-main system for eight apartments in the Brahe Place building (average occupancy level)

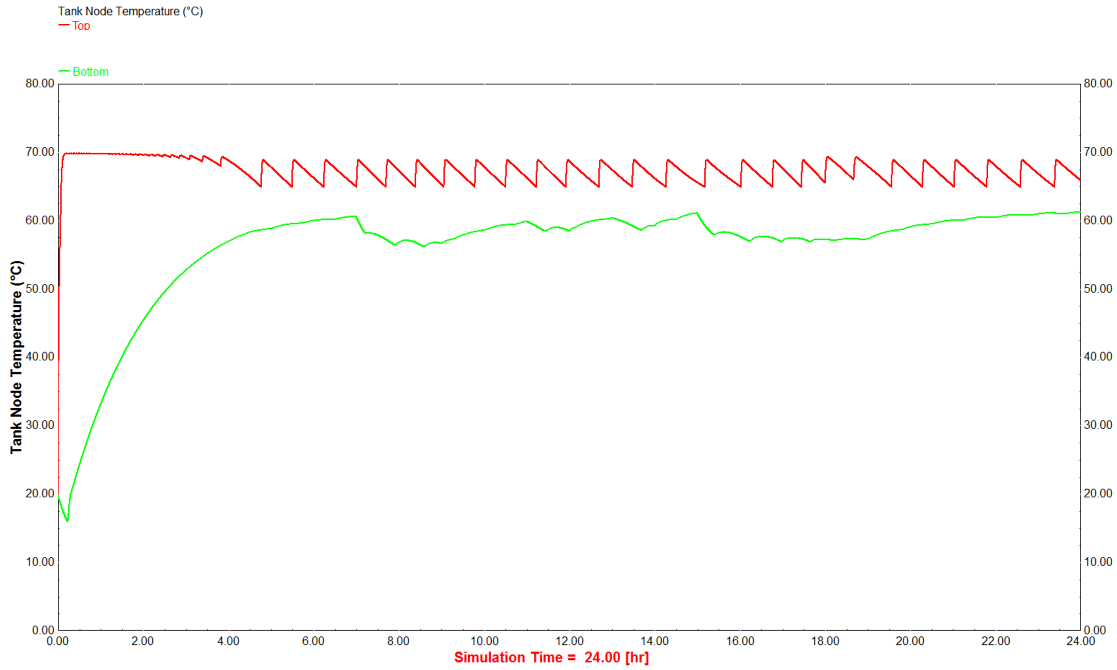

Figure C-7: Daily (for January) storage tank temperature profile by solar-boosted gas ring-main system for eight apartments in the Brahe Place building (average occupancy level)

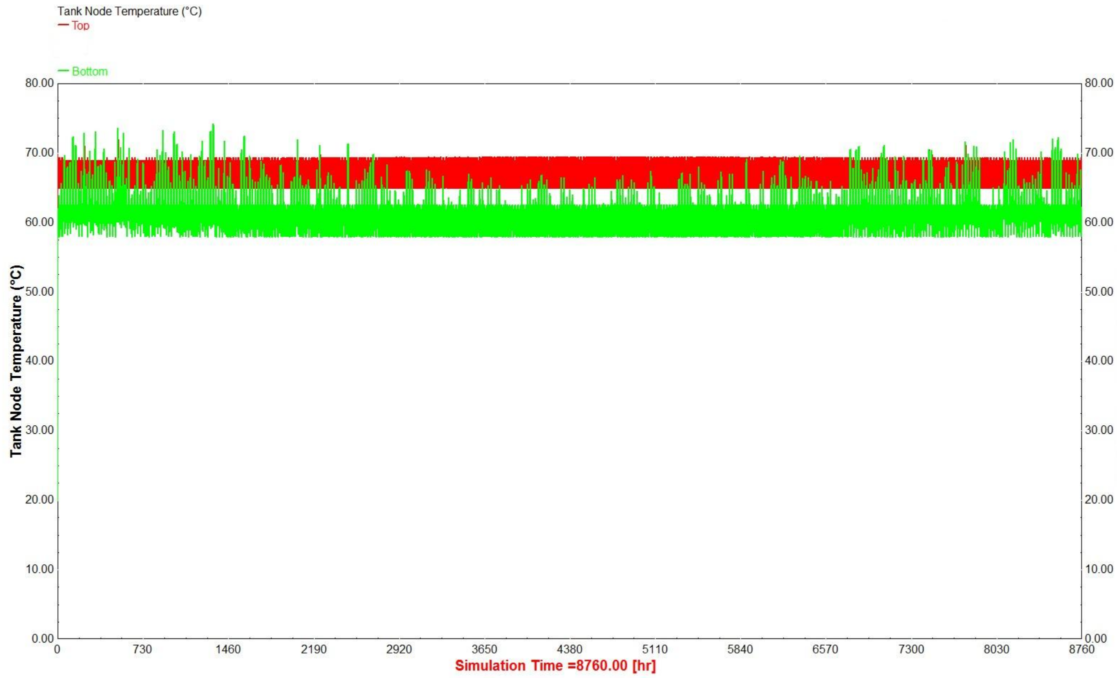

Figure C-8: Annual storage tank temperature profile by solar-boosted gas ring-main system for eight apartments in the Brahe Place building (average occupancy level)

Appendix D: Results graphs of CFEWH system for the Brahe Place building

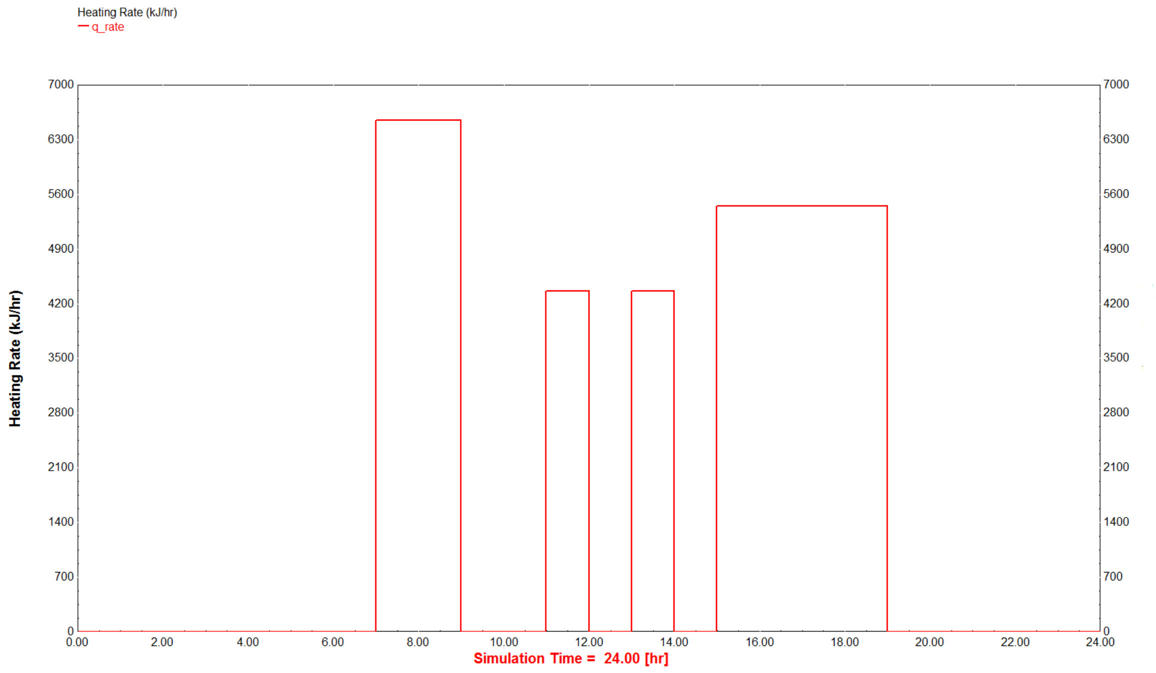

Figure D-1: Daily (for January) heating rate profile by CFEWH system for eight apartments in Brahe Place building (average occupancy level)

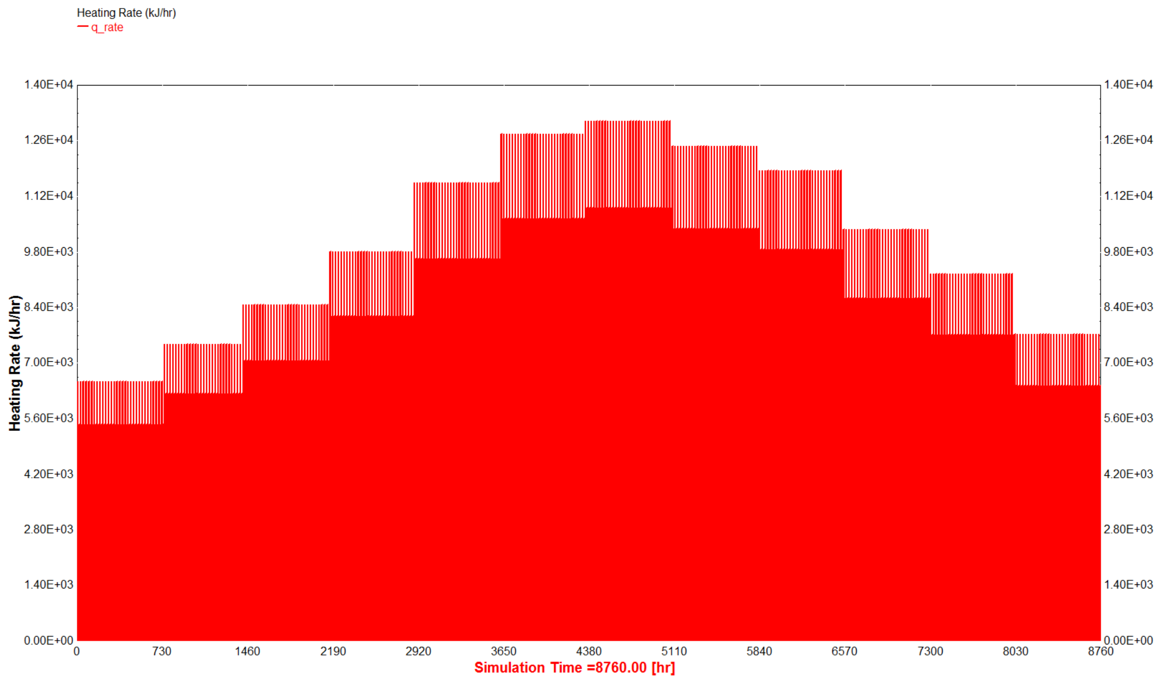

Figure D-2: Annual heating rate profile by CFEWH system for eight apartments in Brahe Place building (average occupancy level)