PRELIMINARY INVESTIGATION INTO SOLAR THERMAL COMBI-SYSTEM PERFORMANCE

by

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Abstract

Solar thermal combi-systems use solar energy to provide thermal energy for space heating and domestic hot water. These systems come in many different designs and configurations, and their performance is dependent on many different factors such as location, solar collector type and orientation, and thermal storage size. In this study, two different combi-system configurations (a basic combi-system, and a single-tank combi-system) as well a stand-alone solar space heating system and a stand-alone solar domestic hot water system were investigated using TRNSYS models and simulations, and the thermal performances were compared using different combinations of solar collector and heat exchanger types, different locations, and a sensitivity analysis was performed using the basic solar combi-system.

Using Toronto as the reference location, the performance of the solar stand-alone and combi-systems were compared using combinations of solar collector types (glazed vs. vacuum tube) and heat exchanger types (fixed effectiveness vs. natural convection). Each system combination was optimized for collector flow rate and tilt angle, and all systems were given the same solar collector area, thermal storage volume, and load profiles. This analysis revealed that the glazed type solar collector performed best when the heating load was continuous throughout the year, whereas the vacuum tube solar collector performed best with systems that had heating loads concentrated in the winter. Further comparisons of these systems were done using reference locations: Boulder, Colorado; Seattle, Washington; Winnipeg, Manitoba; and Toronto, Ontario. Results showed that the single-tank solar combi-system with internal stratifiers in the thermal storage tank outperformed the other solar thermal system configurations, although if examined solely based on space heating performance, the basic combi-system with preferential charging of the space heating thermal store had the best performance.

Lastly, a sensitivity analysis of the basic combi-system was conducted, again using Toronto as the reference location. Several parameters were considered, including: the solar collector tilt angle and azimuth, the solar collector size, flow rate through the collector loop, thermal storage tank size, heat exchanger effectiveness, number of tank nodes, hydronic-floor supply temperature, and hydronic-floor R-value. Of these, the solar collector parameters and the hydronic-floor supply temperature had the greatest impact on the overall system performance.

Acknowledgements

I would like to thank everyone who made completing this degree possible. I would also like to acknowledge my supervisor and the rest of my defence committee, and my friends and fellow co-workers in the Solar Calorimetry Laboratory. Finally to my parents and family, I want to express my appreciation for all your love and support.

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Nomenclature

A_c	Collector area [m²]
A_{coll}	Collector area [m²]
A_{cs}	Cross-sectional area of the tank [m²]
A_{heated}	Area of the hydronic-floor [m²]
A_{sur}	Area of the surface between the tank and the environment [m²]
$AUST$	Area-weighted temperature of all indoor surfaces (excluding the floor) [°C]
C_c	Capacity rate for the cold fluid stream [W/°C]
C_e	Cost of electricity [$/kWh]
C_f	Cost of fuel [$/kWh]
C_{forced}	Capacity rate of the forced flow [W/°C]
C_h	Capacity rate for the hot fluid stream [W/°C]
C_{min}	Lower capacity rate of the two fluid streams [W/°C]
C_{NC}	Capacity rate of the natural convection flow [W/°C]
C_p	Specific heat [J/kg-K]
C_{p_c}	Specific heat for the cold fluid [J/kg-K]
C_{p_h}	Specific heat for the hot fluid [J/kg-K]
$C_{p\,l}$	Specific heat of the material as a liquid [J/kg-K]
$C_{p\,s}$	Specific heat of the material as a solid [J/kg-K]
$C_{ratio\,mod}$	Modified capacity ratio [-]
D_i	Inner diameter of the tube [m]
D_o	Outer diameter of the tube [m]
E	Energy [J]
E_{aux}	Primary energy used by the additional auxiliary component(s) in a solar system to meet the thermal load [kWh];
$E_{aux,test}$	Auxiliary heating energy used during the 6 day test sequence [kWh]
$E_{aux,year}$	Annual auxiliary heating energy required [kWh]
E_{ref}	Primary energy used by the reference system to meet the thermal load [kWh]
E_{total}	Total primary energy load of the solar combi-system [kWh]

$E_{total,ref}$	Total primary energy load of the reference system [kWh]
$E_{total,ref}$	Total monthly energy consumption for the reference system [kWh]
F'	Collector efficiency factor [-]
F_R'	Collector heat exchanger efficiency factor [-]
F_s	Solar fraction [-]
$F_{s\,DHW}$	Solar fraction of the domestic hot water loop [-]
$F_{s\,SH}$	Solar fraction of the space heating loop [-]
F_{sav}	Solar savings fraction [-]
FSC	Fractional solar consumption [-]
F_{system}	System and load dependent prediction correction [-]
$f_{sav,\mathrm{ext}}$	Extended fractional thermal energy savings [-]
$f_{sav,therm}$	Fractional thermal energy savings [-]
f_{si}	Fractional savings indicator [-]
G_T	Radiation on the tilted collector surface [W/m²]
H	Enthalpy of the phase change [J/kg]
HDD	Annual number of heating degree days [°C days]
$\overline{H}_T$	Average monthly radiation incident on the collector surface each day [J/m²]
I_T	Total monthly radiation on the tilted collector surface [kWh/m²]
$K_{\tau\alpha}$	Incidence angle modifier [-]
k_c	Thermal conductivity of each flooring layer [W/m-K]
k_{fluid}	Thermal conductivity of the fluid [W/m-K]
k_p	Thermal conductivity of the poured floor [W/m-K]
k_t	Thermal conductivity of the tube [W/m-K]
L	Total monthly heating load (both space and hot water) [J]
M	Spacing between adjacent tubes [m]
M_i	Mass of the fluid in node i [kg]
m	Mass [kg]
$\dot{m}$	Mass flow rate [kg/s]
$\dot{m}_c$	Mass flow rate for the cold fluid stream [kg/s]
$\dot{m}_h$	Mass flow rate for the hot fluid stream [kg/s]

$\dot{m}_{i-1\rightarrow i}$	Mass flow rate of fluid entering from the node above [kg/s]
$\dot{m}_{i+1\rightarrow i}$	Mass flow rate of fluid entering from the node below [kg/s]
$\dot{m}_{in}$	Mass flow rate of fluid entering from outside the tank [kg/s]
$\dot{m}_{NC}$	Natural convection mass flow rate [kg/s]
$\dot{m}_{out}$	Mass flow rate of fluid leaving node i [kg/s]
N	Number of days in the month [-]
Q_{aux}	Additional auxiliary energy required to meet the total load when part of the energy is supplied by the solar system [kWh]
Q_{aux}	Thermal load of the auxiliary heater(s) in the solar system [kWh]
$Q_{aux\ DHW}$	Thermal load of the auxiliary domestic hot water heater solar thermal system [kWh]
$Q_{aux,e}$	Total amount of electricity used by the solar system [kWh]
$Q_{aux,f}$	Total amount of fuel used by the solar system [kWh]
$Q_{aux\ SH}$	Thermal load of the auxiliary space heater in the solar thermal system [kWh]
Q_{boiler}	Thermal energy load supplied by the boiler in the solar system [kWh]
$Q_{boiler,ref}$	Thermal energy provided by the boiler in the reference system [kWh]
$Q_{el.heater}$	Thermal energy load supplied by the electrical heating element in the solar system [kWh]
Q_{load}	Thermal energy delivered to the heating load [kWh]
$Q_{load,test}$	Measured domestic hot water and space heating load during the test [kWh]
$Q_{load,year}$	Annual domestic hot water and space heating load [kWh]
$Q_{penalty,red}$	Penalty applied if the solar system is unable to meet the required hot water or space heating demands [kWh]
Q_{ref}	Energy input delivered by a (non-solar) reference system to meet the total load [kWh]
Q_{ref}	Thermal load of the reference system [kWh]
$Q_{ref\ DHW}$	Thermal load of the domestic hot water reference system [kWh]
$Q_{ref,f}$	Total amount of fuel required by the non-solar reference system [kWh]
$Q_{ref\ SH}$	Thermal load of the space heating reference system [kWh]
$Q_{SH\ \Delta t}$	Space heating load for the time interval [kWh]
$Q_{SH\ annual}$	Space heating energy target [kWh]
Q_{sol}	Solar contribution [kWh]

$Q_{sol\,DHW}$	Solar contribution of the domestic hot water loop (measured in terms of thermal energy) [kWh]
$Q_{sol\,SH}$	Solar contribution of the space heating loop (measured in terms of thermal energy) [kWh]
$\dot{Q}_{aux}$	Heating rate from the auxiliary heater [W]
$\dot{Q}_{cond}$	Heat transfer rate due to conduction [W]
$\dot{Q}_{cond}$	Vertical thermal conduction between nodes [W]
$\dot{Q}_{flow}$	Rate energy added to the node due to the flow of fluid [W]
$\dot{Q}_{loss}$	Heat loss from node i to the environment [W]
$\dot{Q}_{losses}$	Rate energy lost to the environment [W]
$\dot{Q}_{max}$	Maximum potential heat transfer rate across the heat exchanger [W]
$\dot{Q}_{SH}$	Space heating load [W]
$\dot{Q}_{tot}$	Total heat transfer rate across the heat exchanger [W]
$\dot{Q}_{u}$	Energy output from the solar collector [kW]
q_{conv}	Heat transfer due to natural convection [W/m²]
q_{rad}	Heat transfer due to radiation [W/m²]
q_{tot}	Total heat flux [W/m²]
r	Flow rate correction [-]
r_c	Thermal resistance of active panel surface covers (for hydronic heating/cooling systems) [m² K/W]
r_p	Thermal resistance of the panel body [m² K/W]
r_s	Thermal resistance between the tube and panel body per unit spacing between tubes [m K/W]
r_t	Thermal resistance of the tube wall [m K/W]
r_u	Characteristic resistance of the hydronic-floor [m² K/W]
T	Temperature [°C], [K]
T^*	Melting temperature of the material [K]
T_a	Ambient temperature [°C]
T_{amb}	Ambient temperature [°C]
$T_{amb,max}$	Maximum annual ambient temperature [°C]
T_{ave}	Average temperature [°C]

T_{ci}	Cold side inlet temperature [°C]
T_{co}	Cold side outlet temperature [°C]
T_{env}	Temperature of the environment [°C]
$T_{forced,i}$	Inlet temperature on the forced flow side [°C]
T_{hi}	Hot side inlet temperature [°C]
T_{ho}	Hot side outlet temperature [°C]
T_i	Temperature of node i [°C]
T_i	Inlet temperature of the collector fluid [°C]
T_{i-1}	Temperature of node i–1 [°C]
T_{i+1}	Temperature of node i+1 [°C]
T_{in}	Inlet temperature [°C]
T_{mains}	Mains water temperature [°C]
$T_{NC,i}$	Inlet temperature on the natural convection side [°C]
T_{out}	Outlet temperature [°C]
T_{ref}	Reference temperature [K], [°C]
T_{room}	Room temperature [°C]
T_{sur}	Surface temperature of the hydronic-floor [°C]
T_w	Average water temperature [°C]
$\bar{T}_a$	Monthly average ambient temperature [°C]
$\bar{T}_{amb}$	Average annual ambient temperature [°C]
UA	Overall heat transfer coefficient for the building [kW/°C]
UA_{R-2000}	Overall heat transfer rate based on the R-2000 Standard [kW/°C]
U_L	Overall collector loss coefficient [W/m²-K]
U_{sur}	Per unit area heat loss coefficient for the surface [W/m²-K]
V	Interior heated volume of the residence [m^3]
W_{par}	Parasitic energy load of the solar system [kWh]
$\mathrm{W}_{par,ref}$	Parasitic energy load of the reference system [kWh]
x_c	Thickness of each layer of the hydronic-floor [m]
x_p	Thickness of the poured portion of the floor (measured from the center of the tube) [m]

Greek Symbols

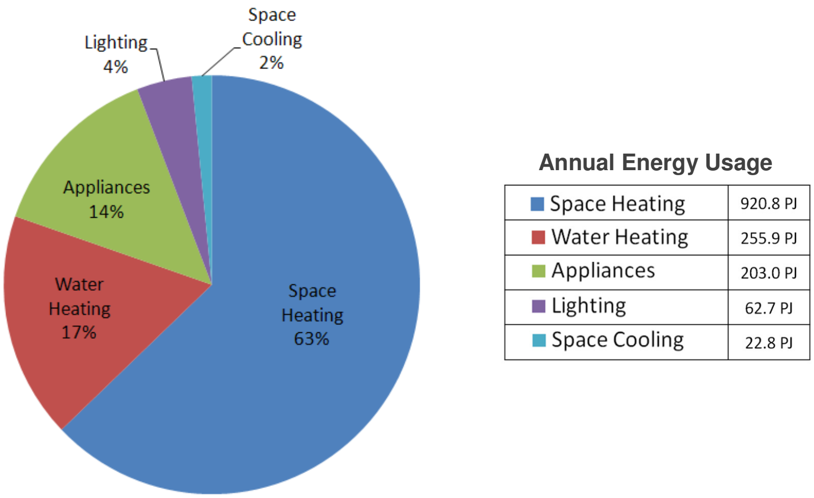
ΔP	Pressure difference [Pa]
ΔT	Temperature difference [°C], [K]
Δt	Length of time/time interval [s], [hrs]
Δx	Centre to centre distance between nodes [m]
ε	Heat exchanger effectiveness [-]
ε_{mod}	Modified heat exchanger effectiveness [-]
η	Instantaneous solar collector efficiency [-]
η_{boiler}	Mean annual combi-system boiler efficiency [-]
$\eta_{boiler,ref}$	Mean annual reference system efficiency [-]
η_{coll}	Collection efficiency [-]
η_{el}	Electrical efficiency for the parasitic loads [-]
$\eta_{el.heater}$	Annual electrical generation efficiency
θ	Incidence angle [°]
$(\overline{\tau\alpha})$	Average monthly transmittance-absorbance product [-]

Chapter 1

Introduction

1.1 Background

Global energy consumption and green house gas emissions have been steadily increasing over the past century and Canada is no exception to this trend [1]. Canada has one of the highest per capita residential energy consumptions in the world [2] and in 2008 the total energy use by the Canadian residential sector was 1465.3 PJ of energy, producing over 42.8 Mt of carbon dioxide (CO_2) emissions [3]. Of the energy consumed, 62.8% of it was used for space heating and 17.5 % used for domestic hot water heating [3], Figure 1.1. Therefore, over 80% of residential energy consumption is used for heating, and shows that there is great potential for energy and greenhouse gas savings if these loads can be met using clean renewable energy.



🟦 Space Heating	920.8 PJ
🟥 Water Heating	255.9 PJ
🟩 Appliances	203.0 PJ
🟪 Lighting	62.7 PJ
🟦 Space Cooling	22.8 PJ

Figure 1.1: Breakdown of Canadian residential energy consumption by end-use (Adapted from: [3])

One alternative to traditional space heating and domestic hot water energy sources like natural gas, oil, and electricity is solar thermal energy. There are many types of solar thermal systems, and applications can vary from heating swimming pools and buildings, to driving chemical processes, and even heating fluid to drive turbines and produce electricity. Solar energy is considered a clean renewable energy source, and in 2009 it is estimated that over 60,000 metric tons of CO_2 emissions were avoided in Canada through the use of solar thermal systems [4]. Solar thermal systems used for residential heating applications typically have three main components: solar collectors, used to heat a fluid; thermal storage, used to store the thermal energy until it is needed; and a distribution or delivery system, used to supply heat to a thermal load, e.g., space heating or domestic hot water system.

1.2 Solar Collectors

Solar thermal systems use the sun's energy to heat a fluid. This can be accomplished using a variety of different types of apparatus e.g., concentrating or "flat-plate" solar collectors that use air or liquid as a heat transfer medium. Unlike photovoltaic (PV) cells that produce electricity, these devices are designed to collect thermal energy. Although thermal energy is typically less useful than electricity (most household appliances run on electricity), solar thermal collectors can be much more efficient than PV cells, making them ideally suited for applications requiring thermal energy.

1.2.1 Concentrating Collectors

Concentrating collectors are normally used in applications where very high temperature fluids are required such as industrial processes and large-scale power generation sites. This type of collector uses mirrors or reflectors to focus the sun's energy along a pipe or vertical column containing fluid. By focusing the sun's energy in this fashion, concentrating collectors can operate at temperatures as high as 800°C [5]. These systems tend to be very sensitive to changes in solar angle and are therefore designed to track the sun's movement to maximize energy collection over the day. For small installations, like those used in single family residences, concentrating collectors are impractical; therefore this type of collector will not be considered in this investigation.

1.2.2 Thermal Air Collectors

Solar thermal air collectors generally use a black absorber plate to collect solar energy which is then transferred to air when it passes over (or under) the plate. Since air has a relatively low heat capacity, storing the energy and transferring it to heat water can be more difficult and inefficient. This is why thermal air collectors are most commonly found in systems that preheat makeup air in large scale industrial, commercial, and agricultural applications, with collector areas ranging from 50 to 10,000 m^2 [4].

1.2.3 Thermal Liquid Collectors

Thermal liquid solar collectors are similar to air based collectors. This type of collector generally has a much lower operating temperature than concentrating collectors with energy delivered at temperatures typically not more than 100°C above the ambient temperature [5]. Since liquids usually have a much higher heat capacity than air, solar systems using a liquid collector fluid are able to heat water and store energy more effectively than air collectors, making them the best choice for residential sized solar space heating and hot water systems.

1.3 Thermal Energy Storage

One drawback of solar energy is that it is not a constant resource. The available energy at any given location can vary with time of day, year, and the local weather. To maximize the usable energy from a solar collector, a thermal storage unit is typically required. As shown in Figure 1.2, when the useful collector gain is greater than the load, the excess energy can be stored for use later in time, for example during a cloudy period or at night.

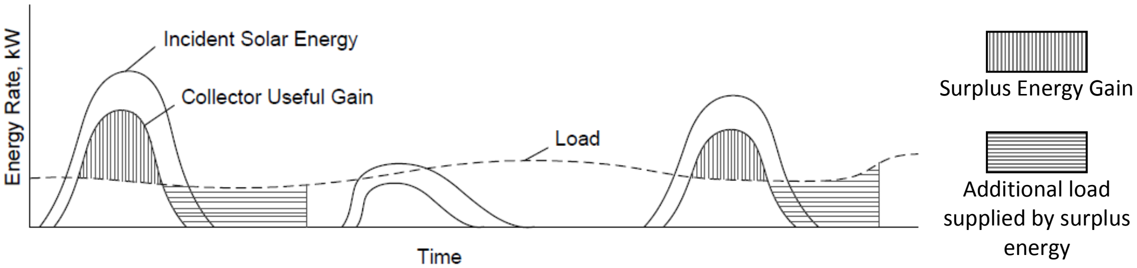


Figure 1.2: Application of thermal storage in a solar heating system (Source: [6])

An ideal thermal storage unit should be compact, low cost, and have few thermal losses. The solar collector should be able to easily charge (transfer energy into) the storage unit at as low a temperature as possible, and the storage unit should also be able to transfer energy to the load at the required temperature (discharging). In addition, the storage medium should be able to go through multiple charging and discharging cycles without a loss in capacity or decrease in performance.

Thermal storage can take a variety of different forms. Extremely large thermal storage units are capable of seasonal storage, i.e., storing excess energy during the summer for later use in the fall and winter, while smaller volumes are capable of storing heat overnight or for a few days. Different storage media can also be used. The International Energy Agency (IEA) Task 32 identified three different types of storage materials suitable for residential solar thermal systems: chemical, phase change and sensible heat storage media [7].

1.3.1 Sensible Heat Storage

Using sensible heat is the most common means of storing thermal energy. When a material is heated, energy is stored within it and can be measured as an increase in temperature. Provided this temperature increase is not accompanied by a change in the material's physical state or chemical composition then the energy stored by the material is considered sensible heat. In general, the amount of energy stored using sensible heat can be calculated as:

$$E = mC_p\left(T - T_{ref}\right) \tag{1.1}$$

where:

E is the amount of stored thermal energy [J];
m is the mass of the material [kg];
C_p is the specific heat of the material [J/kg-K];
T is the temperature of the material [K]; and
T_{ref} is a reference temperature [K].

Water is a very good thermal storage medium, although concrete slabs, glycol, and other substances can also be used. Water is safe and inexpensive, it has a high heat capacity, and hot water tanks are available in a wide variety of shapes and sizes, making water storage extremely popular. This makes water storage the most common thermal storage medium used in solar thermal systems.

1.3.2 Latent Heat Storage

The thermal energy absorbed by a material during a phase change is referred to as latent heat. In systems where phase change in a material is used to store energy, the material is commonly referred to as phase change material (PCM). For a material to be a candidate for PCM storage it should show little change in density (volume) during the phase change [8]. In practice most PCMs used for thermal storage change from solid to liquid when being heated or charged. Ideally, phase changes occur at a constant temperature and if it accompanied by a high latent heat effect, large amounts of energy can be stored within a small temperature range. When the PCM is above the material's melting point, the stored energy can be calculated as:

$$E = m\left[C_{p\,s}\left(T^{*} - T_{ref}\right) + H + C_{p\,l}\left(T - T^{*}\right)\right] \tag{1.2}$$

where:

E is the amount of stored thermal energy [J];
m is the mass of the material [kg];
$C_{p\,s}$ is the specific heat of the material as a solid [J/kg-K];
$C_{p\,l}$ is the specific heat of the material as a liquid [J/kg-K];
H is the enthalpy of the phase change [J/kg];
T is the temperature of the material [K];
T^{*} is the melting temperature of the material [K]; and
T_{ref} is the reference temperature [K].

To be practical, combi-system thermal stores would need the PCM's melting temperature to occur between 45 and 70°C. Paraffins, salt hydrates, and fatty acids are all types of phase change materials that are commonly used in industrial applications, however these materials are often more expensive than water, have a limited peak discharge power when in solid state, and can deteriorate over time [8].

1.3.3 Chemical Energy Storage

For a chemical to be considered for use in a thermal store, it must possess a few key properties. Consider the reversible reaction following chemical reaction:

$$AB + Heat \leftrightarrow A + B \tag{1.3}$$

When charging the store, heat is added causing the reaction to proceed from left to right, separating the compound AB into products A and B. Conversely, when discharging the store, the reaction proceeds from right to left. The reactants A and B combine in an exothermic reaction producing the compound AB and releasing heat. For a chemical to be considered for thermal storage, all the compounds, A, B, and AB, must exist in a stable form, and the charging products A and B should be easily separated so that they can be stored separately [5].

Unlike sensible and latent heat storage, chemical storage has the potential to be a very good long-term or seasonal store of energy. Thermal energy used to charge the chemical store is converted to chemical potential energy minimizing the sensible heat losses if the charging products (A and B) are stored over long periods of time. One chemical being researched for chemical storage is magnesium sulphate heptahydrate ($MgSO_4{\cdot}7H_2O$). When heated, it dehydrates and separates into magnesium sulphate ($MgSO_4$) and water vapour [9] [10]. Unfortunately this thermo-chemical heat storage method is still in the development and not commercially available.

1.4 Solar Combi-systems

In addition to containing solar collectors and a thermal storage system, solar thermal systems also require a heat distribution system which supplies energy to a load. These loads can range from space heating, hot water heating, or even industrial process heat in the case of commercial systems. Residential systems designed to meet or offset both space heating and hot water loads are commonly referred to as combi-systems. The advantage of combining these two systems together is that the domestic hot water component allows the system to be utilized year round. While combi-systems are not very common in North America, there are many commercially available combi-systems in Europe. These systems come in a variety of different sizes and configuration, with collector arrays ranging from 2 to 50 m^2 and storage tanks ranging from 250 to 5000 l [11]. Despite these differences all combi-systems have the same basic components: a collector loop (containing the solar collectors and connected to the thermal storage unit), a space heating loop, and a domestic hot water loop. See Figure 1.3.

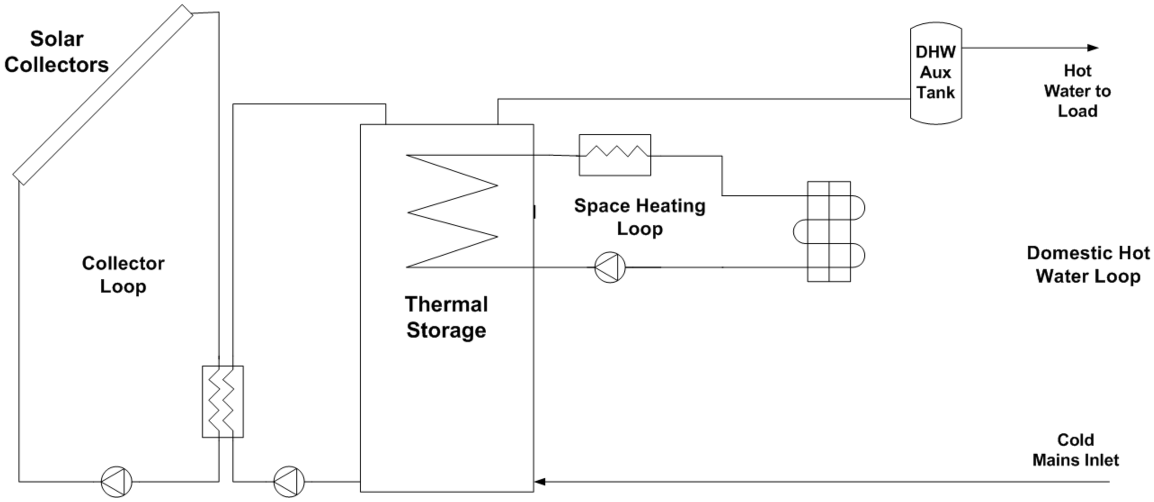
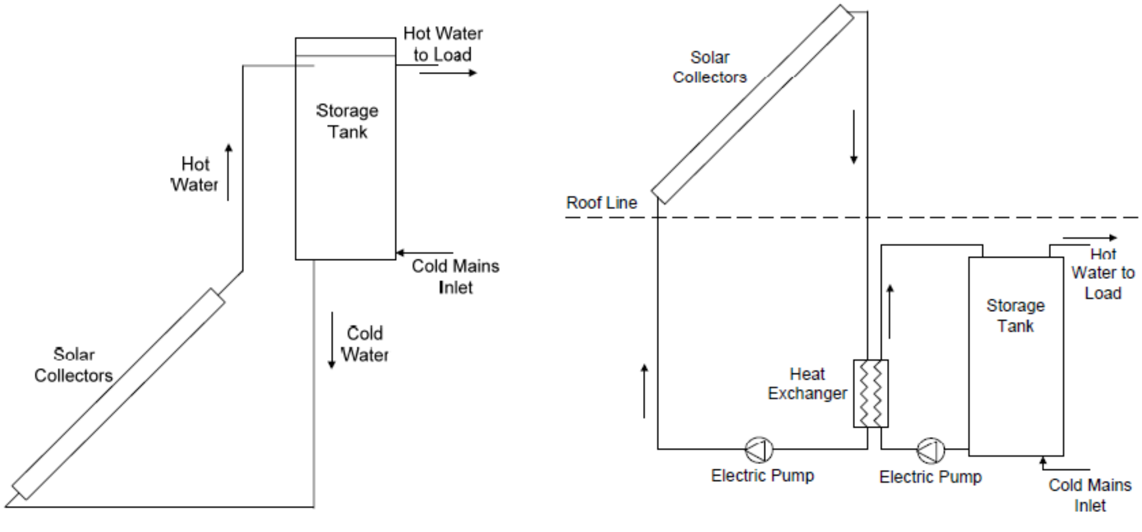


Figure 1.3: Example of a solar combi-system

1.4.1 Collector Loop

The collector loop contains the solar collector and is the part of the system that is exposed to the elements outside. The solar collector can be connected to the rest of the system in a number of different ways. Two examples are depicted in Figure 1.4.



(a) Natural Circulation Configuration (b) Forced Circulation Configuration

Figure 1.4: Examples of collector loop configurations (Source: [6])

Figure 1.4(a) shows an example of a natural circulation (themosyphon) configuration with the collector fluid entering the storage tank directly. With a natural circulation arrangement, the fluid in the collector loop relies on natural convection to circulate. This occurs as the fluid in the collector is heated and becomes less dense, causing it to rise. As it rises, cold fluid from the bottom of the storage tank flows to replace it, resulting in circulation within the collector loop. However, for this to work, the storage tank must be located above the level of the collectors, and care must be taken to minimize flow resistance in the pipes that would impede the circulation of the fluid. This placement of the storage tank is not always practical especially when working with combi-systems that require large thermal stores. Furthermore, if this type of system is operating in cold or freezing temperatures there is a risk of freezing and high heat losses, especially if the storage tank is mounted outside (e.g., on a roof).

Another collector loop design, depicted in Figure 1.4(b), shows a system with a pump used to circulate the collector fluid. Unlike the natural circulation loop described above, the collector fluid is not used as the storage media, but instead is passed through a heat exchanger transferring the collected energy to the thermal store. This allows for two different fluids to be used: one in the collector loop, and a second in the storage tank.

Since sections of the collector loop are located outside the building envelope, some type of freeze protection is needed if the system is going to operate during the winter when the temperature can fall below freezing. There are two techniques commonly employed to address this problem, using an antifreeze fluid (like a glycol solution) or a drain-back system.

Antifreeze systems often use a configuration that employs a non-freezing fluid in the solar collector loop, and a heat exchanger to transfer heat from the collector loop to a second fluid in the thermal store, typically water, Figure 1.4(b). An expansion tank is also often required in the collector loop to accommodate the expansion and contraction of the fluid, preventing pipe connections from rupturing and air from entering the system.

Drain-back systems, on the other hand, are designed such that when fluid is not circulating in the collector loop, the exterior collector and pipes are emptied or drained of fluid, thus preventing freezing. A drain-back system may employ an air pocket within the thermal store which allows gravity to drain the collector when the pump is turned off, Figure 1.5. Other systems may use a separate, smaller, tank to accommodate the drained collector fluid. During the design and installation of drain-back systems, the arrangement of the collector and piping must be planned and installed with care to ensure a steep enough incline to drain the system and prevent collector fluid from remaining within the exterior portions of the system when not in use to prevent freezing.

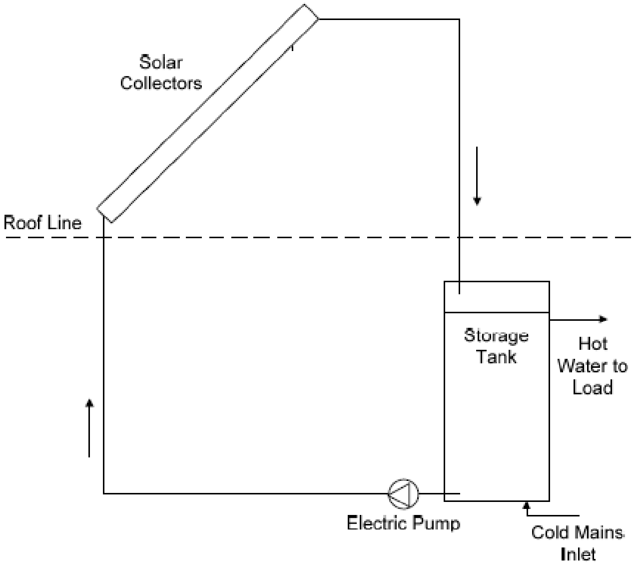
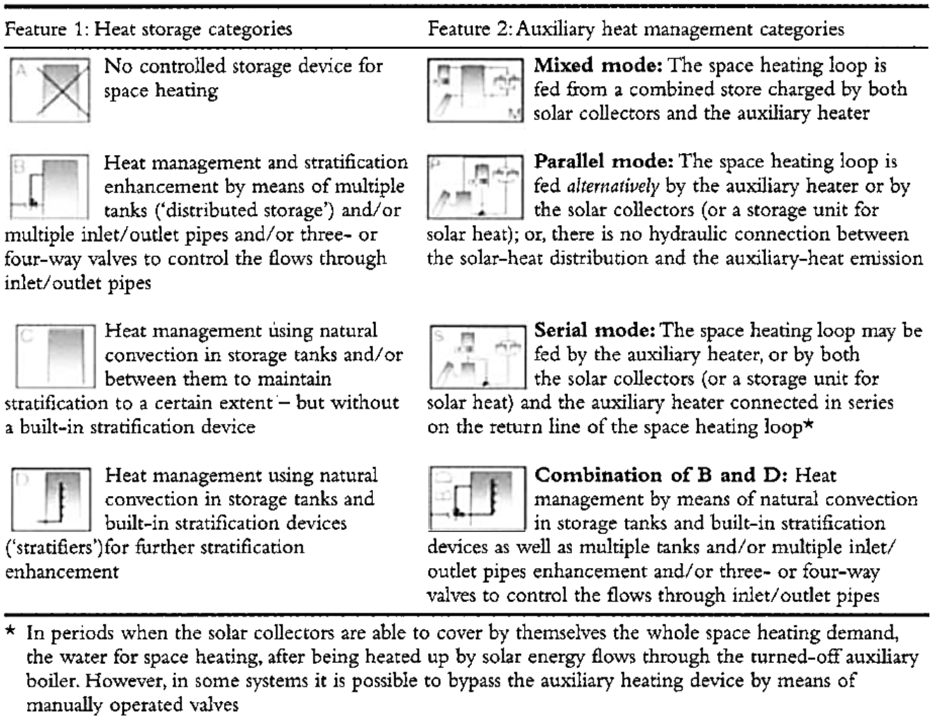


Figure 1.5: Example of a drain-back system (Source: [6])

1.4.2 Space Heating and Hot Water Loops

As their names suggest, the space heating and domestic hot water loops supply energy to the space heating and domestic hot water loads respectively. These loops can be integrated with the collector loop in a variety of different ways, and the IEA's Task 26 developed a classification system for solar combi-systems [11]. As Table 1.1 illustrates, the classification of solar combi-systems can be determined by two main features, the thermal heat storage type, and the auxiliary heat management strategy.

Table 1.1: IEA Task 26 classification of solar combi-systems



Feature 1: Heat storage categories	Feature 2: Auxiliary heat management categories
A: No controlled storage device for space heating	M: **Mixed mode:** The space heating loop is fed from a combined store charged by both solar collectors and the auxiliary heater
B: Heat management and stratification enhancement by means of multiple tanks ('distributed storage') and/or multiple inlet/outlet pipes and/or three- or four-way valves to control the flows through inlet/outlet pipes	P: **Parallel mode:** The space heating loop is fed *alternatively* by the auxiliary heater or by the solar collectors (or a storage unit for solar heat); or, there is no hydraulic connection between the solar-heat distribution and the auxiliary-heat emission
C: Heat management using natural convection in storage tanks and/or between them to maintain stratification to a certain extent – but without a built-in stratification device	S: **Serial mode:** The space heating loop may be fed by the auxiliary heater, or by both the solar collectors (or a storage unit for solar heat) and the auxiliary heater connected in series on the return line of the space heating loop*
D: Heat management using natural convection in storage tanks and built-in stratification devices ('stratifiers') for further stratification enhancement	**Combination of B and D:** Heat management by means of natural convection in storage tanks and built-in stratification devices as well as multiple tanks and/or multiple inlet/outlet pipes enhancement and/or three- or four-way valves to control the flows through inlet/outlet pipes

* In periods when the solar collectors are able to cover by themselves the whole space heating demand, the water for space heating, after being heated up by solar energy flows through the turned-off auxiliary boiler. However, in some systems it is possible to bypass the auxiliary heating device by means of manually operated valves

Source: [11]

Since this classification system is concerned primarily with the space heating loop, the design of systems within the same category can greatly differ depending on how the domestic hot water loop is integrated. The domestic hot water loop can either share or have its own auxiliary heat source, and the thermal storage media can use the collector fluid, domestic hot water, space heating fluid, or even be a self contained unit.

1.4.3 Existing Combi-systems

Very few residential solar combi-systems are in operation in Canada. At the end of 2012, only 2% of the solar thermal capacity installed in Canada and the US were combi-systems while 21% were domestic hot water systems, and the majority (75%) were used for swimming pool heating [12]. Despite this, demonstration houses are being built to show the potential of alternative residential heating options, and in 2012 almost 9% (1240 m² gross collector area) of evacuated tube and glazed liquid solar collector sales were used in combi-systems for single family homes [13].

One Canadian project that has incorporated a liquid based solar combi-system into the building design is the Riverdale NetZero house. This residence is located in Edmonton, Alberta, and was built as part of the Canada Mortgage and Housing Corporation (CMHC) Equilibrium Sustainable Housing Demonstration Initiative [14]. Each unit of this duplex has its own 22 m² solar thermal collector array with a 300 L domestic hot water storage tank and a 17 000 L space heating storage tank, and this system is predicted to provide 28.4% of the space heating load.

The European solar combi-system market is much larger than Canada's. In 2012 the Solar Heating & Cooling Programme (SHC) reported that approximately 42.8 GW_{th} of solar thermal collectors were operating in Europe (of which 18% was used by solar combi-systems), compared to the approximately 0.87 GW_{th} in Canada [12]. In particular, as of 2013 there were 16.9 million squar metres of glazed solar collectors in operation in Germany alone; almost 40% of the total glazed collector area in operation in the EU28 plus Switzerland [15].

One example of a commercially available combi-system is the SolvisMax Gas, manufactured by SOLVIS GmbH & Co. KG [16]. This system has been on the market in Germany since 1997, and as of 2002 had sold over 3000 units [11]. As depicted in Figure 1.6, the combi-system consists of a collector loop (in green), a domestic hot water loop (in blue), and a space heating loop (in red) which also contains the thermal energy storage unit. This tank contains the auxiliary heat supply and uses two internal stratifiers or diffusers to maintain thermal stratification within the tank. The auxiliary heat management is a mixed mode type meaning the storage tank feeding the space heating loop is charged by both the solar collectors and the auxiliary heater [17]. This system is identified by the IEA Solar Heating & Cooling Programme Task 26 as Combi-System #15 [11].

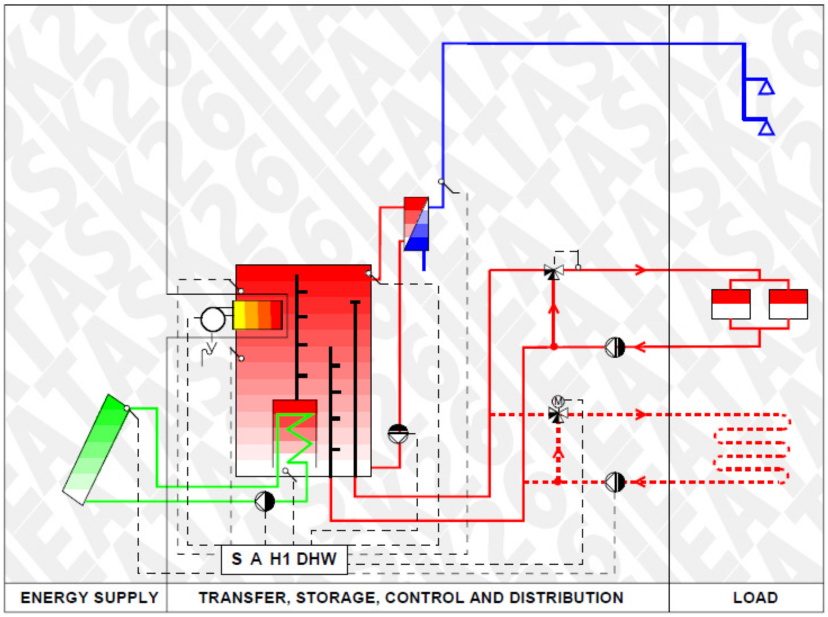


Figure 1.6: Task 26 System #15 design schematic (Source: [18])

Another combi-system configuration is the IEA SHC Task 26 Generic System #1, Figure 1.7. This system was developed at the end of the 1970s and was the main solar combi-system installed in France between 1986 and 1992 [11]. The majority of the components in this system come factory-assembled in compact units making installation easy, and making it possible for home owners to save on installation costs by installing the system themselves [11].

In the IEA SHC Task 26 Generic System #1, heat from the solar collectors can be directed to either charging the domestic hot water storage tank, or it can be supplied directly to the space heating load (hydronically heated floors). Unlike the Task 26 System #15 (described above), this system has no thermal storage for space heating and the auxiliary heat source is independent from the combi-system (e.g., pellet stove, electric baseboard heaters, gas furnace ...). Here a parallel heat management strategy is used since there is no hydraulic connection between the solar combi-system and the auxiliary space heating source.

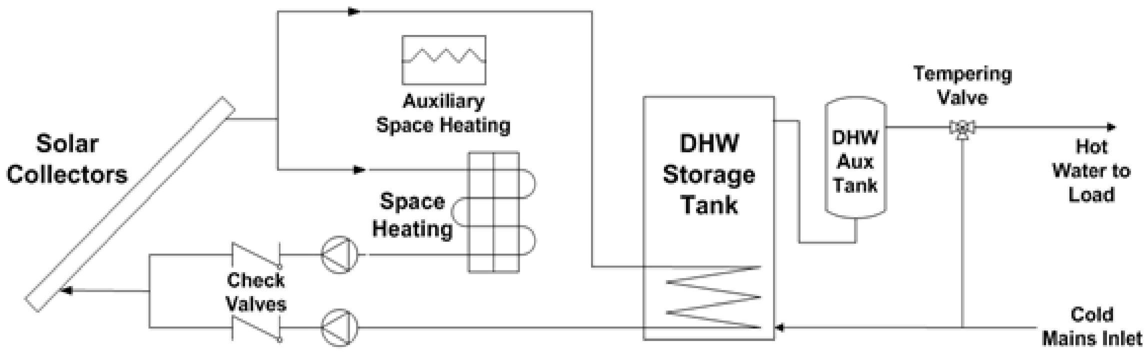


Figure 1.7: Task 26 System #1 design schematic

A review of previous work shows that a variety of combi-system configurations have been developed, and standardized methods for determining solar combi-system performance are needed to account for differences in available solar energy, space heating loads, and domestic hot water loads. Further discussion of previous solar combi-system investigations and performance indices can be found in Chapter 2. The following section outlines and defines the research undertaken in the thesis and describes the study methodology.

1.5 Problem Definition

With a continuously increasing demand for clean energy, solar combi-systems offer an alternative to traditional residential space heating and domestic hot water energy sources like oil, natural gas, and electricity. However, with so many variations in design and configuration, determining which systems are best suited for a North American market warrants investigation.

The objectives of this preliminary study were to evaluate the potential of different solar thermal combi-systems to meet the residential heating requirements for single family dwellings in the Northern US and Canada, and to compare the relative performance of the different systems.

1.5.1 Scope

The scope of this study was limited to:

- development of three solar combi-system designs: stand-alone systems, basic combi-system, and single-tank system;
- comparison of the theoretical thermal performance of select solar combi-systems will be made disregarding stagnation control and parasitic energy use (e.g., pump and controller loads) which is usually small compared to the thermal loads of solar combi-system;
- systems studied will be intended to supply only space heating and domestic hot water loads (i.e., without consideration for space cooling and electric generation);
- only systems using liquid solar thermal collectors will be considered;
- only systems using short term water based thermal storage will be studied (i.e., seasonal storage systems were not investigated); and
- combi-system operation in a Canadian/Northern US climate/market.

1.5.2 Methodology

The performance of the investigated systems was determined through modelling and simulation with the simulation software package TRNSYS. Generic space heating and domestic hot water loads were determined using Meteonorm (for Canadian locations) or TMY (for US locations) weather data. The systems were individually optimized for tilt angle and flow rate before further analysis was conducted to evaluate the relative performance of different systems and location. Further sensitivity analysis on the effect of thermal storage size, stratification, collector size, and heat exchanger effectiveness was also investigated. An overview schematic of the study methodology is shown in Figure 1.8.

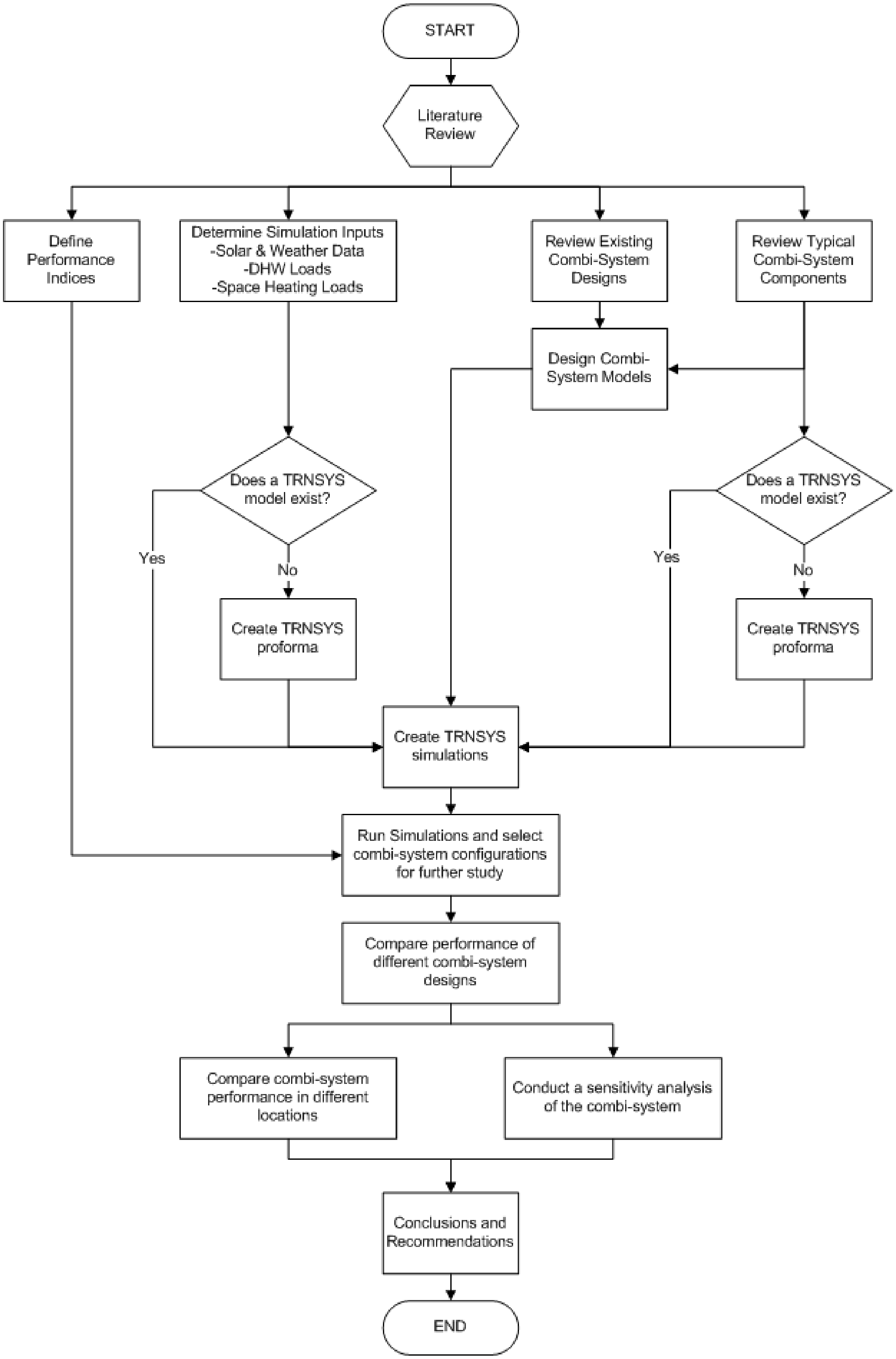


Figure 1.8: Overview of thesis outline

Chapter 2

Literature Review

2.1 Solar Fraction

Before any solar systems can be compared, it is necessary to define indices that can be used to quantify and compare a system's performance. There are different parameters that can be used, however when comparing solar combi-systems, the most common parameter used is the solar fraction. Nominally, the solar fraction of a solar thermal system is defined as the fraction of the heating load that is supplied by solar energy. In its simplest form, this can be expressed as:

$$F_s = \frac{Q_{sol}}{Q_{load}} \tag{2.1}$$

where:

F_s is the solar fraction [-];
Q_{sol} is the solar energy delivered directly to the load [kWh]; and
Q_{load} is the thermal energy delivered to the heating load [kWh].

However, this definition of the solar fraction can be misleading and imprecise. For instance, the term Q_{load} does not include any energy losses the system might have. This means the actual energy required by the system may be larger, which if accounted for, would reduce the solar fraction. Furthermore, depending on if and where auxiliary thermal energy is delivered to the heating load, it may not be possible to measure Q_{sol} directly.

To address these fallibilities, the solar fraction can be redefined as:

$$F_s = \frac{Q_{ref} - Q_{aux}}{Q_{ref}} \tag{2.2}$$

where:

F_s is the solar fraction [-];
Q_{ref} is the energy input delivered by a (non-solar) reference system to meet the total load [kWh]; and
Q_{aux} is the additional auxiliary energy required to meet the total load when part of the energy is supplied by the solar system [kWh].

Here the reference system is usually defined as an equivalent non-solar system. With this definition, the solar fraction can be thought of as the percentage of the reference system's load that can be offset with the addition of a solar energy system. By defining the solar contribution as the difference between the reference load and the solar system's auxiliary load, additional system losses introduced by the solar component are accounted for, and the solar fraction reflects the energy savings as compared to the reference system.

Even with this second solar fraction definition, i.e., Equation (2.2), there can still be some ambiguity. There are various ways the reference system load and the solar system auxiliary load can be defined. For instance, the loads can be specified in terms of thermal energy consumption or secondary energy (oil, electricity, natural gas) consumption, and the parasitic loads from the pumps and controllers may or may not be included in the calculation.

The concept of the solar fraction has been further refined in different ways. Duffie and Beckman describe a term called the solar savings fraction (F_{sav}) [5]. This term factors in the economical cost of the different energy sources used, including any additional energy needed for parasitic loads and can be calculated as:

$$F_{sav} = \frac{C_f Q_{ref,f} - C_f Q_{aux,f} - C_e Q_{aux,e}}{C_f Q_{ref,f}} \tag{2.3}$$

where:

F_{sav} is the solar savings fraction [-];
C_f is the cost of fuel [\$/kWh];
C_e is the cost of electricity [\$/kWh];
$Q_{ref,f}$ is the total amount of fuel required by the non-solar reference system [kWh];
$Q_{aux,f}$ is the total amount of fuel used by the solar system [kWh]; and
$Q_{aux,e}$ is the total amount of electricity used by the solar system [kWh].

This definition assumes the parasitic energy used by the reference system is negligible compared to that of the solar system, and that the thermal energy is supplied by a fuel, although this term could easily be adjusted to reflect a system that uses electricity to supply the thermal load.

The IEA SHC Task 26 also defined similar terms to evaluate the performance of solar combi-systems: the fractional thermal energy savings ($f_{sav,therm}$), the extended fractional energy savings ($f_{sav,ext}$), and the fractional savings indicator (f_{si}) [11]. The fractional thermal savings is calculated as:

$$f_{sav,therm} = 1 - \frac{E_{aux}}{E_{ref}} \tag{2.4}$$

where:

$f_{sav,therm}$ is the fractional thermal energy savings [-];
E_{aux} is the primary energy used by the additional auxiliary component(s) in solar system to meet the thermal load [kWh]; and
E_{ref} is the primary energy used by the reference system to meet the thermal load [kWh].

As the name suggests, the fractional thermal energy savings only considers the thermal energy used and does not account for parasitic energy. The calculation uses secondary energy sources for consistency, and has been further defined by the IEA SHC Task 26 as:

$$f_{sav,therm} = 1 - \frac{\frac{Q_{boiler}}{\eta_{boiler}} + \frac{Q_{el.heater}}{\eta_{el.heater}}}{\frac{Q_{boiler,ref}}{\eta_{boiler,ref}}} \tag{2.5}$$

where:

$f_{sav,therm}$ is the fractional thermal energy savings [-];
Q_{boiler} is the thermal energy load supplied by the boiler in the solar system [kWh];
$Q_{el.heater}$ is the thermal energy load supplied by the electrical heating element in the solar system [kWh];
$Q_{boiler,ref}$ is the thermal energy provided by the boiler in the reference system [kWh];
η_{boiler} is the mean annual efficiency of the boiler in the solar system [-];
$\eta_{el.heater}$ is the annual electrical generation efficiency [-]; and
$\eta_{boiler,ref}$ is the mean annual efficiency of the boiler in the reference system [-].

The efficiencies (η_{boiler}, $\eta_{el.heater}$, and $\eta_{boiler,ref}$) are used to convert the thermal energy used by the system into the equivalent amount of secondary energy. Here, η_{boiler} and $\eta_{boiler,ref}$ are determined based on the lower heating value and do not take into account the energy used in the refining and transportation of the fuels. The electrical generation efficiency, $\eta_{el.heater}$, is given an efficiency of 90% for systems that use only renewable electrical energy sources like PV and hydroelectric, and an efficiency of 40% for all other systems [11].

The extended fractional energy savings ($f_{sav,ext}$) is an extension on the previous definition. This parameter compares the total energy consumption of both the solar and reference systems by adding additional terms for the parasitic energy. It is calculated as:

$$f_{sav,ext} = 1 - \frac{E_{total}}{E_{total,ref}} \tag{2.6}$$

where:

$f_{sav,\mathrm{ext}}$ is the extended fractional thermal energy savings [-];
E_{total} is total primary energy load of the solar system [kWh]; and
$E_{total,ref}$ is total primary energy load of the reference system [kWh].

Again, this calculation relies on all energy loads being converted into primary energy and has been further defined by the IEA SHC Task 26 as:

$$f_{sav,ext} = 1 - \frac{E_{aux} + \frac{W_{par}}{\eta_{el}}}{E_{ref} + \frac{W_{par,ref}}{\eta_{el}}} \tag{2.7}$$

where:

$f_{sav,\mathrm{ext}}$ is the extended fractional thermal energy savings [-];
W_{par} is the parasitic energy load of the solar system [kWh];
$\mathrm{W}_{par,ref}$ is the parasitic energy load of the reference system [kWh]; and
η_{el} is the electrical efficiency for the parasitic loads [-].

Here it is assumed that the parasitic energy is limited to electrical devices and an electrical efficiency (η_{el}) of 40% was used for all IEA SHC Task 26 systems [11].

Lastly, the fractional savings indicator further refines the fractional energy savings definition by making adjustments for systems that are unable to supply the required domestic hot water or space heating loads. It can be calculated by:

$$f_{si} = 1 - \frac{E_{total} + Q_{penalty,red}}{E_{total,ref}} \tag{2.8}$$

where:

f_{si} is the fractional savings indicator [-];
E_{total} is total primary energy load of the solar system [kWh];
$E_{total,ref}$ is total primary energy load of the reference system [kWh]; and
$Q_{penalty,red}$ is the penalty applied if the solar system is unable to meet the required hot water or space heating demands [kWh].

This term may be important when considering systems that have limited energy available (e.g., homes that operate off-the grid) or where economical cost savings are being optimized (e.g., using a control strategy that limits auxiliary electrical heating to off-peak hours). However, in systems where these factors are not a concern (i.e. $Q_{penalty,red}$ = 0), the fractional savings indicator (f_{si}) is equal to the extended fractional thermal energy savings ($f_{sav,\mathrm{ext}}$).

2.2 Collaborative Combi-System Initiatives

As described in Chapter 1, solar combi-systems come in many different shapes and sizes, and the research into solar combi-systems is just as varied. Coordinated research projects include the International Energy Agency (IEA) Solar Heating and Cooling (SHC) Programme Task 26 on solar combi-systems. This collaboration was commissioned in 1998 and its goal was to coordinate research and further the development of solar combi-systems and solar combi-system testing and certification standards [11]. As part of this task, a market survey was conducted and over 20 different commercially available combi-system designs were identified and 4 standardized reference buildings were defined: three single family houses and a multi-family house, all located in Zurich, Switzerland [19]. General strategies for optimizing combi-system performance ($f_{sav,\mathrm{ext}}$ and $f_{sav,\mathrm{therm}}$) were identified as: keeping boiler efficiencies as high as possible, keeping the collector inlet as cold as possible (to increase the solar collector performance), avoiding temperature losses through mixing (i.e. maintaining thermal stratification in thermal stores) to minimize heat losses, and using efficient pumps or eliminating pumps where possible (e.g., a natural circulation system) to minimize the parasitic load [20].

Another collaborative European study on solar combi-systems was the conducted by Altener as a sister study to the IEA's Task 26. This project was started in 2001 with the aim of collecting practical information on real installed solar combi-systems [21]. Part of this project consisted of the building and documenting of approximately 200 solar combi-systems [22]. As a result, a number of common integration problems were identified and a document outlining these problems and solutions was produced and disseminated to installers [23].

2.3 Solar Combi-System Studies

Streicher et al. performed a sensitivity analysis using 9 of the combi-systems identified in the IEA SHC Task 26 [18]. These systems were modelled in TRNSYS and the parameters investigated were: climate (Carpentras, France; Zurich, Switzerland; and Stockholm Sweden), solar collector (area, slope, azimuth, mass flow rate, and control method), thermal storage (volume, insulation, location of heat exchanges, location of sensors, location of inlets and outlets, control settings), boiler, and heat load[1]. As expected, the solar fraction was highest for systems operating in Carpentras where the climate was the warmest and had the greatest amount of solar radiation, followed by Zurich, and finally Stockholm where the climate was the coldest and had the least amount of solar radiation. Analysis of the solar collector parameters showed that the collector size had the greatest effect on $f_{sav,\mathrm{ext}}$ and the collector flow rate had very little effect. Thermal storage parameters that had the greatest effect on $f_{sav,\mathrm{ext}}$ were the location of the collector outlet position (it is best to use the solar collector to heat water from the bottom of the tank as opposed to the top) and the amount of insulation on the sides of the tank. A comparison

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[1] The building loads are the reference building used by the IEA SHC Task 26 and is described in detail in Structure of the Reference Buildings of Task 26 by Streicher and Heimrath [19]

of the 9 combi-systems using the FSC method (described in Section 2.4), showed that System #15, Figure 1.6, had the best performance based on $f_{sav,therm}$, but was surpassed by System #3a at FSC values above 0.5 when $f_{sav,\mathrm{ext}}$ was used to measure performance [18].

Lundh et al. studied the influence of large thermal storage size, and geometry on solar combi-system performance, looking at single-tank thermal storage arrangements with volumes ranging from 2m³ to 10m³ (2000 l to 10000 l) and an auxiliary thermal storage tank ranging in size from 100 l to 600 l [24]. A single-family home located in Zurich, Switzerland[2] with 30 m² of solar collector area was used for the simulations. Results from this study showed that system performance ($f_{sav,therm}$) increased as the storage volume increased up until 6m², at which point the performance remained largely the same. Their simulations also showed that large thermal stores are much less sensitive to variations in the tank height to diameter ratio, especially if they are well insulated, and in most cases, configurations with an internal auxiliary store (located in the main thermal storage unit) outperformed those where the auxiliary store was located externally. However, it should be noted that at the time this study was conducted, there were no existing hot water storage tanks with the size and geometry investigated in the study [22], and constraints like basement ceiling height and entrance door dimensions further limit the potential for using a single large tank for thermal storage in existing homes.

Hugo et al. used the program TRNSYS to model and investigated the performance of a solar combi-system with seasonal storage for a single-story (with basement) detached house located in Montreal, Quebec with a total area of 210 m² [25]. The combi-system investigated used a large seasonal storage tank with internal stratifiers and space heating was achieved through a hydronic radiant heated floor with a variable speed pump, Figure 2.1. The performance was simulated for a period of two years with the first year used to prime the system and the second

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[2] This building load (SFH 60kWh/m²a) is one of the reference building used by the IEA SHC Task 26 and is described in detail in Structure of the Reference Buildings of Task 26 by Streicher and Heimrath [19]

year used to evaluate system performance. The simulations showed that a combi-system with a vacuum tube collector area of 51.4 m² and a storage tank volume of 38.6 m³ resulted in a solar fraction of 100%. Despite this stellar performance, the seasonal storage tank used in the simulations was modelled as a 5.2 m tall vertical cylindrical storage tank, the cumulative height of the basement and first floor of the house, making the diameter approximately 3 m (not including insulation). This does not seem practical for a home located in the city.

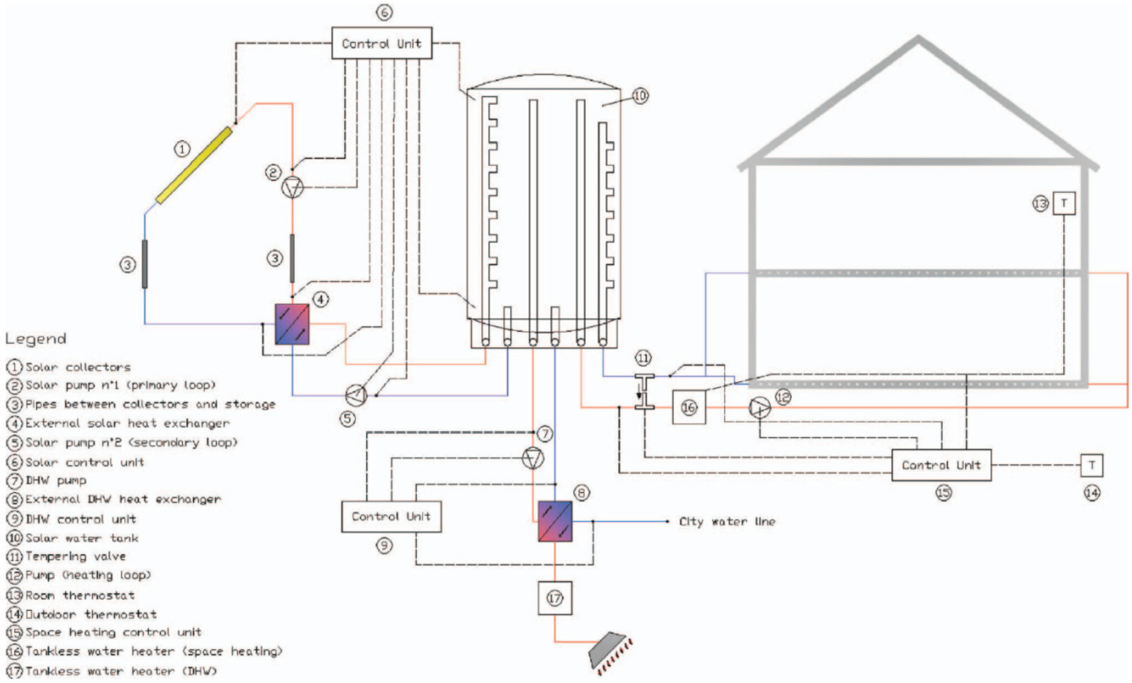

Figure 2.1: Schematic of combi-system with seasonal storage investigated by Hugo et al. (Source: [25])

Andersen et al. investigated the effect of three different control strategies on operation costs, using a single family home located in Denmark. All three strategies used the same base solar combi-system with a main storage volume of 750*l* and internal stratifiers [26]. In the first control strategy (smart solar heating system), the auxiliary heating was limited to off-peak hours between 2 am and 5 am (when the cost of electricity was low). The auxiliary volume and temperature set point were also adjusted monthly based on the weather forecasts, and set to ensure the energy demand was fully met without requiring electricity at peak prices. The second control strategy used a semi-smart solar heating system which also limited the auxiliary heating to off-peak hours, but had a fixed auxiliary volume (750*l*) and set point (90°C). In the third control strategy, a traditional solar heating system was used with a fixed auxiliary volume (240*l*) and set point (50°C) was used, and the auxiliary heating was not restricted to off-peak hours. Results from the TRNSYS simulations showed that the traditional system required the least auxiliary energy, followed by the smart system and then the semi-smart system, however, if the hourly price of electricity is considered (energy rates for Denmark during 2009) then the smart system becomes the least expensive to run and the traditional and semi-smart systems have similar operating costs.

Bertsch et al. used simulations to examine the use of open and closed solid sorption (thermo-chemical storage) systems for homes located in Zurich, Switzerland [27]. Both system types require high temperatures (180°C to 200°C) which resulted in most of the charging occurring during the summer months, and making these types of systems better suited for seasonal storage applications.

2.4 Design Tools and Characterization

The performance of solar combi-systems depends on a large number of variables such as the local weather and climate, occupant behaviour, building construction, collector orientation, not to mention the system configuration and sizing. Conducting year-long tests to measure the performance of combi-systems can be impractical because of the time involved and also the variability of the weather that cannot always be adequately controlled or simulated. This can make determining and comparing system performance very difficult, so many techniques and methods have been developed to simplify this calculation.

2.4.1 Experiment Based Methods

Experiment based methods for characterizing solar combi-systems use the actual system components to test the system and are typically conducted in a lab setting where the solar input and heating loads can be controlled. An example of an experimental method is the Direct Characterization (DC) test procedure [11] [28] [29].

The DC test procedure tests solar combi-system as a single unit using a 6 day test sequence. The system is first preconditioned and the solar input and the heating loads are simulated based on two winter, two summer, and two spring/autumn days for a particular location. From this 6 day test sequence, the annual final energy use is calculated according to [29]:

$$E_{aux,year} = \left(\frac{Q_{load,year}}{Q_{load,test}}\right) E_{aux,test}\, F_{system} \tag{2.9}$$

where:

$E_{aux,year}$ is the annual auxiliary heating energy required [kWh];
$Q_{load,year}$ is the annual domestic hot water and space heating load [kWh];
$Q_{load,test}$ is the measured domestic hot water and space heating load during the test [kWh];
$E_{aux,test}$ is the auxiliary heating energy used during the 6 day test sequence [kWh]; and
F_{system} is a system and load dependent prediction correction [-].

To develop and test the DC method, Naron and Visser used computer simulations to model combi-systems in two single family houses[3] located in Zurich, Switzerland with annual heating loads of 60 kWh/m² and 100 kWh/m² [28]. First two different sized combi-systems were used to optimize the test sequence for each of the heating loads, then using the optimized sequences an additional 8 combi-systems were used to develop a correction formula to correct for the thermal storage volume. This test procedure has been shown to apply to solar combi-systems with thermal stores between 1500 and 2000 litres, and less than 15 to 20 m² of collector area. Using the correction formula for storage volume, the prediction error for systems in this size

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[3] These building loads (SFH 60 kWh/m²a and 100 kWh/m²a) are reference building used by the IEA SHC Task 26 and is described in detail in Structure of the Reference Buildings of Task 26 by Streicher and Heimrath [19]

range is less than 5%, however the authors were unable to extrapolate the test results from the smaller heating load to accurately predict the performance with the larger heating load [28].

Another experiment based characterization method is the Concise Cycle Test (CCT) method [30]. This procedure is similar to the DC test except it uses a 12 day test sequence to assess the combi-system performance and the space heating load is not predetermined, instead the building is simulated allowing the system's controller(s) to decide how and when heat is supplied to the load. This model was developed using a single family house located in Switzerland with an annual heating load of 15500 kWh/a. Vogelsanger used this method to test four systems, all with storage volumes around 700*l* and collector areas between 10 m² and 15 m² [30]. These tests were able to reveal discrepancies in actual and intended performance based on incorrect controller setting, making this test method suitable for verifying the correct operation of solar combi-systems, however its accuracy in predicting system performance is yet to be determined.

2.4.2 Simulation Based Methods

Simulation based characterization methods rely on computer modelling and simulation of solar combi-systems to determine system performance, and aid in the development of simplified correlations to describe performance in a variety of conditions. With computers becoming increasingly powerful reducing the computational time it takes to run complex simulations, these correlations are perhaps not as important as they once were, however they are still useful for quick "back of the envelope" calculations and providing a means of describing a system's performance over a range of conditions.

One example of a simulation based characterization method is the f-chart method. It is a technique used for estimating the annual thermal performance of solar thermal systems for buildings. It was developed using the results of multiple numerical simulations which were the correlated in terms of the two dimensionless variables [5]:

$$X = \frac{A_c F_R' U_L \left(T_{ref} - \bar{T}_a\right) \Delta t}{L} \tag{2.10}$$

and

$$Y = \frac{A_c F_R' (\overline{\tau\alpha}) \bar{H}_T N}{L} \tag{2.11}$$

where:

A_c is the collector area [m²];
F_R' is the collector heat exchanger efficiency factor [-];
U_L is the overall collector loss coefficient [W/m²-K];
Δt is the length of the month [s];
$\bar{T}_a$ is the monthly average ambient temperature [°C];
T_{ref} is an empirically derived reference temperature [100°C];
L is the total monthly heating load (both space and hot water) [J];
$\bar{H}_T$ is the average monthly radiation incident on the collector surface each day [J/m²];
N is the number of days in the month [-]; and
$(\overline{\tau\alpha})$ is the average monthly transmittance-absorbance product [-].

Using these two parameters, the fraction of the monthly load supplied by the solar thermal system can then be determined by entering the values into the appropriate equation or using a look-up table for the system type considered.

With this method, correlations can be created for a wide variety of solar systems including: liquid combi-systems, solar domestic hot water systems, air heating systems, and solar cooling systems. However, correlations for each different type and arrangement of system must be developed separately. This means sizing systems using this method can be accomplished with relative ease, but to compare different system configurations, individual correlations must already exist for each system arrangement.

A second example of a simulation based method is the fractional solar consumption or FSC method. This method is an alternative to the f-chart method and provides a way for systems in different locations to be compared [11] [31] [32] [33]. It was developed as part of the IEA's Task 26 and it introduced a new dimensionless parameter:

$$FSC = \frac{\sum_{Jan}^{Dec} min\big((E_{total,ref}),\ (A_{coll} I_T)\big)}{\sum_{Jan}^{Dec} E_{total,ref}} \tag{2.12}$$

where:

FSC is the fractional solar consumption [-];
$E_{total,ref}$ is the total monthly energy consumption for the reference system [kWh];
A_{coll} is the area of the collector [m²]; and
I_T is the total monthly radiation on the tilted collector surface [kWh/m²].

Referring to Figure 2.2, the FSC is calculated by dividing the usable solar energy (Region 2) by the total reference load (Regions 1 + 2).

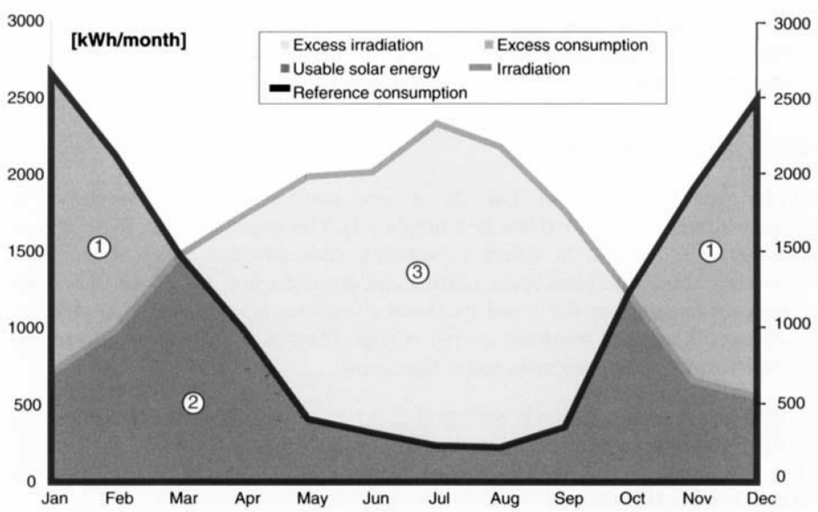

Figure 2.2: Example monthly plot of energy consumption and solar radiation (Source: [11])

The FSC can be thought of as the maximum theoretical fractional energy savings provided the solar thermal system does not employ any long-term seasonal storage. The closer the system's solar fraction is to the FSC, the better the system performance. The FSC can also be used to characterize the performance of individual combi-systems. The solar fraction can be expressed in the form:

$$F_s = a\,FSC^2 + \,b\,FSC + c \tag{2.13}$$

where:

F_s is the solar fraction [-];
FSC is the fractional solar consumption [-]; and
a, b, and c are the coefficients of the solar combi-system [-].

This second order relationship has been validated using simulations, and a wide range of parameters [31], and like the f-chart method, a different correlation is needed for each combi-system configuration.

Other simulation based characterization methods have been developed based on the FSC method. One such design tool is the Task 26 nomogram. It can be used to quickly estimate the performance of systems based in one of the reference climates (Carpentras, France; Zurich, Switzerland; or Stockholm, Sweden) [11] [32]. The program CombiSun is another example. It is a computer based version of the nomogram and it provides users with additional locations to choose from. Lastly, the extended FSC procedure modifies the FSC term so that it can be used to characterize systems with seasonal storage capabilities [34].

2.4.3 Hybrid Methods

Hybrid characterization methods require both physical and computer simulations. The the Component Testing – System Simulation or CTSS method [11] is an example of a hybrid method. The CTSS method can be applied to almost any combi-system. it relies on separately characterizing the main components individually (experiment based testing), and then using a component-based simulation program (like TRNSYS) to predict the thermal performance. This method was validated by Kerskes using a solar combi-system mounted to a low energy single family dwelling in Germany. Detailed measurements lasted three years and showed an $f_{sav,therm}$ of 22%, and a comparison of these results to the CTSS method ($f_{sav,therm}$ = 23%) showed an error of 5% when predicting the long term performance of a combi-system [35].

Other hybrid methods have also been developed. The AC/DC Test developed by Bales [36], was a combination of the CTSS and DC test procedures. It comprised of an annual calculation (AC) that was done using computer simulations, and a direct characterization (DC) test which was the precursor to the DC test procedure. A comparison of the CTSS method with the AC/DC method was conducted by Druck and Bachmann [37]. The combi-system used for the comparison was a "tank-in-tank" system with a nominal storage volume of 600 *l*, Figure 2.3, the heating load was modelled as a single family house located in Zurich, Switzerland[4], and two collector sizes were used (7 m² and 14 m²). In both comparisons, the AC/DC method produced higher F_S values (7 m²: AC/DC – 30.9 %, CTSS – 24.6 %; 14 m²: AC/DC – 41.6 %, CTSS – 30.8 %). This discrepancy can be partially attributed to the reduction of a complete year into a 6 day test sequence which allows the effects of seasonal storage to appear in the shortened test sequence. At this point the AC/DC method is not suitable for comparing different systems based on annual performance.

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[4] This building load (SFH 60kWh/m²a) is one of the reference building used by the IEA SHC Task 26 and is described in detail in Structure of the Reference Buildings of Task 26 by Streicher and Heimrath [19]

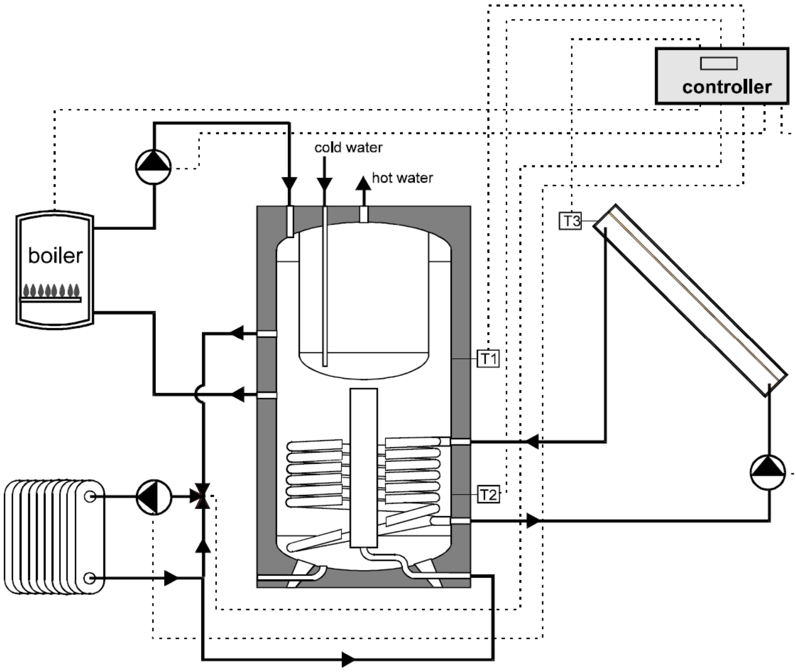


Figure 2.3: Schematic of the "tank-in-tank" solar combi-system used by Druck et al. to compare the CTSS and AC/DC methods (Source: [37])

Chapter 3

Model Simulations

The simulation of solar thermal combi-systems can be separated into three general parts: the inputs, outputs, and the combi-system model, Figure 3.1. The inputs are parameters that are independent of the combi-system. These are related to location (available solar energy and weather conditions), house size (space heating load), and hot water usage (domestic hot water load). The simulation uses the inputs along with a computer model of the combi-system to predict the system performance (eg. solar fraction, solar contribution, collector efficiency) which allows different combi-system configurations to be compared using exactly the same weather and load data.

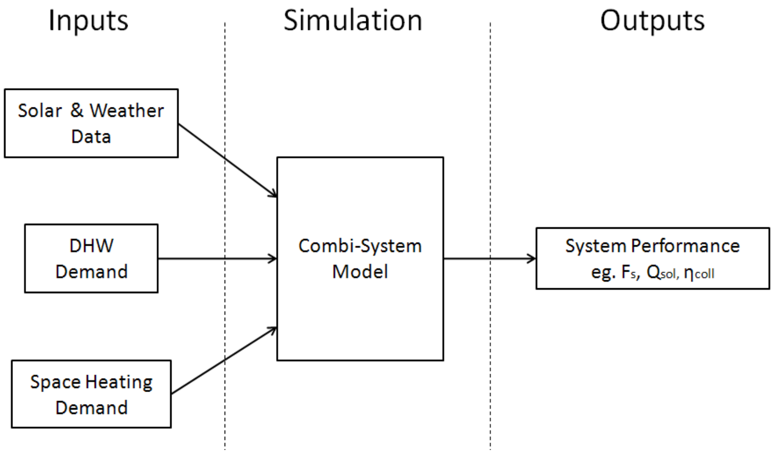


Figure 3.1: General combi-system simulation components

3.1 TRNSYS

The modelling and simulation of the solar systems for this study were completed in TRNSYS 16 (a TRaNsient System Simulation program). TRNSYS was developed by the Solar Energy Laboratory at the University of Wisconsin-Madison, and was designed to simulate thermal and electrical systems. Some of the main applications for which it is used are simulating solar systems, low energy buildings, HVAC systems, renewable energy systems, and fuel cells [38]. TRNSYS has two main functions: a user interface to model systems, and a simulation engine to calculate the performance of the system.

TRNSYS 16 provides a graphical user interface, Figure 3.2, where individual component models (referred to as proforma in TRNSYS) can be connected to create complete systems. These component models are created separately and compiled into a .dll format which is then used by TRNSYS during the simulation. This gives the user the flexibility to develop their own component models in a wide variety of languages while still being compatible with TRNSYS. For a detailed discussion of the components used in the combi-system models, see Appendix A.

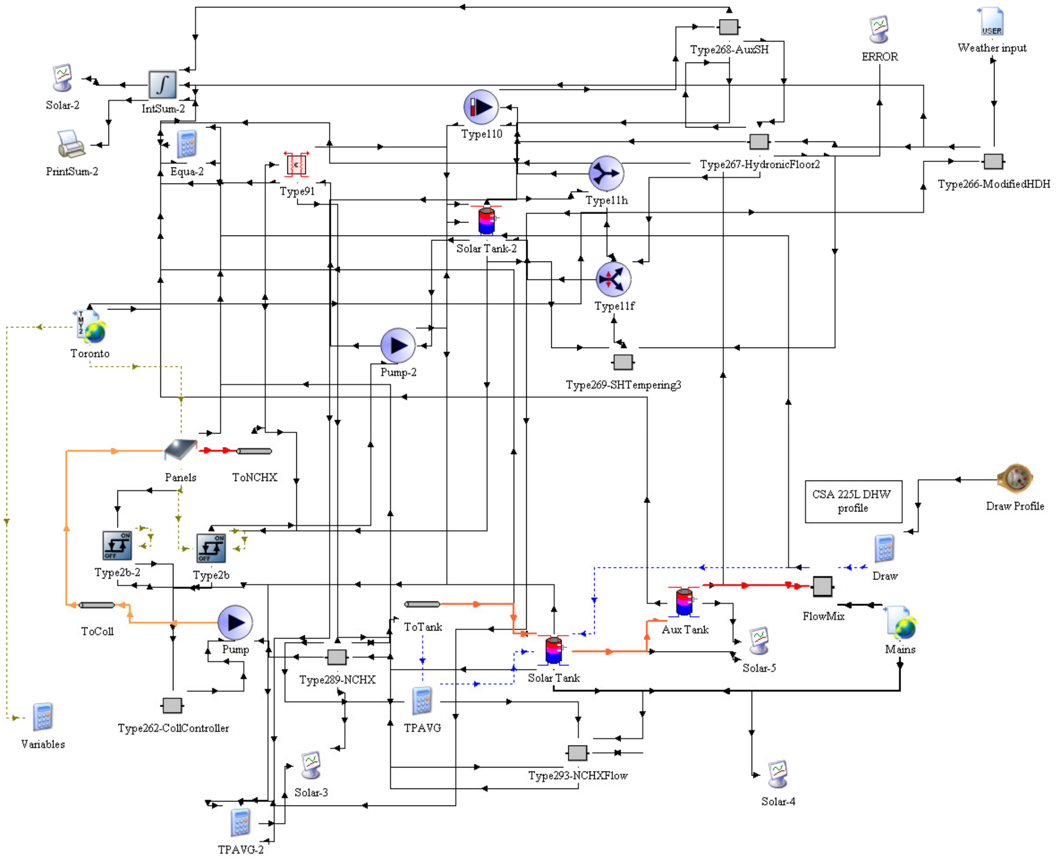


Figure 3.2: Example of a combi-system modelled in TRNSYS

The simulation engine part of TRNSYS is primarily an equation solving program that can simulate the behaviour of transient systems by using a successive substitution method to iteratively solve the system at every time step until specified convergence criteria are met [39]. Unlike other types of simulations where the flow of information is linear, TRNSYS' iterative solving method means there is no component hierarchy established and the effects of all components are propagated throughout the entire system when solving. TRNSYS also has a built in solver for differential equations that may be defined in the component models. The convergence criteria and maximum number of iterations used are listed in Table 3.1.

Table 3.1: TRNSYS Simulation Details

Parameter	Value
Time Step	0.05 hours
Max Iterations (Before 'WARNING')	1000
Convergence Tolerance	0.01
Integration Tolerance	0.01

In TRNSYS, each component or proforma is modelled separately; some standard models are included with TRNSYS or available through third parties like TESS [40], and others can be user-created. Most of these standard components are designed with the focus on thermal energy, and do not factor in pressure drops. This limits the simulation capabilities to evaluating the thermal performance of the system and not the associated parasitic energy used by pumps, controllers, tempering valves, and other active components. See Appendix B for user-created proforma used in the simulations.

3.2 Weather Data

The weather data sets included in the TRNSYS 16 package were used to simulate the climate in the simulations. The data sets for Canadian locations were generated using Meteonorm V, a program produced by Meteotest. The radiation and weather database contained in this software package is based on at least 10 years of collected data depending on the parameter, and the program is capable of generating hourly weather data sets that simulate a typical year and that are suitable for solar applications [41]. The Meteonorm data files included in TRNSYS were generated using the default settings in Meteonorm and saved using the .tm2 output format so that they would be compatible with the standard TRNSYS weather data components [43].

For US locations, TRNSYS provided Typical Meteorological Year 2 (TMY2) data sets. These files were developed by the National Renewable Energy Laboratory (NREL), part of the US Department of Energy, and are intended to be used for computer simulations of solar energy systems. Like the Meteonorm data sets, these files contain yearlong data sets with hourly values for solar radiation, ambient temperature, and other meteorological elements. The data for these files were selected to reflect typical conditions so that the long term performance of solar systems could be evaluated [44].

Since it is impractical to measure and record radiation data on many surfaces at different tilt angles and azimuths, most weather stations only measure the radiation on a flat horizontal plane. This means, however, that when modelling solar collectors at angles other than horizontal, the radiation on this tilted surface must be calculated. This was accomplished using the Perez sky model which is widely accepted as the most accurate method for finding the radiation on a tilted surface [5] [45] [46].

3.3 Space Heating Load

Residential space heating loads are dependent on multiple factors including location, orientation, building type and construction, furnishing, and occupant behaviour. On average, residential space heating in Canada accounts for over 60% of a home's energy consumption [3]. With such a large fraction of energy devoted to space heating, even small improvements to a home's insulation and air tightness can result in appreciable energy savings. For this reason, it is more efficient and economical to first ensure the residence is well insulated and sealed before considering adding any solar space heating system. It is for these reasons that the space heating load was selected to reflect an energy efficient home.

The space heating load selected for the simulations is a modified heating degree-hour model based on the R-2000 Standard (Appendix A for details). This standard was developed by Natural Resources Canada in partnership with Canada's residential construction industry to promote the use of cost-effective energy-efficient building practices and technologies [47]. The R-2000 Standard is a performance based standard. It sets technical performance standards for energy efficiency, air tightness, and environmental responsibility in the home, as well as energy performance targets for space heating and domestic hot water. This standard also considers the indoor air quality of the house and can be applied to the design of Net-Zero Energy homes [48] [49].

For the simulations, a house with a total floor area of 185.6 m² (2000 ft²) and 2.44 m (8 ft) ceilings was selected, and in keeping with the R-2000 Standard, a reference temperature of 18°C was used, thus giving the following modified heating degree hour space heating load:

$$\dot{Q}_{SH} = \begin{cases} 0, & if\ T_{ave} \geq 18°C\ or\ T_{amb} \geq 18°C \\ 0.075\ (18°C - T_{amb}), & otherwise \end{cases} \tag{3.1}$$

where:

$\dot{Q}_{SH}$ is the space heating load [kW];
T_{ave} is the average daily temperature [°C]; and
T_{amb} is the ambient temperature [°C].

The house was modelled using a hydronic-floor for space heating with a heated area of 160 m² and a characteristic floor thermal resistance of 0.2 m²-K/W. See Appendix A for further details.

3.4 Domestic Hot Water Load

When modelling any hot water system, knowledge of the hot water load profile is important. Studies by Perlman and Mills [50], Fairey and Parker [51], DeOreo and Mayer [52], and Aguilar et al. [53] have all looked at hot water usage in the residential sector. Several factors that affect domestic hot water consumption include: flow rate, household occupancy rate, installed appliances, climate and season, and the individual consumer's behaviour and preferences. In a literature review of domestic water heating in Canada by the Canadian Building Energy End-Use Data and Analysis Centre (CBEEDAC), they found that studies from the US and Canada showed the daily domestic hot water consumption to range from 128.1 to 1096.4 l/day per household, and an average per capita hot water consumption of 47 to 167 l/day [53]. With so much variation in actual hot water usage, a standardized load profile was used for the simulations.

In keeping with the space heating load, the R-2000 Standard was used as a guideline for determining the hot water load. The R-2000 Standard suggests a daily hot water draw of 225L/day at 55°C be used for simulations. Thus, the Canadian Standards Association (CSA) Standard for Solar Domestic Hot Water Systems hot water load profile with a daily draw of 225L/day was used without any modifications for different usage patterns on weekends or seasonal changes in hot water usage, Figure 3.3, [54].

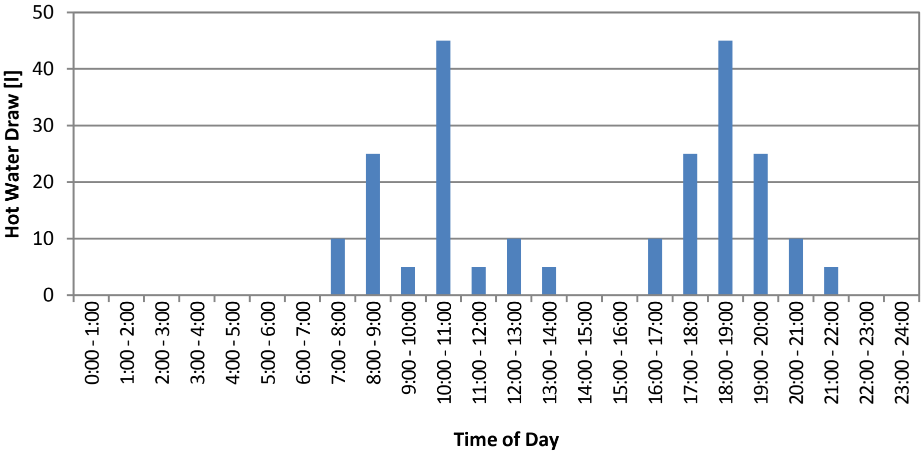


Figure 3.3: CSA hot water draw profile (225L/day)

The temperature of the mains water entering the domestic hot water loop was modelled using TRNSYS Type 15. This mains water temperature model was developed by Christensen and Burch, and is based on a ground distribution system [55]. The mains water temperature is calculated as:

$$T_{mains} = (\bar{T}_{amb} + offset) + ratio\left(\frac{T_{amb,max}}{2}\right)\sin\left(\frac{360}{365}(day - 15 - lag) - 90\right) \tag{3.2}$$

where:

T_{mains} is the mains water temperature [°C];
$\bar{T}_{amb}$ is the average annual ambient temperature [°C];
$T_{amb,max}$ is maximum annual ambient temperature [°C];
day is the number value of the day of the year (1: Jan. 1^{st}, 365: Dec. 31^{st});

and the offset, ratio, and lag values used were given as follows [55]:

$$offset = 3°\text{C} \tag{3.3}$$

$$ratio = 0.22 + 0.0056(\bar{T}_{amb} - 6.67) \tag{3.4}$$

$$lag = 1.67 - 0.56(\bar{T}_{amb} - 6.67) \tag{3.5}$$

This model (using the Toronto Meteonorm data set for the average and maximum annual temperatures) was compared to mains water temperatures in Toronto from 2009 [56]. As seen in Figure 3.4, the actual and simulated water temperatures correspond well.

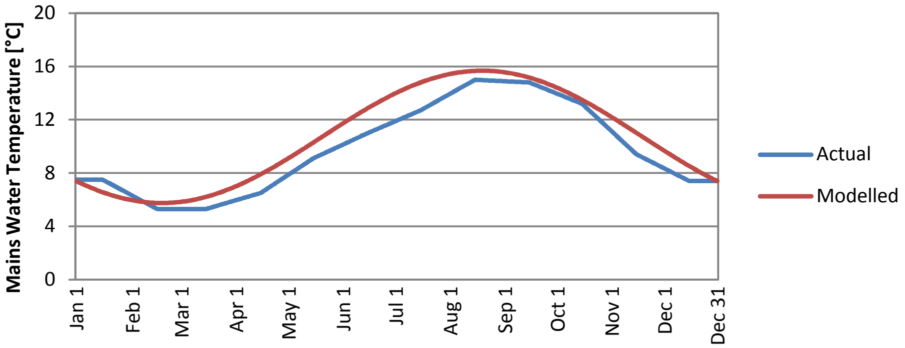


Figure 3.4: Actual and modelled mains water temperature variation for Toronto

3.5 Performance Indices

Solar thermal system performance can be measured in a variety of different ways, and as discussed in Chapter 2, definitions can vary. For this study, three main indices were used. These were: the collection efficiency, the solar contribution, and the solar fraction.

The collection efficiency is defined as the ratio of useful energy gain to the radiation incident on the collector surface over a specified time period and is calculated by [5]:

$$\eta_{coll} = \frac{\int \dot{Q}_u \, dt}{A_c \int G_T \, dt} \tag{3.6}$$

where:

η_{coll} is the collection efficiency [-];
$\dot{Q}_u$ is the energy output from the solar collector [kW];
A_c is the area of the solar collector [m²]; and
G_T is the solar radiation on the tilted surface [kW/m²].

As outlined in Section 2.1, the solar fraction can be defined in a variety of different ways. The performance of both the solar thermal systems and the reference systems were done in terms of thermal energy (i.e. the energy source and actual primary or secondary energy consumption is not factored into these calculations) since TRNSYS simulates the thermal performance of systems, and parasitic energy consumption was not included in solar thermal systems nor the reference systems performance. For the purposes of this study, the solar contribution and solar fraction were defined as:

$$Q_{sol} = Q_{ref} - Q_{aux} \tag{3.7}$$

where:

Q_{sol} is the solar contribution (measured in terms of thermal energy) [kWh];
Q_{ref} is the thermal load of the reference system [kWh]; and
Q_{aux} is the thermal load of the auxiliary heater(s) in the solar system [kWh];

and

$$F_s = \frac{Q_{sol}}{Q_{ref}} \tag{3.8}$$

where:

F_s is the solar fraction [-];
Q_{sol} is the solar contribution (measured in terms of thermal energy) [kWh]; and
Q_{ref} is the thermal heating load for the reference system [kWh].

This solar fraction calculation is similar to the fractional thermal energy savings ($f_{sav,therm}$) term defined by the IEA's Task 26, Equation (2.4). Both terms only measure the thermal energy consumption of the solar system, however this definition keeps the energy consumptions in terms of thermal energy and whereas the IEA definition adjusted the thermal energy consumption to account for the primary or secondary energy source. By keeping all calculations in terms of thermal energy, the efficiencies of the auxiliary heaters do not affect the solar fraction calculation, thus the results could be applied to other auxiliary heating methods (provided the same configuration and control strategy were used).

Since the reference systems (defined below) were independent of one another, it was possible to consider the performance of the domestic hot water and space heating loops separately. Here the domestic hot water loop performance was calculated as:

$$Q_{sol\ DHW} = Q_{ref\ DHW} - Q_{aux\ DHW} \tag{3.9}$$

$$F_{s\ DHW} = \frac{Q_{sol\ DHW}}{Q_{ref\ DHW}} \tag{3.10}$$

where:

$Q_{sol\ DHW}$ is the solar contribution of the domestic hot water loop (measured in terms of thermal energy) [kWh];
$F_{s\ DHW}$ is the solar fraction of the domestic hot water loop [-];
$Q_{ref\ DHW}$ is the thermal load of the domestic hot water reference system [kWh]; and
$Q_{aux\ DHW}$ is the thermal load of the auxiliary domestic hot water heater solar thermal system [kWh].

And the space heating loop performance was calculated as:

$$Q_{sol\,SH} = Q_{ref\,SH} - Q_{aux\,SH} \tag{3.11}$$

$$F_{s\,SH} = \frac{Q_{sol\,SH}}{Q_{ref\,SH}} \tag{3.12}$$

where:

$Q_{sol\,SH}$ is the solar contribution of the space heating loop (measured in terms of thermal energy) [kWh];
$F_{s\,SH}$ is the solar fraction of the space heating loop [-];
$Q_{ref\,SH}$ is the thermal load of the space heating reference system [kWh]; and
$Q_{aux\,SH}$ is the thermal load of the auxiliary space heater in the solar thermal system [kWh].

3.5.1 Reference Systems

To evaluate the performance of the systems under investigation, two separate reference systems were defined: one for the domestic hot water load, and a second for the space heating load. Together, these models were used to determine the thermal energy required by comparable non-solar space heating and domestic hot water systems.

The reference domestic hot water system was modelled with an electric hot water tank, Figure 3.5. This system used the same draw profile and hot water and mains water temperatures as the investigated solar thermal systems. In this system, the domestic hot water load is measured as the total thermal energy transferred to the system by the heater. This measurement includes both the tank losses and the energy delivered to the load.

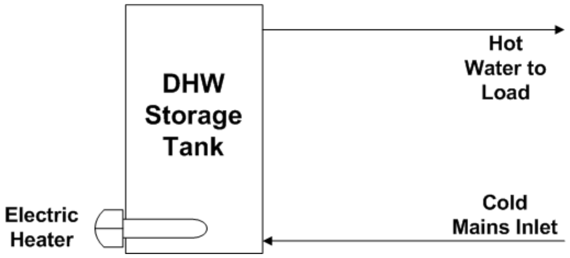


Figure 3.5: Reference hot water system

This is the same hot water tank model that was used as the auxiliary hot water heater in the investigated solar thermal systems.

The reference space heating system, Figure 3.6, was modelled using the same heating load and hydronic-floor as described in Appendix A. A variable speed pump was used to circulate water through the system and in electric heater was used to heat the fluid. Since only the thermal energy load is considered, the space heating load was measured by the energy consumption of the heater.

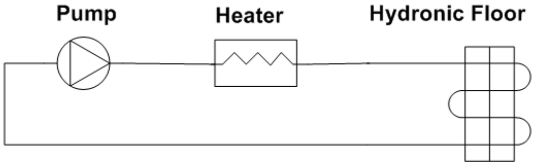


Figure 3.6: Reference space heating system

Chapter 4

Solar Thermal Systems

Three types of solar thermal system arrangements were examined. These were: separate stand-alone solar domestic hot water and space heating systems, a basic solar combi-system, and a single-tank solar combi-system. Each of these arrangements had the same general sizing for collector area, thermal storage, hot water delivery temperature as described in Section 4.1, and each system was individually optimized for collector type and tilt angle, heat exchanger type, and collector flow rate. The systems were considered optimized when the annual solar fraction was maximized. See Appendix C for example TRNSYS models in the text based deck (.dck) format.

4.1 General Combi-System Sizing

To reduce the number of variables when comparing different types of systems, key parameters were standardized, Table 4.1. Toronto was selected as the reference location for the initial comparison with a room temperature of 20 °C and hot water temperature of 55 °C. For the initial comparisons, a total solar collector area of 18 m^2 was used, the floor delivery temperature was set at 40 °C with a space heating storage volume of 810 L and a hot water storage volume of 270 L. Since the selection of large commercially available tanks (810 L) is limited, and incorporating a tank that large into a home can be quite a challenge, three 270 L tanks connected in parallel were instead used to make up the 810 L storage volume for the space heating system.

Table 4.1: Main component system sizing

Parameter	Value
Location	Toronto
Total Collector Area	18 m²
Collector Orientation – Azimuth	0° (South facing)
Hot Water Storage Volume	270 L
Space Heating Storage Volume	810 L (3 x 270 L)
Hot Water Delivery Temperature	55 °C
Room Temperature	20 °C
Floor Delivery Temperature	40 °C

With the systems given the same main component sizing, the optimized system was found by maximizing the solar fraction using the following parameters: solar collector type, heat exchanger type, collector flow rate, and collector tilt angle, see Table 4.2.

Table 4.2: Optimization parameters

Parameter	Value
Collector Type	Glazed Flat Plate; or Vacuum Tube
Heat Exchanger Type and Size	Plate Heat Exchanger (modelled as a fixed effectiveness heat exchanger: $\varepsilon = 0.7$, and pump flow rates selected such that hot and cold capacity rates are equal); or Natural Convection Heat Exchanger (1NCHX/270L storage)
Collector Flow Rate	2 to 75 kg/hr-m²
Collector Tilt Angles	0° to 90°

4.2 Stand-Alone Solar Domestic Hot Water System

The stand-alone solar domestic hot water system, Figure 4.1, was modelled based on existing solar domestic hot water designs. This system had a solar collector area of 6 m² and a thermal store with a volume of 270L. To ensure this system was always able to meet the hot water demand, a 170L tank with a built in electric heater was added as a backup followed by a tempering valve to limit the hot water temperature to 55°C and prevent scalding.

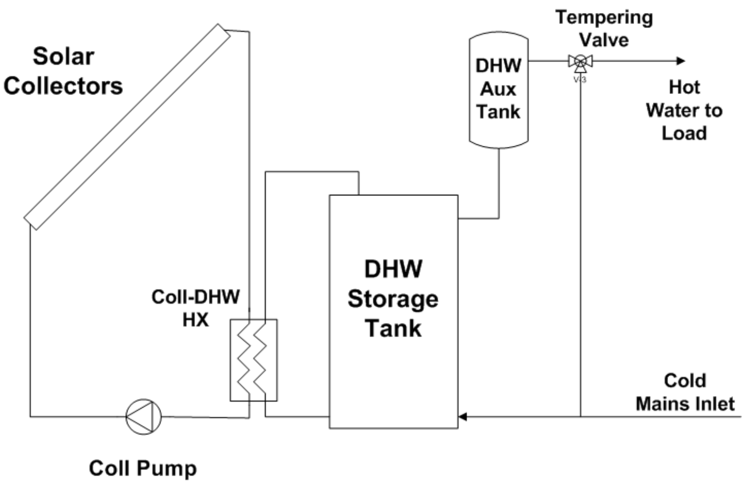


Figure 4.1: Schematic of a stand-alone solar domestic hot water system

The optimization results, Table 4.3, showed that the best combination for a stand-alone solar domestic hot water system was a glazed flat plate collector combined with a natural convection heat exchanger. The results also showed that the optimal collector tilt angle for all the combinations of the stand-alone solar domestic hot water system was 38° while the optimal flow rate for glazed collectors was 60 kg/hr and 30-40 kg/hr for tube collectors. The systems with natural convection heat exchangers performed better than those with the fixed effectiveness heat exchangers, likely due to better thermal stratification within the storage tank.

Table 4.3: Optimized stand-alone domestic hot water system performance

Configuration	Collector Type	DHW HX Type	Tilt Angle	Collector Flow Rate	DHW Performance		
					$Q_{sol\ DHW}$	$F_{s\ DHW}$	η_{coll}
(i)	Glazed	NCHX	38°	60 kg/hr	2795 kWh	0.61	0.37
(ii)	Tube	NCHX	38°	40 kg/hr	2784 kWh	0.61	0.37
(iii)	Glazed	Constant $\varepsilon = 0.7$	38°	60 kg/hr	2650 kWh	0.58	0.37
(iv)	Tube	Constant $\varepsilon = 0.7$	38°	30 kg/hr	2714 kWh	0.59	0.36

Optimal system component combination is highlighted

Based on these results, glazed flat plate collector and natural convection heat exchanger combination was selected for further analysis.

4.3 Stand-Alone Solar Space Heating System

To compliment the stand-alone solar domestic hot water system, the stand-alone solar space heating system was designed with a 12 m² solar collector array and 810 L of thermal storage, Figure 4.2. The thermal storage was modelled as three 270 L tanks in parallel with perfect flow division between each tank. If natural convection heat exchangers were used, these were also modelled in parallel with an equal fraction of the collector flow through each one.

Like the reference space heating system, the auxiliary heater in the space heating loop was assumed to be ideal, i.e., 100% efficient. The tempering valve was used to prevent the temperature of the water supplied to the floor from becoming too hot, and when needed, could be used to bypass the tank completely.

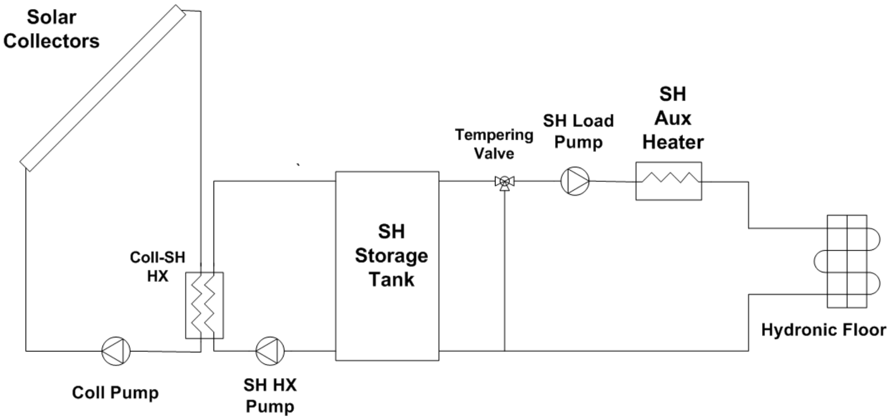


Figure 4.2: Schematic of a stand-alone solar space heating system

The optimization results, Table 4.4, showed that the best stand-alone space heating system was comprised of a vacuum tube solar collector and natural convection heat exchangers. The optimal collector tilt angle for all the combinations of this system was 53° while the optimal flow rate was different for every combination, with higher flow rates for the fixed effectiveness heat exchanger and glazed flat plate collector. In this case, the type of collector seemed to have the greatest effect on the performance of the system as compared to the type of heat exchanger.

The systems that used vacuum tube collectors had a noticeably greater solar fraction than those that used glazed flat plate collectors.

Table 4.4: Optimized stand-alone space heating system performance

Configuration	System	Collector Type	SH HX Type	Tilt Angle	Collector Flow Rate	SH Performance		
						$Q_{sol\ SH}$	$F_{s\ SH}$	η_{coll}
(i)	SSH	Glazed	Constant $\varepsilon = 0.7$	53°	240 kg/hr	3090 kWh	0.42	0.29
(ii)	SSH	Tube	Constant $\varepsilon = 0.7$	53°	180 kg/hr	3312 kWh	0.45	0.32
(iii)	SSH	Glazed	NCHX	53°	144 kg/hr	3066 kWh	0.42	0.27
(iv)	SSH	Tube	NCHX	53°	120 kg/hr	3357 kWh	0.46	0.29

Optimal system component combination is highlighted

Based on these results, the vacuum tube collector and natural convection heat exchanger combination was selected for further analysis.

4.4 Basic Solar Combi-system

A basic combi-system was defined by connecting the stand-alone domestic hot water and space heating systems with a single solar collector loop, Figure 4.3. With this type of system, both heating loads had their own separate storage and auxiliary heating systems, and were charged in series. Like the stand-alone systems, the space heating loop had a storage tank volume of 810 L and the hot water loop had a storage tank volume of 270 L. However, the collector area for this system was 18m², the area of the combined collector areas for the two stand-alone systems.

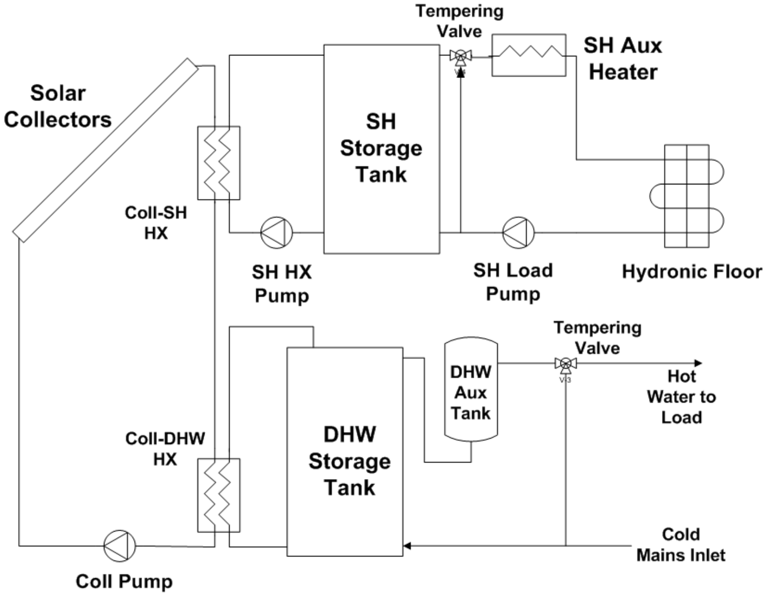


Figure 4.3: Schematic of a basic solar combi-system with preferential charging of the space heating storage tank and a natural convection heat exchanger on the DHW storage tank

In addition to optimizing the system for the parameters listed in Table 4.2, the order that the space heating and domestic hot water storage tanks were charged was also considered. To ensure that neither of the storage tanks could overheat, the first heat exchanger was always specified as a pumped plate heat exchanger (modelled as a fixed effectiveness heat exchanger, $\varepsilon = 0.7$) where the pump on the tank side could be used to control when the first tank was being charged. If a natural convection heat exchanger was used on the second tank, its size was proportional to the storage tank volume (i.e., each 270 L tank would be conneted to its own natural convetion heat exchanger). The configurations investigated are listed in Table 4.5.

Table 4.5: List of basic combi-system configurations

Configuration	Collector Type	DHW HX Type	SH HX Type	Charging Order (1st -> 2nd)
(i)	Glazed	NCHX	Constant $\varepsilon = 0.7$	SH->DHW
(ii)	Tube	NCHX	Constant $\varepsilon = 0.7$	SH->DHW
(iii)	Glazed	Constant $\varepsilon = 0.7$	Constant $\varepsilon = 0.7$	SH->DHW
(iv)	Tube	Constant $\varepsilon = 0.7$	Constant $\varepsilon = 0.7$	SH->DHW
(v)	Glazed	Constant $\varepsilon = 0.7$	NCHX	DHW->SH
(vi)	Tube	Constant $\varepsilon = 0.7$	NCHX	DHW->SH
(vii)	Glazed	Constant $\varepsilon = 0.7$	Constant $\varepsilon = 0.7$	DHW->SH
(viii)	Tube	Constant $\varepsilon = 0.7$	Constant $\varepsilon = 0.7$	DHW->SH

In the configurations where the first thermal store was connected to the collector loop through a pumped plate heat exchanger and the second store was connected using a natural convection heat exchanger (configurations (i), (ii), (v) & (vi)), two controllers were used to control the system charging, Table 4.6. For the other configurations ((iii), (iv), (vii) & (viii)) where both the space heating and domestic hot water stores were conneted to the collector loop using pumped plate heat exchanger, three controllers were used to control system charging, Table 4.7. See Appendix A for controller details.

Table 4.6: Controller strategy for basic combi-system configurations (i), (ii), (v), & (vi)

	Controller A	**Controller B**	**Collector Loop Pump**	**1st Store HX Pump**
Hot Reference	**Collector Outlet**	**Collector Outlet**		
Cold Reference	**1st Store - Bottom**	**2nd Store - Bottom**		
Signal	0	0	OFF	OFF
	1	0	ON	ON
	0	1	ON	OFF
	1	1	ON	ON

0: Hot Reference Temp < Cold Reference Temp 1: Hot Reference Temp > Cold Reference Temp

Table 4.7: Controller strategy for basic combi-system configurations (iii), (iv), (vii), & (viii)

	Controller A	Controller B	Controller C	Collector Loop Pump	1st Store HX Pump	2nd Store HX Pump
Hot Reference	**Collector Outlet**	**Collector Outlet**	**1st Store HX – Colletor Loop Outlet**			
Cold Reference	**1st Store – Bottom**	**2st Store – Bottom**	**2st Store – Bottom**			
Signal	0	0	0	OFF	OFF	OFF
	1	0	0	ON	ON	OFF
	0	1	0	ON	OFF	ON
	0	0	1	OFF	OFF	OFF
	1	1	0	ON	ON	OFF
	1	0	1	ON	ON	ON
	0	1	1	ON	OFF	ON
	1	1	1	ON	ON	ON

0: Hot Reference Temp < Cold Reference Temp 1: Hot Reference Temp > Cold Reference Temp

Charging simulations were conducted to examine the effect of tank order when charging. These were modelled with a pumped flat plate heat exchanger (with a fixed effectiveness of 0.7) and a hot side (collector side) flow of 300 kg/hr. The space heating tanks (3 x 270 L) were initially set to a temperature of 20 °C (room temperature) and the hot water tank (270 L) was initially set to a temperature of 5 °C (to approximate the mains water temperature). A 50% glycol mixture (by volume) was used to charge the tanks and was supplied to the system at a constant temperature of 50 °C.

The simulations showed that when the tanks were arranged in a series charging configuration, the first tank was preferentially charged, Figure 4.4 and Figure 4.5. This was especially evident when the tanks were ordered with the domestic hot water storeage tank before the space heating storage tanks. In this situation, the space heating tanks did not begin to charge until the bottom of the hot water tank had reached a temperature of around 35 °C, at about 1 hour into the charge.

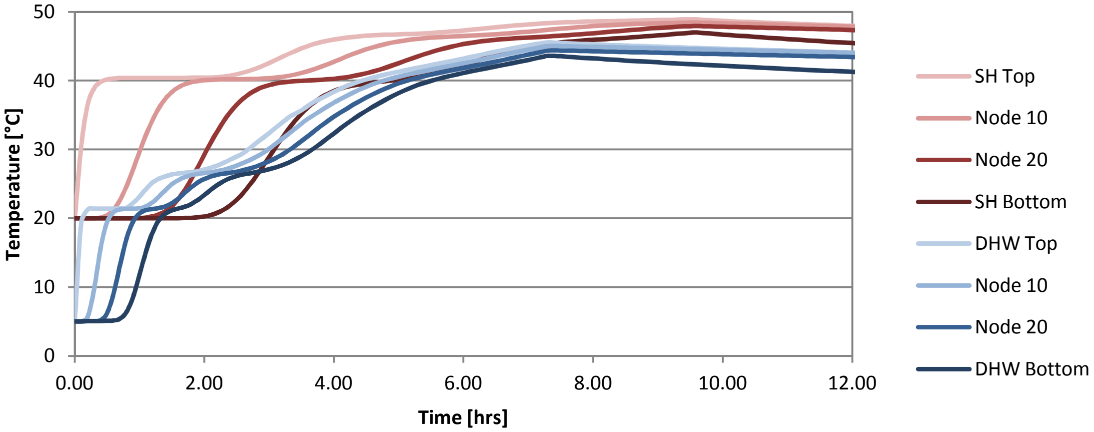


Figure 4.4: Temperature profile of a basic combi-system being charged with the space heating storage charged preferentially over the domestic hot water store (SH->DHW) using fixed effectiveness heat exchangers

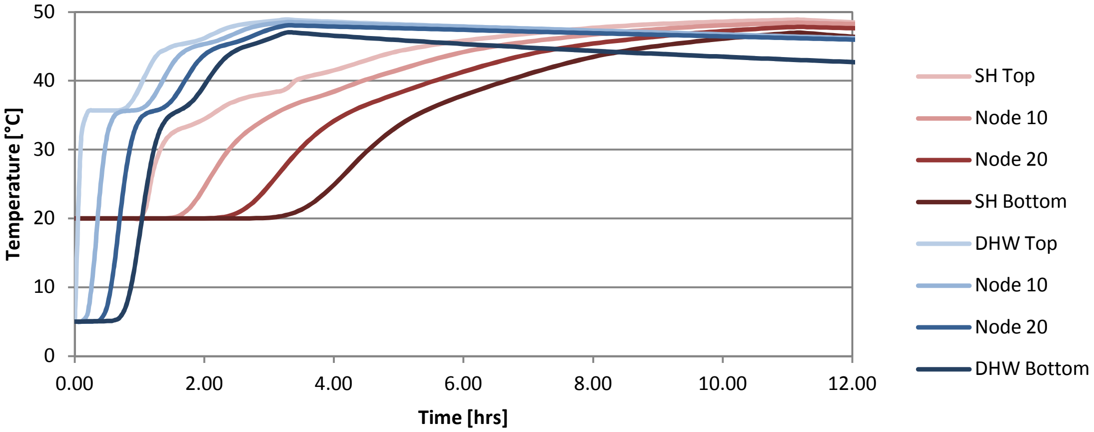


Figure 4.5: Temperature profile of a basic combi-system being charged with the domestic hot water storage charged preferentially over the space heating store (DHW->SH) using fixed effectiveness heat exchangers

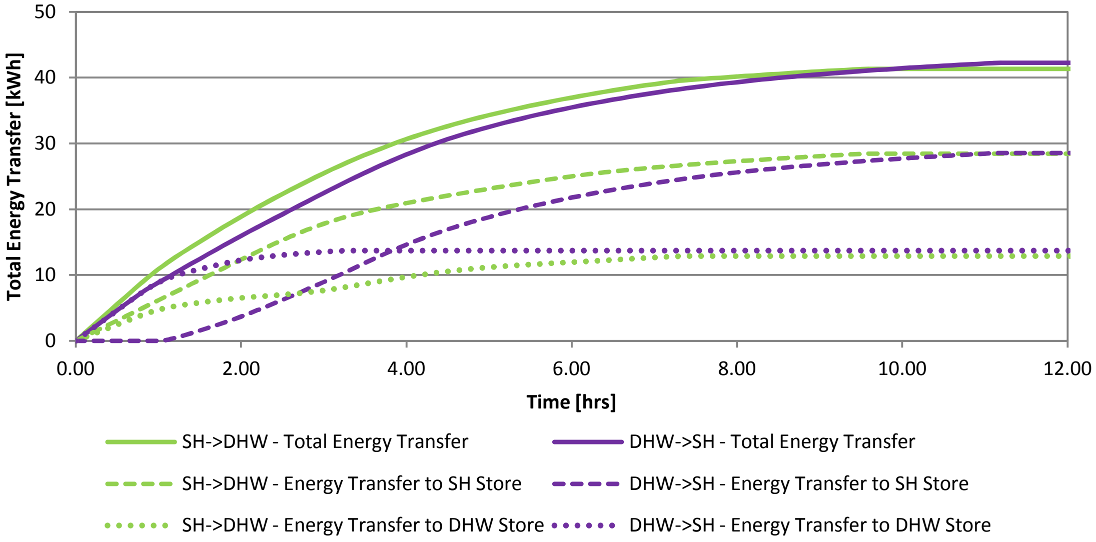
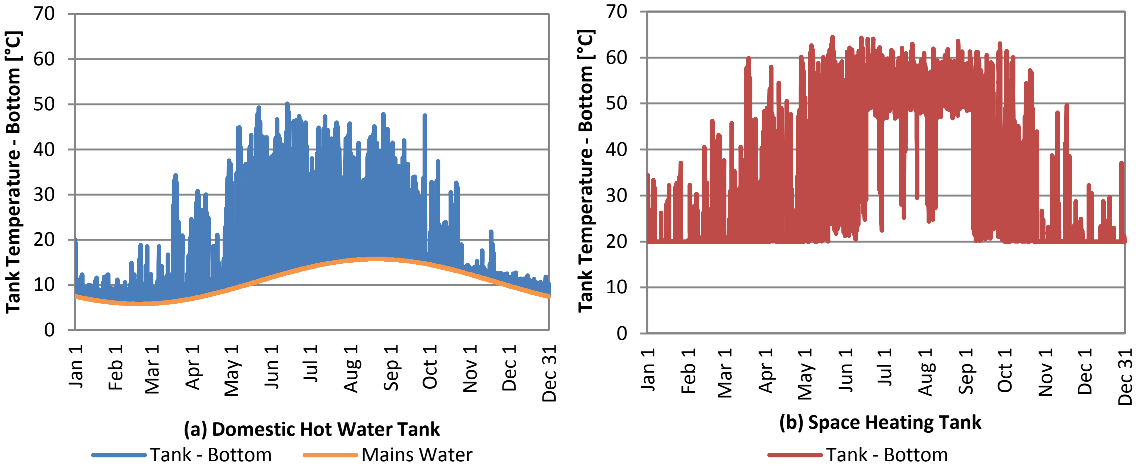


Figure 4.6: Comparison of the total energy transferred to the thermal stores in the preferential charging of the space heating store (SH->DHW) and the preferential charging of the domestic hot water store (DHW->SH) configurations

Due to the preferential charging configuration, the high temperature cut-off for the first tank was set at a lower temperature (70 °C) and the high temperature cut-off for the second tank remained at 90 °C. Doing this meant that the controller considered the first store fully charged once the temperature at the top of the tank reached 70 °C, at which point the controller would not try to charge the first thermal store and only act to charge the second thermal store (which was considered fully charged when the fluid at the top of the tank reached 90 °C). While this did not correct the charging imbalance, it increased the usable thermal capacity of the second tank.

The fluid at the bottom of the hot water tank is typically colder than the fluid at the bottom of the space heating tanks since the hot water tank is supplied by the cities mains water supply while the space heating tank is refilled using return fluid from the hydronic-floor. Observing the temperature at the bottom of the thermal storage tanks in the optimized basic combi-system configuration (ii) where the space heating tank was preferentially charged over the domestic hot water tank, this phenomenon could be seen. As shown in Figure 4.7, the temperature at the bottom of the domestic hot water storage tank never drops below the mains water temperature, and the temperature of the space heating storage tank never drops below room temperature (20 °C).



(a) Domestic Hot Water Tank

(b) Space Heating Tank

Figure 4.7: Temperature at the bottom of the domestic hot water and space heating storage tanks for the optimized basic combi-system configuration (ii)

Furthermore, with the sole exception of the initial temperatures at the very beginning of the simulation, the temperature at the bottom of the space heating tank was always higher than the temperature at the bottom of the domestic hot water tank, Figure 4.8. Since this configuration used a natural convection heat exchanger between the collector loop and the domestic hot water tank, the minimum temperature difference of 4°C between the bottom of the thermal storage tanks confirms that there was never any potential for reverse siphoning in the natural convection heat exchanger, and thus energy transfer from the domestic hot water tank back into the collector loop.

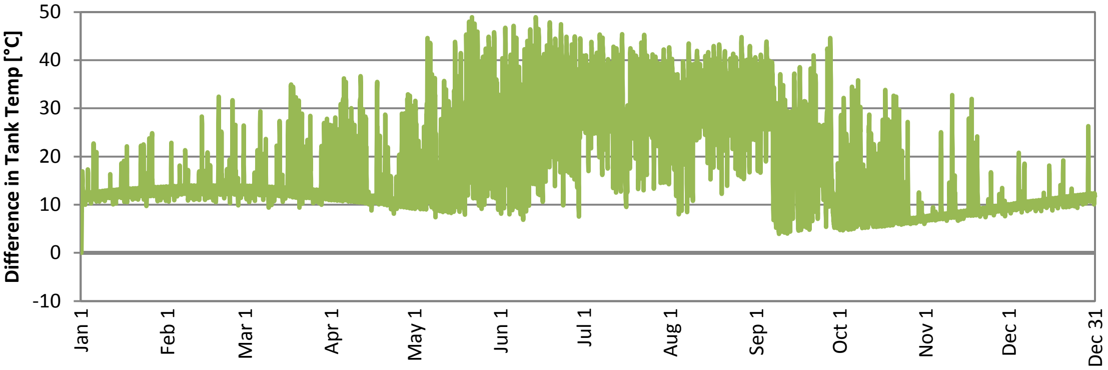


Figure 4.8: Temperature difference between the bottom of the space heating and domestic hot water storage tanks for the optimized basic combi-system configuration (ii)

The optimized performance of the basic solar combi-systems, Table 4.8, showed that system (ii) had the highest solar fraction. This system was configured with the collector fluid charging the space heating storage tank before the hot water storage tank, a vacuum tube collector array, and a natural convection heat exchanger on the hot water storage tank. The results showed that the systems had an overall higher solar fraction when vacuum tube collectors were used, and that the use of a natural convection heat exchanger to charge the second tank also slightly increased the overall system performance.

Table 4.8: Optimized basic combi-system performance

Config	Tilt Angle	Collector Flow Rate	SH Performance		DHW Performance		Overall Performance		
			$Q_{sol\ SH}$	$F_{s\ SH}$	$Q_{sol\ DHW}$	$F_{s\ DHW}$	Q_{sol}	F_s	η_{coll}
(i)	47°	360 kg/hr	3352 kWh	0.46	2586 kWh	0.57	5939 kWh	0.50	0.31
(ii)	51°	300 kg/hr	3627 kWh	0.49	2720 kWh	0.60	6347 kWh	0.53	0.33
(iii)	47°	360 kg/hr	3279 kWh	0.45	2702 kWh	0.59	5981 kWh	0.50	0.33
(iv)	47°	300 kg/hr	3532 kWh	0.48	2780 kWh	0.61	6312 kWh	0.53	0.34
(v)	50°	180 kg/hr	2653 kWh	0.36	3202 kWh	0.70	5854 kWh	0.49	0.31
(vi)	49°	180 kg/hr	3018 kWh	0.41	3181 kWh	0.70	6199 kWh	0.52	0.34
(vii)	50°	360 kg/hr	2970 kWh	0.40	2874 kWh	0.63	5844 kWh	0.49	0.34
(viii)	50°	300 kg/hr	3259 kWh	0.44	2917 kWh	0.64	6176 kWh	0.52	0.35

Optimal system component combination is highlighted

As expected from the charging simulations, the order of the tanks also influenced the individual space heating and hot water solar contributions. The systems where the space heating storage tank was charged first showed a higher space heating solar contribution than those that charged the hot water tanks first. Similarly, the converse was true for the hot water solar contribution. Systems that charged the hot water tank first showed a higher hot water solar contribution than the systems that charged the space heating tank first. The charging order also affected the overall total system solar contribution. The optimization simulations showed that charging the space heating tank first increased the overall solar fraction as compared to charging the hot water tank first. This was consistent with the charging simulations.

Another element that affected the performance of the system was the type of collector. The models that used vacuum tube collectors consistently outperformed the equivalent flat plate glazed collector system by around 3%. Although the type of collector did not greatly affect the performance of the stand-alone solar domestic hot water system, the vacuum tube collectors did increase the performance of the stand-alone solar space heating system. Since space heating is the dominant load on an annual basis, it is reasonable expect the same type of collector to work well for both systems.

4.5 Single-tank Solar Combi-system

The single-tank solar combi-system was based on the IEA Task 26 System #15, and selected as an example of a highly optimized combi-system design. Unlike the basic solar combi-system (described in section 4.4), in this system energy for the space heating and domestic hot water loops was stored in a single-tank. Here, the storage tank was modelled with internal stratifiers on the tank inlets to maintain thermal stratification and prevent temperature inversions from occurring in the thermal store.

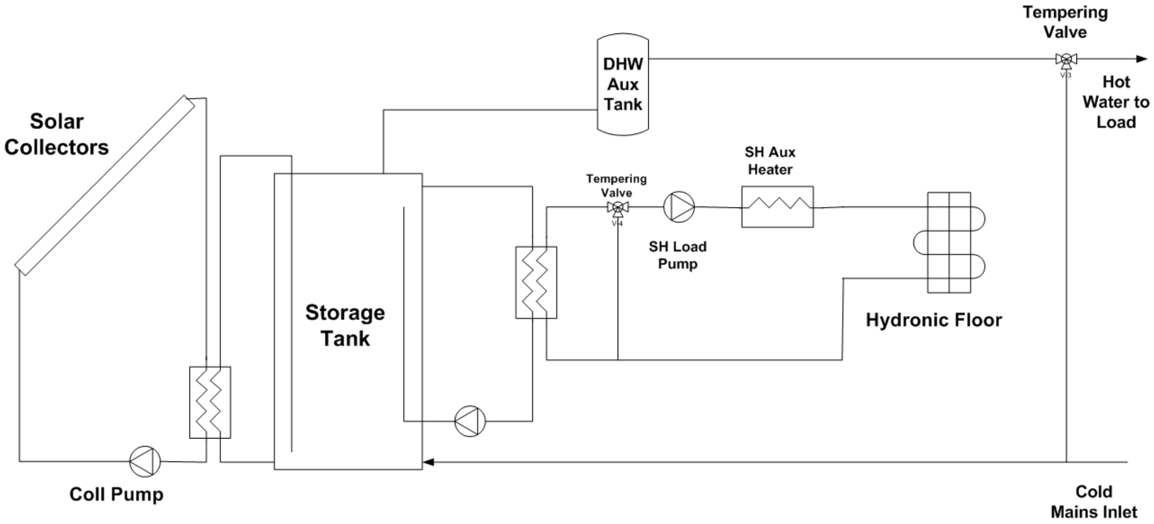


Figure 4.9: Schematic of a single-tank solar combi-system with the storage tank located in the DHW loop

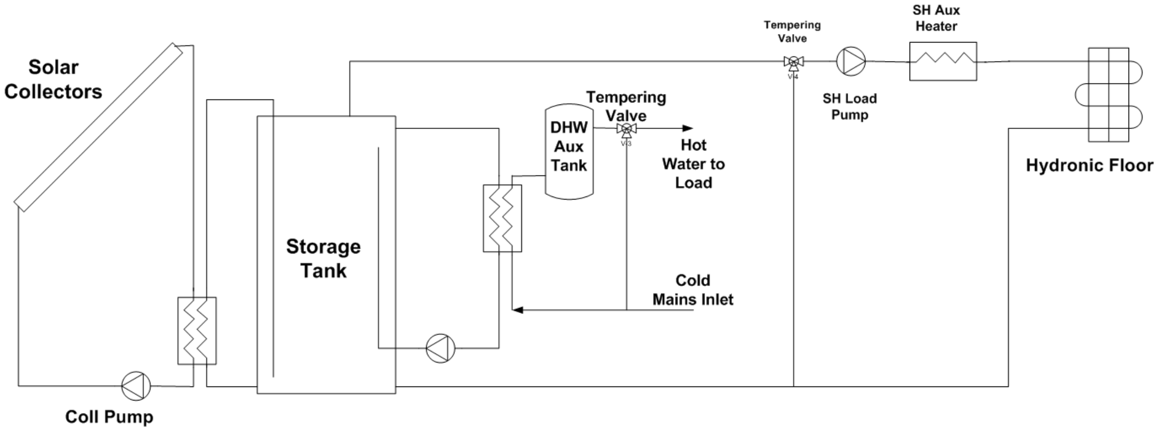


Figure 4.10: Schematic of a single-tank solar combi-system with the storage tank located in the space heating loop

In this model, the thermal storage was included as part of either the space heating loop or the domestic hot water loop. Like the basic solar combi-system, the single-tank system had a collector area of 18 m² and a total thermal storage size of 1080 L (modelled as 4 x 270 L tanks connected in parallel). Since this system was chosen as an example of a highly optimized combi-system design, a perfect heat exchanger (effectiveness = 1) was used to transfer energy from the energy store to the heating loop that did not include thermal storage tank. Both tank location configurations were considered when optimizing the system, Table 4.9, and if used, the natural convection heat exchanger was sized proportionally to the thermal store.

Table 4.9: List of single-tank combi-system configurations

Configuration	Collector Type	Collector Loop – Thermal Store HX Type	Tank Location
(i)	Glazed	Constant $\varepsilon = 0.7$	DHW Loop
(ii)	Tube	Constant $\varepsilon = 0.7$	DHW Loop
(iii)	Glazed	Constant $\varepsilon = 0.7$	SH Loop
(iv)	Tube	Constant $\varepsilon = 0.7$	SH Loop
(v)	Glazed	NCHX	DHW Loop
(vi)	Tube	NCHX	DHW Loop
(vii)	Glazed	NCHX	SH Loop
(viii)	Tube	NCHX	SH Loop

The optimized performance of the basic solar combi-systems, Table 4.10, showed that systems (ii) and (vi) had the highest overall performance. In both of these configurations, a vacuum tube solar collector was used with the thermal store located in the domestic hot water loop, Figure 4.9, however configuration (ii) used a fixed effectiveness heat exchanger and configuration (vi) used a natural convection heat exchanger. Although the overall performance of these systems was the same, the different flow rates and heat exchanger types resulted in slightly different space heating and domestic hot water performances and solar collection efficiency.

Table 4.10: Optimized single-tank combi-system performance

Config	Tilt Angle	Collector Flow Rate	SH Performance		DHW Performance		Overall Performance		
			$Q_{sol\,SH}$	$F_{s\,SH}$	$Q_{sol\,DHW}$	$F_{s\,DHW}$	Q_{sol}	F_s	η_{coll}
(i)	49°	360 kg/hr	3342 kWh	0.45	2934 kWh	0.64	6275 kWh	0.53	0.34
(ii)	50°	240 kg/hr	3506 kWh	0.48	3066 kWh	0.67	6572 kWh	0.55	0.36
(iii)	49°	360 kg/hr	3365 kWh	0.46	2835 kWh	0.62	6201 kWh	0.52	0.34
(iv)	51°	240 kg/hr	3561 kWh	0.48	2993 kWh	0.66	6554 kWh	0.55	0.36
(v)	49°	200 kg/hr	3169 kWh	0.43	2995 kWh	0.66	6164 kWh	0.52	0.32
(vi)	50°	180 kg/hr	3467 kWh	0.47	3105 kWh	0.68	6572 kWh	0.55	0.35
(vii)	48°	200 kg/hr	3194 kWh	0.43	2907 kWh	0.64	6101 kWh	0.51	0.32
(viii)	49	144	3459 kWh	0.47	3059 kWh	0.67	6518 kWh	0.55	0.35

Optimal system component combinations are highlighted

It should be noted that one of the main benefits to natural convection heat exchangers is their ability to maintain higher levels of stratification within the thermal store as compared to a pumped heat exchanger. However, the internal stratifiers in this tank model allowed both heat exchanger types to operate and maintain high levels of thermal stratification in the tank.

The optimized system configurations used for further investigations are listed in Table 4.11. For the single-tank combi-systems, generally the systems modelled with fixed effectiveness heat exchangers (connecting the collector loop to the storage tank) outperformed those with natural convection heat exchanger systems. Therefore configuration (ii) with the fixed effectiveness heat exchanger was chosen as the representative configuration for this system type.

Table 4.11: List of optimal solar thermal system configurations

System Type	Configuration	Collector Type	DHW HX Type	SH HX Type	Storage Tank Location/Charging Order
Stand-Alone Domestic Hot Water System	(i)	Glazed	NCHX	-	DHW Loop
Stand-Alone Space Heating System	(iv)	Tube	-	NCHX	SH Loop
Basic Combi-System	(ii)	Tube	NCHX	Constant $\varepsilon = 0.7$	SH -> DHW
Single-Tank Combi-System	(ii)	Tube	Constant $\varepsilon = 0.7$	-	DHW Loop

Chapter 5

Comparison of Combi-System Types

Using the optimized solar combi-systems found in Chapter 4, further comparisons were conducted using Toronto as the reference location. In a typical year, the average daily solar radiation is 4 kWh/m² (on a south facing surface inclined 50°), however, the actual intensity varies with time of day, time of year, and the local weather. Using the reference systems, heating loads, and solar collector sizing described in Chapter 4, with a collector plane tilt angle of 50° to calculate the available solar energy, Figure 5.1 shows the average solar energy available and the reference heating loads.

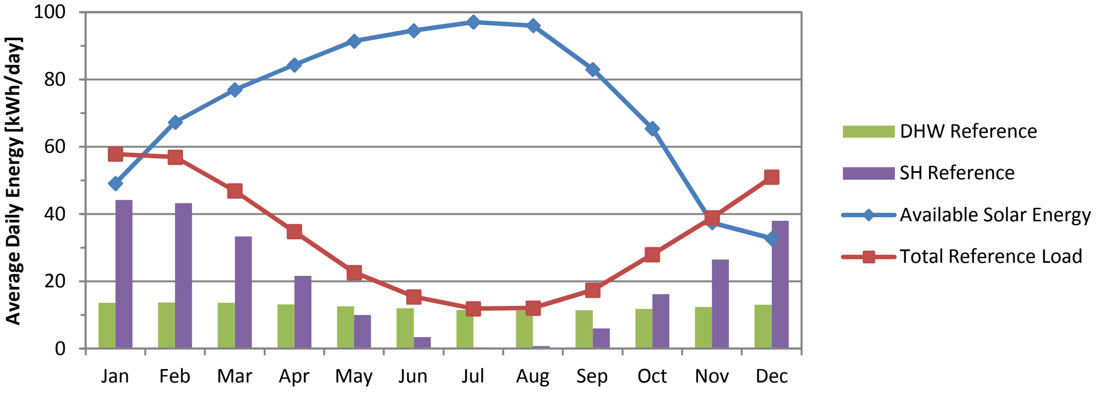


Figure 5.1: Monthly available solar energy (18m² collector area with 50° tilt angle) and reference system hot water and space heating loads.

As Figure 5.1 shows, the available solar energy peaks during the summer when the space heating load is minimal, and decreases during the winter when the space heating load is the largest. The domestic hot water load on the other hand remains fairly stable throughout the entire year. Using these parameters, the fractional solar consumption (FSC) was calculated as 0.926, Equation (2.12).

5.1 Results

Shown below are the simulation results, shown as a monthly performance of each of the solar thermal systems. The solar energy transferred from the solar collector loop to the thermal store (not to be confused with the solar contribution, Q_{sol}) and the auxiliary energy from the auxiliary heat source(s) are plotted as a bar graph in kWh/day and the load (domestic hot water, space heating, or total combined load) is graphed on top. In many instances the combined energy entering the system from both the solar collector loop and the auxiliary heat sources is greater than the energy required to meet the load. This discrepancy is a result of thermal energy losses within the system, namely thermal losses from the storage and domestic hot water tanks, etc..

The stand-alone solar domestic hot water system performance, Figure 5.2, shows that the most solar energy was transferred to the system during the summer when the available solar energy was greatest. During the winter, on the other hand, the auxiliary contribution was much more significant. The overall energy transferred into the system by both the solar collector loop and the auxiliary heater is greater than the domestic hot water load since there are thermal losses associated with the storage tank and especially during the summer, there are times when the system is capable of supplying more hot water than is consumed.

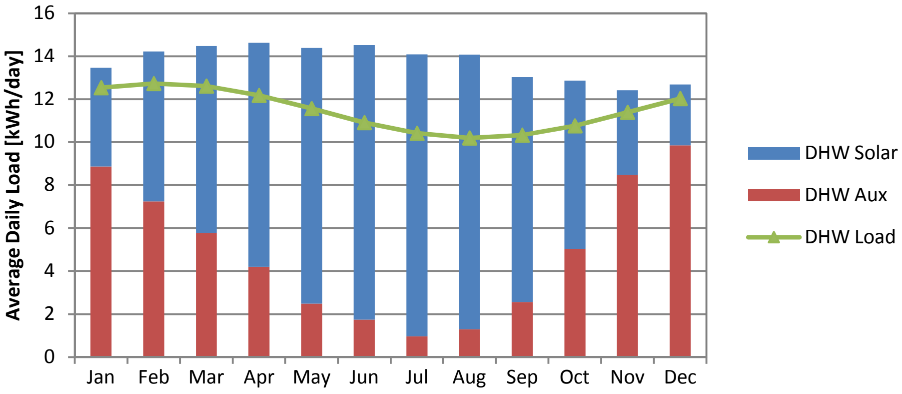


Figure 5.2: Stand-alone solar domestic hot water system performance

The monthly performance of the stand-alone solar space heating system, Figure 5.3, shows that during the winter there is very little excess energy supplied to the system. During the period from May to September, almost all the energy supplied to the space heating system is from the solar collector loop, and very little energy input is required from the auxiliary heater. It should also be noted that during the summer when the space heating load drops almost to zero, the collector loop still charges the thermal storage tank, hence the solar energy added to the system despite little to no heat load, which can lead to system overheating.

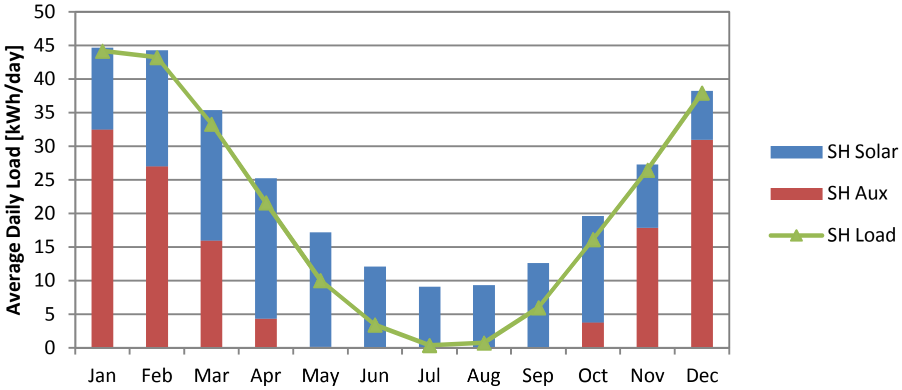


Figure 5.3: Stand-alone solar space heating system performance

The performance of the basic solar combi-system domestic hot water and space heating loops is very similar to that of their respective stand-alone solar domestic hot water and space heating systems. As shown in Figure 5.4, both the domestic hot water and space heating loops are charged predominantly by the solar collector loop during the summer, with the auxiliary heat source supplying more of the heating load during the winter. Both loops also experience over charging of their thermal stores during the summer, where more energy is added to the loop by both the solar collector loop and the auxiliary heat source than is required by the respective load.

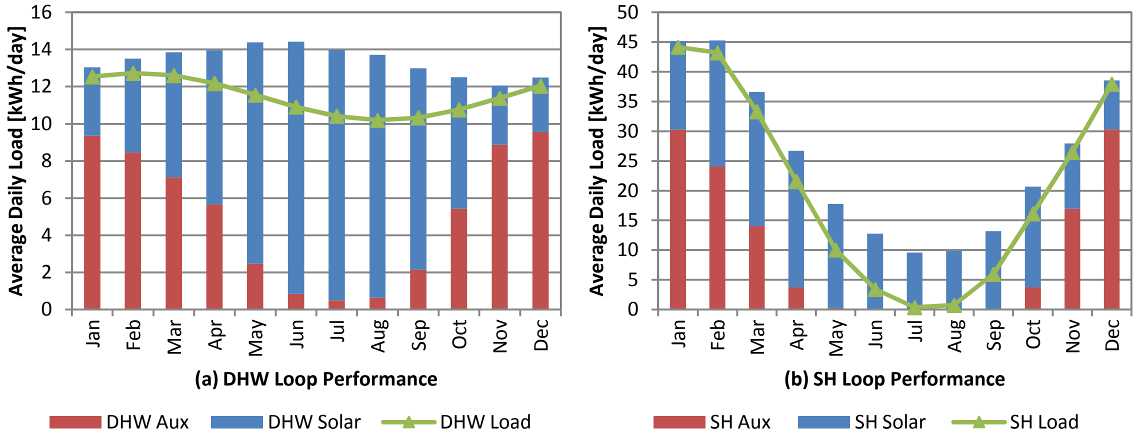


Figure 5.4: Basic solar combi-system performance of (a) the domestic hot water loop and (b) the space heating loop

As described in Chapter 4, the single-tank solar combi-system configuration selected for further comparison had a single thermal storage tank as part of the hot water heating loop. The solar collector loop was able to heat the water in this tank and the space heating loop could also use the energy stored in this tank via a heat exchanger. The solar energy supplied to the space heating loop was calculated as the energy supplied by the thermal storage tank, and the solar energy supplied to the domestic hot water loop was calculated as the energy from the collector loop less the solar energy supplied to the space heating loop. As shown in Figure 5.5, the total amount of energy supplied to the space heating loop matched the space heating load, whereas the total energy entering the domestic hot water loop was greater than the hot water load, most notably during the summer months. This difference occurred due to the fact that in the single-tank solar combi-system, the space heating loop did not contain any thermal storage and only drew energy from the thermal storage tank in the domestic hot water loop when there was a space heating load. The domestic hot water loop, on the other hand, contained the only thermal storage for this combi-system, and as such it was sized for the both the space heating and the domestic hot water loads. This made it much larger than the thermal stores in the stand-alone solar domestic hot water system and the basic combi-system, and thus capable of accepting more energy from the solar collector loop.

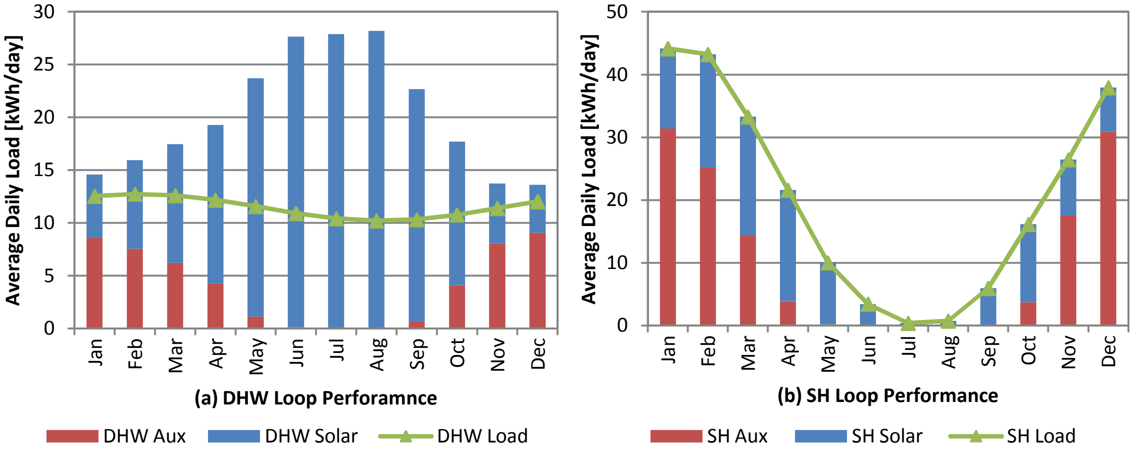


Figure 5.5: Single-tank solar combi-system performance of (a) the domestic hot water loop and (b) the space heating loop

5.2 Discussion

The solar fraction was used to compare the performance of the different systems investigated in this chapter since, as previously shown, the energy supplied to the system by the solar collector loop is not a good indication of how much the auxiliary heat source contribution could be reduced by.

A comparison of the domestic hot water supplies, Figure 5.6, showed that the single-tank combi-system had the best annual performance, with an annual solar fraction of 0.67 for the domestic hot water load. The stand-alone solar domestic hot water system had the second best performance with an annual solar fraction of 0.61. This system had similar solar fractions to the single-tank solar combi-system from January to April, however, during the summer it was out performed by both combi-systems. The lower performance during the summer can be explained by the size of the solar collector. The stand-alone solar domestic hot water system has a solar collector area of 6m² whereas the solar combi-systems each have a solar collector area of 18 m². Even though the solar collector for stand-alone solar domestic hot water system is positioned at a lower tilt angle, suggesting it should perform better in the summer, the space heating load during the summer is extremely low, allowing almost all the energy from the larger solar collector arrays in the solar combi-systems to be directed to supplying the domestic hot water load.

The basic solar combi-system had the lowest solar fraction of the three domestic hot water systems with an annual solar fraction of 0.60. Unlike the single-tank solar combi-system which has the thermal storage in the domestic hot water loop, the configuration of the basic solar combi-system used here has the space heating loop charging preferentially over the domestic hot water loop, contributing to a lower solar fraction for the hot water load.

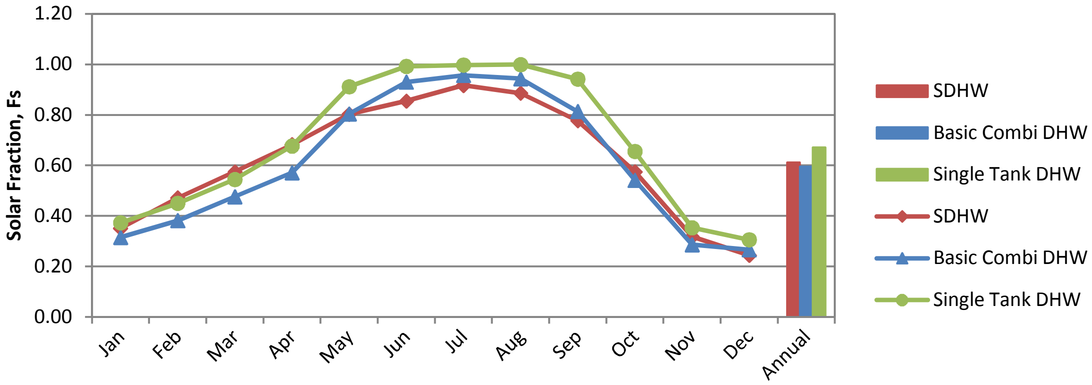


Figure 5.6: Comparison of the domestic hot water performance of the stand-alone solar domestic hot water system, basic solar combi-system, and the single-tank solar combi-system

When comparing the performance of the space heating capabilities of the different systems, the basic solar combi-system performed the best with an annual space heating solar fraction of 0.49 followed by the single-tank solar combi-system with a solar fraction of 0.48 and then the stand-alone solar space heating system with a solar fraction of 0.46, Figure 5.7. The monthly performance of all three of these systems was very close, unlike the domestic hot water performance where there were clearly differences in the performance of various systems at different times of the year. One anomaly that should be noted is the slight dip in solar fraction in July for the single-tank solar combi-system. Since both the hot water loop and the space heating loop share a single thermal energy store in the single-tank solar combi-system, hot water usage in the summer may occasionally cause the water in the top of the thermal store to drop below the required 40 °C for space heating, requiring additional energy to be added by the auxiliary heat source. Despite this, the heating load in the summer is extremely small, amplifying minute contributions of the auxiliary heater in calculations of solar fraction. Furthermore, compared to the heating load during the winter, the summer space heating load is extremely small and so the overall impact this slight drop in performance has on the overall annual solar fraction is negligible.

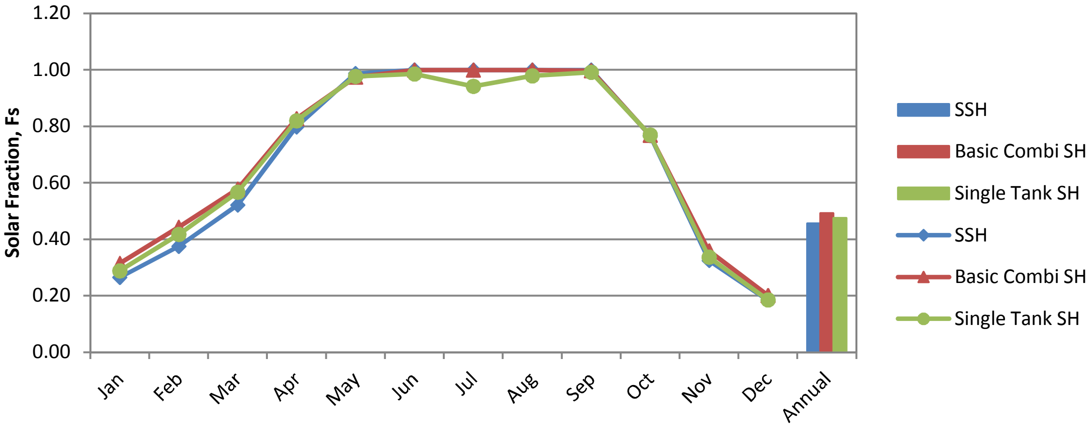


Figure 5.7: Comparison of the space heating performance of the stand-alone solar space heating system, basic solar combi-system, and the single-tank solar combi-system

Depicted in Figure 5.8 is the monthly and annual solar fraction for the combined stand-alone solar domestic hot water and space heating systems, the basic solar combi-system, and the single-tank solar combi-system. Here it can be seen that the single-tank solar combi-system had the best performance with a solar fraction of 0.55, followed by the basic solar combi-system with a solar fraction of 0.53 and then the combined performance of the stand-alone systems with a solar fraction of 0.52. Both combi-systems outperformed the stand-alone solar systems, showing that gains in performance can be made by coupling the domestic hot water and space heating loops, and combining the solar collector arrays.

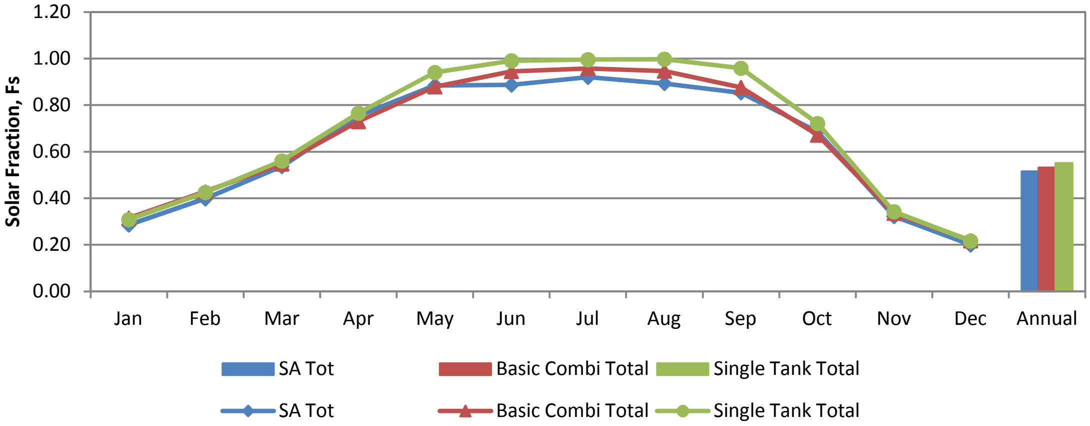


Figure 5.8: Comparison of the combined domestic hot water and space heating performance of the stand-alone solar domestic hot water system with the stand-alone solar space heating system, basic solar combi-system, and the single-tank solar combi-system

Given the domestic hot water and space heating loads, and the available solar energy, this FSC (Fractional Solar Consumption) can be thought of as an upper limit for the total annual solar fraction (both hot water and space heating), Equation (2.12). As stated previously, the FSC for Toronto given the previously stated parameters is 0.926. This is significantly more than the solar fractions found for all of the systems investigated, indicating there is still room to improve the performance of all solar thermal systems without adding seasonal storage.

Chapter 6

Climate Performance

The performance of solar combi-systems can greatly vary with location. Not only can the climate and available solar energy differ, but the space heating load and even the amount of energy required for heating hot water are functions of the location. Using the same system configurations as discussed in Chapter 4, each type of solar thermal system was optimized for collector flow rate and collector tilt angle for the following North American locations: Toronto, Ontario; Winnipeg, Manitoba; Seattle, Washington; and Boulder, Colorado. As shown in Table 6.1, the annual space hating reference load varied for each of the locations considered while there was less variation in the domestic hot water reference loads.

Table 6.1: Annual climate loads for Boulder, Seattle, Winnipeg, and Toronto

Location	Annual DHW Reference Load	Annual SH Reference Load	Total Annual Heating Loads	Annual Available Solar Energy*
Boulder	4348 kWh	6119 kWh	10467 kWh	35091 kWh
Seattle	4260 kWh	4894 kWh	9154 kWh	24487 kWh
Winnipeg	4991 kWh	10505 kWh	15496 kWh	31298 kWh
Toronto	4569 kWh	7361 kWh	11930 kWh	26521 kWh

*18m² solar collector area and tilt angle optimized for the basic solar combi-system
(Boulder: 55°, Seattle: 50°, Winnipeg: 60°, Toronto: 51°)

Figure 6.1 shows the reference load for each of the locations investigated as well as the available solar energy (as optimized for the basic combi-system with an 18 m² collector area). This figure shows that despite the variations in annual reference loads and available solar energy, all locations investigated had very similar loads and available energy during the summer and the difference were most prevalent during the winter months. As this figure shows, the FSC (Fractional Solar Consumption, Equation (2.12)) for all of these locations is very high, with FSC values greater than 0.90. Despite similar FSC values though, the ratio of available solar energy to total load for these locations was much more varied with ratios ranging from 3.35 in Boulder to 2.02 in Winnipeg, Table 6.2, meaning that given the solar collector size and position, the available solar energy in these locations exceeded the total heating load by the given factor.

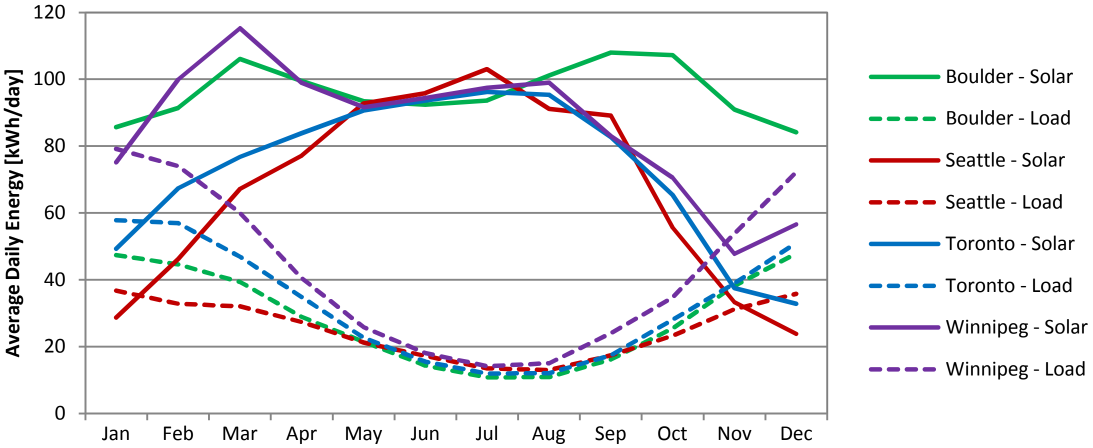


Figure 6.1: Climate characteristics (available solar energy and combined space heating and hot water loads) for Toronto, Boulder, Seattle, and Winnipeg

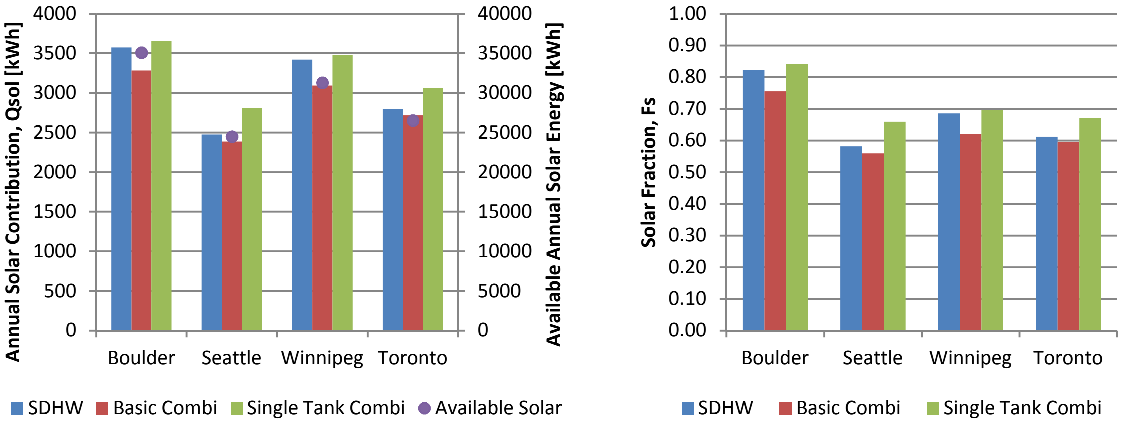
Table 6.2: Location characteristics for Boulder, Seattle, Winnipeg, and Toronto

Location	Latitude	FSC*	Available solar energy to total load ratio*
Boulder	40° N	1.00	3.35
Seattle	48° N	0.93	2.68
Winnipeg	50° N	0.95	2.02
Toronto	44° N	0.93	2.22

*18m² solar collector area and tilt angle optimized for the basic solar combi-system (Boulder: 55°, Seattle: 50°, Winnipeg: 60°, Toronto: 51°)

6.1 Results & Discussion

The collector flow rate and tilt angle for the stand-alone solar domestic hot water and stand-alone space heating systems, basic solar combi-system, and single-tank solar combi-system were optimized for each of the locations investigated. Looking at the annual domestic hot water performance, overall Boulder and Winnipeg had greater solar energy contributions than Seattle and Toronto. As shown in Figure 6.2(a), there is a clear correlation between the available solar energy (as defined in Table 6.1) and the domestic hot water solar contribution. This trend was also apparent in the domestic hot water solar fraction, Figure 6.2(b), since the hot water load for all four locations was similar.

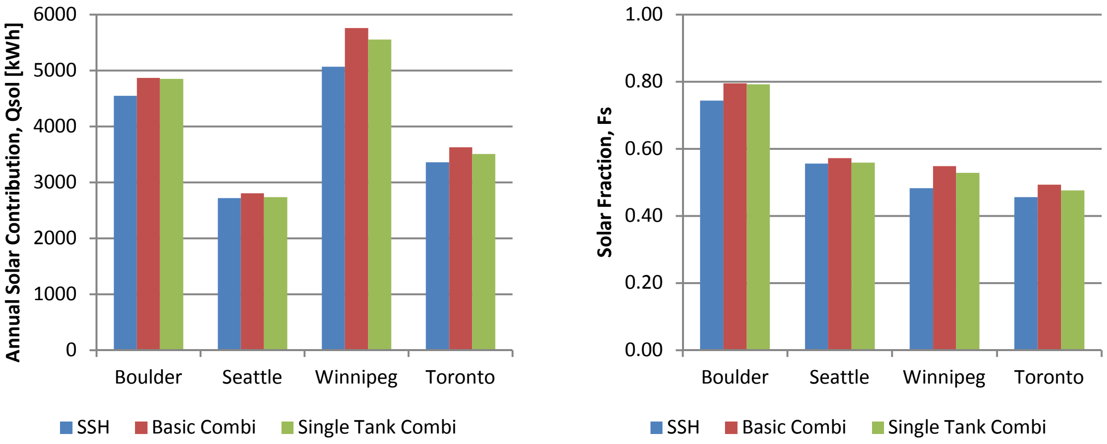


(a) Annual Solar Contribution (b) Solar Fraction

Figure 6.2: Domestic hot water performance for different solar thermal systems configurations and locations.

The differences in performance between the solar thermal systems types in Boulder, Seattle, and Winnipeg were also similar to those found in Toronto. Again, the domestic hot water performance of the basic solar combi-system with the preferential charging of the space heating thermal storage tank was out performed by both the stand-alone domestic hot water system and single-tank combi-system. The single-tank combi-system also had the highest annual domestic hot water solar contribution in all locations, but in Boulder and Winnipeg the stand-alone domestic hot water system performance was closer to that of the single-tank combi-system than the basic combi-system.

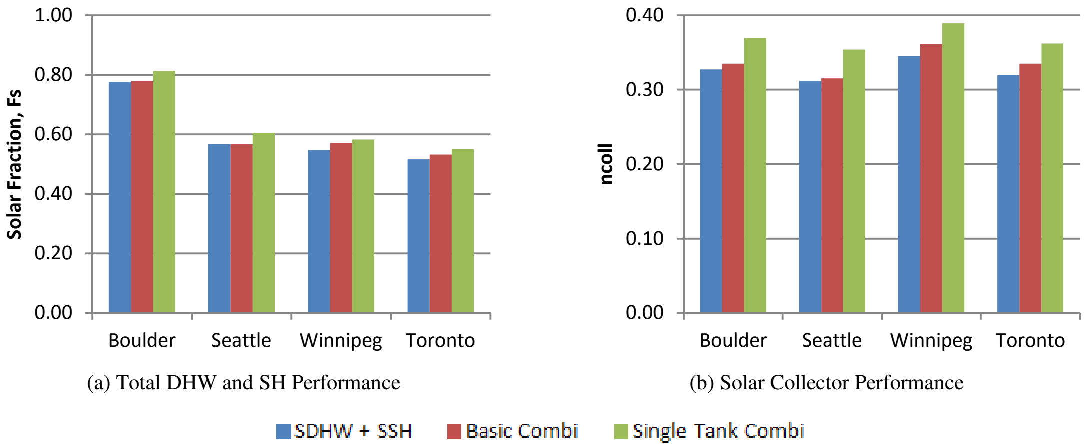
The annual space heating solar contribution, Figure 6.3(a), was highest in Winnipeg (where the space heating load was the greatest), followed by Boulder (where the available solar energy was the greatest), then Toronto, and finally Seattle. Since the space heating loads in these locations were all different (unlike the domestic hot water loads which were similar), the solar fraction for relative solar fractions do not match the annual solar contribution. Again, the relative differences in space heating performance of the different system types in Boulder, Seattle, and Winnipeg were similar to those found in Toronto. The basic combi-system with the preferential charging of the space heating storage tank performed the best, followed by the single-tank combi-system, and then the stand-alone space heating system.



(a) Annual Solar Contribution (b) Solar Fraction

Figure 6.3: Space heating performance for different solar thermal systems configurations and locations.

The total annual solar fraction and collector efficiency are shown in Figure 6.4. These results have been normalized for the heating load and available solar energy respectively. The solar fraction results seem to correspond to the FSC values for these locations. Seattle, Winnipeg, and Toronto all had very similar FSC values (ranging from 0.93 – 0.95) and solar fractions (ranging from 0.51 – 0.61), whereas Boulder had an FSC value of 1.00 and much higher solar fractions ranging from 0.77 to 0.81 for the different system configurations. It should be noted that since the maximum FSC value possible is 1, all systems with solar collector arrays large enough to have a usable solar energy equal to the load are given the same FSC value. This doesn’t allow for differentiating between systems beyond a certain size and thus FSC values of 1 should not be included if using the FSC method to describe solar thermal systems.



(a) Total DHW and SH Performance

(b) Solar Collector Performance

Figure 6.4: Annual total system and solar collector performance of solar combi-systems configurations in different locations

Lastly, the solar collector performance for these systems, Figure 6.4 (b), shows that like the results for Toronto, the single-tank solar combi-system had the best performance in all locations, followed by the basic combi-system and then the stand-alone solar systems. The location did not appear to play a significant role in the solar collector performance as compared to the system type.

Chapter 7

Sensitivity Analysis

The performance of solar combi-systems can be affected by a number of different factors. The simulations in Chapter 4, Chapter 5, and Chapter 6 were optimized for collector flow rate and tilt angle, while other parameters like thermal storage tank size, collector azimuth, and space heating floor characteristics were fixed. To determine the effect variations of these parameters can have on the performance of solar combi-systems, a sensitivity analysis was conducted. The basic solar combi-system configuration (ii) was selected as the base system. Although the single-tank solar combi-system generally outperformed the basic solar combi-system, the basic solar combi-system was selected as an optimal system design and was modelled using a thermal storage tank that promoted thermal stratification. Currently this type of tank is not widely available in North America and the actual performance of these tanks does not usually match the idealized performance of the model.

The sensitivity analysis was divided into three general areas: the solar collector, thermal storage, and heating systems. For the solar collector, the effect of the collector tilt angle, azimuth, and size were considered as well as the flow rate. For the thermal storage, the size of the domestic hot water and space heating storage tanks, the heat exchanger effectiveness, and the number of nodes used in the tank models was considered. Lastly, for the heating systems, the space heating load floor delivery temperature and floor R-value were investigated.

7.1 Solar Collector Sensitivity

In the base solar combi-system configuration, the solar collector was set at a tilt angle of 51°, where the overall system performance was maximized. As shown in Figure 7.1, lower tilt angles produced higher domestic hot water annual solar contributions (with a maximum tilt angle around 35°), while the space heating annual solar contribution was maximized at a higher tilt angle of around 55°, and both the hot water and space heating performances decreased at very high tilt angles. The tilt angles that maximize the hot water and space heating annual performance were consistent with the optimized tilt angles found for the stand-alone solar domestic hot water system (optimized tilt angle of 38°) and the stand-alone solar space heating system (optimized tilt angle of 53°). Since the space heating load is largest in the winter with very little heating required during the summer, the higher solar collector tilt angle is better optimized for the lower solar altitude angle in the winter, whereas since the hot water load is fairly stable throughout the year, the lower solar collector tilt angle is better for a constant year round load. Overall, the difference in optimal tilt angles for the hot water and space heating loads means that small variations in collector tilt angle have little effect on the total system solar fraction, but the overall performance drops off significantly when the solar collectors are near flat (0° tilt angle) or near vertical (90° tilt angle).

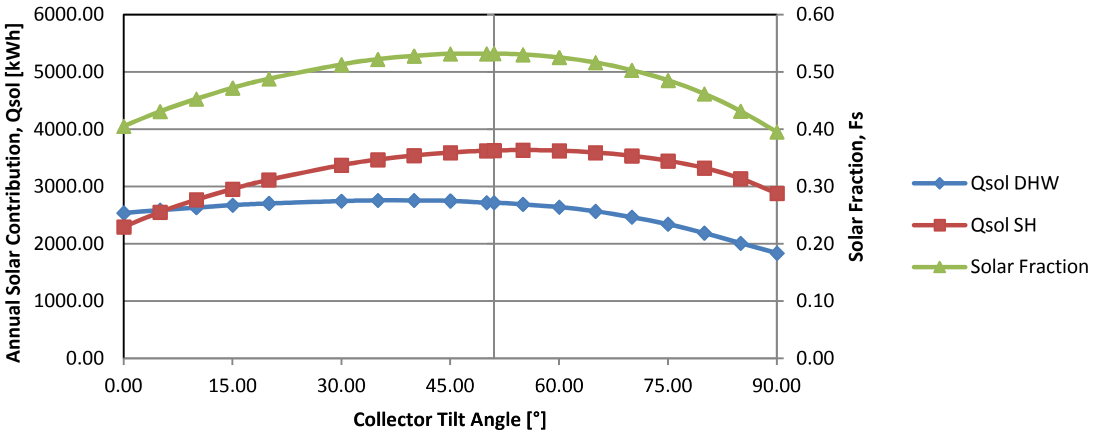


Figure 7.1: Basic combi-system - solar collector tilt angle sensitivity

In the base solar combi-system configuration, the solar collector was oriented with an azimuth 0° (south facing). Similar to the solar collector tilt angle sensitivity, small variations in the solar collector azimuth from south facing had little effect on the total solar fraction, however as the azimuth was inclined further from south, the solar fraction decreased noticeably, consistent with the annual total radiation on the tilted collector surface. As shown in Figure 7.2, this trend was also mirrored in the space heating annual solar contribution as well as in the domestic hot water annual solar contribution, although to a much lesser extent. This result was influenced by a combination of the configuration of the basic solar combi-system which preferentially charged the space heating storage tank, and the difference in return/mains water temperature of the space heating and domestic hot water loops.

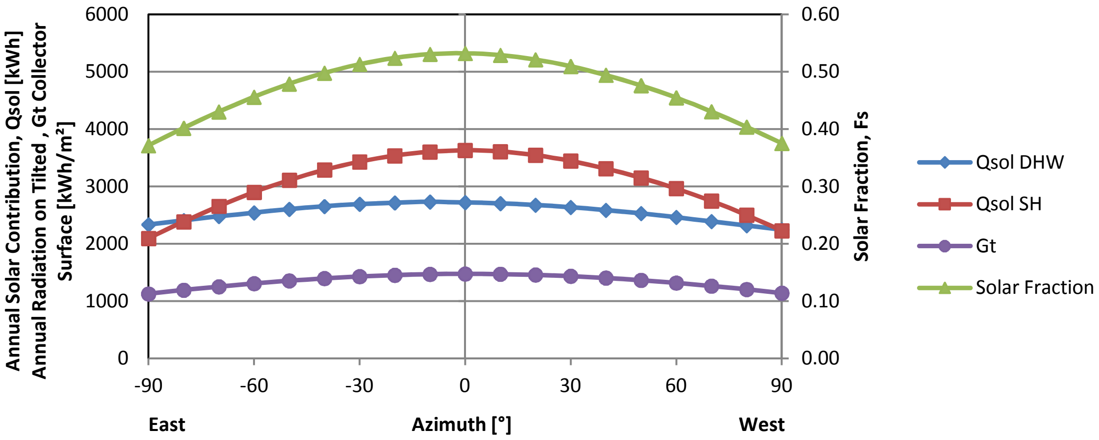


Figure 7.2: Basic combi-system - solar collector azimuth angle sensitivity

Since the space heating storage tank was charged preferentially over the domestic hot water storage tank, the difference in the annual radiation on the tilted collector surface had the greatest effect on the annual space heating solar contribution. Additionally, the minimum return temperature for the space heating storage tank was room temperature (20°C) while the minimum mains temperature for Toronto was lower, varying between 5°C and 16°C, depending on the time of year. This meant that while the solar collector loop was charging the space heating storage tank, the solar collector loop fluid leaving the space heating loop heat exchanger was above the minimum mains water temperature, and could still be used to charge the domestic hot water storage tank, explaining the why the domestic hot water performance was only minimally affected with the changes in solar collector azimuth.

In the base solar combi-system configuration, the solar collector had an area of 18m². As shown in Figure 7.3, both the space heating and domestic hot water annual solar contributions and the overall solar fraction increased as the solar collector area increased. Despite preferential charging of the space heating thermal storage tank over the domestic hot water storage tank, up to a collector size of approximately 9 m² the annual solar contribution for the domestic hot water load was greater than that of the space heating load. With a smaller collector area, the fluid in the solar collector loop was not able to reach as high a temperature. Since the minimum return water temperature for the space heating storage tank was higher than the minimum mains water temperature supplying the domestic hot water storage tank, the collector loop was still able to transfer energy to the domestic hot water when the collector fluid temperature was too cold to charge the space heating store (but sill above the mains water temperature).

The performance of this combi-system was contrasted with the collector efficiency which decreased as the solar collector area increased. As explained in Chapter 3, the collector efficiency is the ratio of energy output by the solar collector to the energy incident on the collector surface. As the solar collector area increases, the solar collector loop is able to supply more energy to the heating loads at a higher temperature. However, a higher supply temperature also results in greater thermal losses in the collector loop, resulting in the decrease in collector efficiency.

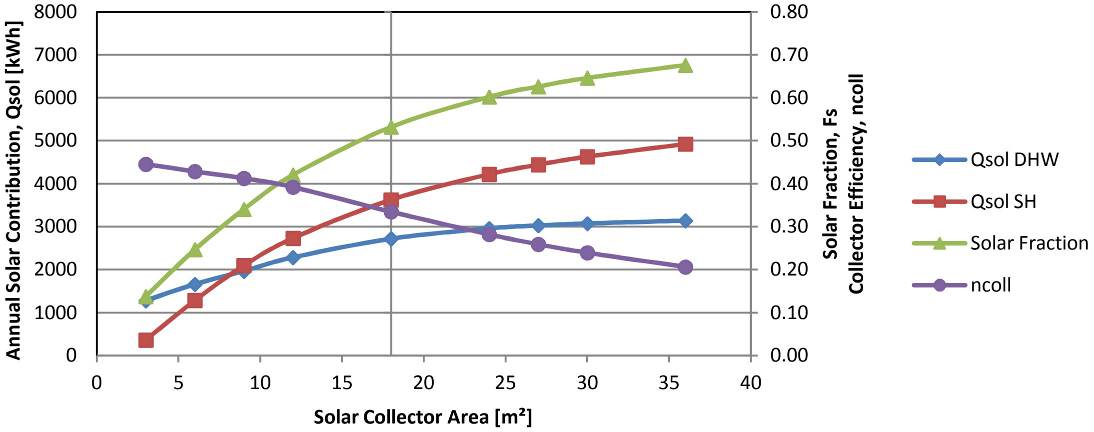


Figure 7.3: Basic combi-system - solar collector size sensitivity

In the base solar combi-system configuration, the solar collector loop flow rate was set to 216 kg/hr, where the overall system performance was maximized. As shown in Figure 7.4, very low flow rates favoured the domestic hot water performance. However, as the flow rate increased the space heating performance also increased, causing the domestic hot water performance to decrease as a result of the combi-system configuration favouring the space heating loop.

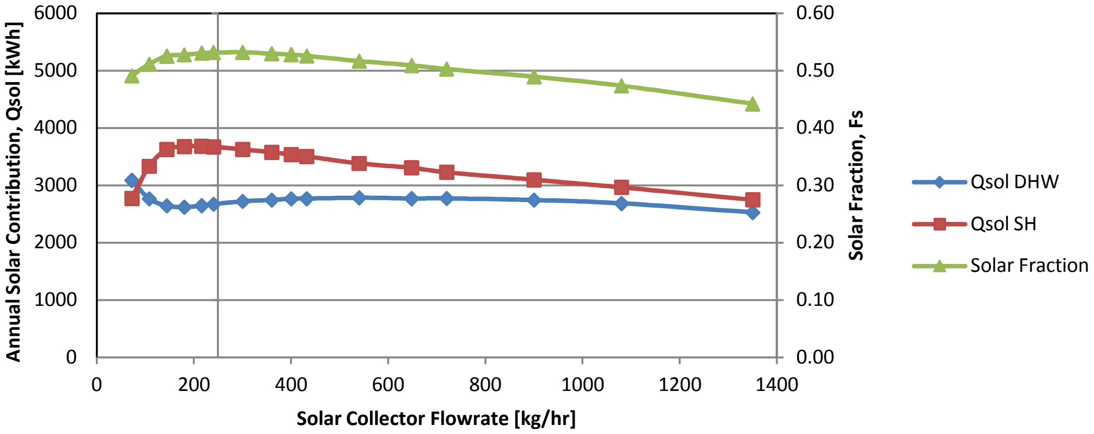


Figure 7.4: Basic combi-system - solar collector flow rate sensitivity

7.2 Thermal Storage Sensitivity

In the base solar combi-system configuration, the space heating thermal storage tank was given a volume of 0.81 m^3. Figure 7.5 shows the variation of annual solar contribution and solar fraction for different space heating tank sizes. It can be seen from these results that at small tank volumes, the space heating annual solar contribution increases with tank size while the domestic hot water annual solar contribution decreases. This is a result of the charging order of the two thermal storage tanks; the space heating tank getting charged preferentially over the domestic hot water tank. Since very small space heating storage tanks have smaller thermal capacity and will become fully charged faster, more of the energy from the solar collector loop will be available to charge the domestic hot water storage tank.

At a space heating tank volume of around 0.54 m^3, the solar fraction evens out and remains fairly constant with increasing tank volume, showing that too small a tank volume negatively affects the overall system performance, while an oversized tank only minimally affects the overall system performance. However, it should be noted that at the other end of the spectrum, with very large tank volumes, the solar fraction starts decreasing slightly. This is due to the increased surface area that accompanies the larger tank volume and subsequent higher thermal losses from the tank, the increase capacity of the space heating store negatively impacting the domestic hot water loop performance, and the increased volume of each tank node in the tank model potentially resulting in more mixing (especially in the topmost node).

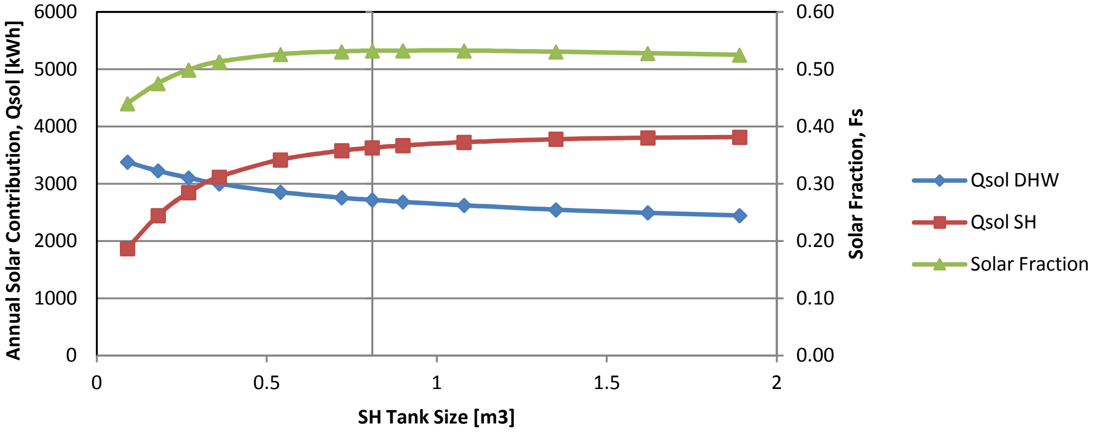


Figure 7.5: Basic combi-system - space heating thermal storage tank size sensitivity

In the base solar combi-system configuration, the heat exchanger connecting the solar collector loop to the space heating storage tank had a fixed effectiveness of 0.7. As shown in Figure 7.6, the space heating annual solar contribution increases as the heat exchanger effectiveness increases until it reaches a value of 0.7 at which point the solar contribution starts to decrease. At low effectiveness values, the amount of energy the heat exchanger can transfer to the space heating store is limited by the effectiveness, however at very high effectiveness values, the top of the space heating storage tank becomes charged much faster, with a greater degree of stratification, limiting the overall energy transfer to that tank due to the controller parameters since the pump circulating space heating fluid through the heat exchanger is not turned on as frequently due to the high temperature cut-off. As with the space heating tank sensitivity, since the space heating tank is charged preferentially over the domestic hot water tank, lower annual solar contribution for the space heating load are matched with higher annual solar contributions for the domestic hot water load, resulting in a relatively stable overall solar fraction.

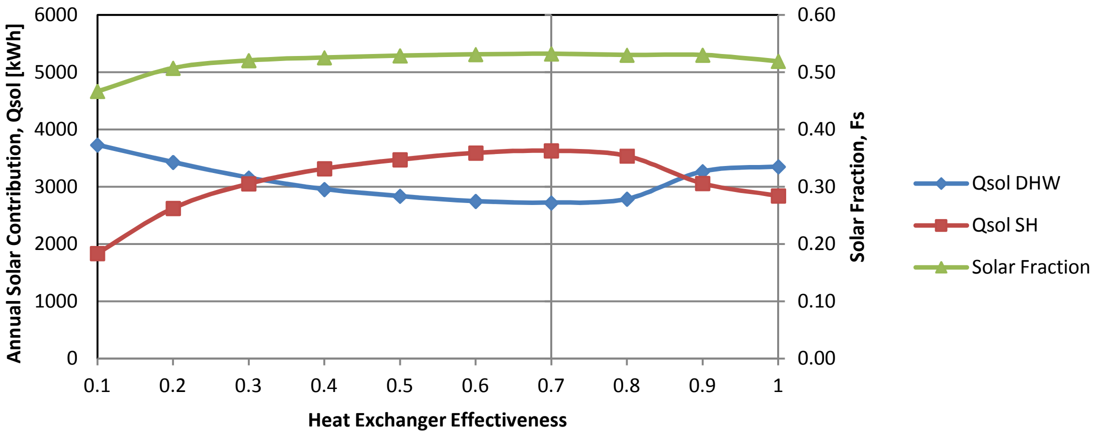


Figure 7.6: Basic combi-system - solar collector space heating loop heat exchanger effectiveness sensitivity

In the base solar combi-system configuration, the domestic hot water thermal storage tank was given a volume of 0.27 m^3. As shown in Figure 7.7, the both the domestic hot water annual solar contribution and overall solar fraction decreased with smaller tank size, but stabilized with tanks around 0.24 m^3 and greater. Similar to the space heating tank size sensitivity, at small volumes the domestic hot water solar contribution was limited by the storage capacity, resulting in higher space heating solar contributions, while larger tank sizing had little effect on the system performance.

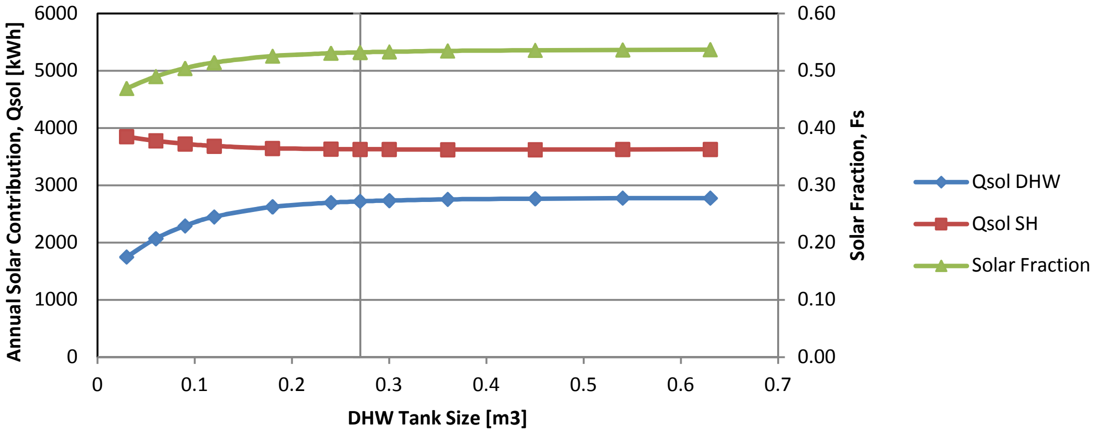


Figure 7.7: Basic combi-system - domestic hot water thermal storage tank size sensitivity

As discussed in Appendix A, the number of nodes used in the tank model roughly corresponds to the level of stratification within the tank. In the base solar combi-system configuration, the storage tanks were simulated using 30 nodes. As shown in Figure 7.8, the number of nodes has a relatively small effect on the overall solar fraction, although with very few nodes, the system performance does decrease. It should be noted that in these simulations, the tank model only accounts for mixing due to thermal inversion; mixing due to other factors (such as jet mixing) was not taken into account.

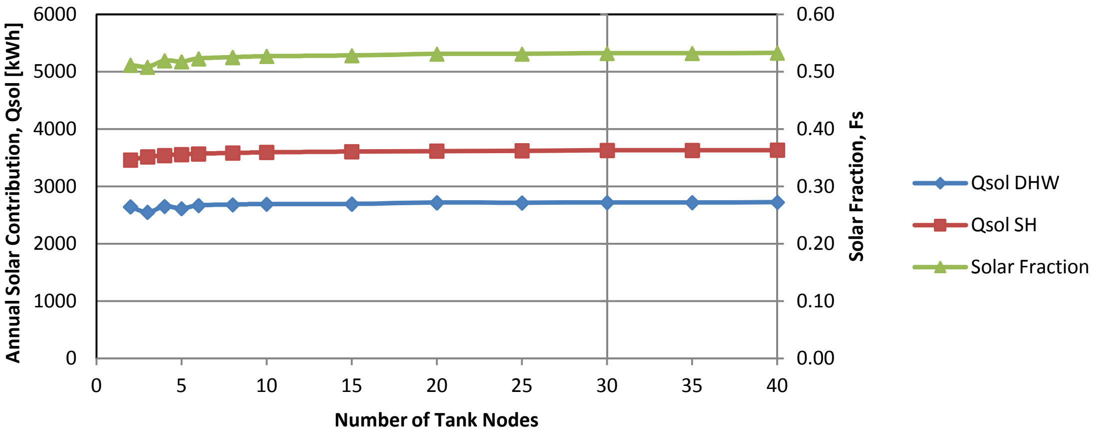


Figure 7.8: Basic combi-system - tank model, number of tank nodes sensitivity

7.3 Heating System Sensitivity

The hydronic-floor model used to simulate the space heating load used a fixed fluid-delivery temperature with a variable speed pump, and a floor with a constant R-value. In the base solar combi-system configuration, the fluid-delivery temperature was set at 40°C. As shown in Figure 7.9 both the space heating annual solar contribution and overall solar fraction decrease as the fluid-delivery temperature increases. This would seem to indicate that a low delivery temperature should be used, however, a lower delivery temperature requires a greater flow rate.

Since these simulations only looked at the thermal energy performance of the system, the additional parasitic energy required to run a higher speed pump should be balanced with the thermal energy savings associated with a lower delivery temperature.

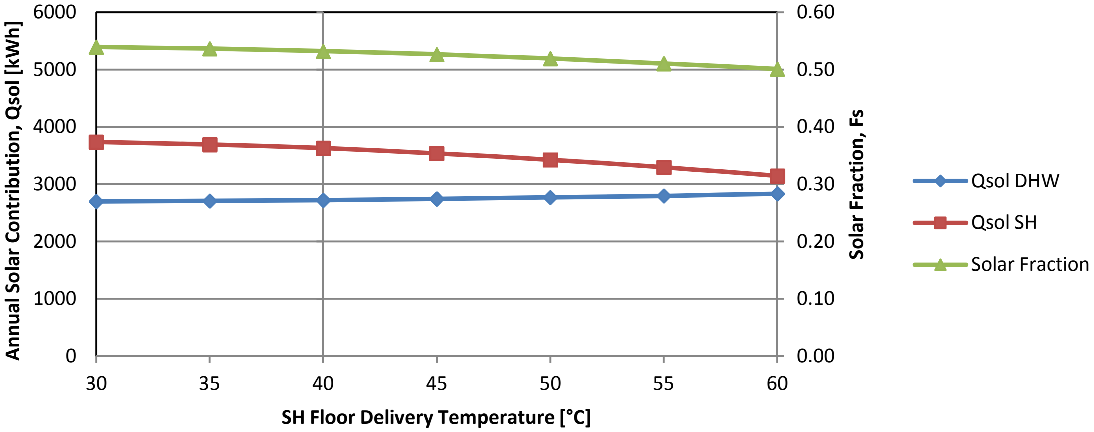


Figure 7.9: Basic combi-system - hydronic-floor model fluid-delivery temperature sensitivity

In the base solar combi-system configuration, an R-value of 0.2 m-K/W was used for the floor. As shown in Figure 7.10, variations in floor R-values had little effect on the system performance although the overall solar fraction was slightly higher with low floor thermal resistance. At R-values greater than 1, however, the floor delivery temperature (of 40°C) was not high enough to meet the space heating load. Thus, to accommodate floor structures with higher R-values, a higher floor delivery temperature is required, and as shown in Figure 7.9, higher delivery temperatures correspond to a decrease in overall system performance.

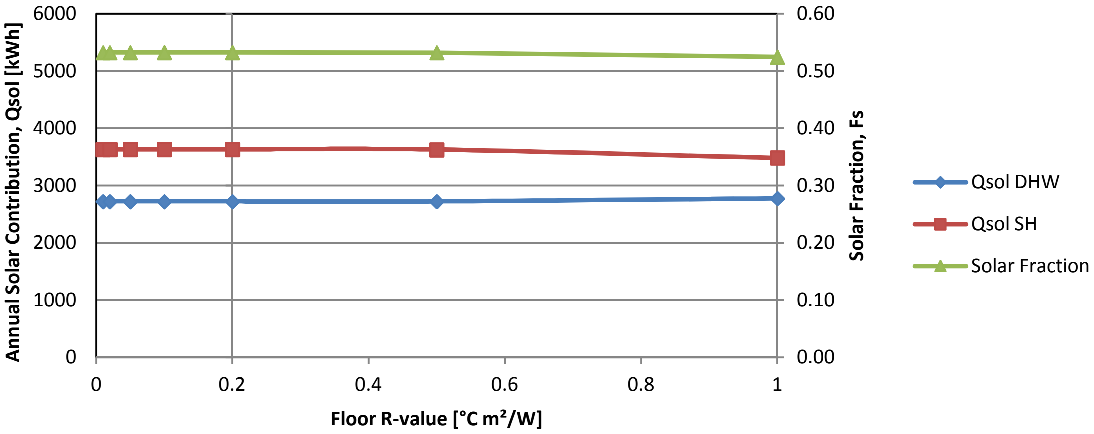


Figure 7.10: Basic combi-system - space heating floor model – R-value sensitivity

Chapter 8

Conclusions and Recommendations

Computer modelling and simulation of solar thermal systems facilitates the comparison of different system configurations with varying parameters like location, component sizing, and operational settings. From the analysis of thermal system configurations in Chapter 4, the use of a natural convection heat exchanger (relative to the fixed effectiveness heat exchanger model) improved the performance of the stand-alone domestic hot water system and the use of vacuum tube solar collectors (relative to glazed flat plate collectors) most improved the performance of the stand-alone space heating system. This trend was also observed in the optimized basic combi-system configuration, and although the optimized single-tank combi-system used a fixed effectiveness heat exchanger, the tank model included internal stratifiers which prevented thermal inversions from occurring, one of the main benefits of using natural convection heat exchangers.

Comparisons of the different solar thermal systems revealed that the single-tank combi-system consistently outperformed the other systems in all locations. This system had the advantage of using internal stratifiers in the thermal storage tank which prevented mixing due to thermal inversions. The relative performances of the basic combi-system and the stand-alone solar thermal systems exhibited some variation between locations. In Toronto and Winnipeg where the ratio of heating load to available solar energy was higher, the basic combi-system performed better than the stand-alone systems. However, in Seattle and Boulder where the ratio of heating load to available solar energy was lower, both the stand-alone systems and the basic combi-system had similar solar fractions.

The sensitivity analysis of the basic solar combi-system showed that the solar collector parameters and the hydronic-floor fluid-delivery temperature had the greatest impact on system performance. For other parameters like the thermal storage tank sizes and the number of nodes used in the tank models, decreases in these parameters from the base value resulted in a large drop in performance while increases in the parameter from the base value had a much smaller effect. The hydronic-floor R-value, on the other hand, had the smallest impact on performance, provided the hydronic-floor delivery temperature was sufficient. Overall, small changes in most parameter values from the reference value had little effect on the system performance, the exceptions to this being the solar collector size and the floor delivery temperature, making these parameters significant when optimizing system performance.

Future work should include validation of the full basic solar combi-system model. Even though the single-tank solar combi-system consistently outperformed the basic combi-system, the single-tank system used an ideal tank model with internal stratifiers, something that is not readily available in North America. Additionally, one of the limitations of these simulations was the exclusion of the parasitic energy required to operate components like controllers and pumps. The controller loads would typically be negligible compared to the heating load, but the energy required by the pumps would have an effect on the overall system performance. In addition to the information from the simulations, the pump loads would depend on the pressure drop within the system. The pressure drop is affected by variables like changes in elevation, pipe diameter, bends and turns in the piping, which are not directly related to the heating load, but more closely related to the configuration of the house and the location of the system components like the hot water tanks, solar collector array, and layout of the hydronic space heating system. If a full combi-system were to be integrated into a house (as opposed to a "hardware-in the loop" simulation in the lab) for the validation, the parasitic pump and controller loads could also be modelled to reflect the actual system arrangement and included in the simulation.

Lastly, although not investigated here, another consideration for solar combi-systems is the disparity between the peak available solar energy in the summer and the peak space heating load in the winter. As recorded in Table 6.2, with the solar collector arrays as defined, the available solar energy to total load ratio varied from 2 to over 3 times the thermal load for Boulder, Seattle, Toronto, and Winnipeg. Despite this, the FSC values ranged from 0.93 to 1.00 and the solar fraction for these systems were in the range of 0.5 to 0.8. Although sensitivity analysis showed that doubling the size of the thermal store did not significantly increase the system performance, incorporating seasonal thermal storage into the combi-system may be one way to increase the system performance and collector efficiency without increasing the solar array size, or alternatively gain the same performance from a smaller solar array. Further investigation into the performance of solar combi-systems with seasonal storage is recommended.

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Appendix A

Component Selection and Modelling

A.1 Operating Fluids

The indoor components of the investigated systems used water as their circulating fluid. Not only is water is a very good fluid for transporting and storing heat due to its high heat capacity, it is also inexpensive and non-toxic. However, since parts of the collector loop are exposed to the elements, and the system is expected to operate during the heating system (i.e., winter), a fluid with a lower freezing point is required to prevent damage to the system during the winter. To address this problem, a 50% (by volume) propylene glycol solution was selected for use in the collector loop. At this concentration, the collector fluid had a freezing point of -34°C and the system was protected against bursting at temperatures as low as -50°C [57]. Both the water and glycol solution properties were assumed to remain constant and be independent of temperature.

A.1.1 Properties - Water

Fluid properties for water used in TRNSYS simulations. These values were assumed to be constant (i.e. independent of temperature) and were taken at 40°C, Table A.1.

Table A.1: Fluid Properties of Water

Property	Value
Specific Heat (C_p)	4.180 kJ/kg-K
Density (ρ)	991 kg/m^3
Thermal Conductivity	0.632 W/m-K
Boiling Point	100 °C

Water properties at 40°C (Source: [58])

A.1.2 Properties - Glycol Solution

Fluid properties for glycol solution used in TRNSYS simulations. This was a 50% glycol solution by volume at 20°C and these values were assumed to be constant (i.e. independent of temperature).

Table A.2: Fluid Properties of Glycol Solution

Property	Value
Specific Heat (C_p)	3.53 kJ/kg-K
Density (ρ)	1044 kg/m^3

Glycol solution 50% by volume at 20°C (Source: [57])

A.2 Liquid Solar Collectors

The three main types of liquid solar thermal collectors are: evacuated tube collectors, glazed flat plate collectors, and unglazed flat plate collectors. Each of these types of collectors has different performance characteristics, lending themselves to different applications. Under the same environmental conditions and collector orientation, the efficiency of a collector depends on the temperature difference between the inlet fluid temperature and the ambient temperature.

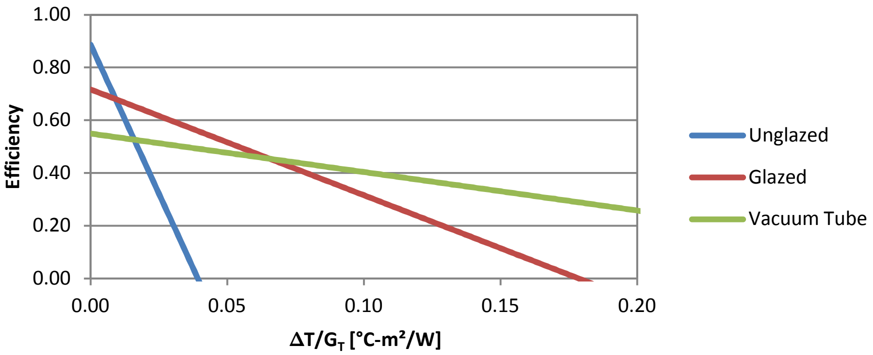


Figure A.1: Typical efficiency curves of different liquid solar thermal collectors

As shown in Figure A.1, of the three types of liquid collectors, unglazed collectors have the highest efficiency at small temperature differences, but their performance drops off drastically as that temperature difference increases. In Canada, these collectors are almost exclusively used for pool heating [4]. In the summer when residential pools are in use, the ambient temperature and the temperature of the pool water being heated are very close, allowing the collector to operate at a very high efficiency. Glazed and evacuated tube collectors, on the other hand, have a much larger working temperature range, making them better suited for year round and winter operation, and these are the two types of collectors that will be considered.

There are many organizations that test solar thermal collectors; in North America, the Solar Rating and Certification Corporation (SRCC) is the most respected. It is an independent third-party certification entity that administers a certification, rating, and labelling program for solar collectors and complete solar domestic hot water systems. Most agencies, including the SRCC, use the following efficiency equation to characterize the performance of the collectors it tests:

$$\eta = a_0 - a_1 \frac{(\Delta T)}{G_T} - a_2 \frac{(\Delta T)^2}{G_T} \tag{A.1}$$

where:

η is the instantaneous efficiency [-];
a_0, a_1, and a_2 are the efficiency coefficients [-], [W/m²-K] and [W/m²-K²];
ΔT is the temperature difference between the collector fluid and ambient [°C]; and
G_T is the radiation on the tilted collector surface [W/m²].

In the case of the SRCC, the area is based on the gross area of the collector and the temperature difference is based on the inlet fluid temperature, i.e.:

$$\Delta T = T_{in} - T_{amb} \tag{A.2}$$

where:

ΔT is the temperature difference between the collector fluid and ambient [°C];
T_{in} is the inlet temperature [°C]; and
T_{amb} is the ambient temperature [°C].

However, some standards will use the net aperture area as the collector area, and calculate ΔT using the average fluid temperature or outlet temperature i.e.:

$$\Delta T = T_{ave} - T_{amb} \tag{A.3}$$

or

$$\Delta T = T_{out} - T_{amb} \tag{A.4}$$

where:

ΔT is the temperature difference between the collector fluid and ambient [°C];
T_{ave} is the average temperature [°C];
T_{out} is the outlet temperature [°C]; and
T_{amb} is the ambient temperature [°C].

The SRCC test method specifies that the thermal performance collector tests must be conducted when the insolation incident to the collector is within 30 degrees of a vector normal to the collector surface [59]. A correction factor, known as the incidence angle modifier (IAM), is then used to make adjustments for the direction of the incident solar radiation relative to the collector plane. This incidence angle modifier ($K_{\tau\alpha}$), is multiplied by the a_0 term in the efficiency curve.

Glazed flat plate collectors are considered symmetrical, i.e., the change in performance due to incidence angle is the same regardless of the direction. For these types of collectors IAM is often approximated as [60]:

$$K_{\tau\alpha} = 1 - b_0\left(\frac{1}{\cos\theta} - 1\right) - b_1\left(\frac{1}{\cos\theta} - 1\right)^2 \tag{A.5}$$

where:

$K_{\tau\alpha}$ is the incidence angle modifier [-];
b_0 and b_1 are incidence angle modifier coefficients [-], [W/m²-K] and [W/m²-K²]; and
θ is the incidence angle [°].

Both coefficients b_0 and b_1 are determined through testing the collector at different incidence angles.

Vacuum tube collectors, on the other hand, are sensitive to the angle of insolation with respect to both the longitudinal (θ_l) and transverse (θ_t) orientation of the collector tubes, Figure

A.2. For these collectors, two sets of IAMs are used, one for each direction. These IAMs are derived from testing results and are often given tabular form.

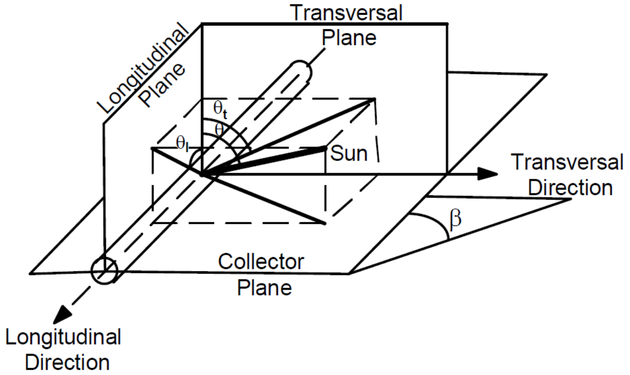


Figure A.2: Vacuum tube collector incidence angle planes (Source: [60])

In addition to the incidence angle modifier, a flow rate correction is also needed if the collectors are operated at a flow rate different from the one they were tested at. This correction can be calculated using the data from the test condition and the new operating flow rate. The flow rate correction is used to adjust the collector efficiency (η), and is calculated [60]:

$$r = \frac{\left.\frac{\dot{m}C_p}{A_c\,F'U_L}\left(1 - e^{-AF'U_L/\dot{m}C_p}\right)\right|_{actual}}{\left.\frac{\dot{m}C_p}{A_c\,F'U_L}\left(1 - e^{-AF'U_L/\dot{m}C_p}\right)\right|_{test}} \tag{A.6}$$

where:

r is the flow rate correction [-];
$\dot{m}$ is the mass flow rate [kg/s];
C_p is the specific heat of the fluid [J/kg-K];
A_c is the collector area [m²];
F' is the collector efficiency factor [-]; and
U_L is the collector’s overall loss coefficient [W/m²-K].

Since the collectors are liquid based, the dependence of $F'U_L$ on flow rate is small so $F'U_L$ can be assumed to be independent of flow rate and the same value can be used for both the actual and test conditions [5] [60]. Using test conditions $F'U_L$ can be calculated as:

$$F'U_L = -\frac{\dot{m}C_p}{A_c}\ln\left(1 - \frac{(a_1 + a_2\Delta T)A_c}{\dot{m}C_p}\right) \tag{A.7}$$

where:

$\dot{m}$ is the mass flow rate at test conditions [kg/s];

C_p is the specific heat of the test fluid [J/kg-K];

A_c is the collector area [m²];

a_1 and a_2 are efficiency coefficients from the efficiency equation [W/m²-K] and [W/m²-K²]; and

ΔT is the difference between the collector fluid at the inlet and ambient temperature [K].

Based on these modifiers, the collector efficiency can be modelled as:

$$\eta = r\left(K_{\tau\alpha}\, a_0 - a_1\frac{(\Delta T)}{G_T} - a_2\frac{(\Delta T)^2}{G_T}\right) \tag{A.8}$$

where:

η is the instantaneous efficiency [-];

r is the flow rate correction [-];

$K_{\tau\alpha}$ is the incidence angle modifier [-];

a_0, a_1 and a_2 are efficiency coefficients [-], [W/m²-K] and [W/m²-K²];

ΔT is the difference between the collector fluid at the inlet and ambient temperature [K]; and

G_T is the radiation on the tilted collector surface [W/m²].

Equation (A.8) can only model the collector performance when liquid is flowing through the collector. When stagnating, energy is not transferred to the rest of the system, but the outlet temperature is still needed for the controller. To address this, collector stagnation was assumed to instantly reach steady-state where the efficiency of the collector was zero and the collector fluid was at a uniform temperature (i.e., $T_{in} = T_{out}$). This gives the following equation [61] [62]:

$$0 = K_{\tau\alpha}\, a_0 - a_1 \frac{(T_{out} - T_{amb})}{G_T} - a_2 \frac{(T_{out} - T_{amb})^2}{G_T} \tag{A.9}$$

which can be rearranged as:

$$T_{out} = \frac{-a_1 + \sqrt{a_1^2 + 4a_0 a_2 G_T K_{\tau\alpha}}}{2a_2} + T_{amb} \tag{A.10}$$

where:

T_{out} is the outlet temperature [°C];
T_{amb} is the ambient temperature [°C];
a_0, a_1, and a_2 are the efficiency coefficients [-], [W/m²-K], and [W/m²-K²];
$K_{\tau\alpha}$ is the incidence angle modifier [-]; and
G_T is the radiation on the tilted collector surface [W/m²].

Typically stagnation is an undesirable condition for solar thermal collectors since it can result in denaturing and loss of collector fluid if the system is not properly designed. However, these simulations were conducted to evaluate the potential of the system, not the actual performance, so stagnation control was not included in the models.

A.2.1 Properties - Glazed Flat Plate Collector

TRNSYS Performa: Type 1

Efficiency Equation:

$$\eta = 0.717 - 4.01410\, \frac{T_i - T_a}{G_T} - 0.01872 \frac{(T_i - T_a)^2}{G_T} \tag{A.11}$$

where:

η is the instantaneous efficiency [-];
T_i is the inlet temperature of the collector fluid [°C];
T_a is the ambient temperature [°C]; and
G_T is the radiation on the tilted collector surface [W/m²].

Incident Angle Modifier:

$$\mathrm{K}_{\tau\alpha} = 1 - 0.110 \frac{1}{\cos\theta} - 0.051 \frac{1}{\cos^2\theta} \tag{A.12}$$

where:

$K_{\tau\alpha}$ is the incidence angle modifier [-]; and
θ is the incidence angle [°].

A.2.2 Properties - Vacuum Tube Collector

TRNSYS Performa: Type 71

Efficiency Equation:

$$\eta = 0.549 - 1.4585\,\frac{T_i - T_a}{G_T} - 0.00436\,\frac{(T_i - T_a)^2}{G_T} \qquad \text{(A.13)}$$

where:

η is the instantaneous efficiency [-];
T_i is the inlet temperature of the collector fluid [°C];
T_a is the ambient temperature [°C]; and
G_T is the radiation on the tilted collector surface [W/m²].

Table A.3: Incident Angle Modifier

		Transversal Incidence Angle							
		0°	**10°**	**20°**	**30°**	**40°**	**50°**	**60°**	**90°**
Longitudinal Incidence Angle	**0°**	1	1	1.02	1.03	1.01	0.94	0.8	0
	10°	1	1	1.02	1.03	1.01	0.94	0.8	0
	20°	0.99	0.99	1.0098	1.0197	0.9999	0.9306	0.792	0
	30°	0.98	0.98	0.9996	1.0094	0.9898	0.9212	0.784	0
	40°	0.96	0.96	0.9792	0.9888	0.9696	0.9024	0.768	0
	50°	0.92	0.92	0.9384	0.9476	0.9292	0.8648	0.736	0
	60°	0.86	0.86	0.8772	0.8858	0.8686	0.8084	0.688	0
	90°	0	0	0	0	0	0	0	0

Based on Kingspan collector performance data

A.2.3 Properties - Collector Loop Thermal Losses

In addition to the solar collector, additional thermal losses in the solar collector loop were simulated with pipes leading into and out of the solar thermal collector on the outside of the building.

TRNSYS Proforma: Type 31

Table A.4: Collector Loop Pipe Parameters

Parameter	**Value**
Inside Diameter	0.007725 m
Pipe Length	7.6 m
Loss Coefficient	20 kJ/hr-m²-K

Based on work by Julien Renaud

A.2.4 Properties - Collector Loop Pump Controllers

TRNSYS Proforma: Type 2b, Type262*

*Non-standard (user-defined) TRNSYS proforma, Appendix B

Table A.5: Collector Loop Pump Controller Parameters

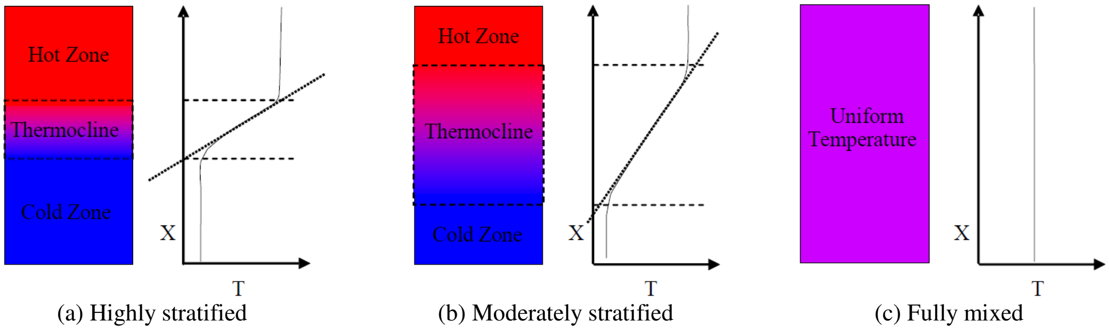
Parameter	Value
Number of Oscillations	5
Upper Dead Band dT	10°C
Lower Dead Band dT	3°C
High Limit Cut-Out Temperature	90°C
	70°C (basic combi-system configuration – first tank in series)

A.3 Tanks/Energy Storage

Thermal Storage is very important in solar thermal systems. Since the solar resource is by no means constant, it is critical to have some sort of means to store thermal energy to maximize the performance of the system. Water based sensible heat thermal storage systems come in a variety of different designs and sizes. To be effective storage units, these tanks should not only be well insulated with few thermal losses, but they should also maintain a high degree of thermal stratification.

A.3.1 Thermal Stratification

Generally speaking, water becomes less dense as its temperature increases, and it's this phenomenon that causes thermal stratification. Thermal stratification occurs when the fluid in a thermal store separates into layers based on temperature. This creates a temperature gradient within the tank (referred to as a thermocline), which separates the hot fluid at the top and the cold fluid at the bottom of the tank. This stratification can increase the temperature of the hot water available at the top of the tank which can lead to higher solar fractions [63] [64] [65]. As depicted in Figure A.3, all three tanks contain the same total energy, but have varying degrees of stratification. In the highly stratified tank (a), there is a large volume of hot water available at the top of the tank whereas in the fully mixed tank (c), the tank is at a uniform temperature and the water available at the top of the tank is at a lower temperature. Stratification levels within a tank are affected by a number of different factors like thermal conduction of the fluid and the tank, thermal inversion and plume entrainment, and jet mixing; and many researchers have investigated these effects.



(a) Highly stratified (b) Moderately stratified (c) Fully mixed

Figure A.3: Varying levels of stratification in thermal stores with the same total energy (Source: [6])

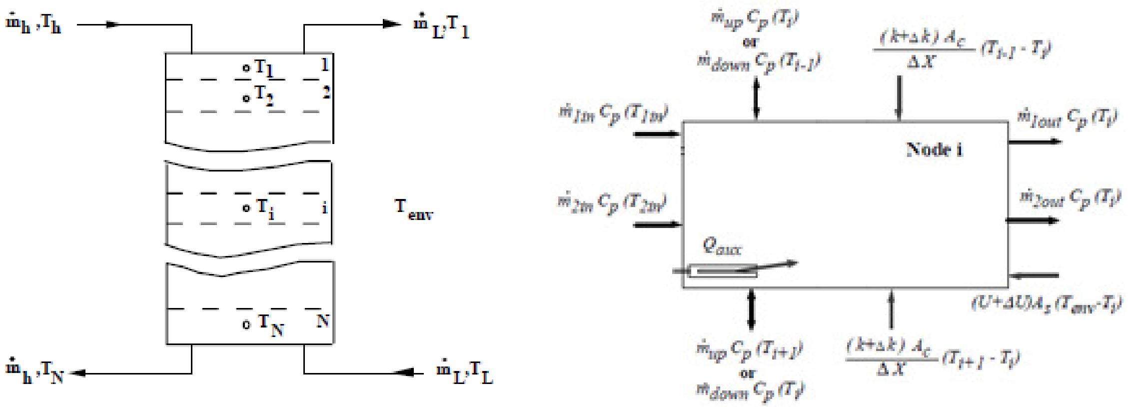
Thermal inversion occurs when the fluid temperature at any given level in the store either become warmer than the fluid above it, or cooler than the fluid below it. Natural convection will cause mixing and act to destratify the store. When this happens, a thermal plume can form and its momentum can cause mixing to occur beyond the area of the temperature inversion. With hot water tanks, temperature inversion might occur if the fluid entering the tank is a different temperature than the fluid at that inlet level, an immersed heat exchangers is used to either charge or discharge the tank, or if an auxiliary heater is incorporated into the tank.

To maintain the maximum level of stratification, auxiliary heaters and supply side (charging) immersed heat exchangers should be located at the top of the tank while load side (discharging) immersed heat exchangers should be located at the bottom of the tank, and strict controls should be used to ensure the heat exchangers do not inadvertently reverse functions. For the heat exchanger, the heat transfer rate between the heat exchanger fluid and the tank depends on the temperature difference between the two fluids; thus placing immersed heat exchangers to maximize the thermal stratification can greatly reduce their performance and negate any of the benefits to having a stratified store. With fluid entering the tank, the ideal situation would be for the inlet to be at a level where the incoming fluid is at the same temperature as the fluid at the inlet location (or the bottom or top of the tank if the fluid is either colder or hotter than any of the fluid in the tank). Devices commonly referred to as diffusers or stratifiers have been developed to direct incoming fluid to the correct temperature level. Multiple inlets, porous tubes, flexible buoyant hoses, and rigid tubes have all been investigated as possible stratifiers [66] [67] [68].

Jet mixing occurs when the momentum of fluid entering (or draining) the tank produces mixing in that region. One way to prevent this is by reducing the flow rate (velocity) of the fluid entering the tank. This possibility has been studied by Cataford [63], Hollands and Lightstone [64], Cristofari et al. [65], and they have shown that low flow in stratified tanks will increase the overall system performance. Another method was investigated by Shah and Furbo. They used numerical and experimental tests to show adding baffle to interrupt the flow could reduce the jet mixing and increase the thermal stratification within storage tanks [69].

A.3.2 Tank Models

Two different tank models were used: the TESS Rectangular Storage Tank (Type 531), and the TRNSYS Stratified Fluid Storage Tank (Type 60). Both tanks were modelled using a 1-dimensional fixed-node model. This type of model divides the fluid in the tank into N equally sized horizontal nodes (control volumes) with the same horizontal cross-sectional area, and each node is modelled as a fully mixed volume with no horizontal temperature gradients, Figure A.4.



(a) Tank model

(b) None energy balance

Figure A.4: Visual depiction of (a) tank model with N nodes, and (b) node energy balance (Source: [60])

At every time step, each node is initially modelled individually using an energy balance equation that accounted for all energy entering and leaving which then allows the temperature change in the node to be calculated. Heat can be transferred in and out of a node through fluid flow entering and leaving the node, conduction between nodes, losses to the environment, and auxiliary heaters, Figure A.4(b). Not all nodes will be affected by all these types of heat transfer, but in general, the energy balance for node i can be expressed as:

$$\left(M_i C_p\right)\frac{dT_i}{dt} = \dot{Q}_{flow} + \dot{Q}_{cond} - \dot{Q}_{losses} + \dot{Q}_{aux} \tag{A.14}$$

where:

M_i is the mass of the fluid in node i [kg];
C_p is specific heat of the fluid in the tank [J/kg-K];
T_i is the temperature of the fluid node i [°C];
t is time [s];
$\dot{Q}_{flow}$ is the rate energy is added to the node due to the flow of fluid [W];
$\dot{Q}_{cond}$ is the heat transfer rate due to conduction [W];
$\dot{Q}_{losses}$ is rate energy is lost to the environment [W]; and
$\dot{Q}_{aux}$ is the heating rate from the auxiliary heater [W].

Fluid enter the node can come from either an adjacent node or outside the tank. Similarly, fluid can leave the node by moving to an adjacent node or flowing out of the tank. To cover all these possibilities, the heat transfer for node i is calculated as:

$$\dot{Q}_{flow} = \dot{m}_{i-1\rightarrow i} C_p T_{i-1} + \dot{m}_{i+1\rightarrow i} C_p T_{i+1} + \sum \dot{m}_{in} C_p T_{in} - \sum \dot{m}_{out} C_p T_i \qquad \text{(A.15)}$$

where:

$\dot{Q}_{flow}$ is the rate energy is added to the node due to the flow of fluid [W];
C_p is the specific heat of the fluid [J/kg-K];
$\dot{m}_{i-1\rightarrow i}$ is the mass flow rate of fluid entering from the node above [kg/s];
$\dot{m}_{i+1\rightarrow i}$ is the mass flow rate of fluid entering from the node below [kg/s];
$\dot{m}_{in}$ is the mass flow rate of fluid entering from outside the tank [kg/s];
$\dot{m}_{out}$ is the mass flow rate of fluid leaving node i [kg/s];
T_{i-1} is the temperature of node i–1 [°C];
T_{i+1} is the temperature of node i+1 [°C];
T_{in} is the temperature of the incoming fluid [°C]; and
T_i is the temperature of the tank node [°C].

Heat can also be transferred between nodes through conduction in the tank walls and the fluid. Vertical thermal conduction in the tank walls can greatly reduce the stratification and therefore the performance of a solar thermal system. Even if the tank is well insulated from the environment, a high thermal conductivity of the inner lining can negatively affect the stratification and therefore the overall performance of the solar thermal system. However, as part of the system design, it is assumed that the tanks are lined with a material that has a low thermal conductivity and that the vertical effect of the tank wall thermal conductivity can be ignored. With this assumption, the conductive heat transfer into node is limited to the conduction through the fluid and can be calculated as:

$$\dot{Q}_{cond} = \frac{k_{fluid}A_{cs}}{\Delta x}\,(T_{i+1} - T_i) + \frac{k_{fluid}A_{cs}}{\Delta x}\,(T_{i-1} - T_i) \tag{A.16}$$

where:

$\dot{Q}_{cond}$ is the vertical thermal conduction between nodes [W];
k_{fluid} is the thermal conductivity of the fluid [W/m-K];
A_{cs} is the cross-sectional area of the tank [m²];
Δx is the centre to centre distance between nodes [m];
T_{i+1} is the temperature of node i+1 [°C];
T_i is the temperature of node i [°C]; and
T_{i-1} is the temperature of node i–1 [°C].

As stated previously, the cross-section of the tank A_{cs} is assumed to be constant, and since the model assumes the nodes are all of equal height, Δx is simply the height of a node.

Heat can also be lost through the tank walls from a node to the environment. For node i, this can be calculated as:

$$\dot{Q}_{loss} = \sum A_{sur}U_{sur}(T_i - T_{env}) \tag{A.17}$$

where:

$\dot{Q}_{loss}$ is the heat loss from node i to the environment [W];
A_{sur} is the area of the surface between the tank and the environment [m²];
U_{sur} is the per unit area heat loss coefficient for the surface [W/m²-K];
T_i is the temperature of node i [°C]; and
T_{env} is the temperature of the environment [°C].

To keep the tank model scalable, a uniform U-value was used for all the tank surfaces in model. This assumption is supported by research by Cruickshank and Harrison who show that simulated results using a uniform U-value still closely agree with experimental data [70].

The last form of heat transfer into a node that this model considers is through the use of heating elements within the tank. The solar thermal systems investigated are all modelled using electric auxiliary heaters in the tanks. Since only thermal energy is considered, the thermal energy contribution to node i can be calculated directly as: $\dot{Q}_{aux}$; which is the equivalent of assuming the electric element is 100% efficient.

With this model, temperature inversion is handled after the new temperatures for the tank nodes have been calculated. If the temperature in two adjacent nodes is inversed (i.e., the temperature in the upper node is cooler than the temperature in the lower node), then the two nodes are mixed. This process is repeated until all temperature inversions are resolved.

Other assumptions required by the 1-dimensional fixed-node model are: fluid flowing up or down within the tank are mixed with each node before continuing to the next one, the velocity of fluid entering and leaving the tank must be low enough that any jet mixing effects are limited to a single node, and the effects of conduction through the tank wall and heat loss to the environment must be small enough so horizontal temperature gradients can considered negligible. This last assumption is supported by work by Jaluria and Gupta [71], and Cruickshank and Harrison [70] who found that the horizontal temperature variation in hot water tanks was minimal.

The number of nodes used to model the thermal store affects the performance of the tank. The number of nodes roughly corresponds to the level of thermal stratification [72]. For instance, a single node tank would be the akin to a fully mixed tank whereas a tank with 100 nodes would be highly stratified. Thus, when modelling a tank's performance, too many nodes may over predict the level of stratification while too few nodes may result in too much mixing.

The TRNSYS tank model Type 60 allows the user to specify up to 2 inlets and 2 outlets, as well as 100 nodes to be defined per tank. This model was the primary component used to model tanks in the simulations in this investigation. The TESS tank model Type 531 on the other hand, only allows a maximum of 20 nodes to be used per tank. However, this model allows the user to specify many more paired inlets and outlets and add stratifiers to the fluid inlets, and was used to model tanks that required these specific properties.

A.3.3 Properties - Thermal Storage Tank

TRNSYS Proforma: Type 60 (standard tank model) and Type 531 (tank model with internal thermal stratifiers)

Table A.6: Thermal Storage Tank Parameters

Parameter	Value
Number of Nodes	30 (Type 60) 20 (Type 531)
Height	1.5 m
Volume	270 L
Perimeter (Diameter)	1.5 m (0.48 m)
U-value [70]	1.21 W/m2-K
Inlet 1 height	1.5 m
Outlet 1 height	1.5 m
Inlet 2 height	0.29 m
Outlet 2 height	0.29 m

A.3.4 Properties - Domestic Hot Water Auxiliary Tank and Heat Source

Table A.7: DHW Auxiliary Tank Parameters

Parameter	Value
Number of Nodes	10
Height	1 m
Volume	170 L
U-value	1.21 W/m²-K
Inlet height	0.05 m
Outlet height	1 m
Heater Location	0.5 m
Thermostat Location	0.5 m

Based on Rheem Professional 170 L tank

A.4 Heat Exchangers

Since glycol was used as the collector fluid to prevent freezing in the winter, heat exchangers were used to transfer heat from the collector fluid to the storage tank(s). Two types of heat exchangers were considered, pumped flat plate heat exchangers and natural convection heat exchangers (external side-arm thermosyphon flow heat exchangers).

A.4.1 Fixed-Effectiveness Heat Exchanger

The flat plate heat exchanger was model using the fixed effectiveness TRNSYS component Type 91. In this model, the heat exchanger is assumed to be perfectly insulated (i.e., no heat loss to the environment), and the flow is assumed to be in the counterflow orientation, Figure A.5.

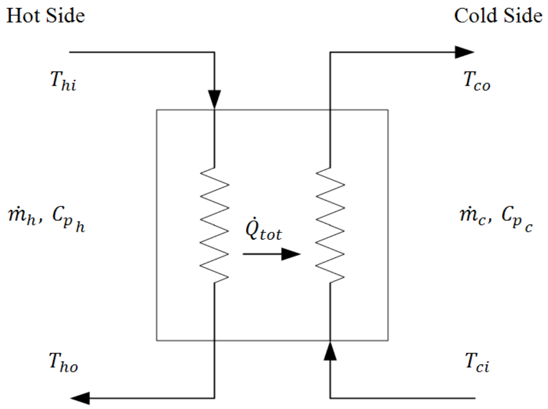


Figure A.5: Counter flow heat exchanger

Using the effectiveness method [60] [73], the capacity rate for each fluid stream is defined as:

$$C_h = \dot{m}_h C_{p_h} \tag{A.18}$$

$$C_c = \dot{m}_c C_{p_c} \tag{A.19}$$

and the total heat transfer rate is:

$$\dot{Q}_{tot} = C_h\,(T_{hi} - T_{ho}) = C_c\,(T_{co} - T_{ci}) \tag{A.20}$$

where:

C_h and C_c are the capacity rates for the hot and cold fluid streams respectively [W/°C];
$\dot{m}_h$ and $\dot{m}_c$ are the mass flow rates for the hot and cold fluid streams respectively [kg/s];
C_{p_h} and C_{p_c} are the specific heats for the hot and cold fluids respectively [J/kg-K];
$\dot{Q}_{tot}$ is the total heat transfer rate across the heat exchanger [W];
T_{hi} and T_{ho} are the hot side inlet and outlet temperatures respectively [°C]; and
T_{ci} and T_{co} are the cold side inlet and outlet temperatures respectively [°C].

The maximum heat transfer rate is:

$$\dot{Q}_{max} = C_{min}\,(T_{hi} - T_{ci}) \tag{A.21}$$

where:

$\dot{Q}_{max}$ is the maximum potential heat transfer rate across the heat exchanger [W];
C_{min} is the lower capacity rate of the two fluid streams [W/°C]; and
T_{hi} and T_{ci} are the hot and cold side inlet temperatures respectively [°C].

Using the maximum heat transfer rate, the effectiveness, ϵ, can then be calculated:

$$\varepsilon = \frac{\dot{Q}_{tot}}{\dot{Q}_{max}} \tag{A.22}$$

where:

ε is the effectiveness [-];
$\dot{Q}_{tot}$ is the total heat transfer rate across the heat exchanger [W]; and
$\dot{Q}_{max}$ is the maximum potential heat transfer rate across the heat exchanger [W].

Thus, given the hot and cold side inlet temperatures and flow rates, as well as the heat exchanger effectiveness, the total heat transfer rate $\dot{Q}_{tot}$ can be calculated:

$$\dot{Q}_{tot} = \varepsilon\,\dot{Q}_{max} \tag{A.23}$$

and the outlet temperatures can be found:

$$T_{ho} = T_{hi} - \left(\frac{\dot{Q}_{tot}}{C_h}\right) \tag{A.24}$$

$$T_{co} = T_{ci} + \left(\frac{\dot{Q}_{tot}}{C_c}\right) \tag{A.25}$$

where:

$\dot{Q}_{tot}$ is the total heat transfer rate across the heat exchanger [W];
ε is the effectiveness [-];
$\dot{Q}_{max}$ is the maximum potential heat transfer rate across the heat exchanger [W];
C_h and C_c are the capacity rates for the hot and cold fluid streams respectively [W/°C];
T_{hi} and T_{ho} are the hot side inlet and outlet temperatures respectively [°C]; and
T_{ci} and T_{co} are the cold side inlet and outlet temperatures respectively [°C].

A.4.2 Properties - Fixed Effectiveness Heat Exchanger

TRNSYS Proforma: Type 91

A.4.3 Natural Convection Heat Exchanger

Natural convection heat exchangers have been shown to improve the performance of solar thermal systems by increasing the thermal stratification in the thermal store. Instead of using a pump to circulate the storage fluid through the charging heat exchanger, natural convection heat exchangers rely on buoyancy driven thermosyphon flow. This phenomenon occurs because the fluid's density decreases as its temperature increases, causing the fluid to want to rise. By taking advantage of this, it not only makes it possible to eliminate a pump from the system, but the natural convection self regulates the flow through the heat exchanger and reduces thermal inversions in the tank when charging, Figure A.6.

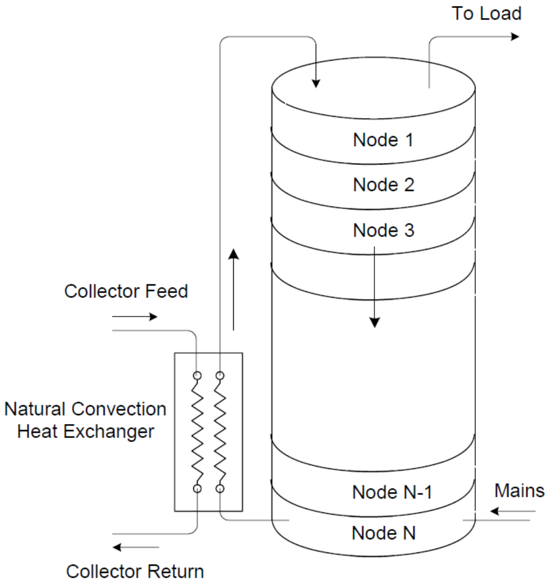


Figure A.6: A liquid thermal storage tank divided into N horizontal nodes and a natural convection heat exchanger (Source: [6])

Like the fixed effectiveness heat exchanger model, the natural convection model is based on a counter flow arrangement. However, since only the hot side flow is forced, a fixed effectiveness model is not sufficient to describe the performance. Many people have developed empirical and theoretical models have been developed for tube-in-shell [74] [75], coil-in-shell

[76] [77], and compact plate [78] [79] [80] heat exchangers operating in a natural convection arrangement.

Fraser et al. [76] showed that natural convection heat exchangers can be modelled using two relationships, one to describe the heat exchanger performance, and a second to determine the cold (natural convection) side flow rate. Unlike typical heat exchanger models, the relationship used to describe the natural convection heat exchanger used the following set of modified performance indices:

$$\varepsilon_{mod} = \frac{\dot{Q}_{tot}}{C_{forced}\left(T_{forced,i} - T_{NC,i}\right)} \tag{A.26}$$

and

$$C_{ratio\,mod} = \frac{C_{NC}}{C_{forced}} \tag{A.27}$$

where:

ε_{mod} is the modified effectiveness [-];
$C_{ratio\,mod}$ is the modified capacity ratio [-];
$\dot{Q}_{tot}$ is the total heat transfer across the heat exchanger [W];
$T_{forced,i}$ is the inlet temperature on the forced flow side [°C];
$T_{NC,i}$ is the inlet temperature on the natural convection side [°C];
C_{forced} is the capacity rate of the forced flow [W/°C]; and
C_{NC} is the capacity rate of the natural convection flow [W/°C].

In the configurations investigated in this study, the natural convection heat exchanger is located between the collector loop and the storage tank. This means the flow on the hot side (collector) will be forced, and the flow on the cold side (tank) will be due to natural convection. When operating in this arrangement, Lin et al. [79] showed that the natural convection mass flow rate and the modified effectiveness could be described by:

$$\dot{m}_{NC} = a * (\Delta P)^b \tag{A.28}$$

and

$$\varepsilon_{mod} = c * C_{ratio\,mod}^2 + d * C_{ratio\,mod} \tag{A.29}$$

where:

$\dot{m}_{NC}$ is the natural convection mass flow rate [kg/s];
ε_{mod} is the modified effectiveness [-];
ΔP is the hydrostatic pressure difference across the natural convection loop [Pa];
$C_{ratio\,mod}$ is the modified capacity ratio [-]; and
a, b, c, and d are empirically derived constants.

These empirical relationships have been used to characterize natural convection heat exchangers and simulate their performance by calculating the flow rate of the natural convection side of the heat exchanger and the modified effectiveness. However, since it is not possible to have a cold side outlet temperature that exceeds the hot side inlet temperature, the modified effectiveness (ε_{mod}) may not be greater than the capacity ratio, and also must not exceed a value of 1.

A.4.4 Properties - Natural Convection Heat Exchanger

TRNSYS Proforma: Type 31, Type 289*, and Type 293*
*Non-standard (user-defined) TRNSYS proforma, Appendix B

Table A.8: Natural Convection Heat Exchanger Parameters

Parameter	Value
Tank Height	1.5 m
Heat Exchanger Height	0.29 m
Thermosiphon Pipe Inside Diameter	0.018 m
Thermosiphon Pipe Length	0.60 m
Thermosiphon Pipe Loss Coefficient	4 kJ/hr-m²-K

Natural Convetion Heat Exchanger Modified Effectiveness Equation:

$$\varepsilon_{mod} = -0.3488 * C_{ratio\,mod}^2 + 1.1402 * C_{ratio\,mod} \tag{A.30}$$

where:

ε_{mod} is the modified effectiveness [-]; and
$C_{ratio\,mod}$ is the modified capacity ratio [-], Equation (A.27).

Natural Convection (Cold-Side) Flow Rate Equation:

$$\dot{m} = 2.388\,\Delta P^{0.6505} \tag{A.31}$$

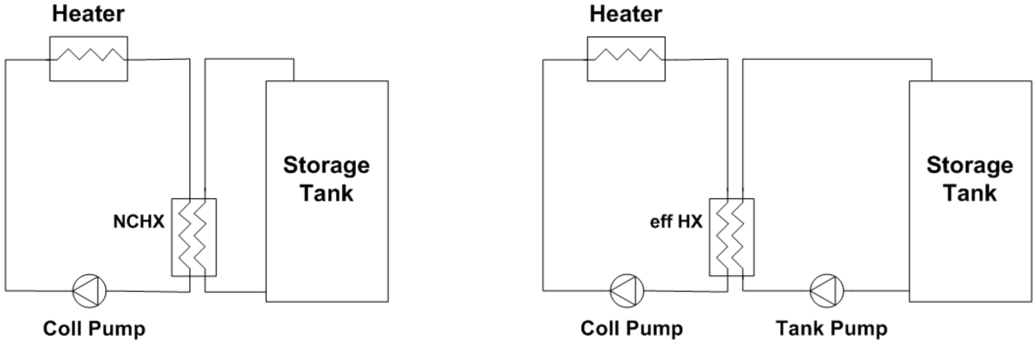
where:

$\dot{m}$ is the natural convection (cold side) flow rate [kg/hr]; and

ΔP is the net pressure head across the natural convection loop [Pa].

A.4.5 Comparison of Heat Exchanger Types

To better illustrate the difference in performance between the fixed effectiveness heat exchanger and natural convection heat exchanger models, tank charging simulations were compared using the different heat exchanger models (constant collector flow rate: 72 kg/hr, and tank volume: 270 L). Collector fluid entering at a constant temperature of 50°C was circulated continuously through the hot side of the heat exchanger, Figure A.7. Using the same parameters as in the combi-system simulations, the fixed effectiveness heat exchanger was modelled with a constant effectiveness of 0.7 and the cold side flow rate was selected such that both the hot and cold side had the same capacity rate.



(a) Natural Convection Heat Exchanger Configuration (b) Fixed Effectiveness Heat Exchanger Configuration

Figure A.7: Schematics of tank charging simulation models

As shown in Figure A.8, uder these conditions, the heat transfer rate for both heat exchangers was comparable and both heat exchangers were able to maintain tank stratification, Figure A.9 and Figure A.10. However, the temperature distribution within the tanks was quite different due to the different tank-side flow rates of the two heat exchanger types, Figure A.11.

The fixed effectiveness heat exchanger model shows a recirctulation of the storage tank fluid, resulting in the step-like temperature graph. The flow through the thermosypon (tank) side of the natural convection heat exchanger, on the other hand, reduces as the tank becomes charged, limiting the amount of recirculation within the tank. This leads to a higher level of stratification as compared to the fixed effectiveness model, which is advantageous for distributed hot water draws.

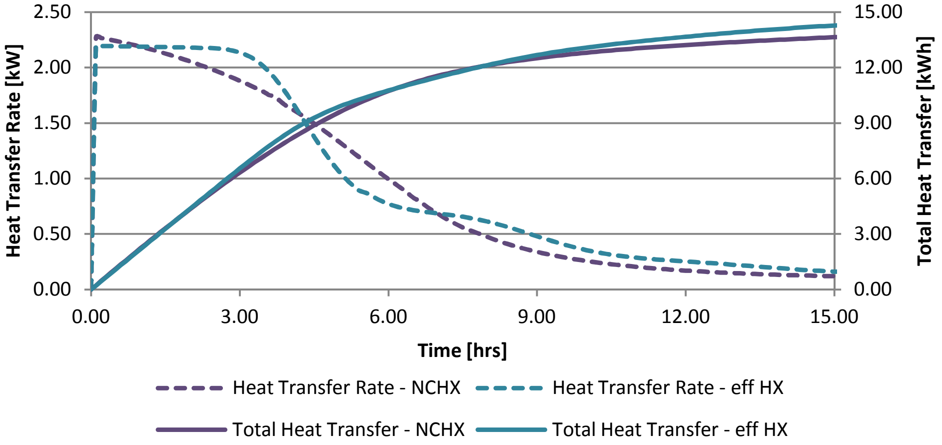


Figure A.8: Heat transfer rate and total heat transfer of charging of thermal storage tanks using natural convection and fixed effectiveness heat exchangers

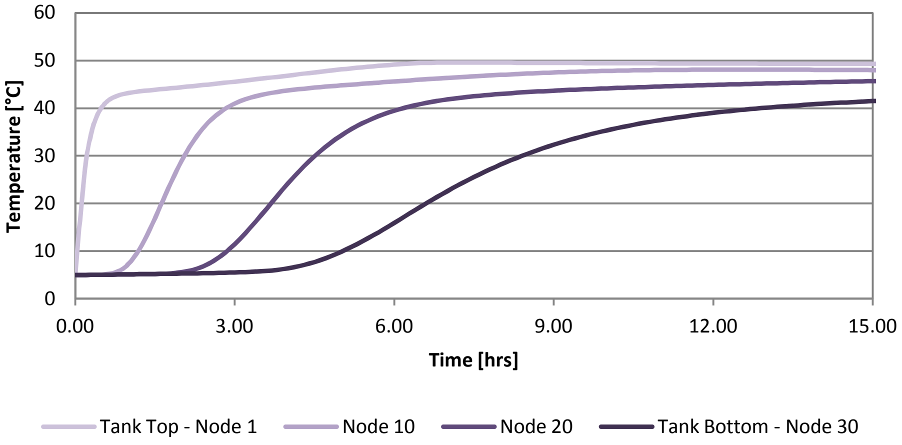


Figure A.9: Tank temperature distribution during charging with a natural convection heat exchanger

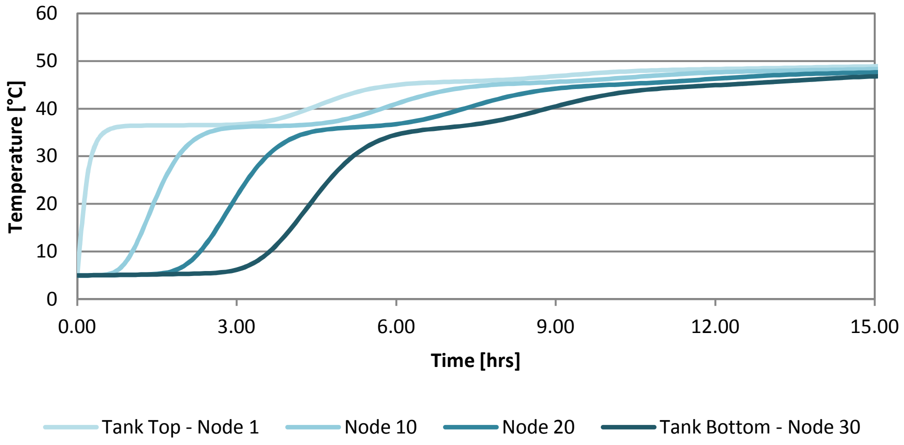


Figure A.10: Tank temperature distribution during charging with a fixed effectiveness heat exchanger

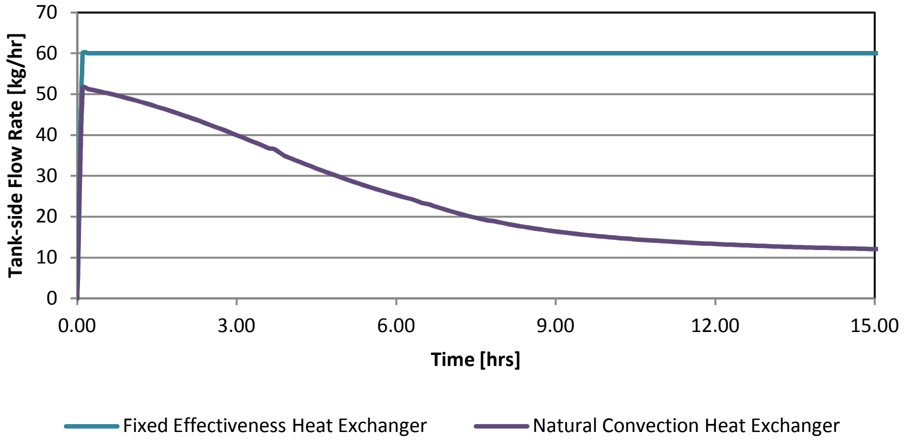


Figure A.11: Tank-side flow rate charging of thermal storage tanks using natural convection and fixed effectiveness heat exchangers

A.5 Space Heating Load

Residential space heating loads are dependent on multiple factors including location, orientation, building type and construction, furnishing, and occupant behaviour. It is for this reason that Klein et al. [81] suggests a simple space heating load model is adequate for simulating the performance of solar heating system. They propose using an energy per degree-time model:

$$Q_{SH\,\Delta t} = UA(T_{ref} - T_{amb})^{+}\,\Delta t \tag{A.32}$$

where:

$Q_{SH\,\Delta t}$ is the space heating load for the time interval [kWh];
UA is the overall heat transfer coefficient for the building [kW/°C];
T_{ref} is the reference temperature [°C];
T_{amb} is the average ambient temperature for the time interval [°C]; and
Δt is the time interval [hrs].

Typical time steps for this type of model are hours and days, referred to as heating degree-hour (HDH) and heating degree-day (HDD) models respectively. While these models may not be sophisticated enough to accurately reflect the variations in heating loads due to fenestration, thermal mass, and occupant behaviour, they have been shown to accurately reflect the overall heating load provided an appropriate heat transfer coefficient (UA) is selected [82]. Furthermore, since the primarily focus of this thesis is on comparing the performance of different combi-systems, a simple heating model was deemed sufficient.

On average, residential space heating in Canada accounts for over 60% of a home's energy consumption [3]. With such a large fraction of energy devoted to space heating, even small improvements to a home's insulation and air tightness can result in appreciable energy savings. For this reason, it is more efficient and economical to first ensure the residence is well insulated and sealed before considering adding any solar space heating system. It is for these reasons that the space heating load was selected to reflect an energy efficient home.

The space heating load was based on the R-2000 Standard. This standard was developed by Natural Resources Canada in partnership with Canada's residential construction industry to promote the use of cost-effective energy-efficient building practices and technologies [47]. The R-2000 Standard is a performance based standard. It sets technical performance standards for energy efficiency, air tightness, and environmental responsibility in the home, as well as energy performance targets for space heating and domestic hot water. This standard also considers the indoor air quality of the house and can be applied to the design of Net-Zero Energy homes [48] [48] [49] [49].

The R-2000 annual space heating energy consumption target for electrical heating systems is given by the following equation [83]:

$$Q_{SH\,annual} = \left(49\frac{HDD}{6000}\right)\left(40 + \frac{V}{2.5}\right) \tag{A.33}$$

where:

$Q_{SH\,annual}$ is the space heating energy target [kWh];
HDD is the annual number of heating degree days for the location [°C days]; and
V is the interior heated volume of the residence [m^3].

Using this equation to generate a degree-hour heating model produces an UA value of:

$$UA_{R-2000} = \frac{1}{24}\left(\frac{49}{6000}\right)\left(40 + \frac{V}{2.5}\right) \tag{A.34}$$

where:

UA_{R-2000} is the overall heat transfer rate based on the R-2000 Standard [kW/°C]; and
V is the interior heated volume of the residence [m^3].

Since hourly weather data is available, the following modified heating degree-hour model was used to calculate the heating load:

$$\dot{Q}_{SH} = \begin{cases} 0, & if\ T_{ave} \geq T_{ref}\ or\ T_{amb} \geq T_{ref} \\ UA_{R-2000}(T_{ref} - T_{amb}), & otherwise \end{cases} \tag{A.35}$$

where:

$\dot{Q}_{SH}$ is the space heating load [kW];
T_{ave} is the average daily temperature [°C];
T_{ref} is the reference temperature [°C];
T_{amb} is the ambient temperature [°C]; and
UA_{R-2000} is the overall heat transfer rate based on the R-2000 Standard [kW/°C].

Since this heating model uses hourly time steps, the diurnal temperature variation, and thus heating load, is reflected in the model. Furthermore, by discounting the heating load on days where the average daily temperature is above the reference temperature, the model eliminates heating in the summer when the nightly temperature may drop below the reference temperature, but the heating system would not be turned on. Lastly, by using a reference temperature (T_{ref}) of

18°C, this model still generates the same annual heating load as stated in the R-2000 Standard despite using a degree-hour calculation.

A.5.1 Space Heating Model

Liquid based solar space heating systems can use a number of different methods to transfer heat to the living space. Some of the most common systems are: forced air, hot water radiators, or hydronic-floors. The choice of heating method can greatly affect the performance of a solar space heating system. For this investigation, a hydronic-floor heating system was selected.

In general, hydronic-floor heating systems use lower supply water temperatures than other methods to obtain the same heating rate [84]. The ability to heat a space using low temperatures makes hydronic-floors well suited for solar thermal applications. This is supported by research by Haddad et al. that showed solar heating systems using hydronic-floors perform better than those that use a forced-air system [85].

The hydronic-floor model was taken from the 2008 ASHRAE Handbook on HVAC Systems and Equipment [86]. In this model, the heat transfer rate between the floor surface and the room is expressed as two heat fluxes: the heat transfer due to thermal radiation and heat transfer due to natural convection. For a typical room, the heat transfer due to thermal radiation can be expressed as:

$$q_{rad} = 5 \times 10^{-8}[(T_{sur} + 273.15)^4 - (AUST + 273.15)^4] \tag{A.36}$$

and heat transfer due to natural convection:

$$q_{conv} = 2.13|T_{sur} - T_{room}|^{0.31}(T_{sur} - T_{room}) \tag{A.37}$$

where:

q_{rad} is the heat transfer due to radiation [W/m²];
q_{conv} is the heat transfer due to natural convection [W/m²];
T_{sur} is the surface temperature of the hydronic-floor [°C];
T_{room} is the room temperature [°C]; and
$AUST$ is the area-weighted temperature of all indoor surfaces (excluding the floor) [°C].

This gives a combined heat flux of:

$$q_{tot} = q_{rad} + q_{conv} \tag{A.38}$$

which can be calculated using the space heated load and the area of the heated floor:

$$q_{tot} = \frac{\dot{Q}_{SH}}{A_{heated}} \tag{A.39}$$

where:

q_{tot} is the total heat flux [W/m²];
$\dot{Q}_{SH}$ is the space heating load [W]; and
A_{heated} is the area of the hydronic-floor [m²].

According to the 2007 Survey of Household Energy Use, the mode dwelling temperature during winter for Canadian households is 20°C [3]. This was used as the room temperature in the simulations. In most cases, the $AUST$ and the room temperature are almost identical, with differences only occurring when the surfaces are poorly insulated from the outside [86]. Given the modelled house is assumed to be energy efficient and well insulated, the $AUST$ was assumed to be equal to the room temperature (T_{room}). Based on these quantities, the following third order approximation was used to solve for the surface temperature of the floor (T_{sur}) based on the heat flux (q_{tot}) determined by the space heating load model:

$$T_{sur} = 2.0 \times 10^{-7} \left(q_{tot}\right)^3 - 0.0002 \left(q_{tot}\right)^2 + 0.1183\, q_{tot} + 20 \tag{A.40}$$

where:

T_{sur} is the surface temperature of the hydronic-floor [°C]; and
q_{tot} is the total heat flux [W/m²].

The heat flux through the floor (between the fluid and the floor surface) is calculated using a resistance model. Since the heating load already includes all thermal losses, the back surface of the floor was assumed to be adiabatic. From this, the average water temperature can be calculated by:

$$T_w = T_{sur} + q_{tot}\, r_u \tag{A.41}$$

where:

T_w is the average water temperature [°C];
T_{sur} is the surface temperature of the hydronic-floor [°C];
q_{tot} is the total heat flux [W/m²]; and
r_u is the the characteristic resistance of the hydronic-floor [m² K/W].

For these simulations, a heated area of 160 m² and a characteristic resistance of 0.2 m²-K/W were chosen to reflect the floor assembly.

A.5.2 Parameters - Space Heating Thermal Load

TRNSYS Proforma: Type 266*

*Non-standard (user-defined) TRNSYS proforma, Appendix B

Table A.9: Modified Heating Degree Hour Parameters

Parameter	Value
Reference Temperature[1]	18°C
Interior Heated Volume of House[2]	450 m³ (≈ 2000 ft² x 8 ft)

[1] T_{ref} in Equation (A.35)

[2] V in Equation (A.34)

A.5.3 Hydronic-Floor Thermal Resistance

The characteristic resistance of the floor was given by [86], also Figure A.12:

$$r_u = r_t M + r_s M + r_p + r_c \tag{A.42}$$

where:

r_u is the characteristic resistance of the floor [m² K/W];
r_t is the thermal resistance of the tube wall [m K/W];
r_s is the thermal resistance between the tube and panel body per unit spacing between tubes [m K/W];
r_p is the thermal resistance of the panel body [m² K/W];
r_c is the thermal resistance of active panel surface covers [m² K/W]; and
M is the spacing between adjacent tubes [m].

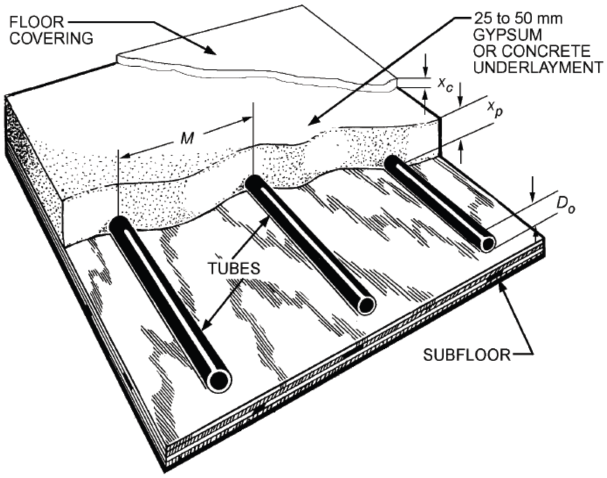


Figure A.12: Hydronic-floor schematic (Source: [86])

The thermal resistance of a tube wall was calculated by [86]:

$$r_t = \frac{\ln(D_o/D_i)}{2\pi k_t} \tag{A.43}$$

where:

r_t is the thermal resistance of the tube wall [m K/W];
D_o is the outer diameter of the tube [m];
D_i is the inner diameter of the tube [m]; and
k_t is the thermal conductivity of the tube [W/m-K].

For a poured type floor system [86]:

$$r_p = \frac{x_p - (D_0/2)}{k_p} \tag{A.44}$$

and:

$$r_s \approx 0 \tag{A.45}$$

where:

r_p is the thermal resistance of the panel body [m² K/W];
r_s is the thermal resistance between the tube and panel body per unit spacing between tubes [m K/W];
x_p is the thickness of the poured portion of the floor (measured from the center of the tube) [m];
D_o is the outer diameter of the tube [m]; and
k_p is the thermal conductivity of the poured floor [W/m-K].

Lastly, the resistance of the floor covering was calculated by [86]:

$$r_c = \sum \frac{x_c}{k_c} \tag{A.46}$$

where:

r_c is the thermal resistance of active panel surface covers [m^2 K/W];
x_c is the thickness of each layer [m]; and
k_c is the thermal conductivity of each layer [W/m-K].

Table A.10: Hydronic-Floor Sizing and Materials

Parameter	Value	Description
Tube Spacing, M	0.30 m	
Tube Inner Diameter, D_i	0.012069 m (0.475”)	Based on ½” PEX Tubing (Source: [87])
Tube Outer Diameter, D_o	0.015875 m (0.625”)	Based on ½” PEX Tubing (Source: [87])
Tube Thermal Conductivity, k_t	0.38 W/m-K	PEX tubing (Source: [86])
Poured Floor Thickness, x_p	0.035 m	Approximately 1” concrete covering tubes
Poured Floor Thermal Conductivity, k_p	1.37 W/m-K	Concrete (1-2-4 mix) (Source: [73])
Floor Covering Thickness, x_c	0.00635 m (1/4”)	Typical thickness for on cork tiles: 3/16” – 5/16”
Floor Covering Thermal Conductivity, k_c	0.043 W/m-K	Corkboard (Source: [73])

Table A.11: Calculation of Characteristic Resistance of the Floor

Using equations (A.42) to (A.46) and the parameters listed in Table A.10:

$$r_t = \frac{\ln(D_o/D_i)}{2\pi k_t} = \frac{\ln(0.015875/0.012069)}{2\pi(0.38)} = 0.1149\ \frac{m\ K}{W}$$

$$r_p = \frac{x_p - (D_0/2)}{k_p} = \frac{0.035 - (0.015875/2)}{1.37} = 0.0198\ \frac{m^2\ K}{W}$$

$$r_s \approx 0$$

$$r_c = \sum \frac{x_c}{k_c} = \frac{0.00635}{0.043} = 0.1477\ \frac{m^2\ K}{W}$$

$$r_u = r_t M + r_s M + r_p + r_c = 0.1149\ (0.3) + 0(0.3) + 0.0198 + 0.1477 = 0.2020 \approx 0.2\ \frac{m^2\ K}{W}$$

A.5.4 Parameters - Hydronic-Floor Model

TRNSYS Proforma: Type 270* and Type 271*
*Non-standard (user-defined) TRNSYS proforma, Appendix B

Table A.12: Hydronic-Floor Parameters

Parameter	Value
R-Value	0.2 m^2-K/W
Area of Heated Floor	160 m^2

A.5.5 Parameters - Space Heating Auxiliary Heater

TRNSYS Proforma: Type 268*

*Non-standard (user-defined) TRNSYS proforma, Appendix B

A.6 TRNSYS Parameters

Global parameter values used for TRNSYS simulations.

Table A.13: TRNSYS Simulation Details

Parameter	**Value**
Time Step	0.05 hours
Max Iterations (Before 'WARNING')	1000
Convergence Tolerance	0.01
Integration Tolerance	0.01

A.7 Pumps

A.7.1 Parameters - Constant Flow Rate Pumps

TRNSYS Proforma: Type 3

Table A.14: Constant Flow Rate Pump Parameters

Parameter	**Value**
Maximum Power	0 (parasitic power not considered)
Power Coefficient	0 (parasitic power not considered)
Conversion Coefficient (fraction of pump power converted to fluid thermal energy)	0

A.7.2 Parameters - Variable Flow Rate Pump

TRNSYS Proforma: Type 110

Table A.15: Variable Flow Rate Pump Parameters

Parameter	Value
Rated Flow Rate	250 kg/hr (parasitic power not considered)
Rated Power	0 (parasitic power not considered)
Motor Heat Loss Fraction	0 (parasitic power not considered)
Number of Power Coefficients	1 (parasitic power not considered)
Power Coefficient	0 (parasitic power not considered)
Total Pump Efficiency	1 (parasitic power not considered)
Motor Efficiency	1 (parasitic power not considered)

A.8 Tempering Valves

A.8.1 Parameters - Domestic Hot Water Tempering Valve

TRNSYS Proforma: Type 210*
*Non-standard (user-defined) TRNSYS proforma, Appendix B

Table A.16: Domestic Hot Water Tempering Valve Parameters

Parameter	Value
Hot Water Temperature Set Point	55°C

A.8.2 Parameters - Space Heating Tempering Valve

TRNSYS Proforma: Type 11f, Type 11h, and Type 269*
*Non-standard (user-defined) TRNSYS proforma, Appendix B

Appendix B

Non-Standard (User-Defined) TRNSYS Components

Listed here are the non-standard (user-defined) TRNSYS components used in the simulations.

B.1 TYPE 210 – FlowMix

This TRNSYS proforma acts as the tempering valve for the domestic hot water load.

Source: this proforma was taken from work by Julien Renaud.

Table B.1: TYPE 210 - Parameters

Number	Name	Description
1	TSET	Temperature set point for domestic hot water [°C]

Table B.2: TYPE 210 - Inputs

Number	Name	Description
1	TCOLD	Temperature of the cold (mains) water [°C]
2	THOT	Temperature of the hot water (from tank) [°C]
3	FLTAP	Total flow rate of the domestic hot water to load [kg/hr]

Table B.3: TYPE 210 - Outputs

Number	Name	Description
1	FLCOLD	Flow rate of cold (mains) water to load [kg/hr]
2	FLHOT	Flow rate of hot water (from tank) to load [kg/hr]
3	QLOAD	Power required to meet domestic hot water load [kJ/hr]
4	QTANK	Energy transferred to domestic hot water load from hot water source (tank) [kJ/hr]

Derivatives: None

B.2 TYPE 262 – Collector Controller

This TRNSYS proforma controls the collector pump by combining the pump signals for the space heating and hot water thermal storage tanks.

Parameters: None

Table B.4: TYPE 262 - Inputs

Number	Name	Description
1	SH_SIG	Collector pump signal based on the space heating store
2	DHW_SIG	Collector pump signal based on the hot water store
3	SH_PUMP_SIG	Space heating store collector pump signal

Table B.5: TYPE 262 - Outputs

Number	Name	Description
1	SIG_OUT	Collector pump signal

Derivatives: None

Table B.6: TYPE 262 - FORTRAN Code

```
                               SUBROUTINE TYPE262 (TIME,XIN,OUT,T,DTDT,PAR,INFO,ICNTRL,*)
C************************************************************************
C Object: CollController
C Simulation Studio Model: Type262-CollController
C
C Author:
C Editor:
C Date:    March 04, 2011 last modified: March 04, 2011
C
C
C ***
C *** Model Parameters
C ***

C ***
C *** Model Inputs
C ***
C                              SH_SIG    - [-Inf;+Inf]
23723723823823923924024024C                         SH_PUMP_SIG         - [-Inf;+Inf]
C                              SH_PUMP_SIG         - [-Inf;+Inf]

C ***
C *** Model Outputs
C ***
C                              SIG_OUT   - [-Inf;+Inf]

C ***
C *** Model Derivatives
C ***

C (Comments and routine interface generated by TRNSYS Studio)
C************************************************************************
```

```
C    TRNSYS acess functions (allow to acess TIME etc.)
      USE TrnsysConstants
      USE TrnsysFunctions

C-----------------------------------------------------------------------------------------------------------------------
C    REQUIRED BY THE MULTI-DLL VERSION OF TRNSYS
      !DEC$ATTRIBUTES DLLEXPORT :: TYPE262                                        !SET THE CORRECT TYPE NUMBER HERE
C-----------------------------------------------------------------------------------------------------------------------
C-----------------------------------------------------------------------------------------------------------------------
C    TRNSYS DECLARATIONS
      IMPLICIT NONE                      !REQUIRES THE USER TO DEFINE ALL VARIABLES BEFORE USING THEM

          DOUBLE PRECISION XIN !THE ARRAY FROM WHICH THE INPUTS TO THIS TYPE WILL BE RETRIEVED
          DOUBLE PRECISION OUT !THE ARRAY WHICH WILL BE USED TO STORE THE OUTPUTS FROM THIS TYPE
          DOUBLE PRECISION TIME          !THE CURRENT SIMULATION TIME - YOU MAY USE THIS VARIABLE BUT DO NOT SET IT!
          DOUBLE PRECISION PAR !THE ARRAY FROM WHICH THE PARAMETERS FOR THIS TYPE WILL BE RETRIEVED
          DOUBLE PRECISION STORED !THE STORAGE ARRAY FOR HOLDING VARIABLES FROM TIMESTEP TO TIMESTEP
          DOUBLE PRECISION T             !AN ARRAY CONTAINING THE RESULTS FROM THE DIFFERENTIAL EQUATION SOLVER
          DOUBLE PRECISION DTDT          !AN ARRAY CONTAINING THE DERIVATIVES TO BE PASSED TO THE DIFF.EQ. SOLVER
          INTEGER*4 INFO(15)             !THE INFO ARRAY STORES AND PASSES VALUABLE INFORMATION TO AND FROM THIS TYPE
          INTEGER*4 NP,NI,NOUT,ND        !VARIABLES FOR THE MAXIMUM NUMBER OF PARAMETERS,INPUTS,OUTPUTS AND DERIVATIVES
          INTEGER*4 NPAR,NIN,NDER        !VARIABLES FOR THE CORRECT NUMBER OF PARAMETERS,INPUTS,OUTPUTS AND DERIVATIVES
          INTEGER*4 IUNIT,ITYPE          !THE UNIT NUMBER AND TYPE NUMBER FOR THIS COMPONENT
          INTEGER*4 ICNTRL               !AN ARRAY FOR HOLDING VALUES OF CONTROL FUNCTIONS WITH THE NEW SOLVER
          INTEGER*4 NSTORED              !THE NUMBER OF VARIABLES THAT WILL BE PASSED INTO AND OUT OF STORAGE
          CHARACTER*3 OCHECK             !AN ARRAY TO BE FILLED WITH THE CORRECT VARIABLE TYPES FOR THE OUTPUTS
          CHARACTER*3 YCHECK             !AN ARRAY TO BE FILLED WITH THE CORRECT VARIABLE TYPES FOR THE INPUTS
C-----------------------------------------------------------------------------------------------------------------------

C-----------------------------------------------------------------------------------------------------------------------
C    USER DECLARATIONS - SET THE MAXIMUM NUMBER OF PARAMETERS (NP), INPUTS (NI),
C    OUTPUTS (NOUT), AND DERIVATIVES (ND) THAT MAY BE SUPPLIED FOR THIS TYPE
      PARAMETER (NP=0,NI=3,NOUT=1,ND=0,NSTORED=0)
C-----------------------------------------------------------------------------------------------------------------------

C-----------------------------------------------------------------------------------------------------------------------
C    REQUIRED TRNSYS DIMENSIONS
      DIMENSION XIN(NI),OUT(NOUT),PAR(NP),YCHECK(NI),OCHECK(NOUT),
          1   STORED(NSTORED),T(ND),DTDT(ND)
      INTEGER NITEMS
C-----------------------------------------------------------------------------------------------------------------------
C-----------------------------------------------------------------------------------------------------------------------
C    ADD DECLARATIONS AND DEFINITIONS FOR THE USER-VARIABLES HERE


C    PARAMETERS

C    INPUTS
      DOUBLE PRECISION SH_SIG
      DOUBLE PRECISION DHW_SIG
      DOUBLE PRECISION SH_PUMP_SIG

C    OUTPUTS
          DOUBLE PRECISION SIG_OUT

C-----------------------------------------------------------------------------------------------------------------------
C       READ IN THE VALUES OF THE PARAMETERS IN SEQUENTIAL ORDER

C-----------------------------------------------------------------------------------------------------------------------
C    RETRIEVE THE CURRENT VALUES OF THE INPUTS TO THIS MODEL FROM THE XIN ARRAY IN SEQUENTIAL ORDER

      SH_SIG=XIN(1)
      DHW_SIG=XIN(2)
      SH_PUMP_SIG=XIN(3)
             IUNIT=INFO(1)
             ITYPE=INFO(2)
```

```
C---------------------------------------------------------------------------------------------------------------------
C    SET THE VERSION INFORMATION FOR TRNSYS
      IF(INFO(7).EQ.-2) THEN
             INFO(12)=16
             RETURN 1
          ENDIF
C---------------------------------------------------------------------------------------------------------------------

C---------------------------------------------------------------------------------------------------------------------
C    DO ALL THE VERY LAST CALL OF THE SIMULATION MANIPULATIONS HERE
      IF (INFO(8).EQ.-1) THEN
             RETURN 1
          ENDIF
C---------------------------------------------------------------------------------------------------------------------

C---------------------------------------------------------------------------------------------------------------------
C    PERFORM ANY 'AFTER-ITERATION' MANIPULATIONS THAT ARE REQUIRED HERE
C    e.g. save variables to storage array for the next timestep
      IF (INFO(13).GT.0) THEN
             NITEMS=0
C            STORED(1)=... (if NITEMS > 0)
C        CALL setStorageVars(STORED,NITEMS,INFO)
             RETURN 1
          ENDIF
C
C---------------------------------------------------------------------------------------------------------------------

C---------------------------------------------------------------------------------------------------------------------
C    DO ALL THE VERY FIRST CALL OF THE SIMULATION MANIPULATIONS HERE
      IF (INFO(7).EQ.-1) THEN

C       SET SOME INFO ARRAY VARIABLES TO TELL THE TRNSYS ENGINE HOW THIS TYPE IS TO WORK
         INFO(6)=NOUT
         INFO(9)=1
             INFO(10)=0       !STORAGE FOR VERSION 16 HAS BEEN CHANGED

C       SET THE REQUIRED NUMBER OF INPUTS, PARAMETERS AND DERIVATIVES THAT THE USER SHOULD SUPPLY IN THE INPUT FILE
C       IN SOME CASES, THE NUMBER OF VARIABLES MAY DEPEND ON THE VALUE OF PARAMETERS TO THIS MODEL....
         NIN=NI
             NPAR=NP
             NDER=ND

C       CALL THE TYPE CHECK SUBROUTINE TO COMPARE WHAT THIS COMPONENT REQUIRES TO WHAT IS SUPPLIED IN
C       THE TRNSYS INPUT FILE
             CALL TYPECK(1,INFO,NIN,NPAR,NDER)

C       SET THE NUMBER OF STORAGE SPOTS NEEDED FOR THIS COMPONENT
         NITEMS=0
C            CALL setStorageSize(NITEMS,INFO)

C       RETURN TO THE CALLING PROGRAM
         RETURN 1

      ENDIF
C---------------------------------------------------------------------------------------------------------------------

C---------------------------------------------------------------------------------------------------------------------
C    DO ALL OF THE INITIAL TIMESTEP MANIPULATIONS HERE - THERE ARE NO ITERATIONS AT THE INTIAL TIME
      IF (TIME .LT. (getSimulationStartTime() +
     . getSimulationTimeStep()/2.D0)) THEN

C       SET THE UNIT NUMBER FOR FUTURE CALLS
         IUNIT=INFO(1)
         ITYPE=INFO(2)

C       CHECK THE PARAMETERS FOR PROBLEMS AND RETURN FROM THE SUBROUTINE IF AN ERROR IS FOUND
C         IF(...) CALL TYPECK(-4,INFO,0,"BAD PARAMETER #",0)
```

```
C       PERFORM ANY REQUIRED CALCULATIONS TO SET THE INITIAL VALUES OF THE OUTPUTS HERE
C                    SIG_OUT
                              OUT(1)=0

C       PERFORM ANY REQUIRED CALCULATIONS TO SET THE INITIAL STORAGE VARIABLES HERE
         NITEMS=0
C            STORED(1)=...

C       PUT THE STORED ARRAY IN THE GLOBAL STORED ARRAY
C         CALL setStorageVars(STORED,NITEMS,INFO)

C       RETURN TO THE CALLING PROGRAM
         RETURN 1

      ENDIF
C-----------------------------------------------------------------------------------------------------------------------

C-----------------------------------------------------------------------------------------------------------------------
C    *** ITS AN ITERATIVE CALL TO THIS COMPONENT ***
C-----------------------------------------------------------------------------------------------------------------------


C-----------------------------------------------------------------------------------------------------------------------
C    RETRIEVE THE VALUES IN THE STORAGE ARRAY FOR THIS ITERATION
C      NITEMS=
C         CALL getStorageVars(STORED,NITEMS,INFO)
C      STORED(1)=
C-----------------------------------------------------------------------------------------------------------------------
C-----------------------------------------------------------------------------------------------------------------------
C    CHECK THE INPUTS FOR PROBLEMS
C      IF(...) CALL TYPECK(-3,INFO,'BAD INPUT #',0,0)
C         IF(IERROR.GT.0) RETURN 1
C-----------------------------------------------------------------------------------------------------------------------
C-----------------------------------------------------------------------------------------------------------------------
C    *** PERFORM ALL THE CALCULATION HERE FOR THIS MODEL. ***
C-----------------------------------------------------------------------------------------------------------------------

C                   ADD YOUR COMPONENT EQUATIONS HERE; BASICALLY THE EQUATIONS THAT WILL
C                   CALCULATE THE OUTPUTS BASED ON THE PARAMETERS AND THE INPUTS. REFER TO
C                   CHAPTER 3 OF THE TRNSYS VOLUME 1 MANUAL FOR DETAILED INFORMATION ON
C                   WRITING TRNSYS COMPONENTS.



C    INPUTS
      !DOUBLE PRECISION SH_SIG
      !DOUBLE PRECISION DHW_SIG
      !DOUBLE PRECISION SH_PUMP_SIG

C    OUTPUTS
          !DOUBLE PRECISION SIG_OUT


          IF (SH_PUMP_SIG == 0) THEN
                    SIG_OUT = DHW_SIG
          ELSE
                    SIG_OUT = SH_SIG
          ENDIF





C-----------------------------------------------------------------------------------------------------------------------
```

```
C-----------------------------------------------------------------------------------------------------------------------
C-----------------------------------------------------------------------------------------------------------------------
C    SET THE STORAGE ARRAY AT THE END OF THIS ITERATION IF NECESSARY
C      NITEMS=
C      STORED(1)=
C         CALL setStorageVars(STORED,NITEMS,INFO)
C-----------------------------------------------------------------------------------------------------------------------
C-----------------------------------------------------------------------------------------------------------------------
C    REPORT ANY PROBLEMS THAT HAVE BEEN FOUND USING CALLS LIKE THIS:
C      CALL MESSAGES(-1,'put your message here','MESSAGE',IUNIT,ITYPE)
C      CALL MESSAGES(-1,'put your message here','WARNING',IUNIT,ITYPE)
C      CALL MESSAGES(-1,'put your message here','SEVERE',IUNIT,ITYPE)
C      CALL MESSAGES(-1,'put your message here','FATAL',IUNIT,ITYPE)
C-----------------------------------------------------------------------------------------------------------------------
C-----------------------------------------------------------------------------------------------------------------------
C    SET THE OUTPUTS FROM THIS MODEL IN SEQUENTIAL ORDER AND GET OUT

C                     SIG_OUT
                               OUT(1)= SIG_OUT

C-----------------------------------------------------------------------------------------------------------------------
C    EVERYTHING IS DONE - RETURN FROM THIS SUBROUTINE AND MOVE ON
      RETURN 1
      END
C-----------------------------------------------------------------------------------------------------------------------
```

B.3 TYPE 266 – ModifiedHDH

This TRNSYS proforma calculates the space heating load based on a modified heating degree hour model, Chapter 3.3.

Table B.7: TYPE 266 - Parameters

Number	Name	Description
1	T_REF	Reference temperature for modified heating degree day calculation [°C]
2	VOL	Volume of heated space in house [m³]

Table B.8: TYPE 266 - Inputs

Number	Name	Description
1	T_AMB	Ambient temperature (hourly average) [°C]
2	T_AVE	Average daily temperature [°C]

Table B.9: TYPE 266 - Outputs

Number	Name	Description
1	Q_KW	Space heating load [kW]
2	FOO	Extra output for debugging
3	BAR	Extra output for debugging

Derivatives: None

Table B.10: TYPE 266 - FORTRAN Code

```
                              SUBROUTINE TYPE266 (TIME,XIN,OUT,T,DTDT,PAR,INFO,ICNTRL,*)
C***********************************************************************
C Object: ModifiedHDH
C Simulation Studio Model: Type266-ModifiedHDH
C
C Author:
C Editor:
C Date:    June 23, 2011 last modified: June 23, 2011
C
C
C ***
C *** Model Parameters
C ***
C                             T_REF     - [-Inf;+Inf]
C                             VOL       - [-Inf;+Inf]

C ***
C *** Model Inputs
C ***
C                             T_AMB     - [-Inf;+Inf]
C                             T_AVE     - [-Inf;+Inf]

C ***
C *** Model Outputs
C ***
```

```
C                             Q_KW      - [-Inf;+Inf]
C                             FOO       - [-Inf;+Inf]
C                             BAR       - [-Inf;+Inf]

C ***
C *** Model Derivatives
C ***

C (Comments and routine interface generated by TRNSYS Studio)
C************************************************************************

C    TRNSYS acess functions (allow to acess TIME etc.)
      USE TrnsysConstants
      USE TrnsysFunctions

C-----------------------------------------------------------------------------------------------------------------------
C    REQUIRED BY THE MULTI-DLL VERSION OF TRNSYS
      !DEC$ATTRIBUTES DLLEXPORT :: TYPE266                                        !SET THE CORRECT TYPE NUMBER HERE
C-----------------------------------------------------------------------------------------------------------------------
C-----------------------------------------------------------------------------------------------------------------------
C    TRNSYS DECLARATIONS
      IMPLICIT NONE                       !REQUIRES THE USER TO DEFINE ALL VARIABLES BEFORE USING THEM

          DOUBLE PRECISION XIN !THE ARRAY FROM WHICH THE INPUTS TO THIS TYPE WILL BE RETRIEVED
          DOUBLE PRECISION OUT !THE ARRAY WHICH WILL BE USED TO STORE THE OUTPUTS FROM THIS TYPE
          DOUBLE PRECISION TIME          !THE CURRENT SIMULATION TIME - YOU MAY USE THIS VARIABLE BUT DO NOT SET IT!
          DOUBLE PRECISION PAR !THE ARRAY FROM WHICH THE PARAMETERS FOR THIS TYPE WILL BE RETRIEVED
          DOUBLE PRECISION STORED !THE STORAGE ARRAY FOR HOLDING VARIABLES FROM TIMESTEP TO TIMESTEP
          DOUBLE PRECISION T             !AN ARRAY CONTAINING THE RESULTS FROM THE DIFFERENTIAL EQUATION SOLVER
          DOUBLE PRECISION DTDT          !AN ARRAY CONTAINING THE DERIVATIVES TO BE PASSED TO THE DIFF.EQ. SOLVER
          INTEGER*4 INFO(15)             !THE INFO ARRAY STORES AND PASSES VALUABLE INFORMATION TO AND FROM THIS TYPE
          INTEGER*4 NP,NI,NOUT,ND        !VARIABLES FOR THE MAXIMUM NUMBER OF PARAMETERS,INPUTS,OUTPUTS AND DERIVATIVES
          INTEGER*4 NPAR,NIN,NDER        !VARIABLES FOR THE CORRECT NUMBER OF PARAMETERS,INPUTS,OUTPUTS AND DERIVATIVES
          INTEGER*4 IUNIT,ITYPE          !THE UNIT NUMBER AND TYPE NUMBER FOR THIS COMPONENT
          INTEGER*4 ICNTRL               !AN ARRAY FOR HOLDING VALUES OF CONTROL FUNCTIONS WITH THE NEW SOLVER
          INTEGER*4 NSTORED              !THE NUMBER OF VARIABLES THAT WILL BE PASSED INTO AND OUT OF STORAGE
          CHARACTER*3 OCHECK             !AN ARRAY TO BE FILLED WITH THE CORRECT VARIABLE TYPES FOR THE OUTPUTS
          CHARACTER*3 YCHECK             !AN ARRAY TO BE FILLED WITH THE CORRECT VARIABLE TYPES FOR THE INPUTS
C-----------------------------------------------------------------------------------------------------------------------

C-----------------------------------------------------------------------------------------------------------------------
C    USER DECLARATIONS - SET THE MAXIMUM NUMBER OF PARAMETERS (NP), INPUTS (NI),
C    OUTPUTS (NOUT), AND DERIVATIVES (ND) THAT MAY BE SUPPLIED FOR THIS TYPE
      PARAMETER (NP=2,NI=2,NOUT=3,ND=0,NSTORED=0)
C-----------------------------------------------------------------------------------------------------------------------

C-----------------------------------------------------------------------------------------------------------------------
C    REQUIRED TRNSYS DIMENSIONS
      DIMENSION XIN(NI),OUT(NOUT),PAR(NP),YCHECK(NI),OCHECK(NOUT),
          1   STORED(NSTORED),T(ND),DTDT(ND)
      INTEGER NITEMS
C-----------------------------------------------------------------------------------------------------------------------
C-----------------------------------------------------------------------------------------------------------------------
C    ADD DECLARATIONS AND DEFINITIONS FOR THE USER-VARIABLES HERE


C    PARAMETERS
      DOUBLE PRECISION T_REF
      DOUBLE PRECISION VOL

C    INPUTS
      DOUBLE PRECISION T_AMB
      DOUBLE PRECISION T_AVE

C    OUTPUTS
          DOUBLE PRECISION Q_KW
          DOUBLE PRECISION FOO
```

```
          DOUBLE PRECISION BAR

C    LOCAL
          DOUBLE PRECISION UA

C-----------------------------------------------------------------------------------------------------------------------
C       READ IN THE VALUES OF THE PARAMETERS IN SEQUENTIAL ORDER
      T_REF=PAR(1)
      VOL=PAR(2)

C-----------------------------------------------------------------------------------------------------------------------
C    RETRIEVE THE CURRENT VALUES OF THE INPUTS TO THIS MODEL FROM THE XIN ARRAY IN SEQUENTIAL ORDER

      T_AMB=XIN(1)
      T_AVE=XIN(2)
             IUNIT=INFO(1)
             ITYPE=INFO(2)

C-----------------------------------------------------------------------------------------------------------------------
C    SET THE VERSION INFORMATION FOR TRNSYS
      IF(INFO(7).EQ.-2) THEN
             INFO(12)=16
             RETURN 1
          ENDIF
C-----------------------------------------------------------------------------------------------------------------------

C-----------------------------------------------------------------------------------------------------------------------
C    DO ALL THE VERY LAST CALL OF THE SIMULATION MANIPULATIONS HERE
      IF (INFO(8).EQ.-1) THEN
             RETURN 1
          ENDIF
C-----------------------------------------------------------------------------------------------------------------------

C-----------------------------------------------------------------------------------------------------------------------
C    PERFORM ANY 'AFTER-ITERATION' MANIPULATIONS THAT ARE REQUIRED HERE
C    e.g. save variables to storage array for the next timestep
      IF (INFO(13).GT.0) THEN
             NITEMS=0
C            STORED(1)=... (if NITEMS > 0)
C        CALL setStorageVars(STORED,NITEMS,INFO)
             RETURN 1
          ENDIF
C
C-----------------------------------------------------------------------------------------------------------------------

C-----------------------------------------------------------------------------------------------------------------------
C    DO ALL THE VERY FIRST CALL OF THE SIMULATION MANIPULATIONS HERE
      IF (INFO(7).EQ.-1) THEN

C       SET SOME INFO ARRAY VARIABLES TO TELL THE TRNSYS ENGINE HOW THIS TYPE IS TO WORK
         INFO(6)=NOUT
         INFO(9)=1
             INFO(10)=0        !STORAGE FOR VERSION 16 HAS BEEN CHANGED

C       SET THE REQUIRED NUMBER OF INPUTS, PARAMETERS AND DERIVATIVES THAT THE USER SHOULD SUPPLY IN THE INPUT FILE
C       IN SOME CASES, THE NUMBER OF VARIABLES MAY DEPEND ON THE VALUE OF PARAMETERS TO THIS MODEL....
         NIN=NI
             NPAR=NP
             NDER=ND

C       CALL THE TYPE CHECK SUBROUTINE TO COMPARE WHAT THIS COMPONENT REQUIRES TO WHAT IS SUPPLIED IN
C       THE TRNSYS INPUT FILE
             CALL TYPECK(1,INFO,NIN,NPAR,NDER)

C       SET THE NUMBER OF STORAGE SPOTS NEEDED FOR THIS COMPONENT
         NITEMS=0
C            CALL setStorageSize(NITEMS,INFO)
```

```
C       RETURN TO THE CALLING PROGRAM
         RETURN 1

      ENDIF
C-----------------------------------------------------------------------------------------------------------------------

C-----------------------------------------------------------------------------------------------------------------------
C    DO ALL OF THE INITIAL TIMESTEP MANIPULATIONS HERE - THERE ARE NO ITERATIONS AT THE INTIAL TIME
      IF (TIME .LT. (getSimulationStartTime() +
     . getSimulationTimeStep()/2.D0)) THEN

C       SET THE UNIT NUMBER FOR FUTURE CALLS
         IUNIT=INFO(1)
         ITYPE=INFO(2)

C       CHECK THE PARAMETERS FOR PROBLEMS AND RETURN FROM THE SUBROUTINE IF AN ERROR IS FOUND
C         IF(...) CALL TYPECK(-4,INFO,0,"BAD PARAMETER #",0)

C       PERFORM ANY REQUIRED CALCULATIONS TO SET THE INITIAL VALUES OF THE OUTPUTS HERE
C                     Q_KW
                               OUT(1)=0
C                     FOO
                               OUT(2)=0
C                     BAR
                               OUT(3)=0

C       PERFORM ANY REQUIRED CALCULATIONS TO SET THE INITIAL STORAGE VARIABLES HERE
         NITEMS=0
C            STORED(1)=...

C       PUT THE STORED ARRAY IN THE GLOBAL STORED ARRAY
C         CALL setStorageVars(STORED,NITEMS,INFO)

C       RETURN TO THE CALLING PROGRAM
         RETURN 1

      ENDIF
C-----------------------------------------------------------------------------------------------------------------------

C-----------------------------------------------------------------------------------------------------------------------
C    *** ITS AN ITERATIVE CALL TO THIS COMPONENT ***
C-----------------------------------------------------------------------------------------------------------------------


C-----------------------------------------------------------------------------------------------------------------------
C    RETRIEVE THE VALUES IN THE STORAGE ARRAY FOR THIS ITERATION
C      NITEMS=
C          CALL getStorageVars(STORED,NITEMS,INFO)
C      STORED(1)=
C-----------------------------------------------------------------------------------------------------------------------
C-----------------------------------------------------------------------------------------------------------------------
C    CHECK THE INPUTS FOR PROBLEMS
C      IF(...) CALL TYPECK(-3,INFO,'BAD INPUT #',0,0)
C          IF(IERROR.GT.0) RETURN 1
C-----------------------------------------------------------------------------------------------------------------------
C-----------------------------------------------------------------------------------------------------------------------
C    *** PERFORM ALL THE CALCULATION HERE FOR THIS MODEL. ***
C-----------------------------------------------------------------------------------------------------------------------

C                    ADD YOUR COMPONENT EQUATIONS HERE; BASICALLY THE EQUATIONS THAT WILL
C                    CALCULATE THE OUTPUTS BASED ON THE PARAMETERS AND THE INPUTS. REFER TO
C                    CHAPTER 3 OF THE TRNSYS VOLUME 1 MANUAL FOR DETAILED INFORMATION ON
C                    WRITING TRNSYS COMPONENTS.


C    PARAMETERS
```

```
      !DOUBLE PRECISION T_REF
      !DOUBLE PRECISION VOL

C    INPUTS
      !DOUBLE PRECISION T_AMB
      !DOUBLE PRECISION T_AVE

C    OUTPUTS
          !DOUBLE PRECISION Q_KW
          !DOUBLE PRECISION FOO
          !DOUBLE PRECISION BAR

C    LOCAL
          !DOUBLE PRECISION UA


          Q_KW = 0.0
          FOO = 0.0
          BAR = 0.0
          UA = 0.0


          IF ((T_AMB >= T_REF) .OR. (T_AVE >= T_REF)) THEN
                    Q_KW = 0.0
          ELSE
                    UA = (49.0/6000.0)*((VOL / 2.5) + 40.0)/24.0
                    Q_KW = UA * (T_REF - T_AMB)
          ENDIF


          !Q_KW = Q_KW * 1000.0
          !Q_KW = FLOOR(Q_KW)
          !Q_KW = Q_KW / 1000.0






C-----------------------------------------------------------------------------------------------------------------------

C-----------------------------------------------------------------------------------------------------------------------
C-----------------------------------------------------------------------------------------------------------------------
C    SET THE STORAGE ARRAY AT THE END OF THIS ITERATION IF NECESSARY
C      NITEMS=
C      STORED(1)=
C         CALL setStorageVars(STORED,NITEMS,INFO)
C-----------------------------------------------------------------------------------------------------------------------
C-----------------------------------------------------------------------------------------------------------------------
C    REPORT ANY PROBLEMS THAT HAVE BEEN FOUND USING CALLS LIKE THIS:
C      CALL MESSAGES(-1,'put your message here','MESSAGE',IUNIT,ITYPE)
C      CALL MESSAGES(-1,'put your message here','WARNING',IUNIT,ITYPE)
C      CALL MESSAGES(-1,'put your message here','SEVERE',IUNIT,ITYPE)
C      CALL MESSAGES(-1,'put your message here','FATAL',IUNIT,ITYPE)
C-----------------------------------------------------------------------------------------------------------------------
C-----------------------------------------------------------------------------------------------------------------------
C    SET THE OUTPUTS FROM THIS MODEL IN SEQUENTIAL ORDER AND GET OUT

C                    Q_KW
                              OUT(1)= Q_KW
C                    FOO
                              OUT(2)= FOO
C                    BAR
                              OUT(3)= BAR

C-----------------------------------------------------------------------------------------------------------------------
```

```
C    EVERYTHING IS DONE - RETURN FROM THIS SUBROUTINE AND MOVE ON
      RETURN 1
      END
C----------------------------------------------------------------------------------------------------------------------
```

B.4 TYPE 268 – AuxSH

This TRNSYS proforma simulates the auxiliary heat source for the space heating loop.

Table B.11: TYPE 268 - Parameters

Number	Name	Description
1	CP	Specific heat of fluid in the space heating loop [kJ/kg-K]

Table B.12: TYPE 268 - Inputs

Number	Name	Description
1	TEMP_IN	Temperature of fluid entering the auxiliary heat source [°C]
2	FLOW_IN	Flow rate of fluid entering the auxiliary heat source [kg/hr]
3	T_SET	Desired minimum temperature of the fluid exiting the auxiliary heat source [°C]

Table B.13: TYPE 268 - Outputs

Number	Name	Description
1	TEMP_OUT	Temperature of fluid exiting the auxiliary heat source [°C]
2	FLOW_OUT	Flow rate of fluid exiting the auxiliary heat source [kg/hr]
3	Q_OUT_KW	Energy added to the fluid [kW]
4	FOO	Extra output for debugging
5	BAR	Extra output for debugging

Derivatives: None

Table B.14: TYPE 268 - FORTRAN Code

```
                               SUBROUTINE TYPE268 (TIME,XIN,OUT,T,DTDT,PAR,INFO,ICNTRL,*)
C************************************************************************
C Object: AuxSH
C Simulation Studio Model: Type268-AuxSH
C
C Author:
C Editor:
C Date:     June 27, 2011 last modified: June 27, 2011
C
C
C ***
C *** Model Parameters
C ***
C                              CP         - [-Inf;+Inf]

C ***
C *** Model Inputs
C ***
C                              TEMP_IN    - [-Inf;+Inf]
C                              FLOW_IN    - [-Inf;+Inf]
C                              T_SET      - [-Inf;+Inf]

C ***
C *** Model Outputs
C ***
```

```
C                              TEMP_OUT  - [-Inf;+Inf]
C                              FLOW_OUT  - [-Inf;+Inf]
C                              Q_OUT_KW  - [-Inf;+Inf]
C                              FOO       - [-Inf;+Inf]
C                              BAR       - [-Inf;+Inf]

C ***
C *** Model Derivatives
C ***

C (Comments and routine interface generated by TRNSYS Studio)
C************************************************************************

C    TRNSYS acess functions (allow to acess TIME etc.)
      USE TrnsysConstants
      USE TrnsysFunctions

C-----------------------------------------------------------------------------------------------------------------------
C    REQUIRED BY THE MULTI-DLL VERSION OF TRNSYS
      !DEC$ATTRIBUTES DLLEXPORT :: TYPE268                                       !SET THE CORRECT TYPE NUMBER HERE
C-----------------------------------------------------------------------------------------------------------------------
C-----------------------------------------------------------------------------------------------------------------------
C    TRNSYS DECLARATIONS
      IMPLICIT NONE                      !REQUIRES THE USER TO DEFINE ALL VARIABLES BEFORE USING THEM

          DOUBLE PRECISION XIN !THE ARRAY FROM WHICH THE INPUTS TO THIS TYPE WILL BE RETRIEVED
          DOUBLE PRECISION OUT !THE ARRAY WHICH WILL BE USED TO STORE THE OUTPUTS FROM THIS TYPE
          DOUBLE PRECISION TIME          !THE CURRENT SIMULATION TIME - YOU MAY USE THIS VARIABLE BUT DO NOT SET IT!
          DOUBLE PRECISION PAR !THE ARRAY FROM WHICH THE PARAMETERS FOR THIS TYPE WILL BE RETRIEVED
          DOUBLE PRECISION STORED !THE STORAGE ARRAY FOR HOLDING VARIABLES FROM TIMESTEP TO TIMESTEP
          DOUBLE PRECISION T             !AN ARRAY CONTAINING THE RESULTS FROM THE DIFFERENTIAL EQUATION SOLVER
          DOUBLE PRECISION DTDT          !AN ARRAY CONTAINING THE DERIVATIVES TO BE PASSED TO THE DIFF.EQ. SOLVER
          INTEGER*4 INFO(15)             !THE INFO ARRAY STORES AND PASSES VALUABLE INFORMATION TO AND FROM THIS TYPE
          INTEGER*4 NP,NI,NOUT,ND        !VARIABLES FOR THE MAXIMUM NUMBER OF PARAMETERS,INPUTS,OUTPUTS AND DERIVATIVES
          INTEGER*4 NPAR,NIN,NDER        !VARIABLES FOR THE CORRECT NUMBER OF PARAMETERS,INPUTS,OUTPUTS AND DERIVATIVES
          INTEGER*4 IUNIT,ITYPE          !THE UNIT NUMBER AND TYPE NUMBER FOR THIS COMPONENT
          INTEGER*4 ICNTRL               !AN ARRAY FOR HOLDING VALUES OF CONTROL FUNCTIONS WITH THE NEW SOLVER
          INTEGER*4 NSTORED              !THE NUMBER OF VARIABLES THAT WILL BE PASSED INTO AND OUT OF STORAGE
          CHARACTER*3 OCHECK             !AN ARRAY TO BE FILLED WITH THE CORRECT VARIABLE TYPES FOR THE OUTPUTS
          CHARACTER*3 YCHECK             !AN ARRAY TO BE FILLED WITH THE CORRECT VARIABLE TYPES FOR THE INPUTS
C-----------------------------------------------------------------------------------------------------------------------

C-----------------------------------------------------------------------------------------------------------------------
C    USER DECLARATIONS - SET THE MAXIMUM NUMBER OF PARAMETERS (NP), INPUTS (NI),
C    OUTPUTS (NOUT), AND DERIVATIVES (ND) THAT MAY BE SUPPLIED FOR THIS TYPE
      PARAMETER (NP=1,NI=3,NOUT=5,ND=0,NSTORED=0)
C-----------------------------------------------------------------------------------------------------------------------

C-----------------------------------------------------------------------------------------------------------------------
C    REQUIRED TRNSYS DIMENSIONS
      DIMENSION XIN(NI),OUT(NOUT),PAR(NP),YCHECK(NI),OCHECK(NOUT),
          1   STORED(NSTORED),T(ND),DTDT(ND)
      INTEGER NITEMS
C-----------------------------------------------------------------------------------------------------------------------
C-----------------------------------------------------------------------------------------------------------------------
C    ADD DECLARATIONS AND DEFINITIONS FOR THE USER-VARIABLES HERE


C    PARAMETERS
      DOUBLE PRECISION CP

C    INPUTS
      DOUBLE PRECISION TEMP_IN
      DOUBLE PRECISION FLOW_IN
      DOUBLE PRECISION T_SET

C    OUTPUTS
```

```
          DOUBLE PRECISION TEMP_OUT
          DOUBLE PRECISION FLOW_OUT
          DOUBLE PRECISION Q_OUT_KW
          DOUBLE PRECISION FOO
          DOUBLE PRECISION BAR


C-----------------------------------------------------------------------------------------------------------------------
C       READ IN THE VALUES OF THE PARAMETERS IN SEQUENTIAL ORDER
      CP=PAR(1)

C-----------------------------------------------------------------------------------------------------------------------
C    RETRIEVE THE CURRENT VALUES OF THE INPUTS TO THIS MODEL FROM THE XIN ARRAY IN SEQUENTIAL ORDER

      TEMP_IN=XIN(1)
      FLOW_IN=XIN(2)
      T_SET=XIN(3)
             IUNIT=INFO(1)
             ITYPE=INFO(2)

C-----------------------------------------------------------------------------------------------------------------------
C    SET THE VERSION INFORMATION FOR TRNSYS
      IF(INFO(7).EQ.-2) THEN
             INFO(12)=16
             RETURN 1
          ENDIF
C-----------------------------------------------------------------------------------------------------------------------

C-----------------------------------------------------------------------------------------------------------------------
C    DO ALL THE VERY LAST CALL OF THE SIMULATION MANIPULATIONS HERE
      IF (INFO(8).EQ.-1) THEN
             RETURN 1
          ENDIF
C-----------------------------------------------------------------------------------------------------------------------

C-----------------------------------------------------------------------------------------------------------------------
C    PERFORM ANY 'AFTER-ITERATION' MANIPULATIONS THAT ARE REQUIRED HERE
C    e.g. save variables to storage array for the next timestep
      IF (INFO(13).GT.0) THEN
             NITEMS=0
C            STORED(1)=... (if NITEMS > 0)
C        CALL setStorageVars(STORED,NITEMS,INFO)
             RETURN 1
          ENDIF
C
C-----------------------------------------------------------------------------------------------------------------------

C-----------------------------------------------------------------------------------------------------------------------
C    DO ALL THE VERY FIRST CALL OF THE SIMULATION MANIPULATIONS HERE
      IF (INFO(7).EQ.-1) THEN

C       SET SOME INFO ARRAY VARIABLES TO TELL THE TRNSYS ENGINE HOW THIS TYPE IS TO WORK
         INFO(6)=NOUT
         INFO(9)=1
             INFO(10)=0        !STORAGE FOR VERSION 16 HAS BEEN CHANGED

C       SET THE REQUIRED NUMBER OF INPUTS, PARAMETERS AND DERIVATIVES THAT THE USER SHOULD SUPPLY IN THE INPUT FILE
C       IN SOME CASES, THE NUMBER OF VARIABLES MAY DEPEND ON THE VALUE OF PARAMETERS TO THIS MODEL....
         NIN=NI
             NPAR=NP
             NDER=ND

C       CALL THE TYPE CHECK SUBROUTINE TO COMPARE WHAT THIS COMPONENT REQUIRES TO WHAT IS SUPPLIED IN
C       THE TRNSYS INPUT FILE
             CALL TYPECK(1,INFO,NIN,NPAR,NDER)

C       SET THE NUMBER OF STORAGE SPOTS NEEDED FOR THIS COMPONENT
```

```
         NITEMS=0
C            CALL setStorageSize(NITEMS,INFO)

C        RETURN TO THE CALLING PROGRAM
         RETURN 1

      ENDIF
C-----------------------------------------------------------------------------------------------------------------------

C-----------------------------------------------------------------------------------------------------------------------
C     DO ALL OF THE INITIAL TIMESTEP MANIPULATIONS HERE - THERE ARE NO ITERATIONS AT THE INTIAL TIME
      IF (TIME .LT. (getSimulationStartTime() +
     . getSimulationTimeStep()/2.D0)) THEN

C        SET THE UNIT NUMBER FOR FUTURE CALLS
         IUNIT=INFO(1)
         ITYPE=INFO(2)

C        CHECK THE PARAMETERS FOR PROBLEMS AND RETURN FROM THE SUBROUTINE IF AN ERROR IS FOUND
C          IF(...) CALL TYPECK(-4,INFO,0,"BAD PARAMETER #",0)

C        PERFORM ANY REQUIRED CALCULATIONS TO SET THE INITIAL VALUES OF THE OUTPUTS HERE
C                      TEMP_OUT
                                OUT(1)=0
C                      FLOW_OUT
                                OUT(2)=0
C                      Q_OUT_KW
                                OUT(3)=0
C                      FOO
                                OUT(4)=0
C                      BAR
                                OUT(5)=0

C        PERFORM ANY REQUIRED CALCULATIONS TO SET THE INITIAL STORAGE VARIABLES HERE
         NITEMS=0
C            STORED(1)=...

C        PUT THE STORED ARRAY IN THE GLOBAL STORED ARRAY
C          CALL setStorageVars(STORED,NITEMS,INFO)

C        RETURN TO THE CALLING PROGRAM
         RETURN 1

      ENDIF
C-----------------------------------------------------------------------------------------------------------------------

C-----------------------------------------------------------------------------------------------------------------------
C     *** ITS AN ITERATIVE CALL TO THIS COMPONENT ***
C-----------------------------------------------------------------------------------------------------------------------



C-----------------------------------------------------------------------------------------------------------------------
C     RETRIEVE THE VALUES IN THE STORAGE ARRAY FOR THIS ITERATION
C       NITEMS=
C           CALL getStorageVars(STORED,NITEMS,INFO)
C       STORED(1)=
C-----------------------------------------------------------------------------------------------------------------------
C-----------------------------------------------------------------------------------------------------------------------
C     CHECK THE INPUTS FOR PROBLEMS
C       IF(...) CALL TYPECK(-3,INFO,'BAD INPUT #',0,0)
C           IF(IERROR.GT.0) RETURN 1
C-----------------------------------------------------------------------------------------------------------------------
C-----------------------------------------------------------------------------------------------------------------------
C     *** PERFORM ALL THE CALCULATION HERE FOR THIS MODEL. ***
C-----------------------------------------------------------------------------------------------------------------------

C                     ADD YOUR COMPONENT EQUATIONS HERE; BASICALLY THE EQUATIONS THAT WILL
```

```
C                    CALCULATE THE OUTPUTS BASED ON THE PARAMETERS AND THE INPUTS. REFER TO
C                    CHAPTER 3 OF THE TRNSYS VOLUME 1 MANUAL FOR DETAILED INFORMATION ON
C                    WRITING TRNSYS COMPONENTS.



C    PARAMETERS
      !DOUBLE PRECISION CP

C    INPUTS
      !DOUBLE PRECISION TEMP_IN
      !DOUBLE PRECISION FLOW_IN
      !DOUBLE PRECISION T_SET

C    OUTPUTS
          !DOUBLE PRECISION TEMP_OUT
          !DOUBLE PRECISION FLOW_OUT
          !DOUBLE PRECISION Q_OUT_KW
          !DOUBLE PRECISION FOO
          !DOUBLE PRECISION BAR

          TEMP_OUT = 0.0
          FLOW_OUT = 0.0
          Q_OUT_KW = 0.0
          FOO = 0.0
          BAR = 0.0

          IF (FLOW_IN <= 0.0) THEN
                    TEMP_OUT = TEMP_IN
                    FLOW_OUT = FLOW_IN
                    Q_OUT_KW = 0.0

          ELSEIF (TEMP_IN >= T_SET) THEN
                    TEMP_OUT = TEMP_IN
                    FLOW_OUT = FLOW_IN
                    Q_OUT_KW = 0.0

          ELSE
                    TEMP_OUT = T_SET
                    FLOW_OUT = FLOW_IN
                    Q_OUT_KW = (T_SET - TEMP_IN) * CP * FLOW_IN / 3600.0


          ENDIF



C-----------------------------------------------------------------------------------------------------------------------

C-----------------------------------------------------------------------------------------------------------------------
C-----------------------------------------------------------------------------------------------------------------------
C    SET THE STORAGE ARRAY AT THE END OF THIS ITERATION IF NECESSARY
C      NITEMS=
C      STORED(1)=
C         CALL setStorageVars(STORED,NITEMS,INFO)
C-----------------------------------------------------------------------------------------------------------------------
C-----------------------------------------------------------------------------------------------------------------------
C    REPORT ANY PROBLEMS THAT HAVE BEEN FOUND USING CALLS LIKE THIS:
C      CALL MESSAGES(-1,'put your message here','MESSAGE',IUNIT,ITYPE)
C      CALL MESSAGES(-1,'put your message here','WARNING',IUNIT,ITYPE)
C      CALL MESSAGES(-1,'put your message here','SEVERE',IUNIT,ITYPE)
C      CALL MESSAGES(-1,'put your message here','FATAL',IUNIT,ITYPE)
C-----------------------------------------------------------------------------------------------------------------------
C-----------------------------------------------------------------------------------------------------------------------
C    SET THE OUTPUTS FROM THIS MODEL IN SEQUENTIAL ORDER AND GET OUT

C                     TEMP_OUT
```

```
                               OUT(1)= TEMP_OUT
C                     FLOW_OUT
                               OUT(2)= FLOW_OUT
C                     Q_OUT_KW
                               OUT(3)= Q_OUT_KW
C                     FOO
                               OUT(4)= FOO
C                     BAR
                               OUT(5)= BAR

C-----------------------------------------------------------------------------------------------------------------------
C    EVERYTHING IS DONE - RETURN FROM THIS SUBROUTINE AND MOVE ON
      RETURN 1
      END
C-----------------------------------------------------------------------------------------------------------------------
```

B.5 TYPE 269 – SHTempering3

This TRNSYS proforma sets the control signal for the space heating loop tempering valve.

Parameters: None

Table B.15: TYPE 269 - Inputs

Number	Name	Description
1	FLOOR_TEMP	Outlet temperature from the hydronic-floor [°C]
2	TANK_TEMP	Outlet temperature of space heating thermal storage tank to the space heating loop [°C]
3	SET_TEMP	Required delivery temperature to the hydronic-floor [°C]

Table B.16: TYPE 269 - Outputs

Number	Name	Description
1	X	Control signal for diverter valve 0:Bypass tank; 1:All flow through tank
2	FOO	Extra output for debugging
3	BAR	Extra output for debugging

Derivatives: None

Table B.17: TYPE 269 - FORTRAN Code

```
                              SUBROUTINE TYPE269 (TIME,XIN,OUT,T,DTDT,PAR,INFO,ICNTRL,*)
C**********************************************************************
C Object: SHTempering3
C Simulation Studio Model: Type269-SHTempering3
C
C Author:
C Editor:
C Date:    June 28, 2011 last modified: June 28, 2011
C
C
C ***
C *** Model Parameters
C ***

C ***
C *** Model Inputs
C ***
C                             FLOOR_TEMP- [-Inf;+Inf]
C                             TANK_TEMP - [-Inf;+Inf]
C                             SET_TEMP  - [-Inf;+Inf]

C ***
C *** Model Outputs
C ***
C                             X         - [-Inf;+Inf]
C                             FOO       - [-Inf;+Inf]
C                             BAR       - [-Inf;+Inf]

C ***
```

```
C *** Model Derivatives
C ***

C (Comments and routine interface generated by TRNSYS Studio)
C************************************************************************

C    TRNSYS acess functions (allow to acess TIME etc.)
      USE TrnsysConstants
      USE TrnsysFunctions

C-----------------------------------------------------------------------------------------------------------------------
C    REQUIRED BY THE MULTI-DLL VERSION OF TRNSYS
      !DEC$ATTRIBUTES DLLEXPORT :: TYPE269                                        !SET THE CORRECT TYPE NUMBER HERE
C-----------------------------------------------------------------------------------------------------------------------
C-----------------------------------------------------------------------------------------------------------------------
C    TRNSYS DECLARATIONS
      IMPLICIT NONE                      !REQUIRES THE USER TO DEFINE ALL VARIABLES BEFORE USING THEM

          DOUBLE PRECISION XIN !THE ARRAY FROM WHICH THE INPUTS TO THIS TYPE WILL BE RETRIEVED
          DOUBLE PRECISION OUT !THE ARRAY WHICH WILL BE USED TO STORE THE OUTPUTS FROM THIS TYPE
          DOUBLE PRECISION TIME          !THE CURRENT SIMULATION TIME - YOU MAY USE THIS VARIABLE BUT DO NOT SET IT!
          DOUBLE PRECISION PAR !THE ARRAY FROM WHICH THE PARAMETERS FOR THIS TYPE WILL BE RETRIEVED
          DOUBLE PRECISION STORED !THE STORAGE ARRAY FOR HOLDING VARIABLES FROM TIMESTEP TO TIMESTEP
          DOUBLE PRECISION T             !AN ARRAY CONTAINING THE RESULTS FROM THE DIFFERENTIAL EQUATION SOLVER
          DOUBLE PRECISION DTDT          !AN ARRAY CONTAINING THE DERIVATIVES TO BE PASSED TO THE DIFF.EQ. SOLVER
          INTEGER*4 INFO(15)             !THE INFO ARRAY STORES AND PASSES VALUABLE INFORMATION TO AND FROM THIS TYPE
          INTEGER*4 NP,NI,NOUT,ND        !VARIABLES FOR THE MAXIMUM NUMBER OF PARAMETERS,INPUTS,OUTPUTS AND DERIVATIVES
          INTEGER*4 NPAR,NIN,NDER        !VARIABLES FOR THE CORRECT NUMBER OF PARAMETERS,INPUTS,OUTPUTS AND DERIVATIVES
          INTEGER*4 IUNIT,ITYPE          !THE UNIT NUMBER AND TYPE NUMBER FOR THIS COMPONENT
          INTEGER*4 ICNTRL               !AN ARRAY FOR HOLDING VALUES OF CONTROL FUNCTIONS WITH THE NEW SOLVER
          INTEGER*4 NSTORED              !THE NUMBER OF VARIABLES THAT WILL BE PASSED INTO AND OUT OF STORAGE
          CHARACTER*3 OCHECK             !AN ARRAY TO BE FILLED WITH THE CORRECT VARIABLE TYPES FOR THE OUTPUTS
          CHARACTER*3 YCHECK             !AN ARRAY TO BE FILLED WITH THE CORRECT VARIABLE TYPES FOR THE INPUTS
C-----------------------------------------------------------------------------------------------------------------------

C-----------------------------------------------------------------------------------------------------------------------
C    USER DECLARATIONS - SET THE MAXIMUM NUMBER OF PARAMETERS (NP), INPUTS (NI),
C    OUTPUTS (NOUT), AND DERIVATIVES (ND) THAT MAY BE SUPPLIED FOR THIS TYPE
      PARAMETER (NP=0,NI=3,NOUT=3,ND=0,NSTORED=0)
C-----------------------------------------------------------------------------------------------------------------------

C-----------------------------------------------------------------------------------------------------------------------
C    REQUIRED TRNSYS DIMENSIONS
      DIMENSION XIN(NI),OUT(NOUT),PAR(NP),YCHECK(NI),OCHECK(NOUT),
          1   STORED(NSTORED),T(ND),DTDT(ND)
      INTEGER NITEMS
C-----------------------------------------------------------------------------------------------------------------------
C-----------------------------------------------------------------------------------------------------------------------
C    ADD DECLARATIONS AND DEFINITIONS FOR THE USER-VARIABLES HERE


C    PARAMETERS

C    INPUTS
      DOUBLE PRECISION FLOOR_TEMP
      DOUBLE PRECISION TANK_TEMP
      DOUBLE PRECISION SET_TEMP

C    OUTPUTS
          DOUBLE PRECISION X
          DOUBLE PRECISION FOO
          DOUBLE PRECISION BAR

C-----------------------------------------------------------------------------------------------------------------------
C       READ IN THE VALUES OF THE PARAMETERS IN SEQUENTIAL ORDER

C-----------------------------------------------------------------------------------------------------------------------
```

```
C    RETRIEVE THE CURRENT VALUES OF THE INPUTS TO THIS MODEL FROM THE XIN ARRAY IN SEQUENTIAL ORDER

      FLOOR_TEMP=XIN(1)
      TANK_TEMP=XIN(2)
      SET_TEMP=XIN(3)
             IUNIT=INFO(1)
             ITYPE=INFO(2)

C-----------------------------------------------------------------------------------------------------------------------
C    SET THE VERSION INFORMATION FOR TRNSYS
      IF(INFO(7).EQ.-2) THEN
             INFO(12)=16
             RETURN 1
          ENDIF
C-----------------------------------------------------------------------------------------------------------------------

C-----------------------------------------------------------------------------------------------------------------------
C    DO ALL THE VERY LAST CALL OF THE SIMULATION MANIPULATIONS HERE
      IF (INFO(8).EQ.-1) THEN
             RETURN 1
          ENDIF
C-----------------------------------------------------------------------------------------------------------------------

C-----------------------------------------------------------------------------------------------------------------------
C    PERFORM ANY 'AFTER-ITERATION' MANIPULATIONS THAT ARE REQUIRED HERE
C    e.g. save variables to storage array for the next timestep
      IF (INFO(13).GT.0) THEN
             NITEMS=0
C            STORED(1)=... (if NITEMS > 0)
C        CALL setStorageVars(STORED,NITEMS,INFO)
             RETURN 1
          ENDIF
C
C-----------------------------------------------------------------------------------------------------------------------

C-----------------------------------------------------------------------------------------------------------------------
C    DO ALL THE VERY FIRST CALL OF THE SIMULATION MANIPULATIONS HERE
      IF (INFO(7).EQ.-1) THEN

C       SET SOME INFO ARRAY VARIABLES TO TELL THE TRNSYS ENGINE HOW THIS TYPE IS TO WORK
         INFO(6)=NOUT
         INFO(9)=1
             INFO(10)=0       !STORAGE FOR VERSION 16 HAS BEEN CHANGED

C       SET THE REQUIRED NUMBER OF INPUTS, PARAMETERS AND DERIVATIVES THAT THE USER SHOULD SUPPLY IN THE INPUT FILE
C       IN SOME CASES, THE NUMBER OF VARIABLES MAY DEPEND ON THE VALUE OF PARAMETERS TO THIS MODEL....
         NIN=NI
             NPAR=NP
             NDER=ND

C       CALL THE TYPE CHECK SUBROUTINE TO COMPARE WHAT THIS COMPONENT REQUIRES TO WHAT IS SUPPLIED IN
C       THE TRNSYS INPUT FILE
             CALL TYPECK(1,INFO,NIN,NPAR,NDER)

C       SET THE NUMBER OF STORAGE SPOTS NEEDED FOR THIS COMPONENT
         NITEMS=0
C            CALL setStorageSize(NITEMS,INFO)

C       RETURN TO THE CALLING PROGRAM
         RETURN 1

      ENDIF
C-----------------------------------------------------------------------------------------------------------------------

C-----------------------------------------------------------------------------------------------------------------------
C    DO ALL OF THE INITIAL TIMESTEP MANIPULATIONS HERE - THERE ARE NO ITERATIONS AT THE INTIAL TIME
      IF (TIME .LT. (getSimulationStartTime() +
```

```
     . getSimulationTimeStep()/2.D0)) THEN

C       SET THE UNIT NUMBER FOR FUTURE CALLS
         IUNIT=INFO(1)
         ITYPE=INFO(2)

C       CHECK THE PARAMETERS FOR PROBLEMS AND RETURN FROM THE SUBROUTINE IF AN ERROR IS FOUND
C         IF(...) CALL TYPECK(-4,INFO,0,"BAD PARAMETER #",0)

C       PERFORM ANY REQUIRED CALCULATIONS TO SET THE INITIAL VALUES OF THE OUTPUTS HERE
C                    X
                              OUT(1)=0
C                    FOO
                              OUT(2)=0
C                    BAR
                              OUT(3)=0

C       PERFORM ANY REQUIRED CALCULATIONS TO SET THE INITIAL STORAGE VARIABLES HERE
         NITEMS=0
C            STORED(1)=...

C       PUT THE STORED ARRAY IN THE GLOBAL STORED ARRAY
C         CALL setStorageVars(STORED,NITEMS,INFO)

C       RETURN TO THE CALLING PROGRAM
         RETURN 1

      ENDIF
C-----------------------------------------------------------------------------------------------------------------------

C-----------------------------------------------------------------------------------------------------------------------
C    *** ITS AN ITERATIVE CALL TO THIS COMPONENT ***
C-----------------------------------------------------------------------------------------------------------------------


C-----------------------------------------------------------------------------------------------------------------------
C    RETRIEVE THE VALUES IN THE STORAGE ARRAY FOR THIS ITERATION
C      NITEMS=
C         CALL getStorageVars(STORED,NITEMS,INFO)
C      STORED(1)=
C-----------------------------------------------------------------------------------------------------------------------
C-----------------------------------------------------------------------------------------------------------------------
C    CHECK THE INPUTS FOR PROBLEMS
C      IF(...) CALL TYPECK(-3,INFO,'BAD INPUT #',0,0)
C         IF(IERROR.GT.0) RETURN 1
C-----------------------------------------------------------------------------------------------------------------------
C-----------------------------------------------------------------------------------------------------------------------
C    *** PERFORM ALL THE CALCULATION HERE FOR THIS MODEL. ***
C-----------------------------------------------------------------------------------------------------------------------

C                   ADD YOUR COMPONENT EQUATIONS HERE; BASICALLY THE EQUATIONS THAT WILL
C                   CALCULATE THE OUTPUTS BASED ON THE PARAMETERS AND THE INPUTS. REFER TO
C                   CHAPTER 3 OF THE TRNSYS VOLUME 1 MANUAL FOR DETAILED INFORMATION ON
C                   WRITING TRNSYS COMPONENTS.



C    INPUTS
      !DOUBLE PRECISION FLOOR_TEMP
      !DOUBLE PRECISION TANK_TEMP
      !DOUBLE PRECISION SET_TEMP

C    OUTPUTS
          !DOUBLE PRECISION X           -> 0:Bypass tank, 1:All flow through tank
          !DOUBLE PRECISION FOO
          !DOUBLE PRECISION BAR
```

```
          X = 0.0
          FOO = 0.0
          BAR = 0.0


          IF (FLOOR_TEMP == TANK_TEMP) THEN
                    X = 0.0
          ELSEIF (TANK_TEMP > FLOOR_TEMP) THEN
                    IF (FLOOR_TEMP >= SET_TEMP) THEN
                              X = 0.0
                    ELSEIF (TANK_TEMP <= SET_TEMP) THEN
                              X = 1.0
                    ELSE
                              X = (SET_TEMP - FLOOR_TEMP) / (TANK_TEMP - FLOOR_TEMP)
                    ENDIF
          ELSE
          !TANK_TEMP < FLOOR_TEMP
                    X = 0.0
          ENDIF

          !X = X * 1000.0
          !X = FLOOR(X)
          !X = X / 1000.0


C-----------------------------------------------------------------------------------------------------------------------

C-----------------------------------------------------------------------------------------------------------------------
C-----------------------------------------------------------------------------------------------------------------------
C    SET THE STORAGE ARRAY AT THE END OF THIS ITERATION IF NECESSARY
C      NITEMS=
C      STORED(1)=
C         CALL setStorageVars(STORED,NITEMS,INFO)
C-----------------------------------------------------------------------------------------------------------------------
C-----------------------------------------------------------------------------------------------------------------------
C    REPORT ANY PROBLEMS THAT HAVE BEEN FOUND USING CALLS LIKE THIS:
C      CALL MESSAGES(-1,'put your message here','MESSAGE',IUNIT,ITYPE)
C      CALL MESSAGES(-1,'put your message here','WARNING',IUNIT,ITYPE)
C      CALL MESSAGES(-1,'put your message here','SEVERE',IUNIT,ITYPE)
C      CALL MESSAGES(-1,'put your message here','FATAL',IUNIT,ITYPE)
C-----------------------------------------------------------------------------------------------------------------------
C-----------------------------------------------------------------------------------------------------------------------
C    SET THE OUTPUTS FROM THIS MODEL IN SEQUENTIAL ORDER AND GET OUT

C                    X
                              OUT(1)= X
C                    FOO
                              OUT(2)= FOO
C                    BAR
                              OUT(3)= BAR

C-----------------------------------------------------------------------------------------------------------------------
C    EVERYTHING IS DONE - RETURN FROM THIS SUBROUTINE AND MOVE ON
      RETURN 1
      END
C-----------------------------------------------------------------------------------------------------------------------
```

B.6 TYPE 270 – SH-Signal

This TRNSYS proforma calculates the appropriate signal and flow rate for the hydronic-floor space heating system.

Table B.18: TYPE 270 - Parameters

Number	Name	Description
1	R_FLOOR	Thermal resistance of the floor [m² K/W]
2	CP	Specific heat of hydronic-floor fluid [kJ/kg-K]
3	DTEMP_SET	Desired room temperature set point [°C] This parameter was not used. For simulations it was assigned a value of 0.
4	TIN_SET	Set point temperature of the fluid supplied to the hydronic-floor [°C]
5	A_HEATED	Heated floor area of the house [m²]
6	FLOW_MAX	Maximum flow rate of the variable speed pump [kg/hr]

Table B.19: TYPE 270 - Inputs

Number	Name	Description
1	Q_SH_KW	Space heating load [kW]
2	T_ROOM	Room temperature [°C]
3	FOO_IN	Extra input for debugging
4	BAR_IN	Extra input for debugging

Table B.20: TYPE 270 - Outputs

Number	Name	Description
1	PUMP_SIGNAL	Signal to variable speed pump
2	TIN_IDEAL	Calculated fluid supply temperature to hydronic-floor [°C]
3	TOUT_IDEAL	Calculated fluid return temperature from hydronic-floor [°C]
4	FLOW_IDEAL	Calculated flow rate [kg/hr]
5	FOO_OUT	Extra output for debugging
6	BAR_OUT	Extra output for debugging

Derivatives: None

Table B.21: TYPE 270 - FORTRAN Code

```
                               SUBROUTINE TYPE270 (TIME,XIN,OUT,T,DTDT,PAR,INFO,ICNTRL,*)
C************************************************************************
C Object: SH-Signal
C Simulation Studio Model: Type270-SH-Signal
C
C Author:
C Editor:
C Date:     August 02, 2011 last modified: August 02, 2011
C
```

```
C
C ***
C *** Model Parameters
C ***
C                              R_FLOOR   - [-Inf;+Inf]
C                              CP        - [-Inf;+Inf]
C                              DTEMP_SET - [-Inf;+Inf]
C                              TIN_SET   - [-Inf;+Inf]
C                              A_HEATED  - [-Inf;+Inf]
C                              FLOW_MAX  - [-Inf;+Inf]

C ***
C *** Model Inputs
C ***
C                              Q_SH_KW   - [-Inf;+Inf]
C                              T_ROOM    - [-Inf;+Inf]
C                              FOO_IN    - [-Inf;+Inf]
C                              BAR_IN    - [-Inf;+Inf]

C ***
C *** Model Outputs
C ***
C                              PUMP_SIGNAL          - [-Inf;+Inf]
C                              TIN_IDEAL - [-Inf;+Inf]
C                              TOUT_IDEAL- [-Inf;+Inf]
C                              FLOW_IDEAL- [-Inf;+Inf]
C                              FOO_OUT   - [-Inf;+Inf]
C                              BAR_OUT   - [-Inf;+Inf]

C ***
C *** Model Derivatives
C ***

C (Comments and routine interface generated by TRNSYS Studio)
C************************************************************************

C    TRNSYS acess functions (allow to acess TIME etc.)
      USE TrnsysConstants
      USE TrnsysFunctions

C-----------------------------------------------------------------------------------------------------------------------
C    REQUIRED BY THE MULTI-DLL VERSION OF TRNSYS
      !DEC$ATTRIBUTES DLLEXPORT :: TYPE270                                        !SET THE CORRECT TYPE NUMBER HERE
C-----------------------------------------------------------------------------------------------------------------------
C-----------------------------------------------------------------------------------------------------------------------
C    TRNSYS DECLARATIONS
      IMPLICIT NONE                      !REQUIRES THE USER TO DEFINE ALL VARIABLES BEFORE USING THEM

          DOUBLE PRECISION XIN !THE ARRAY FROM WHICH THE INPUTS TO THIS TYPE WILL BE RETRIEVED
          DOUBLE PRECISION OUT !THE ARRAY WHICH WILL BE USED TO STORE THE OUTPUTS FROM THIS TYPE
          DOUBLE PRECISION TIME          !THE CURRENT SIMULATION TIME - YOU MAY USE THIS VARIABLE BUT DO NOT SET IT!
          DOUBLE PRECISION PAR !THE ARRAY FROM WHICH THE PARAMETERS FOR THIS TYPE WILL BE RETRIEVED
          DOUBLE PRECISION STORED !THE STORAGE ARRAY FOR HOLDING VARIABLES FROM TIMESTEP TO TIMESTEP
          DOUBLE PRECISION T             !AN ARRAY CONTAINING THE RESULTS FROM THE DIFFERENTIAL EQUATION SOLVER
          DOUBLE PRECISION DTDT          !AN ARRAY CONTAINING THE DERIVATIVES TO BE PASSED TO THE DIFF.EQ. SOLVER
          INTEGER*4 INFO(15)             !THE INFO ARRAY STORES AND PASSES VALUABLE INFORMATION TO AND FROM THIS TYPE
          INTEGER*4 NP,NI,NOUT,ND        !VARIABLES FOR THE MAXIMUM NUMBER OF PARAMETERS,INPUTS,OUTPUTS AND DERIVATIVES
          INTEGER*4 NPAR,NIN,NDER        !VARIABLES FOR THE CORRECT NUMBER OF PARAMETERS,INPUTS,OUTPUTS AND DERIVATIVES
          INTEGER*4 IUNIT,ITYPE          !THE UNIT NUMBER AND TYPE NUMBER FOR THIS COMPONENT
          INTEGER*4 ICNTRL               !AN ARRAY FOR HOLDING VALUES OF CONTROL FUNCTIONS WITH THE NEW SOLVER
          INTEGER*4 NSTORED              !THE NUMBER OF VARIABLES THAT WILL BE PASSED INTO AND OUT OF STORAGE
          CHARACTER*3 OCHECK             !AN ARRAY TO BE FILLED WITH THE CORRECT VARIABLE TYPES FOR THE OUTPUTS
          CHARACTER*3 YCHECK             !AN ARRAY TO BE FILLED WITH THE CORRECT VARIABLE TYPES FOR THE INPUTS
C-----------------------------------------------------------------------------------------------------------------------

C-----------------------------------------------------------------------------------------------------------------------
C    USER DECLARATIONS - SET THE MAXIMUM NUMBER OF PARAMETERS (NP), INPUTS (NI),
```

```
C    OUTPUTS (NOUT), AND DERIVATIVES (ND) THAT MAY BE SUPPLIED FOR THIS TYPE
      PARAMETER (NP=6,NI=4,NOUT=6,ND=0,NSTORED=0)
C----------------------------------------------------------------------------------------------------------------------

C----------------------------------------------------------------------------------------------------------------------
C    REQUIRED TRNSYS DIMENSIONS
      DIMENSION XIN(NI),OUT(NOUT),PAR(NP),YCHECK(NI),OCHECK(NOUT),
          1   STORED(NSTORED),T(ND),DTDT(ND)
      INTEGER NITEMS
C----------------------------------------------------------------------------------------------------------------------
C----------------------------------------------------------------------------------------------------------------------
C    ADD DECLARATIONS AND DEFINITIONS FOR THE USER-VARIABLES HERE


C    PARAMETERS
      DOUBLE PRECISION R_FLOOR
      DOUBLE PRECISION CP
      DOUBLE PRECISION DTEMP_SET
      DOUBLE PRECISION TIN_SET
      DOUBLE PRECISION A_HEATED
      DOUBLE PRECISION FLOW_MAX

C    INPUTS
      DOUBLE PRECISION Q_SH_KW
      DOUBLE PRECISION T_ROOM
      DOUBLE PRECISION FOO_IN
      DOUBLE PRECISION BAR_IN

C    OUTPUTS
          DOUBLE PRECISION PUMP_SIGNAL
          DOUBLE PRECISION TIN_IDEAL
          DOUBLE PRECISION TOUT_IDEAL
          DOUBLE PRECISION FLOW_IDEAL
          DOUBLE PRECISION FOO_OUT
          DOUBLE PRECISION BAR_OUT

C    LOCAL
          DOUBLE PRECISION Q_TOT
          DOUBLE PRECISION T_SUR
          DOUBLE PRECISION T_AVE
          DOUBLE PRECISION LMTD
          DOUBLE PRECISION M_DOT
          DOUBLE PRECISION TEMP


C----------------------------------------------------------------------------------------------------------------------
C       READ IN THE VALUES OF THE PARAMETERS IN SEQUENTIAL ORDER
      R_FLOOR=PAR(1)
      CP=PAR(2)
      DTEMP_SET=PAR(3)
      TIN_SET=PAR(4)
      A_HEATED=PAR(5)
      FLOW_MAX=PAR(6)

C----------------------------------------------------------------------------------------------------------------------
C    RETRIEVE THE CURRENT VALUES OF THE INPUTS TO THIS MODEL FROM THE XIN ARRAY IN SEQUENTIAL ORDER

      Q_SH_KW=XIN(1)
      T_ROOM=XIN(2)
      FOO_IN=XIN(3)
      BAR_IN=XIN(4)
             IUNIT=INFO(1)
             ITYPE=INFO(2)

C----------------------------------------------------------------------------------------------------------------------
C    SET THE VERSION INFORMATION FOR TRNSYS
      IF(INFO(7).EQ.-2) THEN
```

```
             INFO(12)=16
             RETURN 1
          ENDIF
C---------------------------------------------------------------------------------------------------------------------

C---------------------------------------------------------------------------------------------------------------------
C    DO ALL THE VERY LAST CALL OF THE SIMULATION MANIPULATIONS HERE
      IF (INFO(8).EQ.-1) THEN
             RETURN 1
          ENDIF
C---------------------------------------------------------------------------------------------------------------------

C---------------------------------------------------------------------------------------------------------------------
C    PERFORM ANY 'AFTER-ITERATION' MANIPULATIONS THAT ARE REQUIRED HERE
C    e.g. save variables to storage array for the next timestep
      IF (INFO(13).GT.0) THEN
             NITEMS=0
C            STORED(1)=...  (if NITEMS > 0)
C        CALL setStorageVars(STORED,NITEMS,INFO)
             RETURN 1
          ENDIF
C
C---------------------------------------------------------------------------------------------------------------------

C---------------------------------------------------------------------------------------------------------------------
C    DO ALL THE VERY FIRST CALL OF THE SIMULATION MANIPULATIONS HERE
      IF (INFO(7).EQ.-1) THEN

C       SET SOME INFO ARRAY VARIABLES TO TELL THE TRNSYS ENGINE HOW THIS TYPE IS TO WORK
         INFO(6)=NOUT
         INFO(9)=1
             INFO(10)=0        !STORAGE FOR VERSION 16 HAS BEEN CHANGED

C       SET THE REQUIRED NUMBER OF INPUTS, PARAMETERS AND DERIVATIVES THAT THE USER SHOULD SUPPLY IN THE INPUT FILE
C       IN SOME CASES, THE NUMBER OF VARIABLES MAY DEPEND ON THE VALUE OF PARAMETERS TO THIS MODEL....
         NIN=NI
             NPAR=NP
             NDER=ND

C       CALL THE TYPE CHECK SUBROUTINE TO COMPARE WHAT THIS COMPONENT REQUIRES TO WHAT IS SUPPLIED IN
C       THE TRNSYS INPUT FILE
             CALL TYPECK(1,INFO,NIN,NPAR,NDER)

C       SET THE NUMBER OF STORAGE SPOTS NEEDED FOR THIS COMPONENT
         NITEMS=0
C            CALL setStorageSize(NITEMS,INFO)

C       RETURN TO THE CALLING PROGRAM
         RETURN 1

      ENDIF
C---------------------------------------------------------------------------------------------------------------------

C---------------------------------------------------------------------------------------------------------------------
C    DO ALL OF THE INITIAL TIMESTEP MANIPULATIONS HERE - THERE ARE NO ITERATIONS AT THE INTIAL TIME
      IF (TIME .LT. (getSimulationStartTime() +
     . getSimulationTimeStep()/2.D0)) THEN

C       SET THE UNIT NUMBER FOR FUTURE CALLS
         IUNIT=INFO(1)
         ITYPE=INFO(2)

C       CHECK THE PARAMETERS FOR PROBLEMS AND RETURN FROM THE SUBROUTINE IF AN ERROR IS FOUND
C         IF(...) CALL TYPECK(-4,INFO,0,"BAD PARAMETER #",0)

C       PERFORM ANY REQUIRED CALCULATIONS TO SET THE INITIAL VALUES OF THE OUTPUTS HERE
C                    PUMP_SIGNAL
```

```
                               OUT(1)=0
C                     TIN_IDEAL
                               OUT(2)=0
C                     TOUT_IDEAL
                               OUT(3)=0
C                     FLOW_IDEAL
                               OUT(4)=0
C                     FOO_OUT
                               OUT(5)=0
C                     BAR_OUT
                               OUT(6)=0

C       PERFORM ANY REQUIRED CALCULATIONS TO SET THE INITIAL STORAGE VARIABLES HERE
         NITEMS=0
C            STORED(1)=...

C       PUT THE STORED ARRAY IN THE GLOBAL STORED ARRAY
C         CALL setStorageVars(STORED,NITEMS,INFO)

C       RETURN TO THE CALLING PROGRAM
         RETURN 1

      ENDIF
C-----------------------------------------------------------------------------------------------------------------------

C-----------------------------------------------------------------------------------------------------------------------
C    *** ITS AN ITERATIVE CALL TO THIS COMPONENT ***
C-----------------------------------------------------------------------------------------------------------------------


C-----------------------------------------------------------------------------------------------------------------------
C    RETRIEVE THE VALUES IN THE STORAGE ARRAY FOR THIS ITERATION
C      NITEMS=
C         CALL getStorageVars(STORED,NITEMS,INFO)
C      STORED(1)=
C-----------------------------------------------------------------------------------------------------------------------
C-----------------------------------------------------------------------------------------------------------------------
C    CHECK THE INPUTS FOR PROBLEMS
C      IF(...) CALL TYPECK(-3,INFO,'BAD INPUT #',0,0)
C         IF(IERROR.GT.0) RETURN 1
C-----------------------------------------------------------------------------------------------------------------------
C-----------------------------------------------------------------------------------------------------------------------
C    *** PERFORM ALL THE CALCULATION HERE FOR THIS MODEL. ***
C-----------------------------------------------------------------------------------------------------------------------

C                    ADD YOUR COMPONENT EQUATIONS HERE; BASICALLY THE EQUATIONS THAT WILL
C                    CALCULATE THE OUTPUTS BASED ON THE PARAMETERS AND THE INPUTS. REFER TO
C                    CHAPTER 3 OF THE TRNSYS VOLUME 1 MANUAL FOR DETAILED INFORMATION ON
C                    WRITING TRNSYS COMPONENTS.


C    PARAMETERS
      !DOUBLE PRECISION R_FLOOR
      !DOUBLE PRECISION CP
      !DOUBLE PRECISION DTEMP_SET
      !DOUBLE PRECISION TIN_SET
      !DOUBLE PRECISION A_HEATED
      !DOUBLE PRECISION FLOW_MAX

C    INPUTS
      !DOUBLE PRECISION Q_SH_KW
      !DOUBLE PRECISION T_ROOM
      !DOUBLE PRECISION FOO_IN
      !DOUBLE PRECISION BAR_IN

C    OUTPUTS
          !DOUBLE PRECISION PUMP_SIGNAL
```

```
          !DOUBLE PRECISION TIN_IDEAL
          !DOUBLE PRECISION TOUT_IDEAL
          !DOUBLE PRECISION FLOW_IDEAL
          !DOUBLE PRECISION FOO_OUT
          !DOUBLE PRECISION BAR_OUT

C    LOCAL
          !DOUBLE PRECISION Q_TOT
          !DOUBLE PRECISION T_SUR
          !DOUBLE PRECISION T_AVE
          !DOUBLE PRECISION LMTD
          !DOUBLE PRECISION M_DOT
          !DOUBLE PRECISION TEMP

          PUMP_SIGNAL = 0.0
          TIN_IDEAL = T_ROOM
          TOUT_IDEAL = T_ROOM
          FLOW_IDEAL = 0.0
          FOO_OUT = 0.0
          BAR_OUT = 0.0
          Q_TOT = 0.0
          T_SUR = T_ROOM
          T_AVE = T_ROOM
          LMTD = 0.0
          M_DOT = 0.0
          TEMP = 0.0


          IF (Q_SH_KW < 0.001) THEN
                    PUMP_SIGNAL = 0.0
                    TIN_IDEAL = T_ROOM
                    TOUT_IDEAL = T_ROOM
                    FLOW_IDEAL = 0.0

          ELSE
                    Q_TOT = Q_SH_KW *1000.0 / A_HEATED

                    T_SUR = (2.0 * 10.0 ** (-7.0))*(Q_TOT ** 3.0)
                    T_SUR = T_SUR - (0.0002 * Q_TOT ** 2.0)
                    T_SUR = T_SUR + (0.1183 * Q_TOT) + 20.0

                    LMTD = Q_TOT * R_FLOOR

                    T_AVE = T_SUR + LMTD

          !DEFAULT IS FIXED INLET TEMPERATURE
                    IF (TIN_SET > 0.0) THEN
                              TIN_IDEAL = TIN_SET
                              TOUT_IDEAL = TIN_IDEAL - 2.0 * (TIN_IDEAL - T_AVE)
                              M_DOT = Q_SH_KW * 3600.0 / CP / (TIN_IDEAL - TOUT_IDEAL)

                              IF (TOUT_IDEAL < T_ROOM) THEN
                                        TOUT_IDEAL = T_ROOM
                                        M_DOT = Q_SH_KW*3600.0 / CP / (TIN_IDEAL - TOUT_IDEAL)
                              ENDIF

                              IF (M_DOT > FLOW_MAX) THEN
                                        M_DOT = FLOW_MAX
                                        TEMP = Q_SH_KW * 3600.0 / CP / M_DOT

                                        TIN_IDEAL = T_AVE + (TEMP/ 2.0)
                                        TOUT_IDEAL = T_AVE - (TEMP / 2.0)
                                        M_DOT = Q_SH_KW * 3600.0 / CP / (TIN_IDEAL - TOUT_IDEAL)

                                        IF (TOUT_IDEAL < T_ROOM) THEN
                                                  TOUT_IDEAL = T_ROOM
                                                  TIN_IDEAL = TOUT_IDEAL + 2.0 * (T_AVE - TOUT_IDEAL)
```

```
                                        M_DOT = Q_SH_KW*3600.0 / CP / (TIN_IDEAL - TOUT_IDEAL)
                              ENDIF

                              IF (M_DOT > FLOW_MAX) THEN
                                        M_DOT = FLOW_MAX
                                        TIN_IDEAL = TOUT_IDEAL + (Q_SH_KW*3600.0 / CP / M_DOT)
                              ENDIF

                    ENDIF

                    PUMP_SIGNAL = M_DOT / FLOW_MAX
                    FLOW_IDEAL = M_DOT

          ELSEIF (DTEMP_SET > T_ROOM) THEN
                    TIN_IDEAL = T_AVE + (DTEMP_SET / 2.0)
                    TOUT_IDEAL = T_AVE - (DTEMP_SET / 2.0)
                    M_DOT = Q_SH_KW * 3600.0 / CP / (TIN_IDEAL - TOUT_IDEAL)

                    IF (TOUT_IDEAL < T_ROOM) THEN
                              TOUT_IDEAL = T_ROOM
                              TIN_IDEAL = TOUT_IDEAL + 2.0 * (T_AVE - TOUT_IDEAL)
                              M_DOT = Q_SH_KW*3600.0 / CP / (TIN_IDEAL - TOUT_IDEAL)
                    ENDIF

                    IF (M_DOT > FLOW_MAX) THEN
                              M_DOT = FLOW_MAX
                              TIN_IDEAL = TOUT_IDEAL + (Q_SH_KW*3600.0 / CP / M_DOT)
                    ENDIF

                    PUMP_SIGNAL = M_DOT / FLOW_MAX
                    FLOW_IDEAL = M_DOT

          ELSE

                    PUMP_SIGNAL = 0.0
                    TIN_IDEAL = T_ROOM
                    TOUT_IDEAL = T_ROOM
                    FLOW_IDEAL = 0.0
          ENDIF


ENDIF







C-----------------------------------------------------------------------------------------------------------------------

C-----------------------------------------------------------------------------------------------------------------------
C-----------------------------------------------------------------------------------------------------------------------
C    SET THE STORAGE ARRAY AT THE END OF THIS ITERATION IF NECESSARY
C      NITEMS=
C      STORED(1)=
C         CALL setStorageVars(STORED,NITEMS,INFO)
C-----------------------------------------------------------------------------------------------------------------------
C-----------------------------------------------------------------------------------------------------------------------
C    REPORT ANY PROBLEMS THAT HAVE BEEN FOUND USING CALLS LIKE THIS:
C      CALL MESSAGES(-1,'put your message here','MESSAGE',IUNIT,ITYPE)
C      CALL MESSAGES(-1,'put your message here','WARNING',IUNIT,ITYPE)
C      CALL MESSAGES(-1,'put your message here','SEVERE',IUNIT,ITYPE)
C      CALL MESSAGES(-1,'put your message here','FATAL',IUNIT,ITYPE)
C-----------------------------------------------------------------------------------------------------------------------
C-----------------------------------------------------------------------------------------------------------------------
```

```
C    SET THE OUTPUTS FROM THIS MODEL IN SEQUENTIAL ORDER AND GET OUT

C                    PUMP_SIGNAL
                              OUT(1)= PUMP_SIGNAL
C                    TIN_IDEAL
                              OUT(2)= TIN_IDEAL
C                    TOUT_IDEAL
                              OUT(3)= TOUT_IDEAL
C                    FLOW_IDEAL
                              OUT(4)= FLOW_IDEAL
C                    FOO_OUT
                              OUT(5)= FOO_OUT
C                    BAR_OUT
                              OUT(6)= BAR_OUT

C-----------------------------------------------------------------------------------------------------------------------
C    EVERYTHING IS DONE - RETURN FROM THIS SUBROUTINE AND MOVE ON
      RETURN 1
      END
C-----------------------------------------------------------------------------------------------------------------------
```

B.7 TYPE 271 – HydronicFloor3

This TRNSYS proforma simulates the performance of a hydronically heated floor.

Table B.22: TYPE 271 - Parameters

Number	Name	Description
1	CP	Specific heat of hydronic-floor fluid [kJ/kg-K]
2	R_FLOOR	Thermal resistance of the floor [m² K/W]
3	A_HEATED	Heated floor area of the house [m²]
4	FLOW_MAX	Maximum flow rate of the variable speed pump [kg/hr]
5	DTEMP_SET	Desired room temperature set point [°C] This parameter was not used. For simulations it was assigned a value of 0.
6	TIN_SET	Set point temperature of the fluid supplied to the hydronic-floor [°C]

Table B.23: TYPE 271 - Inputs

Number	Name	Description
1	FLOW_IN	Flow rate of fluid through the hydronic-floor [kg/hr]
2	TEMP_IN	Fluid temperature of fluid supplied to the hydronic-floor [°C]
3	T_ROOM	Room temperature [°C]
4	Q_SH_KW	Space heating load [kW]
5	IDEAL_FLOW	Calculated flow rate (from TYPE270) [kg/hr]
6	IDEAL_TIN	Calculated fluid supply temperature to hydronic-floor (from TYPE270) [°C]
7	IDEAL_TOUT	Calculated fluid return temperature from hydronic-floor (from TYPE270) [°C]
8	FOO_IN	Extra input for debugging
9	BAR_IN	Extra input for debugging

Table B.24: TYPE 271 - Outputs

Number	Name	Description
1	Q_ACTUAL_KW	Actual heat transfer from hydronic-floor to room [kW]
2	TEMP_OUT	Outlet fluid temperature from hydronic-floor [°C]
3	FLOW_OUT	Flow rate of fluid through the hydronic-floor [kg/hr]
4	Q_ADD_KW	Deficit in energy required to maintain room temperature [kW]
5	FOO_OUT	Extra output for debugging
6	BAR_OUT	Extra output for debugging

Derivatives: None

Table B.25: TYPE 271 - FORTRAN Code

```
                               SUBROUTINE TYPE271 (TIME,XIN,OUT,T,DTDT,PAR,INFO,ICNTRL,*)
C************************************************************************
C Object: HydronicFloor
C Simulation Studio Model: Type271-HydronicFloor3
```

```
C
C Author:
C Editor:
C Date:    August 02, 2011 last modified: August 02, 2011
C
C
C ***
C *** Model Parameters
C ***
C                              CP        - [-Inf;+Inf]
C                              R_FLOOR   - [-Inf;+Inf]
C                              A_HEATED  - [-Inf;+Inf]
C                              FLOW_MAX  - [-Inf;+Inf]
C                              DTEMP_SET - [-Inf;+Inf]
C                              TIN_SET   - [-Inf;+Inf]

C ***
C *** Model Inputs
C ***
C                              FLOW_IN   - [-Inf;+Inf]
C                              TEMP_IN   - [-Inf;+Inf]
C                              T_ROOM    - [-Inf;+Inf]
C                              Q_SH_KW   - [-Inf;+Inf]
C                              IDEAL_FLOW- [-Inf;+Inf]
C                              IDEAL_TIN - [-Inf;+Inf]
C                              IDEAL_TOUT- [-Inf;+Inf]
C                              FOO_IN    - [-Inf;+Inf]
C                              BAR_IN    - [-Inf;+Inf]

C ***
C *** Model Outputs
C ***
C                              Q_ACTUAL_KW          - [-Inf;+Inf]
C                              TEMP_OUT  - [-Inf;+Inf]
C                              FLOW_OUT  - [-Inf;+Inf]
C                              Q_ADD_KW  - [-Inf;+Inf]
C                              FOO_OUT   - [-Inf;+Inf]
C                              BAR_OUT   - [-Inf;+Inf]

C ***
C *** Model Derivatives
C ***

C (Comments and routine interface generated by TRNSYS Studio)
C************************************************************************

C    TRNSYS acess functions (allow to acess TIME etc.)
      USE TrnsysConstants
      USE TrnsysFunctions

C-----------------------------------------------------------------------------------------------------------------------
C    REQUIRED BY THE MULTI-DLL VERSION OF TRNSYS
      !DEC$ATTRIBUTES DLLEXPORT :: TYPE271                                        !SET THE CORRECT TYPE NUMBER HERE
C-----------------------------------------------------------------------------------------------------------------------
C-----------------------------------------------------------------------------------------------------------------------
C    TRNSYS DECLARATIONS
      IMPLICIT NONE                      !REQUIRES THE USER TO DEFINE ALL VARIABLES BEFORE USING THEM

          DOUBLE PRECISION XIN !THE ARRAY FROM WHICH THE INPUTS TO THIS TYPE WILL BE RETRIEVED
          DOUBLE PRECISION OUT !THE ARRAY WHICH WILL BE USED TO STORE THE OUTPUTS FROM THIS TYPE
          DOUBLE PRECISION TIME          !THE CURRENT SIMULATION TIME - YOU MAY USE THIS VARIABLE BUT DO NOT SET IT!
          DOUBLE PRECISION PAR !THE ARRAY FROM WHICH THE PARAMETERS FOR THIS TYPE WILL BE RETRIEVED
          DOUBLE PRECISION STORED !THE STORAGE ARRAY FOR HOLDING VARIABLES FROM TIMESTEP TO TIMESTEP
          DOUBLE PRECISION T             !AN ARRAY CONTAINING THE RESULTS FROM THE DIFFERENTIAL EQUATION SOLVER
          DOUBLE PRECISION DTDT          !AN ARRAY CONTAINING THE DERIVATIVES TO BE PASSED TO THE DIFF.EQ. SOLVER
          INTEGER*4 INFO(15)             !THE INFO ARRAY STORES AND PASSES VALUABLE INFORMATION TO AND FROM THIS TYPE
          INTEGER*4 NP,NI,NOUT,ND        !VARIABLES FOR THE MAXIMUM NUMBER OF PARAMETERS,INPUTS,OUTPUTS AND DERIVATIVES
```

```
          INTEGER*4 NPAR,NIN,NDER        !VARIABLES FOR THE CORRECT NUMBER OF PARAMETERS,INPUTS,OUTPUTS AND DERIVATIVES
          INTEGER*4 IUNIT,ITYPE          !THE UNIT NUMBER AND TYPE NUMBER FOR THIS COMPONENT
          INTEGER*4 ICNTRL               !AN ARRAY FOR HOLDING VALUES OF CONTROL FUNCTIONS WITH THE NEW SOLVER
          INTEGER*4 NSTORED              !THE NUMBER OF VARIABLES THAT WILL BE PASSED INTO AND OUT OF STORAGE
          CHARACTER*3 OCHECK             !AN ARRAY TO BE FILLED WITH THE CORRECT VARIABLE TYPES FOR THE OUTPUTS
          CHARACTER*3 YCHECK             !AN ARRAY TO BE FILLED WITH THE CORRECT VARIABLE TYPES FOR THE INPUTS
C----------------------------------------------------------------------------------------------------------------------

C----------------------------------------------------------------------------------------------------------------------
C    USER DECLARATIONS - SET THE MAXIMUM NUMBER OF PARAMETERS (NP), INPUTS (NI),
C    OUTPUTS (NOUT), AND DERIVATIVES (ND) THAT MAY BE SUPPLIED FOR THIS TYPE
      PARAMETER (NP=6,NI=9,NOUT=6,ND=0,NSTORED=0)
C----------------------------------------------------------------------------------------------------------------------

C----------------------------------------------------------------------------------------------------------------------
C    REQUIRED TRNSYS DIMENSIONS
      DIMENSION XIN(NI),OUT(NOUT),PAR(NP),YCHECK(NI),OCHECK(NOUT),
          1   STORED(NSTORED),T(ND),DTDT(ND)
      INTEGER NITEMS
C----------------------------------------------------------------------------------------------------------------------
C----------------------------------------------------------------------------------------------------------------------
C    ADD DECLARATIONS AND DEFINITIONS FOR THE USER-VARIABLES HERE


C    PARAMETERS
      DOUBLE PRECISION CP
      DOUBLE PRECISION R_FLOOR
      DOUBLE PRECISION A_HEATED
      DOUBLE PRECISION FLOW_MAX
      DOUBLE PRECISION DTEMP_SET
      DOUBLE PRECISION TIN_SET

C    INPUTS
      DOUBLE PRECISION FLOW_IN
      DOUBLE PRECISION TEMP_IN
      DOUBLE PRECISION T_ROOM
      DOUBLE PRECISION Q_SH_KW
      DOUBLE PRECISION IDEAL_FLOW
      DOUBLE PRECISION IDEAL_TIN
      DOUBLE PRECISION IDEAL_TOUT
      DOUBLE PRECISION FOO_IN
      DOUBLE PRECISION BAR_IN

C    OUTPUTS
          DOUBLE PRECISION Q_ACTUAL_KW
          DOUBLE PRECISION TEMP_OUT
          DOUBLE PRECISION FLOW_OUT
          DOUBLE PRECISION Q_ADD_KW
          DOUBLE PRECISION FOO_OUT
          DOUBLE PRECISION BAR_OUT

C    LOCAL
          DOUBLE PRECISION FLOW_ABS
          DOUBLE PRECISION TEMP_ABS




C----------------------------------------------------------------------------------------------------------------------
C       READ IN THE VALUES OF THE PARAMETERS IN SEQUENTIAL ORDER
      CP=PAR(1)
      R_FLOOR=PAR(2)
      A_HEATED=PAR(3)
      FLOW_MAX=PAR(4)
      DTEMP_SET=PAR(5)
      TIN_SET=PAR(6)
```

```
C-----------------------------------------------------------------------------------------------------------------------
C    RETRIEVE THE CURRENT VALUES OF THE INPUTS TO THIS MODEL FROM THE XIN ARRAY IN SEQUENTIAL ORDER

      FLOW_IN=XIN(1)
      TEMP_IN=XIN(2)
      T_ROOM=XIN(3)
      Q_SH_KW=XIN(4)
      IDEAL_FLOW=XIN(5)
      IDEAL_TIN=XIN(6)
      IDEAL_TOUT=XIN(7)
      FOO_IN=XIN(8)
      BAR_IN=XIN(9)
             IUNIT=INFO(1)
             ITYPE=INFO(2)

C-----------------------------------------------------------------------------------------------------------------------
C    SET THE VERSION INFORMATION FOR TRNSYS
      IF(INFO(7).EQ.-2) THEN
             INFO(12)=16
             RETURN 1
          ENDIF
C-----------------------------------------------------------------------------------------------------------------------

C-----------------------------------------------------------------------------------------------------------------------
C    DO ALL THE VERY LAST CALL OF THE SIMULATION MANIPULATIONS HERE
      IF (INFO(8).EQ.-1) THEN
             RETURN 1
          ENDIF
C-----------------------------------------------------------------------------------------------------------------------

C-----------------------------------------------------------------------------------------------------------------------
C    PERFORM ANY 'AFTER-ITERATION' MANIPULATIONS THAT ARE REQUIRED HERE
C    e.g. save variables to storage array for the next timestep
      IF (INFO(13).GT.0) THEN
             NITEMS=0
C            STORED(1)=... (if NITEMS > 0)
C        CALL setStorageVars(STORED,NITEMS,INFO)
             RETURN 1
          ENDIF
C
C-----------------------------------------------------------------------------------------------------------------------

C-----------------------------------------------------------------------------------------------------------------------
C    DO ALL THE VERY FIRST CALL OF THE SIMULATION MANIPULATIONS HERE
      IF (INFO(7).EQ.-1) THEN

C       SET SOME INFO ARRAY VARIABLES TO TELL THE TRNSYS ENGINE HOW THIS TYPE IS TO WORK
         INFO(6)=NOUT
         INFO(9)=1
             INFO(10)=0        !STORAGE FOR VERSION 16 HAS BEEN CHANGED

C       SET THE REQUIRED NUMBER OF INPUTS, PARAMETERS AND DERIVATIVES THAT THE USER SHOULD SUPPLY IN THE INPUT FILE
C       IN SOME CASES, THE NUMBER OF VARIABLES MAY DEPEND ON THE VALUE OF PARAMETERS TO THIS MODEL....
         NIN=NI
             NPAR=NP
             NDER=ND

C       CALL THE TYPE CHECK SUBROUTINE TO COMPARE WHAT THIS COMPONENT REQUIRES TO WHAT IS SUPPLIED IN
C       THE TRNSYS INPUT FILE
             CALL TYPECK(1,INFO,NIN,NPAR,NDER)

C       SET THE NUMBER OF STORAGE SPOTS NEEDED FOR THIS COMPONENT
         NITEMS=0
C            CALL setStorageSize(NITEMS,INFO)

C       RETURN TO THE CALLING PROGRAM
         RETURN 1
```

```
      ENDIF
C-----------------------------------------------------------------------------------------------------------------------

C-----------------------------------------------------------------------------------------------------------------------
C    DO ALL OF THE INITIAL TIMESTEP MANIPULATIONS HERE - THERE ARE NO ITERATIONS AT THE INTIAL TIME
      IF (TIME .LT. (getSimulationStartTime() +
     . getSimulationTimeStep()/2.D0)) THEN

C       SET THE UNIT NUMBER FOR FUTURE CALLS
         IUNIT=INFO(1)
         ITYPE=INFO(2)

C       CHECK THE PARAMETERS FOR PROBLEMS AND RETURN FROM THE SUBROUTINE IF AN ERROR IS FOUND
C         IF(...) CALL TYPECK(-4,INFO,0,"BAD PARAMETER #",0)

C       PERFORM ANY REQUIRED CALCULATIONS TO SET THE INITIAL VALUES OF THE OUTPUTS HERE
C                    Q_ACTUAL_KW
                              OUT(1)=0
C                    TEMP_OUT
                              OUT(2)=0
C                    FLOW_OUT
                              OUT(3)=0
C                    Q_ADD_KW
                              OUT(4)=0
C                    FOO_OUT
                              OUT(5)=0
C                    BAR_OUT
                              OUT(6)=0

C       PERFORM ANY REQUIRED CALCULATIONS TO SET THE INITIAL STORAGE VARIABLES HERE
         NITEMS=0
C            STORED(1)=...

C       PUT THE STORED ARRAY IN THE GLOBAL STORED ARRAY
C         CALL setStorageVars(STORED,NITEMS,INFO)

C       RETURN TO THE CALLING PROGRAM
         RETURN 1

      ENDIF
C-----------------------------------------------------------------------------------------------------------------------

C-----------------------------------------------------------------------------------------------------------------------
C    *** ITS AN ITERATIVE CALL TO THIS COMPONENT ***
C-----------------------------------------------------------------------------------------------------------------------


C-----------------------------------------------------------------------------------------------------------------------
C    RETRIEVE THE VALUES IN THE STORAGE ARRAY FOR THIS ITERATION
C      NITEMS=
C          CALL getStorageVars(STORED,NITEMS,INFO)
C      STORED(1)=
C-----------------------------------------------------------------------------------------------------------------------
C-----------------------------------------------------------------------------------------------------------------------
C    CHECK THE INPUTS FOR PROBLEMS
C      IF(...) CALL TYPECK(-3,INFO,'BAD INPUT #',0,0)
C          IF(IERROR.GT.0) RETURN 1
C-----------------------------------------------------------------------------------------------------------------------
C-----------------------------------------------------------------------------------------------------------------------
C    *** PERFORM ALL THE CALCULATION HERE FOR THIS MODEL. ***
C-----------------------------------------------------------------------------------------------------------------------

C                   ADD YOUR COMPONENT EQUATIONS HERE; BASICALLY THE EQUATIONS THAT WILL
C                   CALCULATE THE OUTPUTS BASED ON THE PARAMETERS AND THE INPUTS. REFER TO
C                   CHAPTER 3 OF THE TRNSYS VOLUME 1 MANUAL FOR DETAILED INFORMATION ON
C                   WRITING TRNSYS COMPONENTS.
```

```
C    PARAMETERS
      !DOUBLE PRECISION CP
      !DOUBLE PRECISION R_FLOOR
      !DOUBLE PRECISION A_HEATED
      !DOUBLE PRECISION FLOW_MAX
      !DOUBLE PRECISION DTEMP_SET
      !DOUBLE PRECISION TIN_SET

C    INPUTS
      !DOUBLE PRECISION FLOW_IN
      !DOUBLE PRECISION TEMP_IN
      !DOUBLE PRECISION T_ROOM
      !DOUBLE PRECISION Q_SH_KW
      !DOUBLE PRECISION IDEAL_FLOW
      !DOUBLE PRECISION IDEAL_TIN
      !DOUBLE PRECISION IDEAL_TOUT
      !DOUBLE PRECISION FOO_IN
      !DOUBLE PRECISION BAR_IN

C    OUTPUTS
          !DOUBLE PRECISION Q_ACTUAL_KW
          !DOUBLE PRECISION TEMP_OUT
          !DOUBLE PRECISION FLOW_OUT
          !DOUBLE PRECISION Q_ADD_KW
          !DOUBLE PRECISION FOO_OUT
          !DOUBLE PRECISION BAR_OUT

C    LOCAL
          !DOUBLE PRECISION FLOW_ABS
          !DOUBLE PRECISION TEMP_ABS

          Q_ACTUAL_KW = 0.0
          TEMP_OUT = T_ROOM
          FLOW_OUT = FLOW_IN
          Q_ADD_KW = 0.0
          FOO_OUT = 0.0
          BAR_OUT = 0.0

          FLOW_ABS = ABS(FLOW_IN - IDEAL_FLOW)
          TEMP_ABS = ABS(TEMP_IN - IDEAL_TIN)

          BAR_OUT = TEMP_IN - IDEAL_TIN


          IF (Q_SH_KW < 0.001) THEN
                    Q_ACTUAL_KW = 0.0
                    TEMP_OUT = TEMP_IN
                    FLOW_OUT = FLOW_IN
                    Q_ADD_KW = 0.0

                    BAR_OUT = 0.0

          ELSEIF ((FLOW_ABS < 0.01) .AND. (TEMP_ABS < 0.001)) THEN
          !         TEMP_OUT = IDEAL_TOUT
          !         FLOW_OUT = FLOW_IN
          !         Q_ACTUAL_KW = FLOW_IN * CP * (TEMP_IN - TEMP_OUT) / 3600.0
          !         Q_ADD_KW = Q_SH_KW - Q_ACTUAL_KW

                    FLOW_OUT = FLOW_IN
                    Q_ACTUAL_KW = Q_SH_KW
                    Q_ADD_KW = 0.0
                    TEMP_OUT  = TEMP_IN - (Q_SH_KW * 3600.0 / FLOW_IN / CP)

          ELSEIF (TEMP_IN > IDEAL_TIN) THEN
                    FLOW_OUT = FLOW_IN
```

```
                     Q_ACTUAL_KW = Q_SH_KW
                     Q_ADD_KW = 0.0
                     TEMP_OUT  = TEMP_IN - (Q_SH_KW * 3600.0 / FLOW_IN / CP)


          ELSE
                     Q_ACTUAL_KW = 0.0
                     TEMP_OUT = IDEAL_TOUT
                     FLOW_OUT = FLOW_IN
                     Q_ADD_KW = 0.0
                     FOO_OUT = 1.0
          ENDIF





C-----------------------------------------------------------------------------------------------------------------------

C-----------------------------------------------------------------------------------------------------------------------
C-----------------------------------------------------------------------------------------------------------------------
C    SET THE STORAGE ARRAY AT THE END OF THIS ITERATION IF NECESSARY
C      NITEMS=
C      STORED(1)=
C         CALL setStorageVars(STORED,NITEMS,INFO)
C-----------------------------------------------------------------------------------------------------------------------
C-----------------------------------------------------------------------------------------------------------------------
C    REPORT ANY PROBLEMS THAT HAVE BEEN FOUND USING CALLS LIKE THIS:
C      CALL MESSAGES(-1,'put your message here','MESSAGE',IUNIT,ITYPE)
C      CALL MESSAGES(-1,'put your message here','WARNING',IUNIT,ITYPE)
C      CALL MESSAGES(-1,'put your message here','SEVERE',IUNIT,ITYPE)
C      CALL MESSAGES(-1,'put your message here','FATAL',IUNIT,ITYPE)
C-----------------------------------------------------------------------------------------------------------------------
C-----------------------------------------------------------------------------------------------------------------------
C    SET THE OUTPUTS FROM THIS MODEL IN SEQUENTIAL ORDER AND GET OUT

C                     Q_ACTUAL_KW
                               OUT(1)= Q_ACTUAL_KW
C                     TEMP_OUT
                               OUT(2)= TEMP_OUT
C                     FLOW_OUT
                               OUT(3)= FLOW_OUT
C                     Q_ADD_KW
                               OUT(4)= Q_ADD_KW
C                     FOO_OUT
                               OUT(5)= FOO_OUT
C                     BAR_OUT
                               OUT(6)= BAR_OUT

C-----------------------------------------------------------------------------------------------------------------------
C    EVERYTHING IS DONE - RETURN FROM THIS SUBROUTINE AND MOVE ON
      RETURN 1
      END
C-----------------------------------------------------------------------------------------------------------------------
```

B.8 TYPE 289 – NCHX

In conjunction with TRNSYS proforma TYPE 293 – NCHXFlow, this proforma models the performance of a natural convection heat exchanger.

Table B.26: TYPE 289 - Parameters

Number	Name	Description
1	CP_HOT	Specific heat of the hot side fluid [kJ/kg K]
2	CP_COLD	Specific heat of the cold side fluid [kJ/kg K]
3	C	Modified effectiveness coefficient c, where: $\varepsilon_{mod} = c * C_{ratio\,mod}^2 + d * C_{ratio\,mod} + e$
4	D	Modified effectiveness coefficient d, where: $\varepsilon_{mod} = c * C_{ratio\,mod}^2 + d * C_{ratio\,mod} + e$
5	E	Modified effectiveness coefficient e, where: $\varepsilon_{mod} = c * C_{ratio\,mod}^2 + d * C_{ratio\,mod} + e$

Table B.27: TYPE 289 - Inputs

Number	Name	Description
1	THOT_IN	Hot-side inlet temperature [°C]
2	FHOT_IN	Hot-side inlet flow rate [kg/hr]
3	TCOLD_IN	Cold-side inlet temperature [°C]
4	FCOLD_IN	Cold-side inlet flow rate [kg/hr]
5	T_AMB	Ambient temperature [°C]
6	TEMP_START	Hot-side temperature require to start natural convection (cold-side) flow [°C]
7	FLOW_START	Natural convection (cold-side) start-up flow rate [kg/hr]
8	FOO_IN	Extra input for debugging
9	BAR_IN	Extra input for debugging

Table B.28: TYPE 289 - Outputs

Number	Name	Description
1	THOT_OUT	Hot-side outlet temperature [°C]
2	FHOT_OUT	Hot-side outlet flow rate [kg/hr]
3	TCOLD_OUT	Cold-side outlet temperature [°C]
4	FCOLD_OUT	Cold-side outlet flow rate [kg/hr]
5	THX_AVE	Average HX temperature [°C]
6	QT_KJH	Heat transfer rate across HX [kJ/hr]
7	QT_KW	Heat transfer rate across HX [kW]
8	EFF_MOD	Modified effectiveness (QT / (CR_HOT * (D_TEMP)))
9	EFF	Effectiveness (QT / (min(CR_HOT, CR_COLD) * (D_TEMP)))
10	FOO_OUT	Extra output for debugging
11	BAR_OUT	Extra output for debugging

Derivatives: None

Table B.29: TYPE 289 - FORTRAN Code

```
                              SUBROUTINE TYPE289 (TIME,XIN,OUT,T,DTDT,PAR,INFO,ICNTRL,*)
C***********************************************************************
C Object: NCHX
C Simulation Studio Model: Type289-NCHX
C
C Author:
C Editor:
C Date:    July 14, 2011 last modified: July 14, 2011
C
C
C ***
C *** Model Parameters
C ***
C                             CP_HOT    - [-Inf;+Inf]
C                             CP_COLD   - [-Inf;+Inf]
C                             C         - [-Inf;+Inf]
C                             D         - [-Inf;+Inf]
C                             E         - [-Inf;+Inf]

C ***
C *** Model Inputs
C ***
C                             THOT_IN   - [-Inf;+Inf]
C                             FHOT_IN   - [-Inf;+Inf]
C                             TCOLD_IN  - [-Inf;+Inf]
C                             FCOLD_IN  - [-Inf;+Inf]
C                             T_AMB     - [-Inf;+Inf]
C                             TEMP_START- [-Inf;+Inf]
C                             FLOW_START- [-Inf;+Inf]
C                             FOO_IN    - [-Inf;+Inf]
C                             BAR_IN    - [-Inf;+Inf]

C ***
C *** Model Outputs
C ***
C                             THOT_OUT  - [-Inf;+Inf]
C                             FHOT_OUT  - [-Inf;+Inf]
C                             TCOLD_OUT - [-Inf;+Inf]
C                             FCOLD_OUT - [-Inf;+Inf]
C                             THX_AVE   - [-Inf;+Inf]
C                             QT_KJH    - [-Inf;+Inf]
C                             QT_KW     - [-Inf;+Inf]
C                             EFF_MOD   - [-Inf;+Inf]
C                             EFF       - [-Inf;+Inf]
C                             FOO_OUT   - [-Inf;+Inf]
C                             BAR_OUT   - [-Inf;+Inf]

C ***
C *** Model Derivatives
C ***

C (Comments and routine interface generated by TRNSYS Studio)
C***********************************************************************

C    TRNSYS acess functions (allow to acess TIME etc.)
      USE TrnsysConstants
      USE TrnsysFunctions

C-----------------------------------------------------------------------------------------------------------------------
C    REQUIRED BY THE MULTI-DLL VERSION OF TRNSYS
      !DEC$ATTRIBUTES DLLEXPORT :: TYPE289                                       !SET THE CORRECT TYPE NUMBER HERE
C-----------------------------------------------------------------------------------------------------------------------
C-----------------------------------------------------------------------------------------------------------------------
C    TRNSYS DECLARATIONS
      IMPLICIT NONE                     !REQUIRES THE USER TO DEFINE ALL VARIABLES BEFORE USING THEM
```

```
          DOUBLE PRECISION XIN !THE ARRAY FROM WHICH THE INPUTS TO THIS TYPE WILL BE RETRIEVED
          DOUBLE PRECISION OUT !THE ARRAY WHICH WILL BE USED TO STORE THE OUTPUTS FROM THIS TYPE
          DOUBLE PRECISION TIME          !THE CURRENT SIMULATION TIME - YOU MAY USE THIS VARIABLE BUT DO NOT SET IT!
          DOUBLE PRECISION PAR !THE ARRAY FROM WHICH THE PARAMETERS FOR THIS TYPE WILL BE RETRIEVED
          DOUBLE PRECISION STORED !THE STORAGE ARRAY FOR HOLDING VARIABLES FROM TIMESTEP TO TIMESTEP
          DOUBLE PRECISION T             !AN ARRAY CONTAINING THE RESULTS FROM THE DIFFERENTIAL EQUATION SOLVER
          DOUBLE PRECISION DTDT          !AN ARRAY CONTAINING THE DERIVATIVES TO BE PASSED TO THE DIFF.EQ. SOLVER
          INTEGER*4 INFO(15)             !THE INFO ARRAY STORES AND PASSES VALUABLE INFORMATION TO AND FROM THIS TYPE
          INTEGER*4 NP,NI,NOUT,ND        !VARIABLES FOR THE MAXIMUM NUMBER OF PARAMETERS,INPUTS,OUTPUTS AND DERIVATIVES
          INTEGER*4 NPAR,NIN,NDER        !VARIABLES FOR THE CORRECT NUMBER OF PARAMETERS,INPUTS,OUTPUTS AND DERIVATIVES
          INTEGER*4 IUNIT,ITYPE          !THE UNIT NUMBER AND TYPE NUMBER FOR THIS COMPONENT
          INTEGER*4 ICNTRL               !AN ARRAY FOR HOLDING VALUES OF CONTROL FUNCTIONS WITH THE NEW SOLVER
          INTEGER*4 NSTORED              !THE NUMBER OF VARIABLES THAT WILL BE PASSED INTO AND OUT OF STORAGE
          CHARACTER*3 OCHECK             !AN ARRAY TO BE FILLED WITH THE CORRECT VARIABLE TYPES FOR THE OUTPUTS
          CHARACTER*3 YCHECK             !AN ARRAY TO BE FILLED WITH THE CORRECT VARIABLE TYPES FOR THE INPUTS
C---------------------------------------------------------------------------------------------------------------------

C---------------------------------------------------------------------------------------------------------------------
C    USER DECLARATIONS - SET THE MAXIMUM NUMBER OF PARAMETERS (NP), INPUTS (NI),
C    OUTPUTS (NOUT), AND DERIVATIVES (ND) THAT MAY BE SUPPLIED FOR THIS TYPE
      PARAMETER (NP=5,NI=9,NOUT=11,ND=0,NSTORED=0)
C---------------------------------------------------------------------------------------------------------------------

C---------------------------------------------------------------------------------------------------------------------
C    REQUIRED TRNSYS DIMENSIONS
      DIMENSION XIN(NI),OUT(NOUT),PAR(NP),YCHECK(NI),OCHECK(NOUT),
          1   STORED(NSTORED),T(ND),DTDT(ND)
      INTEGER NITEMS
C---------------------------------------------------------------------------------------------------------------------
C---------------------------------------------------------------------------------------------------------------------
C    ADD DECLARATIONS AND DEFINITIONS FOR THE USER-VARIABLES HERE


C    PARAMETERS
      DOUBLE PRECISION CP_HOT
      DOUBLE PRECISION CP_COLD
      DOUBLE PRECISION C
      DOUBLE PRECISION D
      DOUBLE PRECISION E

C    INPUTS
      DOUBLE PRECISION THOT_IN
      DOUBLE PRECISION FHOT_IN
      DOUBLE PRECISION TCOLD_IN
      DOUBLE PRECISION FCOLD_IN
      DOUBLE PRECISION T_AMB
      DOUBLE PRECISION TEMP_START
      DOUBLE PRECISION FLOW_START
      DOUBLE PRECISION FOO_IN
      DOUBLE PRECISION BAR_IN

C    OUTPUTS
          DOUBLE PRECISION THOT_OUT
          DOUBLE PRECISION FHOT_OUT
          DOUBLE PRECISION TCOLD_OUT
          DOUBLE PRECISION FCOLD_OUT
          DOUBLE PRECISION THX_AVE
          DOUBLE PRECISION QT_KJH
          DOUBLE PRECISION QT_KW
          DOUBLE PRECISION EFF_MOD
          DOUBLE PRECISION EFF
          DOUBLE PRECISION FOO_OUT
          DOUBLE PRECISION BAR_OUT

C    LOCAL
          DOUBLE PRECISION CR_HOT
```

```
          DOUBLE PRECISION CR_COLD
          DOUBLE PRECISION C_RATIO
          DOUBLE PRECISION D_TEMP


C----------------------------------------------------------------------------------------------------------------------
C       READ IN THE VALUES OF THE PARAMETERS IN SEQUENTIAL ORDER
      CP_HOT=PAR(1)
      CP_COLD=PAR(2)
      C=PAR(3)
      D=PAR(4)
      E=PAR(5)

C----------------------------------------------------------------------------------------------------------------------
C    RETRIEVE THE CURRENT VALUES OF THE INPUTS TO THIS MODEL FROM THE XIN ARRAY IN SEQUENTIAL ORDER

      THOT_IN=XIN(1)
      FHOT_IN=XIN(2)
      TCOLD_IN=XIN(3)
      FCOLD_IN=XIN(4)
      T_AMB=XIN(5)
      TEMP_START=XIN(6)
      FLOW_START=XIN(7)
      FOO_IN=XIN(8)
      BAR_IN=XIN(9)
             IUNIT=INFO(1)
             ITYPE=INFO(2)

C----------------------------------------------------------------------------------------------------------------------
C    SET THE VERSION INFORMATION FOR TRNSYS
      IF(INFO(7).EQ.-2) THEN
             INFO(12)=16
             RETURN 1
          ENDIF
C----------------------------------------------------------------------------------------------------------------------

C----------------------------------------------------------------------------------------------------------------------
C    DO ALL THE VERY LAST CALL OF THE SIMULATION MANIPULATIONS HERE
      IF (INFO(8).EQ.-1) THEN
             RETURN 1
          ENDIF
C----------------------------------------------------------------------------------------------------------------------

C----------------------------------------------------------------------------------------------------------------------
C    PERFORM ANY 'AFTER-ITERATION' MANIPULATIONS THAT ARE REQUIRED HERE
C    e.g. save variables to storage array for the next timestep
      IF (INFO(13).GT.0) THEN
             NITEMS=0
C            STORED(1)=... (if NITEMS > 0)
C        CALL setStorageVars(STORED,NITEMS,INFO)
             RETURN 1
          ENDIF
C
C----------------------------------------------------------------------------------------------------------------------

C----------------------------------------------------------------------------------------------------------------------
C    DO ALL THE VERY FIRST CALL OF THE SIMULATION MANIPULATIONS HERE
      IF (INFO(7).EQ.-1) THEN

C       SET SOME INFO ARRAY VARIABLES TO TELL THE TRNSYS ENGINE HOW THIS TYPE IS TO WORK
         INFO(6)=NOUT
         INFO(9)=1
             INFO(10)=0        !STORAGE FOR VERSION 16 HAS BEEN CHANGED

C       SET THE REQUIRED NUMBER OF INPUTS, PARAMETERS AND DERIVATIVES THAT THE USER SHOULD SUPPLY IN THE INPUT FILE
C       IN SOME CASES, THE NUMBER OF VARIABLES MAY DEPEND ON THE VALUE OF PARAMETERS TO THIS MODEL....
         NIN=NI
```

```
             NPAR=NP
             NDER=ND

C       CALL THE TYPE CHECK SUBROUTINE TO COMPARE WHAT THIS COMPONENT REQUIRES TO WHAT IS SUPPLIED IN
C       THE TRNSYS INPUT FILE
             CALL TYPECK(1,INFO,NIN,NPAR,NDER)

C       SET THE NUMBER OF STORAGE SPOTS NEEDED FOR THIS COMPONENT
         NITEMS=0
C            CALL setStorageSize(NITEMS,INFO)

C       RETURN TO THE CALLING PROGRAM
         RETURN 1

      ENDIF
C-----------------------------------------------------------------------------------------------------------------------

C-----------------------------------------------------------------------------------------------------------------------
C    DO ALL OF THE INITIAL TIMESTEP MANIPULATIONS HERE - THERE ARE NO ITERATIONS AT THE INTIAL TIME
      IF (TIME .LT. (getSimulationStartTime() +
     . getSimulationTimeStep()/2.D0)) THEN

C       SET THE UNIT NUMBER FOR FUTURE CALLS
         IUNIT=INFO(1)
         ITYPE=INFO(2)

C       CHECK THE PARAMETERS FOR PROBLEMS AND RETURN FROM THE SUBROUTINE IF AN ERROR IS FOUND
C         IF(...) CALL TYPECK(-4,INFO,0,"BAD PARAMETER #",0)

C       PERFORM ANY REQUIRED CALCULATIONS TO SET THE INITIAL VALUES OF THE OUTPUTS HERE
C                    THOT_OUT
                               OUT(1)=0
C                    FHOT_OUT
                               OUT(2)=0
C                    TCOLD_OUT
                               OUT(3)=0
C                    FCOLD_OUT
                               OUT(4)=0
C                    THX_AVE
                               OUT(5)=0
C                    QT_KJH
                               OUT(6)=0
C                    QT_KW
                               OUT(7)=0
C                    EFF_MOD
                               OUT(8)=0
C                    EFF
                               OUT(9)=0
C                    FOO_OUT
                               OUT(10)=0
C                    BAR_OUT
                               OUT(11)=0

C       PERFORM ANY REQUIRED CALCULATIONS TO SET THE INITIAL STORAGE VARIABLES HERE
         NITEMS=0
C            STORED(1)=...

C       PUT THE STORED ARRAY IN THE GLOBAL STORED ARRAY
C         CALL setStorageVars(STORED,NITEMS,INFO)

C       RETURN TO THE CALLING PROGRAM
         RETURN 1

      ENDIF
C-----------------------------------------------------------------------------------------------------------------------

C-----------------------------------------------------------------------------------------------------------------------
```

```
C    *** ITS AN ITERATIVE CALL TO THIS COMPONENT ***
C-----------------------------------------------------------------------------------------------------------------------



C-----------------------------------------------------------------------------------------------------------------------
C    RETRIEVE THE VALUES IN THE STORAGE ARRAY FOR THIS ITERATION
C      NITEMS=
C         CALL getStorageVars(STORED,NITEMS,INFO)
C      STORED(1)=
C-----------------------------------------------------------------------------------------------------------------------
C-----------------------------------------------------------------------------------------------------------------------
C    CHECK THE INPUTS FOR PROBLEMS
C      IF(...) CALL TYPECK(-3,INFO,'BAD INPUT #',0,0)
C         IF(IERROR.GT.0) RETURN 1
C-----------------------------------------------------------------------------------------------------------------------
C-----------------------------------------------------------------------------------------------------------------------
C    *** PERFORM ALL THE CALCULATION HERE FOR THIS MODEL. ***
C-----------------------------------------------------------------------------------------------------------------------

C                   ADD YOUR COMPONENT EQUATIONS HERE; BASICALLY THE EQUATIONS THAT WILL
C                   CALCULATE THE OUTPUTS BASED ON THE PARAMETERS AND THE INPUTS. REFER TO
C                   CHAPTER 3 OF THE TRNSYS VOLUME 1 MANUAL FOR DETAILED INFORMATION ON
C                   WRITING TRNSYS COMPONENTS.



C    PARAMETERS
      !DOUBLE PRECISION CP_HOT -> Heat capacity of hot-side fluid [kJ/kg-K]
      !DOUBLE PRECISION CP_COLD          -> Heat capacity of cold-side fluid [kJ/kg-K]
      !DOUBLE PRECISION C                          -> Modified effectiveness coefficient c, where eff_mod = c*CR²+d*CR+e
      !DOUBLE PRECISION D                          -> Modified effectiveness coefficient d, where eff_mod = c*CR²+d*CR+e
      !DOUBLE PRECISION E                          -> Modified effectiveness coefficient e, where eff_mod = c*CR²+d*CR+e

C    INPUTS
      !DOUBLE PRECISION THOT_IN          -> Hot-side inlet temperature [° C]
      !DOUBLE PRECISION FHOT_IN          -> Hot-side inlet flowrate [kg/hr]
      !DOUBLE PRECISION TCOLD_IN         -> Cold-side inlet temperature [° C]
      !DOUBLE PRECISION FCOLD_IN         -> Cold-side inlet flowrate [kg/hr]
      !DOUBLE PRECISION T_AMB            -> Ambient temperature [° C]
      !DOUBLE PRECISION TEMP_START -> Hot-side temperature require to start NC (cold-side) flow [° C]
      !DOUBLE PRECISION FLOW_START -> Natural convection (cold-side) start-up flow rate [kg/hr]
      !DOUBLE PRECISION FOO_IN
      !DOUBLE PRECISION BAR_IN

C    OUTPUTS
          !DOUBLE PRECISION THOT_OUT     -> Hot-side outlet temperaure [° C]
          !DOUBLE PRECISION FHOT_OUT     -> Hot-side outlet flowrate [kg/hr]
          !DOUBLE PRECISION TCOLD_OUT    -> Cold-side outlet temperature [° C]
          !DOUBLE PRECISION FCOLD_OUT    -> Cold-side outlet flowrate [kg/hr]
          !DOUBLE PRECISION THX_AVE      -> Average HX temperature [° C]
          !DOUBLE PRECISION QT_KJH       -> Heat transfer rate across HX [kJ/hr]
          !DOUBLE PRECISION QT_KW                  -> Heat transfer rate across HX [kW]
          !DOUBLE PRECISION EFF_MOD      -> Modified effectiveness (QT / (CR_HOT * (D_TEMP)))
          !DOUBLE PRECISION EFF                    -> Effectiveness (QT / (min(CR_HOT, CR_COLD) * (D_TEMP)))
          !DOUBLE PRECISION FOO_OUT
          !DOUBLE PRECISION BAR_OUT

C    LOCAL
          !DOUBLE PRECISION CR_HOT       -> Hot-side capacitence rate [kJ/hr-K]
          !DOUBLE PRECISION CR_COLD      -> Cold-side capacitence rate [kJ/hr-K]
          !DOUBLE PRECISION C_RATIO      -> Capacitence ratio (CR_COLD/CR_HOT)
          !DOUBLE PRECISION D_TEMP       -> Temperature difference (Thot_in - Tcold_in) [° C]

          THOT_OUT = THOT_IN
          FHOT_OUT = FHOT_IN
          TCOLD_OUT = TCOLD_IN
          FCOLD_OUT = FCOLD_IN
```

```
THX_AVE = T_AMB
QT_KJH = 0.0
QT_KW = 0.0
EFF_MOD = 0.0
EFF = 0.0
FOO_OUT = 0.0
BAR_OUT = 0.0

CR_HOT = FHOT_IN * CP_HOT
CR_COLD = FCOLD_IN * CP_COLD
C_RATIO = -1.0
D_TEMP = THOT_IN - TCOLD_IN

IF (CR_HOT < 0.000001) THEN
          CR_HOT = 0.0
ENDIF


IF (TEMP_START < 0.0) THEN
          IF ((FCOLD_IN <= 0.0) .AND. (FHOT_IN > 0.0)) THEN
                    CR_COLD = FLOW_START * CP_COLD
                    FOO_OUT = 1.0
          ENDIF
ELSE
          IF ((FCOLD_IN <= 0.0) .AND. (THOT_IN >= TEMP_START)) THEN
                    CR_COLD = FLOW_START * CP_COLD
                    FOO_OUT = 1.0
          ENDIF
ENDIF




IF ((CR_HOT > 0.0) .AND. (CR_COLD > 0.0) .AND. (D_TEMP > 0.0)) THEN
          C_RATIO = CR_COLD / CR_HOT
          EFF_MOD = C*(C_RATIO**2.0) + D*C_RATIO + E

          IF (EFF_MOD < 0.0) THEN
                    EFF_MOD = 0.0
          ENDIF

          IF (EFF_MOD > 1.0) THEN
                    EFF_MOD = 1.0
          ENDIF

          IF (EFF_MOD > C_RATIO) THEN
                    EFF_MOD = C_RATIO
          ENDIF

          QT_KJH = EFF_MOD * CR_HOT * (D_TEMP)
          THOT_OUT = THOT_IN - (QT_KJH / CR_HOT)
          TCOLD_OUT = TCOLD_IN + (QT_KJH / CR_COLD)

ENDIF

THX_AVE = (TCOLD_IN + TCOLD_OUT) / 2.0
QT_KW = QT_KJH / 3600.0
IF ((C_RATIO > 0.0) .AND. (C_RATIO < 1.0)) THEN
          EFF = EFF_MOD / C_RATIO
ELSE
          EFF = EFF_MOD
ENDIF



IF (D_TEMP < 0.0) THEN
          FCOLD_OUT = 0.0
```

```
          ENDIF

          IF ((D_TEMP < 0.0) .AND. (FHOT_IN > 0.0)) THEN
                    FOO_OUT = -0.5
          ENDIF


C-----------------------------------------------------------------------------------------------------------------------

C-----------------------------------------------------------------------------------------------------------------------
C-----------------------------------------------------------------------------------------------------------------------
C    SET THE STORAGE ARRAY AT THE END OF THIS ITERATION IF NECESSARY
C      NITEMS=
C      STORED(1)=
C         CALL setStorageVars(STORED,NITEMS,INFO)
C-----------------------------------------------------------------------------------------------------------------------
C-----------------------------------------------------------------------------------------------------------------------
C    REPORT ANY PROBLEMS THAT HAVE BEEN FOUND USING CALLS LIKE THIS:
C      CALL MESSAGES(-1,'put your message here','MESSAGE',IUNIT,ITYPE)
C      CALL MESSAGES(-1,'put your message here','WARNING',IUNIT,ITYPE)
C      CALL MESSAGES(-1,'put your message here','SEVERE',IUNIT,ITYPE)
C      CALL MESSAGES(-1,'put your message here','FATAL',IUNIT,ITYPE)
C-----------------------------------------------------------------------------------------------------------------------
C-----------------------------------------------------------------------------------------------------------------------
C    SET THE OUTPUTS FROM THIS MODEL IN SEQUENTIAL ORDER AND GET OUT

C                    THOT_OUT
                              OUT(1)= THOT_OUT
C                    FHOT_OUT
                              OUT(2)= FHOT_OUT
C                    TCOLD_OUT
                              OUT(3)= TCOLD_OUT
C                    FCOLD_OUT
                              OUT(4)= FCOLD_OUT
C                    THX_AVE
                              OUT(5)= THX_AVE
C                    QT_KJH
                              OUT(6)= QT_KJH
C                    QT_KW
                              OUT(7)= QT_KW
C                    EFF_MOD
                              OUT(8)= EFF_MOD
C                    EFF
                              OUT(9)= EFF
C                    FOO_OUT
                              OUT(10)= FOO_OUT
C                    BAR_OUT
                              OUT(11)= BAR_OUT

C-----------------------------------------------------------------------------------------------------------------------
C    EVERYTHING IS DONE - RETURN FROM THIS SUBROUTINE AND MOVE ON
      RETURN 1
      END
C-----------------------------------------------------------------------------------------------------------------------
```

B.9 TYPE 293 – NCHXFlow

Used in conjunction with TRNSYS proforma TYPE 289 – NCHX, this proforma models the tank side fluid flow rate of a natural convection heat exchanger. Source: this proforma was taken from work by Cynthia Cruickshank.

Table B.30: TYPE 293 - Parameters

Number	Name	Description
1	HT	Tank height [m]
2	A	Flow rate coefficient a where: $\dot{m} = a\ \Delta P^{b}$
3	B	Flow rate coefficient b where: $\dot{m} = a\ \Delta P^{b}$
4	HEX	Heat exchanger height [m]
5	RELAX	Relaxation factor (not used for these simulations – set to 0)

Table B.31: TYPE 293 - Inputs

Number	Name	Description
1	TCIN	Temperature of fluid entering the cold (natural convection) side of the heat exchanger [°C]
2	TCOUT	Temperature of fluid exiting the cold (natural convection) side of the heat exchanger [°C]
3	TTAVE	Average tank temperature [°C]
4	TPAVE	Average pipe temperature (pipe above heat exchanger connected to tank inlet) [°C]
5	TCOLD	Previous iteration value of TCOUT (used in conjunction with the relaxation factor – connected to output THXOLD)

Table B.32: TYPE 293 - Outputs

Number	Name	Description
1	FLWNC	Flow rate of fluid through the cold (natural convection) side of the heat exchanger[kg/hr]
2	DP	Pressure difference (ΔP) between tank and heat exchanger/pipe used for flow rate calculations (limited to between 0 and 160 Pa) [Pa]
3	THXOLD	Temperature of fluid exiting the cold (natural convection) side of the heat exchanger (used in conjunction with the relaxation factor – connected to input TCOLD) [°C]
4	DP_ACTUAL	Actual pressure difference between tank and heat exchanger/pipe [Pa]

Derivatives: None

Appendix C

TRNSYS Models

Listed here are example TRNSYS models (in .dck format) used in this thesis.

C.1 Reference Domestic Hot Water System

This model is the reference (non-solar) domestic hot water system.

Table C.1: Reference DHW - TRNSYS Model

```
VERSION 16.1
*******************************************************************************
*** TRNSYS input file (deck) generated by TrnsysStudio
*** on Wednesday, August 17, 2011 at 16:01
*** from TrnsysStudio project: C:\Program Files\Trnsys16\MyProjects\ATHESIS\DHW1a4.TPF
*** 
*** If you edit this file, use the File/Import TRNSYS Input File function in 
*** TrnsysStudio to update the project. 
*** 
*** If you have problems, questions or suggestions please contact your local 
*** TRNSYS distributor or mailto:software@cstb.fr 
*** 
*******************************************************************************


*******************************************************************************
*** Units 
*******************************************************************************

*******************************************************************************
*** Control cards
*******************************************************************************
* START, STOP and STEP
CONSTANTS 3
START=0
STOP=8760
STEP=0.05
* User defined CONSTANTS 

SIMULATION      START   STOP    STEP   ! Start time   End time       Time step
TOLERANCES 0.01 0.01                  ! Integration   Convergence
LIMITS 1000 500 30                           ! Max iterations       Max warnings   Trace
limit
DFQ 1                                 ! TRNSYS numerical integration solver method
WIDTH 132                             ! TRNSYS output file width, number of characters
LIST                                  ! NOLIST statement
                                      ! MAP statement
SOLVER 0 1 1                          ! Solver statement    Minimum relaxation factor
       Maximum relaxation factor
NAN_CHECK 0                           ! Nan DEBUG statement
OVERWRITE_CHECK 0                     ! Overwrite DEBUG statement
TIME_REPORT 0                 ! disable time report
EQSOLVER 0                            ! EQUATION SOLVER statement

* Model "Draw Profile" (Type 14)
* 

UNIT 54 TYPE 14         Draw Profile
*$UNIT_NAME Draw Profile
*$MODEL .\Utility\Forcing Functions\Water Draw\Type14b.tmf
*$POSITION 1142 82
*$LAYER Main # 
PARAMETERS 112
0              ! 1 Initial value of time
0              ! 2 Initial value of function
7              ! 3 Time at point-1
0              ! 4 Water draw at point -1
7              ! 5 Time at point-2
0.04444444            ! 6 Water draw at point -2
```

```
7.25           ! 7 Time at point-3
0.04444444             ! 8 Water draw at point -3
7.25           ! 9 Time at point-4
0              ! 10 Water draw at point -4
8              ! 11 Time at point-5
0              ! 12 Water draw at point -5
8              ! 13 Time at point-6
0.11111111             ! 14 Water draw at point -6
8.25           ! 15 Time at point-7
0.11111111             ! 16 Water draw at point -7
8.25           ! 17 Time at point-8
0              ! 18 Water draw at point -8
9              ! 19 Time at point-9
0              ! 20 Water draw at point -9
9              ! 21 Time at point-10
0.02222222             ! 22 Water draw at point -10
9.25           ! 23 Time at point-11
0.02222222             ! 24 Water draw at point -11
9.25           ! 25 Time at point-12
0              ! 26 Water draw at point -12
10             ! 27 Time at point-13
0              ! 28 Water draw at point -13
10             ! 29 Time at point-14
0.2            ! 30 Water draw at point -14
10.25          ! 31 Time at point-15
0.2            ! 32 Water draw at point -15
10.25          ! 33 Time at point-16
0              ! 34 Water draw at point -16
11             ! 35 Time at point-17
0              ! 36 Water draw at point -17
11             ! 37 Time at point-18
0.02222222             ! 38 Water draw at point -18
11.25          ! 39 Time at point-19
0.02222222             ! 40 Water draw at point -19
11.25          ! 41 Time at point-20
0              ! 42 Water draw at point -20
12             ! 43 Time at point-21
0              ! 44 Water draw at point -21
12             ! 45 Time at point-22
0.04444444             ! 46 Water draw at point -22
12.25          ! 47 Time at point-23
0.04444444             ! 48 Water draw at point -23
12.25          ! 49 Time at point-24
0              ! 50 Water draw at point -24
13             ! 51 Time at point-25
0              ! 52 Water draw at point -25
13             ! 53 Time at point-26
0.02222222             ! 54 Water draw at point -26
13.25          ! 55 Time at point-27
0.02222222             ! 56 Water draw at point -27
13.25          ! 57 Time at point-28
0              ! 58 Water draw at point -28
16             ! 59 Time at point-29
0              ! 60 Water draw at point -29
16             ! 61 Time at point-30
0.04444444             ! 62 Water draw at point -30
16.25          ! 63 Time at point-31
0.04444444             ! 64 Water draw at point -31
16.25          ! 65 Time at point-32
0              ! 66 Water draw at point -32
17             ! 67 Time at point-33
0              ! 68 Water draw at point -33

17             ! 69 Time at point-34
0.11111111             ! 70 Water draw at point -34
17.25          ! 71 Time at point-35
0.11111111             ! 72 Water draw at point -35
```

```
17.25          ! 73 Time at point-36
0              ! 74 Water draw at point -36
18             ! 75 Time at point-37
0              ! 76 Water draw at point -37
18             ! 77 Time at point-38
0.2            ! 78 Water draw at point -38
18.25          ! 79 Time at point-39
0.2            ! 80 Water draw at point -39
18.25          ! 81 Time at point-40
0              ! 82 Water draw at point -40
19             ! 83 Time at point-41
0              ! 84 Water draw at point -41
19             ! 85 Time at point-42
0.11111111             ! 86 Water draw at point -42
19.25          ! 87 Time at point-43
0.11111111             ! 88 Water draw at point -43
19.25          ! 89 Time at point-44
0              ! 90 Water draw at point -44
20             ! 91 Time at point-45
0              ! 92 Water draw at point -45
20             ! 93 Time at point-46
0.04444444             ! 94 Water draw at point -46
20.25          ! 95 Time at point-47
0.04444444             ! 96 Water draw at point -47
20.25          ! 97 Time at point-48
0              ! 98 Water draw at point -48
21             ! 99 Time at point-49
0              ! 100 Water draw at point -49
21             ! 101 Time at point-50
0.02222222             ! 102 Water draw at point -50
21.25          ! 103 Time at point-51
0.02222222             ! 104 Water draw at point -51
21.25          ! 105 Time at point-52
0              ! 106 Water draw at point -52
22             ! 107 Time at point-53
0              ! 108 Water draw at point -53
23             ! 109 Time at point-54
0              ! 110 Water draw at point -54
24             ! 111 Time at point-55
0              ! 112 Water draw at point -55
*------------------------------------------------------------------------------

* EQUATIONS "Variables"
*
EQUATIONS 5
CPGE = 3.648
US1 = 0.1*3.6
US2 = 0.8475*3.6 !R-6.7, From Rheem Fury Spec Sheet
L_pipe = 7.6 !25', SRCC
TA = 18.3
*$UNIT_NAME Variables
*$LAYER Main
*$POSITION 55 818

*------------------------------------------------------------------------------


* Model "Mains" (Type 201)
*

UNIT 25 TYPE 201       Mains
*$UNIT_NAME Mains
*$MODEL .\Weather Data Reading and Processing\Weather Processor (TESS)\Typical
Meteorological Year Files Version 2 (TM2)\Type201-2.tmf
*$POSITION 1079 279
*$LAYER Main #
PARAMETERS 9
```

```
2              ! 1 File Type
44             ! 2 Logical unit
3              ! 3 Tilted Surface Radiation Mode
0.2            ! 4 Ground reflectance - no snow
0.7            ! 5 Ground reflectance - snow cover
1              ! 6 Number of surfaces
1              ! 7 Tracking mode
0.0            ! 8 Slope of surface
0              ! 9 Azimuth of surface
*** External files
ASSIGN "C:\Program Files\Trnsys16\Weather\Meteonorm\North-America\CA-ON-Toronto-
716240.tm2" 44
*|? Which file contains the TMY-2 weather data? |1000
*------------------------------------------------------------------------------

* Model "Aux Tank" (Type 60)
*

UNIT 29 TYPE 60        Aux Tank
*$UNIT_NAME Aux Tank
*$MODEL .\Thermal Storage\Detailed Fluid Storage Tank\Vertical Cylinder\Uniform Losses
and Node Heights\1 Inlet, 1 Outlet\Type60d.tmf
*$POSITION 836 253
*$LAYER Water Loop #
PARAMETERS 32
2              ! 1 User-specified inlet positions
0.17           ! 2 Tank volume
1              ! 3 Tank height
-1             ! 4 Tank perimeter
0.05           ! 5 Height of flow inlet 1
1              ! 6 Height of flow outlet 1
-1             ! 7 Not used (inlet 2)
-1             ! 8 Not used (outlet 2)
4.18           ! 9 Fluid specific heat
991            ! 10 Fluid density
4.356          ! 11 Tank loss coefficient
2.2752         ! 12 Fluid thermal conductivity
0              ! 13 Destratification conductivity
100            ! 14 Boiling temperature
1              ! 15 Auxiliary heater mode
.4             ! 16 Height of 1st aux. heater
.4             ! 17 Height of 1st thermostat
57             ! 18 Set point temperature for element 1
3              ! 19 Deadband for heating element 1
10799.999714           ! 20 Maximum heating rate of element 1
0              ! 21 Height of heating element 2
0              ! 22 Height of thermostat 2
57             ! 23 Set point temperature for element 2
2              ! 24 Deadband for heating element 2
0              ! 25 Maximum heating rate of element 2
0              ! 26 Overall loss coefficient for gas flue
20             ! 27 Flue temperature
6              ! 28 Fraction of critical timestep
1              ! 29 Gas heater?
0              ! 30 Number of internal heat exchangers
0              ! 31 Equal sized nodes
0              ! 32 Uniform tank losses
INPUTS 9
12,2           ! FlowMix:FLHOT ->Flow rate at inlet 1
0,0            ! [unconnected] Flow rate at outlet 1
0,0            ! [unconnected] Not used (flow inlet 2)
0,0            ! [unconnected] Not used (flow outlet 2)
25,5           ! Mains:Mains water temperature ->Temperature at inlet 1
0,0            ! [unconnected] Not used (temp inlet 2)
0,0            ! [unconnected] Environment temperature
0,0            ! [unconnected] Control signal for element 1
0,0            ! [unconnected] Control signal for element 2
```

```
*** INITIAL INPUT VALUES
0 -2 -1 -1 20 20 22 1 1
DERIVATIVES 10
TA             ! 1 Initial temperature of node-1
TA             ! 2 Initial temperature of node-2
TA             ! 3 Initial temperature of node-3
TA             ! 4 Initial temperature of node-4
TA             ! 5 Initial temperature of node-5
TA             ! 6 Initial temperature of node-6
TA             ! 7 Initial temperature of node-7
TA             ! 8 Initial temperature of node-8
TA             ! 9 Initial temperature of node-9
TA             ! 10 Initial temperature of node-10
*------------------------------------------------------------------------------

* EQUATIONS "Draw"
*
EQUATIONS 2
DailyLoad = 225*4*0.991
Draw = [54,1]*DailyLoad
*$UNIT_NAME Draw
*$LAYER Water Loop
*$POSITION 1040 168

*------------------------------------------------------------------------------


* Model "FlowMix" (Type 178)
*

UNIT 12 TYPE 178        FlowMix
*$UNIT_NAME FlowMix
*$MODEL .\Hydronics\Flow Mixer\Other Fluids\Type178.tmf
*$POSITION 991 239
*$LAYER Main #
PARAMETERS 1
55             ! 1 TSET
INPUTS 3
25,5           ! Mains:Mains water temperature ->TCOLD
29,5           ! Aux Tank:Temperature of outlet flow 1 ->THOT
Draw           ! Draw:Draw ->FLTAP
*** INITIAL INPUT VALUES
15 20 0
*------------------------------------------------------------------------------

* EQUATIONS "Equa-2"
*
EQUATIONS 4
kWh4 = [12,3] / 3600
kWh5 = [29,12]/3600
kWh8 = [29,12]/3600
new1 = [12,3]/3600
*$UNIT_NAME Equa-2
*$LAYER Main
*$POSITION 326 189

*------------------------------------------------------------------------------


* Model "IntSum-2" (Type 24)
*

UNIT 42 TYPE 24         IntSum-2
*$UNIT_NAME IntSum-2
*$MODEL .\Utility\Integrators\Quantity Integrator\Type24.tmf
*$POSITION 200 207
*$LAYER Main #
```

```
PARAMETERS 2
-1             ! 1 Integration period
0              ! 2 Relative or absolute start time
INPUTS 10
0,0            ! [unconnected] Input to be integrated-1
0,0            ! [unconnected] Input to be integrated-2
0,0            ! [unconnected] Input to be integrated-3
0,0            ! [unconnected] Input to be integrated-4
kWh4           ! Equa-2:kWh4 ->Input to be integrated-5
kWh5           ! Equa-2:kWh5 ->Input to be integrated-6
0,0            ! [unconnected] Input to be integrated-7
0,0            ! [unconnected] Input to be integrated-8
kWh8           ! Equa-2:kWh8 ->Input to be integrated-9
new1           ! Equa-2:new1 ->Input to be integrated-10
*** INITIAL INPUT VALUES
0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
*------------------------------------------------------------------------------

* Model "Solar-2" (Type 65)
*

UNIT 44 TYPE 65        Solar-2
*$UNIT_NAME Solar-2
*$MODEL .\Output\Online Plotter\Online Plotter Without File\Type65d.tmf
*$POSITION 38 168
*$LAYER Main #
PARAMETERS 12
5              ! 1 Nb. of left-axis variables
3              ! 2 Nb. of right-axis variables
0              ! 3 Left axis minimum
10000          ! 4 Left axis maximum
0.0            ! 5 Right axis minimum
10000          ! 6 Right axis maximum
1              ! 7 Number of plots per simulation
12             ! 8 X-axis gridpoints
0              ! 9 Shut off Online w/o removing
-1             ! 10 Logical unit for output file
0              ! 11 Output file units
0              ! 12 Output file delimiter
INPUTS 8
42,1           ! IntSum-2:Result of integration-1 ->Left axis variable-1
42,2           ! IntSum-2:Result of integration-2 ->Left axis variable-2
42,3           ! IntSum-2:Result of integration-3 ->Left axis variable-3
42,6           ! IntSum-2:Result of integration-6 ->Left axis variable-4
42,8           ! IntSum-2:Result of integration-8 ->Left axis variable-5
42,4           ! IntSum-2:Result of integration-4 ->Right axis variable-1
42,5           ! IntSum-2:Result of integration-5 ->Right axis variable-2
42,10          ! IntSum-2:Result of integration-10 ->Right axis variable-3
*** INITIAL INPUT VALUES
TColl_in TColl_in TColl_in AuxDHW DHWLosses SH DHW dhwload
LABELS  3
"Temperatures (C)"
"Insolation (kJ/hr-m^2)"
"Collector"
*------------------------------------------------------------------------------

* Model "PrintSum-2" (Type 25)
*

UNIT 45 TYPE 25        PrintSum-2
*$UNIT_NAME PrintSum-2
*$MODEL .\Output\Printer\User-Supplied Units\Type25b.tmf
*$POSITION 45 242
*$LAYER Main #
PARAMETERS 10
-1             ! 1 Printing interval
START          ! 2 Start time
```

```
STOP           ! 3 Stop time
45             ! 4 Logical unit
1              ! 5 Units printing mode
0              ! 6 Relative or absolute start time
-1             ! 7 Overwrite or Append
-1             ! 8 Print header
0              ! 9 Delimiter
1              ! 10 Print labels
INPUTS 8
42,1           ! IntSum-2:Result of integration-1 ->Input to be printed-1
42,2           ! IntSum-2:Result of integration-2 ->Input to be printed-2
42,3           ! IntSum-2:Result of integration-3 ->Input to be printed-3
42,4           ! IntSum-2:Result of integration-4 ->Input to be printed-4
42,5           ! IntSum-2:Result of integration-5 ->Input to be printed-5
42,7           ! IntSum-2:Result of integration-7 ->Input to be printed-6
42,9           ! IntSum-2:Result of integration-9 ->Input to be printed-7
42,10          ! IntSum-2:Result of integration-10 ->Input to be printed-8
*** INITIAL INPUT VALUES
SH_SOLAR DHW_SOLAR Total_Coll SH_LOAD DHW_LOAD Gt_tilt DHW_AUX SH_AUX

kWh kWh kWh kWh kWh kWh/m2 kWh kWh
*** External files
ASSIGN "***.out" 45
*|? Output file for printed results |1000
*------------------------------------------------------------------------------

* Model "Solar" (Type 65)
*

UNIT 13 TYPE 65        Solar
*$UNIT_NAME Solar
*$MODEL .\Output\Online Plotter\Online Plotter Without File\Type65d.tmf
*$POSITION 720 349
*$LAYER Main #
PARAMETERS 12
1              ! 1 Nb. of left-axis variables
0              ! 2 Nb. of right-axis variables
50             ! 3 Left axis minimum
60             ! 4 Left axis maximum
50             ! 5 Right axis minimum
60             ! 6 Right axis maximum
1              ! 7 Number of plots per simulation
12             ! 8 X-axis gridpoints
0              ! 9 Shut off Online w/o removing
-1             ! 10 Logical unit for output file
0              ! 11 Output file units
0              ! 12 Output file delimiter
INPUTS 1
29,5           ! Aux Tank:Temperature of outlet flow 1 ->Left axis variable
*** INITIAL INPUT VALUES
TColl_in
LABELS  3
"Temperatures (C)"
"Insolation (kJ/hr-m^2)"
"Collector"
*------------------------------------------------------------------------------

END
```

C.2 Stand-Alone Domestic Hot Water System – Configuration (i)

This model configuration is the stand-alone domestic hot water system with a glazed solar collector and a natural convection heat exchanger.

Table C.2: SDHW(i) - TRNSYS Model

```
VERSION 16.1
*******************************************************************************
*** TRNSYS input file (deck) generated by TrnsysStudio
*** on Friday, September 02, 2011 at 10:55
*** from TrnsysStudio project: C:\Program Files\Trnsys16\MyProjects\ATHESIS\1SDHW1a5.TPF
***
*** If you edit this file, use the File/Import TRNSYS Input File function in
*** TrnsysStudio to update the project.
***
*** If you have problems, questions or suggestions please contact your local
*** TRNSYS distributor or mailto:software@cstb.fr
***
*******************************************************************************


*******************************************************************************
*** Units
*******************************************************************************

*******************************************************************************
*** Control cards
*******************************************************************************
* START, STOP and STEP
CONSTANTS 3
START=0
STOP=8760
STEP=0.05
* User defined CONSTANTS

SIMULATION      START   STOP    STEP   ! Start time   End time       Time step
TOLERANCES 0.01 0.05                   ! Integration   Convergence
LIMITS 1000 500 30                            ! Max iterations      Max warnings   Trace
limit
DFQ 1                                  ! TRNSYS numerical integration solver method
WIDTH 132                              ! TRNSYS output file width, number of characters
LIST                                   ! NOLIST statement
                                       ! MAP statement
SOLVER 0 1 1                           ! Solver statement    Minimum relaxation factor
       Maximum relaxation factor
NAN_CHECK 0                            ! Nan DEBUG statement
OVERWRITE_CHECK 0                      ! Overwrite DEBUG statement
TIME_REPORT 0                  ! disable time report
EQSOLVER 0                             ! EQUATION SOLVER statement

* Model "Toronto" (Type 109)
*

UNIT 24 TYPE 109       Toronto
*$UNIT_NAME Toronto
*$MODEL .\Weather Data Reading and Processing\Standard Format\TMY2\Type109-TMY2.tmf
*$POSITION 107 381
*$LAYER Main #
PARAMETERS 4
2              ! 1 Data Reader Mode
43             ! 2 Logical unit
4              ! 3 Sky model for diffuse radiation
```

```
1              ! 4 Tracking mode
INPUTS 3
0,0            ! [unconnected] Ground reflectance
0,0            ! [unconnected] Slope of surface
0,0            ! [unconnected] Azimuth of surface
*** INITIAL INPUT VALUES
0.2 angle 0
*** External files
ASSIGN "C:\Program Files\Trnsys16\Weather\Meteonorm\North-America\CA-ON-Toronto-
716240.tm2" 43
*|? Weather data file |1000
*------------------------------------------------------------------------------

* Model "Draw Profile" (Type 14)
*

UNIT 54 TYPE 14         Draw Profile
*$UNIT_NAME Draw Profile
*$MODEL .\Utility\Forcing Functions\Water Draw\Type14b.tmf
*$POSITION 1142 552
*$LAYER Main #
PARAMETERS 112
0              ! 1 Initial value of time
0              ! 2 Initial value of function
7              ! 3 Time at point-1
0              ! 4 Water draw at point -1
7              ! 5 Time at point-2
0.04444444             ! 6 Water draw at point -2
7.25           ! 7 Time at point-3
0.04444444             ! 8 Water draw at point -3
7.25           ! 9 Time at point-4
0              ! 10 Water draw at point -4
8              ! 11 Time at point-5
0              ! 12 Water draw at point -5
8              ! 13 Time at point-6
0.11111111             ! 14 Water draw at point -6
8.25           ! 15 Time at point-7
0.11111111             ! 16 Water draw at point -7
8.25           ! 17 Time at point-8
0              ! 18 Water draw at point -8
9              ! 19 Time at point-9
0              ! 20 Water draw at point -9
9              ! 21 Time at point-10
0.02222222             ! 22 Water draw at point -10
9.25           ! 23 Time at point-11
0.02222222             ! 24 Water draw at point -11
9.25           ! 25 Time at point-12
0              ! 26 Water draw at point -12
10             ! 27 Time at point-13
0              ! 28 Water draw at point -13
10             ! 29 Time at point-14
0.2            ! 30 Water draw at point -14
10.25          ! 31 Time at point-15
0.2            ! 32 Water draw at point -15
10.25          ! 33 Time at point-16
0              ! 34 Water draw at point -16
11             ! 35 Time at point-17
0              ! 36 Water draw at point -17
11             ! 37 Time at point-18
0.02222222             ! 38 Water draw at point -18
11.25          ! 39 Time at point-19
0.02222222             ! 40 Water draw at point -19
11.25          ! 41 Time at point-20
0              ! 42 Water draw at point -20
12             ! 43 Time at point-21
0              ! 44 Water draw at point -21
12             ! 45 Time at point-22
```

```
0.04444444             ! 46 Water draw at point -22
12.25          ! 47 Time at point-23
0.04444444             ! 48 Water draw at point -23
12.25          ! 49 Time at point-24
0              ! 50 Water draw at point -24
13             ! 51 Time at point-25
0              ! 52 Water draw at point -25
13             ! 53 Time at point-26
0.02222222             ! 54 Water draw at point -26
13.25          ! 55 Time at point-27
0.02222222             ! 56 Water draw at point -27
13.25          ! 57 Time at point-28
0              ! 58 Water draw at point -28
16             ! 59 Time at point-29
0              ! 60 Water draw at point -29
16             ! 61 Time at point-30
0.04444444             ! 62 Water draw at point -30
16.25          ! 63 Time at point-31
0.04444444             ! 64 Water draw at point -31
16.25          ! 65 Time at point-32
0              ! 66 Water draw at point -32
17             ! 67 Time at point-33
0              ! 68 Water draw at point -33
17             ! 69 Time at point-34
0.11111111             ! 70 Water draw at point -34
17.25          ! 71 Time at point-35
0.11111111             ! 72 Water draw at point -35
17.25          ! 73 Time at point-36
0              ! 74 Water draw at point -36
18             ! 75 Time at point-37
0              ! 76 Water draw at point -37
18             ! 77 Time at point-38
0.2            ! 78 Water draw at point -38
18.25          ! 79 Time at point-39
0.2            ! 80 Water draw at point -39
18.25          ! 81 Time at point-40
0              ! 82 Water draw at point -40
19             ! 83 Time at point-41
0              ! 84 Water draw at point -41
19             ! 85 Time at point-42
0.11111111             ! 86 Water draw at point -42
19.25          ! 87 Time at point-43
0.11111111             ! 88 Water draw at point -43
19.25          ! 89 Time at point-44
0              ! 90 Water draw at point -44
20             ! 91 Time at point-45
0              ! 92 Water draw at point -45
20             ! 93 Time at point-46
0.04444444             ! 94 Water draw at point -46
20.25          ! 95 Time at point-47
0.04444444             ! 96 Water draw at point -47
20.25          ! 97 Time at point-48
0              ! 98 Water draw at point -48
21             ! 99 Time at point-49
0              ! 100 Water draw at point -49
21             ! 101 Time at point-50
0.02222222             ! 102 Water draw at point -50
21.25          ! 103 Time at point-51
0.02222222             ! 104 Water draw at point -51
21.25          ! 105 Time at point-52
0              ! 106 Water draw at point -52
22             ! 107 Time at point-53
0              ! 108 Water draw at point -53
23             ! 109 Time at point-54
0              ! 110 Water draw at point -54
24             ! 111 Time at point-55
0              ! 112 Water draw at point -55
```

```
*------------------------------------------------------------------------------

* EQUATIONS "Variables"
*
EQUATIONS 5
CPGE = 3.648
US1 = 0.1*3.6
US2 = 0.8475*3.6 !R-6.7, From Rheem Fury Spec Sheet
L_pipe = 7.6 !25', SRCC
TA = 20
*$UNIT_NAME Variables
*$LAYER Main
*$POSITION 55 818

*------------------------------------------------------------------------------


* Model "Mains" (Type 201)
*

UNIT 25 TYPE 201       Mains
*$UNIT_NAME Mains
*$MODEL .\Weather Data Reading and Processing\Weather Processor (TESS)\Typical
Meteorological Year Files Version 2 (TM2)\Type201-2.tmf
*$POSITION 1015 712
*$LAYER Main #
PARAMETERS 9
2              ! 1 File Type
44             ! 2 Logical unit
3              ! 3 Tilted Surface Radiation Mode
0.2            ! 4 Ground reflectance - no snow
0.7            ! 5 Ground reflectance - snow cover
1              ! 6 Number of surfaces
1              ! 7 Tracking mode
0.0            ! 8 Slope of surface
0              ! 9 Azimuth of surface
*** External files
ASSIGN "C:\Program Files\Trnsys16\Weather\Meteonorm\North-America\CA-ON-Toronto-
716240.tm2" 44
*|? Which file contains the TMY-2 weather data? |1000
*------------------------------------------------------------------------------

* Model "Panels" (Type 1)
*

UNIT 4 TYPE 1   Panels
*$UNIT_NAME Panels
*$MODEL .\Solar Thermal Collectors\Quadratic Efficiency Collector\2nd-Order Incidence
Angle Modifiers\Type1b.tmf
*$POSITION 210 520
*$LAYER Weather - Data Files #
PARAMETERS 11
1              ! 1 Number in series
6              ! 2 Collector area
3.53           ! 3 Fluid specific heat
1              ! 4 Efficiency mode
73.3           ! 5 Tested flow rate
0.717          ! 6 Intercept efficiency
14.45076               ! 7 Efficiency slope
0.067392               ! 8 Efficiency curvature
2              ! 9 Optical mode 2
0.110          ! 10 1st-order IAM
0.051          ! 11 2nd-order IAM
INPUTS 9
7,1            ! ToColl:Outlet temperature ->Inlet temperature
7,2            ! ToColl:Outlet flow rate ->Inlet flowrate
24,1           ! Toronto:Ambient temperature ->Ambient temperature
```

```
24,18          ! Toronto:total radiation on tilted surface ->Incident radiation
24,12          ! Toronto:total radiation on horizontal ->Total horizontal radiation
0,0            ! [unconnected] Horizontal diffuse radiation
0,0            ! [unconnected] Ground reflectance
24,22          ! Toronto:angle of incidence for tilted surface  ->Incidence angle
24,23          ! Toronto:slope of tilted surface ->Collector slope
*** INITIAL INPUT VALUES
TA 0 13 0 0.0 0.0 0.2 0 40
*------------------------------------------------------------------------------

* Model "ToNCHX" (Type 31)
*

UNIT 9 TYPE 31  ToNCHX
*$UNIT_NAME ToNCHX
*$MODEL .\Hydronics\Pipe_Duct\Type31.tmf
*$POSITION 291 520
*$LAYER Water Loop #
PARAMETERS 6
0.007725              ! 1 Inside diameter
L_pipe         ! 2 Pipe length
20             ! 3 Loss coefficient
1044           ! 4 Fluid density
3.53           ! 5 Fluid specific heat
TA             ! 6 Initial fluid temperature
INPUTS 3
4,1            ! Panels:Outlet temperature ->Inlet temperature
4,2            ! Panels:Outlet flowrate ->Inlet flow rate
0,0            ! [unconnected] Environment temperature
*** INITIAL INPUT VALUES
TA 0 TA
*------------------------------------------------------------------------------

* Model "Type289-NCHX" (Type 289)
*

UNIT 49 TYPE 289       Type289-NCHX
*$UNIT_NAME Type289-NCHX
*$MODEL .\My Components\Type289-NCHX.tmf
*$POSITION 384 750
*$LAYER Main #
PARAMETERS 5
3.53           ! 1 CP_HOT
4.18           ! 2 CP_COLD
-0.3488        ! 3 C
1.1402         ! 4 D
0              ! 5 E
INPUTS 9
9,1            ! ToNCHX:Outlet temperature ->THOT_IN
9,2            ! ToNCHX:Outlet flow rate ->FHOT_IN
15,6           ! Solar Tank:Temperature of outlet flow 2 ->TCOLD_IN
56,1           ! Type293-NCHXFlow:FLWNC ->FCOLD_IN
0,0            ! [unconnected] T_AMB
0,0            ! [unconnected] TEMP_START
0,0            ! [unconnected] FLOW_START
0,0            ! [unconnected] FOO_IN
0,0            ! [unconnected] BAR_IN
*** INITIAL INPUT VALUES
TA 0 14.4 0 TA -1 0.001 0 0
*------------------------------------------------------------------------------

* Model "Pump" (Type 3)
*

UNIT 6 TYPE 3   Pump
*$UNIT_NAME Pump
*$MODEL .\Hydronics\Pumps\Single Speed\Type3b.tmf
```

```
*$POSITION 273 712
*$LAYER Controls #
PARAMETERS 5
CollFlow               ! 1 Maximum flow rate
3.53           ! 2 Fluid specific heat
0              ! 3 Maximum power
0              ! 4 Conversion coefficient
0              ! 5 Power coefficient
INPUTS 3
49,1           ! Type289-NCHX:THOT_OUT ->Inlet fluid temperature
49,2           ! Type289-NCHX:FHOT_OUT ->Inlet mass flow rate
40,1           ! Type2b-2:Output control function ->Control signal
*** INITIAL INPUT VALUES
TA 0 1.0
*-------------------------------------------------------------------------------

* Model "ToColl" (Type 31)
*

UNIT 7 TYPE 31  ToColl
*$UNIT_NAME ToColl
*$MODEL .\Hydronics\Pipe_Duct\Type31.tmf
*$POSITION 116 692
*$LAYER Water Loop #
PARAMETERS 6
0.007725               ! 1 Inside diameter
L_pipe         ! 2 Pipe length
20             ! 3 Loss coefficient
1044           ! 4 Fluid density
3.53           ! 5 Fluid specific heat
TA             ! 6 Initial fluid temperature
INPUTS 3
6,1            ! Pump:Outlet fluid temperature ->Inlet temperature
6,2            ! Pump:Outlet flow rate ->Inlet flow rate
0,0            ! [unconnected] Environment temperature
*** INITIAL INPUT VALUES
TA 0 TA
*-------------------------------------------------------------------------------

* EQUATIONS "TPAVG"
*
EQUATIONS 1
TPAVG_AVG = ([49,3] -1) ![16,6]
*$UNIT_NAME TPAVG
*$LAYER Main
*$POSITION 479 800

*-------------------------------------------------------------------------------


* Model "Type293-NCHXFlow" (Type 293)
*

UNIT 56 TYPE 293       Type293-NCHXFlow
*$UNIT_NAME Type293-NCHXFlow
*$MODEL .\My Components\Type293-NCHXFlow.tmf
*$POSITION 653 857
*$LAYER Main #
PARAMETERS 5
1.5            ! 1 HT
2.388          ! 2 A
0.6505         ! 3 B
0.29           ! 4 HEX
0              ! 5 RELAX
INPUTS 5
15,6           ! Solar Tank:Temperature of outlet flow 2 ->TCIN
49,3           ! Type289-NCHX:TCOLD_OUT ->TCOUT
```

```
15,17          ! Solar Tank:Average tank temperature ->TTAVE
TPAVG_AVG             ! TPAVG:TPAVG_AVG ->TPAVE
56,3           ! Type293-NCHXFlow:THXOLD ->TCOLD
*** INITIAL INPUT VALUES
14.4 TA TA TA TA
*------------------------------------------------------------------------------

* Model "ToTank" (Type 31)
*

UNIT 16 TYPE 31         ToTank
*$UNIT_NAME ToTank
*$MODEL .\Hydronics\Pipe_Duct\Type31.tmf
*$POSITION 479 690
*$LAYER Main #
PARAMETERS 6
0.018          ! 1 Inside diameter
0.60           ! 2 Pipe length
4              ! 3 Loss coefficient
991            ! 4 Fluid density
4.18           ! 5 Fluid specific heat
TA             ! 6 Initial fluid temperature
INPUTS 3
49,3           ! Type289-NCHX:TCOLD_OUT ->Inlet temperature
49,4           ! Type289-NCHX:FCOLD_OUT ->Inlet flow rate
0,0            ! [unconnected] Environment temperature
*** INITIAL INPUT VALUES
TA 0 TA
*------------------------------------------------------------------------------

* Model "Solar Tank" (Type 60)
*

UNIT 15 TYPE 60         Solar Tank
*$UNIT_NAME Solar Tank
*$MODEL .\Thermal Storage\Detailed Fluid Storage Tank\Uniform Cross Section\Uniform 
Losses and Node Heights\2 Inlets, 2 Outlets\Type60s.tmf
*$POSITION 626 744
*$LAYER Main #
PARAMETERS 32
2              ! 1 User-specified inlet positions
0.27           ! 2 Tank volume
1.5            ! 3 Tank height
1.5            ! 4 Tank perimeter
1.5            ! 5 Height of flow inlet 1
1.5            ! 6 Height of flow outlet 1
0              ! 7 Height of flow inlet 2
0              ! 8 Height of flow outlet 2
4.18           ! 9 Fluid specific heat
991            ! 10 Fluid density
4.356          ! 11 Tank loss coefficient
2.2752         ! 12 Fluid thermal conductivity
0              ! 13 Destratification conductivity
100            ! 14 Boiling temperature
1              ! 15 Auxiliary heater mode
1.1            ! 16 Height of 1st aux. heater
1.1            ! 17 Height of 1st thermostat
0              ! 18 Set point temperature for element 1
3              ! 19 Deadband for heating element 1
0              ! 20 Maximum heating rate of element 1
1              ! 21 Height of heating element 2
1              ! 22 Height of thermostat 2
0              ! 23 Set point temperature for element 2
3              ! 24 Deadband for heating element 2
0              ! 25 Maximum heating rate of element 2
0              ! 26 Overall loss coefficient for gas flue
20             ! 27 Flue temperature
```

```
6              ! 28 Fraction of critical timestep
0              ! 29 Gas heater?
0              ! 30 Number of internal heat exchangers
0              ! 31 Equal sized nodes
0              ! 32 Uniform tank losses
INPUTS 9
16,2           ! ToTank:Outlet flow rate ->Flow rate at inlet 1
12,2           ! FlowMix:FLHOT ->Flow rate at outlet 1
12,2           ! FlowMix:FLHOT ->Flow rate at inlet 2
0,0            ! [unconnected] Flow rate at outlet 2
16,1           ! ToTank:Outlet temperature ->Temperature at inlet 1
25,5           ! Mains:Mains water temperature ->Temperature at inlet 2
0,0            ! [unconnected] Environment temperature
0,0            ! [unconnected] Control signal for element 1
0,0            ! [unconnected] Control signal for element 2
*** INITIAL INPUT VALUES
0 0 0 -2 TA TA TA 1 1
DERIVATIVES 30
TA             ! 1 Initial temperature of node-1
TA             ! 2 Initial temperature of node-2
TA             ! 3 Initial temperature of node-3
TA             ! 4 Initial temperature of node-4
TA             ! 5 Initial temperature of node-5
TA             ! 6 Initial temperature of node-6
TA             ! 7 Initial temperature of node-7
TA             ! 8 Initial temperature of node-8
TA             ! 9 Initial temperature of node-9
TA             ! 10 Initial temperature of node-10
TA             ! 11 Initial temperature of node-11
TA             ! 12 Initial temperature of node-12
TA             ! 13 Initial temperature of node-13
TA             ! 14 Initial temperature of node-14
TA             ! 15 Initial temperature of node-15
TA             ! 16 Initial temperature of node-16
TA             ! 17 Initial temperature of node-17
TA             ! 18 Initial temperature of node-18
TA             ! 19 Initial temperature of node-19
TA             ! 20 Initial temperature of node-20
TA             ! 21 Initial temperature of node-21
TA             ! 22 Initial temperature of node-22
TA             ! 23 Initial temperature of node-23
TA             ! 24 Initial temperature of node-24
TA             ! 25 Initial temperature of node-25
TA             ! 26 Initial temperature of node-26
TA             ! 27 Initial temperature of node-27
TA             ! 28 Initial temperature of node-28
TA             ! 29 Initial temperature of node-29
TA             ! 30 Initial temperature of node-30
*------------------------------------------------------------------------------

* Model "Aux Tank" (Type 60)
*

UNIT 29 TYPE 60        Aux Tank
*$UNIT_NAME Aux Tank
*$MODEL .\Thermal Storage\Detailed Fluid Storage Tank\Vertical Cylinder\Uniform Losses
and Node Heights\1 Inlet, 1 Outlet\Type60d.tmf
*$POSITION 772 690
*$LAYER Water Loop #
PARAMETERS 32
2              ! 1 User-specified inlet positions
0.17           ! 2 Tank volume
1              ! 3 Tank height
-1             ! 4 Tank perimeter
0.05           ! 5 Height of flow inlet 1
1              ! 6 Height of flow outlet 1
-1             ! 7 Not used (inlet 2)
```

```
-1             ! 8 Not used (outlet 2)
4.18           ! 9 Fluid specific heat
991            ! 10 Fluid density
4.356          ! 11 Tank loss coefficient
2.2752         ! 12 Fluid thermal conductivity
0              ! 13 Destratification conductivity
100            ! 14 Boiling temperature
1              ! 15 Auxiliary heater mode
.5             ! 16 Height of 1st aux. heater
.5             ! 17 Height of 1st thermostat
57             ! 18 Set point temperature for element 1
3              ! 19 Deadband for heating element 1
10799.999714          ! 20 Maximum heating rate of element 1
0              ! 21 Height of heating element 2
0              ! 22 Height of thermostat 2
57             ! 23 Set point temperature for element 2
2              ! 24 Deadband for heating element 2
0              ! 25 Maximum heating rate of element 2
0              ! 26 Overall loss coefficient for gas flue
20             ! 27 Flue temperature
6              ! 28 Fraction of critical timestep
0              ! 29 Gas heater?
0              ! 30 Number of internal heat exchangers
0              ! 31 Equal sized nodes
0              ! 32 Uniform tank losses
INPUTS 9
15,2           ! Solar Tank:Flowrate at outlet 1 ->Flow rate at inlet 1
0,0            ! [unconnected] Flow rate at outlet 1
0,0            ! [unconnected] Not used (flow inlet 2)
0,0            ! [unconnected] Not used (flow outlet 2)
15,5           ! Solar Tank:Temperature of outlet flow 1 ->Temperature at inlet 1
0,0            ! [unconnected] Not used (temp inlet 2)
0,0            ! [unconnected] Environment temperature
0,0            ! [unconnected] Control signal for element 1
0,0            ! [unconnected] Control signal for element 2
*** INITIAL INPUT VALUES
0 -2 -1 -1 20 20 22 1 1
DERIVATIVES 10
TA             ! 1 Initial temperature of node-1
TA             ! 2 Initial temperature of node-2
TA             ! 3 Initial temperature of node-3
TA             ! 4 Initial temperature of node-4
TA             ! 5 Initial temperature of node-5
TA             ! 6 Initial temperature of node-6
TA             ! 7 Initial temperature of node-7
TA             ! 8 Initial temperature of node-8
TA             ! 9 Initial temperature of node-9
TA             ! 10 Initial temperature of node-10
*------------------------------------------------------------------------------

* EQUATIONS "Draw"
*
EQUATIONS 2
DailyLoad = 225*4*0.991
Draw = [54,1]*DailyLoad
*$UNIT_NAME Draw
*$LAYER Water Loop
*$POSITION 999 630

*------------------------------------------------------------------------------


* Model "FlowMix" (Type 178)
*

UNIT 12 TYPE 178       FlowMix
*$UNIT_NAME FlowMix
```

```
*$MODEL .\Hydronics\Flow Mixer\Other Fluids\Type178.tmf
*$POSITION 927 672
*$LAYER Main #
PARAMETERS 1
55             ! 1 TSET
INPUTS 3
25,5           ! Mains:Mains water temperature ->TCOLD
29,5           ! Aux Tank:Temperature of outlet flow 1 ->THOT
Draw           ! Draw:Draw ->FLTAP
*** INITIAL INPUT VALUES
15 20 0
*------------------------------------------------------------------------------

* Model "Type2b-2" (Type 2)
*

UNIT 40 TYPE 2  Type2b-2
*$UNIT_NAME Type2b-2
*$MODEL .\Controllers\Differential Controller w_ Hysteresis\for Temperatures\Solver 0
(Successive Substitution) Control Strategy\Type2b.tmf
*$POSITION 138 626
*$LAYER Main #
*$# NOTE: This control strategy can only be used with solver 0 (Successive substitution)
*$#
PARAMETERS 2
5              ! 1 No. of oscillations
90             ! 2 High limit cut-out
INPUTS 6
4,1            ! Panels:Outlet temperature ->Upper input temperature Th
15,6           ! Solar Tank:Temperature of outlet flow 2 ->Lower input temperature Tl
15,5           ! Solar Tank:Temperature of outlet flow 1 ->Monitoring temperature Tin
40,1           ! Type2b-2:Output control function ->Input control function
0,0            ! [unconnected] Upper dead band dT
0,0            ! [unconnected] Lower dead band dT
*** INITIAL INPUT VALUES
TA TA TA 0 10 3
*------------------------------------------------------------------------------

* EQUATIONS "Equa-2"
*
EQUATIONS 7
kWh2 = [49,6]/3600
kWh3 = [4,3]/3600
kWh4 = [12,3] / 3600
kWh5 = [29,12]/3600
kWh6 = [24,18] / 3600
kWh7 = [15,7]/3600
kWh8 = [29,12]/3600
*$UNIT_NAME Equa-2
*$LAYER Main
*$POSITION 219 178

*------------------------------------------------------------------------------


* Model "IntSum-2" (Type 24)
*

UNIT 42 TYPE 24         IntSum-2
*$UNIT_NAME IntSum-2
*$MODEL .\Utility\Integrators\Quantity Integrator\Type24.tmf
*$POSITION 189 111
*$LAYER Main #
PARAMETERS 2
8760           ! 1 Integration period
0              ! 2 Relative or absolute start time
INPUTS 10
```

```
0,0             ! [unconnected] Input to be integrated-1
kWh2            ! Equa-2:kWh2 ->Input to be integrated-2
kWh3            ! Equa-2:kWh3 ->Input to be integrated-3
0,0             ! [unconnected] Input to be integrated-4
kWh4            ! Equa-2:kWh4 ->Input to be integrated-5
kWh5            ! Equa-2:kWh5 ->Input to be integrated-6
kWh6            ! Equa-2:kWh6 ->Input to be integrated-7
kWh7            ! Equa-2:kWh7 ->Input to be integrated-8
kWh8            ! Equa-2:kWh8 ->Input to be integrated-9
0,0             ! [unconnected] Input to be integrated-10
*** INITIAL INPUT VALUES
0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
*------------------------------------------------------------------------------

* Model "Solar-4" (Type 65)
*

UNIT 59 TYPE 65         Solar-4
*$UNIT_NAME Solar-4
*$MODEL .\Output\Online Plotter\Online Plotter Without File\Type65d.tmf
*$POSITION 880 882
*$LAYER Main #
PARAMETERS 12
10              ! 1 Nb. of left-axis variables
10              ! 2 Nb. of right-axis variables
0               ! 3 Left axis minimum
100             ! 4 Left axis maximum
0               ! 5 Right axis minimum
100             ! 6 Right axis maximum
1               ! 7 Number of plots per simulation
12              ! 8 X-axis gridpoints
0               ! 9 Shut off Online w/o removing
-1              ! 10 Logical unit for output file
0               ! 11 Output file units
0               ! 12 Output file delimiter
INPUTS 20
15,22           ! Solar Tank:Tank temperature - top ->Left axis variable-1
15,25           ! Solar Tank:Temperature of node 1+-2 ->Left axis variable-2
15,27           ! Solar Tank:Temperature of node 1+-4 ->Left axis variable-3
15,29           ! Solar Tank:Temperature of node 1+-6 ->Left axis variable-4
15,31           ! Solar Tank:Temperature of node 1+-8 ->Left axis variable-5
15,33           ! Solar Tank:Temperature of node 1+-10 ->Left axis variable-6
15,35           ! Solar Tank:Temperature of node 1+-12 ->Left axis variable-7
15,37           ! Solar Tank:Temperature of node 1+-14 ->Left axis variable-8
15,39           ! Solar Tank:Temperature of node 1+-16 ->Left axis variable-9
15,41           ! Solar Tank:Temperature of node 1+-18 ->Left axis variable-10
15,43           ! Solar Tank:Temperature of node 1+-20 ->Right axis variable-1
15,45           ! Solar Tank:Temperature of node 1+-22 ->Right axis variable-2
15,47           ! Solar Tank:Temperature of node 1+-24 ->Right axis variable-3
15,49           ! Solar Tank:Temperature of node 1+-26 ->Right axis variable-4
15,51           ! Solar Tank:Temperature of node 1+-28 ->Right axis variable-5
0,0             ! [unconnected] Right axis variable-6
0,0             ! [unconnected] Right axis variable-7
0,0             ! [unconnected] Right axis variable-8
0,0             ! [unconnected] Right axis variable-9
15,23           ! Solar Tank:Tank temperature - bottom ->Right axis variable-10
*** INITIAL INPUT VALUES
Temp Temp Temp Temp Temp Temp Temp Temp Temp Temp Temp Temp Temp Temp Temp
Temp Temp Temp Temp Temp
LABELS  3
"Temperatures (C)"
"Insolation (kJ/hr-m^2)"
"Collector"
*------------------------------------------------------------------------------

* Model "Solar-3" (Type 65)
*
```

```
UNIT 46 TYPE 65         Solar-3
*$UNIT_NAME Solar-3
*$MODEL .\Output\Online Plotter\Online Plotter Without File\Type65d.tmf
*$POSITION 358 872
*$LAYER Main #
PARAMETERS 12
1              ! 1 Nb. of left-axis variables
4              ! 2 Nb. of right-axis variables
-1             ! 3 Left axis minimum
2              ! 4 Left axis maximum
-10            ! 5 Right axis minimum
10             ! 6 Right axis maximum
1              ! 7 Number of plots per simulation
12             ! 8 X-axis gridpoints
0              ! 9 Shut off Online w/o removing
-1             ! 10 Logical unit for output file
0              ! 11 Output file units
0              ! 12 Output file delimiter
INPUTS 5
49,10          ! Type289-NCHX:FOO_OUT ->Left axis variable
0,0            ! [unconnected] Right axis variable-1
0,0            ! [unconnected] Right axis variable-2
0,0            ! [unconnected] Right axis variable-3
0,0            ! [unconnected] Right axis variable-4
*** INITIAL INPUT VALUES
FOO PUMP AUX Tempering Tank
LABELS  3
"Temperatures (C)"
"Insolation (kJ/hr-m^2)"
"Collector"
*------------------------------------------------------------------------------

* Model "Solar-2" (Type 65)
*

UNIT 44 TYPE 65         Solar-2
*$UNIT_NAME Solar-2
*$MODEL .\Output\Online Plotter\Online Plotter Without File\Type65d.tmf
*$POSITION 80 104
*$LAYER Main #
PARAMETERS 12
5              ! 1 Nb. of left-axis variables
2              ! 2 Nb. of right-axis variables
0              ! 3 Left axis minimum
10000          ! 4 Left axis maximum
0.0            ! 5 Right axis minimum
10000          ! 6 Right axis maximum
1              ! 7 Number of plots per simulation
12             ! 8 X-axis gridpoints
0              ! 9 Shut off Online w/o removing
-1             ! 10 Logical unit for output file
0              ! 11 Output file units
0              ! 12 Output file delimiter
INPUTS 7
42,1           ! IntSum-2:Result of integration-1 ->Left axis variable-1
42,2           ! IntSum-2:Result of integration-2 ->Left axis variable-2
42,3           ! IntSum-2:Result of integration-3 ->Left axis variable-3
42,6           ! IntSum-2:Result of integration-6 ->Left axis variable-4
42,8           ! IntSum-2:Result of integration-8 ->Left axis variable-5
42,4           ! IntSum-2:Result of integration-4 ->Right axis variable-1
42,5           ! IntSum-2:Result of integration-5 ->Right axis variable-2
*** INITIAL INPUT VALUES
TColl_in TColl_in TColl_in AuxDHW DHWLosses SH DHW
LABELS  3
"Temperatures (C)"
"Insolation (kJ/hr-m^2)"
```

```
"Collector"
*------------------------------------------------------------------------------

* Model "PrintSum-2" (Type 25)
*

UNIT 45 TYPE 25        PrintSum-2
*$UNIT_NAME PrintSum-2
*$MODEL .\Output\Printer\User-Supplied Units\Type25b.tmf
*$POSITION 87 178
*$LAYER Main #
PARAMETERS 10
8760           ! 1 Printing interval
START          ! 2 Start time
STOP           ! 3 Stop time
45             ! 4 Logical unit
1              ! 5 Units printing mode
0              ! 6 Relative or absolute start time
1              ! 7 Overwrite or Append
-1             ! 8 Print header
0              ! 9 Delimiter
1              ! 10 Print labels
INPUTS 11
42,1           ! IntSum-2:Result of integration-1 ->Input to be printed-1
42,2           ! IntSum-2:Result of integration-2 ->Input to be printed-2
42,3           ! IntSum-2:Result of integration-3 ->Input to be printed-3
42,4           ! IntSum-2:Result of integration-4 ->Input to be printed-4
42,5           ! IntSum-2:Result of integration-5 ->Input to be printed-5
42,7           ! IntSum-2:Result of integration-7 ->Input to be printed-6
42,9           ! IntSum-2:Result of integration-9 ->Input to be printed-7
42,10          ! IntSum-2:Result of integration-10 ->Input to be printed-8
CollFlow              ! Variables-2:CollFlow ->Input to be printed-9
angle          ! Variables-2:angle ->Input to be printed-10
test           ! Variables-2:test ->Input to be printed-11
*** INITIAL INPUT VALUES
SH_SOLAR DHW_SOLAR Total_Coll SH_LOAD DHW_LOAD Gt_tilt DHW_AUX SH_AUX
Coll_Flow ANGLE TEST
kWh kWh kWh kWh kWh kWh/m2 kWh kWh kg/hr ° -
*** External files
ASSIGN "1SDHW1a5par.out" 45
*|? Output file for printed results |1000
*------------------------------------------------------------------------------

* Model "Solar-5" (Type 65)
*

UNIT 61 TYPE 65        Solar-5
*$UNIT_NAME Solar-5
*$MODEL .\Output\Online Plotter\Online Plotter Without File\Type65d.tmf
*$POSITION 859 733
*$LAYER Main #
PARAMETERS 12
10             ! 1 Nb. of left-axis variables
2              ! 2 Nb. of right-axis variables
0              ! 3 Left axis minimum
100            ! 4 Left axis maximum
0              ! 5 Right axis minimum
100000         ! 6 Right axis maximum
1              ! 7 Number of plots per simulation
12             ! 8 X-axis gridpoints
0              ! 9 Shut off Online w/o removing
-1             ! 10 Logical unit for output file
0              ! 11 Output file units
0              ! 12 Output file delimiter
INPUTS 12
29,22          ! Aux Tank:Tank temperature - top ->Left axis variable-1
29,24          ! Aux Tank:Temperature of node 1+-1 ->Left axis variable-2
```

```
29,25          ! Aux Tank:Temperature of node 1+-2 ->Left axis variable-3
29,26          ! Aux Tank:Temperature of node 1+-3 ->Left axis variable-4
29,27          ! Aux Tank:Temperature of node 1+-4 ->Left axis variable-5
29,28          ! Aux Tank:Temperature of node 1+-5 ->Left axis variable-6
29,29          ! Aux Tank:Temperature of node 1+-6 ->Left axis variable-7
29,30          ! Aux Tank:Temperature of node 1+-7 ->Left axis variable-8
29,31          ! Aux Tank:Temperature of node 1+-8 ->Left axis variable-9
29,23          ! Aux Tank:Tank temperature - bottom ->Left axis variable-10
29,13          ! Aux Tank:Element 1 power ->Right axis variable-1
15,5           ! Solar Tank:Temperature of outlet flow 1 ->Right axis variable-2
*** INITIAL INPUT VALUES
Temp Temp Temp Temp Temp Temp Temp Temp Temp Temp Temp Temp
LABELS  3
"Temperatures (C)"
"Insolation (kJ/hr-m^2)"
"temp"
*------------------------------------------------------------------------------

* Model "Type272-Min-Iteration" (Type 272)
*

UNIT 63 TYPE 272       Type272-Min-Iteration
*$UNIT_NAME Type272-Min-Iteration
*$MODEL .\My Components\Type272-Min-Iteration.tmf
*$POSITION 1074 900
*$LAYER Main #
PARAMETERS 1
0              ! 1 C_MIN
INPUTS 2
63,1           ! Type272-Min-Iteration:TIME_OUT ->TIME_OLD
63,2           ! Type272-Min-Iteration:C_OUT ->C_OLD
*** INITIAL INPUT VALUES
0 0
*------------------------------------------------------------------------------

* EQUATIONS "Variables-2"
*
CONSTANTS 3
CollFlow = 60
angle = 0
test = 3
*$UNIT_NAME Variables-2
*$LAYER Main
*$POSITION 88 274

*------------------------------------------------------------------------------


END
```

C.3 Stand-Alone Space Heating System – Configuration (iv)

This model configuration is the stand-alone space heating system with a glazed solar collector and a natural convection heat exchanger.

Table C.3: SSH(iv) - TRNSYS Model

```
VERSION 16.1
********************************************************************************
*** TRNSYS input file (deck) generated by TrnsysStudio
*** on Friday, November 18, 2011 at 16:04
*** from TrnsysStudio project: C:\Program Files\Trnsys16\MyProjects\ATHESIS\2SSH1d6.TPF
***
*** If you edit this file, use the File/Import TRNSYS Input File function in
*** TrnsysStudio to update the project.
***
*** If you have problems, questions or suggestions please contact your local
*** TRNSYS distributor or mailto:software@cstb.fr
***
********************************************************************************


********************************************************************************
*** Units
********************************************************************************

********************************************************************************
*** Control cards
********************************************************************************
* START, STOP and STEP
CONSTANTS 3
START=0
STOP=8760
STEP=0.05
* User defined CONSTANTS

SIMULATION      START   STOP   STEP   ! Start time   End time       Time step
TOLERANCES 0.01 0.05                  ! Integration   Convergence
LIMITS 1000 10000 30                         ! Max iterations      Max warnings   Trace
limit
DFQ 1                                 ! TRNSYS numerical integration solver method
WIDTH 132                             ! TRNSYS output file width, number of characters
LIST                                  ! NOLIST statement
                                      ! MAP statement
SOLVER 0 1 1                          ! Solver statement    Minimum relaxation factor
       Maximum relaxation factor
NAN_CHECK 0                           ! Nan DEBUG statement
OVERWRITE_CHECK 0                     ! Overwrite DEBUG statement
TIME_REPORT 0                ! disable time report
EQSOLVER 0                            ! EQUATION SOLVER statement

* Model "Toronto" (Type 109)
*

UNIT 24 TYPE 109        Toronto
*$UNIT_NAME Toronto
*$MODEL .\Weather Data Reading and Processing\Standard Format\TMY2\Type109-TMY2.tmf
*$POSITION 107 381
*$LAYER Main #
PARAMETERS 4
2              ! 1 Data Reader Mode
43             ! 2 Logical unit
4              ! 3 Sky model for diffuse radiation
```

```
1              ! 4 Tracking mode
INPUTS 3
0,0            ! [unconnected] Ground reflectance
0,0            ! [unconnected] Slope of surface
0,0            ! [unconnected] Azimuth of surface
*** INITIAL INPUT VALUES
0.2 angle 0
*** External files
ASSIGN "C:\Program Files\Trnsys16\Weather\Meteonorm\North-America\CA-ON-Toronto-
716240.tm2" 43
*|? Weather data file |1000
*------------------------------------------------------------------------------

* EQUATIONS "Variables"
*
EQUATIONS 5
CPGE = 3.648
US1 = 0.1*3.6
US2 = 0.8475*3.6 !R-6.7, From Rheem Fury Spec Sheet
L_pipe = 7.6 !25', SRCC
TA = 20
*$UNIT_NAME Variables
*$LAYER Main
*$POSITION 56 818

*------------------------------------------------------------------------------


* Model "Weather input" (Type 9)
*

UNIT 50 TYPE 9  Weather input
*$UNIT_NAME Weather input
*$MODEL .\Utility\Data Readers\Generic Data Files\First Line is Simulation Start\Free
Format\Type9a.tmf
*$POSITION 1116 40
*$LAYER Main #
PARAMETERS 14
2              ! 1 Mode
2              ! 2 Header Lines to Skip
2              ! 3 No. of values to read
24             ! 4 Time interval of data
-1             ! 5 Interpolate or not?-1
1              ! 6 Multiplication factor-1
0              ! 7 Addition factor-1
1              ! 8 Average or instantaneous value-1
-1             ! 9 Interpolate or not?-2
1              ! 10 Multiplication factor-2
0              ! 11 Addition factor-2
1              ! 12 Average or instantaneous value-2
48             ! 13 Logical unit for input file
-1             ! 14 Free format mode
*** External files
ASSIGN "DDCalc.in" 48
*|? Input file name |1000
*------------------------------------------------------------------------------

* Model "Type71 HP200 30" (Type 71)
*

UNIT 49 TYPE 71        Type71 HP200 30
*$UNIT_NAME Type71 HP200 30
*$MODEL .\Solar Thermal Collectors\Evacuated Tube Collector\Type71.tmf
*$POSITION 120 498
*$LAYER Main #
PARAMETERS 11
1              ! 1 Number in series
```

```
12             ! 2 Collector area
3.53           ! 3 Fluid specific heat
1              ! 4 Efficiency mode
19.44          ! 5 Flow rate at test conditions
0.549          ! 6 Intercept efficiency
5.2506         ! 7 Negative of first order efficiency coeficient
0.015696              ! 8 Negative of second order efficiency coeficient
51             ! 9 Logical unit of file containing biaxial IAM data
8              ! 10 Number of longitudinal angles for which IAMs are provided
8              ! 11 Number of transverse angles for which IAMs are provided
INPUTS 10
7,1            ! ToColl:Outlet temperature ->Inlet temperature
7,2            ! ToColl:Outlet flow rate ->Inlet flowrate
24,1           ! Toronto:Ambient temperature ->Ambient temperature
24,18          ! Toronto:total radiation on tilted surface ->Incident radiation
24,20          ! Toronto:sky diffuse radiation on tilted surface ->Incident diffuse
radiation
24,22          ! Toronto:angle of incidence for tilted surface  ->Solar incidence angle
24,10          ! Toronto:solar zenith angle ->Solar zenith angle
24,11          ! Toronto:solar azimuth angle ->Solar azimuth angle
24,23          ! Toronto:slope of tilted surface ->Collector slope
0,0            ! [unconnected] Collector azimuth
*** INITIAL INPUT VALUES
20.0 100.0 10.0 0. 0 0.0 0.0 0.0 20 0.0
*** External files
ASSIGN "Kingspan Data File.txt" 51
*|? What file contains the 2D IAM data? |1000
*------------------------------------------------------------------------------

* Model "ToNCHX" (Type 31)
*

UNIT 9 TYPE 31  ToNCHX
*$UNIT_NAME ToNCHX
*$MODEL .\Hydronics\Pipe_Duct\Type31.tmf
*$POSITION 280 530
*$LAYER Water Loop #
PARAMETERS 6
0.007725              ! 1 Inside diameter
L_pipe         ! 2 Pipe length
20             ! 3 Loss coefficient
1044           ! 4 Fluid density
3.53           ! 5 Fluid specific heat
TA             ! 6 Initial fluid temperature
INPUTS 3
49,1           ! Type71 HP200 30:Outlet temperature ->Inlet temperature
49,2           ! Type71 HP200 30:Outlet flowrate ->Inlet flow rate
0,0            ! [unconnected] Environment temperature
*** INITIAL INPUT VALUES
TA 0 TA
*------------------------------------------------------------------------------

* EQUATIONS "Variables-4"
*
EQUATIONS 1
out1 = [9,2] / 3
*$UNIT_NAME Variables-4
*$LAYER Main
*$POSITION 451 466

*------------------------------------------------------------------------------


* Model "Type289-NCHX" (Type 289)
*

UNIT 38 TYPE 289       Type289-NCHX
```

```
*$UNIT_NAME Type289-NCHX
*$MODEL .\My Components\Type289-NCHX.tmf
*$POSITION 341 420
*$LAYER Main #
PARAMETERS 5
3.53           ! 1 CP_HOT
4.18           ! 2 CP_COLD
-0.3488        ! 3 C
1.1402         ! 4 D
0              ! 5 E
INPUTS 9
9,1            ! ToNCHX:Outlet temperature ->THOT_IN
out1           ! Variables-4:out1 ->FHOT_IN
52,6           ! Solar Tank-2:Temperature of outlet flow 2 ->TCOLD_IN
36,1           ! Type293-NCHXFlow:FLWNC ->FCOLD_IN
0,0            ! [unconnected] T_AMB
0,0            ! [unconnected] TEMP_START
0,0            ! [unconnected] FLOW_START
0,0            ! [unconnected] FOO_IN
0,0            ! [unconnected] BAR_IN
*** INITIAL INPUT VALUES
TA 0 14.4 0 TA -1 0.001 0 0
*------------------------------------------------------------------------------

* Model "Type293-NCHXFlow" (Type 293)
*

UNIT 36 TYPE 293        Type293-NCHXFlow
*$UNIT_NAME Type293-NCHXFlow
*$MODEL .\My Components\Type293-NCHXFlow.tmf
*$POSITION 461 345
*$LAYER Main #
PARAMETERS 5
1.5            ! 1 HT
2.388          ! 2 A
0.6505         ! 3 B
0.29           ! 4 HEX
0              ! 5 RELAX
INPUTS 5
52,6           ! Solar Tank-2:Temperature of outlet flow 2 ->TCIN
38,3           ! Type289-NCHX:TCOLD_OUT ->TCOUT
52,17          ! Solar Tank-2:Average tank temperature ->TTAVE
TPAVG_AVG               ! TPAVG:TPAVG_AVG ->TPAVE
36,3           ! Type293-NCHXFlow:THXOLD ->TCOLD
*** INITIAL INPUT VALUES
14.4 TA TA TA TA
*------------------------------------------------------------------------------

* EQUATIONS "TPAVG"
*
EQUATIONS 1
TPAVG_AVG = ([38,3] -1) ![33,6]
*$UNIT_NAME TPAVG
*$LAYER Main
*$POSITION 319 200

*------------------------------------------------------------------------------



* EQUATIONS "Variables-3"
*
EQUATIONS 1
out2 = [33,2] * 3
*$UNIT_NAME Variables-3
*$LAYER Main
*$POSITION 430 168
```

```
*------------------------------------------------------------------------------


* Model "ToTank" (Type 31)
*

UNIT 33 TYPE 31         ToTank
*$UNIT_NAME ToTank
*$MODEL .\Hydronics\Pipe_Duct\Type31.tmf
*$POSITION 436 249
*$LAYER Main #
PARAMETERS 6
0.018          ! 1 Inside diameter
0.60           ! 2 Pipe length
4              ! 3 Loss coefficient
991            ! 4 Fluid density
4.18           ! 5 Fluid specific heat
TA             ! 6 Initial fluid temperature
INPUTS 3
38,3           ! Type289-NCHX:TCOLD_OUT ->Inlet temperature
38,4           ! Type289-NCHX:FCOLD_OUT ->Inlet flow rate
0,0            ! [unconnected] Environment temperature
*** INITIAL INPUT VALUES
TA 0 TA
*------------------------------------------------------------------------------

* Model "Pump" (Type 3)
*

UNIT 6 TYPE 3   Pump
*$UNIT_NAME Pump
*$MODEL .\Hydronics\Pumps\Single Speed\Type3b.tmf
*$POSITION 284 733
*$LAYER Controls #
PARAMETERS 5
CollFlow               ! 1 Maximum flow rate
3.53           ! 2 Fluid specific heat
0              ! 3 Maximum power
0              ! 4 Conversion coefficient
0              ! 5 Power coefficient
INPUTS 3
38,1           ! Type289-NCHX:THOT_OUT ->Inlet fluid temperature
9,2            ! ToNCHX:Outlet flow rate ->Inlet mass flow rate
5,1            ! Type2b:Output control function ->Control signal
*** INITIAL INPUT VALUES
TA 0 1.0
*------------------------------------------------------------------------------

* Model "ToColl" (Type 31)
*

UNIT 7 TYPE 31  ToColl
*$UNIT_NAME ToColl
*$MODEL .\Hydronics\Pipe_Duct\Type31.tmf
*$POSITION 116 692
*$LAYER Water Loop #
PARAMETERS 6
0.007725               ! 1 Inside diameter
L_pipe         ! 2 Pipe length
20             ! 3 Loss coefficient
1044           ! 4 Fluid density
3.53           ! 5 Fluid specific heat
TA             ! 6 Initial fluid temperature
INPUTS 3
6,1            ! Pump:Outlet fluid temperature ->Inlet temperature
6,2            ! Pump:Outlet flow rate ->Inlet flow rate
0,0            ! [unconnected] Environment temperature
```

```
*** INITIAL INPUT VALUES
TA 0 TA
*------------------------------------------------------------------------------

* Model "Type266-ModifiedHDH" (Type 266)
*

UNIT 37 TYPE 266        Type266-ModifiedHDH
*$UNIT_NAME Type266-ModifiedHDH
*$MODEL .\My Components\Type266-ModifiedHDH.tmf
*$POSITION 1118 196
*$LAYER Main #
PARAMETERS 2
18             ! 1 T_REF
450            ! 2 VOL
INPUTS 2
24,1           ! Toronto:Ambient temperature ->T_AMB
50,2           ! Weather input:Output 2 ->T_AVE
*** INITIAL INPUT VALUES
0 0
*------------------------------------------------------------------------------

* Model "Type270-SH-Signal" (Type 270)
*

UNIT 60 TYPE 270        Type270-SH-Signal
*$UNIT_NAME Type270-SH-Signal
*$MODEL .\My Components\Type270-SH-Signal.tmf
*$POSITION 979 185
*$LAYER Main #
PARAMETERS 6
0.2            ! 1 R_FLOOR
4.18           ! 2 CP
0              ! 3 DTEMP_SET
40             ! 4 TIN_SET
160            ! 5 A_HEATED
250            ! 6 FLOW_MAX
INPUTS 4
37,1           ! Type266-ModifiedHDH:Q_KW ->Q_SH_KW
0,0            ! [unconnected] T_ROOM
0,0            ! [unconnected] FOO_IN
0,0            ! [unconnected] BAR_IN
*** INITIAL INPUT VALUES
0 20 0 0
*------------------------------------------------------------------------------

* Model "Type110" (Type 110)
*

UNIT 55 TYPE 110        Type110
*$UNIT_NAME Type110
*$MODEL .\Hydronics\Pumps\Variable Speed\Type110.tmf
*$POSITION 545 136
*$LAYER Main #
*$# VARIABLE-SPEED PUMP
PARAMETERS 6
250            ! 1 Rated flow rate
4.18           ! 2 Fluid specific heat
0              ! 3 Rated power
0.0            ! 4 Motor heat loss fraction
1              ! 5 Number of power coefficients
0              ! 6 Power coefficient
INPUTS 5
58,1           ! Type11h:Outlet temperature ->Inlet fluid temperature
58,2           ! Type11h:Outlet flow rate ->Inlet fluid flow rate
60,1           ! Type270-SH-Signal:PUMP_SIGNAL ->Control signal
0,0            ! [unconnected] Total pump efficiency
```

```
0,0            ! [unconnected] Motor efficiency
*** INITIAL INPUT VALUES
40 0.0 1.0 1 1
*------------------------------------------------------------------------------

* Model "Type268-AuxSH" (Type 268)
*

UNIT 47 TYPE 268       Type268-AuxSH
*$UNIT_NAME Type268-AuxSH
*$MODEL .\My Components\Type268-AuxSH.tmf
*$POSITION 822 46
*$LAYER Main #
PARAMETERS 1
4.18           ! 1 CP
INPUTS 3
55,1           ! Type110:Outlet fluid temperature ->TEMP_IN
55,2           ! Type110:Outlet flow rate ->FLOW_IN
60,2           ! Type270-SH-Signal:TIN_IDEAL ->T_SET
*** INITIAL INPUT VALUES
0 0 0
*------------------------------------------------------------------------------

* Model "Type271-HydronicFloor3" (Type 271)
*

UNIT 62 TYPE 271       Type271-HydronicFloor3
*$UNIT_NAME Type271-HydronicFloor3
*$MODEL .\My Components\Type271-HydronicFloor3.tmf
*$POSITION 845 302
*$LAYER Main #
PARAMETERS 6
4.18           ! 1 CP
0.2            ! 2 R_FLOOR
160            ! 3 A_HEATED
250            ! 4 FLOW_MAX
0              ! 5 DTEMP_SET
40             ! 6 TIN_SET
INPUTS 9
47,2           ! Type268-AuxSH:FLOW_OUT ->FLOW_IN
47,1           ! Type268-AuxSH:TEMP_OUT ->TEMP_IN
0,0            ! [unconnected] T_ROOM
37,1           ! Type266-ModifiedHDH:Q_KW ->Q_SH_KW
60,4           ! Type270-SH-Signal:FLOW_IDEAL ->IDEAL_FLOW
60,2           ! Type270-SH-Signal:TIN_IDEAL ->IDEAL_TIN
60,3           ! Type270-SH-Signal:TOUT_IDEAL ->IDEAL_TOUT
0,0            ! [unconnected] FOO_IN
0,0            ! [unconnected] BAR_IN
*** INITIAL INPUT VALUES
0 0 20 0 0 0 0 0 0
*------------------------------------------------------------------------------

* Model "Type269-SHTempering3" (Type 269)
*

UNIT 48 TYPE 269       Type269-SHTempering3
*$UNIT_NAME Type269-SHTempering3
*$MODEL .\My Components\Type269-SHTempering3.tmf
*$POSITION 704 420
*$LAYER Main #
INPUTS 3
62,2           ! Type271-HydronicFloor3:TEMP_OUT ->FLOOR_TEMP
52,5           ! Solar Tank-2:Temperature of outlet flow 1 ->TANK_TEMP
60,2           ! Type270-SH-Signal:TIN_IDEAL ->SET_TEMP
*** INITIAL INPUT VALUES
0 0 0
*------------------------------------------------------------------------------
```

```
* Model "Type11f" (Type 11)
*

UNIT 41 TYPE 11        Type11f
*$UNIT_NAME Type11f
*$MODEL .\Hydronics\Flow Diverter\Other Fluids\Type11f.tmf
*$POSITION 693 328
*$LAYER Water Loop #
PARAMETERS 1
2              ! 1 Controlled flow diverter mode
INPUTS 3
62,2           ! Type271-HydronicFloor3:TEMP_OUT ->Inlet temperature
62,3           ! Type271-HydronicFloor3:FLOW_OUT ->Inlet flow rate
48,1           ! Type269-SHTempering3:X ->Control signal
*** INITIAL INPUT VALUES
20.0 100.0 0.5
*------------------------------------------------------------------------------

* Model "Solar Tank-2" (Type 60)
*

UNIT 52 TYPE 60        Solar Tank-2
*$UNIT_NAME Solar Tank-2
*$MODEL .\Thermal Storage\Detailed Fluid Storage Tank\Uniform Cross Section\Uniform
Losses and Node Heights\2 Inlets, 2 Outlets\Type60s.tmf
*$POSITION 540 264
*$LAYER Main #
PARAMETERS 32
2              ! 1 User-specified inlet positions
0.81           ! 2 Tank volume
1.5            ! 3 Tank height
4.5            ! 4 Tank perimeter
1.5            ! 5 Height of flow inlet 1
1.5            ! 6 Height of flow outlet 1
0              ! 7 Height of flow inlet 2
0              ! 8 Height of flow outlet 2
4.18           ! 9 Fluid specific heat
991            ! 10 Fluid density
4.356          ! 11 Tank loss coefficient
2.2752         ! 12 Fluid thermal conductivity
0              ! 13 Destratification conductivity
100            ! 14 Boiling temperature
1              ! 15 Auxiliary heater mode
1.1            ! 16 Height of 1st aux. heater
1.1            ! 17 Height of 1st thermostat
0              ! 18 Set point temperature for element 1
3              ! 19 Deadband for heating element 1
0              ! 20 Maximum heating rate of element 1
1              ! 21 Height of heating element 2
1              ! 22 Height of thermostat 2
0              ! 23 Set point temperature for element 2
3              ! 24 Deadband for heating element 2
0              ! 25 Maximum heating rate of element 2
0              ! 26 Overall loss coefficient for gas flue
20             ! 27 Flue temperature
6              ! 28 Fraction of critical timestep
0              ! 29 Gas heater?
0              ! 30 Number of internal heat exchangers
0              ! 31 Equal sized nodes
0              ! 32 Uniform tank losses
INPUTS 9
out2           ! Variables-3:out2 ->Flow rate at inlet 1
0,0            ! [unconnected] Flow rate at outlet 1
41,4           ! Type11f:Flow rate at outlet 2 ->Flow rate at inlet 2
out2           ! Variables-3:out2 ->Flow rate at outlet 2
33,1           ! ToTank:Outlet temperature ->Temperature at inlet 1
```

```
41,3           ! Type11f:Temperature at outlet 2 ->Temperature at inlet 2
0,0            ! [unconnected] Environment temperature
0,0            ! [unconnected] Control signal for element 1
0,0            ! [unconnected] Control signal for element 2
*** INITIAL INPUT VALUES
0 -2 0 0 TA TA TA 1 1
DERIVATIVES 30
TA             ! 1 Initial temperature of node-1
TA             ! 2 Initial temperature of node-2
TA             ! 3 Initial temperature of node-3
TA             ! 4 Initial temperature of node-4
TA             ! 5 Initial temperature of node-5
TA             ! 6 Initial temperature of node-6
TA             ! 7 Initial temperature of node-7
TA             ! 8 Initial temperature of node-8
TA             ! 9 Initial temperature of node-9
TA             ! 10 Initial temperature of node-10
TA             ! 11 Initial temperature of node-11
TA             ! 12 Initial temperature of node-12
TA             ! 13 Initial temperature of node-13
TA             ! 14 Initial temperature of node-14
TA             ! 15 Initial temperature of node-15
TA             ! 16 Initial temperature of node-16
TA             ! 17 Initial temperature of node-17
TA             ! 18 Initial temperature of node-18
TA             ! 19 Initial temperature of node-19
TA             ! 20 Initial temperature of node-20
TA             ! 21 Initial temperature of node-21
TA             ! 22 Initial temperature of node-22
TA             ! 23 Initial temperature of node-23
TA             ! 24 Initial temperature of node-24
TA             ! 25 Initial temperature of node-25
TA             ! 26 Initial temperature of node-26
TA             ! 27 Initial temperature of node-27
TA             ! 28 Initial temperature of node-28
TA             ! 29 Initial temperature of node-29
TA             ! 30 Initial temperature of node-30
*------------------------------------------------------------------------------

* Model "Type11h" (Type 11)
*

UNIT 58 TYPE 11         Type11h
*$UNIT_NAME Type11h
*$MODEL .\Hydronics\Tee-Piece\Other Fluids\Type11h.tmf
*$POSITION 685 210
*$LAYER Water Loop #
PARAMETERS 1
1              ! 1 Tee piece mode
INPUTS 4
41,1           ! Type11f:Temperature at outlet 1 ->Temperature at inlet 1
41,2           ! Type11f:Flow rate at outlet 1 ->Flow rate at inlet 1
52,5           ! Solar Tank-2:Temperature of outlet flow 1 ->Temperature at inlet 2
52,2           ! Solar Tank-2:Flowrate at outlet 1 ->Flow rate at inlet 2
*** INITIAL INPUT VALUES
20.0 100.0 20.0 100.0
*------------------------------------------------------------------------------

* Model "Type2b" (Type 2)
*

UNIT 5 TYPE 2   Type2b
*$UNIT_NAME Type2b
*$MODEL .\Controllers\Differential Controller w_ Hysteresis\for Temperatures\Solver 0
(Successive Substitution) Control Strategy\Type2b.tmf
*$POSITION 170 626
*$LAYER Main #
```

```
*$# NOTE: This control strategy can only be used with solver 0 (Successive substitution)
*$#
PARAMETERS 2
5              ! 1 No. of oscillations
70             ! 2 High limit cut-out
INPUTS 6
49,1           ! Type71 HP200 30:Outlet temperature ->Upper input temperature Th
52,6           ! Solar Tank-2:Temperature of outlet flow 2 ->Lower input temperature Tl
52,5           ! Solar Tank-2:Temperature of outlet flow 1 ->Monitoring temperature Tin
5,1            ! Type2b:Output control function ->Input control function
0,0            ! [unconnected] Upper dead band dT
0,0            ! [unconnected] Lower dead band dT
*** INITIAL INPUT VALUES
TA TA TA 0 10 3
*------------------------------------------------------------------------------

* EQUATIONS "Equa-2"
*
EQUATIONS 3
kWh = [38,6]/3600*3
kWh3 = [49,3]/3600
kWh6 = [24,18] / 3600
*$UNIT_NAME Equa-2
*$LAYER Main
*$POSITION 217 178

*------------------------------------------------------------------------------


* Model "IntSum-2" (Type 24)
*

UNIT 42 TYPE 24         IntSum-2
*$UNIT_NAME IntSum-2
*$MODEL .\Utility\Integrators\Quantity Integrator\Type24.tmf
*$POSITION 189 111
*$LAYER Main #
PARAMETERS 2
8760           ! 1 Integration period
0              ! 2 Relative or absolute start time
INPUTS 10
kWh            ! Equa-2:kWh ->Input to be integrated-1
0,0            ! [unconnected] Input to be integrated-2
kWh3           ! Equa-2:kWh3 ->Input to be integrated-3
37,1           ! Type266-ModifiedHDH:Q_KW ->Input to be integrated-4
0,0            ! [unconnected] Input to be integrated-5
0,0            ! [unconnected] Input to be integrated-6
kWh6           ! Equa-2:kWh6 ->Input to be integrated-7
0,0            ! [unconnected] Input to be integrated-8
0,0            ! [unconnected] Input to be integrated-9
47,3           ! Type268-AuxSH:Q_OUT_KW ->Input to be integrated-10
*** INITIAL INPUT VALUES
0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
*------------------------------------------------------------------------------

* EQUATIONS "TPAVG-2"
*
EQUATIONS 4
DIFF = [55,2]-[58,2]
AUXDIFF = [55,2]-[47,2]
TemperingDIFF = [62,3] - [58,2]
TankDiff = [41,4] - [52,2]
*$UNIT_NAME TPAVG-2
*$LAYER Main
*$POSITION 202 946

*------------------------------------------------------------------------------
```

```
* Model "Solar-3" (Type 65)
*

UNIT 46 TYPE 65        Solar-3
*$UNIT_NAME Solar-3
*$MODEL .\Output\Online Plotter\Online Plotter Without File\Type65d.tmf
*$POSITION 358 872
*$LAYER Main #
PARAMETERS 12
1              ! 1 Nb. of left-axis variables
4              ! 2 Nb. of right-axis variables
-1             ! 3 Left axis minimum
2              ! 4 Left axis maximum
-10            ! 5 Right axis minimum
10             ! 6 Right axis maximum
1              ! 7 Number of plots per simulation
12             ! 8 X-axis gridpoints
0              ! 9 Shut off Online w/o removing
-1             ! 10 Logical unit for output file
0              ! 11 Output file units
0              ! 12 Output file delimiter
INPUTS 5
38,10          ! Type289-NCHX:FOO_OUT ->Left axis variable
DIFF           ! TPAVG-2:DIFF ->Right axis variable-1
AUXDIFF        ! TPAVG-2:AUXDIFF ->Right axis variable-2
TemperingDIFF          ! TPAVG-2:TemperingDIFF ->Right axis variable-3
TankDiff               ! TPAVG-2:TankDiff ->Right axis variable-4
*** INITIAL INPUT VALUES
FOO PUMP AUX Tempering Tank
LABELS  3
"Temperatures (C)"
"Insolation (kJ/hr-m^2)"
"Collector"
*------------------------------------------------------------------------------

* Model "ERROR" (Type 65)
*

UNIT 39 TYPE 65        ERROR
*$UNIT_NAME ERROR
*$MODEL .\Output\Online Plotter\Online Plotter Without File\Type65d.tmf
*$POSITION 990 50
*$LAYER Main #
PARAMETERS 12
3              ! 1 Nb. of left-axis variables
0              ! 2 Nb. of right-axis variables
0              ! 3 Left axis minimum
40             ! 4 Left axis maximum
-1             ! 5 Right axis minimum
2              ! 6 Right axis maximum
1              ! 7 Number of plots per simulation
12             ! 8 X-axis gridpoints
0              ! 9 Shut off Online w/o removing
-1             ! 10 Logical unit for output file
0              ! 11 Output file units
0              ! 12 Output file delimiter
INPUTS 3
62,5           ! Type271-HydronicFloor3:FOO_OUT ->Left axis variable-1
62,6           ! Type271-HydronicFloor3:BAR_OUT ->Left axis variable-2
0,0            ! [unconnected] Left axis variable-3
*** INITIAL INPUT VALUES
FOO BAR TSET
LABELS  3
"ERROR"
"ERROR"
```

```
"Graph 1"
*-------------------------------------------------------------------------------

* Model "Solar-2" (Type 65)
*

UNIT 44 TYPE 65         Solar-2
*$UNIT_NAME Solar-2
*$MODEL .\Output\Online Plotter\Online Plotter Without File\Type65d.tmf
*$POSITION 80 104
*$LAYER Main #
PARAMETERS 12
5               ! 1 Nb. of left-axis variables
2               ! 2 Nb. of right-axis variables
0               ! 3 Left axis minimum
10000           ! 4 Left axis maximum
0.0             ! 5 Right axis minimum
10000           ! 6 Right axis maximum
1               ! 7 Number of plots per simulation
12              ! 8 X-axis gridpoints
0               ! 9 Shut off Online w/o removing
-1              ! 10 Logical unit for output file
0               ! 11 Output file units
0               ! 12 Output file delimiter
INPUTS 7
42,1            ! IntSum-2:Result of integration-1 ->Left axis variable-1
42,2            ! IntSum-2:Result of integration-2 ->Left axis variable-2
42,3            ! IntSum-2:Result of integration-3 ->Left axis variable-3
42,6            ! IntSum-2:Result of integration-6 ->Left axis variable-4
42,8            ! IntSum-2:Result of integration-8 ->Left axis variable-5
42,4            ! IntSum-2:Result of integration-4 ->Right axis variable-1
42,5            ! IntSum-2:Result of integration-5 ->Right axis variable-2
*** INITIAL INPUT VALUES
TColl_in TColl_in TColl_in AuxDHW DHWLosses SH DHW
LABELS  3
"Temperatures (C)"
"Insolation (kJ/hr-m^2)"
"Collector"
*-------------------------------------------------------------------------------

* Model "PrintSum-2" (Type 25)
*

UNIT 45 TYPE 25         PrintSum-2
*$UNIT_NAME PrintSum-2
*$MODEL .\Output\Printer\User-Supplied Units\Type25b.tmf
*$POSITION 87 178
*$LAYER Main #
PARAMETERS 10
8760            ! 1 Printing interval
START           ! 2 Start time
STOP            ! 3 Stop time
45              ! 4 Logical unit
1               ! 5 Units printing mode
0               ! 6 Relative or absolute start time
-1              ! 7 Overwrite or Append
-1              ! 8 Print header
0               ! 9 Delimiter
1               ! 10 Print labels
INPUTS 11
42,1            ! IntSum-2:Result of integration-1 ->Input to be printed-1
42,2            ! IntSum-2:Result of integration-2 ->Input to be printed-2
42,3            ! IntSum-2:Result of integration-3 ->Input to be printed-3
42,4            ! IntSum-2:Result of integration-4 ->Input to be printed-4
42,5            ! IntSum-2:Result of integration-5 ->Input to be printed-5
42,7            ! IntSum-2:Result of integration-7 ->Input to be printed-6
42,9            ! IntSum-2:Result of integration-9 ->Input to be printed-7
```

```
42,10          ! IntSum-2:Result of integration-10 ->Input to be printed-8
CollFlow               ! Variables-2:CollFlow ->Input to be printed-9
angle          ! Variables-2:angle ->Input to be printed-10
Test           ! Variables-2:Test ->Input to be printed-11
*** INITIAL INPUT VALUES
SH_SOLAR DHW_SOLAR Total_Coll SH_LOAD DHW_LOAD Gt_tilt DHW_AUX SH_AUX
CollFlow ANGLE TEST
kWh kWh kWh kWh kWh kWh/m2 kWh kWh kg/hr ° -
*** External files
ASSIGN "2SSH1d6par.out" 45
*|? Output file for printed results |1000
*------------------------------------------------------------------------------

* Model "Type272-Min-Iteration" (Type 272)
*

UNIT 63 TYPE 272       Type272-Min-Iteration
*$UNIT_NAME Type272-Min-Iteration
*$MODEL .\My Components\Type272-Min-Iteration.tmf
*$POSITION 1074 964
*$LAYER Main #
PARAMETERS 1
0              ! 1 C_MIN
INPUTS 2
63,1           ! Type272-Min-Iteration:TIME_OUT ->TIME_OLD
63,2           ! Type272-Min-Iteration:C_OUT ->C_OLD
*** INITIAL INPUT VALUES
0 0
*------------------------------------------------------------------------------

* EQUATIONS "Variables-2"
*
EQUATIONS 3
CollFlow = 120
Test = 0
angle = 53
*$UNIT_NAME Variables-2
*$LAYER Main
*$POSITION 120 274

*------------------------------------------------------------------------------


END
```

C.4 Basic Combi-System – Configuration (ii)

This model configuration is the basic combi-system with a vacuum tube solar collector and preferential charging of the space heating thermal storage tank. The domestic hot water storage tank is connected to the solar loop using a natural convection heat exchanger and the space heating storage tank is connected using a fixed-effectiveness heat exchanger.

Table C.4: BasicCombi(ii) - TRNSYS Model

```
VERSION 16.1
*******************************************************************************
*** TRNSYS input file (deck) generated by TrnsysStudio
*** on Saturday, September 03, 2011 at 22:50
*** from TrnsysStudio project: C:\Program Files\Trnsys16\MyProjects\ATHESIS\3Combi1b5.TPF
***
*** If you edit this file, use the File/Import TRNSYS Input File function in
*** TrnsysStudio to update the project.
***
*** If you have problems, questions or suggestions please contact your local
*** TRNSYS distributor or mailto:software@cstb.fr
***
*******************************************************************************


*******************************************************************************
*** Units
*******************************************************************************

*******************************************************************************
*** Control cards
*******************************************************************************
* START, STOP and STEP
CONSTANTS 3
START=0
STOP=8760
STEP=0.05
* User defined CONSTANTS

SIMULATION      START  STOP    STEP   ! Start time   End time       Time step
TOLERANCES 0.01 0.05                  ! Integration   Convergence
LIMITS 1000 500 30                           ! Max iterations      Max warnings   Trace
limit
DFQ 1                                 ! TRNSYS numerical integration solver method
WIDTH 132                             ! TRNSYS output file width, number of characters
LIST                                  ! NOLIST statement
                                      ! MAP statement
SOLVER 0 1 1                          ! Solver statement    Minimum relaxation factor
        Maximum relaxation factor
NAN_CHECK 0                           ! Nan DEBUG statement
OVERWRITE_CHECK 0                     ! Overwrite DEBUG statement
TIME_REPORT 0                  ! disable time report
EQSOLVER 0                            ! EQUATION SOLVER statement

* Model "Toronto" (Type 109)
*

UNIT 24 TYPE 109        Toronto
*$UNIT_NAME Toronto
*$MODEL .\Weather Data Reading and Processing\Standard Format\TMY2\Type109-TMY2.tmf
*$POSITION 107 381
```

```
*$LAYER Main #
PARAMETERS 4
2              ! 1 Data Reader Mode
43             ! 2 Logical unit
4              ! 3 Sky model for diffuse radiation
1              ! 4 Tracking mode
INPUTS 3
0,0            ! [unconnected] Ground reflectance
0,0            ! [unconnected] Slope of surface
0,0            ! [unconnected] Azimuth of surface
*** INITIAL INPUT VALUES
0.2 angle 0
*** External files
ASSIGN "C:\Program Files\Trnsys16\Weather\Meteonorm\North-America\CA-ON-Toronto-
716240.tm2" 43
*|? Weather data file |1000
*------------------------------------------------------------------------------

* Model "Draw Profile" (Type 14)
*

UNIT 54 TYPE 14        Draw Profile
*$UNIT_NAME Draw Profile
*$MODEL .\Utility\Forcing Functions\Water Draw\Type14b.tmf
*$POSITION 1120 530
*$LAYER Main #
PARAMETERS 112
0              ! 1 Initial value of time
0              ! 2 Initial value of function
7              ! 3 Time at point-1
0              ! 4 Water draw at point -1
7              ! 5 Time at point-2
0.04444444             ! 6 Water draw at point -2
7.25           ! 7 Time at point-3
0.04444444             ! 8 Water draw at point -3
7.25           ! 9 Time at point-4
0              ! 10 Water draw at point -4
8              ! 11 Time at point-5
0              ! 12 Water draw at point -5
8              ! 13 Time at point-6
0.11111111             ! 14 Water draw at point -6
8.25           ! 15 Time at point-7
0.11111111             ! 16 Water draw at point -7
8.25           ! 17 Time at point-8
0              ! 18 Water draw at point -8
9              ! 19 Time at point-9
0              ! 20 Water draw at point -9
9              ! 21 Time at point-10
0.02222222             ! 22 Water draw at point -10
9.25           ! 23 Time at point-11
0.02222222             ! 24 Water draw at point -11
9.25           ! 25 Time at point-12
0              ! 26 Water draw at point -12
10             ! 27 Time at point-13
0              ! 28 Water draw at point -13
10             ! 29 Time at point-14
0.2            ! 30 Water draw at point -14
10.25          ! 31 Time at point-15
0.2            ! 32 Water draw at point -15
10.25          ! 33 Time at point-16
0              ! 34 Water draw at point -16
11             ! 35 Time at point-17
0              ! 36 Water draw at point -17
11             ! 37 Time at point-18
0.02222222             ! 38 Water draw at point -18
11.25          ! 39 Time at point-19
0.02222222             ! 40 Water draw at point -19
```

```
11.25          ! 41 Time at point-20
0              ! 42 Water draw at point -20
12             ! 43 Time at point-21
0              ! 44 Water draw at point -21
12             ! 45 Time at point-22
0.04444444             ! 46 Water draw at point -22
12.25          ! 47 Time at point-23
0.04444444             ! 48 Water draw at point -23
12.25          ! 49 Time at point-24
0              ! 50 Water draw at point -24
13             ! 51 Time at point-25
0              ! 52 Water draw at point -25
13             ! 53 Time at point-26
0.02222222             ! 54 Water draw at point -26
13.25          ! 55 Time at point-27
0.02222222             ! 56 Water draw at point -27
13.25          ! 57 Time at point-28
0              ! 58 Water draw at point -28
16             ! 59 Time at point-29
0              ! 60 Water draw at point -29
16             ! 61 Time at point-30
0.04444444             ! 62 Water draw at point -30
16.25          ! 63 Time at point-31
0.04444444             ! 64 Water draw at point -31
16.25          ! 65 Time at point-32
0              ! 66 Water draw at point -32
17             ! 67 Time at point-33
0              ! 68 Water draw at point -33
17             ! 69 Time at point-34
0.11111111             ! 70 Water draw at point -34
17.25          ! 71 Time at point-35
0.11111111             ! 72 Water draw at point -35
17.25          ! 73 Time at point-36
0              ! 74 Water draw at point -36
18             ! 75 Time at point-37
0              ! 76 Water draw at point -37
18             ! 77 Time at point-38
0.2            ! 78 Water draw at point -38
18.25          ! 79 Time at point-39
0.2            ! 80 Water draw at point -39
18.25          ! 81 Time at point-40
0              ! 82 Water draw at point -40
19             ! 83 Time at point-41
0              ! 84 Water draw at point -41
19             ! 85 Time at point-42
0.11111111             ! 86 Water draw at point -42
19.25          ! 87 Time at point-43
0.11111111             ! 88 Water draw at point -43
19.25          ! 89 Time at point-44
0              ! 90 Water draw at point -44
20             ! 91 Time at point-45
0              ! 92 Water draw at point -45
20             ! 93 Time at point-46
0.04444444             ! 94 Water draw at point -46
20.25          ! 95 Time at point-47
0.04444444             ! 96 Water draw at point -47
20.25          ! 97 Time at point-48
0              ! 98 Water draw at point -48
21             ! 99 Time at point-49
0              ! 100 Water draw at point -49
21             ! 101 Time at point-50
0.02222222             ! 102 Water draw at point -50
21.25          ! 103 Time at point-51
0.02222222             ! 104 Water draw at point -51
21.25          ! 105 Time at point-52
0              ! 106 Water draw at point -52
22             ! 107 Time at point-53
```

```
0              ! 108 Water draw at point -53
23             ! 109 Time at point-54
0              ! 110 Water draw at point -54
24             ! 111 Time at point-55
0              ! 112 Water draw at point -55
*------------------------------------------------------------------------------

* EQUATIONS "Variables"
*
EQUATIONS 5
CPGE = 3.648
US1 = 0.1*3.6
US2 = 0.8475*3.6 !R-6.7, From Rheem Fury Spec Sheet
L_pipe = 7.6 !25', SRCC
TA = 20
*$UNIT_NAME Variables
*$LAYER Main
*$POSITION 55 818

*------------------------------------------------------------------------------


* Model "Weather input" (Type 9)
*

UNIT 50 TYPE 9  Weather input
*$UNIT_NAME Weather input
*$MODEL .\Utility\Data Readers\Generic Data Files\First Line is Simulation Start\Free
Format\Type9a.tmf
*$POSITION 1116 40
*$LAYER Main #
PARAMETERS 14
2              ! 1 Mode
2              ! 2 Header Lines to Skip
2              ! 3 No. of values to read
24             ! 4 Time interval of data
-1             ! 5 Interpolate or not?-1
1              ! 6 Multiplication factor-1
0              ! 7 Addition factor-1
1              ! 8 Average or instantaneous value-1
-1             ! 9 Interpolate or not?-2
1              ! 10 Multiplication factor-2
0              ! 11 Addition factor-2
1              ! 12 Average or instantaneous value-2
48             ! 13 Logical unit for input file
-1             ! 14 Free format mode
*** External files
ASSIGN "DDCalc.in" 48
*|? Input file name |1000
*------------------------------------------------------------------------------

* Model "Mains" (Type 201)
*

UNIT 25 TYPE 201        Mains
*$UNIT_NAME Mains
*$MODEL .\Weather Data Reading and Processing\Weather Processor (TESS)\Typical
Meteorological Year Files Version 2 (TM2)\Type201-2.tmf
*$POSITION 1015 712
*$LAYER Main #
PARAMETERS 9
2              ! 1 File Type
44             ! 2 Logical unit
3              ! 3 Tilted Surface Radiation Mode
0.2            ! 4 Ground reflectance - no snow
0.7            ! 5 Ground reflectance - snow cover
1              ! 6 Number of surfaces
```

```
1              ! 7 Tracking mode
0.0            ! 8 Slope of surface
0              ! 9 Azimuth of surface
*** External files
ASSIGN "C:\Program Files\Trnsys16\Weather\Meteonorm\North-America\CA-ON-Toronto-
716240.tm2" 44
*|? Which file contains the TMY-2 weather data? |1000
*-------------------------------------------------------------------------------

* Model "Type71 HP200 30" (Type 71)
*

UNIT 65 TYPE 71         Type71 HP200 30
*$UNIT_NAME Type71 HP200 30
*$MODEL .\Solar Thermal Collectors\Evacuated Tube Collector\Type71.tmf
*$POSITION 141 498
*$LAYER Main #
PARAMETERS 11
1              ! 1 Number in series
18             ! 2 Collector area
3.53           ! 3 Fluid specific heat
1              ! 4 Efficiency mode
19.44          ! 5 Flow rate at test conditions
0.549          ! 6 Intercept efficiency
5.2506         ! 7 Negative of first order efficiency coeficient
0.015696               ! 8 Negative of second order efficiency coeficient
51             ! 9 Logical unit of file containing biaxial IAM data
8              ! 10 Number of longitudinal angles for which IAMs are provided
8              ! 11 Number of transverse angles for which IAMs are provided
INPUTS 10
7,1            ! ToColl:Outlet temperature ->Inlet temperature
7,2            ! ToColl:Outlet flow rate ->Inlet flowrate
24,1           ! Toronto:Ambient temperature ->Ambient temperature
24,18          ! Toronto:total radiation on tilted surface ->Incident radiation
24,20          ! Toronto:sky diffuse radiation on tilted surface ->Incident diffuse
radiation
24,22          ! Toronto:angle of incidence for tilted surface  ->Solar incidence angle
24,10          ! Toronto:solar zenith angle ->Solar zenith angle
24,11          ! Toronto:solar azimuth angle ->Solar azimuth angle
24,23          ! Toronto:slope of tilted surface ->Collector slope
0,0            ! [unconnected] Collector azimuth
*** INITIAL INPUT VALUES
20.0 100.0 10.0 0. 0 0.0 0.0 0.0 40 0.0
*** External files
ASSIGN "Kingspan Data File.txt" 51
*|? What file contains the 2D IAM data? |1000
*-------------------------------------------------------------------------------

* Model "ToNCHX" (Type 31)
*

UNIT 9 TYPE 31  ToNCHX
*$UNIT_NAME ToNCHX
*$MODEL .\Hydronics\Pipe_Duct\Type31.tmf
*$POSITION 291 520
*$LAYER Water Loop #
PARAMETERS 6
0.007725               ! 1 Inside diameter
L_pipe         ! 2 Pipe length
20             ! 3 Loss coefficient
1044           ! 4 Fluid density
3.53           ! 5 Fluid specific heat
TA             ! 6 Initial fluid temperature
INPUTS 3
65,1           ! Type71 HP200 30:Outlet temperature ->Inlet temperature
65,2           ! Type71 HP200 30:Outlet flowrate ->Inlet flow rate
0,0            ! [unconnected] Environment temperature
```

```
*** INITIAL INPUT VALUES
TA 0 TA
*------------------------------------------------------------------------------

* Model "Type91" (Type 91)
*

UNIT 35 TYPE 91         Type91
*$UNIT_NAME Type91
*$MODEL .\Heat Exchangers\Constant Effectiveness\Type91.tmf
*$POSITION 339 200
*$LAYER Main #
PARAMETERS 3
.7             ! 1 Heat exchanger effectiveness
3.53           ! 2 Specific heat of hot side fluid
4.18           ! 3 Specific heat of cold side fluid
INPUTS 4
9,1            ! ToNCHX:Outlet temperature ->Hot side inlet temperature
9,2            ! ToNCHX:Outlet flow rate ->Hot side flow rate
53,1           ! Pump-2:Outlet fluid temperature ->Cold side inlet temperature
53,2           ! Pump-2:Outlet flow rate ->Cold side flow rate
*** INITIAL INPUT VALUES
20.0 100.0 20.0 100.0
*------------------------------------------------------------------------------

* Model "Type289-NCHX" (Type 289)
*

UNIT 49 TYPE 289        Type289-NCHX
*$UNIT_NAME Type289-NCHX
*$MODEL .\My Components\Type289-NCHX.tmf
*$POSITION 384 750
*$LAYER Main #
PARAMETERS 5
3.53           ! 1 CP_HOT
4.18           ! 2 CP_COLD
-0.3488        ! 3 C
1.1402         ! 4 D
0              ! 5 E
INPUTS 9
35,1           ! Type91:Hot-side outlet temperature ->THOT_IN
35,2           ! Type91:Hot-side flow rate ->FHOT_IN
15,6           ! Solar Tank:Temperature of outlet flow 2 ->TCOLD_IN
56,1           ! Type293-NCHXFlow:FLWNC ->FCOLD_IN
0,0            ! [unconnected] T_AMB
0,0            ! [unconnected] TEMP_START
0,0            ! [unconnected] FLOW_START
0,0            ! [unconnected] FOO_IN
0,0            ! [unconnected] BAR_IN
*** INITIAL INPUT VALUES
TA 0 14.4 0 TA -1 0.001 0 0
*------------------------------------------------------------------------------

* Model "Pump" (Type 3)
*

UNIT 6 TYPE 3   Pump
*$UNIT_NAME Pump
*$MODEL .\Hydronics\Pumps\Single Speed\Type3b.tmf
*$POSITION 273 712
*$LAYER Controls #
PARAMETERS 5
CollFlow               ! 1 Maximum flow rate
3.53           ! 2 Fluid specific heat
0              ! 3 Maximum power
0              ! 4 Conversion coefficient
0              ! 5 Power coefficient
```

```
INPUTS 3
49,1           ! Type289-NCHX:THOT_OUT ->Inlet fluid temperature
49,2           ! Type289-NCHX:FHOT_OUT ->Inlet mass flow rate
51,1           ! Type262-CollController:SIG_OUT ->Control signal
*** INITIAL INPUT VALUES
TA 0 1.0
*------------------------------------------------------------------------------

* Model "ToColl" (Type 31)
*

UNIT 7 TYPE 31  ToColl
*$UNIT_NAME ToColl
*$MODEL .\Hydronics\Pipe_Duct\Type31.tmf
*$POSITION 116 692
*$LAYER Water Loop #
PARAMETERS 6
0.007725               ! 1 Inside diameter
L_pipe         ! 2 Pipe length
20             ! 3 Loss coefficient
1044           ! 4 Fluid density
3.53           ! 5 Fluid specific heat
TA             ! 6 Initial fluid temperature
INPUTS 3
6,1            ! Pump:Outlet fluid temperature ->Inlet temperature
6,2            ! Pump:Outlet flow rate ->Inlet flow rate
0,0            ! [unconnected] Environment temperature
*** INITIAL INPUT VALUES
TA 0 TA
*------------------------------------------------------------------------------

* EQUATIONS "TPAVG"
*
EQUATIONS 1
TPAVG_AVG = ([49,3] -1) ![16,6]
*$UNIT_NAME TPAVG
*$LAYER Main
*$POSITION 479 800

*------------------------------------------------------------------------------


* Model "Type293-NCHXFlow" (Type 293)
*

UNIT 56 TYPE 293        Type293-NCHXFlow
*$UNIT_NAME Type293-NCHXFlow
*$MODEL .\My Components\Type293-NCHXFlow.tmf
*$POSITION 653 857
*$LAYER Main #
PARAMETERS 5
1.5            ! 1 HT
2.388          ! 2 A
0.6505         ! 3 B
0.29           ! 4 HEX
0              ! 5 RELAX
INPUTS 5
15,6           ! Solar Tank:Temperature of outlet flow 2 ->TCIN
49,3           ! Type289-NCHX:TCOLD_OUT ->TCOUT
15,17          ! Solar Tank:Average tank temperature ->TTAVE
TPAVG_AVG              ! TPAVG:TPAVG_AVG ->TPAVE
56,3           ! Type293-NCHXFlow:THXOLD ->TCOLD
*** INITIAL INPUT VALUES
14.4 TA TA TA TA
*------------------------------------------------------------------------------

* Model "ToTank" (Type 31)
```

```
*

UNIT 16 TYPE 31         ToTank
*$UNIT_NAME ToTank
*$MODEL .\Hydronics\Pipe_Duct\Type31.tmf
*$POSITION 479 690
*$LAYER Main #
PARAMETERS 6
0.018          ! 1 Inside diameter
0.60           ! 2 Pipe length
4              ! 3 Loss coefficient
991            ! 4 Fluid density
4.18           ! 5 Fluid specific heat
TA             ! 6 Initial fluid temperature
INPUTS 3
49,3           ! Type289-NCHX:TCOLD_OUT ->Inlet temperature
49,4           ! Type289-NCHX:FCOLD_OUT ->Inlet flow rate
0,0            ! [unconnected] Environment temperature
*** INITIAL INPUT VALUES
TA 0 TA
*-------------------------------------------------------------------------------

* Model "Solar Tank" (Type 60)
*

UNIT 15 TYPE 60         Solar Tank
*$UNIT_NAME Solar Tank
*$MODEL .\Thermal Storage\Detailed Fluid Storage Tank\Uniform Cross Section\Uniform
Losses and Node Heights\2 Inlets, 2 Outlets\Type60s.tmf
*$POSITION 626 744
*$LAYER Main #
PARAMETERS 32
2              ! 1 User-specified inlet positions
0.27           ! 2 Tank volume
1.5            ! 3 Tank height
1.5            ! 4 Tank perimeter
1.5            ! 5 Height of flow inlet 1
1.5            ! 6 Height of flow outlet 1
0              ! 7 Height of flow inlet 2
0              ! 8 Height of flow outlet 2
4.18           ! 9 Fluid specific heat
991            ! 10 Fluid density
4.356          ! 11 Tank loss coefficient
2.2752         ! 12 Fluid thermal conductivity
0              ! 13 Destratification conductivity
100            ! 14 Boiling temperature
1              ! 15 Auxiliary heater mode
1.1            ! 16 Height of 1st aux. heater
1.1            ! 17 Height of 1st thermostat
0              ! 18 Set point temperature for element 1
3              ! 19 Deadband for heating element 1
0              ! 20 Maximum heating rate of element 1
1              ! 21 Height of heating element 2
1              ! 22 Height of thermostat 2
0              ! 23 Set point temperature for element 2
3              ! 24 Deadband for heating element 2
0              ! 25 Maximum heating rate of element 2
0              ! 26 Overall loss coefficient for gas flue
20             ! 27 Flue temperature
6              ! 28 Fraction of critical timestep
0              ! 29 Gas heater?
0              ! 30 Number of internal heat exchangers
0              ! 31 Equal sized nodes
0              ! 32 Uniform tank losses
INPUTS 9
16,2           ! ToTank:Outlet flow rate ->Flow rate at inlet 1
12,2           ! FlowMix:FLHOT ->Flow rate at outlet 1
```

```
12,2           ! FlowMix:FLHOT ->Flow rate at inlet 2
0,0            ! [unconnected] Flow rate at outlet 2
16,1           ! ToTank:Outlet temperature ->Temperature at inlet 1
25,5           ! Mains:Mains water temperature ->Temperature at inlet 2
0,0            ! [unconnected] Environment temperature
0,0            ! [unconnected] Control signal for element 1
0,0            ! [unconnected] Control signal for element 2
*** INITIAL INPUT VALUES
0 0 0 -2 TA TA TA 1 1
DERIVATIVES 30
TA             ! 1 Initial temperature of node-1
TA             ! 2 Initial temperature of node-2
TA             ! 3 Initial temperature of node-3
TA             ! 4 Initial temperature of node-4
TA             ! 5 Initial temperature of node-5
TA             ! 6 Initial temperature of node-6
TA             ! 7 Initial temperature of node-7
TA             ! 8 Initial temperature of node-8
TA             ! 9 Initial temperature of node-9
TA             ! 10 Initial temperature of node-10
TA             ! 11 Initial temperature of node-11
TA             ! 12 Initial temperature of node-12
TA             ! 13 Initial temperature of node-13
TA             ! 14 Initial temperature of node-14
TA             ! 15 Initial temperature of node-15
TA             ! 16 Initial temperature of node-16
TA             ! 17 Initial temperature of node-17
TA             ! 18 Initial temperature of node-18
TA             ! 19 Initial temperature of node-19
TA             ! 20 Initial temperature of node-20
TA             ! 21 Initial temperature of node-21
TA             ! 22 Initial temperature of node-22
TA             ! 23 Initial temperature of node-23
TA             ! 24 Initial temperature of node-24
TA             ! 25 Initial temperature of node-25
TA             ! 26 Initial temperature of node-26
TA             ! 27 Initial temperature of node-27
TA             ! 28 Initial temperature of node-28
TA             ! 29 Initial temperature of node-29
TA             ! 30 Initial temperature of node-30
*------------------------------------------------------------------------------

* Model "Aux Tank" (Type 60)
*

UNIT 29 TYPE 60         Aux Tank
*$UNIT_NAME Aux Tank
*$MODEL .\Thermal Storage\Detailed Fluid Storage Tank\Vertical Cylinder\Uniform Losses
and Node Heights\1 Inlet, 1 Outlet\Type60d.tmf
*$POSITION 772 690
*$LAYER Water Loop #
PARAMETERS 32
2              ! 1 User-specified inlet positions
0.17           ! 2 Tank volume
1              ! 3 Tank height
-1             ! 4 Tank perimeter
0.05           ! 5 Height of flow inlet 1
1              ! 6 Height of flow outlet 1
-1             ! 7 Not used (inlet 2)
-1             ! 8 Not used (outlet 2)
4.18           ! 9 Fluid specific heat
991            ! 10 Fluid density
4.356          ! 11 Tank loss coefficient
2.2752         ! 12 Fluid thermal conductivity
0              ! 13 Destratification conductivity
100            ! 14 Boiling temperature
1              ! 15 Auxiliary heater mode
```

```
0.501          ! 16 Height of 1st aux. heater
0.501          ! 17 Height of 1st thermostat
57             ! 18 Set point temperature for element 1
3              ! 19 Deadband for heating element 1
10799.999714         ! 20 Maximum heating rate of element 1
0              ! 21 Height of heating element 2
0              ! 22 Height of thermostat 2
57             ! 23 Set point temperature for element 2
2              ! 24 Deadband for heating element 2
0              ! 25 Maximum heating rate of element 2
0              ! 26 Overall loss coefficient for gas flue
20             ! 27 Flue temperature
6              ! 28 Fraction of critical timestep
0              ! 29 Gas heater?
0              ! 30 Number of internal heat exchangers
0              ! 31 Equal sized nodes
0              ! 32 Uniform tank losses
INPUTS 9
15,2           ! Solar Tank:Flowrate at outlet 1 ->Flow rate at inlet 1
0,0            ! [unconnected] Flow rate at outlet 1
0,0            ! [unconnected] Not used (flow inlet 2)
0,0            ! [unconnected] Not used (flow outlet 2)
15,5           ! Solar Tank:Temperature of outlet flow 1 ->Temperature at inlet 1
0,0            ! [unconnected] Not used (temp inlet 2)
0,0            ! [unconnected] Environment temperature
0,0            ! [unconnected] Control signal for element 1
0,0            ! [unconnected] Control signal for element 2
*** INITIAL INPUT VALUES
0 -2 -1 -1 20 20 22 1 1
DERIVATIVES 10
TA             ! 1 Initial temperature of node-1
TA             ! 2 Initial temperature of node-2
TA             ! 3 Initial temperature of node-3
TA             ! 4 Initial temperature of node-4
TA             ! 5 Initial temperature of node-5
TA             ! 6 Initial temperature of node-6
TA             ! 7 Initial temperature of node-7
TA             ! 8 Initial temperature of node-8
TA             ! 9 Initial temperature of node-9
TA             ! 10 Initial temperature of node-10
*------------------------------------------------------------------------------

* EQUATIONS "Draw"
*
EQUATIONS 2
DailyLoad = 225*4*0.991
Draw = [54,1]*DailyLoad

*$UNIT_NAME Draw
*$LAYER Water Loop
*$POSITION 999 630

*------------------------------------------------------------------------------


* Model "FlowMix" (Type 178)
*

UNIT 12 TYPE 178        FlowMix
*$UNIT_NAME FlowMix
*$MODEL .\Hydronics\Flow Mixer\Other Fluids\Type178.tmf
*$POSITION 927 672
*$LAYER Main #
PARAMETERS 1
55             ! 1 TSET
INPUTS 3
25,5           ! Mains:Mains water temperature ->TCOLD
```

```
29,5            ! Aux Tank:Temperature of outlet flow 1 ->THOT
Draw            ! Draw:Draw ->FLTAP
*** INITIAL INPUT VALUES
15 20 0
*------------------------------------------------------------------------------

* Model "Pump-2" (Type 3)
*

UNIT 53 TYPE 3  Pump-2
*$UNIT_NAME Pump-2
*$MODEL .\Hydronics\Pumps\Single Speed\Type3b.tmf
*$POSITION 455 402
*$LAYER Main #
PARAMETERS 5
HXFlow          ! 1 Maximum flow rate
4.18            ! 2 Fluid specific heat
0               ! 3 Maximum power
0               ! 4 Conversion coefficient
0               ! 5 Power coefficient
INPUTS 3
52,6            ! Solar Tank-2:Temperature of outlet flow 2 ->Inlet fluid temperature
52,4            ! Solar Tank-2:Flowrate at outlet 2 ->Inlet mass flow rate
5,1             ! Type2b:Output control function ->Control signal
*** INITIAL INPUT VALUES
TA 0 1.0
*------------------------------------------------------------------------------

* Model "Type266-ModifiedHDH" (Type 266)
*

UNIT 37 TYPE 266        Type266-ModifiedHDH
*$UNIT_NAME Type266-ModifiedHDH
*$MODEL .\My Components\Type266-ModifiedHDH.tmf
*$POSITION 1118 196
*$LAYER Main #
PARAMETERS 2
18              ! 1 T_REF
450             ! 2 VOL
INPUTS 2
24,1            ! Toronto:Ambient temperature ->T_AMB
50,2            ! Weather input:Output 2 ->T_AVE
*** INITIAL INPUT VALUES
0 0
*------------------------------------------------------------------------------

* Model "Type270-SH-Signal" (Type 270)
*

UNIT 60 TYPE 270        Type270-SH-Signal
*$UNIT_NAME Type270-SH-Signal
*$MODEL .\My Components\Type270-SH-Signal.tmf
*$POSITION 979 185
*$LAYER Main #
PARAMETERS 6
0.2             ! 1 R_FLOOR
4.18            ! 2 CP
0               ! 3 DTEMP_SET
40              ! 4 TIN_SET
160             ! 5 A_HEATED
250             ! 6 FLOW_MAX
INPUTS 4
37,1            ! Type266-ModifiedHDH:Q_KW ->Q_SH_KW
0,0             ! [unconnected] T_ROOM
0,0             ! [unconnected] FOO_IN
0,0             ! [unconnected] BAR_IN
*** INITIAL INPUT VALUES
```

```
0 20 0 0
*------------------------------------------------------------------------------

* Model "Type110" (Type 110)
*

UNIT 55 TYPE 110        Type110
*$UNIT_NAME Type110
*$MODEL .\Hydronics\Pumps\Variable Speed\Type110.tmf
*$POSITION 545 136
*$LAYER Main #
*$# VARIABLE-SPEED PUMP
PARAMETERS 6
250            ! 1 Rated flow rate
4.18           ! 2 Fluid specific heat
0              ! 3 Rated power
0.0            ! 4 Motor heat loss fraction
1              ! 5 Number of power coefficients
0              ! 6 Power coefficient
INPUTS 5
58,1           ! Type11h:Outlet temperature ->Inlet fluid temperature
58,2           ! Type11h:Outlet flow rate ->Inlet fluid flow rate
60,1           ! Type270-SH-Signal:PUMP_SIGNAL ->Control signal
0,0            ! [unconnected] Total pump efficiency
0,0            ! [unconnected] Motor efficiency
*** INITIAL INPUT VALUES
40 0.0 1.0 1 1
*------------------------------------------------------------------------------

* Model "Type268-AuxSH" (Type 268)
*

UNIT 47 TYPE 268        Type268-AuxSH
*$UNIT_NAME Type268-AuxSH
*$MODEL .\My Components\Type268-AuxSH.tmf
*$POSITION 822 46
*$LAYER Main #
PARAMETERS 1
4.18           ! 1 CP
INPUTS 3
55,1           ! Type110:Outlet fluid temperature ->TEMP_IN
55,2           ! Type110:Outlet flow rate ->FLOW_IN
60,2           ! Type270-SH-Signal:TIN_IDEAL ->T_SET
*** INITIAL INPUT VALUES
0 0 0
*------------------------------------------------------------------------------

* Model "Type271-HydronicFloor3" (Type 271)
*

UNIT 62 TYPE 271        Type271-HydronicFloor3
*$UNIT_NAME Type271-HydronicFloor3
*$MODEL .\My Components\Type271-HydronicFloor3.tmf
*$POSITION 845 302
*$LAYER Main #
PARAMETERS 6
4.18           ! 1 CP
0.2            ! 2 R_FLOOR
160            ! 3 A_HEATED
250            ! 4 FLOW_MAX
0              ! 5 DTEMP_SET
40             ! 6 TIN_SET
INPUTS 9
47,2           ! Type268-AuxSH:FLOW_OUT ->FLOW_IN
47,1           ! Type268-AuxSH:TEMP_OUT ->TEMP_IN
0,0            ! [unconnected] T_ROOM
37,1           ! Type266-ModifiedHDH:Q_KW ->Q_SH_KW
```

```
60,4           ! Type270-SH-Signal:FLOW_IDEAL ->IDEAL_FLOW
60,2           ! Type270-SH-Signal:TIN_IDEAL ->IDEAL_TIN
60,3           ! Type270-SH-Signal:TOUT_IDEAL ->IDEAL_TOUT
0,0            ! [unconnected] FOO_IN
0,0            ! [unconnected] BAR_IN
*** INITIAL INPUT VALUES
0 0 20 0 0 0 0 0 0
*------------------------------------------------------------------------------

* Model "Type269-SHTempering3" (Type 269)
*

UNIT 48 TYPE 269        Type269-SHTempering3
*$UNIT_NAME Type269-SHTempering3
*$MODEL .\My Components\Type269-SHTempering3.tmf
*$POSITION 704 420
*$LAYER Main #
INPUTS 3
62,2           ! Type271-HydronicFloor3:TEMP_OUT ->FLOOR_TEMP
52,5           ! Solar Tank-2:Temperature of outlet flow 1 ->TANK_TEMP
60,2           ! Type270-SH-Signal:TIN_IDEAL ->SET_TEMP
*** INITIAL INPUT VALUES
0 0 0
*------------------------------------------------------------------------------

* Model "Type11f" (Type 11)
*

UNIT 41 TYPE 11         Type11f
*$UNIT_NAME Type11f
*$MODEL .\Hydronics\Flow Diverter\Other Fluids\Type11f.tmf
*$POSITION 693 328
*$LAYER Water Loop #
PARAMETERS 1
2              ! 1 Controlled flow diverter mode
INPUTS 3
62,2           ! Type271-HydronicFloor3:TEMP_OUT ->Inlet temperature
62,3           ! Type271-HydronicFloor3:FLOW_OUT ->Inlet flow rate
48,1           ! Type269-SHTempering3:X ->Control signal
*** INITIAL INPUT VALUES
20.0 100.0 0.5
*------------------------------------------------------------------------------

* Model "Solar Tank-2" (Type 60)
*

UNIT 52 TYPE 60         Solar Tank-2
*$UNIT_NAME Solar Tank-2
*$MODEL .\Thermal Storage\Detailed Fluid Storage Tank\Uniform Cross Section\Uniform
Losses and Node Heights\2 Inlets, 2 Outlets\Type60s.tmf
*$POSITION 551 264
*$LAYER Main #
PARAMETERS 32
2              ! 1 User-specified inlet positions
0.81           ! 2 Tank volume
1.5            ! 3 Tank height
4.5            ! 4 Tank perimeter
1.5            ! 5 Height of flow inlet 1
1.5            ! 6 Height of flow outlet 1
0              ! 7 Height of flow inlet 2
0              ! 8 Height of flow outlet 2
4.18           ! 9 Fluid specific heat
991            ! 10 Fluid density
4.356          ! 11 Tank loss coefficient
2.2752         ! 12 Fluid thermal conductivity
0              ! 13 Destratification conductivity
100            ! 14 Boiling temperature
```

```
1              ! 15 Auxiliary heater mode
1.1            ! 16 Height of 1st aux. heater
1.1            ! 17 Height of 1st thermostat
0              ! 18 Set point temperature for element 1
3              ! 19 Deadband for heating element 1
0              ! 20 Maximum heating rate of element 1
1              ! 21 Height of heating element 2
1              ! 22 Height of thermostat 2
0              ! 23 Set point temperature for element 2
3              ! 24 Deadband for heating element 2
0              ! 25 Maximum heating rate of element 2
0              ! 26 Overall loss coefficient for gas flue
20             ! 27 Flue temperature
6              ! 28 Fraction of critical timestep
0              ! 29 Gas heater?
0              ! 30 Number of internal heat exchangers
0              ! 31 Equal sized nodes
0              ! 32 Uniform tank losses
INPUTS 9
53,2           ! Pump-2:Outlet flow rate ->Flow rate at inlet 1
0,0            ! [unconnected] Flow rate at outlet 1
41,4           ! Type11f:Flow rate at outlet 2 ->Flow rate at inlet 2
53,2           ! Pump-2:Outlet flow rate ->Flow rate at outlet 2
35,3           ! Type91:Cold-side outlet temperature ->Temperature at inlet 1
41,3           ! Type11f:Temperature at outlet 2 ->Temperature at inlet 2
0,0            ! [unconnected] Environment temperature
0,0            ! [unconnected] Control signal for element 1
0,0            ! [unconnected] Control signal for element 2
*** INITIAL INPUT VALUES
0 -2 0 0 TA TA TA 1 1
DERIVATIVES 30
TA             ! 1 Initial temperature of node-1
TA             ! 2 Initial temperature of node-2
TA             ! 3 Initial temperature of node-3
TA             ! 4 Initial temperature of node-4
TA             ! 5 Initial temperature of node-5
TA             ! 6 Initial temperature of node-6
TA             ! 7 Initial temperature of node-7
TA             ! 8 Initial temperature of node-8
TA             ! 9 Initial temperature of node-9
TA             ! 10 Initial temperature of node-10
TA             ! 11 Initial temperature of node-11
TA             ! 12 Initial temperature of node-12
TA             ! 13 Initial temperature of node-13
TA             ! 14 Initial temperature of node-14
TA             ! 15 Initial temperature of node-15
TA             ! 16 Initial temperature of node-16
TA             ! 17 Initial temperature of node-17
TA             ! 18 Initial temperature of node-18
TA             ! 19 Initial temperature of node-19
TA             ! 20 Initial temperature of node-20
TA             ! 21 Initial temperature of node-21
TA             ! 22 Initial temperature of node-22
TA             ! 23 Initial temperature of node-23
TA             ! 24 Initial temperature of node-24
TA             ! 25 Initial temperature of node-25
TA             ! 26 Initial temperature of node-26
TA             ! 27 Initial temperature of node-27
TA             ! 28 Initial temperature of node-28
TA             ! 29 Initial temperature of node-29
TA             ! 30 Initial temperature of node-30
*------------------------------------------------------------------------------

* Model "Type11h" (Type 11)
*

UNIT 58 TYPE 11        Type11h
```

```
*$UNIT_NAME Type11h
*$MODEL .\Hydronics\Tee-Piece\Other Fluids\Type11h.tmf
*$POSITION 685 210
*$LAYER Water Loop #
PARAMETERS 1
1              ! 1 Tee piece mode
INPUTS 4
41,1           ! Type11f:Temperature at outlet 1 ->Temperature at inlet 1
41,2           ! Type11f:Flow rate at outlet 1 ->Flow rate at inlet 1
52,5           ! Solar Tank-2:Temperature of outlet flow 1 ->Temperature at inlet 2
52,2           ! Solar Tank-2:Flowrate at outlet 1 ->Flow rate at inlet 2
*** INITIAL INPUT VALUES
20.0 100.0 20.0 100.0
*------------------------------------------------------------------------------

* Model "Type2b-2" (Type 2)
*

UNIT 40 TYPE 2  Type2b-2
*$UNIT_NAME Type2b-2
*$MODEL .\Controllers\Differential Controller w_ Hysteresis\for Temperatures\Solver 0
(Successive Substitution) Control Strategy\Type2b.tmf
*$POSITION 138 626
*$LAYER Main #
*$# NOTE: This control strategy can only be used with solver 0 (Successive substitution)
*$#
PARAMETERS 2
5              ! 1 No. of oscillations
90             ! 2 High limit cut-out
INPUTS 6
65,1           ! Type71 HP200 30:Outlet temperature ->Upper input temperature Th
15,6           ! Solar Tank:Temperature of outlet flow 2 ->Lower input temperature Tl
15,5           ! Solar Tank:Temperature of outlet flow 1 ->Monitoring temperature Tin
40,1           ! Type2b-2:Output control function ->Input control function
0,0            ! [unconnected] Upper dead band dT
0,0            ! [unconnected] Lower dead band dT
*** INITIAL INPUT VALUES
TA TA TA 0 10 3
*------------------------------------------------------------------------------

* Model "Type262-CollController" (Type 262)
*

UNIT 51 TYPE 262       Type262-CollController
*$UNIT_NAME Type262-CollController
*$MODEL .\My Components\Type262-CollController.tmf
*$POSITION 200 804
*$LAYER Main #
INPUTS 3
5,1            ! Type2b:Output control function ->SH_SIG
40,1           ! Type2b-2:Output control function ->DHW_SIG
5,1            ! Type2b:Output control function ->SH_PUMP_SIG
*** INITIAL INPUT VALUES
0 0 0
*------------------------------------------------------------------------------

* Model "Type2b" (Type 2)
*

UNIT 5 TYPE 2   Type2b
*$UNIT_NAME Type2b
*$MODEL .\Controllers\Differential Controller w_ Hysteresis\for Temperatures\Solver 0
(Successive Substitution) Control Strategy\Type2b.tmf
*$POSITION 243 629
*$LAYER Main #
*$# NOTE: This control strategy can only be used with solver 0 (Successive substitution)
*$#
```

```
PARAMETERS 2
5              ! 1 No. of oscillations
70             ! 2 High limit cut-out
INPUTS 6
65,1           ! Type71 HP200 30:Outlet temperature ->Upper input temperature Th
35,3           ! Type91:Cold-side outlet temperature ->Lower input temperature Tl
52,5           ! Solar Tank-2:Temperature of outlet flow 1 ->Monitoring temperature Tin
5,1            ! Type2b:Output control function ->Input control function
0,0            ! [unconnected] Upper dead band dT
0,0            ! [unconnected] Lower dead band dT
*** INITIAL INPUT VALUES
TA TA TA 0 10 3
*------------------------------------------------------------------------------

* EQUATIONS "Equa-2"
*
EQUATIONS 8
kWh = [35,5]/3600
kWh2 = [49,6]/3600
kWh3 = [65,3]/3600
kWh4 = [12,3] / 3600
kWh5 = [29,12]/3600
kWh6 = [24,18] / 3600
kWh7 = [15,7]/3600
kWh8 = [29,12]/3600
*$UNIT_NAME Equa-2
*$LAYER Main
*$POSITION 219 178

*------------------------------------------------------------------------------


* Model "IntSum-2" (Type 24)
*

UNIT 42 TYPE 24         IntSum-2
*$UNIT_NAME IntSum-2
*$MODEL .\Utility\Integrators\Quantity Integrator\Type24.tmf
*$POSITION 189 111
*$LAYER Main #

PARAMETERS 2
8760           ! 1 Integration period
0              ! 2 Relative or absolute start time
INPUTS 10
kWh            ! Equa-2:kWh ->Input to be integrated-1
kWh2           ! Equa-2:kWh2 ->Input to be integrated-2
kWh3           ! Equa-2:kWh3 ->Input to be integrated-3
37,1           ! Type266-ModifiedHDH:Q_KW ->Input to be integrated-4
kWh4           ! Equa-2:kWh4 ->Input to be integrated-5
kWh5           ! Equa-2:kWh5 ->Input to be integrated-6
kWh6           ! Equa-2:kWh6 ->Input to be integrated-7
kWh7           ! Equa-2:kWh7 ->Input to be integrated-8
kWh8           ! Equa-2:kWh8 ->Input to be integrated-9
47,3           ! Type268-AuxSH:Q_OUT_KW ->Input to be integrated-10
*** INITIAL INPUT VALUES
0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
*------------------------------------------------------------------------------

* EQUATIONS "TPAVG-2"
*
EQUATIONS 4
DIFF = [55,2]-[58,2]
AUXDIFF = [55,2]-[47,2]
TemperingDIFF = [62,3] - [58,2]
TankDiff = [41,4] - [52,2]
*$UNIT_NAME TPAVG-2
```

```
*$LAYER Main
*$POSITION 202 946

*------------------------------------------------------------------------------


* Model "Solar-4" (Type 65)
*

UNIT 59 TYPE 65        Solar-4
*$UNIT_NAME Solar-4
*$MODEL .\Output\Online Plotter\Online Plotter Without File\Type65d.tmf
*$POSITION 880 882
*$LAYER Main #
PARAMETERS 12
10             ! 1 Nb. of left-axis variables
10             ! 2 Nb. of right-axis variables
0              ! 3 Left axis minimum
100            ! 4 Left axis maximum
0              ! 5 Right axis minimum
100            ! 6 Right axis maximum
1              ! 7 Number of plots per simulation
12             ! 8 X-axis gridpoints
0              ! 9 Shut off Online w/o removing
-1             ! 10 Logical unit for output file
0              ! 11 Output file units
0              ! 12 Output file delimiter
INPUTS 20
15,22          ! Solar Tank:Tank temperature - top ->Left axis variable-1
15,25          ! Solar Tank:Temperature of node 1+-2 ->Left axis variable-2
15,27          ! Solar Tank:Temperature of node 1+-4 ->Left axis variable-3
15,29          ! Solar Tank:Temperature of node 1+-6 ->Left axis variable-4
15,31          ! Solar Tank:Temperature of node 1+-8 ->Left axis variable-5
15,33          ! Solar Tank:Temperature of node 1+-10 ->Left axis variable-6
15,35          ! Solar Tank:Temperature of node 1+-12 ->Left axis variable-7
15,37          ! Solar Tank:Temperature of node 1+-14 ->Left axis variable-8
15,39          ! Solar Tank:Temperature of node 1+-16 ->Left axis variable-9
15,41          ! Solar Tank:Temperature of node 1+-18 ->Left axis variable-10
15,43          ! Solar Tank:Temperature of node 1+-20 ->Right axis variable-1
15,45          ! Solar Tank:Temperature of node 1+-22 ->Right axis variable-2
15,47          ! Solar Tank:Temperature of node 1+-24 ->Right axis variable-3
15,49          ! Solar Tank:Temperature of node 1+-26 ->Right axis variable-4
15,51          ! Solar Tank:Temperature of node 1+-28 ->Right axis variable-5
0,0            ! [unconnected] Right axis variable-6
0,0            ! [unconnected] Right axis variable-7
0,0            ! [unconnected] Right axis variable-8
0,0            ! [unconnected] Right axis variable-9
15,23          ! Solar Tank:Tank temperature - bottom ->Right axis variable-10
*** INITIAL INPUT VALUES
Temp Temp Temp Temp Temp Temp Temp Temp Temp Temp Temp Temp Temp Temp Temp
Temp Temp Temp Temp Temp
LABELS  3
"Temperatures (C)"
"Insolation (kJ/hr-m^2)"
"Collector"
*------------------------------------------------------------------------------

* Model "Solar-3" (Type 65)
*

UNIT 46 TYPE 65        Solar-3
*$UNIT_NAME Solar-3
*$MODEL .\Output\Online Plotter\Online Plotter Without File\Type65d.tmf
*$POSITION 358 872
*$LAYER Main #
PARAMETERS 12
1              ! 1 Nb. of left-axis variables
```

```
4               ! 2 Nb. of right-axis variables
-1              ! 3 Left axis minimum
2               ! 4 Left axis maximum
-10             ! 5 Right axis minimum
10              ! 6 Right axis maximum
1               ! 7 Number of plots per simulation
12              ! 8 X-axis gridpoints
0               ! 9 Shut off Online w/o removing
-1              ! 10 Logical unit for output file
0               ! 11 Output file units
0               ! 12 Output file delimiter
INPUTS 5
49,10           ! Type289-NCHX:FOO_OUT ->Left axis variable
DIFF            ! TPAVG-2:DIFF ->Right axis variable-1
AUXDIFF         ! TPAVG-2:AUXDIFF ->Right axis variable-2
TemperingDIFF           ! TPAVG-2:TemperingDIFF ->Right axis variable-3
TankDiff                ! TPAVG-2:TankDiff ->Right axis variable-4
*** INITIAL INPUT VALUES
FOO PUMP AUX Tempering Tank
LABELS  3
"Temperatures (C)"
"Insolation (kJ/hr-m^2)"
"Collector"
*------------------------------------------------------------------------------

* Model "ERROR" (Type 65)
*

UNIT 39 TYPE 65         ERROR
*$UNIT_NAME ERROR
*$MODEL .\Output\Online Plotter\Online Plotter Without File\Type65d.tmf
*$POSITION 990 50
*$LAYER Main #
PARAMETERS 12
3               ! 1 Nb. of left-axis variables
0               ! 2 Nb. of right-axis variables
0               ! 3 Left axis minimum
40              ! 4 Left axis maximum
-1              ! 5 Right axis minimum
2               ! 6 Right axis maximum
1               ! 7 Number of plots per simulation
12              ! 8 X-axis gridpoints
0               ! 9 Shut off Online w/o removing
-1              ! 10 Logical unit for output file
0               ! 11 Output file units
0               ! 12 Output file delimiter
INPUTS 3
62,5            ! Type271-HydronicFloor3:FOO_OUT ->Left axis variable-1
62,6            ! Type271-HydronicFloor3:BAR_OUT ->Left axis variable-2
0,0             ! [unconnected] Left axis variable-3
*** INITIAL INPUT VALUES
FOO BAR TSET
LABELS  3
"ERROR"
"ERROR"
"Graph 1"
*------------------------------------------------------------------------------

* Model "Solar-2" (Type 65)
*

UNIT 44 TYPE 65         Solar-2
*$UNIT_NAME Solar-2
*$MODEL .\Output\Online Plotter\Online Plotter Without File\Type65d.tmf
*$POSITION 80 104
*$LAYER Main #
PARAMETERS 12
```

```
5              ! 1 Nb. of left-axis variables
2              ! 2 Nb. of right-axis variables
0              ! 3 Left axis minimum
10000          ! 4 Left axis maximum
0.0            ! 5 Right axis minimum
10000          ! 6 Right axis maximum
1              ! 7 Number of plots per simulation
12             ! 8 X-axis gridpoints
0              ! 9 Shut off Online w/o removing
-1             ! 10 Logical unit for output file
0              ! 11 Output file units
0              ! 12 Output file delimiter
INPUTS 7
42,1           ! IntSum-2:Result of integration-1 ->Left axis variable-1
42,2           ! IntSum-2:Result of integration-2 ->Left axis variable-2
42,3           ! IntSum-2:Result of integration-3 ->Left axis variable-3
42,6           ! IntSum-2:Result of integration-6 ->Left axis variable-4
42,8           ! IntSum-2:Result of integration-8 ->Left axis variable-5
42,4           ! IntSum-2:Result of integration-4 ->Right axis variable-1
42,5           ! IntSum-2:Result of integration-5 ->Right axis variable-2
*** INITIAL INPUT VALUES
TColl_in TColl_in TColl_in AuxDHW DHWLosses SH DHW
LABELS  3
"Temperatures (C)"
"Insolation (kJ/hr-m^2)"
"Collector"
*-------------------------------------------------------------------------------

* Model "PrintSum-2" (Type 25)
*

UNIT 45 TYPE 25         PrintSum-2
*$UNIT_NAME PrintSum-2
*$MODEL .\Output\Printer\User-Supplied Units\Type25b.tmf
*$POSITION 87 178
*$LAYER Main #
PARAMETERS 10
8760           ! 1 Printing interval
START          ! 2 Start time
STOP           ! 3 Stop time
45             ! 4 Logical unit
1              ! 5 Units printing mode
0              ! 6 Relative or absolute start time
-1             ! 7 Overwrite or Append
-1             ! 8 Print header
0              ! 9 Delimiter
1              ! 10 Print labels
INPUTS 12
42,1           ! IntSum-2:Result of integration-1 ->Input to be printed-1
42,2           ! IntSum-2:Result of integration-2 ->Input to be printed-2
42,3           ! IntSum-2:Result of integration-3 ->Input to be printed-3
42,4           ! IntSum-2:Result of integration-4 ->Input to be printed-4
42,5           ! IntSum-2:Result of integration-5 ->Input to be printed-5
42,7           ! IntSum-2:Result of integration-7 ->Input to be printed-6
42,9           ! IntSum-2:Result of integration-9 ->Input to be printed-7
42,10          ! IntSum-2:Result of integration-10 ->Input to be printed-8
CollFlow               ! Variables-2:CollFlow ->Input to be printed-9
HXFlow         ! Variables-2:HXFlow ->Input to be printed-10
angle          ! Variables-2:angle ->Input to be printed-11
Test           ! Variables-2:Test ->Input to be printed-12
*** INITIAL INPUT VALUES
SH_SOLAR DHW_SOLAR Total_Coll SH_LOAD DHW_LOAD Gt_tilt DHW_AUX SH_AUX
CollFlow HXFlow ANGLE TEST
kWh kWh kWh kWh kWh kWh/m2 kWh kWh kg/hr kg/hr ° -
*** External files
ASSIGN "3combi1b5par.out" 45
*|? Output file for printed results |1000
```

```
*-------------------------------------------------------------------------------

* Model "Solar-5" (Type 65)
*

UNIT 61 TYPE 65         Solar-5
*$UNIT_NAME Solar-5

*$MODEL .\Output\Online Plotter\Online Plotter Without File\Type65d.tmf
*$POSITION 859 733
*$LAYER Main #
PARAMETERS 12
10             ! 1 Nb. of left-axis variables
2              ! 2 Nb. of right-axis variables
0              ! 3 Left axis minimum
100            ! 4 Left axis maximum
0              ! 5 Right axis minimum
100000         ! 6 Right axis maximum
1              ! 7 Number of plots per simulation
12             ! 8 X-axis gridpoints
0              ! 9 Shut off Online w/o removing
-1             ! 10 Logical unit for output file
0              ! 11 Output file units
0              ! 12 Output file delimiter
INPUTS 12
29,22          ! Aux Tank:Tank temperature - top ->Left axis variable-1
29,24          ! Aux Tank:Temperature of node 1+-1 ->Left axis variable-2
29,25          ! Aux Tank:Temperature of node 1+-2 ->Left axis variable-3
29,26          ! Aux Tank:Temperature of node 1+-3 ->Left axis variable-4
29,27          ! Aux Tank:Temperature of node 1+-4 ->Left axis variable-5
29,28          ! Aux Tank:Temperature of node 1+-5 ->Left axis variable-6
29,29          ! Aux Tank:Temperature of node 1+-6 ->Left axis variable-7
29,30          ! Aux Tank:Temperature of node 1+-7 ->Left axis variable-8
29,31          ! Aux Tank:Temperature of node 1+-8 ->Left axis variable-9
29,23          ! Aux Tank:Tank temperature - bottom ->Left axis variable-10
29,13          ! Aux Tank:Element 1 power ->Right axis variable-1
15,5           ! Solar Tank:Temperature of outlet flow 1 ->Right axis variable-2
*** INITIAL INPUT VALUES
Temp Temp Temp Temp Temp Temp Temp Temp Temp Temp Temp Temp
LABELS  3
"Temperatures (C)"
"Insolation (kJ/hr-m^2)"
"temp"
*-------------------------------------------------------------------------------

* Model "Type272-Min-Iteration" (Type 272)
*

UNIT 63 TYPE 272        Type272-Min-Iteration
*$UNIT_NAME Type272-Min-Iteration
*$MODEL .\My Components\Type272-Min-Iteration.tmf
*$POSITION 1042 889
*$LAYER Main #
PARAMETERS 1
0              ! 1 C_MIN
INPUTS 2
63,1           ! Type272-Min-Iteration:TIME_OUT ->TIME_OLD
63,2           ! Type272-Min-Iteration:C_OUT ->C_OLD
*** INITIAL INPUT VALUES
0 0
*-------------------------------------------------------------------------------

* EQUATIONS "Variables-2"
*
EQUATIONS 4
CollFlow = 300
HXFlow = 250
```

```
Test = 3
angle = 51
*$UNIT_NAME Variables-2
*$LAYER Main
*$POSITION 78 285

*------------------------------------------------------------------------------


END
```

C.5 Single-Tank Combi-System – Configuration (ii)

This model configuration is the single-tank combi-system with a vacuum tube solar collector. The thermal storage tank is located in the domestic hot water loop and is connected to the solar loop with a fixed effectiveness heat exchanger.

Table C.5: Single-TankCombi(ii) - TRNSYS Model

```
VERSION 16.1
*******************************************************************************
*** TRNSYS input file (deck) generated by TrnsysStudio
*** on Sunday, September 04, 2011 at 20:53
*** from TrnsysStudio project: C:\Program Files\Trnsys16\MyProjects\ATHESIS\4Combi3d6.TPF
***
*** If you edit this file, use the File/Import TRNSYS Input File function in
*** TrnsysStudio to update the project.
***
*** If you have problems, questions or suggestions please contact your local
*** TRNSYS distributor or mailto:software@cstb.fr
***
*******************************************************************************


*******************************************************************************
*** Units
*******************************************************************************

*******************************************************************************
*** Control cards
*******************************************************************************
* START, STOP and STEP
CONSTANTS 3
START=0
STOP=8760
STEP=0.05
* User defined CONSTANTS

SIMULATION      START   STOP   STEP   ! Start time   End time       Time step
TOLERANCES 0.01 0.05                  ! Integration   Convergence
LIMITS 1000 1000 30                          ! Max iterations       Max warnings   Trace
limit
DFQ 1                                 ! TRNSYS numerical integration solver method
WIDTH 132                             ! TRNSYS output file width, number of characters
LIST                                  ! NOLIST statement
                                      ! MAP statement
SOLVER 0 1 1                          ! Solver statement    Minimum relaxation factor
        Maximum relaxation factor
NAN_CHECK 0                           ! Nan DEBUG statement
OVERWRITE_CHECK 0                     ! Overwrite DEBUG statement
TIME_REPORT 0                 ! disable time report
EQSOLVER 0                            ! EQUATION SOLVER statement

* Model "Toronto" (Type 109)
*

UNIT 24 TYPE 109        Toronto
*$UNIT_NAME Toronto
*$MODEL .\Weather Data Reading and Processing\Standard Format\TMY2\Type109-TMY2.tmf
*$POSITION 96 434
*$LAYER Main #
PARAMETERS 4
```

```
2              ! 1 Data Reader Mode
43             ! 2 Logical unit
4              ! 3 Sky model for diffuse radiation
1              ! 4 Tracking mode
INPUTS 3
0,0            ! [unconnected] Ground reflectance
0,0            ! [unconnected] Slope of surface
0,0            ! [unconnected] Azimuth of surface
*** INITIAL INPUT VALUES
0.2 angle 0
*** External files
ASSIGN "C:\Program Files\Trnsys16\Weather\Meteonorm\North-America\CA-ON-Toronto-
716240.tm2" 43
*|? Weather data file |1000
*------------------------------------------------------------------------------

* Model "Draw Profile" (Type 14)
*

UNIT 54 TYPE 14         Draw Profile
*$UNIT_NAME Draw Profile
*$MODEL .\Utility\Forcing Functions\Water Draw\Type14b.tmf
*$POSITION 1142 552
*$LAYER Main #
PARAMETERS 112
0              ! 1 Initial value of time
0              ! 2 Initial value of function
7              ! 3 Time at point-1
0              ! 4 Water draw at point -1
7              ! 5 Time at point-2
0.04444444             ! 6 Water draw at point -2
7.25           ! 7 Time at point-3
0.04444444             ! 8 Water draw at point -3
7.25           ! 9 Time at point-4
0              ! 10 Water draw at point -4
8              ! 11 Time at point-5
0              ! 12 Water draw at point -5
8              ! 13 Time at point-6
0.11111111             ! 14 Water draw at point -6
8.25           ! 15 Time at point-7
0.11111111             ! 16 Water draw at point -7
8.25           ! 17 Time at point-8
0              ! 18 Water draw at point -8
9              ! 19 Time at point-9
0              ! 20 Water draw at point -9
9              ! 21 Time at point-10
0.02222222             ! 22 Water draw at point -10
9.25           ! 23 Time at point-11
0.02222222             ! 24 Water draw at point -11
9.25           ! 25 Time at point-12
0              ! 26 Water draw at point -12
10             ! 27 Time at point-13
0              ! 28 Water draw at point -13
10             ! 29 Time at point-14
0.2            ! 30 Water draw at point -14
10.25          ! 31 Time at point-15
0.2            ! 32 Water draw at point -15
10.25          ! 33 Time at point-16
0              ! 34 Water draw at point -16
11             ! 35 Time at point-17
0              ! 36 Water draw at point -17
11             ! 37 Time at point-18
0.02222222             ! 38 Water draw at point -18
11.25          ! 39 Time at point-19
0.02222222             ! 40 Water draw at point -19
11.25          ! 41 Time at point-20
0              ! 42 Water draw at point -20
```

```
12             ! 43 Time at point-21
0              ! 44 Water draw at point -21
12             ! 45 Time at point-22
0.04444444             ! 46 Water draw at point -22
12.25          ! 47 Time at point-23
0.04444444             ! 48 Water draw at point -23
12.25          ! 49 Time at point-24
0              ! 50 Water draw at point -24
13             ! 51 Time at point-25
0              ! 52 Water draw at point -25
13             ! 53 Time at point-26
0.02222222             ! 54 Water draw at point -26
13.25          ! 55 Time at point-27
0.02222222             ! 56 Water draw at point -27
13.25          ! 57 Time at point-28
0              ! 58 Water draw at point -28
16             ! 59 Time at point-29
0              ! 60 Water draw at point -29
16             ! 61 Time at point-30
0.04444444             ! 62 Water draw at point -30
16.25          ! 63 Time at point-31
0.04444444             ! 64 Water draw at point -31
16.25          ! 65 Time at point-32
0              ! 66 Water draw at point -32
17             ! 67 Time at point-33
0              ! 68 Water draw at point -33
17             ! 69 Time at point-34
0.11111111             ! 70 Water draw at point -34
17.25          ! 71 Time at point-35
0.11111111             ! 72 Water draw at point -35
17.25          ! 73 Time at point-36
0              ! 74 Water draw at point -36
18             ! 75 Time at point-37
0              ! 76 Water draw at point -37
18             ! 77 Time at point-38
0.2            ! 78 Water draw at point -38
18.25          ! 79 Time at point-39
0.2            ! 80 Water draw at point -39
18.25          ! 81 Time at point-40
0              ! 82 Water draw at point -40
19             ! 83 Time at point-41
0              ! 84 Water draw at point -41
19             ! 85 Time at point-42
0.11111111             ! 86 Water draw at point -42
19.25          ! 87 Time at point-43
0.11111111             ! 88 Water draw at point -43
19.25          ! 89 Time at point-44
0              ! 90 Water draw at point -44
20             ! 91 Time at point-45
0              ! 92 Water draw at point -45
20             ! 93 Time at point-46
0.04444444             ! 94 Water draw at point -46
20.25          ! 95 Time at point-47
0.04444444             ! 96 Water draw at point -47
20.25          ! 97 Time at point-48
0              ! 98 Water draw at point -48
21             ! 99 Time at point-49
0              ! 100 Water draw at point -49
21             ! 101 Time at point-50
0.02222222             ! 102 Water draw at point -50
21.25          ! 103 Time at point-51
0.02222222             ! 104 Water draw at point -51
21.25          ! 105 Time at point-52
0              ! 106 Water draw at point -52
22             ! 107 Time at point-53
0              ! 108 Water draw at point -53
23             ! 109 Time at point-54
```

```
0              ! 110 Water draw at point -54
24             ! 111 Time at point-55
0              ! 112 Water draw at point -55
*------------------------------------------------------------------------------

* EQUATIONS "Variables"
*
EQUATIONS 5
CPGE = 3.648
US1 = 0.1*3.6
US2 = 0.8475*3.6 !R-6.7, From Rheem Fury Spec Sheet
L_pipe = 7.6 !25', SRCC
TA = 20
*$UNIT_NAME Variables
*$LAYER Main
*$POSITION 55 818

*------------------------------------------------------------------------------


* Model "Weather input" (Type 9)
*

UNIT 50 TYPE 9  Weather input
*$UNIT_NAME Weather input
*$MODEL .\Utility\Data Readers\Generic Data Files\First Line is Simulation Start\Free
Format\Type9a.tmf
*$POSITION 1116 40
*$LAYER Main #
PARAMETERS 14
2              ! 1 Mode
2              ! 2 Header Lines to Skip
2              ! 3 No. of values to read
24             ! 4 Time interval of data
-1             ! 5 Interpolate or not?-1
1              ! 6 Multiplication factor-1
0              ! 7 Addition factor-1
1              ! 8 Average or instantaneous value-1
-1             ! 9 Interpolate or not?-2
1              ! 10 Multiplication factor-2
0              ! 11 Addition factor-2
1              ! 12 Average or instantaneous value-2
48             ! 13 Logical unit for input file
-1             ! 14 Free format mode
*** External files
ASSIGN "DDCalc.in" 48
*|? Input file name |1000
*------------------------------------------------------------------------------

* Model "Mains" (Type 201)
*

UNIT 25 TYPE 201        Mains
*$UNIT_NAME Mains
*$MODEL .\Weather Data Reading and Processing\Weather Processor (TESS)\Typical
Meteorological Year Files Version 2 (TM2)\Type201-2.tmf
*$POSITION 1015 712
*$LAYER Main #
PARAMETERS 9
2              ! 1 File Type
44             ! 2 Logical unit
3              ! 3 Tilted Surface Radiation Mode
0.2            ! 4 Ground reflectance - no snow
0.7            ! 5 Ground reflectance - snow cover
1              ! 6 Number of surfaces
1              ! 7 Tracking mode
0.0            ! 8 Slope of surface
```

```
0              ! 9 Azimuth of surface
*** External files
ASSIGN "C:\Program Files\Trnsys16\Weather\Meteonorm\North-America\CA-ON-Toronto-
716240.tm2" 44
*|? Which file contains the TMY-2 weather data? |1000
*------------------------------------------------------------------------------

* Model "Type71 HP200 30" (Type 71)
*

UNIT 43 TYPE 71         Type71 HP200 30
*$UNIT_NAME Type71 HP200 30
*$MODEL .\Solar Thermal Collectors\Evacuated Tube Collector\Type71.tmf
*$POSITION 152 520
*$LAYER Main #
PARAMETERS 11
1              ! 1 Number in series
18             ! 2 Collector area
3.53           ! 3 Fluid specific heat
1              ! 4 Efficiency mode
19.44          ! 5 Flow rate at test conditions
0.549          ! 6 Intercept efficiency
5.2506         ! 7 Negative of first order efficiency coeficient
0.015696              ! 8 Negative of second order efficiency coeficient
52             ! 9 Logical unit of file containing biaxial IAM data
8              ! 10 Number of longitudinal angles for which IAMs are provided
8              ! 11 Number of transverse angles for which IAMs are provided
INPUTS 10
7,1            ! ToColl:Outlet temperature ->Inlet temperature
7,2            ! ToColl:Outlet flow rate ->Inlet flowrate
24,1           ! Toronto:Ambient temperature ->Ambient temperature
24,18          ! Toronto:total radiation on tilted surface ->Incident radiation
24,20          ! Toronto:sky diffuse radiation on tilted surface ->Incident diffuse
radiation
24,22          ! Toronto:angle of incidence for tilted surface  ->Solar incidence angle
24,10          ! Toronto:solar zenith angle ->Solar zenith angle
24,11          ! Toronto:solar azimuth angle ->Solar azimuth angle
24,23          ! Toronto:slope of tilted surface ->Collector slope
0,0            ! [unconnected] Collector azimuth
*** INITIAL INPUT VALUES
20.0 100.0 10.0 0. 0 0.0 0.0 0.0 40 0.0
*** External files
ASSIGN "Kingspan Data File.txt" 52
*|? What file contains the 2D IAM data? |1000
*------------------------------------------------------------------------------

* Model "ToNCHX" (Type 31)
*

UNIT 9 TYPE 31  ToNCHX
*$UNIT_NAME ToNCHX
*$MODEL .\Hydronics\Pipe_Duct\Type31.tmf
*$POSITION 291 520
*$LAYER Water Loop #
PARAMETERS 6
0.007725              ! 1 Inside diameter
L_pipe         ! 2 Pipe length
20             ! 3 Loss coefficient
1044           ! 4 Fluid density
3.53           ! 5 Fluid specific heat
TA             ! 6 Initial fluid temperature
INPUTS 3
43,1           ! Type71 HP200 30:Outlet temperature ->Inlet temperature
43,2           ! Type71 HP200 30:Outlet flowrate ->Inlet flow rate
0,0            ! [unconnected] Environment temperature
*** INITIAL INPUT VALUES
TA 0 TA
```

```
*------------------------------------------------------------------------------

* Model "Type91-2" (Type 91)
*

UNIT 49 TYPE 91         Type91-2
*$UNIT_NAME Type91-2
*$MODEL .\Heat Exchangers\Constant Effectiveness\Type91.tmf
*$POSITION 350 712
*$LAYER Main #
PARAMETERS 3
.7             ! 1 Heat exchanger effectiveness
3.53           ! 2 Specific heat of hot side fluid
4.18           ! 3 Specific heat of cold side fluid
INPUTS 4
9,1            ! ToNCHX:Outlet temperature ->Hot side inlet temperature
9,2            ! ToNCHX:Outlet flow rate ->Hot side flow rate
36,1           ! Pump-3:Outlet fluid temperature ->Cold side inlet temperature
36,2           ! Pump-3:Outlet flow rate ->Cold side flow rate
*** INITIAL INPUT VALUES
20 0 20.0 180
*------------------------------------------------------------------------------

* Model "Pump" (Type 3)
*

UNIT 6 TYPE 3   Pump
*$UNIT_NAME Pump
*$MODEL .\Hydronics\Pumps\Single Speed\Type3b.tmf
*$POSITION 273 712
*$LAYER Controls #
PARAMETERS 5
CollFlow              ! 1 Maximum flow rate
3.53           ! 2 Fluid specific heat
0              ! 3 Maximum power
0              ! 4 Conversion coefficient
0              ! 5 Power coefficient
INPUTS 3
49,1           ! Type91-2:Hot-side outlet temperature ->Inlet fluid temperature
49,2           ! Type91-2:Hot-side flow rate ->Inlet mass flow rate
40,1           ! Type2b-2:Output control function ->Control signal
*** INITIAL INPUT VALUES
TA 0 1.0
*------------------------------------------------------------------------------

* Model "ToColl" (Type 31)
*

UNIT 7 TYPE 31  ToColl
*$UNIT_NAME ToColl
*$MODEL .\Hydronics\Pipe_Duct\Type31.tmf
*$POSITION 116 692
*$LAYER Water Loop #
PARAMETERS 6
0.007725              ! 1 Inside diameter
L_pipe         ! 2 Pipe length
20             ! 3 Loss coefficient
1044           ! 4 Fluid density
3.53           ! 5 Fluid specific heat
TA             ! 6 Initial fluid temperature
INPUTS 3
6,1            ! Pump:Outlet fluid temperature ->Inlet temperature
6,2            ! Pump:Outlet flow rate ->Inlet flow rate
0,0            ! [unconnected] Environment temperature
*** INITIAL INPUT VALUES
TA 0 TA
*------------------------------------------------------------------------------
```

```
* Model "Pump-3" (Type 3)
*

UNIT 36 TYPE 3  Pump-3
*$UNIT_NAME Pump-3
*$MODEL .\Hydronics\Pumps\Single Speed\Type3b.tmf
*$POSITION 435 712
*$LAYER Main #
PARAMETERS 5
HXFlow         ! 1 Maximum flow rate
4.18           ! 2 Fluid specific heat
0              ! 3 Maximum power
0              ! 4 Conversion coefficient
0              ! 5 Power coefficient
INPUTS 3
38,1           ! Type531:Temperature at outlet-1 ->Inlet fluid temperature
38,2           ! Type531:Flow rate at outlet-1 ->Inlet mass flow rate
40,1           ! Type2b-2:Output control function ->Control signal
*** INITIAL INPUT VALUES
TA 0 1.0
*------------------------------------------------------------------------------

* Model "Type531" (Type 531)
*

UNIT 38 TYPE 531        Type531
*$UNIT_NAME Type531
*$MODEL .\Storage Tank Library (TESS)\Flat Bottom Tank\Type531.tmf
*$POSITION 641 814
*$LAYER Main #
*$# CYLINDRICAL STORAGE TANK
PARAMETERS 5
49             ! 1 Logical unit for data file
20             ! 2 # of tank nodes
3              ! 3 Number of ports
0              ! 4 Number of immersed heat exchangers
0              ! 5 Number of miscellaneous heat flows
INPUTS 50
49,3           ! Type91-2:Cold-side outlet temperature ->Inlet temperature for port-1
49,4           ! Type91-2:Cold-side flow rate ->Inlet flow rate for port-1
51,1           ! Type91:Hot-side outlet temperature ->Inlet temperature for port-2
51,2           ! Type91:Hot-side flow rate ->Inlet flow rate for port-2
25,5           ! Mains:Mains water temperature ->Inlet temperature for port-3
12,2           ! FlowMix:FLHOT ->Inlet flow rate for port-3
0,0            ! [unconnected] Top loss temperature
0,0            ! [unconnected] Edge loss temperature for node-1
0,0            ! [unconnected] Edge loss temperature for node-2
0,0            ! [unconnected] Edge loss temperature for node-3
0,0            ! [unconnected] Edge loss temperature for node-4
0,0            ! [unconnected] Edge loss temperature for node-5
0,0            ! [unconnected] Edge loss temperature for node-6
0,0            ! [unconnected] Edge loss temperature for node-7
0,0            ! [unconnected] Edge loss temperature for node-8
0,0            ! [unconnected] Edge loss temperature for node-9
0,0            ! [unconnected] Edge loss temperature for node-10
0,0            ! [unconnected] Edge loss temperature for node-11
0,0            ! [unconnected] Edge loss temperature for node-12
0,0            ! [unconnected] Edge loss temperature for node-13
0,0            ! [unconnected] Edge loss temperature for node-14
0,0            ! [unconnected] Edge loss temperature for node-15
0,0            ! [unconnected] Edge loss temperature for node-16
0,0            ! [unconnected] Edge loss temperature for node-17
0,0            ! [unconnected] Edge loss temperature for node-18
0,0            ! [unconnected] Edge loss temperature for node-19
0,0            ! [unconnected] Edge loss temperature for node-20
0,0            ! [unconnected] Bottom loss temperature
```

```
0,0            ! [unconnected] Gas flue temperature
0,0            ! [unconnected] Inversion mixing flow rate
0,0            ! [unconnected] Auxiliary heat input for node-1
0,0            ! [unconnected] Auxiliary heat input for node-2
0,0            ! [unconnected] Auxiliary heat input for node-3
0,0            ! [unconnected] Auxiliary heat input for node-4
0,0            ! [unconnected] Auxiliary heat input for node-5
0,0            ! [unconnected] Auxiliary heat input for node-6
0,0            ! [unconnected] Auxiliary heat input for node-7
0,0            ! [unconnected] Auxiliary heat input for node-8
0,0            ! [unconnected] Auxiliary heat input for node-9
0,0            ! [unconnected] Auxiliary heat input for node-10
0,0            ! [unconnected] Auxiliary heat input for node-11
0,0            ! [unconnected] Auxiliary heat input for node-12
0,0            ! [unconnected] Auxiliary heat input for node-13
0,0            ! [unconnected] Auxiliary heat input for node-14
0,0            ! [unconnected] Auxiliary heat input for node-15
0,0            ! [unconnected] Auxiliary heat input for node-16
0,0            ! [unconnected] Auxiliary heat input for node-17
0,0            ! [unconnected] Auxiliary heat input for node-18
0,0            ! [unconnected] Auxiliary heat input for node-19
0,0            ! [unconnected] Auxiliary heat input for node-20
*** INITIAL INPUT VALUES
20.0 0.0 20.0 0.0 20.0 0.0 20.0 20.0 20.0 20.0 20.0 20.0 20.0 20.0 20.0 20.0
20.0 20.0 20.0 20.0 20.0 20.0 20.0 20.0 20.0 20.0 20.0 20.0 20.0 -100 0.0 0.0
0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
DERIVATIVES 20
20.0           ! 1 Initial Tank Temperature-1
20.0           ! 2 Initial Tank Temperature-2
20.0           ! 3 Initial Tank Temperature-3
20.0           ! 4 Initial Tank Temperature-4
20.0           ! 5 Initial Tank Temperature-5
20.0           ! 6 Initial Tank Temperature-6
20.0           ! 7 Initial Tank Temperature-7
20.0           ! 8 Initial Tank Temperature-8
20.0           ! 9 Initial Tank Temperature-9
20.0           ! 10 Initial Tank Temperature-10
20.0           ! 11 Initial Tank Temperature-11
20.0           ! 12 Initial Tank Temperature-12
20.0           ! 13 Initial Tank Temperature-13
20.0           ! 14 Initial Tank Temperature-14
20.0           ! 15 Initial Tank Temperature-15
20.0           ! 16 Initial Tank Temperature-16
20.0           ! 17 Initial Tank Temperature-17
20.0           ! 18 Initial Tank Temperature-18
20.0           ! 19 Initial Tank Temperature-19
20.0           ! 20 Initial Tank Temperature-20
*** External files
ASSIGN "531_Combi1a.dat" 49
*|? Which file contains the parameter values for this component? |1000
*------------------------------------------------------------------------------

* Model "Aux Tank" (Type 60)
*

UNIT 29 TYPE 60        Aux Tank
*$UNIT_NAME Aux Tank
*$MODEL .\Thermal Storage\Detailed Fluid Storage Tank\Vertical Cylinder\Uniform Losses
and Node Heights\1 Inlet, 1 Outlet\Type60d.tmf
*$POSITION 772 690
*$LAYER Water Loop #
PARAMETERS 32
2              ! 1 User-specified inlet positions
0.17           ! 2 Tank volume
1              ! 3 Tank height
-1             ! 4 Tank perimeter
0.05           ! 5 Height of flow inlet 1
```

```
1              ! 6 Height of flow outlet 1
-1             ! 7 Not used (inlet 2)
-1             ! 8 Not used (outlet 2)
4.18           ! 9 Fluid specific heat
991            ! 10 Fluid density
4.356          ! 11 Tank loss coefficient
2.2752         ! 12 Fluid thermal conductivity
0              ! 13 Destratification conductivity
100            ! 14 Boiling temperature
1              ! 15 Auxiliary heater mode
.5             ! 16 Height of 1st aux. heater
.5             ! 17 Height of 1st thermostat
57             ! 18 Set point temperature for element 1
3              ! 19 Deadband for heating element 1
10799.999714           ! 20 Maximum heating rate of element 1
0              ! 21 Height of heating element 2
0              ! 22 Height of thermostat 2
57             ! 23 Set point temperature for element 2
2              ! 24 Deadband for heating element 2
0              ! 25 Maximum heating rate of element 2
0              ! 26 Overall loss coefficient for gas flue
20             ! 27 Flue temperature
6              ! 28 Fraction of critical timestep
0              ! 29 Gas heater?
0              ! 30 Number of internal heat exchangers
0              ! 31 Equal sized nodes
0              ! 32 Uniform tank losses
INPUTS 9
38,6           ! Type531:Flow rate at outlet-3 ->Flow rate at inlet 1
0,0            ! [unconnected] Flow rate at outlet 1
0,0            ! [unconnected] Not used (flow inlet 2)
0,0            ! [unconnected] Not used (flow outlet 2)
38,5           ! Type531:Temperature at outlet-3 ->Temperature at inlet 1
0,0            ! [unconnected] Not used (temp inlet 2)
0,0            ! [unconnected] Environment temperature
0,0            ! [unconnected] Control signal for element 1
0,0            ! [unconnected] Control signal for element 2
*** INITIAL INPUT VALUES
0 -2 -1 -1 20 20 22 1 1
DERIVATIVES 10
TA             ! 1 Initial temperature of node-1
TA             ! 2 Initial temperature of node-2
TA             ! 3 Initial temperature of node-3
TA             ! 4 Initial temperature of node-4
TA             ! 5 Initial temperature of node-5
TA             ! 6 Initial temperature of node-6
TA             ! 7 Initial temperature of node-7
TA             ! 8 Initial temperature of node-8
TA             ! 9 Initial temperature of node-9
TA             ! 10 Initial temperature of node-10
*------------------------------------------------------------------------------

* EQUATIONS "Draw"
*
EQUATIONS 2
DailyLoad = 225*4*0.991
Draw = [54,1]*DailyLoad
*$UNIT_NAME Draw
*$LAYER Water Loop
*$POSITION 999 630

*------------------------------------------------------------------------------


* Model "FlowMix" (Type 178)
*
```

```
UNIT 12 TYPE 178        FlowMix
*$UNIT_NAME FlowMix
*$MODEL .\Hydronics\Flow Mixer\Other Fluids\Type178.tmf
*$POSITION 927 672
*$LAYER Main #
PARAMETERS 1
55              ! 1 TSET
INPUTS 3
25,5            ! Mains:Mains water temperature ->TCOLD
29,5            ! Aux Tank:Temperature of outlet flow 1 ->THOT
Draw            ! Draw:Draw ->FLTAP
*** INITIAL INPUT VALUES
15 20 0
*------------------------------------------------------------------------------

* Model "Type266-ModifiedHDH" (Type 266)
*

UNIT 37 TYPE 266        Type266-ModifiedHDH
*$UNIT_NAME Type266-ModifiedHDH
*$MODEL .\My Components\Type266-ModifiedHDH.tmf
*$POSITION 1118 196
*$LAYER Main #
PARAMETERS 2
18              ! 1 T_REF
450             ! 2 VOL
INPUTS 2
24,1            ! Toronto:Ambient temperature ->T_AMB
50,2            ! Weather input:Output 2 ->T_AVE
*** INITIAL INPUT VALUES
0 0
*------------------------------------------------------------------------------

* Model "Type270-SH-Signal" (Type 270)
*

UNIT 60 TYPE 270        Type270-SH-Signal
*$UNIT_NAME Type270-SH-Signal
*$MODEL .\My Components\Type270-SH-Signal.tmf
*$POSITION 979 185
*$LAYER Main #
PARAMETERS 6
0.2             ! 1 R_FLOOR
4.18            ! 2 CP
0               ! 3 DTEMP_SET
40              ! 4 TIN_SET
160             ! 5 A_HEATED
250             ! 6 FLOW_MAX
INPUTS 4
37,1            ! Type266-ModifiedHDH:Q_KW ->Q_SH_KW
0,0             ! [unconnected] T_ROOM
0,0             ! [unconnected] FOO_IN
0,0             ! [unconnected] BAR_IN
*** INITIAL INPUT VALUES
0 20 0 0
*------------------------------------------------------------------------------

* Model "Type110" (Type 110)
*

UNIT 55 TYPE 110        Type110
*$UNIT_NAME Type110
*$MODEL .\Hydronics\Pumps\Variable Speed\Type110.tmf
*$POSITION 545 136
*$LAYER Main #
*$# VARIABLE-SPEED PUMP
PARAMETERS 6
```

```
250            ! 1 Rated flow rate
4.18           ! 2 Fluid specific heat
0              ! 3 Rated power
0.0            ! 4 Motor heat loss fraction
1              ! 5 Number of power coefficients
0              ! 6 Power coefficient
INPUTS 5
58,1           ! Type11h:Outlet temperature ->Inlet fluid temperature
58,2           ! Type11h:Outlet flow rate ->Inlet fluid flow rate
60,1           ! Type270-SH-Signal:PUMP_SIGNAL ->Control signal
0,0            ! [unconnected] Total pump efficiency
0,0            ! [unconnected] Motor efficiency
*** INITIAL INPUT VALUES
40 0.0 1.0 1 1
*------------------------------------------------------------------------------

* Model "Type268-AuxSH" (Type 268)
*

UNIT 47 TYPE 268       Type268-AuxSH
*$UNIT_NAME Type268-AuxSH
*$MODEL .\My Components\Type268-AuxSH.tmf
*$POSITION 822 46
*$LAYER Main #
PARAMETERS 1
4.18           ! 1 CP
INPUTS 3
55,1           ! Type110:Outlet fluid temperature ->TEMP_IN
55,2           ! Type110:Outlet flow rate ->FLOW_IN
60,2           ! Type270-SH-Signal:TIN_IDEAL ->T_SET
*** INITIAL INPUT VALUES
0 0 0
*------------------------------------------------------------------------------

* Model "Type271-HydronicFloor3" (Type 271)
*

UNIT 62 TYPE 271       Type271-HydronicFloor3
*$UNIT_NAME Type271-HydronicFloor3
*$MODEL .\My Components\Type271-HydronicFloor3.tmf
*$POSITION 845 302
*$LAYER Main #
PARAMETERS 6
4.18           ! 1 CP
0.2            ! 2 R_FLOOR
160            ! 3 A_HEATED
250            ! 4 FLOW_MAX
0              ! 5 DTEMP_SET
40             ! 6 TIN_SET
INPUTS 9
47,2           ! Type268-AuxSH:FLOW_OUT ->FLOW_IN
47,1           ! Type268-AuxSH:TEMP_OUT ->TEMP_IN
0,0            ! [unconnected] T_ROOM
37,1           ! Type266-ModifiedHDH:Q_KW ->Q_SH_KW
60,4           ! Type270-SH-Signal:FLOW_IDEAL ->IDEAL_FLOW
60,2           ! Type270-SH-Signal:TIN_IDEAL ->IDEAL_TIN
60,3           ! Type270-SH-Signal:TOUT_IDEAL ->IDEAL_TOUT
0,0            ! [unconnected] FOO_IN
0,0            ! [unconnected] BAR_IN
*** INITIAL INPUT VALUES
0 0 20 0 0 0 0 0 0
*------------------------------------------------------------------------------

* Model "Type269-SHTempering3" (Type 269)
*

UNIT 48 TYPE 269       Type269-SHTempering3
```

```
*$UNIT_NAME Type269-SHTempering3
*$MODEL .\My Components\Type269-SHTempering3.tmf
*$POSITION 704 420
*$LAYER Main #
INPUTS 3
62,2           ! Type271-HydronicFloor3:TEMP_OUT ->FLOOR_TEMP
51,3           ! Type91:Cold-side outlet temperature ->TANK_TEMP
60,2           ! Type270-SH-Signal:TIN_IDEAL ->SET_TEMP
*** INITIAL INPUT VALUES
0 0 0
*------------------------------------------------------------------------------

* EQUATIONS "Variables-3"
*
EQUATIONS 1
cntrout = [60,1] * [48,1]
*$UNIT_NAME Variables-3
*$LAYER Main
*$POSITION 430 338

*------------------------------------------------------------------------------


* Model "Type110-2" (Type 110)
*

UNIT 44 TYPE 110        Type110-2
*$UNIT_NAME Type110-2
*$MODEL .\Hydronics\Pumps\Variable Speed\Type110.tmf
*$POSITION 449 509
*$LAYER Main #
*$# VARIABLE-SPEED PUMP
PARAMETERS 6
250            ! 1 Rated flow rate
4.18           ! 2 Fluid specific heat
0              ! 3 Rated power
0.0            ! 4 Motor heat loss fraction
1              ! 5 Number of power coefficients
0              ! 6 Power coefficient
INPUTS 5
38,3           ! Type531:Temperature at outlet-2 ->Inlet fluid temperature
38,4           ! Type531:Flow rate at outlet-2 ->Inlet fluid flow rate
cntrout        ! Variables-3:cntrout ->Control signal
0,0            ! [unconnected] Total pump efficiency
0,0            ! [unconnected] Motor efficiency
*** INITIAL INPUT VALUES
40 0.0 1.0 1 1
*------------------------------------------------------------------------------

* Model "Type11f" (Type 11)
*

UNIT 41 TYPE 11         Type11f
*$UNIT_NAME Type11f
*$MODEL .\Hydronics\Flow Diverter\Other Fluids\Type11f.tmf
*$POSITION 693 349
*$LAYER Water Loop #
PARAMETERS 1
2              ! 1 Controlled flow diverter mode
INPUTS 3
62,2           ! Type271-HydronicFloor3:TEMP_OUT ->Inlet temperature
62,3           ! Type271-HydronicFloor3:FLOW_OUT ->Inlet flow rate
48,1           ! Type269-SHTempering3:X ->Control signal
*** INITIAL INPUT VALUES
20.0 100.0 0.5
*------------------------------------------------------------------------------
```

```
* Model "Type91" (Type 91)
*

UNIT 51 TYPE 91         Type91
*$UNIT_NAME Type91
*$MODEL .\Heat Exchangers\Constant Effectiveness\Type91.tmf
*$POSITION 553 413
*$LAYER Main #
PARAMETERS 3
1              ! 1 Heat exchanger effectiveness
4.18           ! 2 Specific heat of hot side fluid
4.18           ! 3 Specific heat of cold side fluid
INPUTS 4
44,1           ! Type110-2:Outlet fluid temperature ->Hot side inlet temperature
44,2           ! Type110-2:Outlet flow rate ->Hot side flow rate
41,3           ! Type11f:Temperature at outlet 2 ->Cold side inlet temperature
41,4           ! Type11f:Flow rate at outlet 2 ->Cold side flow rate
*** INITIAL INPUT VALUES
20 0 20.0 180
*------------------------------------------------------------------------------

* Model "Type11h" (Type 11)
*

UNIT 58 TYPE 11         Type11h
*$UNIT_NAME Type11h
*$MODEL .\Hydronics\Tee-Piece\Other Fluids\Type11h.tmf
*$POSITION 685 210
*$LAYER Water Loop #
PARAMETERS 1
1              ! 1 Tee piece mode
INPUTS 4
41,1           ! Type11f:Temperature at outlet 1 ->Temperature at inlet 1
41,2           ! Type11f:Flow rate at outlet 1 ->Flow rate at inlet 1
51,3           ! Type91:Cold-side outlet temperature ->Temperature at inlet 2
41,4           ! Type11f:Flow rate at outlet 2 ->Flow rate at inlet 2
*** INITIAL INPUT VALUES
20.0 100.0 20.0 100.0
*------------------------------------------------------------------------------

* Model "Type2b-2" (Type 2)
*

UNIT 40 TYPE 2  Type2b-2
*$UNIT_NAME Type2b-2
*$MODEL .\Controllers\Differential Controller w_ Hysteresis\for Temperatures\Solver 0
(Successive Substitution) Control Strategy\Type2b.tmf
*$POSITION 138 626
*$LAYER Main #
*$# NOTE: This control strategy can only be used with solver 0 (Successive substitution)
*$#
PARAMETERS 2
5              ! 1 No. of oscillations
90             ! 2 High limit cut-out
INPUTS 6
43,1           ! Type71 HP200 30:Outlet temperature ->Upper input temperature Th
38,1           ! Type531:Temperature at outlet-1 ->Lower input temperature Tl
38,3           ! Type531:Temperature at outlet-2 ->Monitoring temperature Tin
40,1           ! Type2b-2:Output control function ->Input control function
0,0            ! [unconnected] Upper dead band dT
0,0            ! [unconnected] Lower dead band dT
*** INITIAL INPUT VALUES
TA TA TA 0 10 3
*------------------------------------------------------------------------------

* EQUATIONS "TPAVG-2"
*
```

```
EQUATIONS 3
DIFF = [55,2]-[58,2]
AUXDIFF = [55,2]-[47,2]
TemperingDIFF = [62,3] - [58,2]
*$UNIT_NAME TPAVG-2
*$LAYER Main
*$POSITION 202 946

*-------------------------------------------------------------------------------


* Model "Solar-4" (Type 65)
*

UNIT 59 TYPE 65         Solar-4
*$UNIT_NAME Solar-4
*$MODEL .\Output\Online Plotter\Online Plotter Without File\Type65d.tmf
*$POSITION 880 882
*$LAYER Main #
PARAMETERS 12

10             ! 1 Nb. of left-axis variables
10             ! 2 Nb. of right-axis variables
0              ! 3 Left axis minimum
100            ! 4 Left axis maximum
0              ! 5 Right axis minimum
100            ! 6 Right axis maximum
1              ! 7 Number of plots per simulation
12             ! 8 X-axis gridpoints
0              ! 9 Shut off Online w/o removing
-1             ! 10 Logical unit for output file
0              ! 11 Output file units
0              ! 12 Output file delimiter
INPUTS 20
38,21          ! Type531:Tank nodal temperature-1 ->Left axis variable-1
38,23          ! Type531:Tank nodal temperature-3 ->Left axis variable-2
38,25          ! Type531:Tank nodal temperature-5 ->Left axis variable-3
38,27          ! Type531:Tank nodal temperature-7 ->Left axis variable-4
38,29          ! Type531:Tank nodal temperature-9 ->Left axis variable-5
38,31          ! Type531:Tank nodal temperature-11 ->Left axis variable-6
38,33          ! Type531:Tank nodal temperature-13 ->Left axis variable-7
38,35          ! Type531:Tank nodal temperature-15 ->Left axis variable-8
38,37          ! Type531:Tank nodal temperature-17 ->Left axis variable-9
38,40          ! Type531:Tank nodal temperature-20 ->Left axis variable-10
0,0            ! [unconnected] Right axis variable-1
0,0            ! [unconnected] Right axis variable-2
0,0            ! [unconnected] Right axis variable-3
0,0            ! [unconnected] Right axis variable-4
0,0            ! [unconnected] Right axis variable-5
0,0            ! [unconnected] Right axis variable-6
0,0            ! [unconnected] Right axis variable-7
0,0            ! [unconnected] Right axis variable-8
0,0            ! [unconnected] Right axis variable-9
0,0            ! [unconnected] Right axis variable-10
*** INITIAL INPUT VALUES
Temp Temp Temp Temp Temp Temp Temp Temp Temp Temp Temp Temp Temp Temp Temp
Temp Temp Temp Temp Temp
LABELS  3
"Temperatures (C)"
"Insolation (kJ/hr-m^2)"
"Collector"
*-------------------------------------------------------------------------------

* Model "Solar-3" (Type 65)
*

UNIT 46 TYPE 65         Solar-3
```

```
*$UNIT_NAME Solar-3
*$MODEL .\Output\Online Plotter\Online Plotter Without File\Type65d.tmf
*$POSITION 358 872
*$LAYER Main #
PARAMETERS 12
1              ! 1 Nb. of left-axis variables
4              ! 2 Nb. of right-axis variables
-1             ! 3 Left axis minimum
2              ! 4 Left axis maximum
-10            ! 5 Right axis minimum
10             ! 6 Right axis maximum
1              ! 7 Number of plots per simulation
12             ! 8 X-axis gridpoints
0              ! 9 Shut off Online w/o removing
-1             ! 10 Logical unit for output file
0              ! 11 Output file units
0              ! 12 Output file delimiter
INPUTS 5
0,0            ! [unconnected] Left axis variable
DIFF           ! TPAVG-2:DIFF ->Right axis variable-1
AUXDIFF        ! TPAVG-2:AUXDIFF ->Right axis variable-2
TemperingDIFF          ! TPAVG-2:TemperingDIFF ->Right axis variable-3
0,0            ! [unconnected] Right axis variable-4
*** INITIAL INPUT VALUES
FOO PUMP AUX Tempering Tank
LABELS  3
"Temperatures (C)"
"Insolation (kJ/hr-m^2)"
"Collector"
*------------------------------------------------------------------------------

* Model "ERROR" (Type 65)
*

UNIT 39 TYPE 65         ERROR
*$UNIT_NAME ERROR
*$MODEL .\Output\Online Plotter\Online Plotter Without File\Type65d.tmf
*$POSITION 990 50
*$LAYER Main #
PARAMETERS 12
3              ! 1 Nb. of left-axis variables
2              ! 2 Nb. of right-axis variables
0              ! 3 Left axis minimum
40             ! 4 Left axis maximum
-1             ! 5 Right axis minimum
2              ! 6 Right axis maximum
1              ! 7 Number of plots per simulation
12             ! 8 X-axis gridpoints
0              ! 9 Shut off Online w/o removing
-1             ! 10 Logical unit for output file
0              ! 11 Output file units
0              ! 12 Output file delimiter
INPUTS 5
62,5           ! Type271-HydronicFloor3:FOO_OUT ->Left axis variable-1
62,6           ! Type271-HydronicFloor3:BAR_OUT ->Left axis variable-2
47,1           ! Type268-AuxSH:TEMP_OUT ->Left axis variable-3
47,3           ! Type268-AuxSH:Q_OUT_KW ->Right axis variable-1
37,1           ! Type266-ModifiedHDH:Q_KW ->Right axis variable-2
*** INITIAL INPUT VALUES
FOO BAR TSET LOAD_KW LOAD_KW
LABELS  3
"ERROR"
"ERROR"
"Graph 1"
*------------------------------------------------------------------------------

* Model "Solar-5" (Type 65)
```

```
*

UNIT 61 TYPE 65        Solar-5
*$UNIT_NAME Solar-5
*$MODEL .\Output\Online Plotter\Online Plotter Without File\Type65d.tmf
*$POSITION 859 733
*$LAYER Main #
PARAMETERS 12
10             ! 1 Nb. of left-axis variables
2              ! 2 Nb. of right-axis variables
0              ! 3 Left axis minimum
100            ! 4 Left axis maximum
0              ! 5 Right axis minimum
100000         ! 6 Right axis maximum
1              ! 7 Number of plots per simulation
12             ! 8 X-axis gridpoints
0              ! 9 Shut off Online w/o removing
-1             ! 10 Logical unit for output file
0              ! 11 Output file units
0              ! 12 Output file delimiter
INPUTS 12
29,22          ! Aux Tank:Tank temperature - top ->Left axis variable-1
29,24          ! Aux Tank:Temperature of node 1+-1 ->Left axis variable-2
29,25          ! Aux Tank:Temperature of node 1+-2 ->Left axis variable-3
29,26          ! Aux Tank:Temperature of node 1+-3 ->Left axis variable-4
29,27          ! Aux Tank:Temperature of node 1+-4 ->Left axis variable-5
29,28          ! Aux Tank:Temperature of node 1+-5 ->Left axis variable-6
29,29          ! Aux Tank:Temperature of node 1+-6 ->Left axis variable-7
29,30          ! Aux Tank:Temperature of node 1+-7 ->Left axis variable-8
29,31          ! Aux Tank:Temperature of node 1+-8 ->Left axis variable-9
29,23          ! Aux Tank:Tank temperature - bottom ->Left axis variable-10
29,13          ! Aux Tank:Element 1 power ->Right axis variable-1
0,0            ! [unconnected] Right axis variable-2
*** INITIAL INPUT VALUES
Temp Temp Temp Temp Temp Temp Temp Temp Temp Temp Temp Temp
LABELS  3
"Temperatures (C)"
"Insolation (kJ/hr-m^2)"
"temp"
*------------------------------------------------------------------------------

* Model "Type272-Min-Iteration" (Type 272)
*

UNIT 63 TYPE 272       Type272-Min-Iteration
*$UNIT_NAME Type272-Min-Iteration
*$MODEL .\My Components\Type272-Min-Iteration.tmf
*$POSITION 1074 900
*$LAYER Main #
PARAMETERS 1
0              ! 1 C_MIN
INPUTS 2
63,1           ! Type272-Min-Iteration:TIME_OUT ->TIME_OLD
63,2           ! Type272-Min-Iteration:C_OUT ->C_OLD
*** INITIAL INPUT VALUES
0 0
*------------------------------------------------------------------------------

* Model "IntSum" (Type 24)
*

UNIT 52 TYPE 24        IntSum
*$UNIT_NAME IntSum
*$MODEL .\Utility\Integrators\Quantity Integrator\Type24.tmf
*$POSITION 185 78
*$LAYER Main #
PARAMETERS 2
```

```
8760            ! 1 Integration period
0               ! 2 Relative or absolute start time
INPUTS 10
kWh             ! Equa:kWh ->Input to be integrated-1
kWh2            ! Equa:kWh2 ->Input to be integrated-2
kWh3            ! Equa:kWh3 ->Input to be integrated-3
37,1            ! Type266-ModifiedHDH:Q_KW ->Input to be integrated-4
kWh4            ! Equa:kWh4 ->Input to be integrated-5
kWh5            ! Equa:kWh5 ->Input to be integrated-6
kWh6            ! Equa:kWh6 ->Input to be integrated-7
0,0             ! [unconnected] Input to be integrated-8
kWh8            ! Equa:kWh8 ->Input to be integrated-9
47,3            ! Type268-AuxSH:Q_OUT_KW ->Input to be integrated-10
*** INITIAL INPUT VALUES
0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
*------------------------------------------------------------------------------

* EQUATIONS "Equa"
*
EQUATIONS 7
kWh = [51,5]/3600
kWh2 = [49,5]/3600
kWh3 = [43,3]/3600
kWh4 = [12,3] / 3600
kWh5 = [29,12]/3600
kWh6 = [24,18] / 3600
kWh8 = [29,12]/3600
*$UNIT_NAME Equa
*$LAYER Main
*$POSITION 219 178

*------------------------------------------------------------------------------


* Model "Solar-2" (Type 65)
*

UNIT 56 TYPE 65         Solar-2
*$UNIT_NAME Solar-2
*$MODEL .\Output\Online Plotter\Online Plotter Without File\Type65d.tmf
*$POSITION 76 71
*$LAYER Main #
PARAMETERS 12
5               ! 1 Nb. of left-axis variables
2               ! 2 Nb. of right-axis variables
0               ! 3 Left axis minimum
10000           ! 4 Left axis maximum
0.0             ! 5 Right axis minimum
10000           ! 6 Right axis maximum
1               ! 7 Number of plots per simulation
12              ! 8 X-axis gridpoints
0               ! 9 Shut off Online w/o removing
-1              ! 10 Logical unit for output file
0               ! 11 Output file units
0               ! 12 Output file delimiter
INPUTS 7
52,1            ! IntSum:Result of integration-1 ->Left axis variable-1
52,2            ! IntSum:Result of integration-2 ->Left axis variable-2
52,3            ! IntSum:Result of integration-3 ->Left axis variable-3
52,6            ! IntSum:Result of integration-6 ->Left axis variable-4
52,8            ! IntSum:Result of integration-8 ->Left axis variable-5
52,4            ! IntSum:Result of integration-4 ->Right axis variable-1
52,5            ! IntSum:Result of integration-5 ->Right axis variable-2
*** INITIAL INPUT VALUES
TColl_in TColl_in TColl_in AuxDHW DHWLosses SH DHW
LABELS  3
"Temperatures (C)"
```

```
"Insolation (kJ/hr-m^2)"
"Collector"
*-------------------------------------------------------------------------------

* Model "PrintSum" (Type 25)
*

UNIT 64 TYPE 25         PrintSum
*$UNIT_NAME PrintSum
*$MODEL .\Output\Printer\User-Supplied Units\Type25b.tmf
*$POSITION 83 145
*$LAYER Main #
PARAMETERS 10
8760           ! 1 Printing interval
START          ! 2 Start time
STOP           ! 3 Stop time
50             ! 4 Logical unit
1              ! 5 Units printing mode
0              ! 6 Relative or absolute start time
1              ! 7 Overwrite or Append
-1             ! 8 Print header
0              ! 9 Delimiter
1              ! 10 Print labels
INPUTS 12
52,1           ! IntSum:Result of integration-1 ->Input to be printed-1
52,2           ! IntSum:Result of integration-2 ->Input to be printed-2
52,3           ! IntSum:Result of integration-3 ->Input to be printed-3
52,4           ! IntSum:Result of integration-4 ->Input to be printed-4
52,5           ! IntSum:Result of integration-5 ->Input to be printed-5
52,7           ! IntSum:Result of integration-7 ->Input to be printed-6
52,9           ! IntSum:Result of integration-9 ->Input to be printed-7
52,10          ! IntSum:Result of integration-10 ->Input to be printed-8
CollFlow               ! Variables-2:CollFlow ->Input to be printed-9
HXFlow         ! Variables-2:HXFlow ->Input to be printed-10
angle          ! Variables-2:angle ->Input to be printed-11
Test           ! Variables-2:Test ->Input to be printed-12
*** INITIAL INPUT VALUES
SH_SOLAR DHW_SOLAR Total_Coll SH_LOAD DHW_LOAD Gt_tilt DHW_AUX SH_AUX
CollFlow HXFlow ANGLE TEST
kWh kWh kWh kWh kWh kWh/m2 kWh kWh kg/hr kg/hr ° -
*** External files
ASSIGN "4combi3d6par.out" 50
*|? Output file for printed results |1000
*-------------------------------------------------------------------------------

* EQUATIONS "Variables-2"
*
CONSTANTS 4
CollFlow = 36
HXFlow = 30
Test = 4
angle = 50
*$UNIT_NAME Variables-2
*$LAYER Main
*$POSITION 74 252

*-------------------------------------------------------------------------------


END
```