Integrated Modelling and Analysis of a Heat Pump BIPV/T System with Thermal Storage for Load Shifting

Rémi Dumoulin

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By:	Rémi Dumoulin
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Dr. C. Lai *Examiner's name*	Examiner
Dr. F. Nasiri *Examiner's name*	Examiner
Dr. A. Athienitis *Supervisor's name*	Supervisor

Approved by ______________________________

Chair of Department

April 2019 ______________________________

Dean of Faculty

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Abstract

This thesis presents an integrated model and methodology to quantify and demonstrate the thermal flexibility potential of a residential building featuring an air-based building integrated photovoltaic thermal (BIPV/T) system coupled to an air-source heat pump and a water-based sensible thermal energy storage.

A BIPV/T system is used to preheat outdoor air drawn under the PV with a fan, in addition to producing solar electricity. The pre-heated air leaving the BIPV/T cavity in the heating season is sent to the evaporator coil of the air-source heat pump so as to increase its coefficient of performance. The condenser side of the heat pump is connected to a water thermal energy storage from which water is fed to a hydronic air-system used for space heating. An integration with a thermal energy storage as a means of decoupling the loads from the source is proposed with the objective of shifting thermal loads and electrical peak demand so that they are outside the peak demand periods for the grid.

A model was developed and a case study of a residential net-zero energy solar building was simulated in TRNSYS. Rule-based control strategies and a deterministic electrical grid state schedule were used to optimize the profile of the electric demand of the building. The flexibility potential of different design alternatives and control strategies were quantified using load matching grid interaction indicators, energy metrics, and different pricing schemes. The gross energy consumption of the building was reduced by more than 40% during peak grid events, the overall coefficient of performance of the air-source heat pump was improved by 22%, and the cost of electricity was decreased by 46% with the implementation of a variable tariff price structure and a net-metering agreement.

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CONTENTS

LIST OF FIGURES

LIST OF TABLES

NOMENCLATURE

Acronyms

AHU Air Handling Unit

ALPD Average Number of Liters per Day of hot water consumption

ASHP Air-Source Heat Pump

ASHRAE American Society of Heating, Refrigerating and Air-Conditioning Engineers

BAST Building Applied Solar Thermal

BIPV Building Integrated Photovoltaic

BIPV/T Building Integrated Photovoltaic Thermal

BIST Building Integrated Solar Thermal

COP Coefficient of Performance of a heat pump

CWEC Canadian Weather Year for Energy Calculation

DHW Domestic Hot Water

DHWL Domestic How Water Load of the building (daily)

DSM	Demand-Side Management
GHG	Greenhouse Gas
HRV	Heat Recovery Ventilator
$IEA-EBC$	International Energy Agency Energy in Building and Communities
LED	Light-Emitting Diode
$LMGI$	Load Matching and Grid Interaction
LPD	Lighting Power Density
MPC	Model Predictive Control
$NZEB$	Net-Zero Energy Buildings
PV	Photovoltaic
RBC	Rule-Based Control
$RBPC$	Rule-Based Predictive Control
RES	Renewable Energy Sources
RTE	Round-Trip Efficiency
SOC	State of Charge
SPF	Seasonal Perfomance Factor
TES	Thermal Energy Storage
ACH	Air Changes per Hour
HDD	Heating Degree Days
SAASHP	Solar-Assisted Air-Source Heat Pump

Symbols

β_{ref}	PV temperature coefficient ($\frac{\%}{°\mathrm{C}}$)
$\dot{P}_{compressor}$	Compressor power of the heat pump (W)
$\dot{Q}_{BIPV/T}$	Useful heat harvested by the BIPV/T system (W)
$\dot{Q}_{load}$	Heat rate delivered to a load by the heat pump (W)
η_c	Calculated PV electrical efficiency based on module temperature
$\eta_{BIPV/T}$	Combined thermal and electrical efficiency of the BIPV/T system
η_{Tref}	PV electrical efficiency under standard conditions
μ_{air}	Dynamic viscosity ($Pa \cdot s$)
ρ	Density ($\frac{kg}{m^3}$)
A_F	Conditioned floor area of building (m^2)
$A_{BIPV/T}$	Area of the BIPV/T system (m^2)
D_h	Hydraulic diameter (m)
$E_{BIPV/T}$	Electricity generated by the BIPV/T system (W)
$E_{compressor}$	Energy consumed over a time interval of interest of the heat pump compressor (kWh)
E_{fans}	Energy consumed over a time interval of interest of the fans in use in the hvac system (kWh)
E_{pumps}	Energy consumed over a time interval of interest of the pumps in use in the hvac system (kWh)
G	Incident solar radiation ($\frac{kW}{m^2}$)
h_{fluid}	Convective heat transfer coefficient ($\frac{W}{m^2 \cdot °\mathrm{C}}$)
Nu	Nusselt number

O_E	Electricity used by occupants(kWh/day)
Pr	Prandtl number
Q_{load}	Cumulative heat delivered to a load by the heat pump (kWh)
$Q_{storage}$	TES storage capacity (kWh)
R_E	Number of electric range tops
Re	Reynolds number
T_c	PV module temperature (°C)
T_{ref}	PV module reference temperature (°C)
V	Velocity $(\frac{m}{s})$

CHAPTER 1

INTRODUCTION

Buildings are responsible for 35% to 40% of the total final energy consumption in Canada and one third of greenhouse gas emissions [Wei et al., 2018]. They are also key contributors to the peak electricity demand [Wei and Shicong, 2014]. Renewable energy sources (RES) penetration rates to the electrical grid and their contribution to the total energy generation are on the rise. At the local level, buildings such as net-zero energy buildings (NZEB) are becoming both generators and consumers. An increasing interest in greenhouse gas (GHG) emissions reduction, resilience, and innovation is driving the concept of on-site energy generation [Fisch et al., 2013]. Consumers both importing from and exporting to the utility grid are referred to as prosumers [Zafar et al., 2018]. A common way of evaluating the energy performance of prosumers is to look at the on-site energy imported from and exported to the grid on an annual basis; however, as suggested in [Athienitis et al., 2015], net-zero energy performance alone is not enough to fulfill the end-goal of reducing energy use and environmental impact of buildings as it does not account for local demand fluctuations and intrinsic variability of on-site energy generation. Electricity demand over a year is not constant but fluctuates depending on weather conditions and other factors such as use of appliances and working hours. Those fluctuations yield minimum and maximum demands. A maximum demand, also known as a peak power, can require the use of highly responsive power plants, referred to as peaking power plants, which often operate less than 10 percent of the time [Zohuri, 2016]. The responsiveness of peaking power plants comes with financial and environmental costs. Exporting on-site excess energy production to the grid during peak demands can reduce the need for inefficient and polluting peaking power plants [Athienitis et al., 2015] [Belz et al., 2014]. An important enhancement of the NZEB concept will include the notion of load matching and grid interaction, designated by LMGI [Salom et al., 2011]. [Ostergaard et al., 2017] and [Denholm and Hand, 2011] identify energy flexibility as part of the solution. The concept of energy flexibility requires energy storage, which can be either thermal or electrical. [Belz et al., 2014] identify thermal energy storage systems as potential contributors to the end of the worlds' dependency on fossil fuels and the answer to the inherently intermittent contribution of renewable energies to the energy mix.

When incorporating distributed energy sources in the network, power is fed to the grid through the low-voltage side (customer side) of the network. In a low penetration rate of local energy production scenario, on-site energy production may share excess energy with local customers and help decrease transmission losses through the network, but if a large proportion of grid-tied customers over a network generate on-site energy, a fixed hosting capacity may have to be imposed [Etherden and Bollen, 2011]. This is due to the fact that the grid demand may not match the energy production and at times of low demand, voltage rise across the network may reach the upper limit sooner than when more loads are present. Energy produced during such events would have to be curtailed [Stetz et al., 2012].

The International Energy Agency Energy in Building and Communities (IEA-EBC) Annex 67 research project is focused on energy flexible buildings. [Ostergaard et al., 2017] identifies flexibility as part of the solution to the future problems related to building energy systems. Such problems arise from the intrinsic production variability of renewable energy sources. Associated problems include potential energy network instability, congestion, and curtailment. Smart grid can be defined as "an advanced power system with integrated communication infrastructure to enable bi-directional flow of energy and information" in which prosumers will play an important role in demand management [Zafar et al., 2018].

1.1 Objectives

The goal of this work is to develop an integrated model and methodology to quantify the thermal flexibility potential of a residential building featuring a BIPV/T system coupled to an air-source heat pump (ASHP) and a sensible thermal energy storage (TES). The heat source, storage and distribution are taken into consideration and different sizing and operation strategies are explored. Sub-objectives include the evaluation of the electrical efficiency of an air-source air to water heat pump connected in series with a BIPV/T system under a range of design and operating conditions, the quantification of the state of charge of a hot water tank used as a sensible TES relying on a limited number of input parameters to reflect real-life scenario with a limited number of sensors available, and the consideration of stratification when sizing and operating a heating system fitted with a vertical water thermal storage tank. When evaluating the flexibility performance of design and operation options, the efficiency of the TES, the efficiency of the HVAC plant, the time-dependent energy usage, the operation costs, the peak energy usage, the energy shifted during flexibility events and the duration of load shifts are considered. Design recommendations for different priorities (cost savings and time-of-use energy consumption) are proposed. Some of the challenges include comfort, utility grid stability, resilience, and energy cost. Occupants' well being remains the top priority in designing flexible building systems and ensuring proper comfort goes further than thermal considerations. Flexibility strategies should not impact the occupants' behavior in a way that would interfere with their daily routine and comfort level. For this reason, the flexibility options proposed in this work do not rely on occupants to modify their behavior, although this is a possible area of further research.

1.2 Thesis Outline

Chapter 1 provides an introduction to the topic of energy flexibility of buildings in their grid interaction and the rational for thermal load shifting in the current and future RES markets.

Chapter 2 reviews the literature and the current state of knowledge in the field of ASHP coupled to BIPV/T systems, building flexibility and the use of sensible water TES tanks for demand-side management.

Chapter 3 introduces the building archetype used in this study and presents baseline thermal load against which design options incorporating thermal flexibility will be evaluated.

Chapter 4 introduces a 50-node sensible water TES model and proposes a method for obtaining a TES state of charge (SOC) to improve its control. The concept of stratification and its effect on the usable storage capacity is explored.

Chapter 5 considers the integration of a cold-climate ASHP with a BIPV/T model in TRNSYS as part of an integrated model. Thermal flexibility potential during the heating season is explored through 26 design alternatives and design guidelines are proposed.

Chapter 6 presents a summary of this work along with concluding remarks, and future work opportunities.

Part of this work was showcased in the international Solar Decathlon China competition that took place in Dezhou in summer 2018. The Deep Performance Dwelling (DPD) is the residential building archetype used throughout this study. It was built as a demonstration project by Team MTL, a collaboration between McGill and Concordia Universities. It aimed to educate and train young engineers and architects on sustainable and innovative building technologies. The house received numerous prestigious prizes throughout the competition including 1st prizes in architecture, communication, and market appeal as well as third prizes in innovation and engineering juried contests.

Figure 1.1: Team MTL in Dezhou, summer 2018

CHAPTER 2

LITERATURE REVIEW

2.1 BIPV/T Solar Assisted Air-Source Heat Pumps

There are multiple ways through which heat can be extracted from absorbed solar radiation. A common method consists in using dedicated solar thermal collectors (solar thermal). Such collectors can be of flat plates types or evacuated tubes types and are typically used with a liquid as the heat transfer fluid [Kamel and Fung, 2014]. The main application of this technology is domestic hot water heating though it is also used for space heating. Solar collectors installed on buildings can either be applied (ie. installed over a finished building envelope) or integrated (serving a function of the envelope and replacing common construction materials). Terms such as BIST (Building Integrated Solar Thermal) and BAST (Building Applied Solar Thermal) are used to denote those two systems [Maurer et al., 2017]. In contrast with typical solar thermal systems, BIPV/T technology combines electricity and heat generation. In addition to producing electricity, PV modules can also be used to harvest solar heat. While 15-20% of the absorbed incident solar radiation on the panels can be transformed into electricity, an additional portion can be extracted as low-grade heat to be used either for fresh air pre-heating, or as a heat source for an air-source heat pump [Delisle and Kummert, 2016]. Either air or water (or a aqueous mixture with antifreeze) can be used to transfer the absorbed heat from the PV modules. Open loop air systems provide a reliable, low maintenance and low risk opportunity to harvest heat while improving the performance of the solar cells.

[Kotak et al., 2015] studied the impact of using different ground reflectances to better represent the overall albedo of the ground surrounding a PV installation in modelling. It is suggested that the common constant albedo value of 0.2 does not accurately consider varying ground albedo and that locations in the US and in Canada show a strong seasonal dependence. While the 0.2 reflectance value is a good approximate for summer, the snow cover reflectivity is over 0.65 and as high as 0.88 for fresh snow [Kotak et al., 2015]. It is therefore advisable to consider a higher ground reflectance value when analysing and designing PV systems in locations where a snow cover is expected during winter months.

[Dubey et al., 2013] reviewed different correlations linking photovoltaic modules temperature and their electrical efficiency. Silicon based PV modules are typically less effective at producing electricity when operating at high temperatures. Power output depends linearly on the operating temperature of the module. The Evans-Florschuetz correlation is a traditional linear expression for the PV electrical efficiency and is defined as:

$$\eta_c = \eta_{Tref}[1 - \beta_{ref}(T_c - T_{ref})] \tag{2.1}$$

Where:

η_c	calculated electrical efficiency based on cell temperature
η_{Tref}	is the electrical efficiency under standard conditions
β_{ref}	is the temperature coefficient of the module (typically -0.05 %/°C)
T_c	is the module temperature
T_{ref}	is the module temperature at which the reference electrical efficiency is given

Typically, between 15 and 20% of the incident solar radiation on a module is converted to electricity. The remainder of the absorbed portion is converted to heat which is partly transferred back to the ambient air by convection and radiation. In cases of high irradiance, and low wind conditions, module temperatures can reach over 60°C if not properly vented or cooled [Chen et al., 2010]. There has been some work on combining the electrical and heat outputs of solar modules starting as early as the 1970s. Air or a liquid can be used to remove the absorbed heat from the module, effectively making it more efficient while recuperating useful heat for various processes. Pre-heated fresh air in winter can be used for fulfilling the ventilation function of an HVAC system and reducing the amount of sensible heat to be added [Athienitis et al., 2011]. Heated air from a BIPV/T system can also be used to heat the structure of a building by passing it under a concrete slab [Yang and Athienitis, 2015]. Studies have shown increased combined electrical and thermal effiencies of BIPV/T systems in comparison with solar thermal collectors and traditional PV systems installed side-by-side and occupying the same surface area [Delisle and Kummert, 2014].

Some solar systems are standalone assemblies which are independent from buildings. In this case, additional land and a structure for supporting the PV modules are necessary, which contribute to the initial costs of the system [Delisle and Kummert, 2014]. Buildings offer potential for solar energy production due to their large surface areas and different orientations [Delisle and Kummert, 2014] [Saretta et al., 2019]. Initial costs of incorporating photovoltaic (PV) systems can be reduced significantly when installing the modules as part of the building envelope [Yang and Athienitis, 2016]. This type of system is called building-integrated photovoltaic (BIPV). Both in the case of new buildings or retrofits, part of the cladding or the rooftop can be replaced by PV modules. In essence, common materials can effectively be replaced by energy producing construction materials. The incorporation of solar systems on buildings is therefore likely to reduce the average life cycle cost of solar power [Scognamiglio, 2017].

Due to a lower heat capacity than water, air as a heat transfer fluid requires more volumetric flow rate to transfer the same amount of heat as water. Nonetheless, lower installation costs, low maintenance and low risks make air the preferred heat transfer fluid option [Athienitis et al., 2015]. Air systems eliminate the potential downsides associated with water based systems such as corrosion, leaking, of freezing in addition to generating very little noise if the system is designed properly with low pressure drops in the air cavity. An example of a

BIPV/T air manifold is shown in figure 2.1. A schematic of the Solar Decathlon house in which the manifold was installed is shown in 2.2. For similar airflow rates across all cavities, balancing dampers such as the ones shown in figure 2.3 can be used. This allows to regulate the PV temperatures and reduce hot spots in the system.

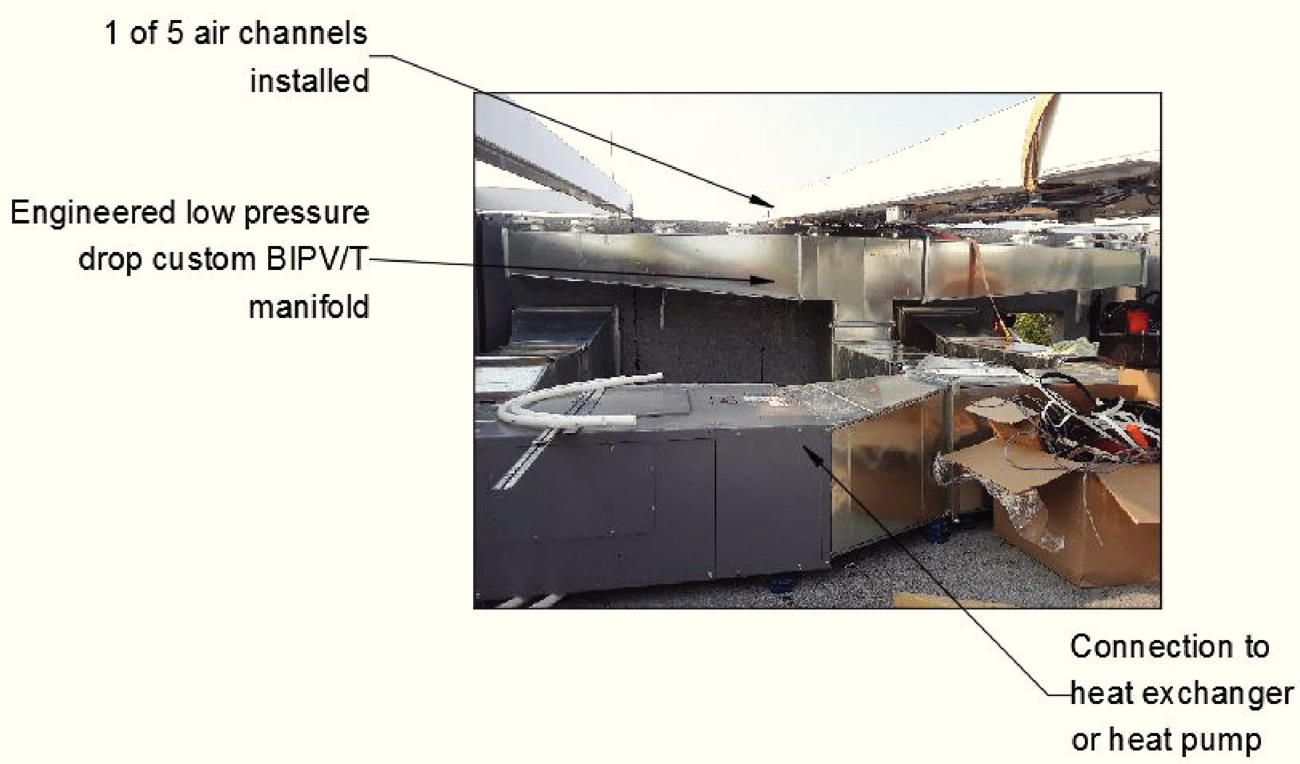

Figure 2.1: Team MTL custom BIPV/T air manifold

The coefficient of performance of a heat pump indicates the efficiency of the plant at transferring heat from a source to a load. In general terms, the COP is the ratio of the desired heat transfer over its associated cost.

The $COP_{heating}$ is denoted as:

$$COP_{heating} = \frac{\dot{Q}_{load}}{\dot{P}_{compressor}} \tag{2.2}$$

Where:

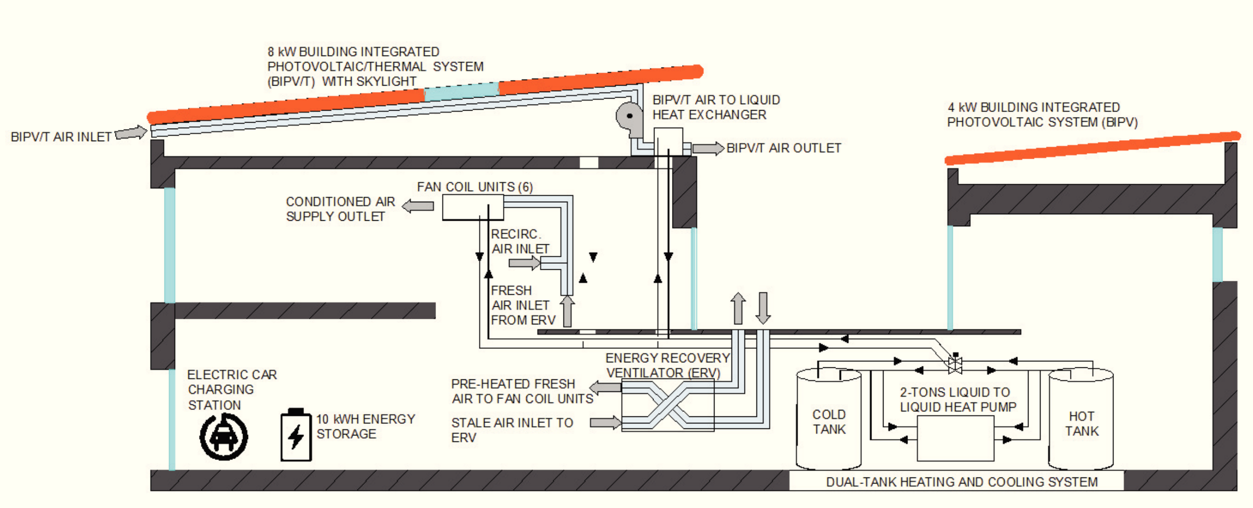

Figure 2.2: Team MTL Deep Performance Dwelling Mechanical systems schematics

Figure 2.3: Example of a custom-made BIPV/T air manifold balancing damper

$COP_{heating}$	is the coefficient of performance of the heat pump in heating mode
$\dot{Q}_{load}$	is the heat rate delivered to the load by the heat pump
$\dot{P}_{compressor}$	is the power used by the compressor

The seasonal performance factor (SPF) is similar to the coefficient of performance in that it is a ratio of loads met over energy consumption. However, it includes all of the equipment used in the mechanical system (pumps and fans) [Chu, 2014].

$$SPF = \frac{Q_{load}}{E_{compressor} + E_{fans} + E_{pumps}} \tag{2.3}$$

Where:

SPF	is the seasonal performance factor
Q_{load}	is the cumulative heat delivered to a load by the heat pump (kWh)
$E_{compressor}$	is the energy consumed over a time interval of interest of the heat pump compressor (kWh)
E_{fans}	is the energy consumed over a time interval of interest of the fans in use in the HVAC system (kWh)
E_{pumps}	is the energy consumed over a time interval of interest of the pumps in use in the HVAC system (kWh)

There is interest in using the low-grade heat output of PVT systems as a heat source for ASHP. Such system can be refered to as Solar-Assisted Air-Source Heat Pump (SAASHP) . This arrangement is mutually beneficial for both systems as the efficiency of the PV installation can be increased while the source-side air temperature of the ASHP can be boosted to improve the coefficient of performance of the heat pump [Hailu et al., 2015] [Kamel et al., 2015]. [Kamel and Fung, 2014] developed a Trnsys PVT model coupled to a ASHP in a sustainable house model. The heat pump considered was an air-to-air type with a direct expansion coil in an air-handling unit (AHU) . The authors did not consider the integration of such a system with a TES. [Hailu et al., 2015] investigated the performance gains of ASHP coupled to a wall-side BIPV/T system and showed improvements in the COP from February through April. [Hailu et al., 2015] indicates that a BIPV/T system coupled to an ASHP could significantly reduce the capital cost in comparison with a ground-source heat pump connected to a geothermal heat exchanger.

[Kamel and Fung, 2014] conducted a review of solar systems integrated with heat pumps and identified a lack investigations in connecting air-based PVT systems with ASHP.

[Athienitis et al., 2011] introduced a combined thermal and electrical efficieny of a BIPV/T system as:

$$\eta_{BIPV/T} = \frac{\dot{Q}_{BIPV/T} + E_{BIPV/T}}{A_{BIPV/T} \cdot G} \tag{2.4}$$

Where:

$\eta_{BIPV/T}$ is the combined thermal and electrical efficiency of the BIPV/T system
$\dot{Q}_{BIPV/T}$ is the useful heat harvested by the BIPV/T system (W)
$E_{BIPV/T}$ is the electricity generated by the BIPV/T system (W)
$A_{BIPV/T}$ is the area of the BIPV/T system (m^2)
G is the incident solar radiation on the BIPV/T surface ($\frac{W}{m^2}$)

If coupled to a heat pump, an equivalent BIPV/T thermal efficiency can be expressed as:

$$\eta_{BIPV/T_{Thermal}} = \frac{\dot{Q}_{BIPV/T} + COP \cdot E_{BIPV/T}}{A_{BIPV/T} \cdot G} \tag{2.5}$$

Where:

COP is the heat pump coefficient of performance

[Kamel and Fung, 2014] suggests the use of TES in solar heat pump systems to offset the negative impacts of non-constant solar radiation intensity, but no guidelines or case studies are proposed. While energy and heat is available at time of high solar radiation, thermal loads are generally the lowest during that period. De-coupling the heat generation plant from the heat distribution plant could therefore increase the use of the heat pump during its peak efficiency window. The following section provides an overview of TES technologies and design considerations.

2.2 Sensible Thermal Energy Storage

Thermal storage refers to the use of a material's mass and specific heat to store thermal energy. It is not a new concept and was in use well before mechanical systems came into play; the earliest forms of space heating and cooling relied on passive thermal storage to increase the comfort levels in buildings. The embedded building thermal mass of ancient heavy constructions absorbed heat during warm periods and rejected this thermal energy to the surroundings when in contact with a cooler medium (often times at night). This helped reduce the temperature variation within the building throughout the day. With the advent of the industrial revolution, active cooling and heating systems became the norm.

While the building mass plays an inherent role as a type of thermal storage, dedicated thermal storage started appearing in buildings in the 1970s as an effort to reduce the peak power demand of energy intensive cooling systems [Dorgan and Elleson, 1993]. This was a response to electricity demand charges imposed by utilities company. Because electricity price was dependent not only on total energy consumption, but also peak power usage, building owners and managers were incentivized to reduce their peak power demand. Since heating needs in commercial and institutional building are typically not fulfilled with electrical heating, thermal storage was mainly used for cooling purposes. Thermal storage is also used in expansions of systems where the current plant no longer fulfill the instantaneous peak loads or to initially reduce the selected chiller capacity in order to save initial and operating costs.

[Sarbu and Sebarchievici, 2018] performed a comprehensive review of thermal energy storage and defined key characteristics used in describing a storage.

The capacity defines the amount of energy stored in the system and depends on the specific heat of the medium, the temperature change, and the mass of material.

$$Q_{storage} = m \cdot c_{p_{fluid}} \cdot (t_f - t_i) \tag{2.6}$$

Where:

$Q_{storage}$	is the energy stored as heat in Joules
m	is the mass of the storage in kg
$c_{p_{fluid}}$	the specific heat of the material in $\frac{J}{kg \cdot K}$
t_f	is the final temperature °C
t_i	is the initial temperature in °C

A storage efficiency (also referred to as the round-trip efficiency [RTE]) is the ratio of the energy input and output of a TES during a charge/discharge cycle. It indicates the energy loss during the charging, storage and discharge periods.

In terms of controls, [Dorgan and Elleson, 1993] identifies two main strategies in using a thermal storage: full storage and partial storage. Full storage refers to a system whose plant is completely off during the defined peak period; in the case of partial storage, part of the peak load is handled by the storage and the remaining load is handled by the plant [ASHRAE, 2012]. The ratio of the average thermal load over the peak cooling load during the design day (analogous to the load factor used in electrical engineering) provides an insight on how much the plant could be downsized depending on the selected operating strategy.

The American Society for Heating, Refrigeration and Air-Conditioning Engineers (ASHRAE) provides guidelines in designing and sizing systems incorporating thermal storage, but the current sizing procedure is for chilled water thermal storage and is aimed at larger commercial to industrial size TES.

In the case of water thermal storage tanks modelling, increasing the number of control volume enables the simulation to better reflect the temperature gradients and heat transfers. [Baldwin and Cruickshank, 2016] conducted a sensitivity analysis comparing energy transfer for storage tanks varying the number of nodes from 12 to 100 and comparing the results with experimental data. It was determined that the 50 node TES was sufficiently accurate. Simulation results showed temperatures changing at a lower rate in comparison with the measurements, but this was explained by the fact that experimental measurements are being taken as spot values whereas node temperatures represent the mean temperature of a whole control volume within the tank which has a lower rate of temperature change [Baldwin and

Cruickshank, 2016].

[Haller et al., 2009] reviewed methods used to characterize thermal stratification in energy storages. The authors identified plume entrainment, inlet jet mixing, and thermal conduction and diffusion as physical processes hindering the thermal stratification phenomenon within a storage. A measure of stratification efficiency was introduced. It was concluded that a precise measurement of stratification at a given time required inside tank temperature measurements and could prove difficult to achieve in commercial applications.

[Kreuzinger et al., 2008] studied the state of charge estimation of stratified storage tanks and emphasized the importance of knowing the time-varying temperature profile within the storage tank from a limited number of inputs. The author proposed the development of a state estimator based on a minimum number of temperature sensors and proposed some guidelines for sensor placement. It was shown that two sensors positioned at the top and bottom of the tank respectively, just off from the mixing regions near the inlets and outlets are adequate. For no flow conditions, when the storage tank is idling, the installation of a third sensor was suggested.

2.3 Energy Flexibility

The IEA-EBC Annex 67 program aims to increase knowledge and quantify the energy flexibility that buildings can provide to the electrical grid [Ostergaard et al., 2017]. As a result of this program, various case studies have been compiled. It is suggested that, for renewable energy sources such as solar and wind energy, flexibility in buildings be used to cope with challenges arising from their intrinsic production variability [Ostergaard et al., 2017] [Chen et al., 2018]. [Zame et al., 2018] are pushing for policies considering energy storage as assets within the electrical grid system; they encourage the deployment of storage-based smart grid systems as an effort to offset risks related to grid instabilities and to help with demand and supply balancing. [Robert et al., 2018] suggests that energy from fossil fuels supplementing grids powered by renewables could be replaced by storage and demand response. The author defines demand response as ”the process of involving users in reducing the stress or congestion on a power system during peak consumption of when generation is insufficient” [Robert et al., 2018].

Although different metrics are currently used across the building sector when quantifying the energy flexibility, three main properties have been identified (duration of shift, energy or power shifted, associated cost or energy loss resulting from flexibility). The research group define energy flexibility in buildings as ”the ability to manage its demand and generation according to local climate conditions, user needs, and energy network requirements” [Ostergaard et al., 2017] [Chen et al., 2018]. Building flexibility potential refers to the technical/physical installation within the building and describe how much energy can be shifted (potential indicators); flexibility depends largely on the objectives of the building owner or operator and the decision making process behind how to utilize the flexibility potential depends on how the performance of the system is indicated (performance indicators). [Lopes et al., 2016] performed a literature review on methodologies used for assessing energy flexibility in buildings.

A common quantification of the flexibility of a system is the number of hours during which the electricity consumption can be delayed or anticipated. This value is specific to a system and dependent on the TES size, the plant capacity, and the thermal behavior of the building. [Stinner et al., 2016] reviewed existing methods for quantifying thermal energy flexibility and proposed indicators for temporal, power, and energy flexibility. The authors underline the importance of quantification in comparing different flexibility options. The proposed temporal indicators are defined for charging and discharging periods as temporal forced and temporal delayed flexibility respectively. Temporal forced flexibility is defined as ”the time the [plant] can operate at maximum power until the TES is completely charged” [Stinner et al., 2016]. It effectively represents the charging capacity of the system. The thermal autonomy of the building is identified by the temporal delayed flexibility value which is the number of hours the system can stay switched off until the TES is considered to be discharged. These values are different for every hour of the year as they include instantaneous thermal loads fulfilled by the system and thermal losses from the TES. A sign convention for flexibility typically uses positive values to denote a forced flexibility event whereas negative values are used to indicated delayed flexibility [Stinner et al., 2016] [Chen et al., 2018] [Foteinaki et al., 2018].

[Salom et al., 2014] identified load matching and grid indicators for buildings with high resolution data. Two of those indicators can be use to quantify the energy usage and on-site production. The demand cover factor is the percentage of the electrical demand covered by on-site energy generation and is an indicator of self generation [Salom et al., 2014]. It can be expressed as:

$$\Gamma_D = \frac{\int_{t1}^{t2} min[P_D, P_S]dt}{\int_{t1}^{t2} P_D dt} \tag{2.7}$$

Where:

Γ_D is the demand cover factor (-)
P_D is the local power demand during the timestep (W)
P_S is the local power supply during the timestep (W)

The supply cover factor, on the other hand is the percentage of the electrical production that is being consumed on-site and is an indicator of self consumption [Salom et al., 2014]. It can be expressed as:

$$\Gamma_S = \frac{\int_{t1}^{t2} min[P_D, P_S]dt}{\int_{t1}^{t2} P_S dt} \tag{2.8}$$

Where:

Γ_S is the supply cover factor (-)

As shown in 2.4 , the Annex 67 proposes a simulation test bed for modelling work.

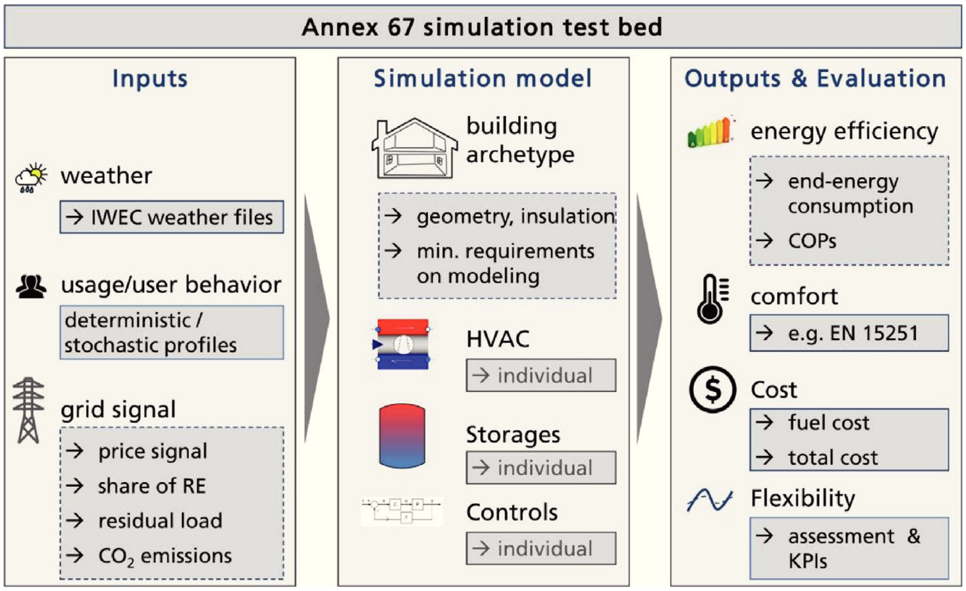

Figure 2.4: Annex 67 proposed simulation test bed [Ostergaard et al., 2017]

While various attempts to incorporate flexibility in buildings have been developed, the Annex 67 program is still working on a common terminology to characterize and label energy flexibility of buildings [Ostergaard et al., 2017]

Energy consumption in buildings is typically dominated by heating and cooling systems [Chen et al., 2018]. It is logical to target these areas when thinking of integrating flexibility in a building operation. Besides, non-schedulable loads such as lights, television, ovens, microwave, and refrigerator are hardly shiftable without affecting the occupants' comfort [Chen et al., 2018]. Also, in a study by [Salpakari and Lund, 2016], shift-able appliances only had a marginal effect on the flexibility of the building.

[Chen et al., 2018] developed a methodology to improve and evaluate energy flexibility of buildings. The authors conducted a review of pre-heating and pre-cooling studies. They indicated that a 2°C temperature reset was shown to reduce the cooling power by 25% and that pre-cooling strategies have been successful in reducing the electric load during peaks by over 80% though care should be taken not to neglect occupants' comfort levels.

[Ali et al., 2014] utilized linear programming to study the optimal operation of partial storage electric heating with dynamic pricing; it was found that the larger storage size equivalent to 40% of the daily heating load yielded the best cost savings. However, the model used idealized thermal storage and direct electric heating as opposed to using a heat pump with varying COP and considering thermal losses from the storage.

[Georges et al., 2017] studied a general method for optimal management of decentralized energy production and HVAC systems with thermal storage. The goal was to minimize the excess energy production delivered to the grid (maximizing on-site consumption) by varying electricity tariffs. [Georges et al., 2017] indicated that there was an interest in mid-afternoon peak PV production for high peak electricity consumption in the evening and identified thermal storage as a better economic decision given the investment costs for electrical storage systems.

[Péan et al., 2018] did a literature review on control strategies aiming to improve the energy flexibility of heat pump systems for buildings. The authors defined demand-side management (DSM) as the adaptation of demand loads to the grid requirements and identifies methods to manage that demand based on the desired outcome (peak shaving, load-shifting, valley filling, self-consumption, and energy use reduction) [Péan et al., 2018]. Heat pumps can be the largest single electricity consumers in a residential building and are therefore a suitable system for demand response applications when coupled to thermal energy storage as explored in [Bode et al., 2017] [Finck et al., 2018].

[Péan et al., 2018] classified control strategies between rule-base controls (RBC) or model predictive control (MPC). RBC can provide significant improvements with regards to energy flexibility while not requiring complex models and the success of such strategies lie in the relative simplicity of their implementation; they can however be limited when it comes to dynamically responding to changes in grid conditions or foreseeing potentially better plant operation [Péan et al., 2018]. MPC on the other hand, determine the best sequence of operation based on a simplified model of the building and an objective function that is optimized for a given horizon and has the potential to adapt to future predicted conditions as opposed to operating based on a feedback loop as is usually the case with RBC [Péan et al., 2018]. A third control strategy combining both RBC and MPC is rule-based predictive controls (RBPC) and provides a simple way of dealing with projections without a mathematical model of the system [Athienitis et al., 2015].

[Li et al., 2017] conducted a large scale survey in the Netherlands on building flexibility and smart grid integration. It was determined that 60% of the respondents were not familiar with the concept and only 11% were identified as potential flexible users. The key motivations for users to partake into energy flexibility strategies were reduction of utility bills, environmental concerns, and improved comfort [Li et al., 2017]. It was pointed out that raising awareness and educating the public would be necessary alongside the provision of financial incentives to push the adoption of smart grid technologies. The flexibility strategies identified in this work included micro-generators, energy storage, smart appliances, energy management systems, and dynamic pricing. From the survey results, the willingness to embrace energy flexibility was closely related to the perception of helpfulness and the effortlessness of the strategy.

[Foteinaki et al., 2018] studied both single unit and multi-residential building types as an effort to quantify energy flexibility. The authors used the thermal mass of the buildings as a storage medium by varying room temperature setpoints by 2 °C. Low-energy buildings showed more potential as heat losses were the main influence governing the flexibility potential of the building followed by the thermal mass [Foteinaki et al., 2018].

Assymetries between the amount of energy added during positive flexibility events (forced flexibility) and the energy curtailed during negative flexibility events (delayed flexibility) were observed in [Foteinaki et al., 2018], [Baeten et al., 2017] [Chen et al., 2018]. [Baeten et al., 2017] studied the implementation of hot water storage tanks with heat pumps and noted a cost increase on the consumer side even though the demand response strategy yielded positive results for the grid operators. Some flexibility studies showed an overall consumption increased as opposed to baseline cases when no flexibility strategies were applied; this increased consumption occurs during low demand periods. Care must therefore be taken when evaluating the performance of buildings based only on energy efficiency metrics since peak demand reduction and increased renewables penetration in the grid will have long term benefits for the environment and customers [Chen et al., 2018]. The key drivers for energy flexibility include dynamic pricing and the presence of a form of storage and building automation system.

2.4 Research Needs and opportunities

Air-based BIPV/T systems are promising for low-grade heat recovery thanks to their low cost, low maintenance, and reliable operation, which is a bonus to the main function of electricity generation. In addition, by cooling the PV panels with forced air flowing under them, their electricity production can be significantly increased [Athienitis et al., 2015]. However, there are limited studies that have studied the integration of BIPV/T systems with an air-source heat pump and the potential energy flexibility. Current SAASHP studies do not emphasize building flexibility and there is a lack of investigation in load shifting achieved through the combination of SAASHP with TES. While energy and heat is available at time of high solar radiation, thermal loads are generally the lowest during that period. More research is needed to study the de-coupling of the heat generation plant from the heat distribution plant as an effort to increase the use of the heat pump during its peak efficiency window. Advancements are needed to improve control systems of TES and their integration with building automation systems. A simple characterization of the instantaneous state of charge of a TES without the use of computationally expensive models is needed if such systems are to be integrated in the market place on a large scale. Storage and demand response could replace peaking power plants and fossil fuels contribution to the grid. Authors also agree that storage-based smart-grids could offset the risks related to grid instabilities arising from the intrinsic variability of electricity generation from RES. However, much remains to be done to integrate these concepts into marketable, scalable design options. While various attempts to incorporate flexibility in buildings have been developed, a common terminology to characterize and label energy flexibility of buildings is still lacking. The need for building thermal flexibility is considered as the driving force behind this work whereas SAASHP and TES are the means to achieve it. No design or operating guidelines are currently available specifically for this type of system. There is therefore a great research opportunity in coupling TES with SAASHPs to achieve and quantify thermal load shifting.

CHAPTER 3

BASELINE BUILDING MODEL

3.1 Building Description

While this work aims to develop design tools for a range of applications and building types, a typical residential row-house is used as an archetype. The building features two-stories and an integrated courtyard. It is representative of the traditional Montreal row-house and urban context of densely populated neighborhoods. It has a heated space of 150 m^2. The house plans and design were developed as a result of the Team MTL entry into the Solar Decathlon China competition that took place during the summer of 2018, but the mechanical systems and envelope considered in this work differ from the actual building. While the original house featured a Passivehaus certified building envelope [Passivehaus Institute, 2019] , the model proposed here uses the Quebec Novoclimat 2.0 standard for a more realistic case-study [Énergie et Ressources Naturelles Québec, 2015].

The house is divided into two main volumes (South and North) by a courtyard located on top of the ground floor as shown in figure 3.1. The ground floor houses the living room, the kitchen, the mechanical room, a bathroom and a studio. The 2nd floor South volume contains 2 bedrooms and a bathroom. The 2nd floor North volume contains another bedroom. For simplicity the building is modeled as three thermal zones (ground floor, 2nd floor South, 2nd floor North). No basements are considered in this analysis and although an actual building of this type would share its side walls with a neighboring building, it is modeled as a standalone structure. A BIPV system is integrated on the two rooftops of the South and North volumes. The South system is of the BIPV/T type and has a capacity of 8 kW under STC; it also has the potential to recover heat whereas the North system has a capacity of 4.8 kW under STC and is naturally vented. The tilt angle of the installed PV systems was 5° due to architectural constraints and the cooling dominated climate of Dezhou, but this work considers a more adequate 45° tilt angle for winter operation to meet heating loads in Montreal (latitude 45° N).

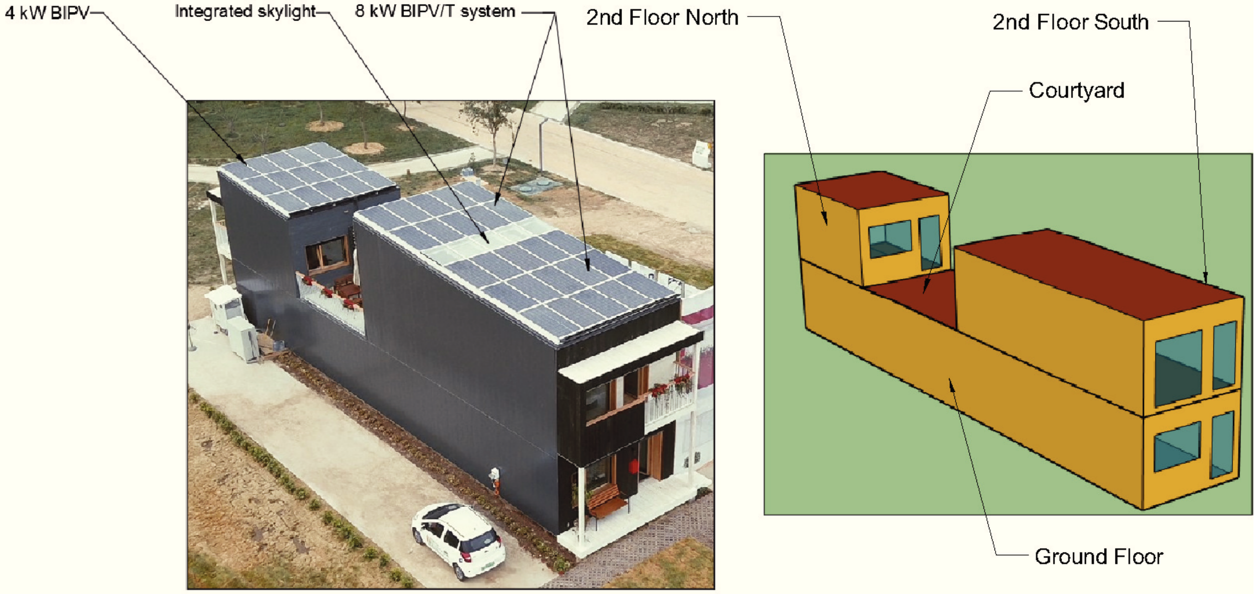

Figure 3.1: Row-house building archetype (left: as-built at Solar Decathlon China 2018 competition, right: Trnsys3D input data file (IDF) in Sketchup

3.2 Modeling Approach

TRNSYS is a transient simulation tool for modeling systems made up of individual components (Types) models. It offers an intuitive visual environment allowing the user to create links between different parts of the model. Each component's source code can be accessed and a mathematical reference is available to indicate which elements modelers should take into consideration when using the models. The different components have traceable references within the literature and are mostly based on published work. Following the mathematical reference literature allows for confident results based on reasonably validated model components and facilitates the integration of a wide range of processes. It was chosen as the modeling tool for this work because of its versatility, its potential to integrate different processes together (solar systems, TES, multi-zone buildings), its ease of use, and the access to mathematical reference for each component.

3.2.1 Building Envelope Characteristics

The envelope characteristics used for this model were obtained from the Novoclimat 2.0 guidelines which are more stringent than the national building code, while proposing more reasonable targets than the Passivehaus standard. Novoclimat is a provincial program in Quebec, Canada aiming to promote high energy performance houses [Énergie et Ressources Naturelles Québec, 2015]. The values chosen are for the Montreal region with annual heating degree days (HDD) between 3500 and 6000. The value used in the building model are summarized in Table 3.1.

Table 3.1: Building envelope characteristics

	R-value ($\frac{m^2.°C}{W}$)	
	Novoclimat	Modeled building
Above ground walls	4.14	4.88
Slab on grade	1.96	2.10
Roof	7.22	7.94
Windows & doors	0.625	0.93

3.2.2 Idealized HVAC Thermal Loads

A first step in estimating the HVAC system equipment's capacities is to determine the thermal loads of the building. Based on the design parameters mentioned previously, a hypothetical unlimited heating capacity HVAC system is used in the simulation to maintain the zone temperatures at the desired setpoint (between 22 °C and 24 °C in this case). This approach considers the thermal inertia of the building elements, but the loads are met instantaneously (as would be the case with a typical air system). An air change rate of 0.3 air changes per hour (ACH) is assumed with no heat recovery. No internal gains or occupancy are considered at this stage. The simulation is run for the whole year for a typical Montreal meteorological year.

The peak hourly heating load was found to be 6 kW on January 26 in the morning in Montreal. The cumulative 4h peak heating load also occurred on that morning. The 4 hour peak heating demand is 23.29 kWh. This information is used to determine the size of the air handler and pumps to be inputted in the model next.

The next stages of this work look at how to better manage these loads based on local electricity and heat production as well as the electrical distribution grid congestion levels. The following chapter considers the modeling of a hot water thermal energy storage in TRNSYS.

CHAPTER 4

SENSIBLE WATER THERMAL ENERGY STORAGE

A thermal storage tank state of charge is based on the acceptable fluid temperature range supplied to the terminal units. In a heating application, the minimum water temperature would be one below which the terminal units do not deliver the adequate amount of heat to the space. Sensible thermal storage tanks capacity is determined by the temperature difference allowed within the tank between the fully charged state to the fully discharged state [Sarbu and Sebarchievici, 2018]. If the supply temperature to the hydronic system is allowed to decrease by 10°C before its depletion and if the water storage tank is assumed to be fully mixed, then the capacity of the storage is simply the mass of the stored liquid multiplied by its specific heat and the temperature differential. This is the relation used to determine the required TES volume for certain relative thermal capacities.

$$Q_{storage} = \frac{m \cdot c_{p_{fluid}} \cdot \Delta T_{supply}}{3600} \tag{4.1}$$

Where:

$Q_{storage}$	is the energy stored as heat in kWh
m	is the mass of the storage in kg
$c_{p_{fluid}}$	the specific heat of the material in $\frac{kJ}{kg \cdot K}$
ΔT_{supply}	is the allowed temperature difference within the storage in °C

For a desired relative TES thermal capacity, the volume of the storage can be calculated.

$$V_{storage} = \frac{\beta_{th} \cdot Q_{4hPeak}}{c_{p_{fluid}} \cdot \Delta T_{supply} \cdot \rho_{fluid} \cdot 3600} \tag{4.2}$$

4.1 Stratification

During operation, if the outlet of the supply water is located near the top of the tank and the return line near the bottom, the temperature at the supply outlet can potentially still be adequate for space heating even if the mean water temperature in the tank has dropped by the design difference of 10°C. This is due to the stratification occurring within the storage medium. To enhance stratification and prevent unnecessary mixing, the flow rate to and from the hydronic loop should be maintained as low as possible. Heat exchangers in the hydronic loop should thus be designed to accommodate lower flowrates and higher temperature differential across the coil to fulfill the required thermal loads as suggested by [Dorgan and Elleson, 1993]. The water flow rate can be modulated with the help of a variable speed pump with a minimum flowrate allowing for the proper operation of the coil and preventing laminar flow that could impede its performance. In a case where minimum flow to the coil is required for proper operation, a three-way mixing valve can be added in the circuit to allow return water from the air conditioning unit to be mixed with the supply line and prevent water from returning to the storage tank thus limiting unnecessary mixing.

As an example of how a storage tanks behavior changes based on the flow control strategy, the 4 hour average peak heating loads of the Novoclimat idealized run from Chapter 3 is used along with 4 different thermal storage sizes. The first size, 0.45m^3, has a theoretical relative storage capacity (β_{th}) of 0.25 and could fulfill all of the heating needs for 25% of the duration of the peak period. The three other sizes, 0.9m^3 and 1.8m^3 and 2.5m^3, have relative capacities (β_{th}) of 0.5 and 1.0 and 1.4 respectively with design supply temperature differentials of 10°C before depletion. All of the TES have heights of 1.8m and are modeled using 50 control volumes in Type 534 (vertical cylindrical storage tank) in TRNSYS. The thermal loads of the building were first extracted from the idealized simulation file for timesteps of 0.1h. Their average was then used as input for a load applied on the hydronic loop exiting the thermal storage tank using Type 682 (heating and cooling loads imposed on a flow stream).

Type 682 is a component that imposes a load on a specified fluid stream. The output of the component is the result of an energy balance at the fluid level. For a given flow rate, the output fluid temperature is calculated for each timestep as:

$$T_{out} = T_{in} + \frac{\dot{Q}}{\dot{m} \cdot c_p} \tag{4.3}$$

Where:

$\dot{Q}$ is the user imposed heat transfer rate (kW)
$\dot{m}$ is the mass flow rate of the fluid ($\frac{kg}{s}$)
c_p is the specific heat of the fluid ($\frac{kJ}{kg \cdot K}$)

The monitored temperature to determine whether the storage is depleted is the outlet temperature at the top of the storage tank (node 4, 0.12m from the top) which supplies fluid to the hydronic loop. The return inlet is located at the bottom of the storage (node 46, 0.12m from the bottom). The initial conditions assume fully mixed water in the TES and consider the storage to be fully charged (all of the nodes are set to 45°C). The boundaries around the storage are considered isothermal (20°C) and the thermal losses are not transferred back to the building in this analysis. The tanks are modeled with a U-value of 0.56 $\frac{W}{m^2 \cdot K}$ at the boundary.

The design water flowrate is determined based on the peak load and the desired temperature drop at the heat exchanger. For a peak load of 6 kW and a load temperature differential of 10°C and 5°C in the hydronic loop, the flow rate can be calculated as:

$$\dot{Q} = \frac{\dot{m} \cdot c_{p_{fluid}} \cdot \Delta T_{load}}{3600} \tag{4.4}$$

$$\dot{V} = \frac{\dot{Q}}{c_{p_{fluid}} \cdot \Delta T_{load} \cdot \rho_{fluid}} \tag{4.5}$$

For ΔT_{load} values of 5°C and of 10°C, the flowrates are 0.14 $\frac{L}{s}$ and 0.28 $\frac{L}{s}$. A simple case where the flow is held constant and where no mixing valve is used is presented below for these two load-side flow rates.

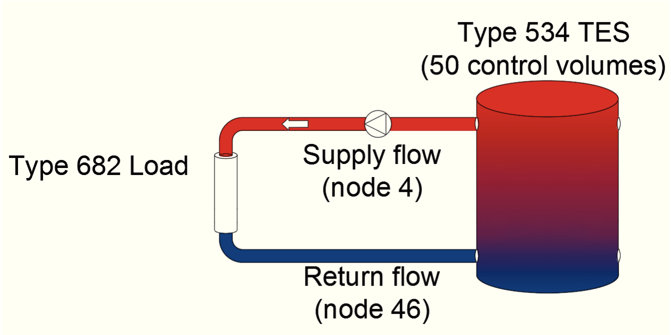

Figure 4.1: Stratified TES simple model in TRNSYS

The amount of energy released from the tank before the monitored temperature drops below the low-temperature limit is calculated for different tank sizes (0.45, 0.9, 1.8, and 2.5 m^3) respectively.

Depending on the hydronic loop design and instantaneous loads, the supply temperature can be allowed a certain temperature drop before considering the storage to be depleted. This analysis presents the effective thermal capacity of the TES for allowed supply temperature drops of 5, 10, and 15°C.The expected capacity using the fully mixed assumption are shown below in Table 4.1. The capacities considering stratification are shown in Table 4.2

	Theoretical Capacity (kWh)		
TES size (m^3)	5°C supply temperature drop	10°C supply temperature drop	15°C supply temperature drop
0.45	2.6	5.3	7.9
0.9	5.3	10.5	15.8
1.8	10.5	21.0	31.5
2.5	14.6	29.2	43.8

Table 4.1: Theoretical TES capacities for different sizes and supply temperature variations (assuming fully mixed conditions)

	Modeled Capacities with Stratification (kWh)					
	5 °C supply temperature drop		10 °C supply temperature drop		15 °C supply temperature drop	
TES size (m^3)	0.14 L/s flow	0.28 L/s flow	0.14 L/s flow	0.28 L/s flow	0.14 L/s flow	0.28 L/s flow
0.45	4.6	3.6	6.6	6.1	9.6	8.6
0.9	9.1	6.6	13.7	11.7	19.4	16.7
1.8	18.8	13.2	26.9	23.3	38.1	34.0
2.5	25.9	18.3	37.1	33.0	53.3	47.2

Table 4.2: Modeled TES capacities for different sizes, load-side flow rates, and supply temperature variations

Figure 4.2 shows the TES capacities for different allowable supply temperature drops, load side flow rates, and tank sizes.

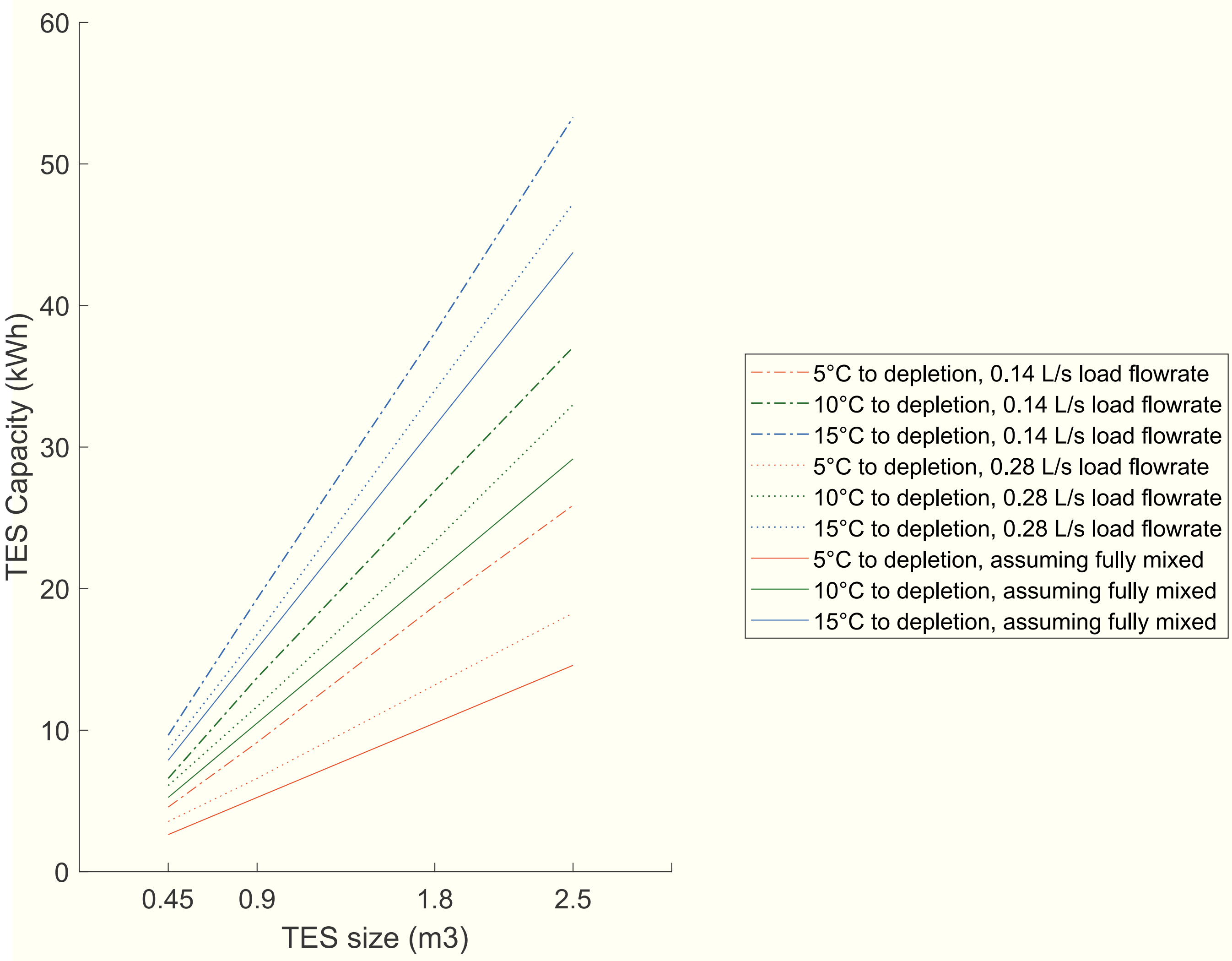

Figure 4.2: TES theoretical vs modeled capacities

It can be seen that assuming fully mixed conditions underestimates the capacity of the storage. Under such conditions, the criteria for considering the storage to be depleted is the average temperature of the storage as opposed to the actual supply temperature serving the hydronic loop. For a load-side temperature differential of 5°C and flowrates of 0.28L/s, capacities increase by 6 to 35% depending on the allowed supply temperature variation before depletion. Reducing the load side flow to 0.14 L/s and increasing the temperature differential to 10 °C within the hydronic loop allows to increase the storage capacity by 21 to 79% over the reference case. The higher capacity increase is typically obtained when supply temperatures are only allowed to decrease by 5°C before depletion. It is during this period that the stratification within the tank is the highest.

	Capacity increase over fully mixed assumption (%)					
	5°C supply temperature drop		10°C supply temperature drop		15°C supply temperature drop	
TES size (m^3)	0.14 L/s flow	0.28 L/s flow	0.14 L/s flow	0.28 L/s flow	0.14 L/s flow	0.28 L/s flow
0.45	74%	35%	26%	16%	22%	10%
0.9	74%	26%	31%	11%	22%	6%
1.8	79%	26%	28%	11%	21%	8%
2.5	78%	25%	27%	13%	22%	8%

Table 4.3: Increase in TES capacities for different sizes, load-side flow rates, and supply temperature variations in comparison with the fully-mixed theoretical case

4.2 State of Charge Definition

For an average load of 5 kW, the duration before the storage depletion is obtained from the simulation runs.

The instantaneous state of charge (SOC) of a TES is an important parameter to quantify when dealing with flexibility/demand response events. It can be used to trigger a charging cycle if deemed necessary based on the instantaneous information received from the utility grid. Because of stratification within the storage tank, it was shown earlier that the average tank temperature underestimates the thermal capacity of the storage. A proportional value between the charged and discharged TES temperature is a simple way of evaluating the SOC. However, the values used in its evaluation may underestimate or overestimate the instantaneous SOC. For practical reasons, a large-scale implementation of sensible water TES would limit the amount of temperature sensors within the tanks. For this reason, approximations based on 3 water temperature readings are proposed here as suggested in [Kreuzinger et al., 2008].

As shown earlier, the thermal capacity of the TES varies based on the allowed temperature fluctuation before depletion, the instantaneous loads, the load-side flow rate, the tank insulation, and the TES dimensions. In real-life operation, a discharge process could start when the tank is not necessarily fully charged. It would therefore be impractical to monitor the energy balance of the tank and compare it with a theoretical capacity. However, to compare potential SOC evaluation strategies, a reference SOC must be established. The simulation with constant loads and flowrates proposed earlier allows to obtain a case-specific capacity. Monitoring the energy balance in the tank during and calculating the ratio of delivered energy over the capacity of the TES gives the theoretical instantaneous SOC of the system. This value is to be used as a reference case to compare to. For a linear load, the SOC will decrease linearly as well.

$$SOC_{reference} = (1 - \frac{Q_{delivered}}{Q_{TES}}) \cdot 100\% \tag{4.6}$$

Considering only the average tank temperature in the evaluation of the SOC and assuming a linear relation, the SOC can be obtained as:

$$SOC_{T_{avg}} = (1 - \frac{T_{charged} - T_{avg}}{T_{charged} - T_{depleted}}) \cdot 100\% \tag{4.7}$$

The average temperature considered above is the mean value between the three temper-

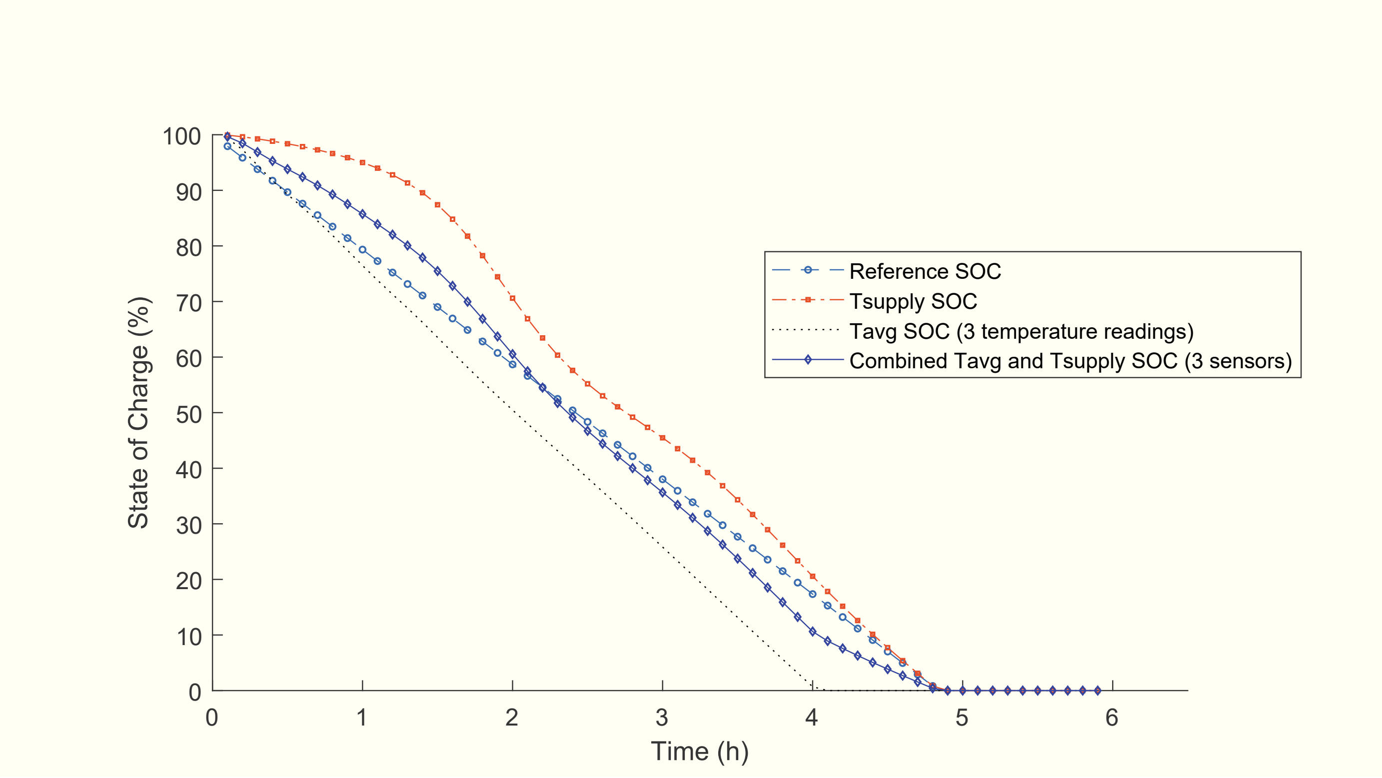

Figure 4.3: Stratified TES SOC evaluations

ature sensors within the tank. The 3-sensors are positioned in node 10, node 25, and node 40 to avoid direct mixing regions as suggested in [Kreuzinger et al., 2008].

Similarly, considering the outlet temperature of the TES when evaluating the SOC gives:

$$SOC_{T_{supply}} = (1 - \frac{T_{charged} - T_{supply}}{T_{charged} - T_{depleted}}) \cdot 100\% \tag{4.8}$$

The supply temperature corresponds to the water temperature of node 4 leaving the tank towards the loads.

Figure 4.3 shows the SOC of the TES for different methods of calculation. The SOC based on the supply temperature overestimates the actual SOC in the beginning of the discharge process because the outlet temperature of the tank remains near the fully charged temperature prior to the mixing starting to occur in the upper portion of the tank. During the charging/discharging process, the supply temperature alone is therefore not an adequate indicator of the SOC.

When considering the average tank temperature to evaluate the SOC, the results are lower than the reference SOC. From the 3-reading average, the storage is shown to be depleted nearly 2 hours before the actual discharge.

However, combining the supply temperature and the average temperature SOC evaluations allows the obtained SOC to reflect the initial discharge while also considering the effect of stratification towards the end of the process. The obtained relation provides a better insight to the building automation system of the current SOC of the storage and does not require extensive computations. Combining the supply temperature SOC with the 3-sensor average SOC yields a better fit throughout the range of the discharge process. The computation of the TES SOC in the following sections of this work will use the combination of the supply temperature and average temperature (3-sensors) as follows:

$$SOC = \frac{SOC_{T_{avg}} + SOC_{T_{supply}}}{2} \tag{4.9}$$

$$SOC = \frac{(1 - \frac{T_{charged} - T_{avg}}{T_{charged} - T_{depleted}}) + (1 - \frac{T_{charged} - T_{supply}}{T_{charged} - T_{depleted}})}{2} \cdot 100\% \tag{4.10}$$

CHAPTER 5

MODELLING OF AN INTEGRATED APPROACH TO ENERGY FLEXIBILITY FOR A SOLAR HOUSE IN TRNSYS

In this chapter, different design options and operation strategies involving the building archetype proposed in chapter 3, and the use of sensible water based TES explored in chapter 4 are considered. The solar systems (both BIPV and BIPV/T) are assumed to have a tilt angle of 45°.

In the modelled system, building heating and cooling loads are handled by a central air handling unit with a hot water coil. Heated air is distributed in each building zone. Fresh air is brought in the building through a heat recovery ventilator (HRV). For the energy analysis, domestic hot water (DHW) needs are fulfilled via an electric water heater. It is assumed that the house features a single range top, a clothes washer, and an electric clothes dryer. This information is used to generate a baseload energy profile for the dwelling.

5.1 Integrated Model Inputs

In the following analysis, the inputs to the model are deterministic and based on fixed schedules for weekdays and weekends. The electrical loads and heat loads associated with the occupancy, and the lighting are based on reasonable assumptions and kept constant throughout the simulation period.

5.1.1 Weather Data

The weather data used in this model is from a Canadian Weather Year for Energy Calculation (CWEC) dataset for Montreal, Canada. The typical winter week of interest used in the different scenarios of this study represent a cold week in February with variations of sky conditions. A daily summary of key weather data is shown in table 5.1. Outdoor temperatures impact the thermal loads of the building and the operation performance of the SAASHP. Solar radiation has a direct effect on both electricity production and the heat harvest potential of the BIPV/T system. Wind velocity dictates the convective heat transfer coefficient used in the TRNSYS BIPV/T model.

Table 5.1: Daily weather data summary for Feb. 12-18

Date	Average outdoor temp. (°C)	Minimum outdoor temp. (°C)	Maximum outdoor temp. (°C)	Max. global horizontal radiation (W/m^2)	Cum. global horizontal radiation (kWh/m^2)	Avg. wind velocity (m/s)
Feb.12	-13.5	-15.6	-9.4	618.6	3.35	9.2
Feb.13	-19.1	-20.9	-15.0	574.0	3.51	4.5
Feb.14	-18.2	-22.8	-13.3	596.9	3.80	2.0
Feb.15	-15.1	-19.7	-10.6	225.0	1.26	3.9
Feb.16	-11.3	-15.3	-7.8	598.2	3.74	4.4
Feb.17	-8.2	-12.2	-2.8	458.0	2.63	2.2
Feb.18	-4.2	-11.6	2.5	524.1	3.17	1.9

5.1.2 Occupancy

The radiative and convective portions of the internal gains due to occupants are assumed to be equal. The occupancy is based on a family of 5 people with a degree of activity corresponding to seated, very light work and adjusted for a normal percentage of men, women and children in the space. This corresponds to average heat gains per occupant of 70W and 35W for sensible and latent heat respectively. The total internal gains under full occupancy (350W sensible and 175W latent) are multiplied by an occupancy presence variation factor shown in table 5.2 based on the time of day [ASHRAE, 2013b].

Table 5.2: Occupancy schedule from [Ahmed et al., 2017]

Time	Occupancy presence variation
06:00 - 09:00	0.5
09:00 - 13:00	0.1
13:00 - 16:00	0.2
16:00 - 19:00	0.5
19:00 - 22:00	0.8
22:00 - 06:00	1.0

5.1.3 Lighting

According to the actual modern light-emitting diode (LED) lighting system implemented in a residential building, the total lighting power density (LPD) was assumed to be equal to 5 W/m^2. This LPD is multiplied by lighting schedule to obtain the heat gains and energy consumption due to lighting for different hours of the day.

Table 5.3: Lighting schedule from [Ahmed et al., 2017]

Time	Fraction of lights ON
06:00 - 10:00	0.15
10:00 - 16:00	0.05
16:00 - 22:00	0.20
22:00 - 00:00	0.15
00:00 - 06:00	0.00

5.1.4 Occupants' Electricity Consumption

For the energy analysis, occupants' electricity consumption is divided in two categories namely: electricity consumption linked to domestic hot water (DHW) usage and electricity consumption linked to processes other than heating, cooling, and DHW. ASHRAE 90.2 standard for low-rise residential building provides general formulae to approximate the daily area-based electricity consumption of occupants and daily electricity consumption linked to each occupant's DHW usage.

For the DHW demand, the average number of liters per days (ALPD) of hot water consumption is first calculated as:

$$ALPD = (CW + B) \cdot NP \tag{5.1}$$

Where:

$ALPD$	is the average Number of Liters per Day of hot water consumption $(\frac{L}{day})$
CW	is average number of liters of hot water used for clothes washing per occupant daily $(7.57\ \frac{L}{day \cdot person})$
B	is average number of liters of hot water used per occupants daily $(50\ \frac{L}{day \cdot person})$
NP	is number of people living in the unit (5 people)

For a family of 5 and a house fitted with a clothes washer, the ALPD is approximated as 288L. With an approximated water main temperature of 5 °C and a hot water supply temperature of 60 °C, the domestic hot water load of the building (DHWL) can be calculated as:

$$DHWL = \frac{ALPD \cdot \rho_{water} \cdot c_{p_{water}} \cdot (60 - 5)}{3600} \tag{5.2}$$

Where:

$DHWL$	is the daily domestic hot water load of the building $(\frac{kWh}{day})$
$ALPD$	is the average Number of Liters per Day of hot water consumption $(\frac{L}{day})$
ρ_{water}	is the density of water $(1\ \frac{kg}{L})$
$c_{p_{water}}$	is the specific heat of water at 20 °C $(4.2\ \frac{kJ}{kg \cdot K})$

$$O_E = A_F \cdot 10.76 \cdot 0.0045 + R_E \cdot (0.9589 + A_F \cdot 10.76 \cdot 0.001) \tag{5.3}$$

Where:

O_E	is the electricity used by occupants(kWh/day)
A_F	is the conditioned floor area of building (m^2)
R_E	is the number of electric range tops

For a floor area of 150 m^2, a single electrical range top, the total electricity usage is approximated at 14.68 kWh per day. The electrical load profile distribution shown in table 5.4 is used to obtain the hourly loads and average power used.

Table 5.4: Occupant and DHW Electricity Consumption Daily Distribution

	Occupants' electricity consumption		DHW electricity consumption	
Time	Load factor (-)	Hourly load (kW)	Load factor (-)	Hourly load (kW)
00:00 - 01:00	0.024	0.352	0.0085	0.142
01:00 - 02:00	0.022	0.322	0.0085	0.142
02:00 - 03:00	0.021	0.308	0.0085	0.142
03:00 - 04:00	0.021	0.308	0.0085	0.142
04:00 - 05:00	0.021	0.308	0.0085	0.142
05:00 - 06:00	0.026	0.382	0.01	0.168
06:00 - 07:00	0.038	0.558	0.075	1.257
07:00 - 08:00	0.059	0.866	0.075	1.257
08:00 - 09:00	0.056	0.822	0.065	1.089
09:00 - 10:00	0.06	0.881	0.065	1.089
10:00 - 11:00	0.059	0.866	0.065	1.089
11:00 - 12:00	0.046	0.675	0.046	0.771
12:00 - 13:00	0.045	0.660	0.046	0.771
13:00 - 14:00	0.03	0.440	0.037	0.620
14:00 - 15:00	0.028	0.411	0.037	0.620
15:00 - 16:00	0.031	0.455	0.037	0.620
16:00 - 17:00	0.057	0.837	0.037	0.620
17:00 - 18:00	0.064	0.939	0.063	1.056
18:00 - 19:00	0.064	0.939	0.063	1.056
19:00 - 20:00	0.052	0.763	0.063	1.056
20:00 - 21:00	0.05	0.734	0.063	1.056
21:00 - 22:00	0.055	0.807	0.051	0.855
22:00 - 23:00	0.044	0.646	0.051	0.855
23:00 - 00:00	0.027	0.396	0.0085	0.142

5.2 TRNSYS Model Development

Figure 5.1 shows an overview of the integrated TRNSYS model. Macros were used to classify components by systems. The following sections look at the different components of the model.

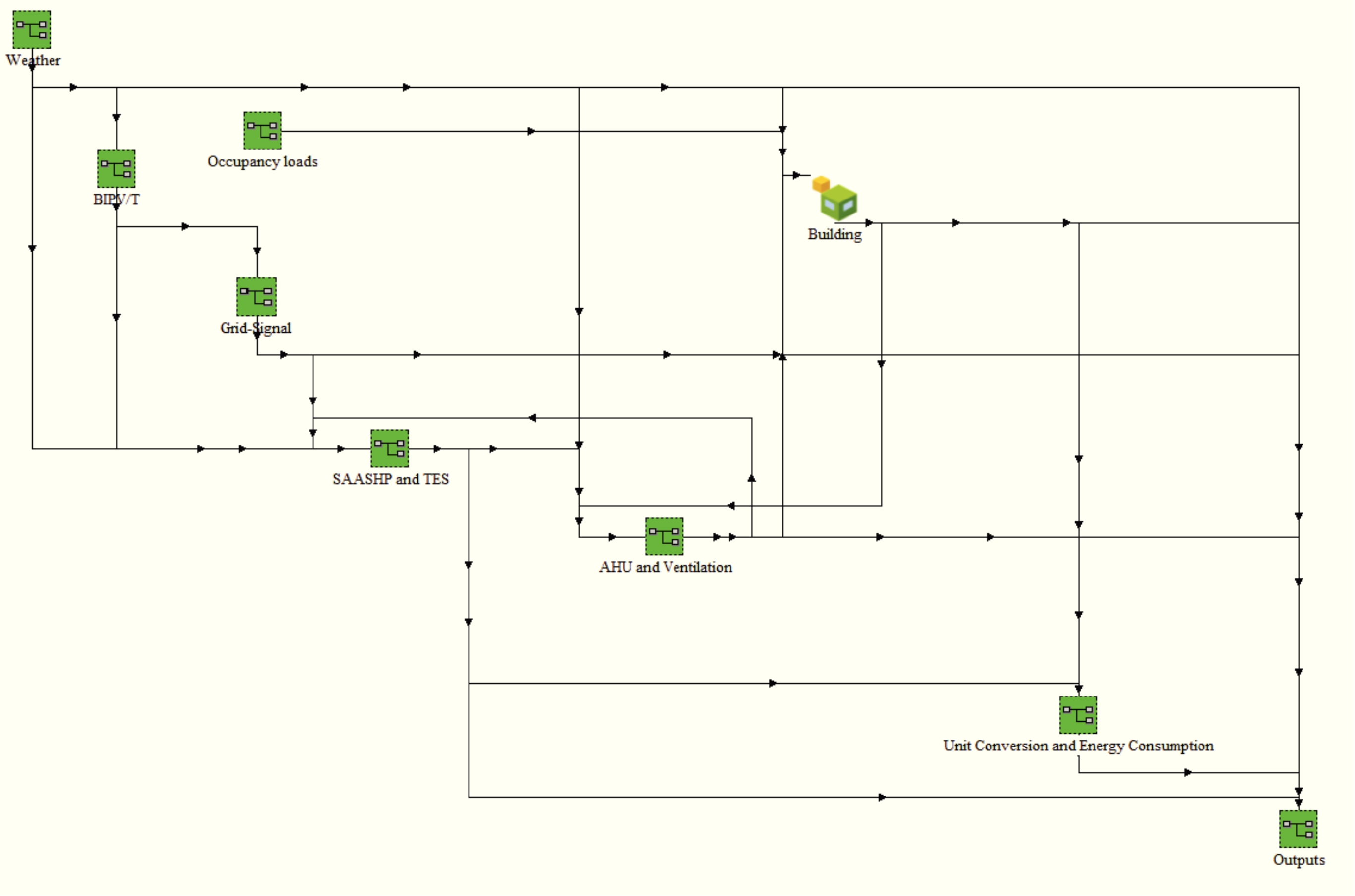

Figure 5.1: TRNSYS Integrated Model Overview

5.2.1 Electrical grid

Based on slightly modified time-of-use pricing of Ontario Energy Board (OEB) and the winter daily consumption profile presented in [Laperrière and Brassard, 2011], three scenarios are defined: buying opportunity, normal operation and selling opportunity. Buying opportunities correspond to the off-peak rate and periods where the electrical grid can easily provide electricity. Normal operations are mid-peak periods where the electrical grid is in between low and high electricity demands. Selling opportunities are on-peak periods where the electrical grid undergoes peak power and could benefit from a demand reduction strategy. These three different real-time states of the electrical grid are indicated as season dependent, scheduled inputs to the virtual controller, but could be varied dynamically or provided one-day ahead to the end-user. The time-dependent grid states are presented below (with the winter afternoon peak extended until 8:30 pm as opposed to the peak period ending at 7:00

pm in the OEB pricing scheme).

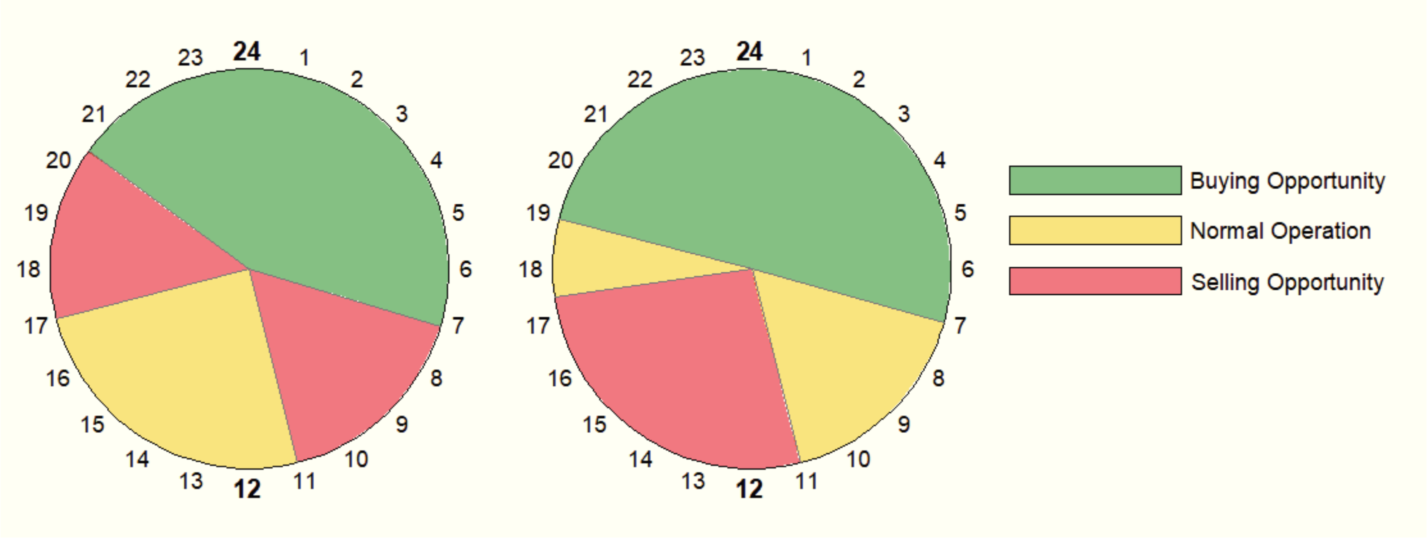

Figure 5.2: Electricity grid states for Winter (Left) and Summer (Right) adapted from [Ontario Energy Board, 2018]

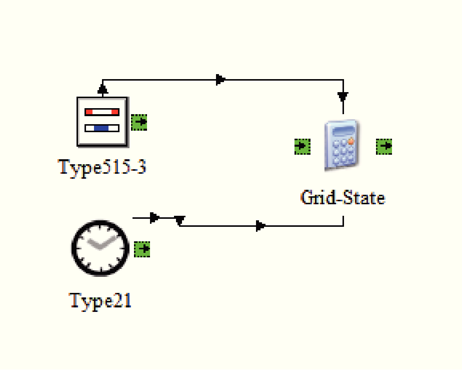

Figure 5.3: Grid Signal TRNSYS Components Macro

In this context, it is assumed that the buyback price of electricity by the grid is the same as the instantaneous selling price in the network. Different pricing schemes are considered in the analysis further into this document.

In the TRNSYS environment, this grid signal is added to the model as a seasonal schedule. The hour of the day of the current timestep and the seasonal schedule are sent to the grid-state calculator which then outputs the current grid-state to other components in the model. The grid signal compontents macro is shown in Figure 5.3.

5.2.2 Solar-Assisted Air Source Heat Pump Coupled to BIPV/T and Thermal Energy Storage Models

The TRNSYS environment allows the users to input their own performance data for the HVAC equipment used in a project. The air-source heat pump performance map of the HP was created as a text file for use with TRNSYS. Type 941 is a single stage air-to-water heat pump model [Thornton et al., 2012b]. For this work, the performance data available from the cold climate heat pump manufacturer Arctic Heat Pumps was used. Data was input as a text file with a specific format for 7 different water temperatures and 9 air temperatures. The water temperatures vary from 15°C to 55°C. The air temperatures vary from −20°C to 35°C. Reference data can be selected arbitrarily through the performance map of the heat pump since the coefficients used in the map are relative to that reference. In this case, the air and water temperatures of 0°C and 40°C were respectively chosen. In the performance map, two values are available for each combination of air and water temperature. The first one is the capacity ratio and the second entry is the COP ratio. The instantaneous capacity under a given set of water and air temperatures is calculated as:

$$Q_{nominal} = Q_{reference} \cdot Cap_{ratio} \tag{5.4}$$

Similarly the instantaneous COP can be calculated as:

$$COP_{nominal} = COP_{reference} \cdot COP_{ratio} \tag{5.5}$$

At each timestep, the power consumption of the HP is calculated as:

$$HP_{Power nominal} = \frac{Q_{nominal}}{COP_{nominal}} \tag{5.6}$$

The performance file is normalized and the rated capacity, compressor power, COP as well as the air-side and water-side mass flow rates for the reference conditions are defined in the parameters of the Type 941 (air-to-water heat pump) [Thornton et al., 2012b]. The values used for these parameters must reflect the functioning of the selected equipment. This study considers the use of three different heat pump capacities. Their corresponding parameters are shown in Table 5.5.

HP Type	Reference Capacity (kW)	Reference COP	Rated water-side flow rate (l/s)	Rated air-side flow rate (m^3/h)
1	8.22	2.82	0.4	1250
2	11.5	2.75	0.7	2500
3	14.5	2.84	0.8	2500

Table 5.5: Air source heat pumps parameters [Arctic Heat Pumps, 2019]

The air-side flow rate of the heat pump specified in the fan manufacturer literature is the same used in the simulations. The air-velocity in the BIPV/T cavity is different depending of the type of heat pump used. The air flow rate on the source side for type 1 heat pump is 1250 m^3/h and corresponds to the fan specifications of a 2-ton residential unit (Arctic Heat Pump 020A) with a 8 kW heating capacity. For such a flow and with a 0.5 m^2 face area, the mean air velocity in the cavity is 0.7 m/s. For type 2 and type 3 heat pumps (Arctic Heat Pump 040A and 060A respectively), the airflow rate through the evaporator is twice the one of type 1. The airflow rate for these models is 2500 m^3/h and correspond to a mean air velocity in the cavity of 1.4 m/s for the given configuration.

BIPV/T Model

TRNSYS 569 is used to model an un-glazed BIPV/T system [Thornton et al., 2012a]. A cross section of the cavity modelled is shown in figure 5.5. The 25 PV modules are disposed over five 10 m long cavities, each of which are 1 m wide. The 10 cm high air cavity is enclosed by insulated mullions and 6 cm of rigid insulation with an aluminium backpan. Air entering the cavity is assumed to be the same temperature as the outside air. For year-round performance, a PV array facing due South with a tilt angle corresponding to the latitude of the building typically yields the highest cumulative incident solar radiation and overall best electricity production [Yang and Athienitis, 2015]. For this reason, a tilt angle of 45° was used in this work.

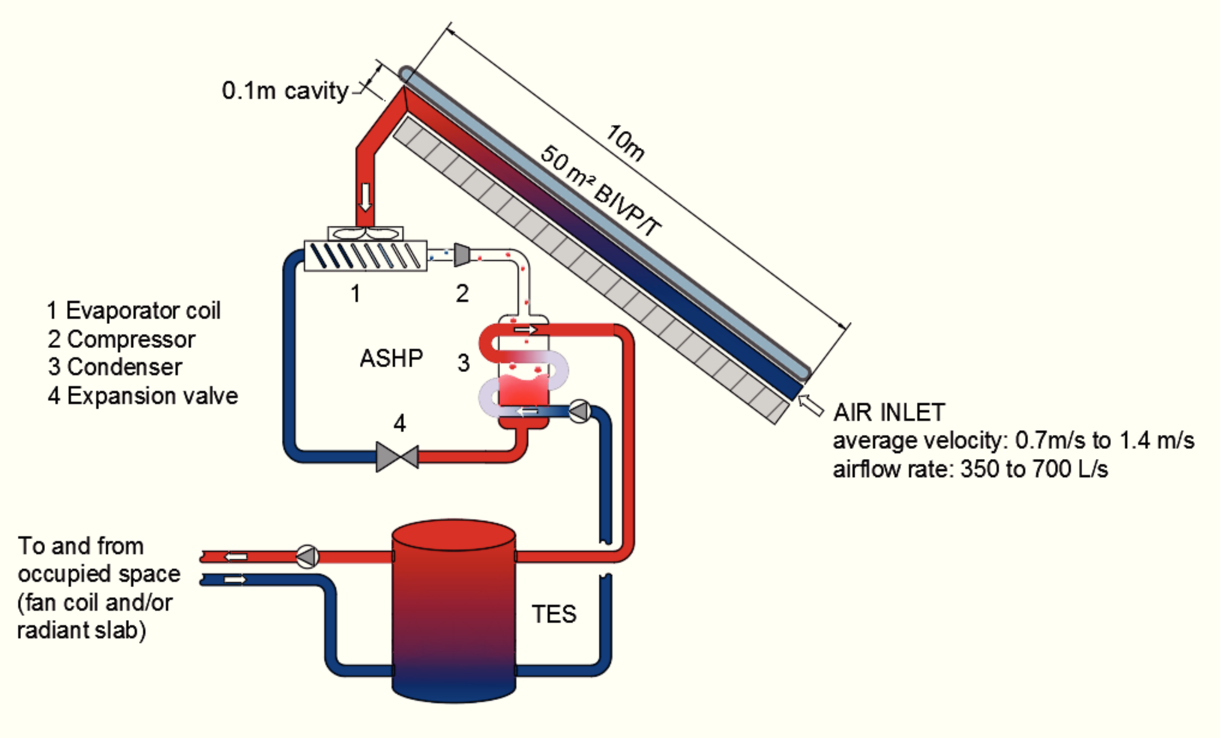

Figure 5.4: BIPV/T and AHSP interaction during heating operation

The heated air leaving the cavity in the heating season is sent to the evaporator coil of the ASHP. The condenser side of the HP is connected to a water TES that could deliver space heating through either an air system or a radiant hydronic system (only the air system is considered in this work). A schematic of the winter operation is shown in figure 5.4.

As previously mentioned, different cavity lengths and airflow rates affect the outlet air temperatures of the cavity. The longer the cavity, the higher the outlet air temperature. However, physical constraints due to the building size limit the dimensions of BIPV/T systems. For this project, the cavities lengths and widths are fixed at 10 m and 1 m respectively.

The BIPV/T system is modeled with TRNSYS Type 569, which is a component representing an un-glazed Building-Integrated PV System [Thornton et al., 2012a]. The longitudinal cross-sectional view in figure 5.6 shows the thermal network model of the system. It is as-

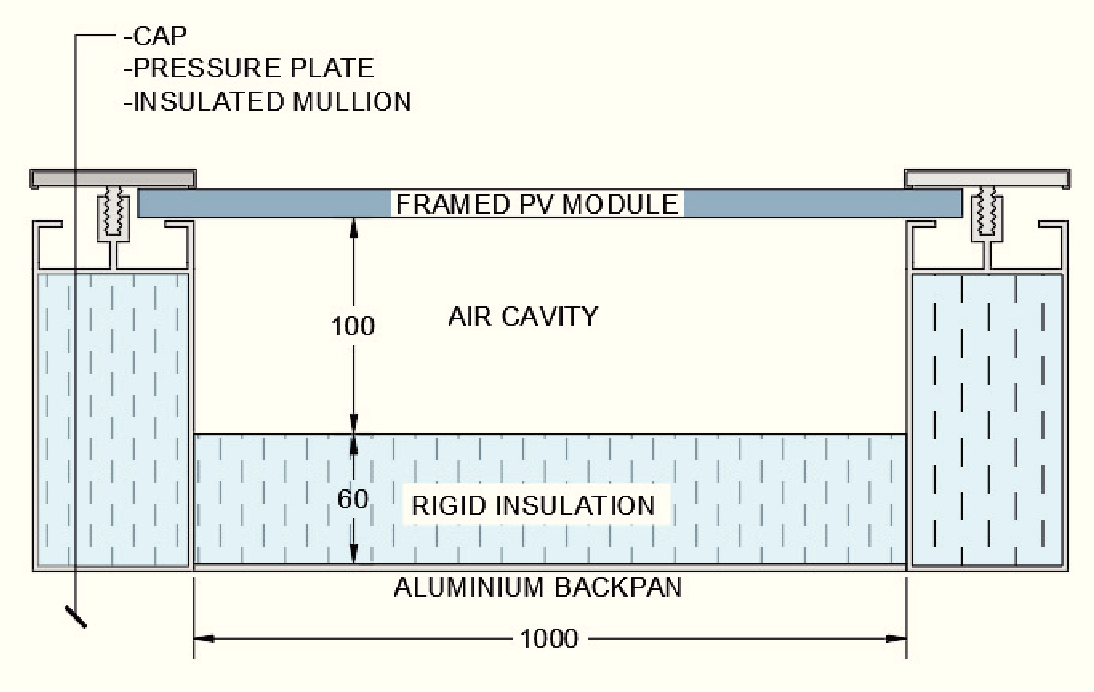

Figure 5.5: BIPV/T Cavity Cross Section

sumed that the semi-conditioned space below the collectors is at a temperature 10°C higher than the outdoor air.

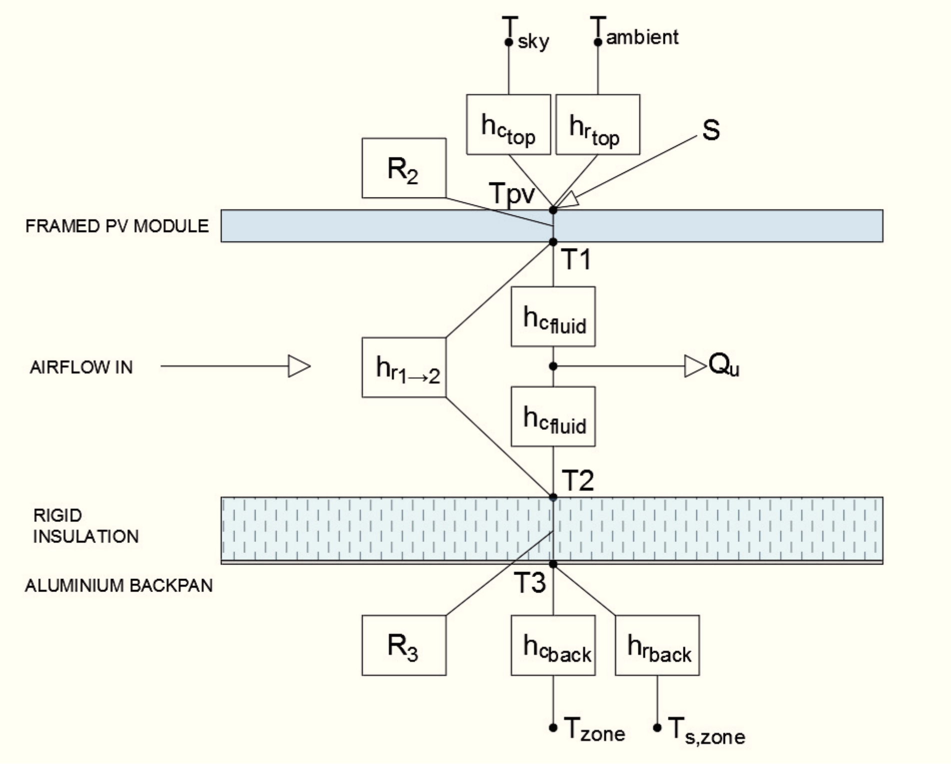

Figure 5.6: BIPV/T Thermal Network

The top heat loss coefficient is added to the model as an empirical linear correlation which was shown to give a good correlation on a full scale installation located in Montreal with a similar inclination and orientation [Rounis et al., 2016]. It can be expressed as:

$$h_{c_{top}} = 4 + 6 \cdot v_{wind} \tag{5.7}$$

Where

$h_{c_{top}}$ is the top heat loss coefficient in $\frac{W}{m^2 \cdot °\text{C}}$

v_{wind} is the wind velocity in $\frac{m}{s}$

T_{sky}	Effective sky temperature (°C)
$T_{ambient}$	Dry bulb outdoor air temperature (°C)
$h_{c_{top}}$	$4 + 6 \cdot Windspeed$ in m/s $(\frac{W}{m^2 \cdot °C})$
$h_{r_{top}}$	$\epsilon_{pv} \cdot \sigma(T_{pv}^2 + T_{sky}^2)(T_{pv} + T_{sky})$
S	$\alpha_{pv} \cdot G_t(1 - \eta_{pv})$
R_2	$0.03 \ \frac{m^2 \cdot °C}{W}$
$h_{c_{fluid}}$	$\frac{Nu \cdot k_{fluid}}{D_h}$
$h_{r_{1 \to 2}}$	$\frac{\sigma(T_1^2 + T_2^2)(T_1 + T_2)}{\frac{1}{\epsilon_1} + \frac{1}{\epsilon_2} - 1}$
Q_u	Heat transferred from collector to air flowing through cavity (W)
R_3	$2 \ \frac{m^2 \cdot °C}{W}$
$h_{r_{back}}$	$\epsilon_{back} \cdot \sigma(T_3^2 + T_{s,zone}^2)(T_3 + T_{s,zone})$
$h_{c_{back}}$	$3 \frac{W}{m^2 \cdot °C}$
T_{zone}	$T_{ambient} + 10$ (°C)
$T_{s,zone}$	$T_{ambient} + 10$ (°C)

Table 5.6: Thermal network variables

For each timestep, the model iteratively solves energy balance equations for the PV surface, the upper air channel surface, the airflow node, at the lower air channel surface and at the back of the lower channel surface.

At the PV surface, the energy balance can be written as:

$$h_{c_{top}}(T_{ambient} - T_{pv}) + h_{r_{top}}(T_{sky} - T_{pv}) + \frac{(T_1 - T_{pv})}{R_2} + S = 0 \tag{5.8}$$

At the upper air channel surface, the energy balance can be written as:

$$\frac{(T_{pv} - T_1)}{R_2} + h_{fluid}(T_{fluid} - T_1) + h_{r_{1 \to 2}}(T_2 - T_1) = 0 \tag{5.9}$$

At the air node, the heat transferred from the upper and lower air channel surfaces to the air is expressed as:

$$h_{fluid}(T_1 - T_{fluid}) + h_{fluid}(T_2 - T_{fluid}) - Q_u = 0 \tag{5.10}$$

For the lower cavity surface, the energy balance is expressed as:

$$\frac{(T_3 - T_2)}{R_3} + h_{fluid}(T_{fluid} - T_2) + h_{r_{1\rightarrow 2}}(T_1 - T_2) = 0 \tag{5.11}$$

For the back cavity surface, the energy balance is expressed as:

$$\frac{(T_2 - T_3)}{R_3} + h_{c_{back}}(T_{zone} - T_3) + h_{r_{back}}(T_{s,zone} - T_3) = 0 \tag{5.12}$$

The convective heat transfer coefficient within the cavity $h_{c_{fluid}}$ is assumed to be constant for both the top and the bottom surfaces. The convective heat transfer coefficient is determined by the average Nu, which indicates the ratio of convection over conduction and depends on the flow regime and the thermo-physical properties of the cooling medium. The Nusselt number calculation used in Type 569 (un-glazed building integrated photovoltaic system) is based on three different correlations depending on the flow regime (no flow, transitional flow, fully developed turbulent flow). The regime is obtained by computing the Reynolds number for the current conditions.

$$Re = \frac{\rho \cdot V \cdot D_h}{\mu_{air}} \tag{5.13}$$

Where

ρ is the density of the fluid in kg/m^3

V is velocity of the fluid in the cavity in m/s

D_h is the hydraulic diameter $(\frac{2 \cdot Cav_{height} \cdot Cav_{width}}{Cav_{height} + Cav_{width}})$

μ_{air} is fluid dynamic viscosity $(\frac{N \cdot s}{m^2})$

When there is no fan induced flow within the cavity, a natural convection heat transfer correlation based on the tilt angle of the collector surface is used. For laminar flow ($Re < 2300$), Nu is equal to 3.66. For turbulent flow ($Re > 2300$), Nu is calculated using the Dittus Boelter correlation. An extension to this work would include the modification of Type 569 (un-glazed building integrated photovoltaic system) to include a more accurate correlation as suggested in [Yang and Athienitis, 2015].

$$Nu = 0.023 \cdot Re^{0.8} \cdot Pr^{0.4} \tag{5.14}$$

Where

Pr is the Prandtl number ($Pr = 0.7$ for air)

The convective heat transfer coefficient within the cavity is expressed as:

$$h_{fluid} = \frac{Nu \cdot k_{air}}{D_h} \tag{5.15}$$

The TRNSYS model graphic user interface (Studio) representing the SAASHP and BIPV/T aspects of this work are shown in 5.7 and 5.8.

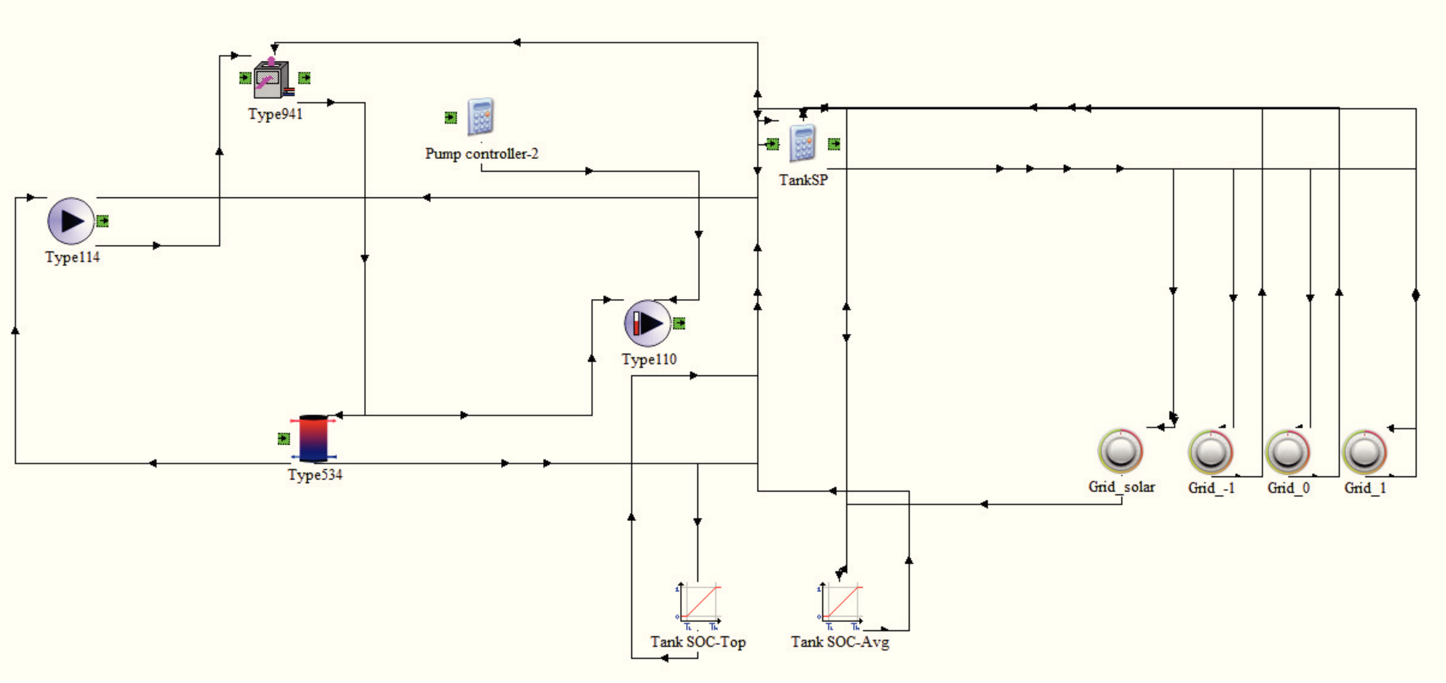

Figure 5.7: SAASHP and TES TRNSYS Components Macro

The state of charge of the storage is calculated with equation 4.10. The condition for operating the heat pump is based on the different sequences of operation shown in sections 5.3 through 5.6.

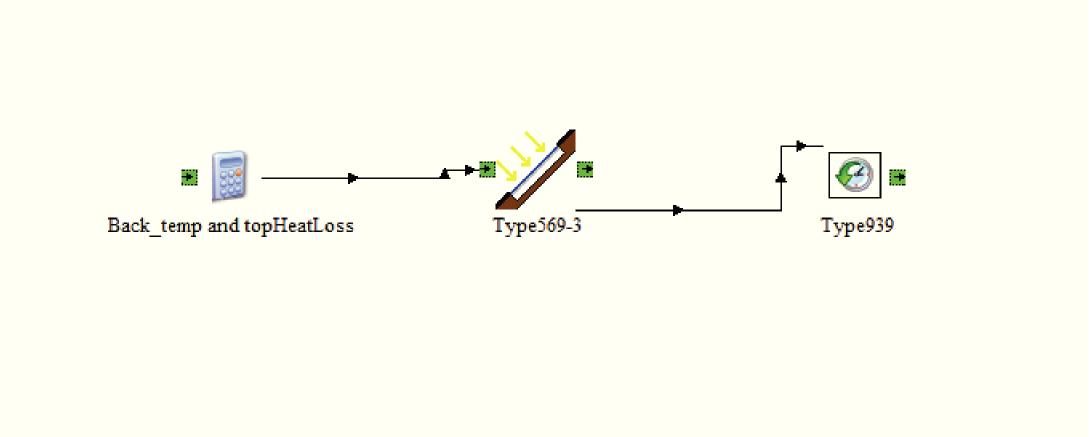

Figure 5.8: BIPV/T TRNSYS Components Macro

Figure 5.8 shows the BIPV/T component as described in 5.2.2. Scenarios presented in sections 5.4 and 5.6 integrate the outlet air of the cavity to the source of the SAASHP.

5.2.3 Air and Water Distribution

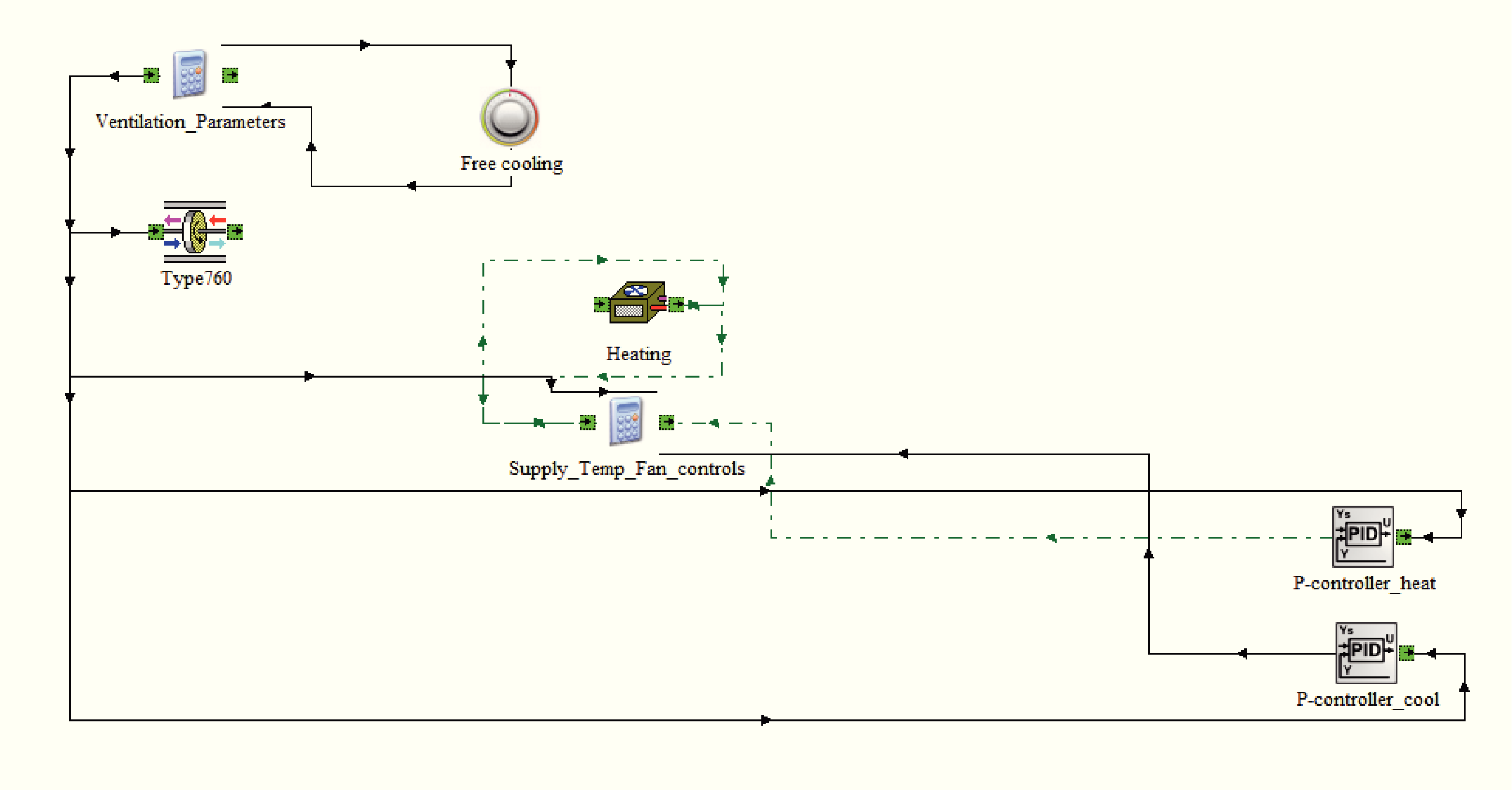

Figure 5.9: AHU and Ventilation TRNSYS Components Macro

An air-handler is modeled in TRNSYS using type 600 (2-pipe fan coil unit) with a coil-bypass factor of 0.1. The system is modelled as a variable air volume air handler with the lowest airflow rate meeting the ventilation requirements (0.3 ACH) of the space and the highest airflow rate meeting the heating loads. For the peak building heating load of 6 kW obtained during the idealized HVAC simulation run, the supply airflow rate to meet the demand can be calculated as:

$$Q_{heating} = \dot{m} \cdot c_p \cdot (T_{supply} - T_{zone})$$

The minimum design airflow rate was found to be 635 $\frac{L}{s}$ or approximately 2750 $\frac{kg}{h}$ (the unit typically used in TRNSYS to denote mass flow rates). The variable speed of the fan is controlled via a proportional control signal based on the zone temperature and the desired setpoint.

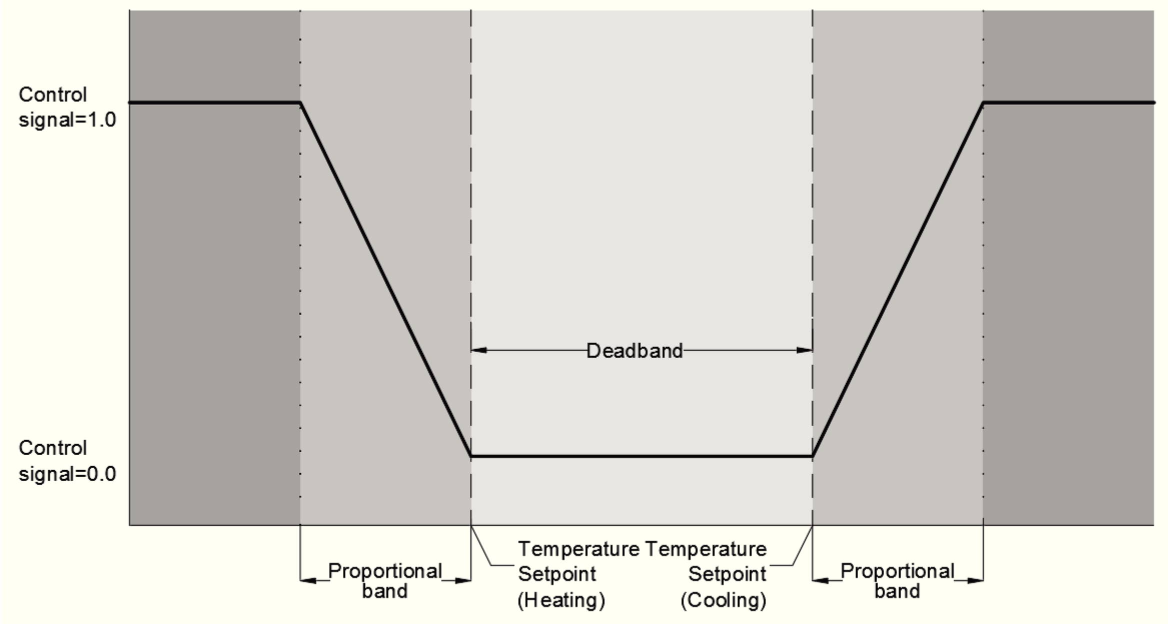

Figure 5.10: Proportional control schematic

The water flow rate in the hydronic system is driven by a variable speed pump with a flow rate designed for a load side ΔT of 10°C at full capacity. The minimum load-side flow rate to fulfill the heating demand of the building with a supply water temperature of 45 °C is 0.14 $\frac{L}{s}$ or 514 $\frac{kg}{h}$

The flow rate is varied to maintain a temperature differential of 10°C between the supply and return temperature of the water to and from the fan coil unit. This aims to promote stratification in the thermal storage tank and avoid unnecessary mixing under part load conditions if the system is fitted with a TES. Details on the rationale for using a variable speed pump and maintain a load side ΔT of 10 °C are discussed in chapter 4.

The pump power is calculated as a function of the part load ratio (PLR) and the energy input ratio as a function of the part load ratio (EIRFPLR). The EIRFPLR coefficients are obtained from a third order polynomial curve fit performed over the pump characteristics from a manufacturer datasheet. The selected fan power at full capacity is 500W (950 L/s or the equivalent of 2000 cfm) and the part load fan power consumption is calculated based on the performance rating method in [ASHRAE, 2013a].

$$EIRFPLR_{fan} = 0.0013 + 0.1470 \cdot PLR_{fan} + 0.9506 \cdot (PLR_{fan})^2 - 0.0998 \cdot (PLR_{fan})^3 \quad (5.16)$$

$$P_{fan} = EIRFPLR_{P_{fan}} \cdot P_{fan_{reference}} \quad (5.17)$$

$$EIRFPLR_{pump} = 0.05 + 1.8 \cdot PLR_{pump} - 2.96 \cdot (PLR_{pump})^2 + 2.13 \cdot (PLR_{pump})^3 \quad (5.18)$$

$$P_{pump} = EIRFPLR_{P_{pump}} \cdot P_{pump_{reference}} \quad (5.19)$$

Where:

$EIRFPLR$	is the energy input ratio as a function of the part load ratio (EIRFPLR)
PLR	is the part load ratio (PLR)
$P_{fan_{reference}}$	is the rated fan power under full load
P_{fan}	is the calculated fan power under part load conditions
$P_{pump_{reference}}$	is the rated pump power under full load
P_{pump}	is the calculated pump power under part load conditions

The capacity of the system is inherently variable based on the water storage tank supply temperature to the hydronic coil. If the system is running without the heat pump (as part of a demand-response control scheme for instance), as the TES is discharged, the entering water temperature of the fan-coil decreased(in case of heating) and the capacity of the system is reduced.

5.2.4 Ventilation

The building model ventilation rate is set to a constant 0.3 air changes per hour (ACH). The fresh air is passed through a heat recovery ventilator with a fixed sensible heat exchanger efficiency of 0.7 when heat recovery is desired. If the average room temperature is above 25°C and the outdoor air temperature is below the zone temperature, the heat recovery function is disabled and air is allowed to enter the space at the outdoor air temperature.

5.2.5 Thermal Mass

The walls, floors and roofs constructions are input with their respective capacitances in the building model. In this case, a lightweight wood structure usually present in Quebec housing is assumed. The zone air capacitance is multiplied by 10 to account for the furniture and the objects present within the indoor spaces.

5.3 Scenario 1: Baseline building operation

In this section, a baseline case with a cold-climate air-source heat pump is presented. The heat pump is sized to fulfill the peak heating demand of the building. The selected heat pump has a relative capacity of 1.3 under rated conditions (8kW heating capacity ASHP). These baseline designs' demand profiles are used as a means of comparison for flexibility strategies involving the use of TES pre-heating and demand response control strategies. No TES is included. This scenario represents a realistic case of commercially available system for an energy efficient building.

The BIPV/T cavity is not being used in this scenario, i.e. the PV is only producing electricity. The sequence of operation of the air handling unit and ventilation is presented as a flow chart in Figure 5.11. The sequence of operation of the ASHP is shown in Figure 5.12

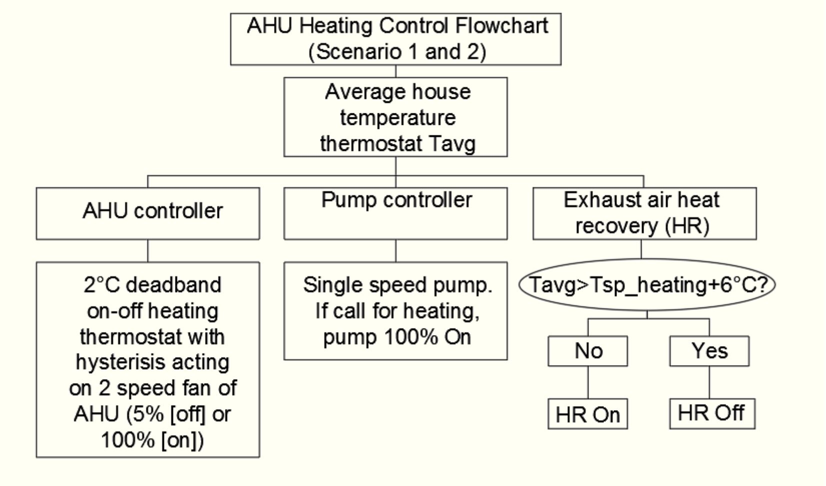

Figure 5.11: AHU and Ventilation Control Flowchart for Scenarios 1 and 2

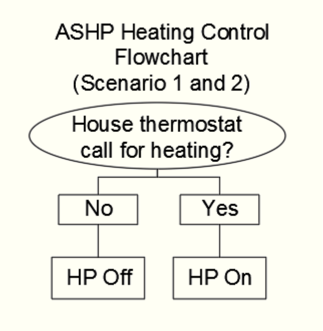

Figure 5.12: Heat Pump Control Flowchart for Scenarios 1 and 2

5.4 Scenario 2: Baseline building operation coupled to BIPV/T System

A slightly more complex system is proposed as scenario 2. In this case, an identical HVAC plant as scenario 1 is presented with the exception of the evaporative side of the ASHP. In this case, the inlet air conditions of the ASHP are obtained after passing through the BIPV/T system when sun is present. The sequence of operation remains the same as scenario 1 with the mean air space temperature of the building used to control both the AHU and the heat pump.

5.5 Scenario 3: Demand-response control strategy and TES

In scenario 3, a TES is incorporated in the model and the control sequence incorporates a feedback from the utility grid. Figures 5.13 and 5.14 show the operation strategies for the air handling unit and the ASHP respectively. Under normal operation, when coupled to a TES, the heat pump cycles based on the SOC of the TES. Once the SOC reaches 20%, the charging cycle begins until it reaches 100% again. When paired to an electrical grid signal, the BAS can vary the TES SOC setpoints and trigger a charging or discharging cycle based on the current grid conditions. If a buying opportunity arises, a charging cycle is initiated right away and the SOC setpoint to start a cycle is increased to 50%. This encourages the utilization of the heat pump while the electricity is available at a cheap price. If a selling opportunity arises, the charging cycle only starts when the storage is fully depleted and stops when the SOC reaches 80% to prevent using expensive grid electricity unnecessarily. If the solar system is producing at more than 20% of its standard testing condition (STC) capacity, a charging cycle is forced and the SOC setpoint to initiate a charge cycle is be increased to 80%. The 80% minimum setpoint is maintained as long as the hourly running average remains above 20% of its rated capacity. This aims to promote self-consumption when on-site generation is possible. Simulations are run for the three different heat pump capacities and 4 different tank sizes. The electricity produced by the PV system is first used to fulfill the instantaneous loads of the building. If excess energy is generated,the remainder is sent to the utility grid.

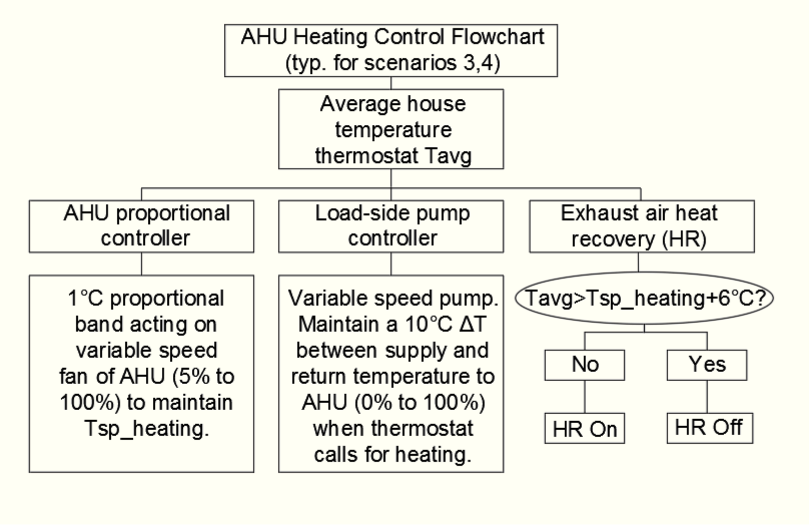

Figure 5.13: AHU and Ventilation Control Flowchart for Scenarios 3 and 4

5.6 Scenario 4: Demand-response control strategy, TES, and BIPV/T coupling

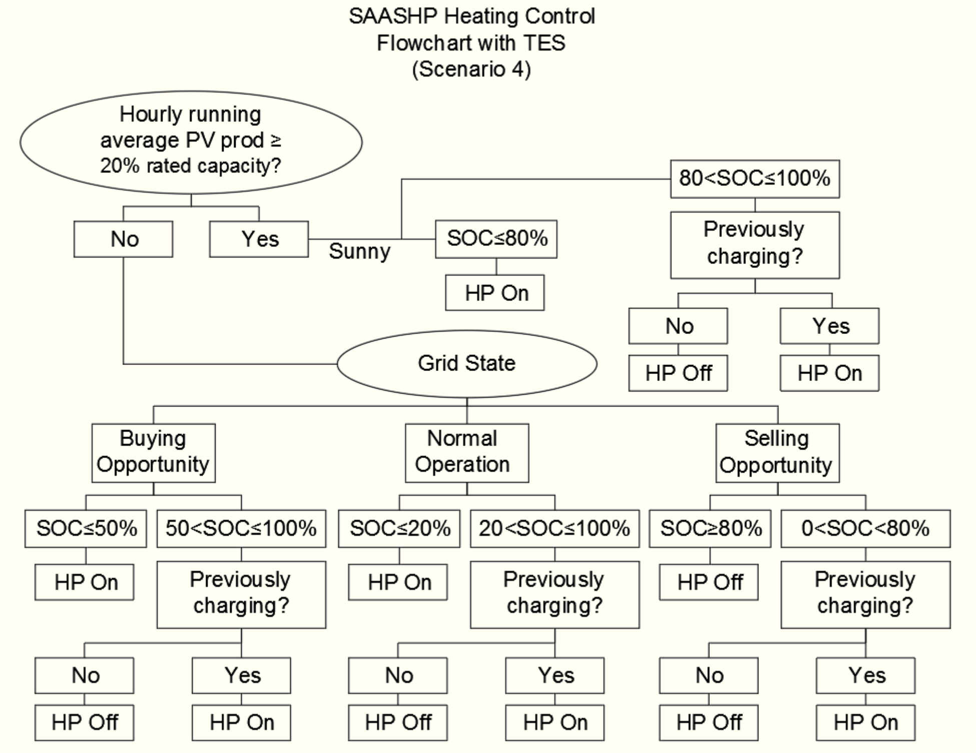

Figure 5.14: Heat Pump Control Flowchart for Scenario 3 and 4

In scenario 4, the same control sequence as scenario 3 is used and the BIPV/T system is integrated on the source side of the SAASHP. As before, the charging cycle can also be triggered if environmental conditions favor the operation of the heat pump. In this case, higher air temperature on the source side of the heat pump increases the COP of performance of the heat pump. Simulations are run for the three different heat pump capacities and 4 different tank sizes Scenario 4 can therefore be thought of as a group of 12 simulations sharing the same control strategy, but having different flexibility potential.

5.7 Simulation Results

The TRNSYS simulation files were modified in Matlab. A total of 26 alternative combinations of control strategies, system capacities, and thermal storage sizes were evaluated against a range of performance metrics. The most notable results are presented here based on three criteria of interest namely time-of-use electricity consumption, energy efficiency, and cost of operation. A summary of the weekly results can be found in Appendix A

A summary of the design alternatives is shown in table 5.7

5.7.1 Time-of-use electricity consumption

The time when energy is being used is of great interest in the case of decentralized electricity production. Although similar equipment sizes are being studied, the 4 control strategies yielded significantly different consumption patterns throughout the simulation week. A complete table of the weekly energy use for all of the alternatives is presented in Appendix A. A summary of the relative energy use for the whole week and then for individual grid states are presented. Negative values indicate reduction in energy use. The first scenario is considered as the reference case. The term relative energy use refers to the ratio of energy used in a given grid state over the energy used in the same grid state for the baseline alternative.

Figure 5.15 shows the relative energy use of the 26 alternatives during the buying oppor-

Table 5.7: Design Alternatives Summary

Alternative Number	Heat Pump Type (1,2,3)	TES Size (L)	Control Strategy
1	1	N/A	Scenario 1 (baseline)
2	1	N/A	Scenario 2
3	1	450	Scenario 3
4	2	450	Scenario 3
5	3	450	Scenario 3
6	1	900	Scenario 3
7	2	900	Scenario 3
8	3	900	Scenario 3
9	1	1800	Scenario 3
10	2	1800	Scenario 3
11	3	1800	Scenario 3
12	1	2500	Scenario 3
13	2	2500	Scenario 3
14	3	2500	Scenario 3
15	1	450	Scenario 4
16	2	450	Scenario 4
17	3	450	Scenario 4
18	1	900	Scenario 4
19	2	900	Scenario 4
20	3	900	Scenario 4
21	1	1800	Scenario 4
22	2	1800	Scenario 4
23	3	1800	Scenario 4
24	1	2500	Scenario 4
25	2	2500	Scenario 4
26	3	2500	Scenario 4

tunity period. This time interval during the day can be identified as a forced flexibility event during which the energy usage is encouraged through the control sequence. In comparison with the reference case, an energy consumption shift of 30% was achieved for alternative 25.

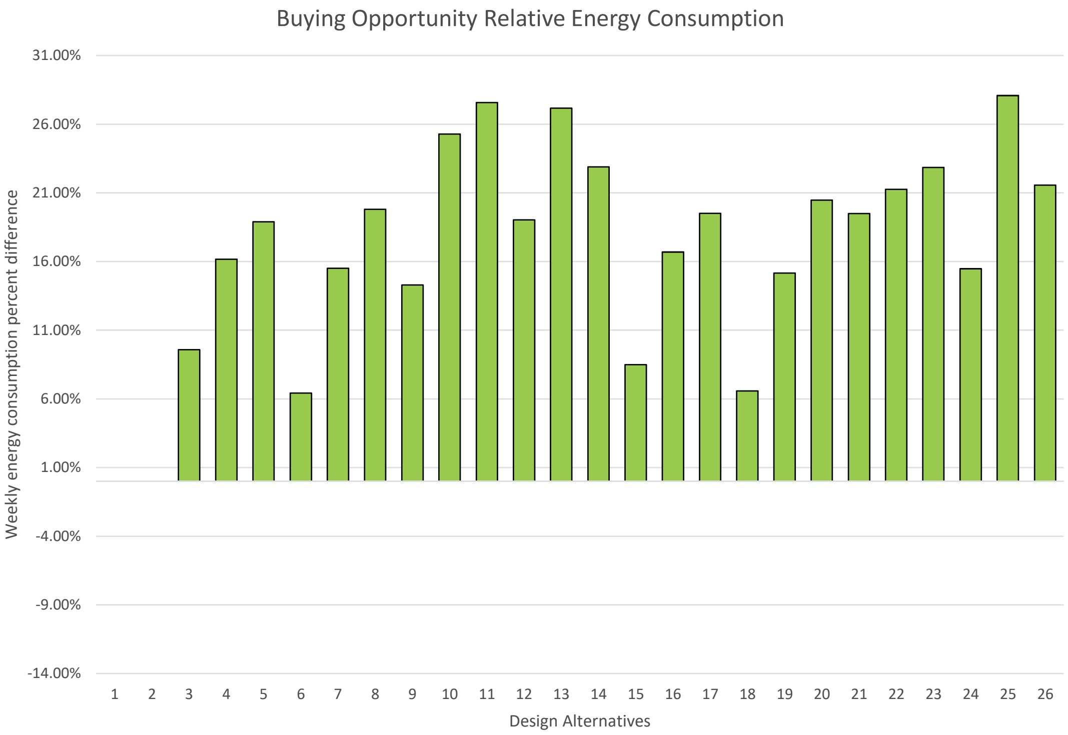

Figure 5.15: Buying Opportunity Relative Electricity Use

Figure 5.16 shows the relative energy use of the 26 alternatives during the normal operation period. During this time interval, for alternatives 1 and 2, energy usage is neither encouraged nor discouraged by the control sequence. For alternatives 2 and up, if the sun is present, the sequence encourages energy usage during the normal operation grid state to maintain the SOC of the TES above 80%. Consumption increased by 55% during normal operation for alternative 24.

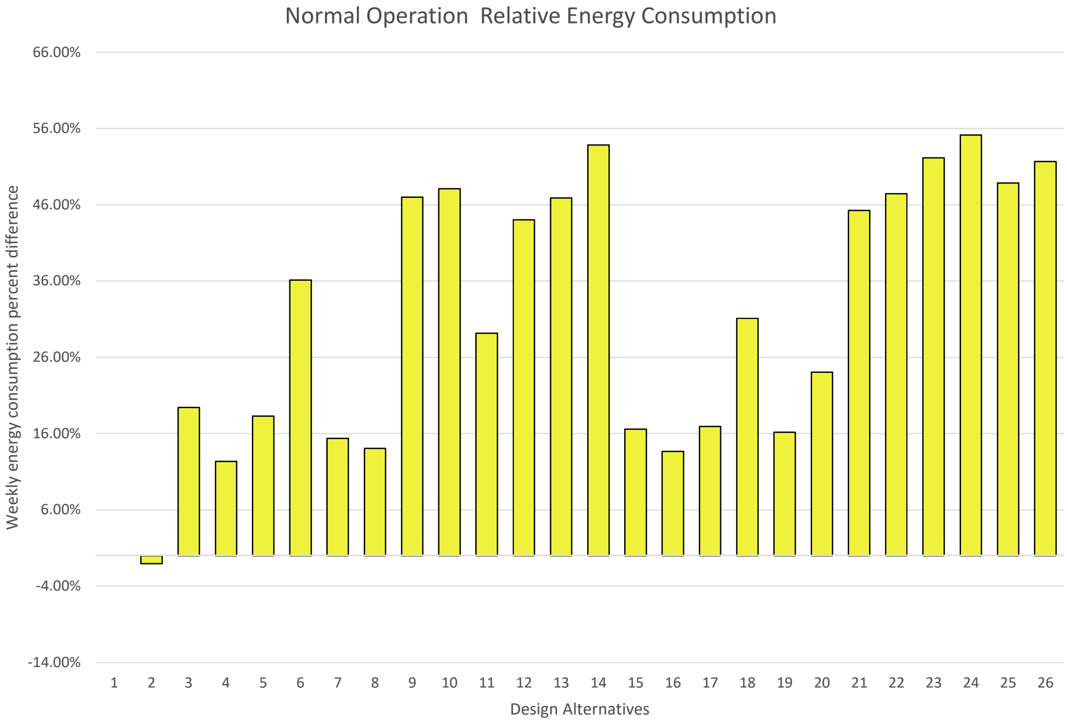

Figure 5.16: Normal Operation Relative Electricity Use

Figure 5.17 shows the relative energy use of the 26 alternatives during the selling opportunity period. This time interval during the day can be identified as a delayed flexibility event during which the energy usage is discouraged through the control sequence. In comparison with the reference case, an energy consumption shift of over 40% was achieved for alternative 24 through 26, all of which use the largest TES size considered in this study. Only by acting on the HVAC loads of the building, the energy consumption reduction during the peaking periods of the grid can be reduced significantly through the use of the simple rule-based control sequence proposed.

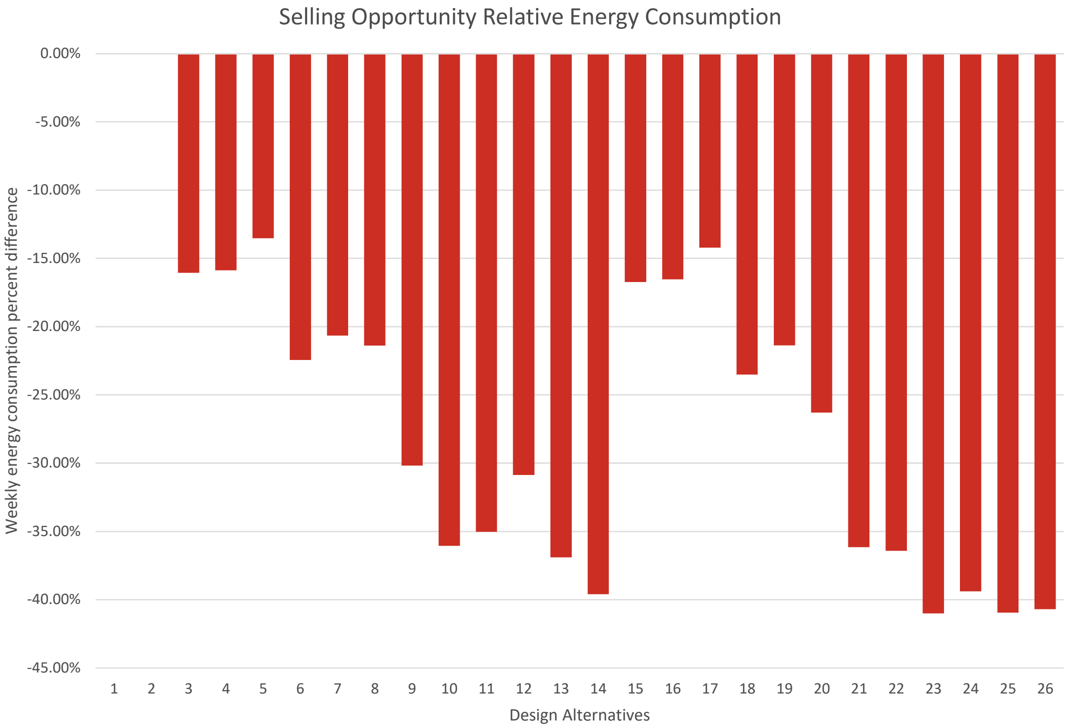

Figure 5.17: Selling Opportunity Relative Electricity Use

Another way to analyze the energy usage for the different grid states is to consider how the total energy consumption is divided over the three grid states. Figure 5.18 shows the usage portion for the normal operation periods of the week. It varies from 17.5% to just above 30% for the alternatives considered.

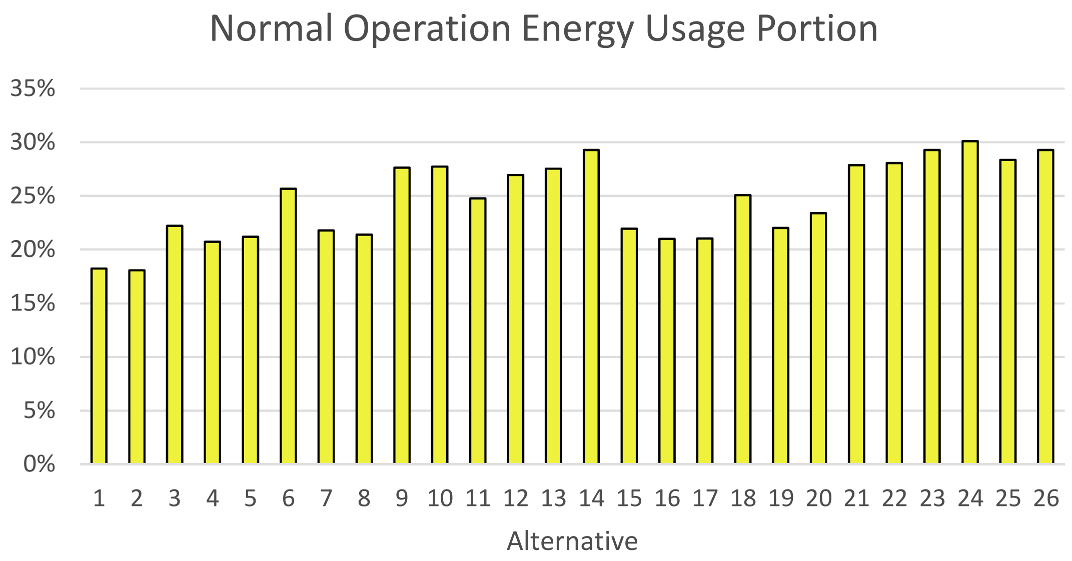

Figure 5.18: Normal Operation Usage Distribution

Figure 5.19 shows the usage portion for the buying opportunity periods of the week in decreasing order. This shows the proportion of the electricity used by the alternatives at night, when the electricity grid is not subject to high peak demands. Since no on-site production occurs during buying opportunity events, there is no effect from on-site energy production and BIPV/T coupling on the energy usage.

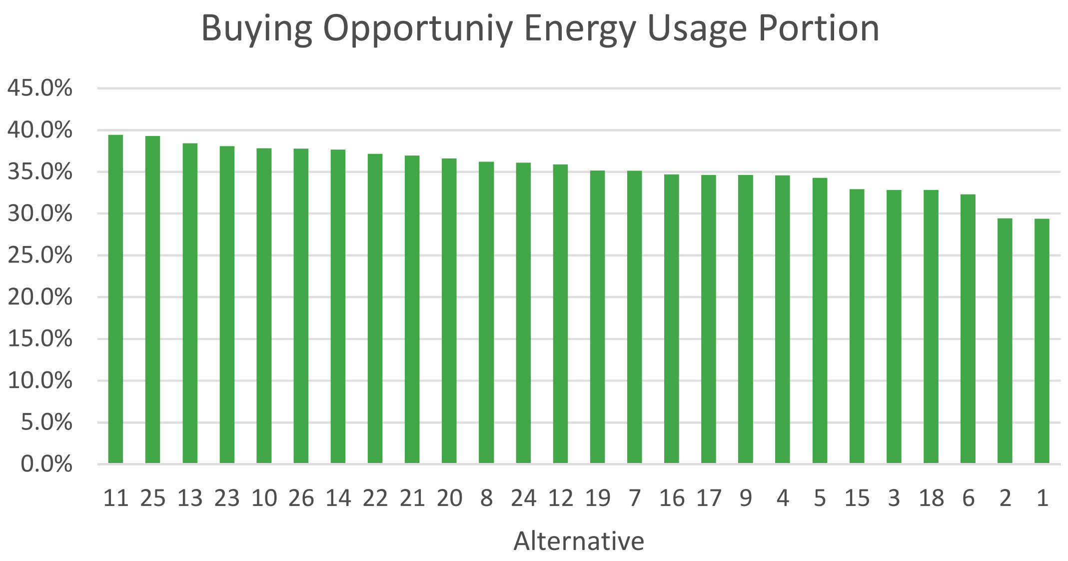

Figure 5.19: Buying Opportunity Usage Distribution

Figure 5.20 shows the usage portion for the selling opportunity periods of the week in increasing order. Alternatives using the smallest portion of their energy during this period of time are the ones with the largest storage size (with the exception of alternative 23, which uses the 1800L TES). It can be seen that the baseline design without demand response control sequencing consumes more than half of its energy during the peak grid time. There is relatively little change in the energy profile of alternatives with different heat pump sizes. As long as the heat pump capacity is capable of charging the TES during low-heat demand periods, the larger TES alternatives show the greatest potential for flexibility. This shows the proportion of the electricity used by the alternatives at night, when the electricity grid is not subject to high peak demands.

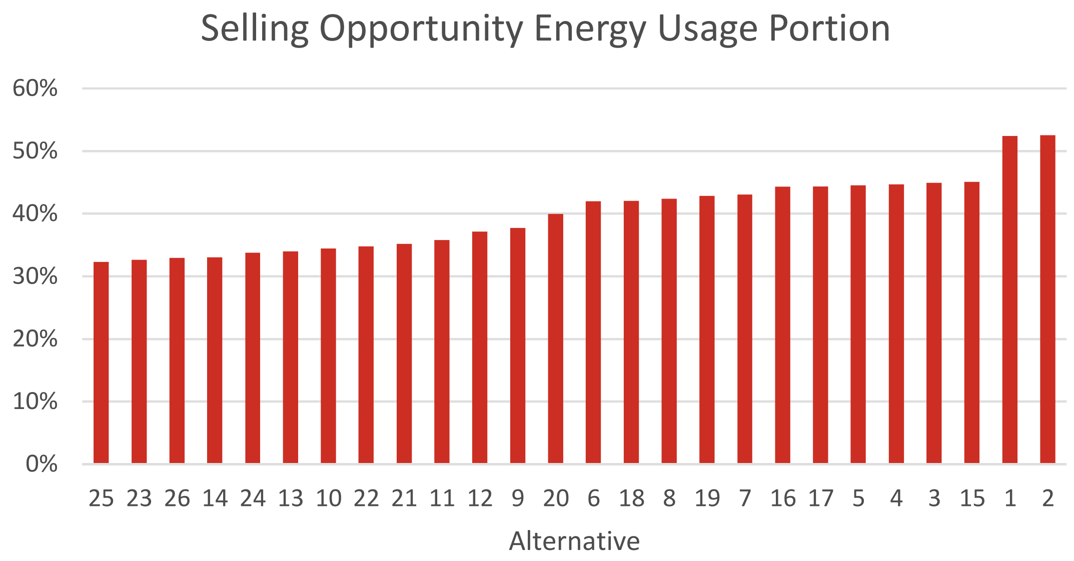

Figure 5.20: Selling Opportunity Usage Distribution

Load Match and Grid Interaction Indicators

Two load-match and grid interaction indicators introduced in Chapter 2 were demand cover factor and supply cover factor. Both indicators are equal to zero if no electricity is being generated for the interval considered. For this reason, the factors were not computed for the buying opportunity period, which occurs at night. Figures 5.21 and 5.22 show the supply cover factors for the normal operation and selling opportunity periods respectively. The supply cover factor indicates how much of the energy generated on site is being consumed locally. Most of the on-site energy production takes place during the normal operation period of the day. Because selling back to the grid is not encouraged during such period, a high supply cover factor is encouraged (promotion of self-consumption). In that regard, alternative

24 performs the best amongst the configurations that were considered. This configuration allows for the on-site energy usage of half of the energy generation as opposed to the baseline case (alternative 1) which only uses 32% of its production locally. For the selling opportunity period, the goal is to export as much electricity as possible to the network to alleviate the strain caused by the peak power demand. The reference case (alternative 1) uses about 67% of what is produced during grid peak hours. Alternative 23 is the best in that regards since it exports over 55% of what it produces during selling opportunity periods (supply cover factor of 0.45).

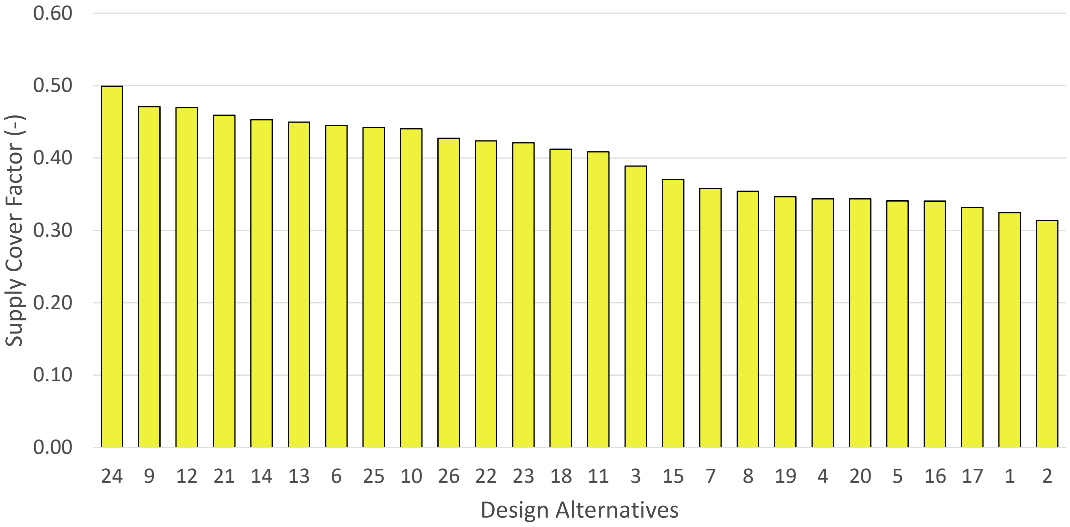

Figure 5.21: Weekly Supply Cover Factors Normal Operation

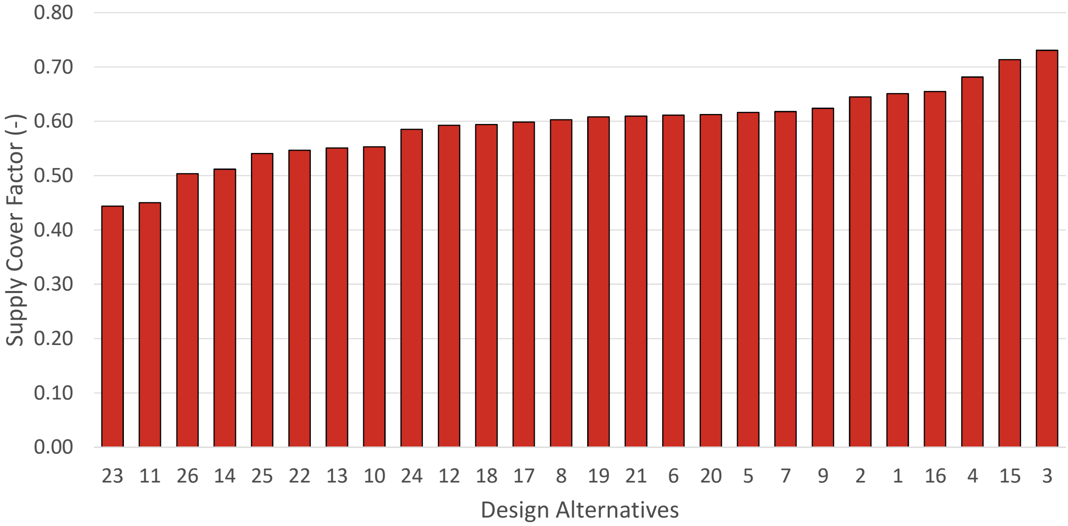

Figure 5.22: Weekly Supply Cover Factors Selling Opportunity

As for the demand cover factor, it indicates how much of the energy consumed locally is being generated on-site during a given time interval. Because the selling opportunity event starts before sun is present, most of the energy consumption during this period does not come from locally produced energy. This is shown by the relatively low demand cover factors in Figure 5.23. Nonetheless, the demand cover factor was increased from the baseline 0.15 up to 0.22 for alternative 24. This is due to the lower energy consumption during the selling opportunity delayed flexibility event.

For the normal operation period shown in Figure 5.24, most of the alternatives' consumptions were covered by local production by over 80%. The remainder of the consumption occurred during periods of low solar irradiance. Again, alternative 24 yielded the best result with a demand cover factor of 0.85.

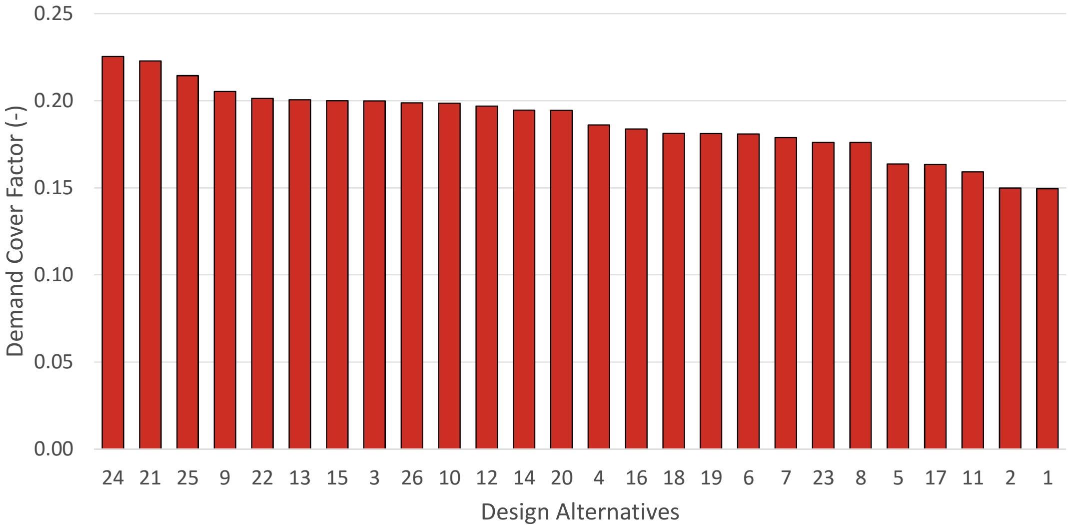

Figure 5.23: Weekly Demand Cover Factors Selling Opportunity

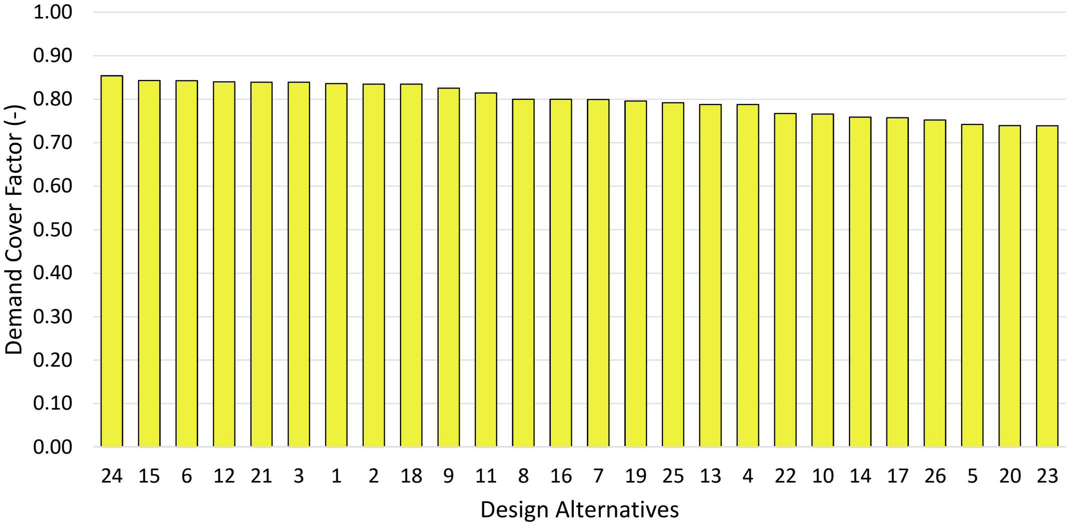

Figure 5.24: Weekly Demand Cover Factors Normal Operation

Daily Energy Profiles

Figure 5.25 shows the average energy production, the energy consumption of the baseline alternative, and the energy consumption profile of alternative 24, which showed the best overall flexibility potential. The average temperature for the chosen day was below −20 °C and the PV production was exceeding the rated capacity of the system thanks to ground reflected solar radiation and sunny conditions. It can be seen for the first 6 hours that both the baseline and the demand-response strategy have a similar load profile. The slightly higher demand of alternative 24 is due to the additional circulation pump in the system fitted with the TES. The baseline design sends water from the ASHP directly to the fan coil. Since the climatic conditions correspond to the peak load of the year, the capacity of the heat pump (which matches the peak heating load of the building) cannot charge the TES. This is reflected by a consumption that persists even during the selling opportunity delayed flexibility event indicated by the red background. Around mid-day, the baseline scenario demand decreases due to the lower space heating needs in the middle of the day. However, alternative 24 takes advantage of the sunny condition to replenish the TES with the heat pump operating under the best conditions given the climatic circumstances. Once the afternoon peak occurs, the heat pump in the baseline scenario is activated due to space heating needs and the electric demand increases to 5 kW and remains at that level for the duration of the selling opportunity. Alternative 24 on the other hand shuts off the heat pump and fulfills the heating needs with the TES and the fan coil unit alone. The 2500L is able to delay the peak heating demand by as much as 4 hours before reaching its 50% SOC during the buying opportunity mode. A charging cycle then takes place starting at 22:00 until the next morning.

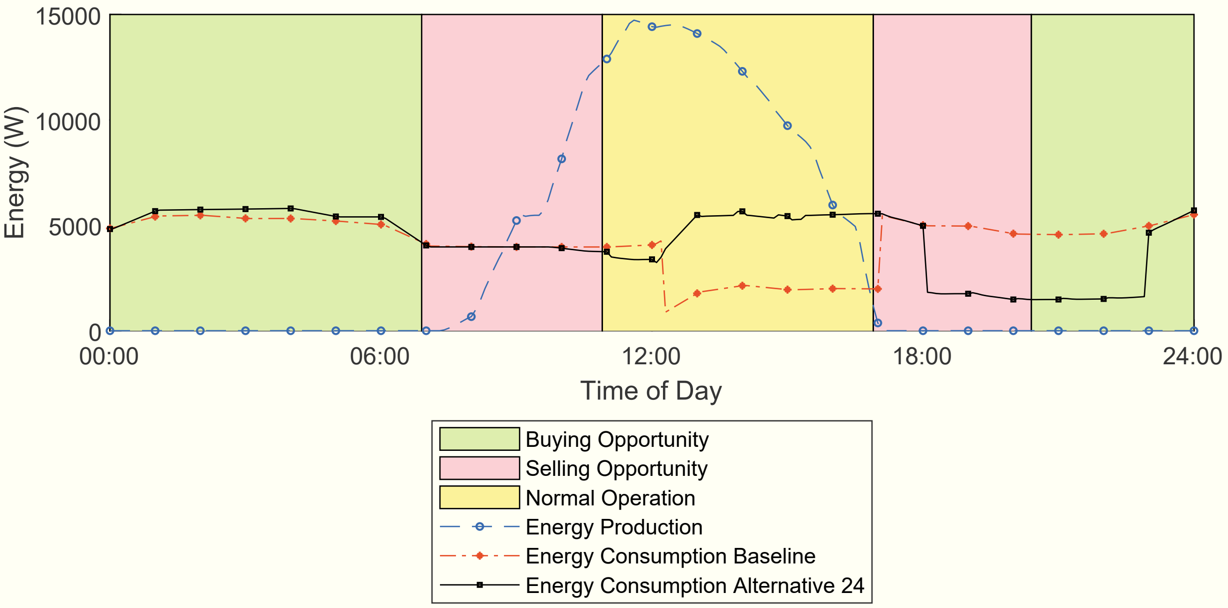

Figure 5.25: Cold and Sunny Winter Day Energy Profile Baseline and Alternative 24

Figure 5.26 shows the same information as 5.25, but for a milder, cloudier day of the same week. The temperature during that day fluctuates between $-10\,^{\circ}\mathrm{C}$ at night and $0\,^{\circ}\mathrm{C}$ at noon. While sun is present in the afternoon, sky conditions are not as sunny as the cold winter day considered before. In this case, the milder night allows alternative 24 to enter the morning selling opportunity delayed flexibility event with a TES that is somewhat charged, but not fully. This allows the energy demand to be reduced to the base loads until the storage is depleted around 9:00. The baseline demand drops right before the end of the selling opportunity event and remains low during the day, not consuming much of the locally produced solar energy. Alternative 24 on the other hand initiates a charging cycle and its TES is able to sustain the heating loads until the next morning before another cycles needs to be initiated. The drop in the baseline load profile at the beginning of the buying opportunity event around 21:00 is explained by the 2 °C hysteresis of the thermostat used in the baseline and the on-off nature of the sequence of operation used for that scenario.

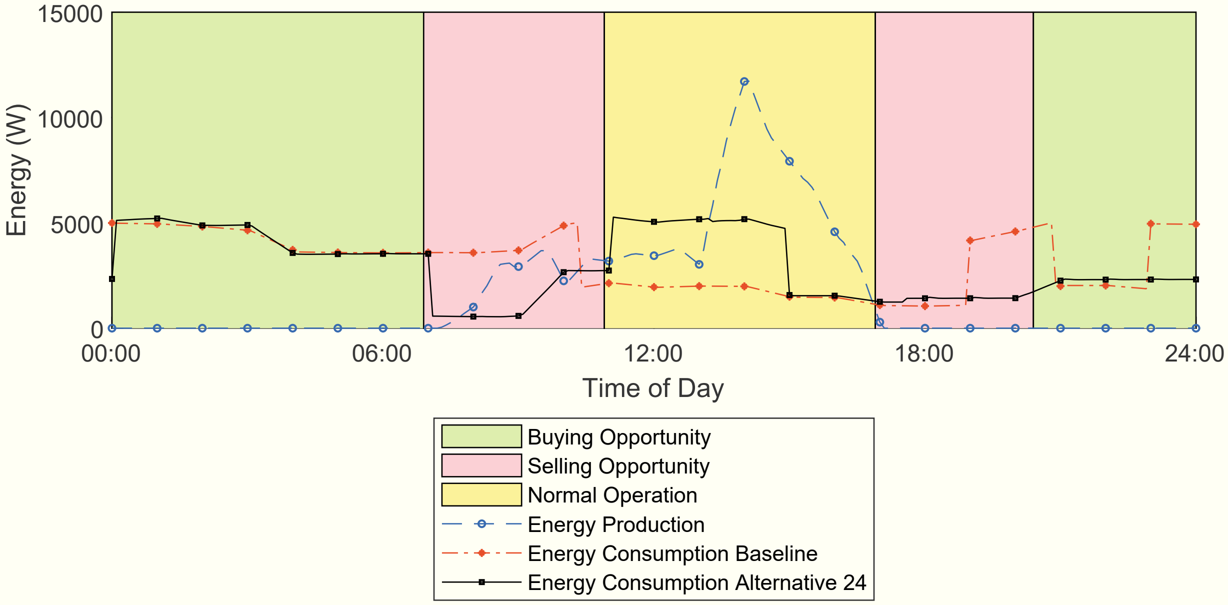

Figure 5.26: Mild Winter Day Energy Profile Baseline and Alternative 24

5.7.2 Energy efficiency and Solar Heat Harvesting

Figure 5.27 shows the total energy use of the 26 alternatives with respect to the baseline case. Surprisingly, most alternatives result in a lower overall energy use throughout the week of simulation. Literature typically indicates that flexibility strategies tend to increase the overall energy consumption. Alternatives 5 and 17, which use the largest capacity heat pump (type 3) with the smallest size TES (450L) undergo a lot of cycling and a slight increase in the overall energy consumption. Alternative 24 offers the lowest overall consumption, which is due to the fact that the smallest size heat pump may operate longer during the day under sunny conditions to charge the TES and thus experience higher COP.

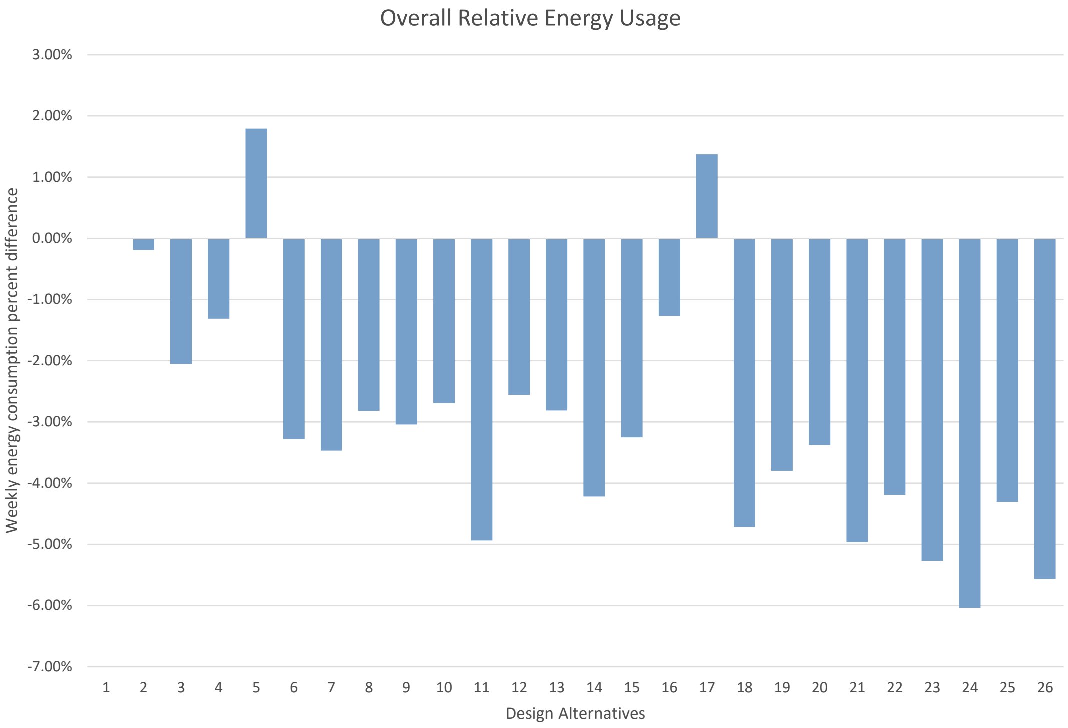

Figure 5.27: Overall Relative Electricity Use

In considering a steady state operation of the heat pump coupled to a BIPV/T system, a direct comparison can be made with the same heat pump operating with outdoor air conditions. The results in Figure 5.28 show the calculated COP of the ASHP for different incident solar radiation ranging from 400 to 1000 $\frac{W}{m^2}$ and different ambient temperatures. The steady state operation considers a 2.5 m/s wind velocity and the use of type 1 heat pump with 0.7 m/s air velocity within the cavity. Across the 10m long cavity, air temperature can rise from 10 °C to nearly 40 °C in comparison with outdoor air. This increase in temperature allows the air source heat pump to perform more efficiently and improves the COP even with incident solar radiation of 400 $\frac{W}{m^2}$. In very cold, clear sky conditions, the COP can be almost doubled.

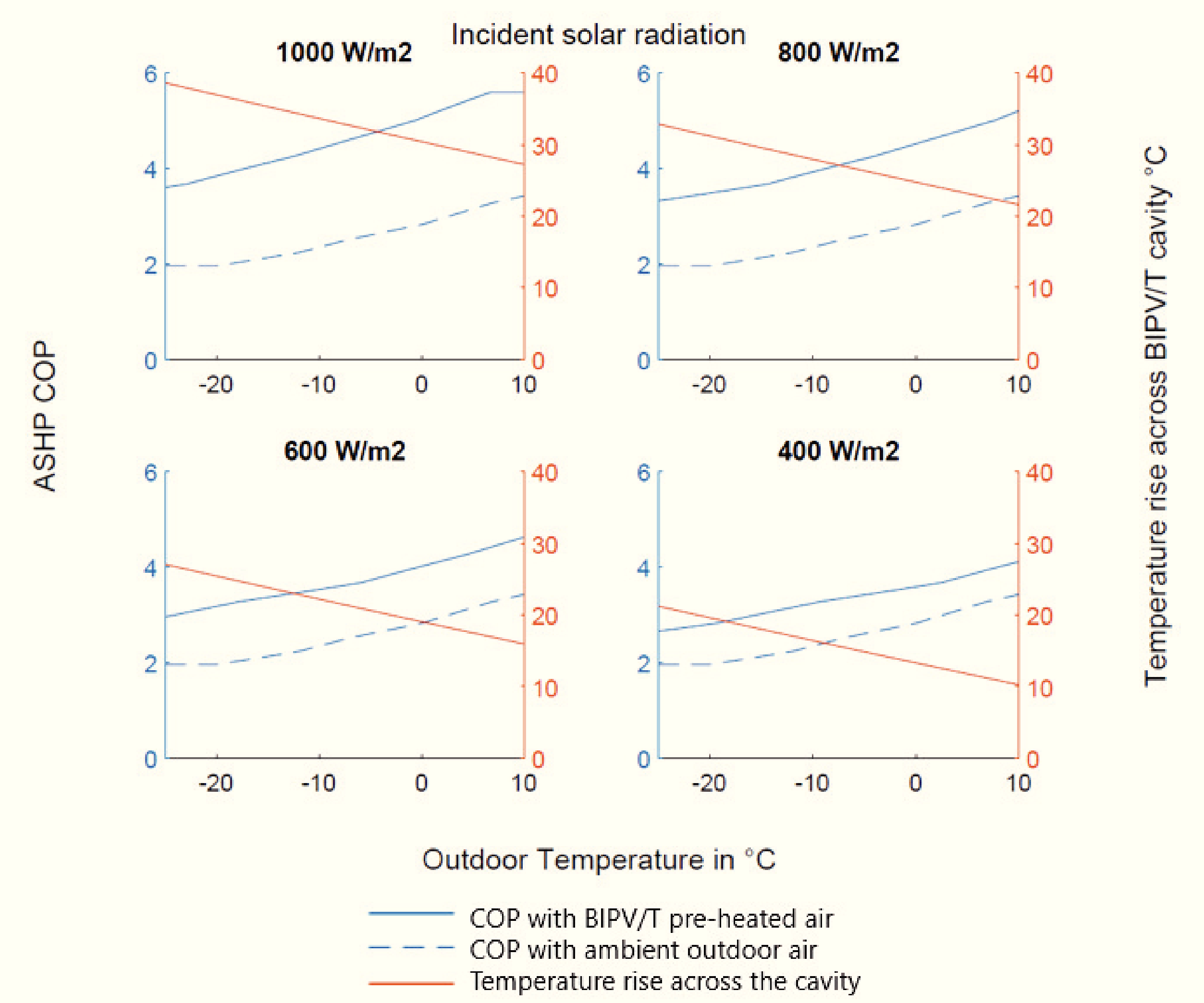

Figure 5.28: BIPV/T Contribution to ASHP COP Under Steady Conditions

Alternatives from control scenarios 3 and 4 share the same sequence of operation with the exception of solar heat harvesting potential being used for scenario 4. The direct contribution of the BIPV/T system is best observed when comparing alternatives with similar TES and ASHP capacities. The weekly average COPs for scenarios 3 and 4 are shown in Figure 5.29.

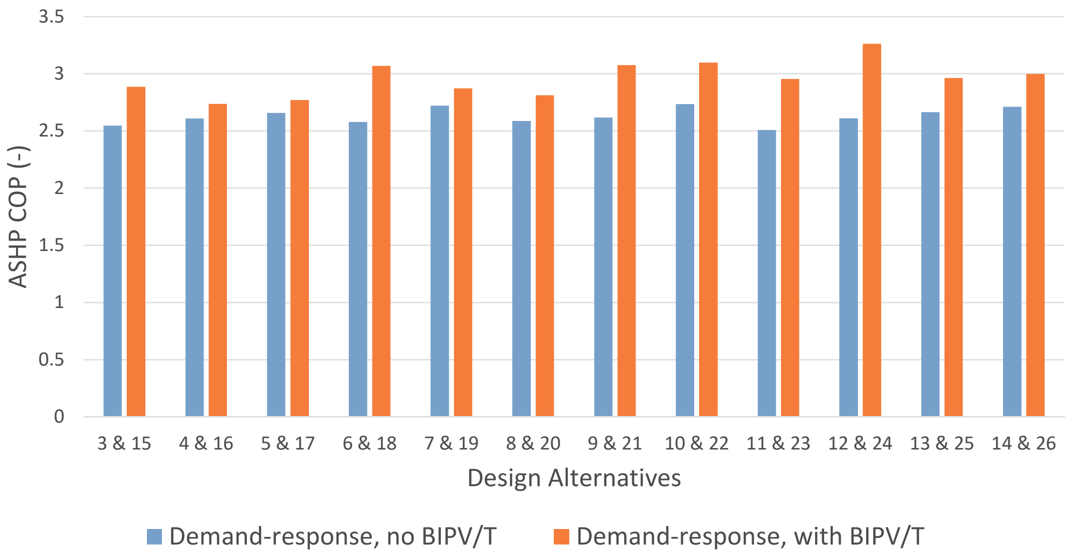

Figure 5.29: BIPV/T Contribution to ASHP COP

No significant gains in efficiency were observed for alternatives with the 450L storage and heat pump types 2 or 3 (alternatives 4,5,16,17). These alternatives also proved less effective in reducing the electricity usage during the selling opportunity period as shown previously in Figure 5.17. The greatest gain in COP was observed for alternative 24 with a increase of 0.65 followed by alternative 18, which showed an increase in COP of 0.49. Both alternatives featured the smaller, type 1 heat pump.

5.7.3 Cost Savings

This section looks at how the different pricing schemes and different design combinations can yield the lowest cost of operation. From the time-of-use energy consumption, an electricity cost is attributed to each kWh used according to three pricing schemes. the pricing schemes considered are presented in table 5.8.

Table 5.8: Pricing Schemes

Grid State	Fixed Energy Price ($/kWh)	Variable Tariff ($/kWh)	Aggressive Variable Tariff ($/kWh)
Buying Opportunity	0.094	0.065	0.047
Normal Operation	0.094	0.094	0.094
Selling Opportunity	0.094	0.132	0.141

A summary of the results expressed as percent differences with respect to the reference case is presented in 5.31 (negative values indicate savings). The first scenario is considered as the reference. First, the pricing schemes are applied without any net-metering agreement.

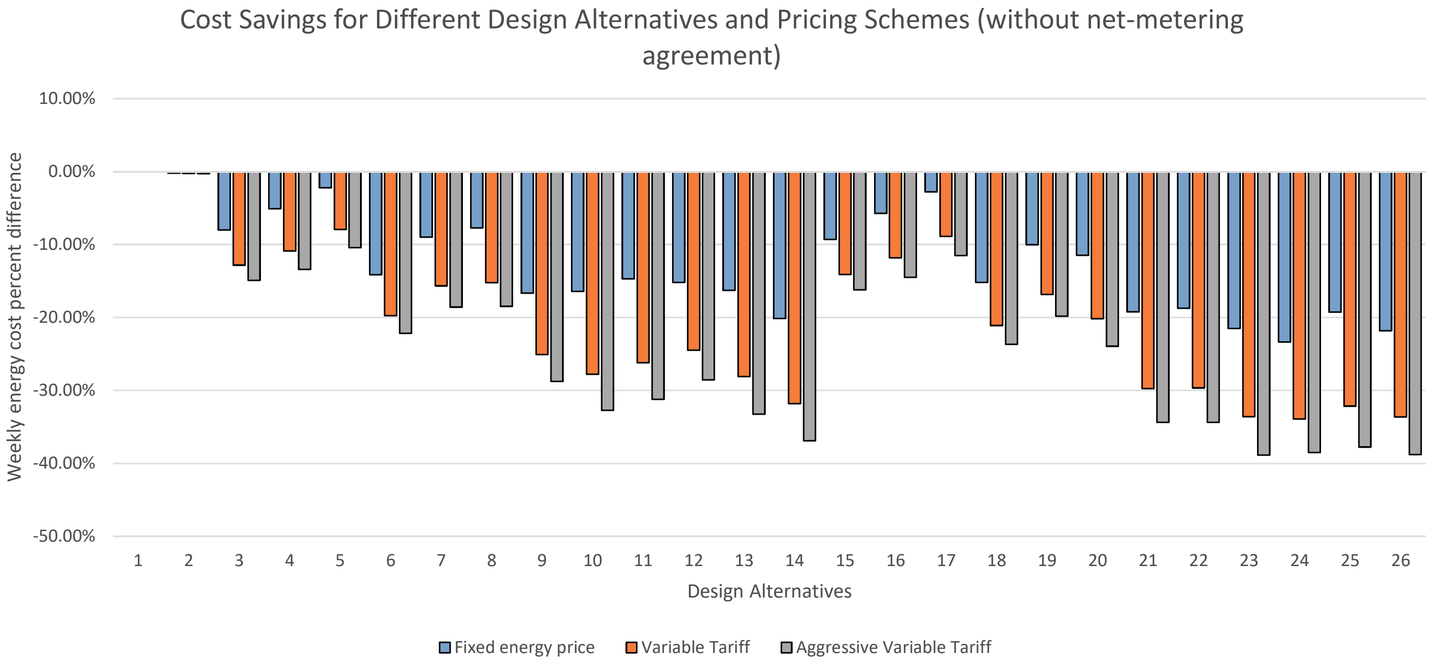

Figure 5.30: Cost Savings for Different Design Alternatives (without net-metering)

It can be observed in Figure 5.30 that all of the alternatives with a demand-response strategy (alternatives 3 and up) offer significant savings, even with a fixed energy price point. This is because of the reduction in curtailed energy and the increase of site-produced energy usage. The best scenario for all tariffs without BIPV/T coupling is alternative 14 (2500L storage tank and type 3 heat pump). The best scenario for all tariffs with BIPV/T is alternative 24 (2500L storage tank and type 1 heat pump). This scenario also offers a longer run-time and reduced cycling since the smaller heat pump is allowed to operate for longer periods of times.

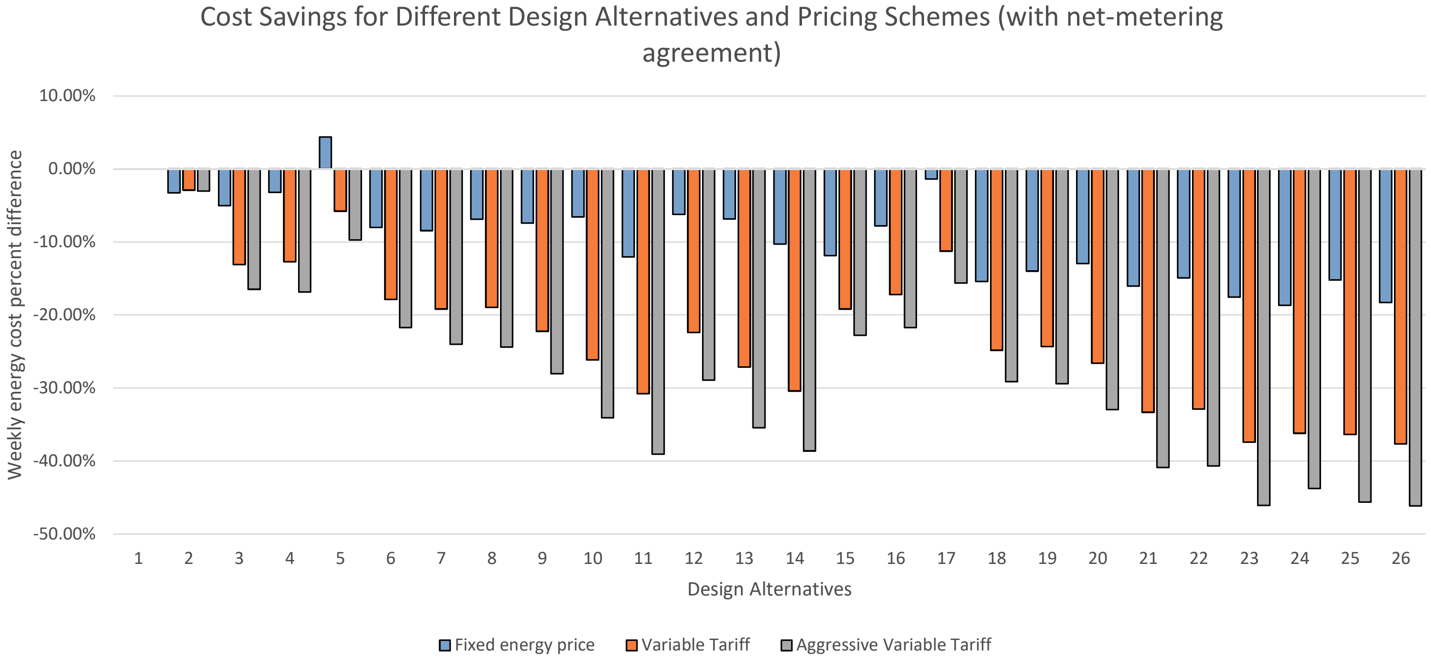

Figure 5.31: Cost Savings for Different Design Alternatives (with net-metering)

In Figure 5.31, a net-metering agreement is considered. For a fixed price point, the best savings (17.5%) were achieved with alternative 24. For variable and aggressive tariffs, alternative 26 (2500 L storage tank and type 3 heat pump) yielded the best savings, but only by a margin in comparison with alternatives 23 to 26 inclusively. Significant savings of over 40% are achieved with the aggressive tariff and net-metering while also promoting energy usage at the right time of day. Overall, for all pricing strategies, with or without net-metering considerations, alternative 24 offers the best compromise.

CHAPTER 6

CONCLUSIONS

Reducing greenhouse gas emissions of buildings through the integration of on-site energy generation from renewables requires flexibility to overcome their inherent variability for high penetration rates to be achieved. Electricity production of solar systems usually does not coincide with the peak heating demand of buildings, but has the potential to enhance the performance of air source heat pumps significantly through solar heat harvesting in BIPV/T systems. Thermal energy storages provide means of decoupling the energy consumption from the loads. Solar assisted air-source heat pumps coupled to thermal energy storage provide better heating efficiencies in addition to having the ability to shift electricity demand. The objective of this work was to develop an integrated approach to quantify the thermal flexibility potential of a residential building featuring a BIPV/T system coupled to an air-source heat pump and sensible thermal energy storage.

A residential building archetype inspired from the 2018 Team MTL entry into the Solar Decathlon China competition was modelled in TRNSYS. A baseline load profile for occupants and their equipment, DHW, and lighting was established. A electrical grid schedule was introduced with low-power demand, mid-peak, and peak power demand periods. 26 alternatives based on 4 main control strategies were evaluated for different combinations of 3 heat pump capacities and 4 TES sizes. Rule-based controls with inputs from the utility grid, the thermal storage state of charge, and the on-site energy production rates were implemented in the model as an effort to shift electric demand.

The performance of each alternative was examined based on their flexibility potential indicated by their time-of-use energy consumption, overall energy usage, energy efficiency, and operational cost.

The baseline design with typical control sequencing and without TES consumed overs half of its energy during peaking grid times whereas the best alternatives consumed 30 to 35% of their respective energy during those periods. The gross energy consumption of the building was reduced by more than 40% during the selling opportunity period which resulted is cost savings of 18%, 37%, and 46% for fixed tariffs, variable tariffs, and aggressive variable tariffs respectively. The energy demand profile for two typical winter days were used to compare the baseline load profile with the best performing alternative. From a design standpoint, the capacity of the TES played a greater role in the performance of the different system configurations than the heat pump capacities. The alternatives with a 2.5 m^3 (37 kWh) resulted in the best flexibility potential. If the ASHP is sized conventionally to fulfil the instantaneous heating needs of the building, it will have enough capacity during most of the year to charge a TES. This would result in less cycling, lower acquisition costs, and lower operation costs. For similar control strategies and installed capacities, systems coupled to the BIPV/T cavity saw an increase in their weekly COP up to 22% and instantaneous COP could be increased by a factor of 2 during cold, clear sky conditions.

6.1 Contributions

A fully integrated TRNSYS model was created that has the ability to perform energy analyses for a range of design options combining the use of a multi-zone building, a sensible thermal energy storage, an air-to-water heat pump, and a BIPV/T system. A state-of-charge evaluation based on a limited set of inputs (three temperature sensors) was integrated in the model as a means to improve the controllability of the thermal energy storage during its intermediate state (not fully charged nor fully depleted). The strategies introduces and investigated allowed to reduce the gross energy consumption of the building by more than 40% during peak grid events. The overall coefficient of performance of the air-source heat pump was improved by 22%, and the cost of electricity was decreased by 46% with the implementation of a variable tariff price structure and a net-metering agreement.

6.2 Future Work

Further research that builds on this work may include:

- The addition of an instantaneous, probabilistic grid signal input to the model to study how the building could cope with unforeseen grid events.
- The study of a thermally activated floor heating/cooling storage as an another mode of thermal storage to be used as a thermal flexibility tool to displace electricity consumption for heating and cooling with a heat pump.
- The study of thermal flexibility of an air-source heat pump in a cooling application where a heat pump could take advantage of cooler night time outdoor temperature to pre-cool a TES, lower the supply cover factor during the day when the cooling demand is the highest, and take advantage of potential high buyback daytime prices.
- The integrated optimization of battery and thermal storage.

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APPENDIX A

SIMULATION RESULTS TABLE

	Alternative	1	2	3	4
	Control strategy (1,2,3,4)	Scenario 1	Scenario 2	Scenario 3	Scenario 3
	Heat pump type (1,2,3)	1	1	1	2
	Storage size (L)	n/a	n/a	450	450
Buying Opportunity	Energy consumption (kWh)	190.5	190.5	208.8	221.3
	HVAC Energy consumption (kWh)	136.3	136.3	148.7	161.3
	Occupants Energy consumption (kWh)	27.3	27.3	30.0	30.0
	DHW Energy consumption (kWh)	26.8	26.8	30.0	30.0
	Energy production (kWh)	0.0	0.0	0.0	0.0
	Supply cover factor (-)	0.0	0.0	0.0	0.0
	Demand cover factor (-)	0.0	0.0	0.0	0.0
	Net Energy Consumption (kWh)	-190.5	-190.5	-208.8	-221.3
Normal Operation	Energy consumption (kWh)	118.2	117.0	141.2	132.9
	HVAC Energy consumption (kWh)	35.4	34.2	49.1	40.7
	Occupants Energy consumption (kWh)	36.7	36.7	46.1	46.1
	DHW Energy consumption (kWh)	46.1	46.1	46.1	46.1
	Energy production (kWh)	304.6	311.2	304.6	304.6
	Supply cover factor (-)	0.3	0.3	0.4	0.3
	Demand cover factor (-)	0.8	0.8	0.8	0.8
	Net Energy Consumption (kWh)	186.4	194.2	163.4	171.8
Selling Opportunity	Energy consumption (kWh)	339.9	339.9	285.3	286.0
	HVAC Energy consumption (kWh)	207.0	207.0	151.0	151.7
	Occupants Energy consumption (kWh)	62.6	62.6	67.1	67.1
	DHW Energy consumption (kWh)	70.3	70.3	67.1	67.1
	Energy production (kWh)	78.1	79.0	78.1	78.1
	Supply cover factor (-)	0.7	0.6	0.7	0.7
	Demand cover factor (-)	0.1	0.1	0.2	0.2
	Net Energy Consumption (kWh)	-261.8	-260.9	-207.2	-207.9
Overall	Energy consumption (kWh)	648.6	647.4	635.3	640.1
	Energy production (kWh)	382.7	390.2	382.7	382.7
	Occupants Energy consumption (kWh)	126.7	126.7	143.2	143.2
	DHW Energy consumption (kWh)	143.2	143.2	143.2	143.2
	Net Energy Consumption (kWh)	-265.9	-257.2	-252.6	-257.4

	Alternative	5	6	7	8
	Control strategy (1,2,3,4)	Scenario 3	Scenario 3	Scenario 3	Scenario 3
	Heat pump type (1,2,3)	3	1	2	3
	Storage size (L)	450	900	900	900
Buying Opportunity	Energy consumption (kWh)	226.5	202.7	220.0	228.2
	HVAC Energy consumption (kWh)	166.4	142.7	160.0	168.2
	Occupants Energy consumption (kWh)	30.0	30.0	30.0	30.0
	DHW Energy consumption (kWh)	30.0	30.0	30.0	30.0
	Energy production (kWh)	0.0	0.0	0.0	0.0
	Supply cover factor (-)	0.0	0.0	0.0	0.0
	Demand cover factor (-)	0.0	0.0	0.0	0.0
	Net Energy Consumption (kWh)	-226.5	-202.7	-220.0	-228.2
Normal Operation	Energy consumption (kWh)	139.9	161.0	136.4	134.9
	HVAC Energy consumption (kWh)	47.7	68.8	44.3	42.7
	Occupants Energy consumption (kWh)	46.1	46.1	46.1	46.1
	DHW Energy consumption (kWh)	46.1	46.1	46.1	46.1
	Energy production (kWh)	304.6	304.6	304.6	304.6
	Supply cover factor (-)	0.3	0.4	0.4	0.4
	Demand cover factor (-)	0.7	0.8	0.8	0.8
	Net Energy Consumption (kWh)	164.7	143.6	168.2	169.7
Selling Opportunity	Energy consumption (kWh)	293.9	263.6	269.7	267.2
	HVAC Energy consumption (kWh)	159.6	129.3	135.4	133.0
	Occupants Energy consumption (kWh)	67.1	67.1	67.1	67.1
	DHW Energy consumption (kWh)	67.1	67.1	67.1	67.1
	Energy production (kWh)	78.1	78.1	78.1	78.1
	Supply cover factor (-)	0.6	0.6	0.6	0.6
	Demand cover factor (-)	0.2	0.2	0.2	0.2
	Net Energy Consumption (kWh)	-215.8	-185.5	-191.6	-189.1
Overall	Energy consumption (kWh)	660.3	627.4	626.1	630.3
	Energy production (kWh)	382.7	382.7	382.7	382.7
	Occupants Energy consumption (kWh)	143.2	143.2	143.2	143.2
	DHW Energy consumption (kWh)	143.2	143.2	143.2	143.2
	Net Energy Consumption (kWh)	-277.6	-244.7	-243.4	-247.6

	Alternative	9	10	11	12
	Control strategy (1,2,3,4)	Scenario 3	Scenario 3	Scenario 3	Scenario 3
	Heat pump type (1,2,3)	1	2	3	1
	Storage size (L)	1800	1800	1800	2500
Buying Opportunity	Energy consumption (kWh)	217.7	238.7	243.0	226.8
	HVAC Energy consumption (kWh)	157.7	178.6	183.0	166.7
	Occupants Energy consumption (kWh)	30.0	30.0	30.0	30.0
	DHW Energy consumption (kWh)	30.0	30.0	30.0	30.0
	Energy production (kWh)	0.0	0.0	0.0	0.0
	Supply cover factor (-)	0.0	0.0	0.0	0.0
	Demand cover factor (-)	0.0	0.0	0.0	0.0
	Net Energy Consumption (kWh)	-217.7	-238.7	-243.0	-226.8
Normal Operation	Energy consumption (kWh)	173.8	175.1	152.8	170.3
	HVAC Energy consumption (kWh)	81.7	83.0	60.6	78.2
	Occupants Energy consumption (kWh)	46.1	46.1	46.1	46.1
	DHW Energy consumption (kWh)	46.1	46.1	46.1	46.1
	Energy production (kWh)	304.6	304.6	304.6	304.6
	Supply cover factor (-)	0.5	0.4	0.4	0.5
	Demand cover factor (-)	0.8	0.8	0.8	0.8
	Net Energy Consumption (kWh)	130.8	129.5	151.9	134.3
Selling Opportunity	Energy consumption (kWh)	237.3	217.3	220.8	235.0
	HVAC Energy consumption (kWh)	103.0	83.1	86.5	100.7
	Occupants Energy consumption (kWh)	67.1	67.1	67.1	67.1
	DHW Energy consumption (kWh)	67.1	67.1	67.1	67.1
	Energy production (kWh)	78.1	78.1	78.1	78.1
	Supply cover factor (-)	0.6	0.6	0.5	0.6
	Demand cover factor (-)	0.2	0.2	0.2	0.2
	Net Energy Consumption (kWh)	-159.2	-139.3	-142.7	-156.9
Overall	Energy consumption (kWh)	628.9	631.2	616.6	632.0
	Energy production (kWh)	382.7	382.7	382.7	382.7
	Occupants Energy consumption (kWh)	143.2	143.2	143.2	143.2
	DHW Energy consumption (kWh)	143.2	143.2	143.2	143.2
	Net Energy Consumption (kWh)	-246.2	-248.5	-233.9	-249.3

	Alternative	13	14	15	16
	Control strategy (1,2,3,4)	Scenario 3	Scenario 3	Scenario 4	Scenario 4
	Heat pump type (1,2,3)	2	3	1	2
	Storage size (L)	2500	2500	450	450
Buying Opportunity	Energy consumption (kWh)	242.2	234.1	206.7	222.3
	HVAC Energy consumption (kWh)	182.2	174.0	146.6	162.2
	Occupants Energy consumption (kWh)	30.0	30.0	30.0	30.0
	DHW Energy consumption (kWh)	30.0	30.0	30.0	30.0
	Energy production (kWh)	0.0	0.0	0.0	0.0
	Supply cover factor (-)	0.0	0.0	0.0	0.0
	Demand cover factor (-)	0.0	0.0	0.0	0.0
	Net Energy Consumption (kWh)	-242.2	-234.1	-206.7	-222.3
Normal Operation	Energy consumption (kWh)	173.7	181.9	137.9	134.4
	HVAC Energy consumption (kWh)	81.5	89.7	45.7	42.3
	Occupants Energy consumption (kWh)	46.1	46.1	46.1	46.1
	DHW Energy consumption (kWh)	46.1	46.1	46.1	46.1
	Energy production (kWh)	304.6	304.6	313.8	315.6
	Supply cover factor (-)	0.4	0.5	0.4	0.3
	Demand cover factor (-)	0.8	0.8	0.8	0.8
	Net Energy Consumption (kWh)	130.9	122.7	175.9	181.2
Selling Opportunity	Energy consumption (kWh)	214.5	205.3	283.0	283.7
	HVAC Energy consumption (kWh)	80.2	71.0	148.7	149.4
	Occupants Energy consumption (kWh)	67.1	67.1	67.1	67.1
	DHW Energy consumption (kWh)	67.1	67.1	67.1	67.1
	Energy production (kWh)	78.1	78.1	79.4	79.6
	Supply cover factor (-)	0.6	0.5	0.7	0.7
	Demand cover factor (-)	0.2	0.2	0.2	0.2
	Net Energy Consumption (kWh)	-136.4	-127.2	-203.6	-204.1
Overall	Energy consumption (kWh)	630.4	621.3	627.5	640.4
	Energy production (kWh)	382.7	382.7	393.1	395.2
	Occupants Energy consumption (kWh)	143.2	143.2	143.2	143.2
	DHW Energy consumption (kWh)	143.2	143.2	143.2	143.2
	Net Energy Consumption (kWh)	-247.7	-238.6	-234.4	-245.2

	Alternative	17	18	19	20
	Control strategy (1,2,3,4)	Scenario 4	Scenario 4	Scenario 4	Scenario 4
	Heat pump type (1,2,3)	3	1	2	3
	Storage size (L)	450	900	900	900
Buying Opportunity	Energy consumption (kWh)	227.7	203.0	219.4	229.5
	HVAC Energy consumption (kWh)	167.6	143.0	159.3	169.4
	Occupants Energy consumption (kWh)	30.0	30.0	30.0	30.0
	DHW Energy consumption (kWh)	30.0	30.0	30.0	30.0
	Energy production (kWh)	0.0	0.0	0.0	0.0
	Supply cover factor (-)	0.0	0.0	0.0	0.0
	Demand cover factor (-)	0.0	0.0	0.0	0.0
	Net Energy Consumption (kWh)	-227.7	-203.0	-219.4	-229.5
Normal Operation	Energy consumption (kWh)	138.3	155.0	137.4	146.7
	HVAC Energy consumption (kWh)	46.1	62.9	45.2	54.6
	Occupants Energy consumption (kWh)	46.1	46.1	46.1	46.1
	DHW Energy consumption (kWh)	46.1	46.1	46.1	46.1
	Energy production (kWh)	315.6	313.8	315.6	315.6
	Supply cover factor (-)	0.3	0.4	0.3	0.3
	Demand cover factor (-)	0.8	0.8	0.8	0.7
	Net Energy Consumption (kWh)	177.3	158.8	178.3	168.9
Selling Opportunity	Energy consumption (kWh)	291.6	260.0	267.3	250.5
	HVAC Energy consumption (kWh)	157.3	125.7	133.0	116.3
	Occupants Energy consumption (kWh)	67.1	67.1	67.1	67.1
	DHW Energy consumption (kWh)	67.1	67.1	67.1	67.1
	Energy production (kWh)	79.6	79.4	79.6	79.6
	Supply cover factor (-)	0.6	0.6	0.6	0.6
	Demand cover factor (-)	0.2	0.2	0.2	0.2
	Net Energy Consumption (kWh)	-212.0	-180.6	-187.6	-170.9
Overall	Energy consumption (kWh)	657.5	618.1	624.0	626.7
	Energy production (kWh)	395.2	393.1	395.2	395.2
	Occupants Energy consumption (kWh)	143.2	143.2	143.2	143.2
	DHW Energy consumption (kWh)	143.2	143.2	143.2	143.2
	Net Energy Consumption (kWh)	-262.3	-224.9	-228.8	-231.5

	Alternative	21	22	23	24
	Control strategy (1,2,3,4)	Scenario 4	Scenario 4	Scenario 4	Scenario 4
	Heat pump type (1,2,3)	1	2	3	1
	Storage size (L)	1800	1800	1800	2500
Buying Opportunity	Energy consumption (kWh)	227.6	231.0	234.0	220.0
	HVAC Energy consumption (kWh)	167.6	170.9	174.0	159.9
	Occupants Energy consumption (kWh)	30.0	30.0	30.0	30.0
	DHW Energy consumption (kWh)	30.0	30.0	30.0	30.0
	Energy production (kWh)	0.0	0.0	0.0	0.0
	Supply cover factor (-)	0.0	0.0	0.0	0.0
	Demand cover factor (-)	0.0	0.0	0.0	0.0
	Net Energy Consumption (kWh)	-227.6	-231.0	-234.0	-220.0
Normal Operation	Energy consumption (kWh)	171.8	174.4	179.9	183.5
	HVAC Energy consumption (kWh)	79.6	82.2	87.8	91.3
	Occupants Energy consumption (kWh)	46.1	46.1	46.1	46.1
	DHW Energy consumption (kWh)	46.1	46.1	46.1	46.1
	Energy production (kWh)	313.8	315.6	315.6	313.8
	Supply cover factor (-)	0.5	0.4	0.4	0.5
	Demand cover factor (-)	0.8	0.8	0.7	0.9
	Net Energy Consumption (kWh)	142.0	141.3	135.7	130.3
Selling Opportunity	Energy consumption (kWh)	217.0	216.1	200.5	206.0
	HVAC Energy consumption (kWh)	82.7	81.8	66.2	71.7
	Occupants Energy consumption (kWh)	67.1	67.1	67.1	67.1
	DHW Energy consumption (kWh)	67.1	67.1	67.1	67.1
	Energy production (kWh)	79.4	79.6	79.6	79.4
	Supply cover factor (-)	0.6	0.5	0.4	0.6
	Demand cover factor (-)	0.2	0.2	0.2	0.2
	Net Energy Consumption (kWh)	-137.7	-136.5	-120.9	-126.6
Overall	Energy consumption (kWh)	616.4	621.4	614.4	609.5
	Energy production (kWh)	393.1	395.2	395.2	393.1
	Occupants Energy consumption (kWh)	143.2	143.2	143.2	143.2
	DHW Energy consumption (kWh)	143.2	143.2	143.2	143.2
	Net Energy Consumption (kWh)	-223.3	-226.2	-219.2	-216.3

	Alternative	25	26
	Control strategy (1,2,3,4)	Scenario 4	Scenario 4
	Heat pump type (1,2,3)	2	3
	Storage size (L)	2500	2500
Buying Opportunity	Energy consumption (kWh)	244.0	231.6
	HVAC Energy consumption (kWh)	183.9	171.5
	Occupants Energy consumption (kWh)	30.0	30.0
	DHW Energy consumption (kWh)	30.0	30.0
	Energy production (kWh)	0.0	0.0
	Supply cover factor (-)	0.0	0.0
	Demand cover factor (-)	0.0	0.0
	Net Energy Consumption (kWh)	-244.0	-231.6
Normal Operation	Energy consumption (kWh)	176.0	179.4
	HVAC Energy consumption (kWh)	83.9	87.2
	Occupants Energy consumption (kWh)	46.1	46.1
	DHW Energy consumption (kWh)	46.1	46.1
	Energy production (kWh)	315.6	315.6
	Supply cover factor (-)	0.4	0.4
	Demand cover factor (-)	0.8	0.8
	Net Energy Consumption (kWh)	139.6	136.3
Selling Opportunity	Energy consumption (kWh)	200.7	201.6
	HVAC Energy consumption (kWh)	66.4	67.3
	Occupants Energy consumption (kWh)	67.1	67.1
	DHW Energy consumption (kWh)	67.1	67.1
	Energy production (kWh)	79.6	79.6
	Supply cover factor (-)	0.5	0.5
	Demand cover factor (-)	0.2	0.2
	Net Energy Consumption (kWh)	-121.1	-122.0
Overall	Energy consumption (kWh)	620.7	612.5
	Energy production (kWh)	395.2	395.2
	Occupants Energy consumption (kWh)	143.2	143.2
	DHW Energy consumption (kWh)	143.2	143.2
	Net Energy Consumption (kWh)	-225.5	-217.3

APPENDIX B

PROGRAMS AND DATA USED FOR SENSIBLE WATER TES

B.1 Matlab Parametric Runs Program for Tank Stratification

```
%% Preparation
clear all
% TRNSYS Exe path
trnExePath = 'C:\Trnsys18\Exe\TRNExe64.exe';
% Root (project) directory
rootDir = 'C:\Users\r_dumo\Dropbox\TRNSYS_docs\MyProjects\Solar Air-
source\Air_distribution\Parametric_stratification\';




% Input (dck) template file

dckTemplateFilePath = ['C:\Users\r_dumo\Dropbox\TRNSYS_docs\MyProjects\Solar
Air-source\Air_distribution\Tank_stratification.dck'];
% Directory for intermediate files
parDir = [rootDir 'ParamRuns\'];


% Create the directory if it does not exist yet
if(~exist(parDir, 'dir'))
    mkdir(parDir);
end

% Read in dck and b18 templates as arrays of strings
dckTemplate = fileread(dckTemplateFilePath);
dckTemplate = splitlines(string(dckTemplate));




%% Parameters and runs


Storage_Type_File={ 'C:\Users\r_dumo\Dropbox\TRNSYS_docs\MyProjects\Solar
Air-source\Air_distribution\Tank\SmallTank_parameters.txt'
                    'C:\Users\r_dumo\Dropbox\TRNSYS_docs\MyProjects\Solar
Air-source\Air_distribution\Tank\MediumTank_parameters.txt'
                    'C:\Users\r_dumo\Dropbox\TRNSYS_docs\MyProjects\Solar
Air-source\Air_distribution\Tank\LargeTank_parameters.txt'
                    'C:\Users\r_dumo\Dropbox\TRNSYS_docs\MyProjects\Solar
Air-source\Air_distribution\Tank\BiggestTank_parameters.txt'};

Storage_Type={'SmallTank\' 'MediumTank\' 'LargeTank\' 'BiggestTank\'};
%Different pump flows (2 and 4 gpm [450 and 900 kg/h])

Pump_flow= [450 900];
Flow_Type={'0.14 Lps\' '0.28 Lps\'};
T_empty= [40 38 36 34 32 30];

Tank_volumes=[0.45 0.9 1.8 2.5];
Target_delta_T=[5 10 15];
Flows=[0.14 0.28];
for j=1:length(Target_delta_T)
for i=1:length(Tank_volumes)
  Target_capacity(i,j)=(Tank_volumes(i)*4.2*Target_delta_T(j))/3.6;
```

```
end
end

nb_storages=4; % Number of storage tank sizes
nb_flows=length(Pump_flow); %Number of pump flows
nb_T_empty=length(T_empty); %Number of discharged temperatures to be modeled



for i_storage=1:nb_storages %allocate the proper storage tank file


    %Creating sub-folders for different storage sizes

    StorageDir{i_storage} = [parDir Storage_Type{i_storage}];

        % Create the directory if it does not exist yet
        if(~exist(StorageDir{i_storage}, 'dir'))
            mkdir(StorageDir{i_storage});
        end

    for i_flow=1:nb_flows

        %Creating sub-folders for different flowrates

        FlowDir{i_storage,i_flow} = [StorageDir{i_storage}
Flow_Type{i_flow}];

        % Create the directory if it does not exist yet
        if(~exist(FlowDir{i_storage,i_flow}, 'dir'))
            mkdir(FlowDir{i_storage,i_flow});
        end

                % Replace variable code with values in dck

        dck_File = strrep(dckTemplate, '901',
sprintf('%02d',Pump_flow(i_flow)));
        dck_File = strrep(dck_File,
'C:\Users\r_dumo\Dropbox\TRNSYS_docs\MyProjects\Solar Air-
source\Air_distribution\Tank\Tank_parameters.txt',...
                   Storage_Type_File{i_storage});


        % Keep track of filenames to run them later

        dckFilePath{i_storage,i_flow} = [FlowDir{i_storage,i_flow}
'Stratification_Run.dck'];

        % Write dck file

        fId = fopen(dckFilePath{i_storage,i_flow}, 'wt', 'n', 'UTF-8');
        fprintf(fId, '%s\n', dck_File);
        fclose(fId);
```

```
         %Run dck files

           [status, ~] = system(['"' trnExePath '" "'
dckFilePath{i_storage,i_flow}]);% '"  /n /h"']);

        delimiterIn = ' ';
        headerlinesIn = 1;

        Output_file{i_storage,i_flow}=[FlowDir{i_storage,i_flow}
'Stratification_Run.out'];

Output_results{i_storage,i_flow}=importdata(Output_file{i_storage,i_flow},del
imiterIn,headerlinesIn);


Output_file_stratification{i_storage,i_flow}=[FlowDir{i_storage,i_flow}
'SOC_calculation.out'];

Output_results_stratification{i_storage,i_flow}=importdata(Output_file_strati
fication{i_storage,i_flow},delimiterIn,headerlinesIn);




Critical_row_35(i_storage,i_flow)=max(find(Output_results{i_storage,i_flow}.d
ata(:,2)>35));

Critical_row_40(i_storage,i_flow)=max(find(Output_results{i_storage,i_flow}.d
ata(:,2)>40));

Critical_row_30(i_storage,i_flow)=max(find(Output_results{i_storage,i_flow}.d
ata(:,2)>30));


Energy_released(i_storage,i_flow)=Output_results{i_storage,i_flow}.data(Criti
cal_row_40(i_storage,i_flow),11);

Energy_released(i_storage+nb_storages,i_flow)=Output_results{i_storage,i_flow
}.data(Critical_row_35(i_storage,i_flow),11);

Energy_released(i_storage+2*nb_storages,i_flow)=Output_results{i_storage,i_fl
ow}.data(Critical_row_30(i_storage,i_flow),11);


Stratification_35(i_storage,i_flow)=mean(Output_results{i_storage,i_flow}.dat
a(1:Critical_row_35(i_storage,i_flow),11));

Stratification_40(i_storage,i_flow)=mean(Output_results{i_storage,i_flow}.dat
a(1:Critical_row_40(i_storage,i_flow),11));

Stratification_30(i_storage,i_flow)=mean(Output_results{i_storage,i_flow}.dat
a(1:Critical_row_30(i_storage,i_flow),11));
```

```
Tank_changes_per_hour(i_storage,i_flow)=(Flows(i_flow)*3.6)/Tank_volumes(i_st
orage);
        for i_emptyT=1:nb_T_empty

%         % Replace variable code with values in dck
% % %         Baseline_start='START=000'; %Simulation start time for baseline
run
% % %         Baseline_stop='STOP=8760'; %Simulation end time for baseline
run
%         dck_File = strrep(dckTemplate, '900',
sprintf('%02d',Pump_flow(i_flow)));
%         dck_File = strrep(dck_File,
'C:\Users\r_dumo\Dropbox\TRNSYS_docs\MyProjects\Solar Air-
source\Air_distribution\Tank\Tank_parameters.txt',...
%                    Storage_Type_File{i_storage});
%         emptytemperature=['45 ' sprintf('%02d',T_empty(i_emptyT))] ;
%         dck_File = strrep(dck_File, '45 35', emptytemperature);
%
%         % Keep track of filenames to run them later
%
%         dckFilePath{i_storage,i_flow,i_emptyT} = [FlowDir{i_storage,i_flow}
'Stratification_Run' sprintf('%02d',T_empty(i_emptyT)) 'C_empty_temp.dck'];
%
%         % Write dck file
%
%         fId = fopen(dckFilePath{i_storage,i_flow,i_emptyT}, 'wt', 'n',
'UTF-8');
%         fprintf(fId, '%s\n', dck_File);
%         fclose(fId);
%
%          %Run dck files
%
%            [status, ~] = system(['"' trnExePath '" "'
dckFilePath{i_storage,i_flow,i_emptyT}]);% '"  /n /h"']);





        end



    end
end
for i_storage=1:4

        Energy_released(i_storage,3)=Target_capacity(i_storage,1);
        Energy_released(i_storage,4)= 100*(Energy_released(i_storage,1)-
Energy_released(i_storage,3))/Energy_released(i_storage,3);
        Energy_released(i_storage,5)= 100*(Energy_released(i_storage,2)-
Energy_released(i_storage,3))/Energy_released(i_storage,3);


Energy_released(i_storage+nb_storages,3)=Target_capacity(i_storage,2);
```

```
        Energy_released(i_storage+nb_storages,4)=
100*(Energy_released(i_storage+nb_storages,1)-
Energy_released(i_storage+nb_storages,3))/Energy_released(i_storage+nb_storag
es,3);

Energy_released(i_storage+nb_storages,5)=100*(Energy_released(i_storage+nb_st
orages,2)-
Energy_released(i_storage+nb_storages,3))/Energy_released(i_storage+nb_storag
es,3);



Energy_released(i_storage+2*nb_storages,3)=Target_capacity(i_storage,3);
        Energy_released(i_storage+2*nb_storages,4)=
100*(Energy_released(i_storage+2*nb_storages,1)-
Energy_released(i_storage+2*nb_storages,3))/Energy_released(i_storage+2*nb_st
orages,3);

Energy_released(i_storage+2*nb_storages,5)=100*(Energy_released(i_storage+2*n
b_storages,2)-
Energy_released(i_storage+2*nb_storages,3))/Energy_released(i_storage+2*nb_st
orages,3);




end
% figure1 = figure('PaperOrientation','landscape','PaperType','B',...
%     'PaperSize',[8.5 5],...
%     'Color',[1 1 1]);
%    axes1 = axes('Parent',figure1,...
%     'Position',[0.153237038696419 0.112121212121212 0.706100067204955
0.714791090157493]);
%
% hold(axes1,'on');
% plot(Output_results_stratification{3,
1}.data(2:70,1),Output_results_stratification{3, 1}.data(2:70,2:7))
% xlim([0 6.5])
% ylim([0 100])
% % Create legend
% legend1=legend('Reference SOC','Tavg SOC (2 temperature readings)','Tavg
SOC (3 temperature readings)','Tsupply SOC','Combined Tavg and Tsupply SOC (3
sensors)',...
%                  'Combined Tavg and Tsupply SOC (2 sensors)');
%
% set(legend1,'Position',[0.648628792524849 0.529581533871257
0.196443002649922 0.130303026690628]);
%
% % Create ylabel
% ylabel('State of Charge (%)');
%
% % Create xlabel
% xlabel('Time (h)');
```

```
figure1 = figure('PaperOrientation','landscape','PaperType','B',...
    'Color',[1 1 1], 'PaperSize',[10 8]);

axes1 = axes('Parent',figure1,...
    'Position',[0.05 0.107462686567164 0.450576307363927 0.817537313432836]);
hold(axes1,'on');
hold(axes1,'on');
plot(Tank_volumes,Energy_released(1:nb_storages,1),'LineStyle','-.',...
    'Color',[0.850980392156863 0.329411764705882 0.101960784313725]);
plot(Tank_volumes,Energy_released(nb_storages+1:2*nb_storages,1),'LineWidth',
0.75,'LineStyle','-.',...
    'Color',[0 0.498039215803146 0]);
plot(Tank_volumes,Energy_released(2*nb_storages+1:3*nb_storages,1),
'LineWidth',0.75,'LineStyle','-.',...
    'Color',[0 0.450980392156863 0.741176470588235]);
plot(Tank_volumes,Energy_released(1:nb_storages,2),'LineStyle',':',...
    'Color',[0.850980392156863 0.329411764705882 0.101960784313725]);
plot(Tank_volumes,Energy_released(nb_storages+1:2*nb_storages,2),'LineWidth',
0.75,'LineStyle',':',...
    'Color',[0 0.498039215803146 0]);
plot(Tank_volumes,Energy_released(2*nb_storages+1:3*nb_storages,2),'LineWidth
',0.75,'LineStyle',':',...
    'Color',[0 0.450980392156863 0.741176470588235]);
plot(Tank_volumes,Energy_released(1:nb_storages,3),'Color',[0.850980392156863
0.329411764705882 0.101960784313725]);
plot(Tank_volumes,Energy_released(nb_storages+1:2*nb_storages,3),'Color',[0
0.498039215803146 0]);
plot(Tank_volumes,Energy_released(2*nb_storages+1:3*nb_storages,3),'Color',[0
0.450980392156863 0.741176470588235]);

xticks([0.45 0.9 1.8 2.5 3]);
xticklabels({'0.45' '0.9' '1.8' '2.5' '3'});

% Create ylabel
ylabel('TES Capacity (kWh)');

% Create xlabel
xlabel('TES size (m3)');

% Uncomment the following line to preserve the X-limits of the axes
xlim(axes1,[0 3]);
% Set the remaining axes properties
set(axes1,'FontSize',14,'XTick',[0.45 0.9 1.8 2.5 3],'XTickLabel',...
    {'0.45','0.9','1.8','2.5',''});
% Create legend
legend1=legend('5°C to depletion, 0.14 L/s load flowrate','10°C to depletion,
0.14 L/s load flowrate','15°C to depletion, 0.14 L/s load flowrate',...
               '5°C to depletion, 0.28 L/s load flowrate','10°C to depletion,
0.28 L/s load flowrate','15°C to depletion, 0.28 L/s load flowrate',...
               '5°C to depletion, assuming fully mixed', '10°C to depletion,
assuming fully mixed','15°C to depletion, assuming fully mixed');

set(legend1,...
    'Position',[0.574951673497123 0.282799222122143 0.330700880094907
0.372400745495957],...
    'FontSize',12);
```

```
print('-fillpage','BestFitFigure','-dpdf')
```

B.2 Matlab Parametric Runs Program for tank SOC

```
%% Preparation
clear all
% TRNSYS Exe path
trnExePath = 'C:\Trnsys18\Exe\TRNExe64.exe';
% Root (project) directory
rootDir = 'C:\Users\r_dumo\Dropbox\TRNSYS_docs\MyProjects\Solar Air-
source\Air_distribution\Parametric_stratification\';



% Input (dck) template file

dckTemplateFilePath = ['C:\Users\r_dumo\Dropbox\TRNSYS_docs\MyProjects\Solar
Air-source\Air_distribution\Tank_stratification.dck'];
% Directory for intermediate files
parDir = [rootDir 'SOCruns\'];


% Create the directory if it does not exist yet
if(~exist(parDir, 'dir'))
    mkdir(parDir);
end

% Read in dck and b18 templates as arrays of strings
dckTemplate = fileread(dckTemplateFilePath);
dckTemplate = splitlines(string(dckTemplate));



%% Parameters and runs


Storage_Type_File={ 'C:\Users\r_dumo\Dropbox\TRNSYS_docs\MyProjects\Solar
Air-source\Air_distribution\Tank\SmallTank_parameters.txt'
                    'C:\Users\r_dumo\Dropbox\TRNSYS_docs\MyProjects\Solar
Air-source\Air_distribution\Tank\MediumTank_parameters.txt'
                    'C:\Users\r_dumo\Dropbox\TRNSYS_docs\MyProjects\Solar
Air-source\Air_distribution\Tank\LargeTank_parameters.txt'
                    'C:\Users\r_dumo\Dropbox\TRNSYS_docs\MyProjects\Solar
Air-source\Air_distribution\Tank\BiggestTank_parameters.txt'};

Storage_Type={'SmallTank\' 'MediumTank\' 'LargeTank\' 'BiggestTank\'};
%Different pump flows (2 and 4 gpm [450 and 900 kg/h])

Pump_flow= [450 900];
Flow_Type={'0.14 Lps\' '0.28 Lps\'};
T_empty= [40 38 36 34 32 30];

Tank_volumes=[0.45 0.9 1.8 2.5];
Target_delta_T=[5 10 15];
Flows=[0.14 0.28];
for j=1:length(Target_delta_T)
for i=1:length(Tank_volumes)
  Target_capacity(i,j)=(Tank_volumes(i)*4.2*Target_delta_T(j))/3.6;
```

```
end
end

nb_storages=4; % Number of storage tank sizes
nb_flows=length(Pump_flow); %Number of pump flows
nb_T_empty=length(T_empty); %Number of discharged temperatures to be modeled



for i_storage=3:3%nb_storages %allocate the proper storage tank file


    %Creating sub-folders for different storage sizes

    StorageDir{i_storage} = [parDir Storage_Type{i_storage}];

        % Create the directory if it does not exist yet
        if(~exist(StorageDir{i_storage}, 'dir'))
            mkdir(StorageDir{i_storage});
        end

    for i_flow=1:1%nb_flows

        %Creating sub-folders for different flowrates

        FlowDir{i_storage,i_flow} = [StorageDir{i_storage}
Flow_Type{i_flow}];

        % Create the directory if it does not exist yet
        if(~exist(FlowDir{i_storage,i_flow}, 'dir'))
            mkdir(FlowDir{i_storage,i_flow});
        end

                % Replace variable code with values in dck

        dck_File = strrep(dckTemplate, '900',
sprintf('%02d',Pump_flow(i_flow)));
        dck_File = strrep(dck_File,
'C:\Users\r_dumo\Dropbox\TRNSYS_docs\MyProjects\Solar Air-
source\Air_distribution\Tank\Tank_parameters.txt',...
                   Storage_Type_File{i_storage});


        % Keep track of filenames to run them later

        dckFilePath{i_storage,i_flow} = [FlowDir{i_storage,i_flow}
'Stratification_Run.dck'];

        % Write dck file

        fId = fopen(dckFilePath{i_storage,i_flow}, 'wt', 'n', 'UTF-8');
        fprintf(fId, '%s\n', dck_File);
        fclose(fId);
```

```
         %Run dck files

           [status, ~] = system(['"' trnExePath '" "'
dckFilePath{i_storage,i_flow}]);% '"  /n /h"']);

        delimiterIn = ' ';
        headerlinesIn = 1;

        Output_file{i_storage,i_flow}=[FlowDir{i_storage,i_flow}
'Stratification_Run.out'];

Output_results{i_storage,i_flow}=importdata(Output_file{i_storage,i_flow},del
imiterIn,headerlinesIn);


Output_file_stratification{i_storage,i_flow}=[FlowDir{i_storage,i_flow}
'SOC_calculation.out'];

Output_results_stratification{i_storage,i_flow}=importdata(Output_file_strati
fication{i_storage,i_flow},delimiterIn,headerlinesIn);




Critical_row_35(i_storage,i_flow)=max(find(Output_results{i_storage,i_flow}.d
ata(:,2)>35));

Critical_row_40(i_storage,i_flow)=max(find(Output_results{i_storage,i_flow}.d
ata(:,2)>40));

Critical_row_30(i_storage,i_flow)=max(find(Output_results{i_storage,i_flow}.d
ata(:,2)>30));


Energy_released(i_storage,i_flow)=Output_results{i_storage,i_flow}.data(Criti
cal_row_40(i_storage,i_flow),11);

Energy_released(i_storage+nb_storages,i_flow)=Output_results{i_storage,i_flow
}.data(Critical_row_35(i_storage,i_flow),11);

Energy_released(i_storage+2*nb_storages,i_flow)=Output_results{i_storage,i_fl
ow}.data(Critical_row_30(i_storage,i_flow),11);


Stratification_35(i_storage,i_flow)=mean(Output_results{i_storage,i_flow}.dat
a(1:Critical_row_35(i_storage,i_flow),11));

Stratification_40(i_storage,i_flow)=mean(Output_results{i_storage,i_flow}.dat
a(1:Critical_row_40(i_storage,i_flow),11));

Stratification_30(i_storage,i_flow)=mean(Output_results{i_storage,i_flow}.dat
a(1:Critical_row_30(i_storage,i_flow),11));
```

```
Tank_changes_per_hour(i_storage,i_flow)=(Flows(i_flow)*3.6)/Tank_volumes(i_st
orage);
    end
end


% figure1 = figure('PaperOrientation','landscape','PaperType','B',...
%     'PaperSize',[8.5 5],...
%     'Color',[1 1 1]);
%    axes1 = axes('Parent',figure1,...
%     'Position',[0.153237038696419 0.112121212121212 0.706100067204955
0.714791090157493]);
%
% hold(axes1,'on');
% plot(Output_results_stratification{3,
1}.data(2:70,1),Output_results_stratification{3, 1}.data(2:70,2:7))
% xlim([0 6.5])
% ylim([0 100])
% % Create legend
% legend1=legend('Reference SOC','Tavg SOC (2 temperature readings)','Tavg
SOC (3 temperature readings)','Tsupply SOC','Combined Tavg and Tsupply SOC (3
sensors)',...
%                  'Combined Tavg and Tsupply SOC (2 sensors)');
%
% set(legend1,'Position',[0.648628792524849 0.529581533871257
0.196443002649922 0.130303026690628]);
%
% % Create ylabel
% ylabel('State of Charge (%)');
%
% % Create xlabel
% xlabel('Time (h)');

%
% figure1 = figure('PaperOrientation','landscape','PaperType','B',...
%     'Color',[1 1 1], 'PaperSize',[10 8]);
%
% axes1 = axes('Parent',figure1,...
%     'Position',[0.05 0.107462686567164 0.450576307363927
0.817537313432836]);
% hold(axes1,'on');
% hold(axes1,'on');
% plot(Tank_volumes,Energy_released(1:nb_storages,1),'LineStyle','-.',...
%     'Color',[0.850980392156863 0.329411764705882 0.101960784313725]);
%
plot(Tank_volumes,Energy_released(nb_storages+1:2*nb_storages,1),'LineWidth',
0.75,'LineStyle','-.',...
%     'Color',[0 0.498039215803146 0]);
% plot(Tank_volumes,Energy_released(2*nb_storages+1:3*nb_storages,1),
'LineWidth',0.75,'LineStyle','-.',...
%     'Color',[0 0.450980392156863 0.741176470588235]);
% plot(Tank_volumes,Energy_released(1:nb_storages,2),'LineStyle',':',...
%     'Color',[0.850980392156863 0.329411764705882 0.101960784313725]);
```

```
%
plot(Tank_volumes,Energy_released(nb_storages+1:2*nb_storages,2),'LineWidth',
0.75,'LineStyle',':',...
%     'Color',[0 0.498039215803146 0]);
%
plot(Tank_volumes,Energy_released(2*nb_storages+1:3*nb_storages,2),'LineWidth
',0.75,'LineStyle',':',...
%     'Color',[0 0.450980392156863 0.741176470588235]);
%
plot(Tank_volumes,Energy_released(1:nb_storages,3),'Color',[0.850980392156863
0.329411764705882 0.101960784313725]);
% plot(Tank_volumes,Energy_released(nb_storages+1:2*nb_storages,3),'Color',[0
0.498039215803146 0]);
%
plot(Tank_volumes,Energy_released(2*nb_storages+1:3*nb_storages,3),'Color',[0
0.450980392156863 0.741176470588235]);
%
% xticks([0.45 0.9 1.8 2.5 3]);
% xticklabels({'0.45' '0.9' '1.8' '2.5' '3'});
%
% % Create ylabel
% ylabel('TES Capacity (kWh)');
%
% % Create xlabel
% xlabel('TES size (m3)');
%
% % Uncomment the following line to preserve the X-limits of the axes
% xlim(axes1,[0 3]);
% % Set the remaining axes properties
% set(axes1,'FontSize',14,'XTick',[0.45 0.9 1.8 2.5 3],'XTickLabel',...
%     {'0.45','0.9','1.8','2.5',''});
% % Create legend
% legend1=legend('5°C to depletion, 0.14 L/s load flowrate','10°C to
depletion, 0.14 L/s load flowrate','15°C to depletion, 0.14 L/s load
flowrate',...
%                 '5°C to depletion, 0.28 L/s load flowrate','10°C to
depletion, 0.28 L/s load flowrate','15°C to depletion, 0.28 L/s load
flowrate',...
%                 '5°C to depletion, assuming fully mixed', '10°C to
depletion, assuming fully mixed','15°C to depletion, assuming fully mixed');
%
% set(legend1,...
%     'Position',[0.574951673497123 0.282799222122143 0.330700880094907
0.372400745495957],...
%     'FontSize',12);
%
% print('-fillpage','BestFitFigure','-dpdf')
```

APPENDIX C

PROGRAMS AND DATA USED FOR INTEGRATED FLEXIBILITY MODEL

C.1 ASHP Manufacturer Data Used for Trnsys Performance Chart Creation

ARCTIC 020A

Power Input (W)

Outdoor Temp. Water Inlet Temp.	-22℃<Tout	-22℃<Tout≤-15℃	-15℃<Tout≤-9℃	-9℃<Tout≤-3℃	-3℃<Tout≤4℃	4℃＜Tout≤11℃	11℃＜Tout≤18℃	18℃＜Tout≤26℃
≤10℃								
10℃＜Ti≤20℃		2050	2108	1881	1907	1883	2038	1734
20℃＜Ti≤32℃		2311	2348	2454	2201	2187	2106	2193
32℃＜Ti≤38℃		2692	2704	2656	2617	2615	2524	2722
38℃＜Ti≤43℃		2895	2934	2868	2913	3020	2706	2989
43℃＜Ti≤48℃		3177	3219	3067	3257	3242	2946	3231
48℃＜Ti≤53℃		3290	3250	3296	3257	3189	3070	3302
53℃<Ti		3259	3236	3320	3271	3245	3105	3149

Heating Capacity (W)

Outdoor Temp. Water Inlet Temp.	-22℃<Tout	-22℃<Tout≤-15℃	-15℃<Tout≤-9℃	-9℃<Tout≤-3℃	-3℃<Tout≤4℃	4℃＜Tout≤11℃	11℃＜Tout≤18℃	18℃＜Tout≤26℃
≤10℃								
10℃＜Ti≤20℃		5809	6860	7200	8290	9824	12657	13351
20℃＜Ti≤32℃		5615	6756	7509	8372	9891	11240	12609
32℃＜Ti≤38℃		5404	6603	7160	8343	9726	10189	12098
38℃＜Ti≤43℃		5501	6633	6993	8220	9786	9861	11905
43℃＜Ti≤48℃		5529	6658	6843	8069	9443	9360	11420
48℃＜Ti≤53℃		5245	6027	6652	7081	8279	8454	10311
53℃<Ti		4544	5240	5668	6284	7306	7718	8817

COP (W/W)

Outdoor Temp. Water Inlet Temp.	-22℃<Tout	-22℃<Tout≤-15℃	-15℃<Tout≤-9℃	-9℃<Tout≤-3℃	-3℃<Tout≤4℃	4℃＜Tout≤11℃	11℃＜Tout≤18℃	18℃＜Tout≤26℃
≤10℃								
10℃＜Ti≤20℃		2.83	3.25	3.82	4.35	5.20	6.21	7.66
20℃＜Ti≤32℃		2.43	2.88	3.06	3.82	4.52	5.34	5.75
32℃＜Ti≤38℃		2.01	2.44	2.69	3.19	3.72	4.04	4.44
38℃＜Ti≤43℃		1.90	2.26	2.44	2.82	3.24	3.64	3.99
43℃＜Ti≤48℃		1.74	2.07	2.24	2.48	2.91	3.18	3.54
48℃＜Ti≤53℃		1.59	1.85	2.02	2.17	2.6	2.75	3.14
53℃<Ti		1.40	1.62	1.70	1.92	2.25	2.49	2.81

ARCTIC HEAT PUMPS

ARCTIC 040A

Power Input (W)

Outdoor Temp.	-22℃<Tout	-22℃<Tout≤-15℃	-15℃<Tout≤-9℃	-9℃<Tout≤-3℃	-3℃<Tout≤4℃	4℃<Tout≤11℃	11℃<Tout≤18℃	18℃<Tout≤26℃	26℃<Tout≤35℃	Tout>35℃
Water Inlet Temp.										
≤10℃										
10℃<Ti≤20℃			2989	2965	2879	2844	2768	2787	2510	2431
20℃<Ti≤32℃			3358	3355	3117	3260	3093	3338	3183	3186
32℃<Ti≤38℃		4082	3975	3941	3788	3706	3769	3876	3941	4077
38℃<Ti≤43℃		4322	4282	4243	4187	4225	4017	4250	4295	4585
43℃<Ti≤48℃		4683	4697	4637	4616	4694	4304	4600	4729	4521
48℃<Ti≤53℃		5012	4870	4956	4678	4708	4721	4684	4701	4561
53℃<Ti		4932	4973	4845	4909	4759	4741	4185	4300	4409

Heating Capacity (W)

Outdoor Temp.	-22℃<Tout	-22℃<Tout≤-15℃	-15℃<Tout≤-9℃	-9℃<Tout≤-3℃	-3℃<Tout≤4℃	4℃<Tout≤11℃	11℃<Tout≤18℃	18℃<Tout≤26℃	26℃<Tout≤35℃	Tout>35℃
Water Inlet Temp.										
≤10℃										
10℃<Ti≤20℃			9482	10782	11204	13750	17330	19719	21159	23807
20℃<Ti≤32℃			9528	11041	11549	13882	16617	19664	22801	24968
32℃<Ti≤38℃		8098	9560	10786	11898	13785	15604	18571	21760	25701
38℃<Ti≤43℃		8265	9337	10430	11533	13534	14404	17655	20988	25041
43℃<Ti≤48℃		8342	9621	10225	11607	13328	13405	16752	20063	22870
48℃<Ti≤53℃		7988	9248	9647	9937	11526	13126	15422	16931	19728
53℃<Ti		6657	7336	8087	9079	9860	11780	11195	13502	16051

COP (W/W)

Outdoor Temp.	-22℃<Tout	-22℃<Tout≤-15℃	-15℃<Tout≤-9℃	-9℃<Tout≤-3℃	-3℃<Tout≤4℃	4℃<Tout≤11℃	11℃<Tout≤18℃	18℃<Tout≤26℃	26℃<Tout≤35℃	Tout>35℃
Water Inlet Temp.										
≤10℃										
10℃<Ti≤20℃			3.17	3.61	3.89	4.84	6.26	7.06	8.45	9.79
20℃<Ti≤32℃			2.84	3.29	3.71	4.26	5.38	5.89	7.18	7.84
32℃<Ti≤38℃		1.99	2.4	2.75	3.14	3.72	4.14	4.79	5.52	6.3
38℃<Ti≤43℃		1.91	2.18	2.46	2.75	3.2	3.58	4.16	4.89	5.46
43℃<Ti≤48℃		1.78	2.05	2.22	2.49	2.85	3.12	3.64	4.23	5.06
48℃<Ti≤53℃		1.59	1.9	1.95	2.12	2.45	2.78	3.3	3.6	4.32
53℃<Ti		1.35	1.48	1.67	1.84	2.07	2.48	2.67	3.14	3.64

ARCTIC 060A

Power Input (W)

Outdoor Temp. Water Inlet Temp.	-22℃<Tout	-22℃<Tout≤-15℃	-15℃<Tout≤-9℃	-9℃<Tout≤- 3℃	-3℃<Tout≤4℃	4℃<Tout≤11℃	11℃<Tout≤18℃	18℃<Tout≤26℃
≤10℃								
10℃<Ti≤20℃		3593	3512	3604	3555	3452	2768	2787
20℃<Ti≤32℃		4044	4013	4149	4091	3982	3093	3338
32℃<Ti≤38℃		4845	4767	4677	4858	4516	3769	3876
38℃<Ti≤43℃		5095	5179	5028	5108	5153	4017	4250
43℃<Ti≤48℃		5575	5566	5234	5626	5776	4304	4600
48℃<Ti≤53℃		5738	5807	5436	5710	5788	4721	4684
53℃<Ti		5779	5734	5779	5646	5675	4741	4185

Heating Capacity (W)

Outdoor Temp. Water Inlet Temp.	-22℃<Tout	-22℃<Tout≤-15℃	-15℃<Tout≤-9℃	-9℃<Tout≤- 3℃	-3℃<Tout≤4℃	4℃<Tout≤11℃	11℃<Tout≤18℃	18℃<Tout≤26℃
≤10℃								
10℃<Ti≤20℃		10088	11878	13083	15011	17064	17330	19719
20℃<Ti≤32℃		9954	11737	13017	15016	17055	16617	19664
32℃<Ti≤38℃		10001	11752	12933	15389	16696	15604	18571
38℃<Ti≤43℃		9834	11759	13003	14520	16853	14404	17655
43℃<Ti≤48℃		9667	11527	12166	14561	16651	13405	16752
48℃<Ti≤53℃		9227	10592	11355	13308	14309	13126	15422
53℃<Ti		8480	9499	10056	11092	12175	11780	11195

COP (W/W)

Outdoor Temp. Water Inlet Temp.	-22℃<Tout	-22℃<Tout≤-15℃	-15℃<Tout≤-9℃	-9℃<Tout≤- 3℃	-3℃<Tout≤4℃	4℃<Tout≤11℃	11℃<Tout≤18℃	18℃<Tout≤26℃
≤10℃								
10℃<Ti≤20℃		2.81	3.38	3.62	4.22	4.92	6.26	7.06
20℃<Ti≤32℃		2.46	2.92	3.14	3.7	4.28	5.38	5.89
32℃<Ti≤38℃		2.07	2.46	2.77	3.17	3.69	4.14	4.79
38℃<Ti≤43℃		1.93	2.26	2.59	2.84	3.27	3.58	4.16
43℃<Ti≤48℃		1.74	2.07	2.32	2.59	2.88	3.12	3.64
48℃<Ti≤53℃		1.62	1.82	2.09	2.33	2.47	2.78	3.3
53℃<Ti		1.47	1.65	1.74	1.96	2.15	2.48	2.67

ARCTIC HEAT PUMPS

C.2 Parametric Runs Program (Scenario 3)

```
%% Preparation
clear all
% TRNSYS Exe path
trnExePath = 'C:\Trnsys18\Exe\TRNExe64.exe';
% Root (project) directory
rootDir = 'C:\Users\r_dumo\Dropbox\TRNSYS_docs\MyProjects\Solar Air-
source\Air_distribution\';
% Input (dck) template file

dckTemplateFilePath = [rootDir
'2019.03.09SDHouse_with_air_distribution_singleThermostat_ASHP_Scenario3.dck'
];
% Building (bui) template file
buiTemplateFilePath = ["C:\Users\r_dumo\Dropbox\TRNSYS_docs\MyProjects\Solar
Air-source\Novoclimat building\'Building_file_Novoclimat.b18"];
% Directory for intermediate files
parDir = [rootDir 'Sc3ParamRuns\'];
% Create the directory if it does not exist yet
if(~exist(parDir, 'dir'))
    mkdir(parDir);
end

% Read in dck and b18 templates as arrays of strings
dckTemplate = fileread(dckTemplateFilePath);
dckTemplate = splitlines(string(dckTemplate));
buiTemplate = fileread(buiTemplateFilePath);
buiTemplate = splitlines(string(buiTemplate));

%% Parameters and runs

Storage_Type_File={ 'C:\Users\r_dumo\Dropbox\TRNSYS_docs\MyProjects\Solar
Air-source\Air_distribution\Tank\SmallTank_parameters.txt'
                    'C:\Users\r_dumo\Dropbox\TRNSYS_docs\MyProjects\Solar
Air-source\Air_distribution\Tank\MediumTank_parameters.txt'
                    'C:\Users\r_dumo\Dropbox\TRNSYS_docs\MyProjects\Solar
Air-source\Air_distribution\Tank\LargeTank_parameters.txt'
                    'C:\Users\r_dumo\Dropbox\TRNSYS_docs\MyProjects\Solar
Air-source\Air_distribution\Tank\BiggestTank_parameters.txt'};

Storage_Type={'SmallTank\' 'MediumTank\' 'LargeTank\' 'BiggestTank\'};
nb_storages=4; % Number of storage tank sizes

% Heat Pump Characteristics

    %Source flow rate
    Sourcepumpflow=[1400 1400 2600];
    Sourcepumppower=[631 631 820];
%     %BIPVT air flow rate
%     BIPVTFlow=[324 650 650];
    %Rated heating capacity
    HPCapacity=[29592 41400 52200];
    %Rated compressor power
    HPPower=[10486 15054 18380];
    HP_type={'8kWHP\' '12kWHP\' '15kWHP\'};
    nb_HP=length(HPPower);
```

```
for i_storage=1:nb_storages %allocate the proper storage tank file
    %Creating sub-folders for different storage sizes

    StorageDir{i_storage} = [parDir Storage_Type{i_storage}];

        % Create the directory if it does not exist yet
        if(~exist(StorageDir{i_storage}, 'dir'))
            mkdir(StorageDir{i_storage});
        end
      for i_HP=1:nb_HP

          HPDir{i_HP} = [StorageDir{i_storage} HP_type{i_HP}];

        % Create the directory if it does not exist yet
        if(~exist( HPDir{i_HP}, 'dir'))
            mkdir( HPDir{i_HP});
        end
    % Write dck file for each case


    % Replace variable code with values in dck
    dck = strrep(dckTemplate, 'Outputfile', 'Outputfile');
    dck = strrep(dck,  "C:\Users\r_dumo\Dropbox\TRNSYS_docs\MyProjects\Solar
Air-source\Air_distribution\Tank\LargeTank_parameters.txt",
Storage_Type_File{i_storage});
%     dck = strrep(dck, '324', sprintf('%02d',BIPVTFlow(i_HP)));
    dck = strrep(dck, '1400', sprintf('%02d',Sourcepumpflow(i_HP)));
    dck = strrep(dck, '631', sprintf('%02d',Sourcepumppower(i_HP)));
    dck = strrep(dck, '29592', sprintf('%02d',HPCapacity(i_HP)));
    dck = strrep(dck, '10486', sprintf('%02d',HPPower(i_HP)));

    dckFilePath{i_storage,i_HP} = [HPDir{i_HP} 'Sc3Run.dck'];

    % Write dck file
    fId = fopen(dckFilePath{i_storage,i_HP}, 'wt', 'n', 'UTF-8');
    fprintf(fId, '%s\n', dck);
    fclose(fId);

      end

end

 %% Run dck files
 for iCase = 1:nb_storages

     for i_HP=1:nb_HP


     [status, ~] = system(['"' trnExePath '" "' dckFilePath{iCase,i_HP} '" /n
/h"']);
     fprintf('Running Case %3d of %3d\n', iCase,nb_storages);
     end
 pause(1)
```

```
 end
% %
% %% Read output file and plot results
% d = readtable([parDir 'AllParamResults.out'], 'FileType', 'Text');
% hold on;
% for i = 1:nSlabThick
%     plot(d.wwr(d.winId == allSlabThick(i)), d.QTot(d.winId ==
allSlabThick(i))/1000);
% end
% legend(num2str(allSlabThick'), 'Location', 'NorthWest');
% xlabel('Window-to-wall ratio [-]');
% ylabel('Total load (QHeat + QCoool) [MWh]');
%
%
% %plot(d.slope, d.Gt/3600);
% %xlabel('slope [°]');
% %ylabel('Incident irradiation [kWh/m²-y]');
```

C.3 Parametric Runs Program (Scenario 4)

```
%% Preparation
clear all
% TRNSYS Exe path
trnExePath = 'C:\Trnsys18\Exe\TRNExe64.exe';
% Root (project) directory
rootDir = 'C:\Users\r_dumo\Dropbox\TRNSYS_docs\MyProjects\Solar Air-
source\Air_distribution\';
% Input (dck) template file

dckTemplateFilePath = [rootDir
'2019.03.09SDHouse_with_air_distribution_singleThermostat_ASHP_Scenario4.dck'
];
% Building (bui) template file
buiTemplateFilePath = ["C:\Users\r_dumo\Dropbox\TRNSYS_docs\MyProjects\Solar
Air-source\Novoclimat building\'Building_file_Novoclimat.b18"];
% Directory for intermediate files
parDir = [rootDir 'Sc4ParamRuns\'];
% Create the directory if it does not exist yet
if(~exist(parDir, 'dir'))
    mkdir(parDir);
end

% Read in dck and b18 templates as arrays of strings
dckTemplate = fileread(dckTemplateFilePath);
dckTemplate = splitlines(string(dckTemplate));
buiTemplate = fileread(buiTemplateFilePath);
buiTemplate = splitlines(string(buiTemplate));

%% Parameters and runs

Storage_Type_File={ 'C:\Users\r_dumo\Dropbox\TRNSYS_docs\MyProjects\Solar
Air-source\Air_distribution\Tank\SmallTank_parameters.txt'
                    'C:\Users\r_dumo\Dropbox\TRNSYS_docs\MyProjects\Solar
Air-source\Air_distribution\Tank\MediumTank_parameters.txt'
                    'C:\Users\r_dumo\Dropbox\TRNSYS_docs\MyProjects\Solar
Air-source\Air_distribution\Tank\LargeTank_parameters.txt'
                    'C:\Users\r_dumo\Dropbox\TRNSYS_docs\MyProjects\Solar
Air-source\Air_distribution\Tank\BiggestTank_parameters.txt'};

Storage_Type={'SmallTank\' 'MediumTank\' 'LargeTank\' 'BiggestTank\'};
nb_storages=4; % Number of storage tank sizes

% Heat Pump Characteristics

    %Source flow rate
    Sourcepumpflow=[1400 1400 2600];
    Sourcepumppower=[631 631 821];
    %BIPVT air flow rate
    BIPVTFlow=[324 650 650];
    %Rated heating capacity
    HPCapacity=[29592 41400 52200];
    %Rated compressor power
    HPPower=[10486 15054 18380];
    HP_type={'8kWHP\' '12kWHP\' '15kWHP\'};
    nb_HP=length(HPPower);
```

```
for i_storage=1:nb_storages %allocate the proper storage tank file
    %Creating sub-folders for different storage sizes

    StorageDir{i_storage} = [parDir Storage_Type{i_storage}];

        % Create the directory if it does not exist yet
        if(~exist(StorageDir{i_storage}, 'dir'))
            mkdir(StorageDir{i_storage});
        end
      for i_HP=1:nb_HP

          HPDir{i_HP} = [StorageDir{i_storage} HP_type{i_HP}];

        % Create the directory if it does not exist yet
        if(~exist( HPDir{i_HP}, 'dir'))
            mkdir( HPDir{i_HP});
        end
    % Write dck file for each case



    % Replace variable code with values in dck
    dck = strrep(dckTemplate, 'Outputfile', 'Outputfile');
    dck = strrep(dck,  "C:\Users\r_dumo\Dropbox\TRNSYS_docs\MyProjects\Solar
Air-source\Air_distribution\Tank\LargeTank_parameters.txt",
Storage_Type_File{i_storage});
    dck = strrep(dck, '324', sprintf('%02d',BIPVTFlow(i_HP)));
    dck = strrep(dck, '1400', sprintf('%02d',Sourcepumpflow(i_HP)));
    dck = strrep(dck, '631', sprintf('%02d',Sourcepumppower(i_HP)));
    dck = strrep(dck, '29592', sprintf('%02d',HPCapacity(i_HP)));
    dck = strrep(dck, '10486', sprintf('%02d',HPPower(i_HP)));

    dckFilePath{i_storage,i_HP} = [HPDir{i_HP} 'Sc4Run.dck'];

    % Write dck file
    fId = fopen(dckFilePath{i_storage,i_HP}, 'wt', 'n', 'UTF-8');
    fprintf(fId, '%s\n', dck);
    fclose(fId);

      end

end

 %% Run dck files
 for iCase = 1:nb_storages

     for i_HP=1:nb_HP
     [status, ~] = system(['"' trnExePath '" "' dckFilePath{iCase,i_HP} '" /n
/h"']);
     fprintf('Running Case %3d of %3d\n', iCase,nb_storages);
     end

 end
%
```

```
% %% Read output file and plot results
% d = readtable([parDir 'AllParamResults.out'], 'FileType', 'Text');
% hold on;
% for i = 1:nSlabThick
%     plot(d.wwr(d.winId == allSlabThick(i)), d.QTot(d.winId ==
allSlabThick(i))/1000);
% end
% legend(num2str(allSlabThick'), 'Location', 'NorthWest');
% xlabel('Window-to-wall ratio [-]');
% ylabel('Total load (QHeat + QCoool) [MWh]');
%
%
% %plot(d.slope, d.Gt/3600);
% %xlabel('slope [°]');
% %ylabel('Incident irradiation [kWh/m²-y]');
```

C.4 Matlab Results Processing Program

```
close all
clear all
nb_storages=4; % Number of storage tank sizes
nb_HP=3; % Number of heat pumps

% Root (project) directory
rootDir = 'C:\Users\r_dumo\Dropbox\TRNSYS_docs\MyProjects\Solar Air-
source\Air_distribution\';
% Directory for intermediate files

Storage_Type={'SmallTank\' 'MediumTank\' 'LargeTank\' 'BiggestTank\'};
HP_type={'8kWHP\' '12kWHP\' '15kWHP\'};


%Scenario1 results
Results{1}=readtable([rootDir 'Sc1Outputfile'], 'Filetype', 'Text');
%Scenario2 results
Results{2}=readtable([rootDir 'Sc2Outputfile'], 'Filetype', 'Text');
%Scenario3 results
k=2;
parDir = [rootDir 'Sc3ParamRuns\'];
for i_storage=1:nb_storages %allocate the proper storage tank file
    %Creating sub-folders for different storage sizes

    StorageDir{i_storage} = [parDir Storage_Type{i_storage}];

      for i_HP=1:nb_HP
        k=k+1;
          HPDir{i_HP} = [StorageDir{i_storage} HP_type{i_HP}];

       Results{k} = readtable([HPDir{i_HP} 'Outputfile'], 'Filetype',
'Text');

      end

end
%Scenario4 results
parDir = [rootDir 'Sc4ParamRuns\'];

for i_storage=1:nb_storages %allocate the proper storage tank file
    %Creating sub-folders for different storage sizes

    StorageDir{i_storage} = [parDir Storage_Type{i_storage}];

      for i_HP=1:nb_HP
        k=k+1;
          HPDir{i_HP} = [StorageDir{i_storage} HP_type{i_HP}];

       Results{k} = readtable([HPDir{i_HP} 'Outputfile'], 'Filetype',
'Text');

      end

end
```

```
for i=1:length(Results)
Results{i}.Properties.VariableNames={'Time' 'HPPowerW' 'FansPowerW'
'PumpsPowerW' 'OccupantsPowerW' 'DHWPowerW' 'BIPVPowerW' 'BIPVTPowerW'
'GridState' 'TESSOC' 'HeatDeliveredHPW' 'HeatDeliveredAHUW' 'TotalPowerProdW'
'TotalPowerConsumptionW' 'Zonetemp' 'MinProdCons' 'SupplyCoverFactor'
'DemandCoverFactor' 'HVACPowerW' 'Test' 'Test1' 'Test2' };
Results{i}{:,16}=min(Results{i}{:,14},Results{i}{:,13});
Results{i}{:,17}=Results{i}{:,16}./ (Results{i}{:,13}+0.00001);% supply cover
factor
Results{i}{:,18}=Results{i}{:,16}./ (Results{i}{:,14}+0.00001);% demand cover
factor
Results{i}{:,19}=Results{i}{:,2}+Results{i}{:,3}+Results{i}{:,4}; % HVAC
energy consumption (W)
Results{i}{:,20}=-Results{i}{:,14}+Results{i}{:,13}; % Net energy consumption
(W) (positive = selling)

gridbuying{i,1}=find(Results{i}{:,9}==1);
gridnormal{i,1}=find(Results{i}{:,9}==0);
gridselling{i,1}=find(Results{i}{:,9}==-1);


   Buying{i,1}=Results{i}(gridbuying{i,1},:);



   Normal{i,1}=Results{i}(gridnormal{i,1},:);


   Selling{i,1}=Results{i}(gridselling{i,1},:);


  Resultsfilename{i}=['Results' num2str(i) '.csv'];
  Buyingfilename{i}=['BuyingOpportunityResults' num2str(i) '.csv'];
  Normalfilename{i}=['NormalOperationResults' num2str(i) '.csv'];
  Sellingfilename{i}=['SellingOpportunityResults' num2str(i) '.csv'];
%
%   writetable(Results{i}, Resultsfilename{i});
%   writetable(Buying{i,1}, Buyingfilename{i});
%   writetable(Normal{i,1}, Normalfilename{i});
%   writetable(Selling{i,1}, Sellingfilename{i});

end


 for i=1:length(Results)
Summarybuying(1,i)=sum(Buying{i}{:,14})*0.1/1000; %Energy consumption (kWh)
Summarybuying(2,i)=sum(Buying{i}{:,19})*0.1/1000; %HVAC Energy consumption
(kWh)
Summarybuying(3,i)=sum(Buying{i}{:,5})*0.1/1000;  %Occupants Energy
consumption (kWh)
Summarybuying(4,i)=sum(Buying{i}{:,6})*0.1/1000;  %DHW Energy consumption
(kWh)
Summarybuying(5,i)=sum(Buying{i}{:,13})*0.1/1000; %Energy production (kWh)
```

```
Summarybuying(6,i)=sum(Buying{i}{:,16})*0.1/1000/(sum(Buying{i}{:,13})*0.1/10
00+0.0001); % overall supply cover factor
Summarybuying(7,i)=sum(Buying{i}{:,16})*0.1/1000/(sum(Buying{i}{:,14})*0.1/10
00+0.0001); % overall supply cover factor
Summarybuying(8,i)=sum(Buying{i}{:,20})*0.1/1000; % Net energy consumption
(kWh)

% Summarybuying(5,i)=sum(Buying{i}{:,11})*0.1/1000; % SAASHP heat delivered
(kWh)
% Summarybuying(6,i)=sum(Buying{i}{:,12})*0.1/1000; % AHU heat delivered
(kWh)
% Summarybuying(7,i)=Summarybuying(6,i)/Summarybuying(5,i); % RTE

Summaryselling(1,i)=sum(Selling{i}{:,14})*0.1/1000; %Energy consumption (kWh)
Summaryselling(2,i)=sum(Selling{i}{:,19})*0.1/1000; %HVAC Energy consumption
(kWh)
Summaryselling(3,i)=sum(Selling{i}{:,5})*0.1/1000;  %Occupants Energy
consumption (kWh)
Summaryselling(4,i)=sum(Selling{i}{:,6})*0.1/1000;  %DHW Energy consumption
(kWh)
Summaryselling(5,i)=sum(Selling{i}{:,13})*0.1/1000; %Energy production (kWh)
Summaryselling(6,i)=sum(Selling{i}{:,16})*0.1/1000/(sum(Selling{i}{:,13})*0.1
/1000+0.0001); % overall supply cover factor
Summaryselling(7,i)=sum(Selling{i}{:,16})*0.1/1000/(sum(Selling{i}{:,14})*0.1
/1000+0.0001); % overall supply cover factor
Summaryselling(8,i)=sum(Selling{i}{:,20})*0.1/1000; % Net energy consumption
(kWh)


Summarynormal(1,i)=sum(Normal{i}{:,14})*0.1/1000; %Energy consumption (kWh)
Summarynormal(2,i)=sum(Normal{i}{:,19})*0.1/1000; %HVAC Energy consumption
(kWh)
Summarynormal(3,i)=sum(Normal{i}{:,5})*0.1/1000;  %Occupants Energy
consumption (kWh)
Summarynormal(4,i)=sum(Normal{i}{:,6})*0.1/1000;  %DHW Energy consumption
(kWh)
Summarynormal(5,i)=sum(Normal{i}{:,13})*0.1/1000; %Energy production (kWh)
Summarynormal(6,i)=sum(Normal{i}{:,16})*0.1/1000/(sum(Normal{i}{:,13})*0.1/10
00+0.0001); % overall supply cover factor
Summarynormal(7,i)=sum(Normal{i}{:,16})*0.1/1000/(sum(Normal{i}{:,14})*0.1/10
00+0.0001); % overall supply cover factor
Summarynormal(8,i)=sum(Normal{i}{:,20})*0.1/1000; % Net energy consumption
(kWh)



Summary(1,i)=sum(Results{i}{:,11})*0.1/1000; % SAASHP heat delivered (kWh)
Summary(2,i)=-sum(Results{i}{:,12})*0.1/1000; % AHU heat delivered (kWh)
Summary(3,i)=Summary(2,i)/Summary(1,i);      % round-trip efficiency

 end


%% Typical winter cold sunny day
```

```
close all
Range=find(Results{1}{:,1}<=912 & Results{1}{:,1}>=888);
% Range=find(Results{1}{:,1}<=1000 & Results{1}{:,1}>=800);

figure1 = figure('PaperOrientation','landscape','PaperType','B',...
    'PaperSize',[8.5 5],...
    'Color',[1 1 1]);
   axes1 = axes('Parent',figure1,...
    'Position',[0.153237038696419 0.112121212121212 0.706100067204955
0.714791090157493]);

hold(axes1,'on');



h1 = line([Results{1}{Range(1),1},Results{1}{Range(1),1}],[-15000
15000],'HandleVisibility','off');
h2 = line([Results{1}{Range(70),1},Results{1}{Range(70),1}],[-15000
15000],'HandleVisibility','off');
h3 = line([Results{1}{Range(110),1},Results{1}{Range(110),1}],[-15000
15000],'HandleVisibility','off');
h4 = line([Results{1}{Range(170),1},Results{1}{Range(170),1}],[-15000
15000],'HandleVisibility','off');
h5 = line([Results{1}{Range(205),1},Results{1}{Range(205),1}],[-15000
15000],'HandleVisibility','off');
h6 = line([Results{1}{Range(241),1},Results{1}{Range(241),1}],[-15000
15000],'HandleVisibility','off');
% Set properties of lines
set([h1 h2 h3 h4 h5 h6],'Color','w','LineWidth',0.0001)
% Add a patch
patch([Results{1}{Range(1),1} Results{1}{Range(70),1} Results{1}{Range(70),1}
Results{1}{Range(1),1}],[-15000 -15000 15000 15000],[0.85 1 0.701
],'HandleVisibility','off')
patch([Results{1}{Range(70),1} Results{1}{Range(110),1}
Results{1}{Range(110),1} Results{1}{Range(70),1}],[-15000 -15000 15000
15000],[1 0.8 0.8],'HandleVisibility','off')
patch([Results{1}{Range(110),1} Results{1}{Range(170),1}
Results{1}{Range(170),1} Results{1}{Range(110),1}],[-15000 -15000 15000
15000],[1 0.92 0.6],'HandleVisibility','off')
patch([Results{1}{Range(170),1} Results{1}{Range(205),1}
Results{1}{Range(205),1} Results{1}{Range(170),1}],[-15000 -15000 15000
15000],[1 0.8 0.8],'HandleVisibility','off')
patch([Results{1}{Range(205),1} Results{1}{Range(241),1}
Results{1}{Range(241),1} Results{1}{Range(205),1}],[-15000 -15000 15000
15000],[0.85 1 0.701],'HandleVisibility','off')

% alpha(0.2)

%
plot(Results{1}{Range(1):Range(length(Range)),1},Results{1}{Range(1):Range(le
ngth(Range)),20});
%
plot(Results{1}{Range(1):Range(length(Range)),1},Results{1}{Range(1):Range(le
ngth(Range)),20});
for i=1:1
```

```
plot(Results{i}{Range(1):Range(length(Range)),1},Results{i}{Range(1):Range(le
ngth(Range)),20});
end

for i=24:26
plot(Results{i}{Range(1):Range(length(Range)),1},Results{i}{Range(1):Range(le
ngth(Range)),20});
end
plot(Results{i}{Range(1):Range(length(Range)),1},Results{i}{Range(1):Range(le
ngth(Range)),21}, 'color', [0 0 0]);
%
plot(Results{25}{Range(1):Range(length(Range)),1},Results{25}{Range(1):Range(
length(Range)),14});
%
plot(Results{26}{Range(1):Range(length(Range)),1},Results{26}{Range(1):Range(
length(Range)),14});
%
plot(Results{24}{Range(1):Range(length(Range)),1},Results{24}{Range(1):Range(
length(Range)),15});
%
plot(Results{25}{Range(1):Range(length(Range)),1},Results{25}{Range(1):Range(
length(Range)),15});
%
plot(Results{26}{Range(1):Range(length(Range)),1},Results{26}{Range(1):Range(
length(Range)),15});
legend
% legend1=legend('Energy Production','Energy Consumption Baseline','Energy
Consumption Alternative 24', 'Location', 'Southoutside');

legend1=legend('1','24','25', '26', 'Location', 'Southoutside');

xlim([888 912])
% xlim([816 840])
% ylim([0 15000])
% xticks([816 822 828 834 840])
xticks([888 894 900 906 912])

xticklabels({'00:00' '06:00' '12:00' '18:00' '24:00'})



% Create ylabel
ylabel({'Energy (W)'});

% Create xlabel
xlabel({'Time of Day'});
% ylim([0 100])
% % Create legend
% legend1=legend('Reference SOC','Tavg SOC (2 temperature readings)','Tavg
SOC (3 temperature readings)','Tsupply SOC','Combined Tavg and Tsupply SOC (3
sensors)',...
%                  'Combined Tavg and Tsupply SOC (2 sensors)');
%
% set(legend1,'Position',[0.648628792524849 0.529581533871257
0.196443002649922 0.130303026690628]);
%
```

```
% % Create ylabel
% ylabel('State of Charge (%)');
%
% % Create xlabel
% xlabel('Time (h)');





print('-fillpage','BestFitFigure','-dpdf')











% for j=1:length(gridnormal{i,1})
%
%
%
% end
% for j=1:length(gridselling{i,1})
%
%
%
% end


% gridbuying{i,1}{2}=Results{i}(gridbuying{i,1}(:,1),14);
% gridnormal{i,1}{2}=Results{i}(gridnormal{i,1}(:,1),14);
% gridselling{i,1}=Results{i}(gridselling{i,1}(:,1),14);

%   r = varfun(@sum, test2{i}(:,1));
%
% results(1,i)=r;
%
%   r = varfun(@sum, test3{i}(:,1));
%
% results(2,i)=r;
%
%   r = varfun(@sum, test4{i}(:,1));
%
% results(3,i)=r;
%
% results(4,i)=varfun(@sum, results(1:3,i));
% results(5,i)=varfun(@sum, Results{i}(:,14));
% percentcontribution(1,i)=results{1,i}/results{4,i}*100;
% percentcontribution(2,i)=results{2,i}/results{4,i}*100;
% percentcontribution(3,i)=results{3,i}/results{4,i}*100;
% percentcontribution(4,i)=sum(percentcontribution(1:3,i));
```

```
%    for k=1:height(Buying{1,1})
%
%
%    Buying{i,1}{k,15}=(min(Buying{i,1}{k,14},Buying{i,1}{k,13})); %minimum
between timestep production and consumption (to be used in supply and demand
cover factors)
%    Buying{i,1}{k,16}=(Buying{i,1}{k,15}./ (Buying{i,1}{k,13}+0.00001));%
supply cover factor
%    Buying{i,1}{k,17}=((Buying{i,1}{k,15})./ (Buying{i,1}{k,14}+0.00001));%
demand cover factor
%    Buying{i,1}{k,18}=sum(Buying{i,1}{k,2:4});% HVAC energy consumption W
%    end
```

```
%
% figure
% %Plot something
% plot(1:1)
% % Add lines
% h1 = line([0 0],[0 24]);
% h2 = line([7 7],[0 24]);
% h3 = line([11 11],[0 24]);
% h4 = line([17 17],[0 24]);
% h5 = line([20.5 20.5],[0 24]);
% h6 = line([24 24],[0 24]);
% % Set properties of lines
% set([h1 h2 h3 h4 h5 h6],'Color','k','LineWidth',0.0001)
% % Add a patch
% patch([0 7 7 0],[0 0 24 24],[0.364705890417099 0.776470601558685
0.364705890417099])
% patch([7 11 11 7],[0 0 24 24],[0.850980401039124 0.352941185235977
0.352941185235977])
% patch([11 17 17 11],[0 0 24 24],[0.929411768913269 0.768627464771271
0.396078437566757])
% patch([17 20.5 20.5 17],[0 0 24 24],[0.850980401039124 0.352941185235977
0.352941185235977])
% patch([20.5 24 24 20.5],[0 0 24 24],[0.364705890417099 0.776470601558685
0.364705890417099])
% % The order of the "children" of the plot determines which one appears on
top.
% % I need to flip it here.
% ylim([0,24]);
% xlim([0,24]);
% xticks([0 7 11 17 20.5 24]);
% set(gca,'children',flipud(get(gca,'children')))
```

APPENDIX D

TRNSYS FILES

D.1 Trnsys Building File

```
*********************************************************************************
*  TRNBuild   3.0.285
*********************************************************************************
*   BUILDING DESCRIPTIONS FILE TRNSYS
*   FOR BUILDING:   C:\Users\r_dumo\Dropbox\TRNSYS_docs\MyProjects\Solar
Air-source\Novoclimat building\'Building_file_Novoclimat.b18
*   GET BY WORKING WITH TRNBuild 1.0 for Windows
*********************************************************************************
*
*--------------------------------------------------------------------------------
*  C o m m e n t s
*--------------------------------------------------------------------------------
*#C Originally created by TRNSIDF Version 1.78
*--------------------------------------------------------------------------------
*  P r o j e c t
*--------------------------------------------------------------------------------
*+++ PROJECT
*+++ TITLE=UNDEFINED
*+++ DESCRIPTION=UNDEFINED
*+++ CREATED=UNDEFINED
*+++ ADDRESS=UNDEFINED
*+++ CITY=UNDEFINED
*+++ SWITCH=UNDEFINED
*--------------------------------------------------------------------------------
*  P r o p e r t i e s
*--------------------------------------------------------------------------------
PROPERTIES
 DENSITY=1.204 : CAPACITY=1.012 : PRESSURE=101325.000 : HVAPOR=2454.0 :
SIGMA=2.041e-007 : RTEMP=293.15
*--- convective heat transfer coefficient calculation ---------------------
 KFLOORUP=7.2 : EFLOORUP=0.31 : KFLOORDOWN=3.888 : EFLOORDOWN=0.31
 KCEILUP=7.2 : ECEILUP=0.31 : KCEILDOWN=3.888 : ECEILDOWN=0.31
 KVERTICAL=5.76 : EVERTICAL=0.3
*--- radiance parameters -------------------
 SCENE_ROTATION_ANGLE=0 : GROUND_IDS= : GROUND_REFLECTANCE=0.2 :
SHADER_REFLECTANCE=0
 CALC_MODE=RAD : LATITUDE=48 : LONGITUDE=-9.2 : TIME_ZONE=-15 : SITE_ELEVATION=200
 AB=5 : AD=1000 : AS=20 : AR=300 : AA=0.1
 LR=6 : ST=0.15 : SJ=1 : LW=0.004 : DJ=0 : DS=0.2 : DR=2 : DP=512
*--- comfort parameters -------------------
 DIAM-SENSOR=0.07 : EPS-SENSOR=0.82 : REFL-SENSOR=0.47 : ELV_AIRSPEED1=0.3 :
ELV_AIRSPEED2=0.7 : ELV_AIRSPEED3=1.2
*--- other -------------------
 FSCAL_TREGENZA=MEDIUM : SHM_MODE=0 : SURFGRID=0.2
*--- daylight  -------------------
 UDIMIN=100 : UDIMAX=2000 : DAMIN=300
*
*++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
TYPES
*++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
*
*--------------------------------------------------------------------------------
*  L a y e r s
*--------------------------------------------------------------------------------
LAYER PUTZ
 CONDUCTIVITY=   2.52 : CAPACITY=      1 : DENSITY=   1400 : PERT=      0 : PENRT=
   0
LAYER KST
 CONDUCTIVITY=  3.564 : CAPACITY=      1 : DENSITY=   1600 : PERT=      0 : PENRT=
   0
LAYER DAEMA
 CONDUCTIVITY=  0.173 : CAPACITY=      1 : DENSITY=     60 : PERT=      0 : PENRT=
   0
```

```
LAYER GIPS
 CONDUCTIVITY=  0.756 : CAPACITY=      1 : DENSITY=    900 : PERT=      0 : PENRT=
   0
LAYER HOLZ
 CONDUCTIVITY=  0.468 : CAPACITY=    2.1 : DENSITY=    600 : PERT=      0 : PENRT=
   0
LAYER BET
 CONDUCTIVITY=   7.56 : CAPACITY=      1 : DENSITY=   2200 : PERT=      0 : PENRT=
   0
LAYER TEPP
 CONDUCTIVITY=  0.288 : CAPACITY=    1.3 : DENSITY=    700 : PERT=      0 : PENRT=
   0
LAYER ESTR
 CONDUCTIVITY=   5.04 : CAPACITY=      1 : DENSITY=   2000 : PERT=      0 : PENRT=
   0
LAYER MIWO
 CONDUCTIVITY=  0.144 : CAPACITY=      1 : DENSITY=     60 : PERT=      0 : PENRT=
   0
LAYER DAEMM
 CONDUCTIVITY=  0.144 : CAPACITY=      1 : DENSITY=     60 : PERT=      0 : PENRT=
   0
LAYER GYMSUM
 CONDUCTIVITY=  0.468 : CAPACITY=      1 : DENSITY=    900 : PERT=      0 : PENRT=
   0
LAYER OSB
 CONDUCTIVITY=  0.468 : CAPACITY=   1.03 : DENSITY=    500 : PERT=      0 : PENRT=
   0
LAYER COMFORTBATTLOAD
 CONDUCTIVITY= 0.1296 : CAPACITY= 1.0516 : DENSITY=  69.44 : PERT=      0 : PENRT=
   0
LAYER ZIP
 CONDUCTIVITY= 0.3744 : CAPACITY=   1.03 : DENSITY=    500 : PERT=      0 : PENRT=
   0
LAYER COMFORTBATTFLANGE
 CONDUCTIVITY= 0.1296 : CAPACITY= 1.0516 : DENSITY=  69.44 : PERT=      0 : PENRT=
   0
LAYER COMFORTBATTWEB
 CONDUCTIVITY= 0.1296 : CAPACITY= 1.0354 : DENSITY=  41.36 : PERT=      0 : PENRT=
   0
LAYER COMFORTBATT
 CONDUCTIVITY=   0.13 : CAPACITY=    0.9 : DENSITY=     80 : PERT=      0 : PENRT=
   0
LAYER CONCRETE
 CONDUCTIVITY=      4 : CAPACITY=      1 : DENSITY=   1400 : PERT=      0 : PENRT=
   0
LAYER PLYWOOD
 CONDUCTIVITY=    0.1 : CAPACITY=    0.1 : DENSITY=    0.1 : PERT=      0 : PENRT=
   0
LAYER HORIZONTAL
 RESISTANCE=    0.047 : PERT=      0 : PENRT=      0
LAYER PERPENDICU
 RESISTANCE=    0.047 : PERT=      0 : PENRT=      0
LAYER RIMBOARD
 CONDUCTIVITY= 0.3744 : CAPACITY=   1.03 : DENSITY=    500 : PERT=      0 : PENRT=
   0
LAYER CONCRETESL
 CONDUCTIVITY=  4.068 : CAPACITY=      1 : DENSITY=   1400 : PERT=      0 : PENRT=
   0
*--------------------------------------------------------------------------------
*  I n p u t s
*--------------------------------------------------------------------------------
INPUTS TGROUND TBOUNDARY SHADE_CLOSE SHADE_OPEN MAX_ISHADE MAX_ESHADE
OccupancySchedule LightingSchedule Supply_air_temp Zone_2_airflow Zone_1_airflow
```

```
Zone_3_airflow Zone_1_ventilation HRV_supply_temp HRV_rel_h Zone_2_ventilation
Zone_3_ventilation
INPUTS_DESCRIPTION
 TGROUND : C : Ground Temperature (boundary temperature used for floors adjacent to
the ground)
 TBOUNDARY : C : Boundary Temperature (boundary temperature used for boundary
floors, walls, ceilings)
 SHADE_CLOSE : kJ/hr.m^2 : threshold of total radiation on facade where shading
device is activated
 SHADE_OPEN : kJ/hr.m^2 : threshold of total radiation on facade where shading
device is deactivated
 MAX_ISHADE : any : max shading factor of internal shading
 MAX_ESHADE : any : max shading factor of external shading
 OccupancySchedule : any : Input
 LightingSchedule : any : Input
 Supply_air_temp : any : Input
 Zone_2_airflow : any : Input
 Zone_1_airflow : any : Input
 Zone_3_airflow : any : Input
 Zone_1_ventilation : any : Input
 HRV_supply_temp : any : Input
 HRV_rel_h : any : Input
 Zone_2_ventilation : any : Input
 Zone_3_ventilation : any : Input
*-------------------------------------------------------------------------------
*  S c h e d u l e s
*-------------------------------------------------------------------------------
SCHEDULE WORKDAY
 HOURS =0.000 8.000 18.000 24.0
 VALUES=0 1. 0 0
SCHEDULE WEEKEND
 HOURS =0.000 1.000 24.0
 VALUES=0 0 0
SCHEDULE WORKLIGHT
 HOURS =0.000 8.000 18.000 24.0
 VALUES=0 1. 0 0
SCHEDULE DAYNIGHT
 HOURS =0.000 6.000 18.000 24.0
 VALUES=0 1. 0 0
SCHEDULE USE
 DAYS=1 2 3 4 5 6 7
 HOURLY=WORKDAY WORKDAY WORKDAY WORKDAY WORKDAY WEEKEND WEEKEND
SCHEDULE LIGHT
 DAYS=1 2 3 4 5 6 7
 HOURLY=WORKLIGHT WORKLIGHT WORKLIGHT WORKLIGHT WORKLIGHT WEEKEND WEEKEND
SCHEDULE SETOFF
 DAYS=1 2 3 4 5 6 7
 HOURLY=DAYNIGHT DAYNIGHT DAYNIGHT DAYNIGHT DAYNIGHT WEEKEND WEEKEND
*-------------------------------------------------------------------------------
*  C O N S T R U C T I O N (Wall, Floor, Ceiling,..)
*-------------------------------------------------------------------------------
CONSTRUCTION EXT_WALL
 LAYERS    = PUTZ  KST   DAEMA HOLZ
 THICKNESS= 0.015 0.08  0.08  0.02
 ABS-FRONT= 0.9   : ABS-BACK= 0.5
 EPS-FRONT= 0.9   : EPS-BACK= 0.9
 HFRONT   = VERTICAL : HBACK= 11
CONSTRUCTION EXT_ROOF
 LAYERS    = PUTZ  BET   DAEMM HOLZ
 THICKNESS= 0.015 0.16  0.15  0.02
 ABS-FRONT= 0.1   : ABS-BACK= 0.5
 EPS-FRONT= 0.9   : EPS-BACK= 0.9
 HFRONT   = CEILING : HBACK= 11
```

```
CONSTRUCTION EXT_FLOOR
 LAYERS    = TEPP  ESTR  MIWO  BET   DAEMA
 THICKNESS= 0.005 0.05  0.03  0.16  0.08
 ABS-FRONT= 0.8   : ABS-BACK= 0.5
 EPS-FRONT= 0.9   : EPS-BACK= 0.9
 HFRONT    = FLOOR : HBACK= 11
CONSTRUCTION BND_CEILING
 LAYERS    = PUTZ  BET   DAEMA HOLZ
 THICKNESS= 0.015 0.16  0.3   0.03
 ABS-FRONT= 0.1   : ABS-BACK= 0.5
 EPS-FRONT= 0.9   : EPS-BACK= 0.9
 HFRONT    = CEILING : HBACK= 11
CONSTRUCTION BND_FLOOR
 LAYERS    = TEPP  ESTR  MIWO  BET   DAEMA GIPS
 THICKNESS= 0.005 0.05  0.03  0.16  0.133 0.013
 ABS-FRONT= 0.8   : ABS-BACK= 0.5
 EPS-FRONT= 0.9   : EPS-BACK= 0.9
 HFRONT    = FLOOR : HBACK= 11
CONSTRUCTION GROUND_FLOOR
 LAYERS    = TEPP  ESTR  DAEMM BET
 THICKNESS= 0.005 0.05  0.121 0.2
 ABS-FRONT= 0.8   : ABS-BACK= 0.5
 EPS-FRONT= 0.9   : EPS-BACK= 0.9
 HFRONT    = FLOOR : HBACK= 11
CONSTRUCTION ADJ_WALL
 LAYERS    = GIPS  MIWO  GIPS
 THICKNESS= 0.013 0.1   0.013
 ABS-FRONT= 0.4   : ABS-BACK= 0.5
 EPS-FRONT= 0.9   : EPS-BACK= 0.9
 HFRONT    = VERTICAL : HBACK= 11
CONSTRUCTION ADJ_CEILING
 LAYERS    = PUTZ  BET   MIWO  ESTR  TEPP
 THICKNESS= 0.015 0.16  0.03  0.05  0.005
 ABS-FRONT= 0.1   : ABS-BACK= 0.5
 EPS-FRONT= 0.9   : EPS-BACK= 0.9
 HFRONT    = CEILING : HBACK= 11
CONSTRUCTION EXT1
 LAYERS    = GYMSUM OSB   COMFORTBATTLOAD ZIP   COMFORTBATTFLANGE COMFORTBATTWEB
COMFORTBATTFLANGE
 THICKNESS= 0.013  0.016 0.05            0.019 0.038             0.001
0.038
 ABS-FRONT= 0.6   : ABS-BACK= 0.7
 EPS-FRONT= 0.9   : EPS-BACK= 0.9
 HFRONT    = VERTICAL : HBACK= 11
CONSTRUCTION R1
 LAYERS    = ZIP   COMFORTBATTFLANGE COMFORTBATTWEB COMFORTBATTFLANGE ZIP
COMFORTBATTLOAD OSB
 THICKNESS= 0.013 0.038             0.05           0.038             0.013 0.14
      0.016
 ABS-FRONT= 0.6   : ABS-BACK= 0.6
 EPS-FRONT= 0.9   : EPS-BACK= 0.9
 HFRONT    = 0.9 : HBACK= 0.9
CONSTRUCTION F2
 LAYERS    = CONCRETESL OSB   HORIZONTAL OSB   PERPENDICU
 THICKNESS= 0.001      0.019 0          0.013 0
 ABS-FRONT= 0.6   : ABS-BACK= 0.6
 EPS-FRONT= 0.9   : EPS-BACK= 0.9
 HFRONT    = FLOOR : HBACK= FLOOR
CONSTRUCTION F1FF
 LAYERS    = CONCRETESL OSB   COMFORTBATTFLANGE COMFORTBATTWEB COMFORTBATTFLANGE ZIP

 THICKNESS= 0.001      0.019 0.038             0.001          0.02
0.016
```

```
 ABS-FRONT= 0.6   : ABS-BACK= 0.6
 EPS-FRONT= 0.9   : EPS-BACK= 0.9
 HFRONT   = 0.9 : HBACK= 0.9
*-------------------------------------------------------------------------------
*  W i n d o w s
*-------------------------------------------------------------------------------
WINDOW EXT_WINDOW1
 WINID=3428 : HINSIDE=11 : HOUTSIDE=64 : SLOPE=-999 : SPACID=4 : WWID=0.77 :
WHEIG=1.08 : FFRAME=0.15 : UFRAME=8.17 : ABSFRAME=0.6 : RISHADE=0 : RESHADE=0 :
REFLISHADE=0.5 : REFLOSHADE=0.5 : CCISHADE=0.5 : EPSFRAME=0.9 : EPSISHADE=0.9 :
ITSHADECLOSE=INPUT 1*SHADE_CLOSE : ITSHADEOPEN=INPUT 1*SHADE_OPEN : FLOWTOAIRNODE=1
: PERT=0 : PENRT=0 : RADMATERIAL=undefined : RADMATERIAL_SHD1=undefined
WINDOW EXT_WINDOW2
 WINID=3428 : HINSIDE=11 : HOUTSIDE=64 : SLOPE=-999 : SPACID=4 : WWID=0.77 :
WHEIG=1.08 : FFRAME=0.15 : UFRAME=8.17 : ABSFRAME=0.6 : RISHADE=0 : RESHADE=0 :
REFLISHADE=0.5 : REFLOSHADE=0.5 : CCISHADE=0.5 : EPSFRAME=0.9 : EPSISHADE=0.9 :
ITSHADECLOSE=INPUT 1*SHADE_CLOSE : ITSHADEOPEN=INPUT 1*SHADE_OPEN : FLOWTOAIRNODE=1
: PERT=0 : PENRT=0 : RADMATERIAL=undefined : RADMATERIAL_SHD1=undefined
WINDOW ADJ_WINDOW1
 WINID=3428 : HINSIDE=11 : HOUTSIDE=64 : SLOPE=-999 : SPACID=4 : WWID=0.77 :
WHEIG=1.08 : FFRAME=0.15 : UFRAME=8.17 : ABSFRAME=0.6 : RISHADE=0 : RESHADE=0 :
REFLISHADE=0.5 : REFLOSHADE=0.5 : CCISHADE=0.5 : EPSFRAME=0.9 : EPSISHADE=0.9 :
ITSHADECLOSE=INPUT 1*SHADE_CLOSE : ITSHADEOPEN=INPUT 1*SHADE_OPEN : FLOWTOAIRNODE=1
: PERT=0 : PENRT=0 : RADMATERIAL=undefined : RADMATERIAL_SHD1=undefined
WINDOW ADJ_WINDOW2
 WINID=3428 : HINSIDE=11 : HOUTSIDE=64 : SLOPE=-999 : SPACID=4 : WWID=0.77 :
WHEIG=1.08 : FFRAME=0.15 : UFRAME=8.17 : ABSFRAME=0.6 : RISHADE=0 : RESHADE=0 :
REFLISHADE=0.5 : REFLOSHADE=0.5 : CCISHADE=0.5 : EPSFRAME=0.9 : EPSISHADE=0.9 :
ITSHADECLOSE=INPUT 1*SHADE_CLOSE : ITSHADEOPEN=INPUT 1*SHADE_OPEN : FLOWTOAIRNODE=1
: PERT=0 : PENRT=0 : RADMATERIAL=undefined : RADMATERIAL_SHD1=undefined
WINDOW skylight
 WINID=3422 : HINSIDE=11 : HOUTSIDE=64 : SLOPE=-999 : SPACID=1 : WWID=0.77 :
WHEIG=1.08 : FFRAME=0.15 : UFRAME=8.17 : ABSFRAME=0.6 : RISHADE=0 : RESHADE=0 :
REFLISHADE=0.5 : REFLOSHADE=0.5 : CCISHADE=0.5 : EPSFRAME=0.9 : EPSISHADE=0.9 :
ITSHADECLOSE=648 : ITSHADEOPEN=576 : FLOWTOAIRNODE=1 : PERT=0 : PENRT=0 :
RADMATERIAL=undefined : RADMATERIAL_SHD1=undefined
*-------------------------------------------------------------------------------
*  G a i n s / L o s s e s
*-------------------------------------------------------------------------------
GAIN Occupants
 CONVECTIVE=630 : RADIATIVE=630 : HUMIDITY=0.256 : ELPOWERFRAC=0 :  ABSOLUTE :
CATEGORY=PEOPLE
GAIN Lighting
 CONVECTIVE=9 : RADIATIVE=9 : HUMIDITY=0 : ELPOWERFRAC=0 :  AREA_RELATED :
CATEGORY=LIGHTS
*-------------------------------------------------------------------------------
*  C o m f o r t
*-------------------------------------------------------------------------------
*-------------------------------------------------------------------------------
*  I n f i l t r a t i o n
*-------------------------------------------------------------------------------
INFILTRATION INFIL001
 AIRCHANGE=0.075
*-------------------------------------------------------------------------------
*  V e n t i l a t i o n
*-------------------------------------------------------------------------------
VENTILATION VENT001
 TEMPERATURE=INPUT 1*HRV_supply_temp
 AIRFLOW=INPUT 1*Zone_1_ventilation
 SPECFANPOWER=0
 SENSHR=0
 RELMINHUM=INPUT 1*HRV_rel_h
 RELMAXHUM=INPUT 1*HRV_rel_h
```

```
 CALCQAHU=0
VENTILATION Airdistributionmain
 TEMPERATURE=INPUT 1*Supply_air_temp
 AIRFLOW=INPUT 1*Zone_1_airflow
 SPECFANPOWER=0
 SENSHR=0
 RELMINHUM=OUTSIDE
 RELMAXHUM=OUTSIDE
 CALCQAHU=0
VENTILATION Airdistribution_secondary_2
 TEMPERATURE=INPUT 1*Supply_air_temp
 AIRFLOW=INPUT 1*Zone_2_airflow
 SPECFANPOWER=0
 SENSHR=0
 RELMINHUM=OUTSIDE
 RELMAXHUM=OUTSIDE
 CALCQAHU=0
VENTILATION Airdistribution_secondary_3
 TEMPERATURE=INPUT 1*Supply_air_temp
 AIRFLOW=INPUT 1*Zone_3_airflow
 SPECFANPOWER=0
 SENSHR=0
 RELMINHUM=OUTSIDE
 RELMAXHUM=OUTSIDE
 CALCQAHU=0
VENTILATION VENT002
 TEMPERATURE=INPUT 1*HRV_supply_temp
 AIRFLOW=INPUT 1*Zone_2_ventilation
 SPECFANPOWER=0
 SENSHR=0
 RELMINHUM=INPUT 1*HRV_rel_h
 RELMAXHUM=INPUT 1*HRV_rel_h
 CALCQAHU=0
VENTILATION VENT003
 TEMPERATURE=INPUT 1*HRV_supply_temp
 AIRFLOW=INPUT 1*Zone_3_ventilation
 SPECFANPOWER=0
 SENSHR=0
 RELMINHUM=INPUT 1*HRV_rel_h
 RELMAXHUM=INPUT 1*HRV_rel_h
 CALCQAHU=0
*--------------------------------------------------------------------------------
*  C o o l i n g
*--------------------------------------------------------------------------------
COOLING COOL001
 ON=22
 POWER=999999999
 HUMIDITY=60
 ELPOWERFRAC=0
 AREA_RELATED_POWER=0
*--------------------------------------------------------------------------------
*  H e a t i n g
*--------------------------------------------------------------------------------
HEATING HEAT001
 ON=22
 POWER=999999999
 HUMIDITY=0
 RRAD=0
 ELPOWERFRAC=0
 AREA_RELATED_POWER=0
*--------------------------------------------------------------------------------
*  D a y l i g h t   C o n t r o l
*--------------------------------------------------------------------------------
```

```
*
*--------------------------------------------------------------------------------
*  Z o n e s
*--------------------------------------------------------------------------------
ZONES CF1795 E348A1 C34EF2
*--------------------------------------------------------------------------------
*  O r i e n t a t i o n s
*--------------------------------------------------------------------------------
HEMISPHERE NORTHERN
ORIENTATIONS H_0_0 S_0_90 W_90_90 N_180_90 E_270_90
INTERNAL_CALCULATION H_0_0 S_0_90 W_90_90 N_180_90 E_270_90
*
*++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
BUILDING
*++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
*
*--------------------------------------------------------------------------------
*  Z o n e  CF1795  /  A i r n o d e  CF1795
*--------------------------------------------------------------------------------
ZONE CF1795
RADIATIONMODE
 BEAM=STANDARD : DIFFUSE=STANDARD : LONGWAVE=STANDARD : GEOMODE=3D_DATA : FSOLAIR=0
DAYLIGHTMODE
 DLSHADE =-1
AIRNODE CF1795
CEILING      =F2         : SURF=  1 : AREA=    17.744 : ADJACENT=E348A1 :
ADJ_SURF=15 : BACK
FLOOR        =F1FF       : SURF=  2 : AREA=    88.165 : BOUNDARY=INPUT 1*TGROUND :
GEOSURF=0.8
WALL         =EXT1       : SURF=  3 : AREA=     9.058 : EXTERNAL : ORI=W_90_90 :
FSKY=0.5 : GEOSURF=0.011337
WINDOW=EXT_WINDOW1 : SURF= 10 : AREA=     1.905 : EXTERNAL : ORI=W_90_90 : FSKY=0.5
: GEOSURF=0.002384
WINDOW=EXT_WINDOW1 : SURF= 11 : AREA=     1.115 : EXTERNAL : ORI=W_90_90 : FSKY=0.5
: GEOSURF=0.001395
WALL         =EXT1       : SURF=  4 : AREA=     7.943 : EXTERNAL : ORI=E_270_90 :
FSKY=0.5 : GEOSURF=0.009942
WINDOW=EXT_WINDOW1 : SURF= 12 : AREA=     1.905 : EXTERNAL : ORI=E_270_90 : FSKY=0.5
: GEOSURF=0.002384
WINDOW=EXT_WINDOW1 : SURF= 13 : AREA=      2.23 : EXTERNAL : ORI=E_270_90 : FSKY=0.5
: GEOSURF=0.002791
WALL         =EXT1       : SURF=  5 : AREA=    67.819 : EXTERNAL : ORI=S_0_90 :
FSKY=0.5 : GEOSURF=0.084883
WALL         =EXT1       : SURF=  6 : AREA=    67.819 : EXTERNAL : ORI=N_180_90 :
FSKY=0.5 : GEOSURF=0.084884
ROOF         =R1         : SURF=  7 : AREA=     26.57 : EXTERNAL : ORI=H_0_0 :
FSKY=1
CEILING      =F2         : SURF=  8 : AREA=    16.586 : ADJACENT=C34EF2 :
ADJ_SURF=28 : BACK
CEILING      =F2         : SURF=  9 : AREA=    14.815 : ADJACENT=C34EF2 :
ADJ_SURF=24 : BACK
 REGIME
 GAIN        = Occupants  : SCALE= 0.5 : GEOPOS= 0 : SCALE2= INPUT
1*OccupancySchedule : FRAC_REFAREA= -1
 GAIN        = Lighting   : SCALE= INPUT 1*LightingSchedule : GEOPOS= 0 : SCALE2= 1
: FRAC_REFAREA= -1
 INFILTRATION= INFIL001
 VENTILATION = VENT001
 VENTILATION = Airdistributionmain
 CAPACITANCE = 3224.72 : VOLUME= 268.727 : REFAREA= 88.165  : TINITIAL= 20      :
PHINITIAL= 50      : WCAPR= 1
*--------------------------------------------------------------------------------
*  Z o n e  E348A1  /  A i r n o d e  E348A1
```

```
*-------------------------------------------------------------------------------
ZONE E348A1
RADIATIONMODE
 BEAM=STANDARD : DIFFUSE=STANDARD : LONGWAVE=STANDARD : GEOMODE=MIXED : FSOLAIR=0
DAYLIGHTMODE
 DLSHADE =-1
AIRNODE E348A1
ROOF         =R1         : SURF= 14 : AREA=    18.532 : EXTERNAL : ORI=H_0_0 :
FSKY=1
WINDOW=skylight   : SURF= 35 : AREA=         2 : EXTERNAL : ORI=H_0_0 : FSKY=1
CEILING      =F2         : SURF= 15 : AREA=    17.744 : ADJACENT=CF1795 : ADJ_SURF=1
: FRONT
WALL         =EXT1       : SURF= 16 : AREA=     7.943 : EXTERNAL : ORI=E_270_90 :
FSKY=0.5 : GEOSURF=0.0285
WINDOW=EXT_WINDOW1 : SURF= 20 : AREA=     1.905 : EXTERNAL : ORI=E_270_90 : FSKY=0.5
: GEOSURF=0.006833
WINDOW=EXT_WINDOW1 : SURF= 21 : AREA=      2.23 : EXTERNAL : ORI=E_270_90 : FSKY=0.5
: GEOSURF=0.008
WALL         =EXT1       : SURF= 17 : AREA=    15.794 : EXTERNAL : ORI=S_0_90 :
FSKY=0.5 : GEOSURF=0.856667
WALL         =EXT1       : SURF= 18 : AREA=    15.794 : EXTERNAL : ORI=N_180_90 :
FSKY=0.5 : GEOSURF=0.056667
WALL         =EXT1       : SURF= 19 : AREA=     9.615 : EXTERNAL : ORI=W_90_90 :
FSKY=0.5 : GEOSURF=0.0345
WINDOW=EXT_WINDOW1 : SURF= 22 : AREA=     0.557 : EXTERNAL : ORI=W_90_90 : FSKY=0.5
: GEOSURF=0.002
WINDOW=EXT_WINDOW1 : SURF= 23 : AREA=     1.905 : EXTERNAL : ORI=W_90_90 : FSKY=0.5
: GEOSURF=0.006833
 REGIME
 GAIN        = Lighting   : SCALE= INPUT 1*LightingSchedule : GEOPOS= 0 : SCALE2= 1
: FRAC_REFAREA= -1
 GAIN        = Occupants  : SCALE= 0.25 : GEOPOS= 0 : SCALE2= INPUT
1*OccupancySchedule : FRAC_REFAREA= -1
 INFILTRATION= INFIL001
 VENTILATION = Airdistribution_secondary_2
 VENTILATION = VENT003
 CAPACITANCE = 818.92  : VOLUME= 68.244  : REFAREA= 0       : TINITIAL= 20      :
PHINITIAL= 50      : WCAPR= 1
*-------------------------------------------------------------------------------
*  Z o n e  C34EF2  /  A i r n o d e  C34EF2
*-------------------------------------------------------------------------------
ZONE C34EF2
RADIATIONMODE
 BEAM=STANDARD : DIFFUSE=STANDARD : LONGWAVE=STANDARD : GEOMODE=3D_DATA : FSOLAIR=0
DAYLIGHTMODE
 DLSHADE =-1
AIRNODE C34EF2
CEILING      =F2         : SURF= 24 : AREA=    14.815 : ADJACENT=CF1795 : ADJ_SURF=9
: FRONT
WALL         =EXT1       : SURF= 25 : AREA=    31.587 : EXTERNAL : ORI=S_0_90 :
FSKY=0.5 : GEOSURF=0.872341
WALL         =EXT1       : SURF= 26 : AREA=     8.981 : EXTERNAL : ORI=W_90_90 :
FSKY=0.5 : GEOSURF=0.020567
WINDOW=EXT_WINDOW1 : SURF= 31 : AREA=     0.557 : EXTERNAL : ORI=W_90_90 : FSKY=0.5
: GEOSURF=0.001277
WINDOW=EXT_WINDOW1 : SURF= 32 : AREA=     2.539 : EXTERNAL : ORI=W_90_90 : FSKY=0.5
: GEOSURF=0.005816
ROOF         =R1         : SURF= 27 : AREA=    41.063 : EXTERNAL : ORI=H_0_0 :
FSKY=1
CEILING      =F2         : SURF= 28 : AREA=    16.586 : ADJACENT=CF1795 : ADJ_SURF=8
: FRONT
WALL         =EXT1       : SURF= 29 : AREA=     6.364 : EXTERNAL : ORI=E_270_90 :
FSKY=0.5 : GEOSURF=0.014574
```

```
WINDOW=EXT_WINDOW1 : SURF= 33 : AREA=     3.809 : EXTERNAL : ORI=E_270_90 : FSKY=0.5
: GEOSURF=0.008723
WINDOW=EXT_WINDOW1 : SURF= 34 : AREA=     1.905 : EXTERNAL : ORI=E_270_90 : FSKY=0.5
: GEOSURF=0.004362
WALL          =EXT1      : SURF= 30 : AREA=    31.587 : EXTERNAL : ORI=N_180_90 :
FSKY=0.5 : GEOSURF=0.07234
 REGIME
 GAIN        = Occupants  : SCALE= 0.25 : GEOPOS= 0 : SCALE2= INPUT
1*OccupancySchedule : FRAC_REFAREA= -1
 GAIN        = Lighting   : SCALE= INPUT 1*LightingSchedule : GEOPOS= 0 : SCALE2= 1
: FRAC_REFAREA= -1
 INFILTRATION= INFIL001
 VENTILATION = Airdistribution_secondary_3
 VENTILATION = VENT003
 CAPACITANCE = 1737.52 : VOLUME= 144.793 : REFAREA= 0       : TINITIAL= 20      :
PHINITIAL= 50      : WCAPR= 1
*--------------------------------------------------------------------------------
*  O u t p u t s
*--------------------------------------------------------------------------------
OUTPUTS
 TRANSFER : TIMEBASE=1.000
 AIRNODES = CF1795
 NTYPES =   1 : TAIR - air temperature of airnode
        =  25 : TOP - obsolete use new comfort outputs (Version 16: Operative
temperature)
        =  30 : QHEAT - sensible heating demand of airnode (positive values)
        =  31 : QCOOL - sensible cooling demand of airnode (positive values)
        = 156 : QELEQUIP - Electric energy demand of "equipment" gains of airnode
[kJ/hr]
        = 155 : QELLIGHT - Electric energy demand of "lights" gains of airnode
[kJ/hr]
 AIRNODES = E348A1
 NTYPES =   1 : TAIR - air temperature of airnode
        =  25 : TOP - obsolete use new comfort outputs (Version 16: Operative
temperature)
        =  30 : QHEAT - sensible heating demand of airnode (positive values)
        =  31 : QCOOL - sensible cooling demand of airnode (positive values)
        = 156 : QELEQUIP - Electric energy demand of "equipment" gains of airnode
[kJ/hr]
        = 155 : QELLIGHT - Electric energy demand of "lights" gains of airnode
[kJ/hr]
 AIRNODES = C34EF2
 NTYPES =   1 : TAIR - air temperature of airnode
        =  25 : TOP - obsolete use new comfort outputs (Version 16: Operative
temperature)
        =  30 : QHEAT - sensible heating demand of airnode (positive values)
        =  31 : QCOOL - sensible cooling demand of airnode (positive values)
        = 156 : QELEQUIP - Electric energy demand of "equipment" gains of airnode
[kJ/hr]
        = 155 : QELLIGHT - Electric energy demand of "lights" gains of airnode
[kJ/hr]
 AIRNODES = CF1795 E348A1 C34EF2
 NTYPES =   2 : QSENS - sensible energy demand of airnode, heating(-), cooling(+)
 AIRNODES = CF1795
 NTYPES = 116 : SURF = 4,  : IT - Incident total radiation on outside of external
surfaces (no shading effects)     [kJ/hr]
 AIRNODES = CF1795
 NTYPES = 116 : SURF = 5,  : IT - Incident total radiation on outside of external
surfaces (no shading effects)     [kJ/hr]
 AIRNODES = CF1795
 NTYPES = 116 : SURF = 3, 6,  : IT - Incident total radiation on outside of external
surfaces (no shading effects)     [kJ/hr]
 AIRNODES = CF1795
```

```
 NTYPES = 114 : SURF = 3, 4, 5, 6,  : IB - Incident direct radiation on outside of
external surfaces (no shading effects)    [kJ/hr]
 AIRNODES = CF1795 E348A1 C34EF2
 NTYPES =  10 : QLATD - latent energy demand of airnode, humidification(-),
dehumidifcation (+)
 AIRNODES = CF1795 E348A1 C34EF2
 NTYPES = 118 : VOLUME - Airnode volume    [m³]
 AIRNODES = CF1795
 NTYPES =  29 : ABSHUM - absolute humidity of airnode air
        =   9 : RELHUM - relativ humidity of airnode air
 AIRNODES = E348A1 C34EF2
 NTYPES =   9 : RELHUM - relativ humidity of airnode air
*--------------------------------------------------------------------------------
*  E n d
*--------------------------------------------------------------------------------
END

_EXTENSION_WINPOOL_START_
BERKELEY LAB WINDOW v7.4.6.0  DOE-2 Data File : Multi Band Calculation : generated
with Trnsys18.std
Unit System : SI
Name        : DOE-2 WINDOW LIB
Desc        : 2-WSV_#3_Ar90
Window ID   : 201
Tilt        : 90.0
Glazings    : 2
Frame       :  3 Wood                  2.270
Spacer      :  2 Class2                0.068   1.550  -0.143
Total Height: 1500.0 mm
Total Width : 1200.0 mm
Glass Height: 1360.3 mm
Glass Width : 1060.3 mm
Mullion     : None
Gap        Thick    Cond  dCond    Vis   dVis   Dens   dDens     Pr     dPr
1 Ar90/Air1 16.0 0.01712  5.410  2.062  6.300  1.711 -0.0060  0.687 -0.0001
2              0       0      0      0      0      0       0      0       0
3              0       0      0      0      0      0       0      0       0
4              0       0      0      0      0      0       0      0       0
5              0       0      0      0      0      0       0      0       0
Angle     0    10    20    30    40    50    60    70    80    90 Hemis
Tsol  0.504 0.507 0.499 0.489 0.475 0.449 0.392 0.284 0.130 0.000 0.418
Abs1  0.171 0.172 0.174 0.178 0.184 0.191 0.197 0.199 0.184 0.000 0.185
Abs2  0.094 0.095 0.103 0.108 0.109 0.112 0.121 0.125 0.086 0.000 0.109
Abs3      0     0     0     0     0     0     0     0     0     0     0
Abs4      0     0     0     0     0     0     0     0     0     0     0
Abs5      0     0     0     0     0     0     0     0     0     0     0
Abs6      0     0     0     0     0     0     0     0     0     0     0
Rfsol 0.230 0.226 0.224 0.225 0.231 0.248 0.290 0.391 0.600 1.000 0.279
Rbsol 0.232 0.226 0.224 0.226 0.237 0.256 0.294 0.382 0.582 0.999 0.280
Tvis  0.717 0.721 0.711 0.697 0.678 0.641 0.559 0.405 0.186 0.000 0.596
Rfvis 0.133 0.127 0.126 0.130 0.142 0.169 0.229 0.365 0.620 1.000 0.207
Rbvis 0.131 0.124 0.121 0.124 0.136 0.160 0.208 0.313 0.540 0.999 0.189
SHGC  0.620   N/A   N/A   N/A   N/A   N/A   N/A   N/A   N/A   N/A   N/A
Tvis_daylight:  0.780
Layer ID#         7199    37003        0        0        0        0
Tir              0.000    0.000        0        0        0        0
Emis F           0.837    0.037        0        0        0        0
Emis B           0.837    0.837        0        0        0        0
Thickness(mm)      6.0      6.0        0        0        0        0
Cond(W/m2-K     ) 166.7    166.7        0        0        0        0
Spectral File  ip_fl_6.ipe 37003_IP_ipl         None         None         None
  None
Overall and Center of Glass Ig U-values (W/m2-K)
```

```
Outdoor Temperature                 -17.8 C      15.6 C      26.7 C      37.8 C
Solar      WdSpd  hcout hrout  hin
(W/m2)     (m/s)     (W/m2-K)
0        0.00   0.00  0.00  0.00  1.35 1.35  1.08 1.08  1.10 1.10  1.12 1.12
0        6.71   0.00  0.00  0.00  1.35 1.35  1.08 1.08  1.10 1.10  1.12 1.12
783        0.00   0.00  0.00  0.00  1.35 1.35  1.08 1.08  1.10 1.10  1.12 1.12
783        6.71   0.00  0.00  0.00  1.35 1.35  1.08 1.08  1.10 1.10  1.12 1.12
BERKELEY LAB WINDOW v7.4.6.0  DOE-2 Data File : Multi Band Calculation : generated
with Trnsys18.std
Unit System : SI
Name        : DOE-2 WINDOW LIB
Desc        : GU_Solar_Neutral_67_CG_Prem_#3_Ar90
Window ID   : 3428
Tilt        : 90.0
Glazings    : 2
Frame       :  3 Wood                 2.270
Spacer      :  2 Class2               0.068   1.550  -0.143
Total Height: 1500.0 mm
Total Width : 1200.0 mm
Glass Height: 1360.3 mm
Glass Width : 1060.3 mm
Mullion     : None
Gap        Thick    Cond  dCond    Vis   dVis   Dens   dDens      Pr     dPr
1 Ar90/Air1 16.0 0.01712  5.410  2.062  6.300  1.711 -0.0060  0.687 -0.0001
2              0       0      0      0      0      0       0      0       0
3              0       0      0      0      0      0       0      0       0
4              0       0      0      0      0      0       0      0       0
5              0       0      0      0      0      0       0      0       0
Angle     0    10    20    30    40    50    60    70    80    90 Hemis
Tsol  0.396 0.401 0.391 0.379 0.366 0.342 0.292 0.202 0.090 0.000 0.319
Abs1  0.312 0.314 0.324 0.332 0.334 0.339 0.357 0.373 0.311 0.001 0.335
Abs2  0.066 0.067 0.072 0.075 0.076 0.078 0.084 0.085 0.058 0.000 0.076
Abs3      0     0     0     0     0     0     0     0     0     0     0
Abs4      0     0     0     0     0     0     0     0     0     0     0
Abs5      0     0     0     0     0     0     0     0     0     0     0
Abs6      0     0     0     0     0     0     0     0     0     0     0
Rfsol 0.226 0.218 0.213 0.214 0.224 0.240 0.267 0.340 0.541 0.999 0.260
Rbsol 0.307 0.298 0.295 0.297 0.307 0.324 0.353 0.425 0.607 0.999 0.341
Tvis  0.547 0.553 0.539 0.522 0.504 0.471 0.401 0.276 0.122 0.000 0.439
Rfvis 0.198 0.188 0.185 0.188 0.201 0.221 0.257 0.345 0.555 0.999 0.244
Rbvis 0.192 0.181 0.175 0.177 0.190 0.211 0.245 0.331 0.543 0.999 0.233
SHGC  0.470   N/A   N/A   N/A   N/A   N/A   N/A   N/A   N/A   N/A   N/A
Tvis_daylight:  0.590
Layer ID#        33035    33010        0         0         0         0
Tir              0.000    0.000        0         0         0         0
Emis F           0.860    0.030        0         0         0         0
Emis B           0.830    0.860        0         0         0         0
Thickness(mm)      6.0      4.0        0         0         0         0
Cond(W/m2-K     ) 166.7    250.0        0         0         0         0
Spectral File 33035_GU_Sol 33010_GU_Cli         None         None         None
  None
Overall and Center of Glass Ig U-values (W/m2-K)
Outdoor Temperature                 -17.8 C      15.6 C      26.7 C      37.8 C
Solar      WdSpd  hcout hrout  hin
(W/m2)     (m/s)     (W/m2-K)
0        0.00   0.00  0.00  0.00  1.34 1.34  1.05 1.05  1.08 1.08  1.10 1.10
0        6.71   0.00  0.00  0.00  1.34 1.34  1.05 1.05  1.08 1.08  1.10 1.10
783        0.00   0.00  0.00  0.00  1.34 1.34  1.05 1.05  1.08 1.08  1.10 1.10
783        6.71   0.00  0.00  0.00  1.34 1.34  1.05 1.05  1.08 1.08  1.10 1.10
BERKELEY LAB WINDOW v7.4.6.0  DOE-2 Data File : Multi Band Calculation : generated
with Trnsys18.std
Unit System : SI
Name        : DOE-2 WINDOW LIB
```

```
Desc        : GU_Solar_Silver_20_#2_Ar90
Window ID   : 3422
Tilt        : 90.0
Glazings    : 2
Frame       :  3 Wood                   2.270
Spacer      :  2 Class2                 0.068   1.550  -0.143
Total Height: 1500.0 mm
Total Width : 1200.0 mm
Glass Height: 1360.3 mm
Glass Width : 1060.3 mm
Mullion     : None
Gap        Thick    Cond  dCond    Vis   dVis   Dens   dDens     Pr     dPr
1 Ar90/Air1 16.0 0.01712  5.410  2.062  6.300  1.711 -0.0060  0.687 -0.0001
2              0       0      0      0      0      0       0      0       0
3              0       0      0      0      0      0       0      0       0
4              0       0      0      0      0      0       0      0       0
5              0       0      0      0      0      0       0      0       0
Angle     0    10    20    30    40    50    60    70    80    90 Hemis
Tsol  0.148 0.149 0.147 0.144 0.140 0.133 0.117 0.086 0.040 0.000 0.124
Abs1  0.513 0.518 0.521 0.522 0.518 0.512 0.503 0.469 0.343 0.001 0.494
Abs2  0.011 0.011 0.011 0.011 0.011 0.011 0.011 0.010 0.007 0.000 0.011
Abs3      0     0     0     0     0     0     0     0     0     0     0
Abs4      0     0     0     0     0     0     0     0     0     0     0
Abs5      0     0     0     0     0     0     0     0     0     0     0
Abs6      0     0     0     0     0     0     0     0     0     0     0
Rfsol 0.328 0.322 0.321 0.323 0.331 0.344 0.370 0.436 0.609 0.999 0.361
Rbsol 0.285 0.280 0.279 0.280 0.287 0.305 0.345 0.442 0.642 1.000 0.332
Tvis  0.190 0.191 0.189 0.185 0.181 0.171 0.150 0.110 0.052 0.000 0.159
Rfvis 0.344 0.338 0.337 0.339 0.347 0.360 0.385 0.450 0.619 0.999 0.376
Rbvis 0.235 0.229 0.228 0.231 0.242 0.265 0.315 0.432 0.660 1.000 0.297
SHGC  0.200   N/A   N/A   N/A   N/A   N/A   N/A   N/A   N/A   N/A   N/A
Tvis_daylight:  0.200
Layer ID#         33039    33000        0        0        0        0
Tir               0.000    0.000        0        0        0        0
Emis F            0.860    0.860        0        0        0        0
Emis B            0.420    0.860        0        0        0        0
Thickness(mm)       6.0      4.0        0        0        0        0
Cond(W/m2-K     ) 166.7    250.0        0        0        0        0
Spectral File 33039_GU_Sol 33000_GU_Flo        None         None         None
  None
Overall and Center of Glass Ig U-values (W/m2-K)
Outdoor Temperature                 -17.8 C      15.6 C      26.7 C      37.8 C
Solar      WdSpd  hcout hrout  hin
(W/m2)     (m/s)     (W/m2-K)
0        0.00   0.00  0.00  0.00  2.07 2.07  2.08 2.08  2.16 2.16  2.23 2.23
0        6.71   0.00  0.00  0.00  2.07 2.07  2.08 2.08  2.16 2.16  2.23 2.23
783        0.00   0.00  0.00  0.00  2.07 2.07  2.08 2.08  2.16 2.16  2.23 2.23
783        6.71   0.00  0.00  0.00  2.07 2.07  2.08 2.08  2.16 2.16  2.23 2.23
*** END OF LIBRARY ***
**************************************************************************************
************************
*WinID   Description                                 Design         U-Value g-value
T-sol Rf-sol T-vis-daylight
**************************************************************************************
************************
   201   2-WSV_#3_Ar90                               6/16/6           1.1  0.62  0.504
0.23  0.78
  3428   GU_Solar_Neutral_67_CG_Prem_#3_Ar90         6/16/4           1.08  0.47  0.396
 0.226  0.59
  3422   GU_Solar_Silver_20_#2_Ar90                  6/16/4           2.16  0.2  0.148
0.328  0.2
_EXTENSION_WINPOOL_END_
```

```
_EXTENSION_BuildingGeometry_START_
vertex 1 0.000000000000 3.048000000000 3.048000000000
vertex 2 0.000000000000 0.000000000000 3.048000000000
vertex 3 5.181600000000 0.000000000000 3.048000000000
vertex 4 5.181600000000 3.962400000000 3.048000000000
vertex 5 3.048000000000 3.962400000000 3.048000000000
vertex 6 3.048000000000 3.048000000000 3.048000000000
vertex 7 22.250400000000 3.962400000000 0.000000000000
vertex 8 22.250400000000 0.000000000000 0.000000000000
vertex 9 0.000000000000 0.000000000000 0.000000000000
vertex 10 0.000000000000 3.962400000000 0.000000000000
vertex 11 15.626106915131 3.962400000000 3.048000000000
vertex 12 15.626106915131 0.000000000000 3.048000000000
vertex 13 18.064506915131 0.000000000000 3.048000000000
vertex 14 18.064506915131 3.962400000000 3.048000000000
vertex 15 0.000000000000 3.962400000000 3.048000000000
vertex 16 0.000000000000 1.265992483540 2.361253045656
vertex 17 0.000000000000 1.265992483540 0.278453045656
vertex 18 0.000000000000 0.351592483540 0.278453045656
vertex 19 0.000000000000 0.351592483540 2.361253045656
vertex 20 0.000000000000 2.623304983540 2.361253045656
vertex 21 0.000000000000 2.623304983540 1.142053045656
vertex 22 0.000000000000 1.708904983540 1.142053045656
vertex 23 0.000000000000 1.708904983540 2.361253045656
vertex 24 22.250400000000 0.000000000000 3.048000000000
vertex 25 22.250400000000 3.962400000000 3.048000000000
vertex 26 22.250400000000 2.769835392222 2.361253045656
vertex 27 22.250400000000 2.769835392222 0.278453045656
vertex 28 22.250400000000 3.684235392222 0.278453045656
vertex 29 22.250400000000 3.684235392222 2.361253045656
vertex 30 22.250400000000 0.451198157647 2.361253045656
vertex 31 22.250400000000 0.451198157647 1.142053045656
vertex 32 22.250400000000 2.279998157647 1.142053045656
vertex 33 22.250400000000 2.279998157647 2.361253045656
vertex 34 11.887200000000 0.000000000000 3.048000000000
vertex 35 11.887200000000 3.962400000000 3.048000000000
vertex 36 0.000000000000 3.962400000000 6.096000000000
vertex 37 0.000000000000 0.000000000000 6.096000000000
vertex 38 5.181600000000 0.000000000000 6.096000000000
vertex 39 5.181600000000 3.962400000000 6.096000000000
vertex 40 5.181600000000 2.604555037662 5.346305864475
vertex 41 5.181600000000 2.604555037662 3.263505864475
vertex 42 5.181600000000 3.518955037662 3.263505864475
vertex 43 5.181600000000 3.518955037662 5.346305864475
vertex 44 5.181600000000 0.395696220748 5.346305864475
vertex 45 5.181600000000 0.395696220748 4.127105864475
vertex 46 5.181600000000 2.224496220748 4.127105864475
vertex 47 5.181600000000 2.224496220748 5.346305864475
vertex 48 0.000000000000 3.484421741773 4.963274305684
vertex 49 0.000000000000 3.484421741773 4.048874305684
vertex 50 0.000000000000 2.874821741773 4.048874305684
vertex 51 0.000000000000 2.874821741773 4.963274305684
vertex 52 0.000000000000 1.265992483540 5.346305864475
vertex 53 0.000000000000 1.265992483540 3.263505864475
vertex 54 0.000000000000 0.351592483540 3.263505864475
vertex 55 0.000000000000 0.351592483540 5.346305864475
vertex 56 11.887200000000 0.000000000000 6.096000000000
vertex 57 22.250400000000 0.000000000000 6.096000000000
vertex 58 11.887200000000 3.962400000000 6.096000000000
vertex 59 11.887200000000 1.917700000000 5.346305864475
vertex 60 11.887200000000 1.917700000000 4.431905864475
vertex 61 11.887200000000 1.308100000000 4.431905864475
vertex 62 11.887200000000 1.308100000000 5.346305864475
```

```
vertex 63 11.887200000000 3.549247743400 5.346305864475
vertex 64 11.887200000000 3.549247743400 3.263505864475
vertex 65 11.887200000000 2.330047743400 3.263505864475
vertex 66 11.887200000000 2.330047743400 5.346305864475
vertex 67 22.250400000000 3.962400000000 6.096000000000
vertex 68 22.250400000000 0.451198157647 5.346305864475
vertex 69 22.250400000000 0.451198157647 3.263505864475
vertex 70 22.250400000000 2.279998157647 3.263505864475
vertex 71 22.250400000000 2.279998157647 5.346305864475
vertex 72 22.250400000000 2.769835392222 5.346305864475
vertex 73 22.250400000000 2.769835392222 3.263505864475
vertex 74 22.250400000000 3.684235392222 3.263505864475
vertex 75 22.250400000000 3.684235392222 5.346305864475


zone CF1795
ceiling 1 1 2 3 4 5 6
floor 2 7 8 9 10
wall 3 15 10 9 2
window 10 16 17 18 19
window 11 20 21 22 23
wall 4 24 8 7 25
window 12 26 27 28 29
window 13 30 31 32 33
wall 5 2 9 8 24
wall 6 25 7 10 15
roof 7 4 3 34 35
ceiling 8 14 13 24 25
ceiling 9 35 34 12 11

zone E348A1
roof 14 36 37 38 39
ceiling 15 4 3 2 1 6 5
wall 16 38 3 4 39
window 20 40 41 42 43
window 21 44 45 46 47
wall 17 37 2 3 38
wall 18 39 4 15 36
wall 19 36 15 2 37
window 22 48 49 50 51
window 23 52 53 54 55

zone C34EF2
ceiling 24 11 12 34 35
wall 25 56 34 24 57
wall 26 58 35 34 56
window 31 59 60 61 62
window 32 63 64 65 66
roof 27 58 56 57 67
ceiling 28 25 24 13 14
wall 29 57 24 25 67
window 33 68 69 70 71
window 34 72 73 74 75
wall 30 67 25 35 58
_EXTENSION_BuildingGeometry_END_


_EXTENSION_VirtualSurfaceGeometry_START_
airnode CF1795
ceiling 20000 11 12 13 14
ceiling 20001 15 1 6 5

airnode E348A1
```

```
ceiling 20002 15 1 6 5

airnode C34EF2
ceiling 20003 11 12 13 14

_EXTENSION_VirtualSurfaceGeometry_END_


_EXTENSION_ExternalShadingGeometry_START_
vertex 76 23.317200000000 3.962400000000 3.048000000000
vertex 77 23.317200000000 0.000000000000 3.048000000000
vertex 78 22.250400000000 0.000000000000 3.048000000000
vertex 79 22.250400000000 3.962400000000 3.048000000000
vertex 80 23.317200000000 3.962400000000 5.586412500000
vertex 81 23.317200000000 0.000000000000 5.586412500000
vertex 82 22.250400000000 0.000000000000 5.586412500000
vertex 83 22.250400000000 3.962400000000 5.586412500000
vertex 84 5.181600000000 3.962400000000 5.725036239832
vertex 85 5.181600000000 0.000000000000 5.725036239832
vertex 86 6.248400000000 0.000000000000 5.725036239832
vertex 87 6.248400000000 3.962400000000 5.725036239832

shader 10001 76 77 78 79
shader 10002 80 81 82 83
shader 10003 84 85 86 87
_EXTENSION_ExternalShadingGeometry_END_


_EXTENSION_GeoPositionGeometry_START_
_EXTENSION_GeoPositionGeometry_END_


_EXTENSION_DaylightSensorPoints_START_
_EXTENSION_DaylightSensorPoints_END_


_EXTENSION_AdditionalDaylightGeometry_START_
_EXTENSION_AdditionalDaylightGeometry_END_


_EXTENSION_VAMPARAMS_START_
_EXTENSION_VAMPARAMS_END_
```

D.2 Type 941 SAASHP Performance File

```
15      25      35      40      45      50      55      !T_water_in

-20     -12     -7      0       7       15      22      30      35      !T_air_in

0.702159022     0.974922379
!Fraction capacity and power at T_air = -20     deg. C and T_water_in = 15
0.82216249      0.713876284
!Fraction capacity and power at T_air = -12     deg. C and T_water_in = 15
0.934882511     0.708144256
!Fraction capacity and power at T_air = -7      deg. C and T_water_in = 15
0.971473164     0.691903511
!Fraction capacity and power at T_air = 0       deg. C and T_water_in = 15
1.192230989     0.679245283
!Fraction capacity and power at T_air = 7       deg. C and T_water_in = 15
1.502644585     0.661093862
!Fraction capacity and power at T_air = 15      deg. C and T_water_in = 15
1.7097893       0.665631717
!Fraction capacity and power at T_air = 22      deg. C and T_water_in = 15
1.8346484       0.599474564
!Fraction capacity and power at T_air = 30      deg. C and T_water_in = 15
2.064250412     0.58060664
!Fraction capacity and power at T_air = 35      deg. C and T_water_in = 15
0.702159022     0.974922379
!Fraction capacity and power at T_air = -20     deg. C and T_water_in = 25
0.826151045     0.80200621
!Fraction capacity and power at T_air = -12     deg. C and T_water_in = 25
0.957339808     0.801289706
!Fraction capacity and power at T_air = -7      deg. C and T_water_in = 25
1.001387323     0.744447098
!Fraction capacity and power at T_air = 0       deg. C and T_water_in = 25
1.203676407     0.77860043
!Fraction capacity and power at T_air = 7       deg. C and T_water_in = 25
1.440821989     0.73871507
!Fraction capacity and power at T_air = 15      deg. C and T_water_in = 25
1.705020376     0.79722952
!Fraction capacity and power at T_air = 22      deg. C and T_water_in = 25
1.977022457     0.760210174
!Fraction capacity and power at T_air = 30      deg. C and T_water_in = 25
2.164918061     0.760926678
!Fraction capacity and power at T_air = 35      deg. C and T_water_in = 25
0.702159022     0.974922379
!Fraction capacity and power at T_air = -20     deg. C and T_water_in = 35
0.828925691     0.949367089
!Fraction capacity and power at T_air = -12     deg. C and T_water_in = 35
0.935229342     0.941246716
!Fraction capacity and power at T_air = -7      deg. C and T_water_in = 35
1.031648314     0.904705039
!Fraction capacity and power at T_air = 0       deg. C and T_water_in = 35
1.195265759     0.885120611
!Fraction capacity and power at T_air = 7       deg. C and T_water_in = 35
1.352987081     0.900167184
!Fraction capacity and power at T_air = 15      deg. C and T_water_in = 35
1.610248851     0.925722474
!Fraction capacity and power at T_air = 22      deg. C and T_water_in = 35
1.886759733     0.941246716
!Fraction capacity and power at T_air = 30      deg. C and T_water_in = 35
2.228474811     0.973728206
!Fraction capacity and power at T_air = 35      deg. C and T_water_in = 35
0.716639209     1.032242656
!Fraction capacity and power at T_air = -20     deg. C and T_water_in = 40
0.809589873     1.022689276
!Fraction capacity and power at T_air = -12     deg. C and T_water_in = 40
0.904361398     1.013374731
```

```
!Fraction capacity and power at T_air = -7      deg. C and T_water_in = 40
1       1                                                               !Fraction
capacity and power at T_air =   0       deg. C and T_water_in = 40
1.173502124     1.009075711
!Fraction capacity and power at T_air = 7       deg. C and T_water_in = 40
1.248937831     0.959398137
!Fraction capacity and power at T_air = 15      deg. C and T_water_in = 40
1.53082459      1.015046573
!Fraction capacity and power at T_air = 22      deg. C and T_water_in = 40
1.819821382     1.025794125
!Fraction capacity and power at T_air = 30      deg. C and T_water_in = 40
2.171247724     1.095056126
!Fraction capacity and power at T_air = 35      deg. C and T_water_in = 40
0.723315703     1.118461906
!Fraction capacity and power at T_air = -20     deg. C and T_water_in = 45
0.834214862     1.121805589
!Fraction capacity and power at T_air = -12     deg. C and T_water_in = 45
0.886586318     1.107475519
!Fraction capacity and power at T_air = -7      deg. C and T_water_in = 45
1.00641637      1.102459995
!Fraction capacity and power at T_air = 0       deg. C and T_water_in = 45
1.155640336     1.121089085
!Fraction capacity and power at T_air = 7       deg. C and T_water_in = 45
1.16231683      1.027943635
!Fraction capacity and power at T_air = 15      deg. C and T_water_in = 45
1.45252753      1.098638643
!Fraction capacity and power at T_air = 22      deg. C and T_water_in = 45
1.739616752     1.129448292
!Fraction capacity and power at T_air = 30      deg. C and T_water_in = 45
1.983005289     1.079770719
!Fraction capacity and power at T_air = 35      deg. C and T_water_in = 45
0.692621174     1.197038452
!Fraction capacity and power at T_air = -20     deg. C and T_water_in = 50
0.801872886     1.163123955
!Fraction capacity and power at T_air = -12     deg. C and T_water_in = 50
0.836469262     1.183663721
!Fraction capacity and power at T_air = -7      deg. C and T_water_in = 50
0.861614498     1.117267733
!Fraction capacity and power at T_air = 0       deg. C and T_water_in = 50
0.999393046     1.124432768
!Fraction capacity and power at T_air = 7       deg. C and T_water_in = 50
1.138125379     1.127537616
!Fraction capacity and power at T_air = 15      deg. C and T_water_in = 50
1.337206278     1.11870074
!Fraction capacity and power at T_air = 22      deg. C and T_water_in = 50
1.468048209     1.122760927
!Fraction capacity and power at T_air = 30      deg. C and T_water_in = 50
1.71056967      1.089324098
!Fraction capacity and power at T_air = 35      deg. C and T_water_in = 50
0.577213214     1.177931693
!Fraction capacity and power at T_air = -20     deg. C and T_water_in = 55
0.636087748     1.187723907
!Fraction capacity and power at T_air = -12     deg. C and T_water_in = 55
0.701205237     1.157153093
!Fraction capacity and power at T_air = -7      deg. C and T_water_in = 55
0.787219284     1.1724385
!Fraction capacity and power at T_air = 0       deg. C and T_water_in = 55
0.854938004     1.136613327
!Fraction capacity and power at T_air = 7       deg. C and T_water_in = 55
1.021416804     1.132314306
!Fraction capacity and power at T_air = 15      deg. C and T_water_in = 55
0.970692795     0.999522331
!Fraction capacity and power at T_air = 22      deg. C and T_water_in = 55
```

```
1.170727478     1.026988297
!Fraction capacity and power at T_air = 30      deg. C and T_water_in = 55
1.391745426     1.053021256
!Fraction capacity and power at T_air = 35      deg. C and T_water_in = 55
```

D.3 Trnsys Dck Input Files (sample file for Scenario 4 shown)

```
VERSION 18
*******************************************************************************
*** TRNSYS input file (deck) generated by TrnsysStudio
*** on Saturday, March 09, 2019 at 12:53
*** from TrnsysStudio project: C:\Users\r_dumo\Dropbox\TRNSYS_docs\MyProjects\Solar
Air-source\Air_distribution\2019.03.09SDHouse_with_air_distribution_singleThermostat
_ASHP_Scenario4.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=800
STOP=1000
STEP=0.1
SIMULATION       START   STOP    STEP   ! Start time    End time        Time step
TOLERANCES 0.001 0.001                  ! Integration    Convergence
LIMITS 30 30 30                         ! Max iterations        Max warnings
Trace limit
DFQ 1                                   ! TRNSYS numerical integration solver method
WIDTH 80                                ! 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
* User defined CONSTANTS
*$USER_CONSTANTS
EQUATIONS 1
nPlots = (STOP-START)/168.
*$USER_CONSTANTS_END


* Model "Type21" (Type 21)
*

UNIT 3 TYPE 21   Type21
*$UNIT_NAME Type21
*$MODEL .\Utility\Time Values\Type21.tmf
*$POSITION 365 578
*$LAYER Main #
PARAMETERS 2
1               ! 1 Mode
0               ! 2 Relative time?
*------------------------------------------------------------------------------
```

```
* Model "Type77" (Type 77)
*

UNIT 4 TYPE 77   Type77
*$UNIT_NAME Type77
*$MODEL .\Physical Phenomena\Simple Ground Temperature Model\Type77.tmf
*$POSITION 259 351
*$LAYER Main #
PARAMETERS 8
1               ! 1 Number of temperature nodes
T_MEAN          ! 2 Mean surface temperature
T_AMPLITUDE             ! 3 Amplitude of surface temperature
t_T_MIN         ! 4 Time shift
8.72            ! 5 Soil thermal conductivity
3200.0          ! 6 Soil density
0.84            ! 7 Soil specific heat
h_depth         ! 8 Depth at point
*------------------------------------------------------------------------------

* Model "OccupancyScheduleType516" (Type 516)
*

UNIT 8 TYPE 516  OccupancyScheduleType516
*$UNIT_NAME OccupancyScheduleType516
*$MODEL .\Applications Library (TESS)\Hourly Schedule\Weekdays Saturdays and
Sundays\Type516.tmf
*$POSITION 707 394
*$LAYER Main #
PARAMETERS 2
151             ! 1 Logical Unit for Data File
1               ! 2 Day on Which 1st Monday Falls
*** External files
ASSIGN "C:\Users\r_dumo\Dropbox\TRNSYS_docs\MyProjects\Solar
Air-source\Air_distribution\Schedules\OccupancySchedule.sl7" 151
*|? Which file contains the slider program results? |1000
*------------------------------------------------------------------------------

* Model "LightingScheduleType516" (Type 516)
*

UNIT 9 TYPE 516  LightingScheduleType516
*$UNIT_NAME LightingScheduleType516
*$MODEL .\Applications Library (TESS)\Hourly Schedule\Weekdays Saturdays and
Sundays\Type516.tmf
*$POSITION 499 394
*$LAYER Main #
PARAMETERS 2
152             ! 1 Logical Unit for Data File
1               ! 2 Day on Which 1st Monday Falls
*** External files
ASSIGN "C:\Users\r_dumo\Dropbox\TRNSYS_docs\MyProjects\Solar
Air-source\Air_distribution\Schedules\LightingSchedule.sl7" 152
*|? Which file contains the slider program results? |1000
*------------------------------------------------------------------------------

* Model "Type15-3" (Type 15)
*

UNIT 10 TYPE 15  Type15-3
*$UNIT_NAME Type15-3
*$MODEL .\Weather Data Reading and Processing\Standard Format\Energy+ Weather Files
(EPW)\Type15-3.tmf
```

```
*$POSITION 147 287
*$LAYER Main #
PARAMETERS 9
3               ! 1 File Type
153             ! 2 Logical unit
5               ! 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
40              ! 8 Slope of surface
0               ! 9 Azimuth of surface
*** External files
ASSIGN "C:\Users\r_dumo\Dropbox\TRNSYS_docs\MyProjects\Solar
Air-source\Weather\CAN_PQ_Montreal.Intl.AP.716270_CWEC.epw" 153
*|? Which file contains the Energy+ weather data? |1000
*------------------------------------------------------------------------------

* Model "Type515-3" (Type 515)
*

UNIT 17 TYPE 515         Type515-3
*$UNIT_NAME Type515-3
*$MODEL .\Applications Library (TESS)\Heating and Cooling Season
Scheduler\Type515.tmf
*$POSITION 370 503
*$LAYER Main #
*$# Heating and Cooling Season Scheduler
PARAMETERS 1
154             ! 1 Logical Unit for Data File
*** External files
ASSIGN "C:\Users\r_dumo\Dropbox\TRNSYS_docs\MyProjects\Solar
Air-source\Air_distribution\Schedules\Heating_cooling_season.hcs" 154
*|? Which file contains the data for this component? |1000
*------------------------------------------------------------------------------

* EQUATIONS "Wizard Settings"
*
EQUATIONS 11
HEMISPHERE = 1
TURN = HEMISPHERE *90 !Rotation angle for building used for adapting azimuth angles
TBOUNDARY = 20
SHADE_CLOSE = 140 * 3.6! Close blinds - radiation on facade in [W/m2 * 3.6]=[kJ/hr]
SHADE_OPEN = 120 * 3.6! Open blinds - radiation on facade in [W/m2 * 3.6]=[kJ/hr]
MAX_ISHADE = 70/100 ! Maximum opaque fraction of internal shading device
MAX_ESHADE = 70/100 ! Maximum opaque fraction of external shading device
h_DEPTH = 1
T_MEAN = 8.0
T_AMPLITUDE = 15.3
t_T_MIN = 28
*$UNIT_NAME Wizard Settings
*$LAYER Main
*$POSITION 160 175
*$UNIT_NUMBER 19

*------------------------------------------------------------------------------


* EQUATIONS "Grid-State"
*
EQUATIONS 4
Grid_state = [17,2]*LT([3,11],7)*1 +  [17,2]*GE([3,11],7)*LT([3,11],11)*0 +
[17,2]*GE([3,11],11)*LT([3,11],17)*-1+  [17,2]*GE([3,11],17)*LT([3,11],19)*0+
```

```
[17,2]*GE([3,11],19)*1+  [17,1]*LE([3,11],7)*1+
[17,1]*GT([3,11],7)*LT([3,11],11)*-1 +   [17,1]*GE([3,11],11)*LT([3,11],17)*0+
[17,1]*GE([3,11],17)*LT([3,11],20)*-1+  [17,1]*GE([3,11],20)*-1
Solar_power_mode = GT(HourlyavgPowerProd/RatedPowerProd,0.2)*1*NE(Grid_state,-1)
HourlyavgPowerProd = [52,2]*5
RatedPowerProd = 1600*5*3.6
*$UNIT_NAME Grid-State
*$LAYER Main
*$POSITION 519 514
*$UNIT_NUMBER 2

*------------------------------------------------------------------------------


* Model "T_Plotter" (Type 65)
*

UNIT 7 TYPE 65   T_Plotter
*$UNIT_NAME T_Plotter
*$MODEL .\Output\Online Plotter\Online Plotter Without File\Type65d.tmf
*$POSITION 1224 891
*$LAYER Main #
PARAMETERS 12
10              ! 1 Nb. of left-axis variables
5               ! 2 Nb. of right-axis variables
-30.0           ! 3 Left axis minimum
80.0            ! 4 Left axis maximum
-2              ! 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 15
10,1            ! Type15-3:Dry bulb temperature ->Left axis variable-1
5,2             ! Building: 2- TOP_CF1795 ->Left axis variable-2
5,8             ! Building: 8- TOP_E348A1 ->Left axis variable-3
5,14            ! Building: 14- TOP_C34EF2 ->Left axis variable-4
11,3            ! Heating:Outlet Air Temperature ->Left axis variable-5
Average_Zone_temp               ! Ventilation_Parameters:Average_Zone_temp ->Left
axis variable-6
0,0             ! [unconnected] Left axis variable-7
0,0             ! [unconnected] Left axis variable-8
0,0             ! [unconnected] Left axis variable-9
3,11            ! Type21:Hour of the day ->Left axis variable-10
Fan_signal              ! Supply_Temp_Fan_controls:Fan_signal ->Right axis
variable-1
65,1            ! Type24:Result of integration ->Right axis variable-2
ERV_HR_status           ! Ventilation_Parameters:ERV_HR_status ->Right axis
variable-3
HPW             ! Power_consumption:HPW ->Right axis variable-4
SOC_combined            ! TankSP:SOC_combined ->Right axis variable-5
*** INITIAL INPUT VALUES
TAMB T_CF1795 T_E348A1 T_C34EF2 Supply_air_temp Average_Zone_temp
HeatingSP TAIR_E348A1 TAIR_C34EF2 Hour Fan_signal CumHPEnergyWh HR_status
HPPowerW TankSOC
LABELS  3
"Operative  Temperature"
"Air  Temperature"
"T_Plotter"
*------------------------------------------------------------------------------
```

```
* Model "Building" (Type 56)
*

UNIT 5 TYPE 56   Building
*$UNIT_NAME Building
*$MODEL .\Loads and Structures\Multi-Zone Building\Type56.tmf
*$POSITION 823 207
*$LAYER Main #
*$#
PARAMETERS 3
150             ! 1 Logical unit for building description file (*.b18, *.b17, *.bui)
0               ! 2 Star network calculation switch
0.50            ! 3 Weighting factor for operative temperature
INPUTS 24
10,1            ! Type15-3:Dry bulb temperature -> 1- TAMB
10,7            ! Type15-3:Percent relative humidity -> 2- RELHUMAMB
10,4            ! Type15-3:Effective sky temperature -> 3- TSKY
10,1            ! Type15-3:Dry bulb temperature -> 4- TSGRD
10,16           ! Type15-3:Solar zenith angle -> 5- AZEN
AAZM_TYPE56             ! Radiation Unit Converter:AAZM_TYPE56 -> 6- AAZM
10,59           ! Type15-3:Ground reflectance -> 7- GRDREF
4,1             ! Type77:Soil Temperature at Node  -> 8- TGROUND
TBOUNDARY               ! Wizard Settings:TBOUNDARY -> 9- TBOUNDARY
SHADE_CLOSE             ! Wizard Settings:SHADE_CLOSE -> 10- SHADE_CLOSE
SHADE_OPEN              ! Wizard Settings:SHADE_OPEN -> 11- SHADE_OPEN
MAX_ISHADE              ! Wizard Settings:MAX_ISHADE -> 12- MAX_ISHADE
MAX_ESHADE              ! Wizard Settings:MAX_ESHADE -> 13- MAX_ESHADE
8,1             ! OccupancyScheduleType516:OccupancyFactor -> 14- OccupancySchedule
9,1             ! LightingScheduleType516:LightingFactor -> 15- LightingSchedule
11,3            ! Heating:Outlet Air Temperature -> 16- Supply_air_temp
Zone2_air               ! Supply_Temp_Fan_controls:Zone2_air -> 17- Zone_2_airflow
Zone1_air               ! Supply_Temp_Fan_controls:Zone1_air -> 18- Zone_1_airflow
Zone3_air               ! Supply_Temp_Fan_controls:Zone3_air -> 19- Zone_3_airflow
Ventilation_zone_1              ! Ventilation_Parameters:Ventilation_zone_1 -> 20-
Zone_1_ventilation
14,6            ! Type760:Fresh Air Temperature -> 21- HRV_supply_temp
14,8            ! Type760:Fresh Air % Relative Humidity -> 22- HRV_rel_h
Ventilation_zone_2              ! Ventilation_Parameters:Ventilation_zone_2 -> 23-
Zone_2_ventilation
Ventilation_zone_3              ! Ventilation_Parameters:Ventilation_zone_3 -> 24-
Zone_3_ventilation
*** INITIAL INPUT VALUES
0 0 0 0 0 -90 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
*** External files
ASSIGN "C:\Users\r_dumo\Dropbox\TRNSYS_docs\MyProjects\Solar Air-source\Novoclimat
building\'Building_file_Novoclimat.b18" 150
*|? Building description file (*.b18, *.b17, *.bui) |1000
*------------------------------------------------------------------------------

* EQUATIONS "Ventilation_Parameters"
*
EQUATIONS 9
Ventilation_rate = Ventilation_zone_1+Ventilation_zone_2+Ventilation_zone_3 !
Ventilation rate in kg/h
ACH = 0.3 ! Desired air changes per hour
Average_Zone_temp = [5,2]*([5,33]/(Total_Volume+0.001))+
[5,14]*([5,35]/(Total_Volume+0.001))+  [5,8]*([5,34]/(Total_Volume+0.001))
Ventilation_zone_1 = [5,33] *ACH*1.27 ! Ventilation rate in kg/h
Ventilation_zone_2 = [5,35] *ACH*1.27 ! Ventilation rate in kg/h
Ventilation_zone_3 = [5,35] *ACH*1.27 ! Ventilation rate in kg/h
ERV_control = LT([16,2],0.5)*1
ERV_HR_status = abs(ERV_control)
```

```
Total_Volume = [5,33]+[5,35]+[5,34]
*$UNIT_NAME Ventilation_Parameters
*$LAYER Main
*$POSITION 540 282
*$UNIT_NUMBER 15

*------------------------------------------------------------------------------


* EQUATIONS "Radiation Unit Converter"
*
EQUATIONS 3
AZEN = [10,16]! [deg] solar zenith angle
AAZM = [10,17] ! [deg] solar azimuth angle
AAZM_TYPE56 = AAZM - (TURN) ! [deg] solar azimuth corrected by building rotation -
Input for Type 56 sun position for SHM and ISM
*$UNIT_NAME Radiation Unit Converter
*$LAYER Main
*$POSITION 397 255
*$UNIT_NUMBER 20

*------------------------------------------------------------------------------


* Model "Heating" (Type 600)
*

UNIT 11 TYPE 600         Heating
*$UNIT_NAME Heating
*$MODEL .\HVAC Library (TESS)\2-Pipe Fan Coil\Mass Flow Based\Type600.tmf
*$POSITION 818 439
*$LAYER Main #
PARAMETERS 11
4.190           ! 1 Specific Heat of Liquid Stream
2               ! 2 Humidity Mode
4000            ! 3 Rated Air Flowrate
1800            ! 4 Rated Fan Power
1               ! 5 Motor Efficiency
1.              ! 6 Motor Heat Loss Fraction
4               ! 7 Number of Power Coefficients
0.0013          ! 8 Power Coefficient-1
0.147           ! 9 Power Coefficient-2
0.9506          ! 10 Power Coefficient-3
-0.0998         ! 11 Power Coefficient-4
INPUTS 14
46,1            ! Type110:Outlet fluid temperature ->Inlet Liquid Temperature
46,2            ! Type110:Outlet flow rate ->Inlet Liquid Flowrate
0,0             ! [unconnected] Return Air Temperature
0,0             ! [unconnected] Return Air Humidity Ratio
0,0             ! [unconnected] Return Air % Relative Humidity
0,0             ! [unconnected] Return Air Pressure
Fan_signal              ! Supply_Temp_Fan_controls:Fan_signal ->Fan Control Signal
0,0             ! [unconnected] Fan Pressure Rise
0,0             ! [unconnected] Coil Pressure Drop
10,1            ! Type15-3:Dry bulb temperature ->Fresh Air Temperature
10,6            ! Type15-3:Humidity ratio ->Fresh Air Humidity Ratio
10,7            ! Type15-3:Percent relative humidity ->Fresh Air % Relative Humidity
0,0             ! [unconnected] Damper Position
Coil_bypass             ! Supply_Temp_Fan_controls:Coil_bypass ->Coil Bypass
Fraction
*** INITIAL INPUT VALUES
45 400 20 0.008 50.0 1.0 0 0. 0 20.0 0.008 50. 0. 0
*------------------------------------------------------------------------------
```

```
* EQUATIONS "Supply_Temp_Fan_controls"
*
EQUATIONS 13
Fan_signal = GT([63,1],0)*abs([63,1])+  EQL([63,1],0)*0.05
Zone1_prop = LT([64,1],0)*0.1+GT([63,1],0)*0.6
Zone2_prop = LT([64,1],0)*0.45+GT([63,1],0)*0.2
Zone3_prop = LT([64,1],0)*0.45+GT([63,1],0)*0.2
Zone1_air = Zone1_prop*[11,6]
Zone2_air = Zone2_prop*[11,6]
Zone3_air = Zone3_prop*[11,6]
Coil_bypass = 0.1
Gain_heat = 1
Gain_cool = 1
T_SP_heating = [17,1]*22+[17,2]*20
T_SP_cooling = [17,1]*28+[17,2]*24
T_SP_ERV = GT(Average_Zone_temp,24)*(T_SP_heating+6)+
LE(Average_Zone_temp,24)*(T_SP_cooling)  !Temperature above which the ERV does not
recover heat
*$UNIT_NAME Supply_Temp_Fan_controls
*$LAYER Main
*$POSITION 822 506
*$UNIT_NUMBER 13

*------------------------------------------------------------------------------


* Model "Type760" (Type 760)
*

UNIT 14 TYPE 760         Type760
*$UNIT_NAME Type760
*$MODEL .\HVAC Library (TESS)\Heat Exchangers\Air-to-Air Heat Exchanger\Sensible
Only with Control Modes\Air-Air Heat Recovery\Type760.tmf
*$POSITION 540 383
*$LAYER Main #
*$# Air-to-Air Heat Recovery
PARAMETERS 3
2               ! 1 Humidity Mode
671.1           ! 2 Rated Power
0               ! 3 Control Mode
INPUTS 15
Average_Zone_temp                ! Ventilation_Parameters:Average_Zone_temp ->Exhaust
Air Temperature
5,36            ! Building: 36- ABSHUM_CF1795 ->Exhaust Air Humidity Ratio
5,37            ! Building: 37- RELHUM_CF1795 ->Exhaust Air % Relative Humidity
Ventilation_rate                 ! Ventilation_Parameters:Ventilation_rate ->Exhaust
Air Flowrate
0,0             ! [unconnected] Exhaust Air Pressure
0,0             ! [unconnected] Exhaust Air Pressure Drop
0,0             ! [unconnected] Fresh Air Temperature
0,0             ! [unconnected] Fresh Air Humidity Ratio
0,0             ! [unconnected] Fresh Air % Relative Humidity
Ventilation_rate                 ! Ventilation_Parameters:Ventilation_rate ->Fresh
Air Flowrate
0,0             ! [unconnected] Fresh Air Pressure
0,0             ! [unconnected] Fresh Air Pressure Drop
0,0             ! [unconnected] Sensible Effectiveness
ERV_control             ! Ventilation_Parameters:ERV_control ->On/Off Control Signal
0,0             ! [unconnected] Control Temperature
*** INITIAL INPUT VALUES
20.0 0.005 60.0 0.0 1.0 0 20.0 0.005 50.0 0.0 1.0 0.0 0.70 1.0 20.0
*------------------------------------------------------------------------------
```

```
* Model "Free cooling" (Type 166)
*

UNIT 16 TYPE 166         Free cooling
*$UNIT_NAME Free cooling
*$MODEL .\Controllers\Simple Thermostat\Type166.tmf
*$POSITION 747 309
*$LAYER Main #
*$# Simple Thermostat
PARAMETERS 2
5                ! 1 No. of oscillations permitted
1                ! 2 Temperature dead band
INPUTS 3
Average_Zone_temp               ! Ventilation_Parameters:Average_Zone_temp
->Monitoring temperature
0,0              ! [unconnected] Heating setpoint
T_SP_ERV                 ! [equation] Cooling setpoint
*** INITIAL INPUT VALUES
20.0 10 T_SP_ERV
*-------------------------------------------------------------------------------

* EQUATIONS "Q_loads_unit_converter"
*
EQUATIONS 12
Zone_1_cooling_W = [5,4]/3.6
Zone_2_cooling_W = [5,16]/3.6
Zone_3_cooling_W = [5,10]/3.6
Zone_1_heating_W = [5,3]/3.6
Zone_2_heating_W = [5,15]/3.6
Zone_3_heating_W = [5,9]/3.6
Net_loads_W = Total_cooling_W-Total_heating_W  ! Positive values indicate net
cooling (heat gains that need to be extracted)
Total_cooling_W = Zone_1_cooling_W+Zone_2_cooling_W+Zone_3_cooling_W
Total_heating_W = Zone_1_heating_W+Zone_2_heating_W+Zone_3_heating_W
AHU_heat_cool_W = [11,11]/3.6
AHU_heat_W = LT(AHU_heat_cool_W,0)*AHU_heat_cool_W
AHU_cool_W = GT(AHU_heat_cool_W,0)*AHU_heat_cool_W
*$UNIT_NAME Q_loads_unit_converter
*$LAYER Main
*$POSITION 949 645
*$UNIT_NUMBER 36

*-------------------------------------------------------------------------------


* Model "System_Plotter-3" (Type 65)
*

UNIT 37 TYPE 65  System_Plotter-3
*$UNIT_NAME System_Plotter-3
*$MODEL \TRNSYS18\Studio\lib\System_Output\TYPE65d.tmf
*$POSITION 1570 741
*$LAYER OutputSystem #
PARAMETERS 12
10               ! 1 Nb. of left-axis variables
0                ! 2 Nb. of right-axis variables
-10000           ! 3 Left axis minimum
10000            ! 4 Left axis maximum
0.0              ! 5 Right axis minimum
1000.0           ! 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 10
Zone_1_cooling_W                ! Q_loads_unit_converter:Zone_1_cooling_W ->Left
axis variable-1
Zone_2_cooling_W                ! Q_loads_unit_converter:Zone_2_cooling_W ->Left
axis variable-2
Zone_3_cooling_W                ! Q_loads_unit_converter:Zone_3_cooling_W ->Left
axis variable-3
Total_cooling_W         ! Q_loads_unit_converter:Total_cooling_W ->Left axis
variable-4
Zone_1_heating_W                ! Q_loads_unit_converter:Zone_1_heating_W ->Left
axis variable-5
Zone_2_heating_W                ! Q_loads_unit_converter:Zone_2_heating_W ->Left
axis variable-6
Zone_3_heating_W                ! Q_loads_unit_converter:Zone_3_heating_W ->Left
axis variable-7
Total_heating_W         ! Q_loads_unit_converter:Total_heating_W ->Left axis
variable-8
Net_loads_W             ! Q_loads_unit_converter:Net_loads_W ->Left axis variable-9
AHU_heat_cool_W         ! Q_loads_unit_converter:AHU_heat_cool_W ->Left axis
variable-10
*** INITIAL INPUT VALUES
Zone_1_cooling_W Zone_2_cooling_W Zone_3_cooling_W Total_cooling_W
Zone_1_heating_W Zone_2_heating_W Zone_3_heating_W Total_heating_W
Net_loads_W Zone_1_cooling_W
LABELS  3
"Sensible Loads (W)"
"Heat transfer rates"
"Idealized_loads"
*------------------------------------------------------------------------------

* Model "Type569-3" (Type 569)
*

UNIT 38 TYPE 569         Type569-3
*$UNIT_NAME Type569-3
*$MODEL .\Electrical Library (TESS)\Building-Integrated PV\Un_Glazed\Interfaces with
Simple Building Models\PV Efficiency Modifiers\Type569-3.tmf
*$POSITION 475 335
*$LAYER Main #
PARAMETERS 16
10               ! 1 Collector Length
1.0              ! 2 Collector Width
0.9              ! 3 Absorptance of PV Surface
0.9              ! 4 Emissivity of PV Surface
0.01             ! 5 Substrate Resistance
0.9              ! 6 Channel Emissivity - Top
0.9              ! 7 Channel Emissivity - Bottom
0.44             ! 8 Back Resistance
0.9              ! 9 Back Emissivity
0.01             ! 10 Channel Height
1                ! 11 PV Efficiency Mode
0.16             ! 12 Reference PV Efficiency
25.0             ! 13 Reference Temperature
3600.0           ! 14 Reference Radiation
-0.005           ! 15 Efficiency Modifier - Temperature
0.000025                ! 16 Efficiency Modifier - Radiation
INPUTS 11
10,1             ! Type15-3:Dry bulb temperature ->Inlet Temperature
0,0              ! [unconnected] Inlet Flowrate
```

```
10,1            ! Type15-3:Dry bulb temperature ->Ambient Temperature
10,4            ! Type15-3:Effective sky temperature ->Sky Temperature
Zone_temp               ! Back_temp and topHeatLoss:Zone_temp ->Zone Temperature
Zone_temp               ! Back_temp and topHeatLoss:Zone_temp ->Back Radiant
Temperature
10,24           ! Type15-3:Total tilted surface radiation for surface ->Incident
Solar Radiation
10,30           ! Type15-3:Slope of surface ->Collector Slope
TopHeatLoss             ! Back_temp and topHeatLoss:TopHeatLoss ->Top Heat Loss
Coefficient
0,0             ! [unconnected] Bottom Heat Loss Coefficient
0,0             ! [unconnected] Atmospheric Pressure
*** INITIAL INPUT VALUES
10 324 10.0 10.0 1 20.0 1000 40 50 11.0 1.
*------------------------------------------------------------------------------

* Model "Type941" (Type 941)
*

UNIT 42 TYPE 941         Type941
*$UNIT_NAME Type941
*$MODEL .\HVAC Library (TESS)\Air-Water Heat Pump\Air Humidity Effects
Neglected\Type941.tmf
*$POSITION 411 276
*$LAYER Main #
*$# The value for power in the catalog data files for both heating and cooling mode
should include the
*$# outdoor fan.
*$#
*$#
*$#
*$#
*$#
*$#
*$#
*$#
*$#
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*$#
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*$#
*$#
*$#
PARAMETERS 16
2               ! 1 Humidity Mode
158             ! 2 Logical Unit for Cooling Data
159             ! 3 Logical Unit for Heating Data
6               ! 4 Number of Water Temperatures - Cooling
7               ! 5 Number of Water Temperatures - Heating
6               ! 6 Number of Dry Bulb Temperatures - Cooling
9               ! 7 Number of Dry Bulb Temperatures - Heating
4.190           ! 8 Specific Heat of Liquid Stream
4.190           ! 9 Specific Heat of DHW Stream
0               ! 10 Blower Power
375             ! 11 Total Air Flowrate
40301           ! 12 Rated Cooling Capacity
7722            ! 13 Rated Cooling Power
29592           ! 14 Rated Heating Capacity
```

```
10486           ! 15 Rated Heating Power
0.0             ! 16 Capacity of Auxiliary
INPUTS 17
58,1            ! Type114:Outlet fluid temperature ->Inlet Liquid Temperature
58,2            ! Type114:Outlet flow rate ->Inlet Liquid Flowrate
38,1            ! Type569-3:Outlet Fluid Temperature ->Inlet Air Temperature
10,6            ! Type15-3:Humidity ratio ->Inlet Air Humidity Ratio
0,0             ! [unconnected] Inlet Air % Relative Humidity
0,0             ! [unconnected] Inlet Air Pressure
0,0             ! [unconnected] Air pressure rise across heat pump
0,0             ! [unconnected] Cooling Control Signal
HPSignal                ! TankSP:HPSignal ->Heating Control Signal
0,0             ! [unconnected] Auxiliary Signal
0,0             ! [unconnected] Inlet DHW Temperature
0,0             ! [unconnected] DHW Flowrate
0,0             ! [unconnected] Desuperheater Temperature - Cooling Mode
0,0             ! [unconnected] Desuperheater Temperature - Heating Mode
0,0             ! [unconnected] Desuperheater UA - Cooling Mode
0,0             ! [unconnected] Desuperheater UA - Heating Mode
0,0             ! [unconnected] Compressor Loss Fraction
*** INITIAL INPUT VALUES
40 900 20.0 0.008 50.0 1.0 0 0 1 0.0 20.0 0 20.0 20.0 0 0 0.1
*** External files
ASSIGN "C:\TRNSYS18\Tess
Models\SampleCatalogData\Air-to-WaterHeatPump\AWHP_Type941_C.dat" 158
*|? Which file contains the heat pump cooling performance data? |1000
ASSIGN "C:\Users\r_dumo\Dropbox\TRNSYS_docs\MyProjects\Solar Air-source\Air to water
hp\Arctic_AWHP_Type941_H.dat" 159
*|? Which file contains the heat pump heating performance data? |1000
*------------------------------------------------------------------------------

* EQUATIONS "Back_temp and topHeatLoss"
*
EQUATIONS 2
Zone_temp = [10,1]+10
TopHeatLoss = 3.6*(5.7+3.8* [10,8])
*$UNIT_NAME Back_temp and topHeatLoss
*$LAYER Main
*$POSITION 290 340
*$UNIT_NUMBER 47

*------------------------------------------------------------------------------


* EQUATIONS "TankSP"
*
EQUATIONS 8
Two_sensor_T_avg = ([49,57]+[49,21])/2
T_full = 45
T_depleted = 35
SOC_combined = 100*([43,1]+[44,1])/2
rate = 10
HPSignal = EQL(Solar_power_mode,0)*(EQL(Grid_state,1)*[56,1]+
EQL(Grid_state,0)*[55,1]+  EQL(Grid_state,-1)*[54,1])+
GT(Solar_power_mode,0)*[51,1]
TDB = EQL(Solar_power_mode,0)*(EQL(Grid_state,1)*46+  EQL(Grid_state,0)*76+
EQL(Grid_state,-1)*76)+  GT(Solar_power_mode,0)*16
TankSOCSetpoint = EQL(Solar_power_mode,0)*(EQL(Grid_state,1)*75+
EQL(Grid_state,0)*60+  EQL(Grid_state,-1)*40)+  GT(Solar_power_mode,0)*90
*$UNIT_NAME TankSP
*$LAYER Main
*$POSITION 852 330
*$UNIT_NUMBER 40
```

```
*------------------------------------------------------------------------------


* Model "Type110" (Type 110)
* 

UNIT 46 TYPE 110	 Type110
*$UNIT_NAME Type110
*$MODEL .\Hydronics\Pumps\Variable Speed\Type110.tmf
*$POSITION 721 479
*$LAYER Main # 
*$# VARIABLE-SPEED PUMP
PARAMETERS 6
1362		! 1 Rated flow rate
4.19		! 2 Fluid specific heat
630		! 3 Rated power
0.0		! 4 Motor heat loss fraction
1		! 5 Number of power coefficients
1.0		! 6 Power coefficient
INPUTS 5
49,1		! Type534:Temperature at Outlet-1 ->Inlet fluid temperature
0,0		! [unconnected] Inlet fluid flow rate
pump_signal		! Pump controller-2:pump_signal ->Control signal
0,0		! [unconnected] Total pump efficiency
0,0		! [unconnected] Motor efficiency
*** INITIAL INPUT VALUES
20.0 0.0 1.0 0.6 0.9 
*------------------------------------------------------------------------------

* EQUATIONS "Pump controller-2"
* 
EQUATIONS 4
pump_signal = GT(required_flow,0)*required_flow/Rated_Pump_flow+
EQL(required_flow,0)*GT(Fan_signal,0)*0.1
DeltaTSP = 10
required_flow = abs([11,11])/(4.2*DeltaTSP)
Rated_Pump_flow = 1362
*$UNIT_NAME Pump controller-2
*$LAYER Main
*$POSITION 585 308
*$UNIT_NUMBER 48

*------------------------------------------------------------------------------


* Model "Type534" (Type 534)
* 

UNIT 49 TYPE 534	 Type534
*$UNIT_NAME Type534
*$MODEL .\Storage Tank Library (TESS)\Cylindrical Storage Tank\Vertical 
Cylinder\Version with Plug-In\Type534.tmf
*$POSITION 443 575
*$LAYER Main # 
PARAMETERS 5
164		! 1 Logical Unit for Data File
50		! 2 Number of Tank Nodes
2		! 3 Number of Ports
0		! 4 Number of Immersed Heat Exchangers
0		! 5 Number of Miscellaneous Heat Flows
INPUTS 108
11,1		! Heating:Exiting Fluid Temperature ->Inlet Temperature for Port-1
```

```
11,2            ! Heating:Exiting Fluid Flowrate ->Inlet Flowrate for Port-1
42,1            ! Type941:Exiting Fluid Temperature ->Inlet Temperature for Port-2
42,2            ! Type941:Exiting Fluid Flowrate ->Inlet Flowrate for Port-2
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] Edge Loss Temperature for Node-21
0,0             ! [unconnected] Edge Loss Temperature for Node-22
0,0             ! [unconnected] Edge Loss Temperature for Node-23
0,0             ! [unconnected] Edge Loss Temperature for Node-24
0,0             ! [unconnected] Edge Loss Temperature for Node-25
0,0             ! [unconnected] Edge Loss Temperature for Node-26
0,0             ! [unconnected] Edge Loss Temperature for Node-27
0,0             ! [unconnected] Edge Loss Temperature for Node-28
0,0             ! [unconnected] Edge Loss Temperature for Node-29
0,0             ! [unconnected] Edge Loss Temperature for Node-30
0,0             ! [unconnected] Edge Loss Temperature for Node-31
0,0             ! [unconnected] Edge Loss Temperature for Node-32
0,0             ! [unconnected] Edge Loss Temperature for Node-33
0,0             ! [unconnected] Edge Loss Temperature for Node-34
0,0             ! [unconnected] Edge Loss Temperature for Node-35
0,0             ! [unconnected] Edge Loss Temperature for Node-36
0,0             ! [unconnected] Edge Loss Temperature for Node-37
0,0             ! [unconnected] Edge Loss Temperature for Node-38
0,0             ! [unconnected] Edge Loss Temperature for Node-39
0,0             ! [unconnected] Edge Loss Temperature for Node-40
0,0             ! [unconnected] Edge Loss Temperature for Node-41
0,0             ! [unconnected] Edge Loss Temperature for Node-42
0,0             ! [unconnected] Edge Loss Temperature for Node-43
0,0             ! [unconnected] Edge Loss Temperature for Node-44
0,0             ! [unconnected] Edge Loss Temperature for Node-45
0,0             ! [unconnected] Edge Loss Temperature for Node-46
0,0             ! [unconnected] Edge Loss Temperature for Node-47
0,0             ! [unconnected] Edge Loss Temperature for Node-48
0,0             ! [unconnected] Edge Loss Temperature for Node-49
0,0             ! [unconnected] Edge Loss Temperature for Node-50
0,0             ! [unconnected] Bottom Loss Temperature
0,0             ! [unconnected] Gas Flue Temperature
0,0             ! [unconnected] Inversion Mixing Flowrate
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
0,0              ! [unconnected] Auxiliary Heat Input for Node-21
0,0              ! [unconnected] Auxiliary Heat Input for Node-22
0,0              ! [unconnected] Auxiliary Heat Input for Node-23
0,0              ! [unconnected] Auxiliary Heat Input for Node-24
0,0              ! [unconnected] Auxiliary Heat Input for Node-25
0,0              ! [unconnected] Auxiliary Heat Input for Node-26
0,0              ! [unconnected] Auxiliary Heat Input for Node-27
0,0              ! [unconnected] Auxiliary Heat Input for Node-28
0,0              ! [unconnected] Auxiliary Heat Input for Node-29
0,0              ! [unconnected] Auxiliary Heat Input for Node-30
0,0              ! [unconnected] Auxiliary Heat Input for Node-31
0,0              ! [unconnected] Auxiliary Heat Input for Node-32
0,0              ! [unconnected] Auxiliary Heat Input for Node-33
0,0              ! [unconnected] Auxiliary Heat Input for Node-34
0,0              ! [unconnected] Auxiliary Heat Input for Node-35
0,0              ! [unconnected] Auxiliary Heat Input for Node-36
0,0              ! [unconnected] Auxiliary Heat Input for Node-37
0,0              ! [unconnected] Auxiliary Heat Input for Node-38
0,0              ! [unconnected] Auxiliary Heat Input for Node-39
0,0              ! [unconnected] Auxiliary Heat Input for Node-40
0,0              ! [unconnected] Auxiliary Heat Input for Node-41
0,0              ! [unconnected] Auxiliary Heat Input for Node-42
0,0              ! [unconnected] Auxiliary Heat Input for Node-43
0,0              ! [unconnected] Auxiliary Heat Input for Node-44
0,0              ! [unconnected] Auxiliary Heat Input for Node-45
0,0              ! [unconnected] Auxiliary Heat Input for Node-46
0,0              ! [unconnected] Auxiliary Heat Input for Node-47
0,0              ! [unconnected] Auxiliary Heat Input for Node-48
0,0              ! [unconnected] Auxiliary Heat Input for Node-49
0,0              ! [unconnected] Auxiliary Heat Input for Node-50
*** INITIAL INPUT VALUES
0 0 0 0 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20
20 20 20
20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 -1 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 0 0 0 0 0 0 0 0 0 0
DERIVATIVES 50
45               ! 1 Initial Tank Temperature-1
45               ! 2 Initial Tank Temperature-2
45               ! 3 Initial Tank Temperature-3
45               ! 4 Initial Tank Temperature-4
45               ! 5 Initial Tank Temperature-5
45               ! 6 Initial Tank Temperature-6
45               ! 7 Initial Tank Temperature-7
45               ! 8 Initial Tank Temperature-8
45               ! 9 Initial Tank Temperature-9
45               ! 10 Initial Tank Temperature-10
45               ! 11 Initial Tank Temperature-11
45               ! 12 Initial Tank Temperature-12
```

```
45              ! 13 Initial Tank Temperature-13
45              ! 14 Initial Tank Temperature-14
45              ! 15 Initial Tank Temperature-15
45              ! 16 Initial Tank Temperature-16
45              ! 17 Initial Tank Temperature-17
45              ! 18 Initial Tank Temperature-18
45              ! 19 Initial Tank Temperature-19
45              ! 20 Initial Tank Temperature-20
45              ! 21 Initial Tank Temperature-21
45              ! 22 Initial Tank Temperature-22
45              ! 23 Initial Tank Temperature-23
45              ! 24 Initial Tank Temperature-24
45              ! 25 Initial Tank Temperature-25
45              ! 26 Initial Tank Temperature-26
45              ! 27 Initial Tank Temperature-27
45              ! 28 Initial Tank Temperature-28
45              ! 29 Initial Tank Temperature-29
45              ! 30 Initial Tank Temperature-30
45              ! 31 Initial Tank Temperature-31
45              ! 32 Initial Tank Temperature-32
45              ! 33 Initial Tank Temperature-33
45              ! 34 Initial Tank Temperature-34
45              ! 35 Initial Tank Temperature-35
45              ! 36 Initial Tank Temperature-36
45              ! 37 Initial Tank Temperature-37
45              ! 38 Initial Tank Temperature-38
45              ! 39 Initial Tank Temperature-39
45              ! 40 Initial Tank Temperature-40
45              ! 41 Initial Tank Temperature-41
45              ! 42 Initial Tank Temperature-42
45              ! 43 Initial Tank Temperature-43
45              ! 44 Initial Tank Temperature-44
45              ! 45 Initial Tank Temperature-45
45              ! 46 Initial Tank Temperature-46
45              ! 47 Initial Tank Temperature-47
45              ! 48 Initial Tank Temperature-48
45              ! 49 Initial Tank Temperature-49
45              ! 50 Initial Tank Temperature-50
*** External files
ASSIGN "C:\Users\r_dumo\Dropbox\TRNSYS_docs\MyProjects\Solar
Air-source\Air_distribution\Tank\LargeTank_parameters.txt" 164
*|? Which file contains the parameter values for this component? |1000
*------------------------------------------------------------------------------

* Model "Tank SOC-Avg" (Type 1669)
*

UNIT 43 TYPE 1669        Tank SOC-Avg
*$UNIT_NAME Tank SOC-Avg
*$MODEL .\Controllers Library (TESS)\Proportional Controller\Type1669.tmf
*$POSITION 883 714
*$LAYER Main #
PARAMETERS 3
1               ! 1 Number of Signals
rate            ! 2 Maximum Rate of Increase
rate            ! 3 Maximum Rate of Decrease
INPUTS 3
T_full          ! [equation] Upper Setpoint Value
T_depleted              ! [equation] Lower Setpoint Value
Two_sensor_T_avg                ! TankSP:Two_sensor_T_avg ->Input Value
*** INITIAL INPUT VALUES
T_full T_depleted 25.0
*------------------------------------------------------------------------------
```

```
* Model "Tank SOC-Top" (Type 1669)
*

UNIT 44 TYPE 1669        Tank SOC-Top
*$UNIT_NAME Tank SOC-Top
*$MODEL .\Controllers Library (TESS)\Proportional Controller\Type1669.tmf
*$POSITION 765 714
*$LAYER Main #
PARAMETERS 3
1                ! 1 Number of Signals
rate             ! 2 Maximum Rate of Increase
rate             ! 3 Maximum Rate of Decrease
INPUTS 3
T_full           ! [equation] Upper Setpoint Value
T_depleted               ! [equation] Lower Setpoint Value
49,21            ! Type534:Tank Nodal Temperature-4 ->Input Value
*** INITIAL INPUT VALUES
T_full T_depleted 25.0
*------------------------------------------------------------------------------

* Model "Grid_solar" (Type 166)
*

UNIT 51 TYPE 166         Grid_solar
*$UNIT_NAME Grid_solar
*$MODEL .\Controllers\Simple Thermostat\Type166.tmf
*$POSITION 1116 585
*$LAYER Main #
*$# Simple Thermostat
PARAMETERS 2
1                ! 1 No. of oscillations permitted
17               ! 2 Temperature dead band
INPUTS 3
SOC_combined             ! TankSP:SOC_combined ->Monitoring temperature
0,0              ! [unconnected] Heating setpoint
0,0              ! [unconnected] Cooling setpoint
*** INITIAL INPUT VALUES
2 90 900
*------------------------------------------------------------------------------

* Model "Type939" (Type 939)
*

UNIT 52 TYPE 939         Type939
*$UNIT_NAME Type939
*$MODEL .\Utility Library (TESS)\Running Totals and Averages\Type939.tmf
*$POSITION 678 340
*$LAYER Main #
*$# Running Totals and Averages
PARAMETERS 3
1                ! 1 Number of Inputs to Watch
1                ! 2 Time Period
0.               ! 3 Average Value for Input
INPUTS 1
38,5             ! Type569-3:Power Production ->Input Value
*** INITIAL INPUT VALUES
0.
*------------------------------------------------------------------------------

* Model "System_Plotter-5" (Type 65)
*
```

```
UNIT 53 TYPE 65  System_Plotter-5
*$UNIT_NAME System_Plotter-5
*$MODEL \TRNSYS18\Studio\lib\System_Output\TYPE65d.tmf
*$POSITION 1240 805
*$LAYER OutputSystem #
PARAMETERS 12
3               ! 1 Nb. of left-axis variables
2               ! 2 Nb. of right-axis variables
0.0             ! 3 Left axis minimum
100             ! 4 Left axis maximum
0.0             ! 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
TDB             ! TankSP:TDB ->Left axis variable-1
TankSOCSetpoint         ! TankSP:TankSOCSetpoint ->Left axis variable-2
SOC_combined            ! TankSP:SOC_combined ->Left axis variable-3
HPSignal                ! TankSP:HPSignal ->Right axis variable-1
SOC_combined            ! [equation] Right axis variable-2
*** INITIAL INPUT VALUES
TDB TankSP SOC Control SOC_combined
LABELS  3
"Temperatures"
"Heat transfer rates"
"Graph 1"
*------------------------------------------------------------------------------

* Model "Grid_-1" (Type 166)
*

UNIT 54 TYPE 166         Grid_-1
*$UNIT_NAME Grid_-1
*$MODEL .\Controllers\Simple Thermostat\Type166.tmf
*$POSITION 1190 586
*$LAYER Main #
*$# Simple Thermostat
PARAMETERS 2
1               ! 1 No. of oscillations permitted
77              ! 2 Temperature dead band
INPUTS 3
SOC_combined            ! TankSP:SOC_combined ->Monitoring temperature
0,0             ! [unconnected] Heating setpoint
0,0             ! [unconnected] Cooling setpoint
*** INITIAL INPUT VALUES
2 40 900
*------------------------------------------------------------------------------

* Model "Grid_0" (Type 166)
*

UNIT 55 TYPE 166         Grid_0
*$UNIT_NAME Grid_0
*$MODEL .\Controllers\Simple Thermostat\Type166.tmf
*$POSITION 1254 586
*$LAYER Main #
*$# Simple Thermostat
PARAMETERS 2
1               ! 1 No. of oscillations permitted
```

```
77              ! 2 Temperature dead band
INPUTS 3
SOC_combined            ! TankSP:SOC_combined ->Monitoring temperature
0,0             ! [unconnected] Heating setpoint
0,0             ! [unconnected] Cooling setpoint
*** INITIAL INPUT VALUES
2 60 900
*------------------------------------------------------------------------------

* Model "Grid_1" (Type 166)
*

UNIT 56 TYPE 166         Grid_1
*$UNIT_NAME Grid_1
*$MODEL .\Controllers\Simple Thermostat\Type166.tmf
*$POSITION 1318 586
*$LAYER Main #
*$# Simple Thermostat
PARAMETERS 2
1               ! 1 No. of oscillations permitted
47              ! 2 Temperature dead band
INPUTS 3
SOC_combined            ! TankSP:SOC_combined ->Monitoring temperature
0,0             ! [unconnected] Heating setpoint
0,0             ! [unconnected] Cooling setpoint
*** INITIAL INPUT VALUES
2 75 900
*------------------------------------------------------------------------------

* EQUATIONS "Power_consumption"
*
EQUATIONS 11
Fan_coilW = [11,8]/3.6
Load_pumpW = [46,3]/3.6
HP_pumpW = [58,3]/3.6
HPW = [42,15]/3.6
Buying_op_power = EQL(Grid_state,1)*Total_power
Selling_op_power = EQL(Grid_state,-1)*Total_power
Normal_op_power = EQL(Grid_state,0)*Total_power
Total_power = HP_pumpW+HPW+Load_pumpW+Fan_coilW+DHW_W+Elec_Occ_W
DHW_W = [60,4]/3.6
Elec_Occ_W = [60,4]/3.6
Pumps_totalW = Load_pumpW+HP_pumpW
*$UNIT_NAME Power_consumption
*$LAYER Main
*$POSITION 833 650
*$UNIT_NUMBER 57

*------------------------------------------------------------------------------


* Model "Type114" (Type 114)
*

UNIT 58 TYPE 114         Type114
*$UNIT_NAME Type114
*$MODEL .\Hydronics\Pumps\Single Speed\Type114.tmf
*$POSITION 241 394
*$LAYER Main #
*$# SINGLE-SPEED PUMP
PARAMETERS 4
1400            ! 1 Rated flow rate
4.19            ! 2 Fluid specific heat
```

```
631             ! 3 Rated power
0.0             ! 4 Motor heat loss fraction
INPUTS 5
49,3            ! Type534:Temperature at Outlet-2 ->Inlet fluid temperature
0,0             ! [unconnected] Inlet fluid flow rate
HPSignal                ! TankSP:HPSignal ->Control signal
0,0             ! [unconnected] Overall pump efficiency
0,0             ! [unconnected] Motor efficiency
*** INITIAL INPUT VALUES
20.0 1000 1.0 0.6 0.9
*------------------------------------------------------------------------------

* Model "System_Plotter-6" (Type 65)
*

UNIT 59 TYPE 65  System_Plotter-6
*$UNIT_NAME System_Plotter-6
*$MODEL \TRNSYS18\Studio\lib\System_Output\TYPE65d.tmf
*$POSITION 1390 805
*$LAYER OutputSystem #
PARAMETERS 12
8               ! 1 Nb. of left-axis variables
2               ! 2 Nb. of right-axis variables
0.0             ! 3 Left axis minimum
5000            ! 4 Left axis maximum
0.0             ! 5 Right axis minimum
1000.0          ! 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 10
Fan_coilW               ! Power_consumption:Fan_coilW ->Left axis variable-1
Load_pumpW              ! Power_consumption:Load_pumpW ->Left axis variable-2
HP_pumpW                ! Power_consumption:HP_pumpW ->Left axis variable-3
HPW             ! Power_consumption:HPW ->Left axis variable-4
Total_power             ! Power_consumption:Total_power ->Left axis variable-5
Buying_op_power         ! Power_consumption:Buying_op_power ->Left axis variable-6
Selling_op_power                ! Power_consumption:Selling_op_power ->Left axis
variable-7
Normal_op_power         ! Power_consumption:Normal_op_power ->Left axis variable-8
0,0             ! [unconnected] Right axis variable-1
0,0             ! [unconnected] Right axis variable-2
*** INITIAL INPUT VALUES
Fan_coilW Load_pumpW HP_pumpW HPW Total_power Buying_op_power Selling_op_power
Normal_op_power label label
LABELS  3
"Power(W)"
"Heat transfer rates"
Power
*------------------------------------------------------------------------------

* Model "DHW & Occupants Elec. Loads" (Type 9)
*

UNIT 60 TYPE 9   DHW & Occupants Elec. Loads
*$UNIT_NAME DHW & Occupants Elec. Loads
*$MODEL .\Utility\Data Readers\Generic Data Files\First Line is Simulation
Start\Free Format\Type9a.tmf
*$POSITION 298 383
*$LAYER Main #
```

```
PARAMETERS 22
2                ! 1 Mode
0                ! 2 Header Lines to Skip
4                ! 3 No. of values to read
1.0              ! 4 Time interval of data
1                ! 5 Interpolate or not?-1
1.0              ! 6 Multiplication factor-1
0                ! 7 Addition factor-1
1                ! 8 Average or instantaneous value-1
1                ! 9 Interpolate or not?-2
1.0              ! 10 Multiplication factor-2
0                ! 11 Addition factor-2
1                ! 12 Average or instantaneous value-2
1                ! 13 Interpolate or not?-3
1.0              ! 14 Multiplication factor-3
0                ! 15 Addition factor-3
1                ! 16 Average or instantaneous value-3
1                ! 17 Interpolate or not?-4
1.0              ! 18 Multiplication factor-4
0                ! 19 Addition factor-4
1                ! 20 Average or instantaneous value-4
165              ! 21 Logical unit for input file
-1               ! 22 Free format mode
*** External files
ASSIGN "C:\Users\r_dumo\Dropbox\TRNSYS_docs\MyProjects\Solar
Air-source\Air_distribution\DHW and Occupants Loads\DHW_and_occupants_loads.txt" 165
*|? Input file name |1000
*-------------------------------------------------------------------------------

* Model "System_Plotter" (Type 65)
*

UNIT 41 TYPE 65  System_Plotter
*$UNIT_NAME System_Plotter
*$MODEL \TRNSYS18\Studio\lib\System_Output\TYPE65d.tmf
*$POSITION 1468 100
*$LAYER OutputSystem #
PARAMETERS 12
2                ! 1 Nb. of left-axis variables
2                ! 2 Nb. of right-axis variables
0.0              ! 3 Left axis minimum
1000.0           ! 4 Left axis maximum
0.0              ! 5 Right axis minimum
1000.0           ! 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 4
14,9             ! Type760:Fresh Air Flowrate  ->Left axis variable-1
16,2             ! Free cooling:Control signal for cooling ->Left axis variable-2
0,0              ! [unconnected] Right axis variable-1
0,0              ! [unconnected] Right axis variable-2
*** INITIAL INPUT VALUES
Fresh Control label label
LABELS  3
"Temperatures"
"Heat transfer rates"
"Graph 1"
*-------------------------------------------------------------------------------
```

```
* EQUATIONS "Power_production"
*
EQUATIONS 4
TotalPowerProd = 5*[38,5]+[50,2]
TotalPowerProd_W = TotalPowerProd/3.6
BIPVprodW = [50,2]/3.6
BIPVTprodW = 5*[38,5]/3.6
*$UNIT_NAME Power_production
*$LAYER Main
*$POSITION 828 724
*$UNIT_NUMBER 45

*------------------------------------------------------------------------------


* Model "Type562h" (Type 562)
*

UNIT 50 TYPE 562         Type562h
*$UNIT_NAME Type562h
*$MODEL .\Electrical Library (TESS)\Simple PV Models\Not Covered\PV Efficiency
Modifiers\Type562h.tmf
*$POSITION 470 505
*$LAYER Main #
PARAMETERS 12
2               ! 1 PV Efficiency Mode
0               ! 2 Cover Mode
30              ! 3 Area
0.44            ! 4 Back Resistance
0.9             ! 5 Top Emissivity
0.9             ! 6 Back Emissivity
0.9             ! 7 Absorptance
0.16            ! 8 Reference PV Efficiency
25.0            ! 9 Reference Temperature
3600.0          ! 10 Reference Radiation
-0.005          ! 11 Efficiency Modifier - Temperature
0.000025                ! 12 Efficiency Modifier - Radiation
INPUTS 7
10,1            ! Type15-3:Dry bulb temperature ->Ambient Temperature
10,4            ! Type15-3:Effective sky temperature ->Sky Temperature
Zone_temp               ! Back_temp and topHeatLoss:Zone_temp ->Zone Temperature
Zone_temp               ! Back_temp and topHeatLoss:Zone_temp ->Back Radiant
Temperature
TopHeatLoss             ! Back_temp and topHeatLoss:TopHeatLoss ->Top Heat Loss
Coefficient
0,0             ! [unconnected] Bottom Heat Loss Coefficient
10,24           ! Type15-3:Total tilted surface radiation for surface ->Incident
Solar Radiation
*** INITIAL INPUT VALUES
10.0 10.0 20.0 20.0 25.0 11.0 0.
*------------------------------------------------------------------------------

* Model "Type1502" (Type 1502)
*

UNIT 61 TYPE 1502        Type1502
*$UNIT_NAME Type1502
*$MODEL .\Controllers Library (TESS)\Simple Thermostat\Simple Heating
Thermostat\Type1502.tmf
*$POSITION 1086 565
*$LAYER Main #
PARAMETERS 4
1               ! 1 Number of Heating Stages
```

```
5               ! 2 # Oscillations Permitted
2.0             ! 3 Temperature Dead Band
0               ! 4 Number of Stage Exceptions
INPUTS 3
Average_Zone_temp               ! Ventilation_Parameters:Average_Zone_temp ->Fluid
Temperature
0,0             ! [unconnected] Lockout Signal
T_SP_Heating            ! [unconnected] Setpoint Temperature for Stage
*** INITIAL INPUT VALUES
20.0 0 T_SP_Heating
*------------------------------------------------------------------------------

* Model "Type1503" (Type 1503)
*

UNIT 62 TYPE 1503        Type1503
*$UNIT_NAME Type1503
*$MODEL .\Controllers Library (TESS)\Simple Thermostat\Simple Cooling
Thermostat\Type1503.tmf
*$POSITION 1086 640
*$LAYER Main #
PARAMETERS 4
1               ! 1 Number of Cooling Stages
5               ! 2 # Oscillations Permitted
2.0             ! 3 Temperature Dead Band
0               ! 4 Number of Stage Exceptions
INPUTS 3
Average_Zone_temp               ! Ventilation_Parameters:Average_Zone_temp ->Fluid
Temperature
0,0             ! [unconnected] Lockout Signal
T_SP_cooling            ! [equation] Setpoint Temperature for Stage
*** INITIAL INPUT VALUES
20.0 0 T_SP_cooling
*------------------------------------------------------------------------------

* Model "P-controller_heat" (Type 23)
*

UNIT 63 TYPE 23  P-controller_heat
*$UNIT_NAME P-controller_heat
*$MODEL .\Controllers\PID Controller\Type23.tmf
*$POSITION 1091 724
*$LAYER Main #
PARAMETERS 2
0               ! 1 Mode
0               ! 2 Maximum number of oscillations
INPUTS 13
T_SP_heating            ! [equation] Setpoint
Average_Zone_temp               ! Ventilation_Parameters:Average_Zone_temp
->Controlled variable
0,0             ! [unconnected] On / Off signal
0,0             ! [unconnected] Minimum control signal
0,0             ! [unconnected] Maximum control signal
0,0             ! [unconnected] Threshold for non-zero output
Gain_heat               ! [equation] Gain constant
0,0             ! [unconnected] Integral time
0,0             ! [unconnected] Derivative time
0,0             ! [unconnected] Tracking time for anti-windup
0,0             ! [unconnected] Fraction of ySet for proportional effect
0,0             ! [unconnected] Fraction of ySet for derivative effect
0,0             ! [unconnected] High-frequency limit on derivative
*** INITIAL INPUT VALUES
T_SP_heating 0 1 -1 1 0 Gain_heat 0 0 -1 1 1 10
```

```
*------------------------------------------------------------------------------

* Model "P-controller_cool" (Type 23)
*

UNIT 64 TYPE 23  P-controller_cool
*$UNIT_NAME P-controller_cool
*$MODEL .\Controllers\PID Controller\Type23.tmf
*$POSITION 1093 799
*$LAYER Main #
PARAMETERS 2
0               ! 1 Mode
0               ! 2 Maximum number of oscillations
INPUTS 13
T_SP_cooling            ! [equation] Setpoint
Average_Zone_temp               ! Ventilation_Parameters:Average_Zone_temp
->Controlled variable
0,0             ! [unconnected] On / Off signal
0,0             ! [unconnected] Minimum control signal
0,0             ! [unconnected] Maximum control signal
0,0             ! [unconnected] Threshold for non-zero output
Gain_cool               ! [equation] Gain constant
0,0             ! [unconnected] Integral time
0,0             ! [unconnected] Derivative time
0,0             ! [unconnected] Tracking time for anti-windup
0,0             ! [unconnected] Fraction of ySet for proportional effect
0,0             ! [unconnected] Fraction of ySet for derivative effect
0,0             ! [unconnected] High-frequency limit on derivative
*** INITIAL INPUT VALUES
T_SP_cooling 0 1 -1 1 0.1 Gain_cool 0 0 -1 1 1 10
*------------------------------------------------------------------------------

* Model "Type24" (Type 24)
*

UNIT 65 TYPE 24  Type24
*$UNIT_NAME Type24
*$MODEL .\Utility\Integrators\Quantity Integrator\Type24.tmf
*$POSITION 1015 773
*$LAYER Main #
PARAMETERS 2
STOP            ! 1 Integration period
0               ! 2 Relative or absolute start time
INPUTS 1
HPW             ! Power_consumption:HPW ->Input to be integrated
*** INITIAL INPUT VALUES
0.0
*------------------------------------------------------------------------------

* Model "Type25c" (Type 25)
*

UNIT 66 TYPE 25  Type25c
*$UNIT_NAME Type25c
*$MODEL .\Output\Printer\Unformatted\No Units\Type25c.tmf
*$POSITION 879 826
*$LAYER Outputs #
PARAMETERS 10
STEP            ! 1 Printing interval
START           ! 2 Start time
STOP            ! 3 Stop time
166             ! 4 Logical unit
0               ! 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 20
HPW             ! Power_consumption:HPW ->Input to be printed-1
Fan_coilW               ! Power_consumption:Fan_coilW ->Input to be printed-2
Pumps_totalW            ! Power_consumption:Pumps_totalW ->Input to be printed-3
Elec_Occ_W              ! Power_consumption:Elec_Occ_W ->Input to be printed-4
DHW_W           ! Power_consumption:DHW_W ->Input to be printed-5
BIPVprodW               ! Power_production:BIPVprodW ->Input to be printed-6
BIPVTprodW              ! Power_production:BIPVTprodW ->Input to be printed-7
Grid_state              ! Grid-State:Grid_state ->Input to be printed-8
SOC_combined            ! TankSP:SOC_combined ->Input to be printed-9
42,9            ! Type941:Heating Heat Transfer to Liquid ->Input to be printed-10
11,11           ! Heating:Total Heat Transfer to Air ->Input to be printed-11
TotalPowerProd_W                ! Power_production:TotalPowerProd_W ->Input to be
printed-12
Total_power             ! Power_consumption:Total_power ->Input to be printed-13
Average_Zone_temp               ! Ventilation_Parameters:Average_Zone_temp ->Input
to be printed-14
0,0             ! [unconnected] Input to be printed-15
0,0             ! [unconnected] Input to be printed-16
0,0             ! [unconnected] Input to be printed-17
0,0             ! [unconnected] Input to be printed-18
0,0             ! [unconnected] Input to be printed-19
0,0             ! [unconnected] Input to be printed-20
*** INITIAL INPUT VALUES
HPPowerW FansPowerW PumpsPowerW OccupantsPowerW DHWPowerW BIPVPowerW
BIPVTPowerW GridState TESSOC HeatdeliveredHP HeatdeliveredAHU TotalPowerProdW
TotalPowerConsW Tavgzone HPPowerW HPPowerW HPPowerW HPPowerW HPPowerW
HPPowerW
*** External files
ASSIGN "Outputfile.txt" 166
*|? Output file for printed results |1000
*------------------------------------------------------------------------------

* Model "System_Plotter-2" (Type 65)
*

UNIT 67 TYPE 65  System_Plotter-2
*$UNIT_NAME System_Plotter-2
*$MODEL \TRNSYS18\Studio\lib\System_Output\TYPE65d.tmf
*$POSITION 1720 100
*$LAYER OutputSystem #
PARAMETERS 12
2               ! 1 Nb. of left-axis variables
2               ! 2 Nb. of right-axis variables
0.0             ! 3 Left axis minimum
1000.0          ! 4 Left axis maximum
0.0             ! 5 Right axis minimum
24              ! 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 4
Grid_state              ! Grid-State:Grid_state ->Left axis variable-1
Solar_power_mode                ! Grid-State:Solar_power_mode ->Left axis variable-2
3,11            ! Type21:Hour of the day ->Right axis variable-1
```

```
0,0             ! [unconnected] Right axis variable-2
*** INITIAL INPUT VALUES
Grid_state Solar_power_mode Hour label
LABELS  3
"Temperatures"
"Heat transfer rates"
"Graph 1"
*------------------------------------------------------------------------------


END
*!LINK_STYLE
*!LINK -1:66
*!CONNECTION_SET 32:32:0:20:8:0:0:0:1:357,300:835,300:835,820:862,820
*!CONNECTION_SET 32:32:0:0:11,14:0:0:0:1:699,501:835,501:835,800:862,800
*!CONNECTION_SET
0:32:20:0:13,12,7,5,4,3,1,2,6:0:0:0:1:1013,653:899,653:899,792:922,792:922,802:880,8
02
*!LINK 50:66
*!CONNECTION_SET 0:32:0:20:9,10:0:0:0:1:438,429:389,429:389,822:864,822
*!LINK -1:7
*!CONNECTION_SET 32:32:0:20:14:0:0:0:1:1047,651:1179,651:1179,885:1207,885
*!CONNECTION_SET 16:32:0:40:1:0:0:0:1:151,75:151,107:1179,107:1179,905:1207,905
*!CONNECTION_SET 16:32:0:40:10:0:0:0:1:340,300:340,332:1179,332:1179,905:1207,905
*!CONNECTION_SET 32:16:0:0:6,13:0:0:0:1:699,485:1179,485:1179,865:1207,865
*!CONNECTION_SET 32:16:0:40:5:0:0:0:1:699,485:1179,485:1179,905:1207,905
*!CONNECTION_SET 32:16:0:20:11:0:0:0:1:699,485:1179,485:1179,885:1207,885
*!LINK 65:7
*!CONNECTION_SET 40:20:0:0:12:0:0:0:1:1038,767:1179,767:1179,865:1207,865
*!LINK -1:65
*!CONNECTION_SET 16:32:0:0:1:0:0:0:1:1031,651:1031,683:974,683:974,747:998,747
*!LINK -1:-1
*!CONNECTION_SET 32:16:0:0:15,16:0:0:0:1:238,176:263,176:263,619:1015,619
*!CONNECTION_SET 32:16:0:16:14,13:0:0:0:1:361,144:901,144:901,635:1015,635
*!CONNECTION_SET 16:32:16:0::0:0:0:1:138,75:138,107:209,107:209,160
*!CONNECTION_SET 16:32:16:0::0:0:0:1:212,192:212,224:330,224:330,267
*!CONNECTION_SET 16:32:16:0:12:0:0:0:1:337,300:337,332:1028,332:1028,619
*!CONNECTION_SET 16:32:0:16::0:0:0:1:150,75:150,107:610,107:610,485:666,485
*!CONNECTION_SET 16:32:0:16::0:0:0:1:339,300:339,332:610,332:610,485:666,485
*!CONNECTION_SET 32:16:16:0:8,7:0:0:0:1:698,485:1030,485:1030,619
*!LINK -1:50
*!CONNECTION_SET 16:32:0:32:26:0:0:0:1:222,192:222,427:436,427
*!CONNECTION_SET 16:32:0:16:27:0:0:0:1:149,75:149,411:434,411
*!CONNECTION_SET 16:32:0:16:154,162:0:0:0:1:335,296:335,328:382,328:382,407:431,407
*!CONNECTION_SET
32:16:0:16:42,41,167,168:0:0:0:1:698,485:755,485:755,385:386,385:386,411:435,411
*!LINK 48:46
*!CONNECTION_SET 20:40:20:0:3:0:0:0:1:529,479:529,503:710,503:710,610:668,610
*!LINK 49:46
*!CONNECTION_SET 40:0:0:0:1:0:0:0:1:422,706:444,706:444,615:633,615:633,610:660,610
*!LINK 49:40
*!CONNECTION_SET 40:40:0:0:6,5:0:0:0:1:411,746:760,746:760,461:778,461
*!LINK 40:42
*!CONNECTION_SET 0:20:19:0:9:0:0:0:1:789,481:599,481:599,396:369,396:369,407
*!LINK 40:51
*!CONNECTION_SET
40:40:40:0:1:0:0:0:1:815,503:1103,503:1103,708:1104,708:1104,718:1080,718
*!LINK 49:58
*!CONNECTION_SET 0:40:0:0:1:0:0:0:1:382,746:355,746:355,615:153,615:153,525:180,525
*!LINK 49:44
*!CONNECTION_SET 20:40:20:0:3:0:0:0:1:389,745:708,745:708,844
*!LINK 40:58
*!CONNECTION_SET 0:20:40:0:3:0:0:0:1:789,481:771,481:771,525:220,525
*!LINK 40:43
```

```
*!CONNECTION_SET 20:0:20:0:3:0:0:0:1:792,455:792,445:828,445:828,828:822,828:822,839
*!LINK 42:49
*!CONNECTION_SET
38:39:20:0:4,3:0:0:0:1:383,448:407,448:407,544:468,544:468,708:397,708
*!LINK 44:40
*!CONNECTION_SET
20:40:0:0:8:0:0:0:1:710,885:710,908:655,908:655,689:760,689:760,461:778,461
*!LINK 58:42
*!CONNECTION_SET 40:40:0:0:2,1:0:0:0:1:87,1116:109,1116:109,958:217,958
*!LINK 43:40
*!CONNECTION_SET 40:40:0:0:7:0:0:0:1:845,887:882,887:882,841:757,841:757,463:775,463
*!LINK 56:40
*!CONNECTION_SET
20:40:0:0:12:0:0:0:1:1267,757:1309,757:1309,451:761,451:761,461:779,461
*!LINK 51:40
*!CONNECTION_SET
20:40:20:0:10:0:0:0:1:1064,762:1064,786:835,786:835,456:799,456:799,467
*!LINK 55:40
*!CONNECTION_SET 20:40:20:0:13:0:0:0:1:1125,758:1167,758:1167,451:721,451:721,462
*!LINK 40:54
*!CONNECTION_SET 40:40:20:0:1:0:0:0:1:818,501:1156,501:1156,717:1138,717
*!LINK 40:56
*!CONNECTION_SET 40:40:20:0:1:0:0:0:1:817,501:1307,501:1307,717:1265,717
*!LINK 40:55
*!CONNECTION_SET 40:40:20:0:1:0:0:0:1:820,501:1222,501:1222,717:1204,717
*!LINK 54:40
*!CONNECTION_SET 20:40:20:0:11:0:0:0:1:1137,759:1179,759:1179,452:797,452:797,463
*!LINK 5:-1
*!CONNECTION_SET 20:40:16:0:6,5,4,3,2,1:0:0:0:1:825,220:1030,220:1030,618
*!CONNECTION_SET 40:40:0:16::0:0:0:1:845,221:864,221:864,459:610,459:610,485:666,485
*!LINK -1:5
*!CONNECTION_SET 32:16:0:0:15,14:0:0:0:1:340,146:761,146:761,183:785,183
*!CONNECTION_SET
16:32:0:0:7,5,2,3,4,13,12,11,10,9,1,6,8:0:0:0:1:137,75:137,107:768,107:768,181:792,1
81
*!CONNECTION_SET
32:16:0:0:18,17,22,20,23,24,21,19,16:0:0:0:1:698,485:781,485:781,181:805,181
*!LINK 19:20
*!CONNECTION_SET 40:20:0:20:1:0:0:0:1:165,89:299,89:299,169:362,169
*!LINK 10:20
*!CONNECTION_SET 40:20:0:40:3,2:0:0:0:1:155,201:299,201:299,189:362,189
*!LINK 47:50
*!CONNECTION_SET 20:40:0:25:5,4,3:0:0:0:1:290,354:290,378:421,378:421,499:452,499
*!LINK 38:52
*!CONNECTION_SET 50:50:0:0:1:0:0:0:1:340,1149:468,1149:468,1109:495,1109
*!LINK 47:38
*!CONNECTION_SET 40:20:0:25:9,6,5:0:0:0:1:144,1129:258,1129:258,1124:290,1124
*!LINK 3:2
*!CONNECTION_SET 40:0:20:40:3:0:0:0:1:519,492:548,492:548,497:650,497:650,468
*!LINK 17:2
*!CONNECTION_SET 16:0:20:0:1,2:0:0:0:1:500,417:500,406:650,406:650,428
*!LINK 50:-1
*!CONNECTION_SET
32:16:16:0:11,10,9:0:0:0:1:466,411:516,411:516,608:1029,608:1029,619
*!CONNECTION_SET 32:16:0:16::0:0:0:1:467,411:610,411:610,485:666,485
*!LINK 64:13
*!CONNECTION_SET 0:0:40:40:2:0:0:0:1:1073,773:915,773:915,520:842,520
*!LINK 63:13
*!CONNECTION_SET 0:20:40:40:1:0:0:0:1:1071,718:915,718:915,520:842,520
*!LINK 15:64
*!CONNECTION_SET 20:0:40:20:2:0:0:0:1:540,256:540,245:1156,245:1156,793:1113,793
*!LINK 15:63
*!CONNECTION_SET 20:0:40:20:2:0:0:0:1:540,256:540,245:1154,245:1154,718:1111,718
```

```
*!LINK 15:62
*!CONNECTION_SET 20:0:42:21:1:0:0:0:1:540,256:540,245:1134,245:1134,634:1111,634
*!LINK 15:61
*!CONNECTION_SET 20:0:21:0:1:0:0:0:1:540,256:540,245:1134,245:1134,538:1090,538
*!LINK 11:13
*!CONNECTION_SET
37:19:0:20:3:4227072:3:0:1:832,531:867,531:867,572:723,572:723,602:796,602
*!LINK 13:11
*!CONNECTION_SET
0:20:37:19:14,7:4227072:3:0:1:801,601:728,601:728,501:873,501:873,530:837,530
*!LINK 16:15
*!CONNECTION_SET 20:40:40:40:7:0:0:0:1:724,243:724,267:595,267:595,216:537,216
*!LINK 15:16
*!CONNECTION_SET 40:0:20:0:1:0:0:0:1:537,176:724,176:724,203
*!LINK 15:14
*!CONNECTION_SET 0:20:0:20:14,1,10,4:0:0:0:1:497,196:439,196:439,297:500,297
*!LINK 15:13
*!CONNECTION_SET 0:20:40:0:5:0:0:0:1:520,276:462,276:462,470:773,470:773,480:842,480
*!LINK -1:41
*!CONNECTION_SET 32:16:0:20:1,2:0:0:0:1:699,485:1411,485:1411,94:1448,94
*!LINK -1:37
*!CONNECTION_SET
16:32:0:20:1,2,3,4,5,6,7,8,9,10:0:0:0:1:1031,651:1031,683:1508,683:1508,735:1550,735
*!LINK -1:59
*!CONNECTION_SET
16:32:0:20:1,2,3,4,5,6,7,8:0:0:0:1:1031,651:1031,683:1328,683:1328,799:1370,799
*!LINK 5:7
*!CONNECTION_SET 20:40:0:40:4,3,2:0:0:0:1:826,221:1179,221:1179,905:1207,905
*!LINK 50:53
*!CONNECTION_SET 32:16:0:20:3,1,2,4:0:0:0:1:468,411:1178,411:1178,799:1220,799
*!LINK 50:7
*!CONNECTION_SET 32:16:0:20:15:0:0:0:1:468,411:1179,411:1179,885:1207,885
*!LINK -1:67
*!CONNECTION_SET 32:16:0:20:2,1,3:0:0:0:1:357,283:1658,283:1658,94:1700,94
*!LINK_STYLE_END
*!TEXT_COMPONENT 1394:1210:1394:1210:1898:1362:Times New
Roman:10:13:0:400:0:0:0:0:0:0:1:0:4:1
*The system is modeled as a residential air handler sensing one average room
temperature as its input. The temperature of the supply air is set to 30 deg C and
12 deg C in heating and cooling mode respectively. The control signal is varied
between 0 an 1 proportionally. The signal is sent to a variable speed fan. The gain
is set to 1 so that the signal reaches 1.0 when the temperature is 1 dec C away from
the setpoint.
*!TEXT_COMPONENT_END
*!TEXT_COMPONENT 1394:944:1394:944:1898:1050:Times New
Roman:10:13:0:400:0:0:0:0:0:0:1:0:4:1
*Based on the time of day and the period of the year (Nov.1 to May 1 is heating
season, May 1 to Nov 1 is cooling season), a grid state is defined. A signal of 0 is
mid-peak/normal operation period. A signal of 1 is a buying opportunity/off-peak
event and a signal of -1 is a peak/selling opportunity event.
*!TEXT_COMPONENT_END
*!TEXT_COMPONENT 1394:1072:1394:1072:1898:1178:Times New
Roman:10:13:0:400:0:0:0:0:0:0:1:0:4:1
*Good winter sunny, cold day is Feb. 4
*Good summer hot day, mild night is July 20
*!TEXT_COMPONENT_END
```