A STUDY ON COMBINATION OF ELECTRICAL HEATER, EXHAUST AIR HEAT RECOVERY UNIT AND SOLAR ENERGY ASSISTED SYSTEM FOR BUILDING VENTILATION

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Gamze ÖZYOĞURTÇU

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We approve the thesis of **Gamze ÖZYOĞURTÇU**

Examining Committee Members:

Assoc. Prof. Dr. Moghtada MOBEDİ
Department of Mechanical Engineering,
İzmir Institute of Technology

Assist. Prof. Dr. Ünver ÖZKOL
Department of Mechanical Engineering,
İzmir Institute of Technology

Assoc. Prof. Dr. Serhan KÜÇÜKA
Department of Mechanical Engineering,
Dokuz Eylül University

04 July 2012

Assoc. Prof. Dr. Moghtada MOBEDİ
Supervisor, Department of
Mechanical Engineering,
İzmir Institute of Technology

Prof. Dr. M. Barış ÖZERDEM
Co-Supervisor, Department of
Energy Systems Engineering,
Bahçeşehir University

Prof. Dr. Metin TANOĞLU
Head of the Department of
Mechanical Engineering

Prof. Dr. R. Tuğrul SENGER
Dean of the Graduate School of
Engineering and Sciences

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Last but not least I leave my beloved little ones, one no longer with us, ones still with me. The most beautiful place in my heart will always be yours.

ABSTRACT

A STUDY ON COMBINATION OF ELECTRICAL HEATER, EXHAUST AIR HEAT RECOVERY UNIT AND SOLAR ENERGY ASSISTED SYSTEM FOR BUILDING VENTILATION

A study on the ventilation of a building by using solar energy, a heat recovery unit and electrical heater (if it is needed) is performed. The heat recovery unit is used to increase temperature of fresh air by using thermal energy of the return air. Then, the thermal energy stored in a sensible tank is employed to increase the temperature of air leaving the heat recovery unit. If the air temperature at the coil outlet is less than the supply temperature, electrical heater is operated. The study is performed by TRNSYS software for the period of 1st of November to 31st of March. The ventilation system operates from 17:00 to 24:00 where a lower ambient temperature exists compared during the day period. The obtained results show that a ventilation system with solar assisted and heat recovery unit can considerably reduce ventilation energy consumption. The use of solar assisted ventilation system with heat recovery unit reduces energy consumption by 80% if it is compared with conventional ventilation system in which only an electrical heater operates. Furthermore, it is found that the design of ventilation systems without energy of electrical heater is possible. The study s performed by using weather data of Izmir city in Turkey. The supply temperature of fresh air is assumed as 22°C.

ÖZET

ELEKTRİK ISITICILI, ISI GERİ KAZANIM ÜNİTELİ VE GÜNEŞ ENERJİSİ DESTEKLİ BÜTÜNLEŞİK BİR SİSTEM İLE BİNA HAVALANDIRMASI ÜZERİNE BİR ÇALIŞMA

Bu çalışma bir binanın güneş enerjisi, ısı geri kazanım ünitesi ve gerekli olduğu durumlarda elektrikli ısıtıcı kullanarak havalandırması üzerine gerçekleştirilmiştir. Isı geri kazanım ünitesi, dönüş havasının enerjisini kullanarak taze havanın sıcaklığını yükseltmek için kullanılmıştır. Daha sonra termal enerji, duyulur bir tankta depolanarak, ısı geri kazanım ünitesinden çıkan havanın sıcaklığını yükseltmek üzere kullanılmıştır. Eğer ısıtma bataryasından çıkan havanın sıcaklığı üfleme sıcaklığından daha düşük ise elektrikli ısıtıcı devreye girmektedir. Bu çalışma TRNSYS yazılımı kullanılarak 1 Kasım 31 Mart arasındaki dönem için gerçekleştirilmiştir. Havalandırma sistemi saat 17:00 ile 24:00 arasında, gündüze göre daha düşük bir dış ortam sıcaklığının olduğu zaman aralığında çalışmaktadır. Elde edilen sonuçlar, güneş enerjisi ve ısı geri kazanım ünitesiyle kombine edilen sistemin havalandırma için harcanan enerji tüketimini düşürdüğünü göstermiştir. Güneş enerjisi ve ısı geri kazanımla desteklenen havalandırma sistemi, sadece elektrikli ısıtıcının kullanıldığı geleneksel havalandırma sistemlerine göre enerji tüketimini %80 düşürmektedir. Bunun yanında bu çalışmada, elektrikli ısıtıcı kullanılmadığı havalandırma sistemlerinin tasarımının da mümkün olduğu görülmüştür. Bu çalışma Türkiye'nin İzmir şehrine ait iklim verileri kullanılarak gerçekleştirilmiştir. Üfleme sıcaklığı 22°C olarak kabul edilmiştir.

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CHAPTER 1

INTRODUCTION

Many people live, work, study or spend their leisure time in buildings having heating, ventilation and air conditioning (HVAC) System in order to provide hot/cold, fresh, and clean indoor air at proper temperature and humidity levels. In this manner, the ventilation process plays one of the most important roles in determining the indoor air quality. Ventilation is a combined process of supplying air from outdoor to inside, and exhausting air from indoor to outside of the building. In addition to this, the distribution of this mixed air is also contained in ventilation process. Air supplied from outside needs to be conditioned and mixed with some amount of indoor air. If fresh air is not supplied for buildings, harmful pollutants such as CO_2 might be accumulated. Interrupted fresh air supply might cause indoor contamination to be increased, as well. It is worthy to note that, improperly designed and operated HVAC systems contribute a lot to Sick Building Syndrome (SBS) whose symptoms are eye, nose, and throat irritations, etc. It is known that, increasing the rate of supplied outdoor air decreases SBS problem. HVAC system with fresh air heats up colder outside air in winter in order to provide comfortable thermal condition. Due to its costly operation, some energy saving strategies can be established during heating up process of cold outdoor air. Nowadays, usage of heat recovery and energy storage is an effective trend. Due to limited fossil fuel resources and their hazardous environmental impacts, utilization of renewable energy resources becomes one of the most important research areas in HVAC systems in recent decades. Solar energy is a reliable and convenient energy resource. However, the variability and discontinuity of solar radiation causes serious difficulties on its application. Thermal energy storage systems have been developed to overcome the problem of solar radiation discontinuity. Thermal energy storage systems can store solar energy during peak periods to utilize it during the lower solar radiation or solar off periods. Solar energy can be stored by sensible, latent or chemical storage systems. Among them, sensible energy storage may be the simplest and the most convenient choice for practical applications.

Fossil fuel consumption and harmful emissions to the environment can be reduced by using sustainable energy sources such as solar energy. It is reported that more than 25% of total energy consumption is due to buildings, with heating and cooling representing a major percentage Mateus and Oliveira (2009) in the European Union. A large fraction of the primary energy budget (40–50%) is consumed by buildings to run heating, ventilation, and air conditioning (HVAC), lighting, appliances and equipment Ortiz et al. (2010). That is why there are many studies on the use of renewable and sustainable energy sources in buildings. Some of the performed studies are presented in Chapter 2. In these studies, solar energy is stored with different methods such as sensible or latent storage and then it is used later on. The stored thermal solar energy can be used in a short or long periods. That is why thermal energy storage is classified to short term or seasonal. Most of the performed studies are seasonal. Solar energy is stored during summer in medium and then it is used during the winter. The storage medium might be ground (soil) or aquifer. The stored energy is then is used in a heating system (or preheating system) of a space in winter season. . In addition to this kind of solar energy use in building heating and cooling systems, there are studies in which the stored thermal energy is used in heat pump during the winter. The stored heat in the medium during the summer is transferred to the outer unit of heat pump which operates as evaporator. Thus, not only the heat which should be transferred to evaporator is provided but also the evaporation temperature of the heat pump is increased and consequently heat pump performance is enhanced. For short term of solar energy storage, applications of domestic water heating systems are used widely. In these systems, the solar energy is used immediately or it is stored in a medium and then is used during night period. There are also studies in which solar energy is stored in the building structures via sensible or latent methods during the day and then they are used at night.

Number of studies on the use of solar energy for ventilation is not too much. As it was mentioned before most of active solar energy storage systems are used in the buildings for space heating or providing domestic hot water. In this study, a method for heating of fresh air supply which is used for ventilation purpose is proposed. There are many spaces for which a large amount of fresh air is required. Theater, cinema, shopping center and seminar rooms are some examples for the spaces with high amount of ventilation air. For these spaces, considerable energy of the HVAC system is consumed to increase the temperature of the fresh air to the temperature of space. Thus large amount of energy consumption for ventilation purposes motivated author to develop a ventilation system assisted by solar energy and heat recovery unit. In conventional system generally a heating coil which is connected to the boiler or an electrical heater is used to increase fresh air temperature. Thus, the aim of this study is to use solar energy and heat recovery unit to minimize energy consumption for ventilation system. Short term energy storage is very appropriate for this purpose. In winter season, there is no doubt that the heat of solar energy can be transferred to are during the day. The main problem might be transfer the stored of the solar thermal energy and then transfer it to the fresh air during the night period. That is why, the present study focused on the storage of solar energy during the day and the release it to the fresh air during the night. A Transient System Simulation (TRNSYS) software is used to simulate the developed system.

TRNSYS is a software used in simulations of thermal and electrical energy transient systems. It has a modular structure consists of user specified components. It recognizes components and the manner in which they are connected to each other. TRNSYS component library is mostly includes thermal and electrical energy systems. Simulation is performed according to weather data or other forcing functions and component parameters and inputs specified by user. TRNSYS gives the flexibility of addition new components defined by user and performing the simulation in different time step basis such as minutes, hours or days.

This thesis has seven chapters. In the second chapter a review on the studies used solar energy for heating purpose and studies on heat recovery unit is performed. In the third chapter, the analyzed systems are described. Three systems are analyzed. The first system consists of supply and return fans, and heating of air is performed by an electrical heater. The second system is similar to the first system but a heat recovery unit is integrated in order to transfer the energy of return air to the fresh air for preheating. The third system is developed to integrate thermal energy storage to the second system. During day time, solar energy is stored in a sensible storage tank and then it is used to heat up fresh air leaving heat recovery unit at the night period. The heating of the fresh air can be called as the first step preheating and the heating of fresh air by stored of the solar energy via heating coil can be called the second step preheating. If the air leaves the second preheating system is not sufficient and below the supply temperature, the electrical heater will be operated. The second step preheating is used to minimize energy consumed by electrical heater. In the fourth chapter system components used for simulation by TRNSYS software are defined. Definitions of component parameters, the input and output data are explained in details.

Fifth chapter presents assigned TRNSYS component types and their specified parameters, input and output data values of the present study. The values of parameter input and output data for all components used in the present study can be found in the fifth chapter. In sixth chapter, the simulation results of the analyzed system are interpreted and the variation of temperature of water used in solar collector and fresh air at different location of the systems are plotted against time. Moreover, the energy consumption for the period from the first of November to the end of March for three systems is found and presented. The results are given via graphics and the necessary discussions are performed. For third system, the effect of component parameters is investigated in detail for optimization of system dimensions. In seventh and final chapter, a conclusion of the study is presented. It should be mentioned that the study is performed based on the weather data of Izmir.

CHAPTER 2

LITERATURE SURVEY

Studies on thermal sensible energy storage can be found in literature. In those studies, the storage medium is mostly water, natural soil, special soils (i.e. gravel, grit or sand) or a combination of these materials. Solar energy is stored in these mediums and then used later. In the most of studies, seasonal storage is preferred. Some samples for these studies are presented here.

Kroll and Ziegler (2011) investigated the use of ground heat storages and evacuated tube solar collectors for meeting the annual heating demand of family-sized houses. In their studies soil is used as the storage material and a seasonal storage System 1s investigated. A schematic view of the analyzed System 1 is shown in Figure 2.1. They found that systems with small interseasonal storages can reach values for the useful heat per square meter of the solar collector and the useful heat per cubic meter storage comparable to those of today’s large scale projects.

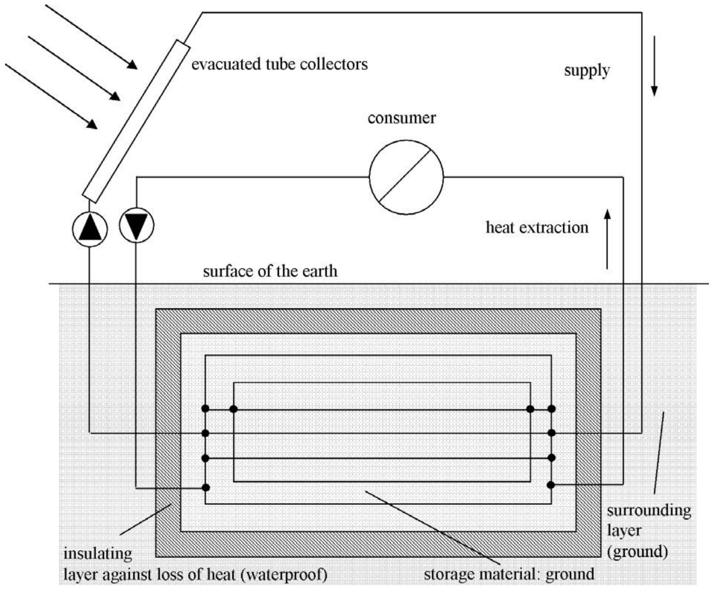


Figure 2.1. System model of the study performed by Kroll and Zeigler
(Source: Kroll and Ziegler 2011)

Simons and Firth (2011) performed a study on life-cycle assessment of a 100% solar fraction thermal supply to a European apartment building using water-based seasonal sensible heat storage. They compared 100% solar heating system recently installed in a Swiss apartment building with five alternative heating systems on the bases of life cycle assessment. The analyzed solar heating system consists of predominantly of two components: the seasonal thermal energy storage vessel and the solar collector field (see Figure 2.2). The storage vessel is an insulated mild steel cylinder containing steel heat exchange coils and three stainless steel boilers in which is heated the potable hot water. Using a range of lifetime scenarios it was found that the solar thermal system displays potentially significant advantages over all other systems in terms of reductions for purchased primary energy (from 84 to 93%) and reductions in GHG emissions (from 59 to 97%).

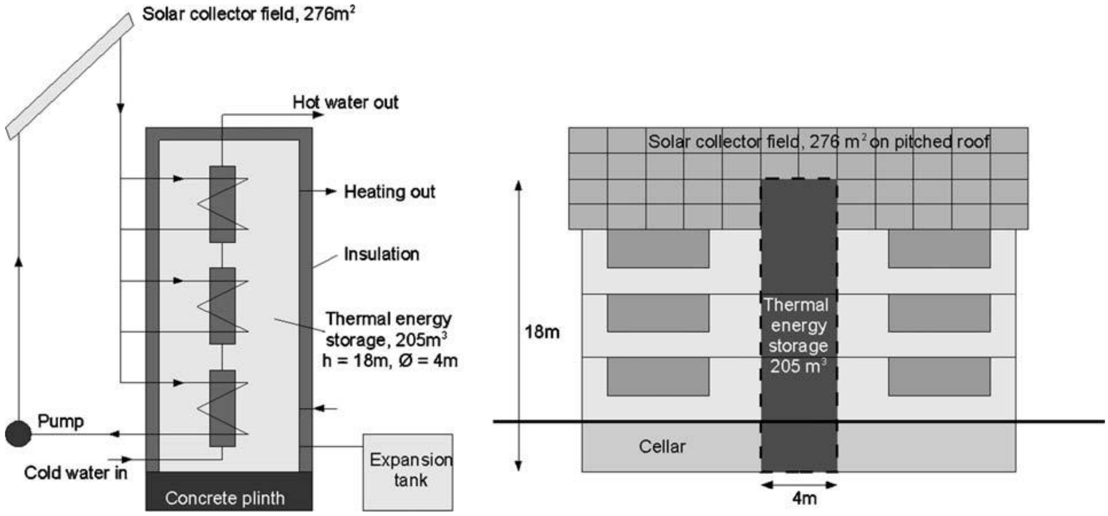


Figure 2.2. The main components and operational flows of the solar thermal system studied by Simons and Firth (Source: Simons and Firth 2011)

Terziotti et al. (2012) studied on the modeling seasonal solar thermal energy storage in a large urban residential building using TRNSYS 16. The Seasonal Solar Thermal Energy Storage (SSTES) system uses two closed fluid (water) loops. One loop runs through solar collectors to heat the fluid, then into coils inside the storage medium. Fluid in the second loop is heated in the storage medium and then sent through a radiant floor, thus heating the building. The storage medium varies depending on the requirements of the system. A basic SSTES system studied by Terziotti et al. is shown in Figure 2.3. Solar collectors are used to heat a sand bed which retains its thermal energy through the winter. That energy is then send into the building via a radiant floors for space heating use. A sand-based storage bed SSTES system for a new five story student housing complex at Virginia Commonwealth University was modeled using TRNSYS Version 16 software. A total of 15 simulations of various storage bed locations and configurations as well as building efficiencies were modeled to determine whether a System 1s feasible for an urban environment. They showed that substantial energy savings are possible. Up to 91% of energy for this large building can be provided by the most efficient SSTES system.

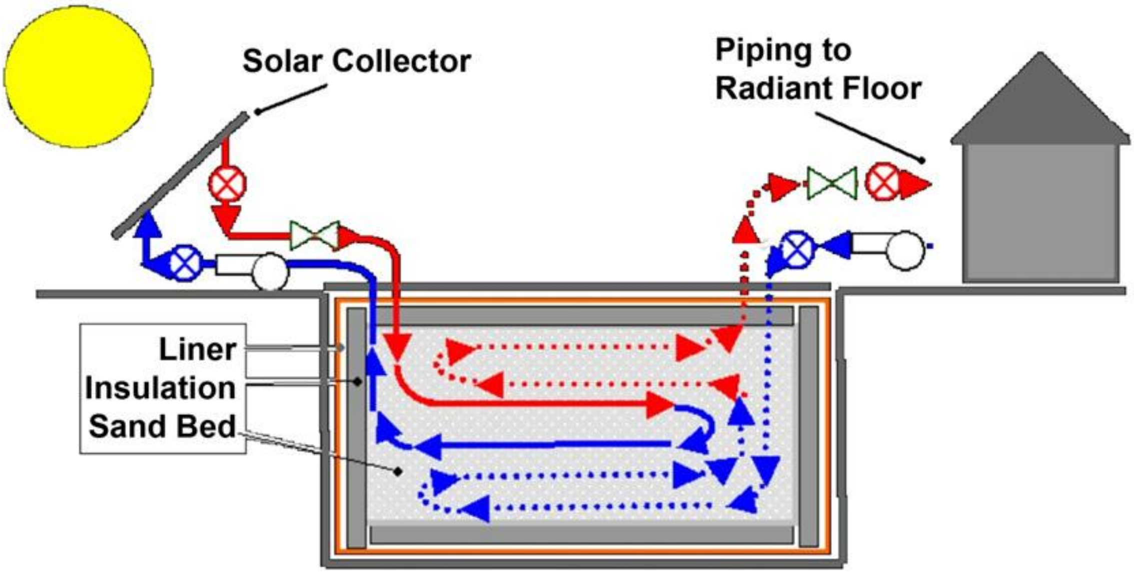


Figure 2.3. Schematic of a basic sand-based SSTES System 1n the study of Terziotti et al.
(Source: Terziotti, Sweet ve McLeskey Jr. 2012)

Studies on the use of heat recovery unit (HRV) for the ventilation systems can be found in literature. For instance, Dodoo et al. (2011) analyzed the impact of ventilation heat recovery (VHR) on the operation primary energy use in residential buildings. They calculated the operation primary energy use of a case-study apartment building both with and without VHR, and using different end-use heating systems including electric resistance heating, bedrock heat pump and district heating based on combined heat and power (CHP) production. VHR increases the electrical energy used for ventilation and reduces the heat energy used for space heating. Significantly greater primary energy savings is achieved when VHR is used in electrical resistance heated buildings than in district heated buildings. For district heated buildings the primary energy savings are small. VHR systems can give substantial final energy reduction, but the primary energy benefit depends strongly on the type of heat supply system, and also on the amount of electricity used for VHR and the air tightness of buildings. The study showed the importance of considering the interactions between heat supply systems and VHR systems to reduce primary energy use in buildings.

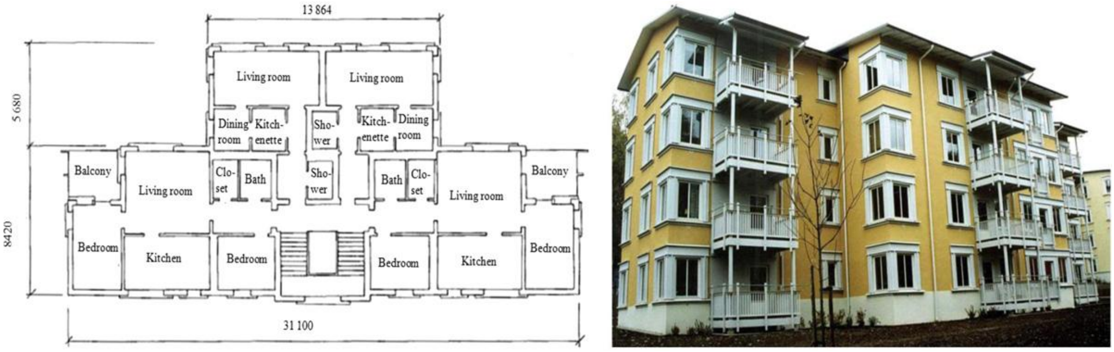


Figure 2.4. The ground floor plan and photograph of the building investigated by Dodoo et al. (Source: Dodoo, Gustavsson and Sathre 2011)

Seara et al. (2011) performed the experimental analysis of an air-to-air heat recovery unit equipped with a sensible polymer plate heat exchanger (PHE), shown in Figure 2.5, for balanced ventilation systems in residential buildings. The PHE was arranged in parallel triangular ducts. An experimental facility was designed to reproduce the typical outdoor and exhaust air conditions with regard to temperature and humidity. The obtained results showed that the heat transfer rate in the PHE decreases almost linearly as the inlet fresh air temperature increases. The PHE thermal efficiency remains nearly constant when varying the fresh air temperature from 5 to 15°C.

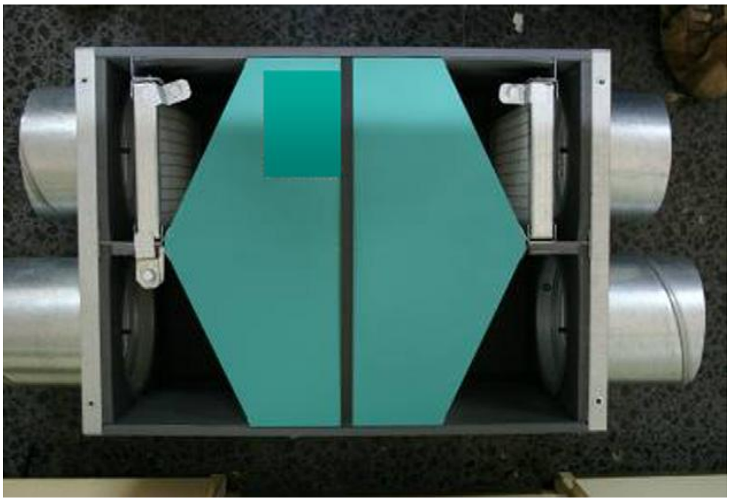


Figure 2.5. Heat Recovery Unit studied by Seara et al.
(Source: Seara, Diz, Uhia, Dopazo, & Ferro, 2011)

(Lazzarin & Gasparella, 1998) performed a technical and economical analysis of heat recovery building ventilation systems. The possible sensible and total heat recovery depends on the climate and on the operating period. Three different climates were considered (Milan, Rome, Palermo). The recovery for unitary air ventilation flow rate was evaluated and the economic savings were analyzed. The reduction in the heating or cooling capacity was also taken into account. Heat recovery in a ventilating system must always be evaluated, since the investment was often profitable.

Fehrm et al. (2002) studied on exhaust air heat recovery in buildings. They investigated systems use exhaust air as the source of heat for the appliances shown in Figure 2.6. The heat recovered is transferred to the fresh air (air-to-air systems) or the domestic hot water or the space heating water (air-to-water or air-to-water or- air systems). In air-to-water-or-air systems, the heat recovered is transferred to the fresh air or the hot water by a temperature control system. The field tests showed that the performance of forced ventilation systems featuring heat recovery equipment is high. However, performance may be weak if buildings and forced ventilation systems are not designed to high standards, installation work is inadequate or the use of heat from the heat recovery System 1s not given priority. Energy consumption may under these circumstances even be higher than in buildings without a forced ventilation system. On average, the installations tested (partly deficient) lowered primary energy consumption by 19.4% and CO_2 emissions by 18.4%. Moreover, 43% of the installations reduced both primary energy consumption and CO_2 emissions by over 25%.

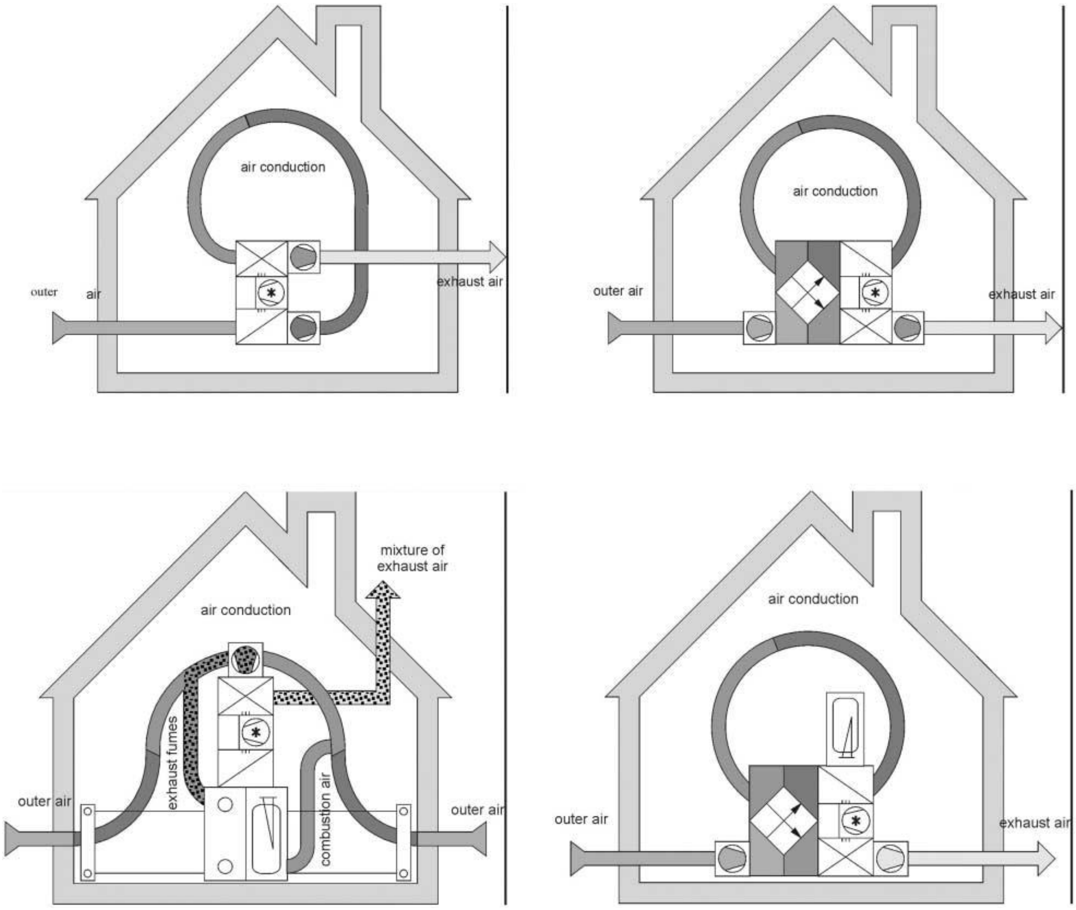


Figure 2.6. Commercial forced ventilation systems featuring heat pumps for heat recovery studied by Fehm et al. (Source: Fehrm, Reiners, & Ungemach, 2002)

Yumrutaş and Ünsal (2012) performed an energy analysis and modeling of a solar assisted house heating system with a heat pump and an underground energy storage tank shown in Figure 2.7. A computer code based on the present model was used to compute the performance parameters for the system under investigation. Results from the study indicated that an operational time span of 5–7 years will be necessary before the system can attain an annually periodic operating condition. Results also indicated a decrease in the annually minimum value of the storage tank temperature with a decrease in the energy storage tank size and/or solar collector area.

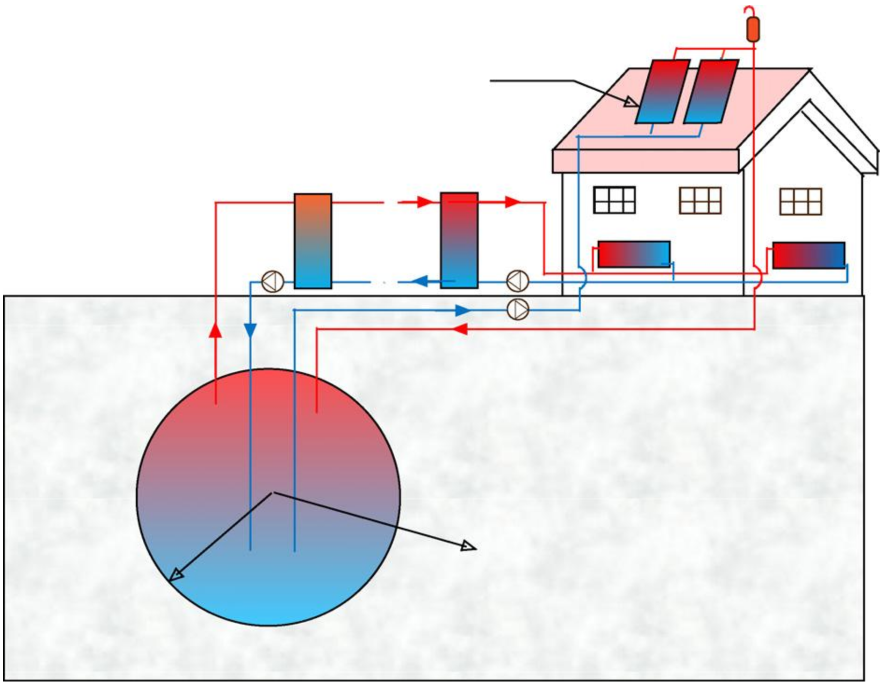


Figure 2.7. The house heating system investigated by Yumrutaş and Ünsal
(Source: Yumrutaş & Ünsal, 2012)

Calise et al. (2010) performed a study on transient analysis and energy optimization of solar heating and cooling systems in various configurations. Three different configurations were considered. In all cases, the solar cooling and heating system was based on the coupling of evacuated solar collectors with a single-stage LiBr–H_2O absorption chiller, and a gas-fired boiler was also included for auxiliary heating, only during the winter season. The layout of the System 1 is shown in Figure 2.8. The simulation model was developed using the TRNSYS software, and included the analysis of the dynamic behavior of the building in which the solar heating and cooling systems were supposed to be installed. The results of the case study were analyzed on monthly and weekly basis. The results were encouraging as for the potential of energy saving.

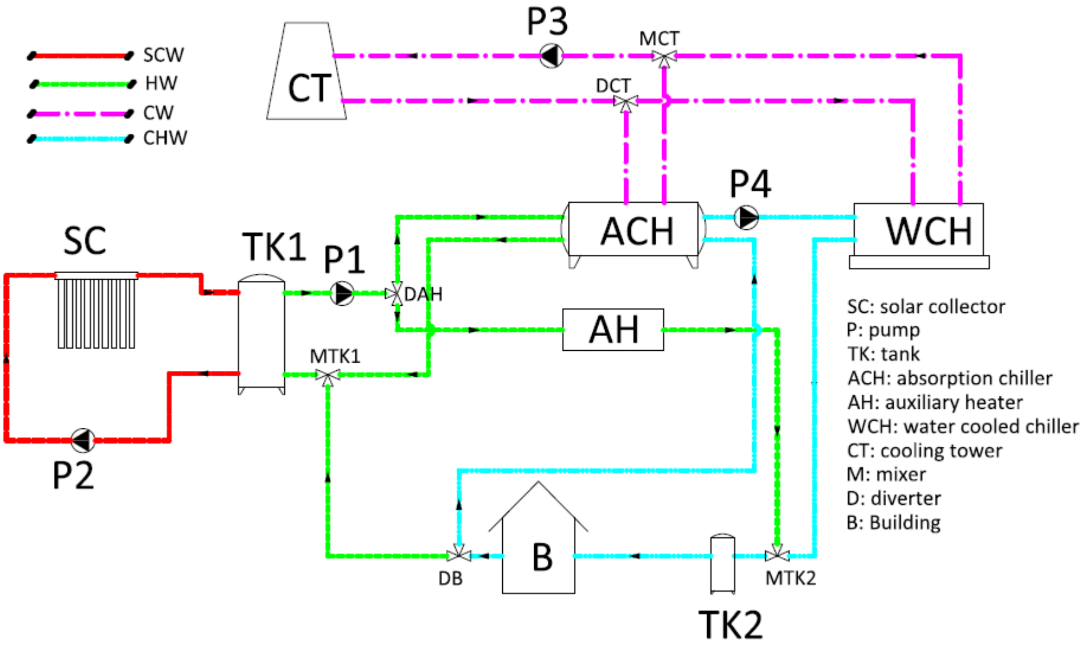


Figure 2.8. The layout of the system analyzed by Calise et al.
(Source: Calise, Dentice d'Acadia, & Palombo, 2010)

Ortiz et al. (2010) modeled a solar-assisted HVAC system with thermal storage for Mechanical Engineering (ME) building of The University of New Mexico in order to predict performance and optimize control parameters. Heating, cooling and shoulder seasons are considered in the study. The ME building solar/thermal HVAC system had several principal components: the solar collector array, hot storage, cold storage, absorption chiller, chilled water heat exchanger, steam heat exchanger, solar heat exchanger, and air handling units. The overall system layout is shown in Figure 2.9. They found that the solar assist can account for over 90% of the total heating requirements if certain energy conservation strategies are adopted. The solar cooling assist can reduce the total external cooling energy requirement by between 33% and 43%, the latter result achieved, surprisingly, at lower solar array operating temperatures.

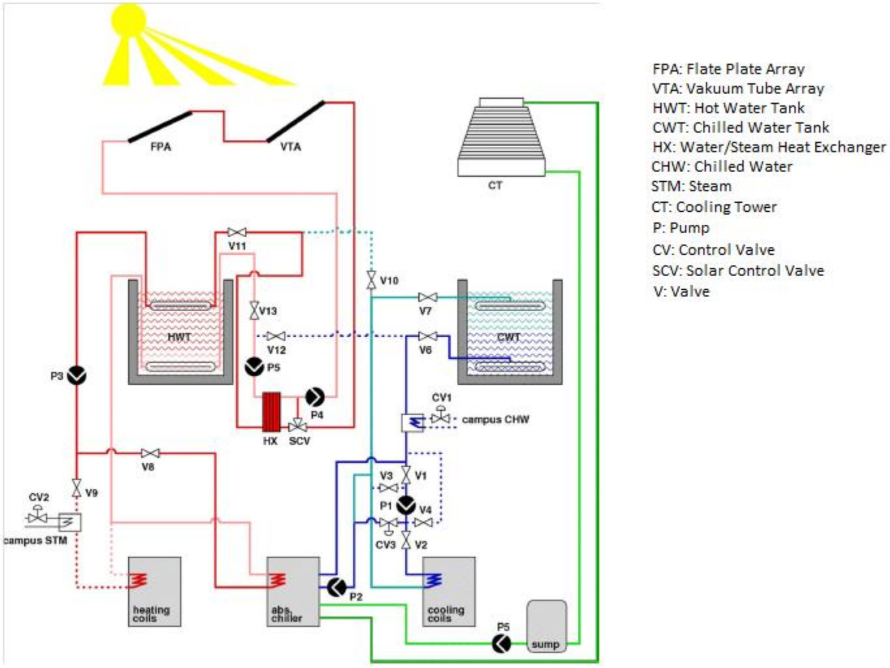


Figure 2.9. Major component block diagram of the system studied by Ortiz et al.
(Source: Ortiz, Barsun, He, Vorobieff, & Mammoli, 2010)

Spur et al. (2006) studied the influence of the domestic hot-water daily draw-off profile on the performance of a hot-water store. An enhanced TRNSYS simulation model, new enhanced-model of store (NEM), of the behavior of a domestic hot-water (DHW) store, with an immersed heat-exchanger (HX), has been developed and validated. A schematic view is presented in Figure 2.10. This model simulates the dynamic heat-depletion and recovery processes in the immersed HX and predicts the transient temperature-patterns for various DHW draw-off versus time profiles. Realistic Daily Profiles (RDPs), based on field studies, were developed to provide representative draw-off patterns for the testing of thermal stores and simulation studies. The effects of these RDPs and five other existing profiles on the store performance were analyzed using the enhanced model. The simulation results indicated the importance of the HX recovery, as well as the number, type and time of occurrence of the draw-offs in the profile, on the thermal store performance. It was concluded that RDP profiles should be used in the performance testing of thermal stores to obtain results that reflect conditions experienced in the field.

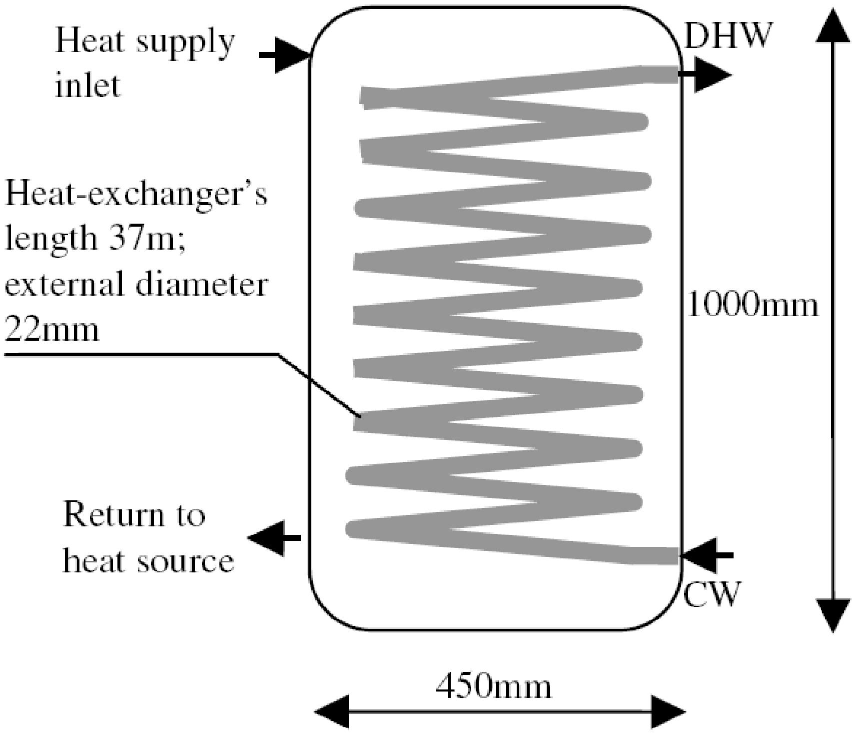


Figure 2.10. Schematic of the enhanced storage tank studied by Spur et al.
(Source: Spur, Fiala, Nevrala, & Probert, 2006)

Zhai et al. (2005) studied on comparison of heating and natural ventilation in a solar house induced by two roof solar collectors. They analyzed two kinds of roof solar collectors (RSCs), namely, the single pass RSC, and the double pass RSC. A schematic view is shown in Figure 2.11.

To evaluate the effects of two RSCs for both space heating and natural ventilation, they developed a single traditional Chinese style house, on which the two RSCs is mounted respectively. Through comparison, they found that the instantaneous efficiency of solar heat collecting for the double pass RSC is higher than that of the single pass one by 10% on average, and natural ventilation air mass flow rate contributed by natural ventilation for the double pass RSC can be improved to a great extent for most cases, indicating that double pass RSC is superior to the single pass one from the points of view of both space heating and natural ventilation. The double pass RSC is therefore more potential for improving indoor thermal environment and energy saving of buildings.

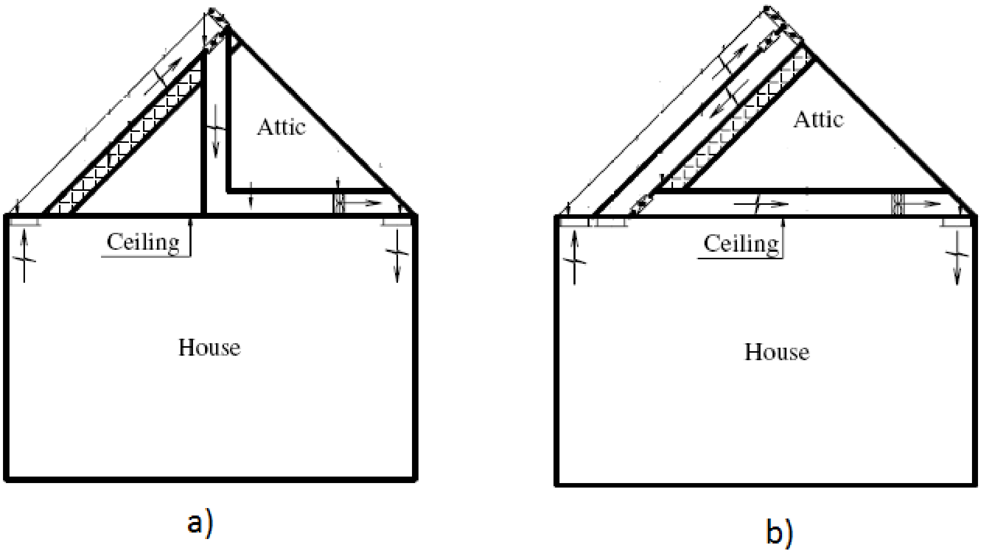


Figure 2.11. Schematic of view of a) single b) double pass roof solar collector system studied by Zhai et al. (Source: Zhai, Dai, & Wang, 2005)

Xi et al. (2011) presented experimental studies on a solar-assisted ground coupled heat pump (SAGCHP) system for space heating. The system was installed at the Hebei Academy of Sciences in Shijiazhuang (lat. N38_030, long. E114_260), China. Solar collectors were in series connection with the borehole array through plate heat exchangers. Four operation modes of the system were investigated throughout the coldest period in winter (Dec 5th to Dec 27th). The heat pump performance, borehole temperature distributions and solar colleting characteristics of the SAGCHP system are analyzed and compared when the system worked in continuous or intermittent modes with or without solar-assisted heating. A schematic view of the system is presented in Figure 2.12. The SAGCHP system is proved to perform space heating with high energy efficiency and satisfactory solar fraction, which is a promising substitute for the conventional heating systems. It is also recommended to use the collected solar thermal energy as an alternative source for the heat pump instead of recharging boreholes for heat storage because of the enormous heat capacity of the earth.

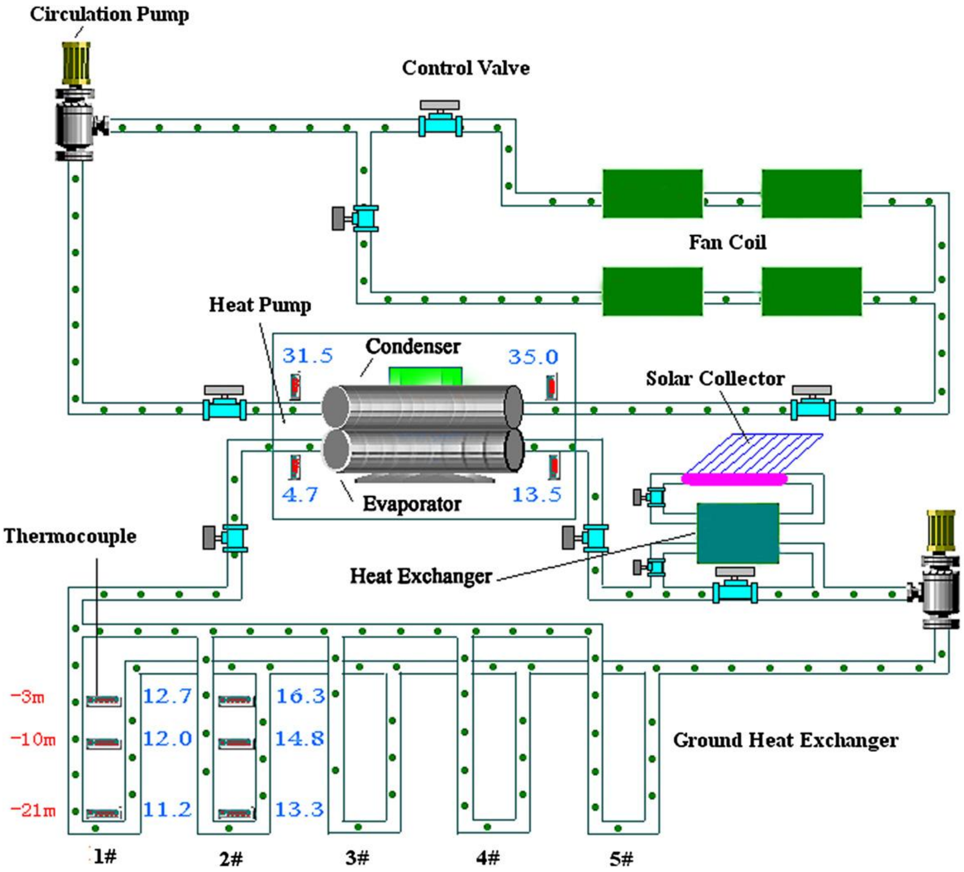


Figure 2.12. Schematic of view of experimental system developed by Xi et al. (Source: Xi, Hongxing, Lin, Jinggang, & Wei, 2011)

CHAPTER 3

DESCRIPTION OF ANALYZED SYSTEMS; SIMULATION DETAILS AND METHODOLOGY

In this chapter, three different systems analyzed in the study are described. The operation principles of the systems are explained in details. The schematic figures of the systems are given. The operational temperature and pressure and operation period of the systems are specified. Brief information on TRNSYS software is given.

3.1. Assumptions and Simulation Conditions

Three different systems are analyzed in the present study. The schematic views of these systems are shown in Figure 3.1. The analyzed systems are ventilation systems. This means that the systems are designed to supply fresh air for indoor space, not to overcome heating or cooling loads. For ventilation systems, the fresh air is generally supplied at indoor temperature. Hence, the fresh air is cooled during summer period or heated in winter before supplying to the indoor space. Although in intelligent ventilation system, the air flow rate can be adjusted according to indoor air quality; in the most application a constant air flow rate is assumed.

The considered assumption and operational condition for the present study are:

- The supplied air to indoor space is 100% fresh outdoor air and no mixing exists.
- The supplied air flow rate is considered constant for all studied cases and it is 1000 m^3/h
- The exhaust air flow rate is constant as 1000 m^3/h. Hence, the supply and exhaust air flow rates are identical.
- The minimum supply air temperature is assumed $22^{\circ}C$ for the all studied cases.
- The simulation of systems is performed for period from 1st of November to 31th of March. Hence, the study is performed only for winter period.

- The systems provide fresh air for the indoor space for the period of 17:00 to 24:00.
- The systems are located in Izmir – Turkey; hence the Izmir weather data are used.
- The working periods of system elements are controlled by automation devices.
- The study is done by using TRNSYS program. The simulation is performed in hourly time steps. Thus, 3624 calculations are performed for the period from 1st of November to 31th of March. An example for the described system can be ventilation systems used in independent stores of shopping centers, restaurants, small theater etc. For these spaces the total fresh air flow rates are around 1000 m^3/h corresponding to the required fresh air for 50 persons. However, the same systems with further air flow rates can be designed for larger spaces.

3.2. Description of Analyzed System

The three studied systems are:

a) System 1: Ventilation system with electrical heater,

b) System 2: Ventilation system with electrical heater and exhaust air heat recovery,

c) System 3: Ventilation system with electrical heater, exhaust air heat recovery and solar energy.

The system operation is described below however more information on the employed components is given in Chapter 4 and 5.

3.2.1. System 1: Ventilation System with Electrical Heater

Figure 3.1 (a) shows ventilation system with electrical heater schematically. The system mainly consists of an Electrical Heater (EH), Supply and Return Fan. As seen, the fresh air at the outdoor condition is heated by an electrical heater and its temperature is increased to the indoor air temperature. A controller is adapted to System 1n order to prevent supply temperature below 22°C. Air flows from outdoor and passes from the supply fan which increases the air pressure. Then, air flows to the electrical heater and its temperature increases to 22°C. As it was mentioned before, the minimum temperature of supply air should be 22°C. The indoor air is directly exhausted to the outdoor by return fan.

3.2.2. System 2: Ventilation System with Electrical Heater and Exhaust Air Heat Recovery

Figure 3.1 (b) shows the second system which is ventilation system with electrical heater and exhaust air heat recovery. The system consists of Return and Supply Fans, Electrical Heater and plate type heat exchanger. In System 2, the return air, which is at 22°C, is pressurized by Return Fan and enters to the Heat Recovery Unit (HRV). Heat is transferred from return air to the fresh air via Heat Recovery Unit. The fresh air passes through the Heat Recovery Unit and being heated before supplying to the indoor by the Supply Fan. If the temperature of the heated air by Heat Recovery Unit is below 22°C, the Electrical Heater automatically starts to operate and it increases air temperature till the set value. It should be mentioned that no air mixing is performed in Heat Recovery Unit.

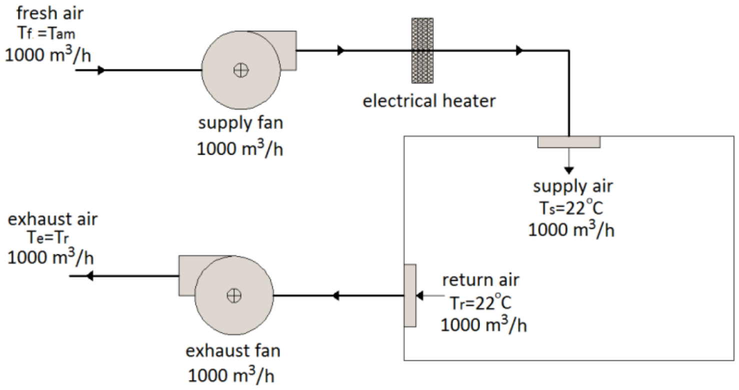
3.2.3. System 3: Ventilation System with Electrical Heater, Exhaust Air Heat Recovery and Solar Energy

The main components of the System 3 are supply and return fans, electrical heater, heat recovery unit and a solar energy storage system, shown in Figure 3.1 (c). The solar energy system mainly consists of vacuumed tube solar collector, sensible heat storage tank and heating coil and two circulation pumps.

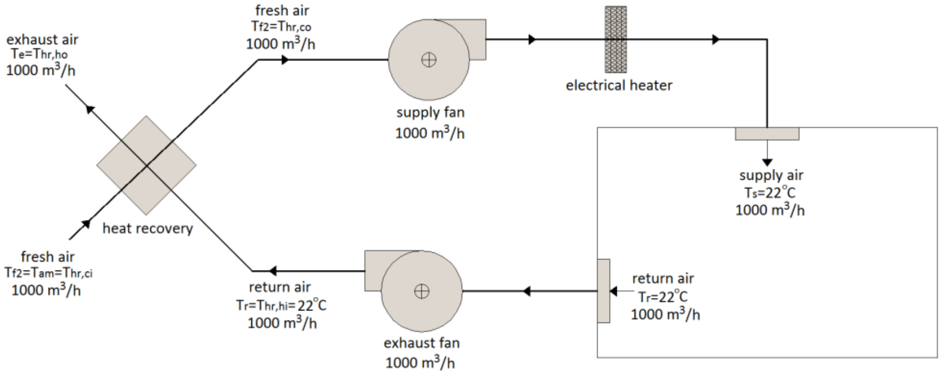
There are two separate loops in the solar energy system. In the first loop, water circulates between Solar Collector (SC) and sensible Storage Tank (ST) by a circulation pump named as Pump 1. In the second loop, the water is circulated between tank and Heating Coil (HC) by another circulation pump named as Pump 2. Solar Collector is used to increase water temperature. Then, water at high temperature enters to the sensible Storage Tank. The heat of circulated water is transferred to the Storage Tank and it leaves Storage Tank at lower temperature. It enters to the Pump 1 and it is pressurized to be circulated in Loop 1. The control of Pump 1 is done by a differential Temperature Controller. It receives average temperature of water Storage Tank and outlet temperature of Solar Collector. If the temperature inside the Storage Tank is greater than Solar Collector outlet temperature, a signal is sent to the Pump 1 and it is stopped. When sun rises, the Solar Collector outlet temperature becomes greater than the temperature of Storage Tank operated the night before. During the sunset, the collector outlet temperature becomes less than Storage Tank temperature. Hence, a signal is sent to Pump 1 to stop circulation. By this way, the temperature of Storage Tank is increased during the day period. Our observation showed that the temperature of water at outlet of Solar Collector may exceed 100°C in warm days during winter. That is why for safety a controller is adapted to the system for temperature controlling of outlet water of Solar Collector. If the temperature of Storage Tank exceeds 90°C, Pump 1 will be stopped.

The operation of Loop 2 is arranged by a Time Controller. It operates from 17:00 to 24:00 which is the ventilation system operation period. At 17:00, the time controller send a signal to Pump 2 and water is circulated through Loop 2. The pressurized water leaves Pump 2 and enters to the Storage Tank. Then, water leaves Storage Tank at high temperature and flows towards Heating Coil. Heat is transferred from hot water, leaves from the Storage Tank, to the air via the Heating Coil. The temperature of water drops in the Heating Coil and water at low temperature enters to the Pump 2. By this way, the heat stored in the tank is transferred to the air flows towards the indoor space.

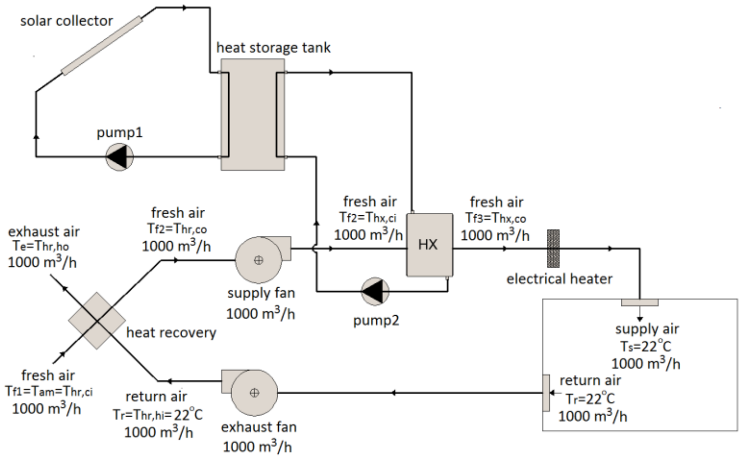
Similar to the System 2, the fresh air is preheated by the Heat Recovery Unit. The temperature of the fresh air is increased by the energy of the exhaust air. Then, the fresh air is passed through the coil heat exchanger supported by the solar energy system. It flows towards the Electrical Heater. If the fresh air temperature is less that 22°C, the Electrical Heater automatically operates and it increases the fresh air temperature to 22°C. As it was mentioned before, the ventilation system operates between 17:00 and 24:00. So, after 24:00 the Supply and Return Fans are switched of automatically. By this way, the solar energy stored in the tank during day period is used to heat fresh air from 17:00 to 24:00.



(a) System 1



(b) System 2



(c) System 3

Figure 3.1. Schematic view of the studied ventilation systems, a) electrical heater system, b) electrical heater and exhaust air heat recovery, c) electrical heater, exhaust air heat recovery and solar energy system.

3.3. Methodology

TRNSYS, commercially available software used to simulate transient HVAC and energy systems, is used to achieve this study. TRNSYS has a modular structure and it has its own system description language. It provides possibility for a user to define specific components, establish a system and to connect the components.

The common components used in a transient system are modeled and stored in TRNSYS library. This library includes many of the components such as solar collector, pumps and fans commonly employed in thermal and electrical energy systems, as well as component routines to handle input of weather data or other time-dependent forcing functions (such as controllers) and output of simulation results as data or graph. Different components and their models are referred as Types in the library. The modular nature of TRNSYS gives the program a flexibility and a facility to add sub program includes a mathematical model to generate a new component which does not exist in the standard TRNSYS library.

HVAC and energy systems are consist of the components connected to each others. Similarly, TRNSYS has been designed such that to generate the required components of a HVAC system and to provide the connection between them.

After definition of a system to TRNSYS program, it solves the system of algebraic and differential equations based on the defined components and connections. The program provides the plotting of diagrams including output variations of defined system for the specified period and the tables having values of the plots.

TRNSYS main applications include: solar systems (solar thermal and photovoltaic systems), low energy buildings and HVAC systems, renewable energy systems, cogeneration, fuel cells.

CHAPTER 4

ANALYSIS OF EMPLOYED TRNSYS ELEMENTS

In this chapter, definition, parameters, input and output data of the components used in the studied system are presented. These information are taken from "input-output-parameter reference" guideline of TRNSYS software and our comments are added to those descriptions.

4.1. Weather Data / Type 109

This component serves the main purpose of reading weather data at regular time intervals from a data file, converting it to a desired system of units and processing the solar radiation data to obtain tilted surface radiation and angle of incidence for an arbitrary number of surfaces. Type 109 reads a weather data file in the standard TMY2 format. The TMY2 format is used by the National Solar Radiation Data Base (USA) but TMY2 files can be generated from many programs, such as Meteonorm.

4.1.1. Weather Data Parameters

Data reader mode: It is the mode of the weather data reader 109. The value 2 means that Type 109 will read standard weather file in the TMY2 format.

Logical unit: This parameter sets the Fortran Logical Unit (file reference number) of the output file. It is used internally by TRNSYS to refer to the file. This parameter will automatically be assigned to a unique value by the TRNSYS Studio.

Sky model for diffuse radiation: This parameter selects the sky model used to calculate diffuse radiation on tilted surfaces. There is 4 different sky model: 1.isotropic sky model, 2.Hay and Davies model, 3.Reindl model and 4.Perez model. The Perez model is usually considered to be the best available model.

Tracking mode: This parameter is used to indicate that the surfaces on which the tilted surface radiation is calculated are tracking the sun. There is 4 different kind of surface: 1.fixed surface, 2.single-axis tracking, vertical axis (fixed slope, variable azimuth), 3.single-axis tracking, axis is in the plane of the surface, 4.two-axis tracking.

4.1.2. Weather Data Inputs

Ground reflectance: It is the reflectance of the ground above which the surface is located. Typical values are 0,2 for ground not covered by snow and 0,7 for ground covered by snow.

Slope of surface: It is the slope of the surface or tracking axis. The slope is positive when tilted in the direction of the azimuth. 0° is horizontal and 90° is vertical facing toward azimuth. It refers to the abstract for details on slope specification for tracking surfaces.

Azimuth of surface: The solar azimuth angle is the angle between the local meridian and the projection of the line of sight of the sun onto the horizontal plane. 0° is facing equator, 90° is facing west, 180° is facing north and 270° is facing east.

4.1.3. Weather Data Outputs

Ambient temperature: It is the outdoor temperature of the place where weather data refers to.

Relative humidity: It is the ambient relative humidity and it is a term used to describe the amount of water vapor in a mixture of air and water vapor.

Wind velocity: It is the wind speed of the place where weather data refers to.

Wind direction: It is the direction of the wind defined by TRNSYS where 0° is south and 180° is north.

Atmospheric pressure: It is the force per unit area exerted against a surface by the weight of air above that surface in the earth's atmosphere.

Extraterrestrial radiation on horizontal: It is the solar radiation outside the earth’s atmosphere.

Solar zenith angle: It is the angle between the local zenith and the line of sight to the sun.

Solar azimuth angle: It is the azimuth angle of the sun. It is most often defined as the angle from due north in a clockwise direction.

Total radiation on horizontal: It is the sum of solar radiations on horizontal surface.

Beam radiation on horizontal: It is the amount of solar radiation from the direction of the sun on horizontal surface.

Sky diffuse radiation on horizontal: It is the radiation component that strikes a point from the sky on the horizontal surface.

Ground reflected diffuse radiation on horizontal: It is the diffuse radiation from the sun which is reflected back into the atmosphere after striking the Earth and comes to the horizontal surface.

Angle of incidence on horizontal surface: It is the angle that a ray (of solar energy) makes with a line perpendicular to the horizontal surface. For example, a surface that directly faces the sun has a solar angle of incidence of zero, but if the surface is parallel to the sun, the angle of incidence is 90°.

Slope of horizontal surface: It is the angle between collector surface and horizontal.

Total radiation on tilted surface: It is the sum of solar radiations on the tilted surface of the solar collector.

Beam radiation on tilted surface: It is the amount of solar radiation from the direction of the sun on the tilted surface of the solar collector.

Sky diffuse radiation on tilted surface: It is the radiation component that strikes a point from the sky on the tilted surface.

Ground reflected diffuse radiation on tilted surface: It is the diffuse radiation from the sun which is reflected back into the atmosphere after striking the Earth and comes to the tilted surface.

Angle of incidence for tilted surface: It is the angle that a ray (of solar energy) makes with a line perpendicular to the tilted surface of the solar collector.

Slope of tilted surface: It is the angle between collector surface and the tilted surface of the solar collector.

4.2. Evacuated Tube Solar Collector / Type 71

The employed solar collector is indicated with Type 71 (see Figure 4.1). Type 71 models the thermal performance of an evacuated tube collector. The total collector array may consist of collectors connected in series and in parallel. The thermal performance of the total collector array is determined by the number of modules in series and the characteristics of each module. The main difference (from a modeling point of view) between an evacuated tube collector and a flat plate collector is in the treatment of incidence angle modifiers (IAMs). Type 71 reads a text file containing a list of transverse and longitudinal IAMs.

Figure 4.1. Evacuated Tube Solar Collector

4.2.1. Solar Collector Parameters

Number in series: The solar collector model can simulate an array of identical solar collectors hooked up in series. This parameter is used to specify how many collectors are hooked up in a series arrangement where the output of the first collector is the inlet to the second collector.

Collector area: The total area of the solar collector array consistent with the supplied efficiency parameters (typically gross area and not net area).

Fluid specific heat: It is the specific heat of the fluid flowing through the solar collector array.

Efficiency mode: The collector efficiency equation can be written as a function of the inlet, average or outlet temperature.

Specify 1 if the collector efficiency parameters are given as a function of the inlet temperature

Specify 2 for a function of the collector average temperature

Specify 3 for a function of the collector outlet temperature

Flow rate at test conditions: Collector flow rate per unit area for efficiency test conditions

Intercept efficiency: This parameter is the y intercept of the collector efficiency curve versus the temperature difference over radiation ratio.

Negative of first order efficiency coefficient: This parameter is the slope of the collector efficiency curve versus the temperature difference / radiation ratio.

Negative of second order efficiency coefficient: This parameter is the curvature of the efficiency curve versus the temperature difference / radiation ratio

Logical unit of file containing biaxial IAM data: FORTRAN Logical unit for file containing biaxial IAM (Incident Angle Modifier) data Make sure that each logical unit specified in an assembly is unique. Incident angle is the angle that a ray of solar energy makes with a line perpendicular to the surface. IAM is a correction coefficient for vacuum tube solar collectors and it is a data given by the collector manufacturer.

Number of longitudinal angles for which IAMs are provided: Number of data points for the IAM (longitudinal direction).

Number of transverse angles for which IAMs are provided: Number of data points for the IAM (transverse direction).

4.2.2. Solar Collector Inputs

Inlet temperature: The temperature of the fluid entering the solar collector.

Inlet flow rate: The flow rate of the fluid entering the solar collector.

Ambient temperature: The temperature of the environment in which the solar collector is located. This temperature will be used for loss calculations.

Incident radiation: The total (beam + diffuse) radiation incident on the plane of the solar collector per unit area.

Incident diffuse radiation: The incident diffuse solar radiation in the plane of the collector, per unit area.

Solar incidence angle: Incidence angle of beam radiation on the collector's surface.

Solar zenith angle: The solar zenith angle is the angle between the vertical and the line of sight of the sun.

Solar azimuth angle: The solar azimuth angle is the angle between the local meridian and the projection of the line of sight of the sun onto the horizontal plane.

Collector slope: The slope of the collector is the angle between the collector surface and the horizontal. 0 presents horizontal. The angle is positive when facing towards the collector surface azimuth. As a general rule, the performance of the collector is somewhat optimized when the collector slope is set to the latitude.

Collector azimuth: The collector surface azimuth is the angle between the local meridian and the projection of the normal to the surface onto the horizontal plane. 0 presents facing the equator, 90° presents facing West, 180° presents facing South in northern hemisphere, North in Southern hemisphere, 270° presents facing East.

4.2.3. Solar Collector Outputs

Outlet temperature: It is the temperature of the fluid exiting the solar collector array

Outlet flow rate: It is the flow rate of the fluid exiting the solar collector array. In this collector type, inlet flow rate is equal to the outlet flow rate.

Useful energy gain: It is the rate of useful energy gain by the solar collector fluid. It is calculated by following relation:

$$Q_u = \dot{m} C_p (\mathrm{T_{out}} - \mathrm{T_{in}})$$

4.3. Single Speed Pump / Type 3b

The considered pumps in this study are single speed. Figure 4.2 shows a single speed pump. It increases pressure of the water flow. In single speed pump applications, water flow rate and pressure and pump electrical consumption are constants.

This pump model computes a mass flow rate using a variable control function, which must have a value between 1 and 0, and a fixed (user-specified) maximum flow capacity. In this instance of Type 3, pump power may also be calculated, either as a linear function of mass flow rate or by a user-defined relationship between mass flow rate and power consumption. A user-specified portion of the pump power is converted to fluid thermal energy. This component sets the flow rate for the rest of the components in the flow loop by multiplying the maximum flow rate (Parameter 1) by the control signal (Input 3).

Figure 4.2. A single speed circulation pump

4.3.1. Single Speed Pump Parameters

Maximum flow rate: It is the maximum flow rate through the pump. The outlet flow rate is simply the maximum flow rate multiplied by the inlet control signal.

Fluid specific heat: It is the specific heat of the fluid flowing through the pump.

Maximum power: It is the maximum pump power consumption. The actual pump power will be the maximum pump power multiplied by a function of the input control signal.

Conversion coefficient: It is the fraction of pump power that is converted to the fluid thermal energy.

Power coefficient: It is a coefficient to specify a non-linear relationship between pump power and fluid flow rate.

4.3.2. Single Speed Pump Inputs

Inlet fluid temperature: It is the temperature of the fluid entering the pump.

Inlet mass flow rate: It is the flow rate of the fluid entering the pump. This input is not used by this component except for convergence checking. The outlet flow rate depends on the maximum flow rate and the input control signal.

Control signal: It is the input control signal to the pump. The flow rate and power are calculated from knowledge of this input:

$\dot{m}_{out} = \dot{m}_{max} \times gamma.$

4.3.3. Single Speed Pump Outputs

Outlet fluid temperature: It is the outlet fluid temperature from the pump. This value is given by following relation:

$T_{out} = T_{in} + (f \times Power)/(\dot{m} \times C_p)$

Outlet flow rate: It is the outlet flow rate which is calculated by:

$\dot{m}_{out} = \dot{m}_{max} \times gamma$

Power consumption: It is the power consumed by the pump. The pump power is calculated from either a linear relationship with flow rate or by a polynomial expression relating pump power to control signal, depending on the parameters supplied by the user.

4.4. Fan / Type 3c

The considered fans in this study are single speed. Figure 4.3 shows a single speed fan. It increases pressure of the air flow. In single speed fan applications, air flow rate and pressure and fan electrical consumption are constants.

This fan model computes a mass flow rate using a variable control function, which must have a value between 1 and 0, and a fixed (user-specified) maximum flow capacity. In this instance of Type 3, fan power consumption is simply set to the rated value whenever the control signal indicates that the fan is in operation. A user-specified portion of the fan power is converted to air stream thermal energy. This component sets the flow rate for the rest of the components in the flow loop by multiplying the maximum flow rate (Parameter 1) by the control signal (Input 3). The mass flow rate input of this component is only for visualization purposes; it is not used except for convergence checking.

Figure 4.3. A Single Speed Fan,

4.4.1. Fan Parameters

Maximum flow rate: The maximum flow rate through the fan. The outlet flow rate is simply the maximum flow rate (this parameter) multiplied by the inlet control signal (Input 3).

Fluid specific heat: The specific heat of the fluid flowing through the fan. The specific heat is used to determine the temperature rise of the fluid through the fan using the following relation:

$$T_{out} = T_{in} + (f \times Power)/(\dot{m} \times C_p)$$

Maximum power: The maximum fan power consumption. The actual fan power will be the maximum fan power multiplied by a function of the input control signal. See the abstract for more details on calculated fan power.

Conversion coefficient: The fraction of fan power that is converted to fluid thermal energy.

$$T_{out} = T_{in} + (f \times Power)/(\dot{m} \times C_p)$$

4.4.2. Fan Inputs

Inlet fluid temperature: The temperature of the fluid entering the fan.

Inlet mass flow rate: The flow rate of the fluid entering the fan. This input is not used by this component except for convergence checking. The outlet flow rate depends on the maximum flow rate and the input control signal. This input is just for visualization purposes.

Control signal: The input control signal to the fan. The flow rate and power are calculated from knowledge of this input:

$$Power = f(Pmax, gamma)$$

$$\dot{m}_{out} = \dot{m}_{max} \times gamma\ ,$$

4.4.3. Fan Outputs

Outlet fluid temperature: The outlet fluid temperature from the fan. It is calculated by following relation:

$$T_{out} = T_{in} + (f \times Power)/(\dot{m} \times C_p)$$

Outlet flow rate: The outlet fluid flowrate is calculated by:

$$\dot{m}_{out} = \dot{m}_{max} \times gamma$$

Power consumption: The power consumed by the fan. The fan power is calculated from either a linear relationship with flow rate or by a polynomial expression relating fan power to control signal, depending on the parameters supplied by the user.

4.5. Vertical Cylinder Tank - Non-Uniform Losses and Node Heights - 2 Inlets, 2 Outlets / Type 60f

Type 60 models a stratified liquid storage tank with two inlets and two outlets (see Figure 4.4). It includes numerous features such as allowing for multiple heat exchangers within the tank and allowing for unmatched numbers of inlet and outlet flows. This instance of Type 60 models a vertically cylindrical tank with two inlet and two outlet flows. Users may also define between 0 and 3 (inclusive) internal heat exchangers. It further includes calculation of losses from the tank to the flue if desired and assumes that all stratification nodes of the tank are uniform in size and that the UAs between each node and the ambient are equal.

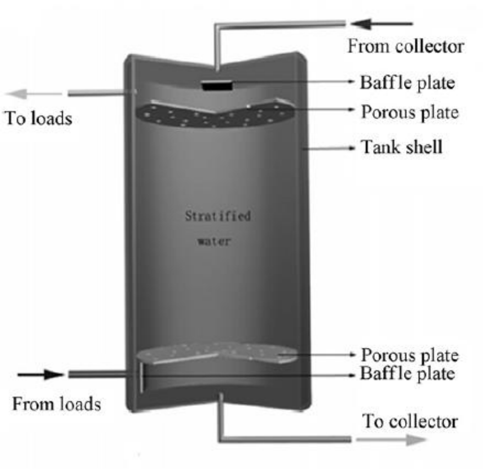


Figure 4.4. Vertical Cylinder Tank

4.5.1. Vertical Cylinder Tank Parameters

User-specified inlet positions: The auxiliary storage tank may operate in one of two models in determining the inlet positions of the flow streams. In this mode (2), the user must specify the locations (nodes) of the entering flow streams. It should be an integer and it can be changed from 1 to 2. This parameter shouldn’t be changed.

Tank volume: It is the actual (not nominal) volume of the storage tank.

Tank height: It is the height of the storage tank. If the tank is a horizontal cylinder, this parameter should be set to the diameter of the storage tank.

Tank perimeter: By setting this parameter to -1, the user is specifying that the tank is cylindrical with a vertical orientation (standing up). This parameter shouldn’t be changed.

Height of flow inlet 1: It is the height of the first inlet to the storage tank above the bottom of the tank. This parameter should be between zero and the total height of the tank.

Height of flow outlet 1: It is the height of the first outlet from the storage tank above the bottom of the tank. This parameter should be between zero and the total height of the tank.

Height of flow inlet 2: It is the height of the second inlet to the storage tank above the bottom of the tank. It should be a real number and it can be changed from zero to infinity. This parameter should be between zero and the total height of the tank.

Height of flow outlet 2: It is the height of the second outlet from the storage tank above the bottom of the tank. This parameter should be between zero and the total height of the tank.

Fluid specific heat: It is the specific heat of the fluid contained in the storage tank.

Fluid density: It is the density of the fluid contained in the storage tank

Tank loss coefficient: It is the average tank loss coefficient per unit area. Different loss coefficients for each node can be modeled by use of the incremental loss coefficient parameters.

Fluid thermal conductivity: It is the thermal conductivity of the fluid contained in the storage tank.

Destratification conductivity: To model de-stratification due to mixing at node interfaces and conduction along the tank wall, the user may enter this additional conductivity parameter. The additional conductivity term is added to the conductivity of the tank fluid and is applied to all nodes. For rough calculations, one may calculate this parameter as the thermal conductivity of the tank wall times the cross sectional area of the tank wall divided by the cross sectional area of the fluid in the storage tank.

Boiling temperature: It is the boiling temperature of the fluid contained in the storage tank.

. **Auxiliary heater mode:** The auxiliary heater may be operated in one of two modes. 1.Master/Slave Relation: The lower heating element is only enabled when the upper heating element is satisfied. In this mode, only one heater may be on at any instant of time. This is a common design in residential electric hot water tanks. 2.Both Enabled: In this mode, both heaters may be on simultaneously. This allows for significantly quicker heating of the water, but not a much higher electrical demand.

Height of 1st auxiliary heater: It is the height of the first auxiliary heater element above the bottom of the storage tank. If there are no auxiliary heaters, set this parameter and thermostat height parameter to any value between 0 and the total tank height. Then simply set either the maximum heating rate or the control signal for this heating element to a constant value of 0.

Height of 1st thermostat: It is the height of the thermostat for the first heating element above the bottom of the storage tank. If there are no heating elements, simply set this parameter to any value between 0 and the total tank height. Then set either the maximum heating rate or the control signal for this heating element to a constant value of 0.

Set point temperature for element 1: It is the set point temperature for the specified heating element. The thermostat will enable the heating element when the temperature of the fluid in the node containing the thermostat falls below $T_{set} - T_{db}$ and continue to heat the fluid until it reaches to set point temperature. T_{set} is this parameter and T_{db} is the dead band temperature.

Dead band for heating element 1: It is the temperature difference for the specified heating element. The thermostat will enable the heating element when the temperature of the fluid in the node containing the thermostat falls below $T_{set} - T_{db}$ and continue to heat the fluid until it reaches the set point temperature.

Maximum heating rate of element 1: It is the maximum heating rate of the heating element. If the specified heating element is not used for the simulation, set the maximum power to 0.

Height of heating element 2: It is the node containing the specified auxiliary heating element. Make sure that the specified node for the heater is between 1 and the total number of nodes specified. Node 1 is the topmost node in the tank.

Height of thermostat 2: It is the node containing the thermostat for the specified auxiliary heater. The thermostat is typically either located in the same node as the heating element or in a node located above the element. Node 1 is the topmost node in the tank.

Set point temperature for element 2: It is the set point temperature for the specified heating element. The thermostat will enable the heating element when the temperature of the fluid in the node containing the thermostat falls below $T_{set} - T_{db}$ and continue to heat the fluid until it reaches the set point temperature.

Dead band for heating element 2: It is the dead band temperature difference for the specified heating element. The thermostat will enable the heating element when the temperature of the fluid in the node containing the thermostat falls below $T_{set} - T_{db}$ and continue to heat the fluid until it reaches the set point temperature.

Maximum heating rate of element 2: It is the maximum heating rate of the heating element. If the specified heating element is not used for the simulation, set the maximum power to 0.

Overall loss coefficient for gas flue: It is the overall loss coefficient of the gas flue when the tank is not being heated. If this tank is not being heated by gas, simply set this parameter to 0.0 and the next parameter (flue temperature) to any reasonable value.

Flue temperature: It is the temperature of the gas flue when the tank is not being heated. This parameter is used to calculate the losses from the storage to the flue when the tank is not being heated. If the tank is not heated with gas, simply set this parameter to any reasonable value and set the previous parameter (flue loss coefficient) to 0.

Fraction of critical time step: To minimize numerical errors, the Type 60 tank model uses its own internal time step. This has the advantage of results being unaffected by the size of the TRNSYS time step. The model internally computes the critical Euler time step. The user then chooses the fraction of the critical time step that will be used. Increasing this parameter will increase the accuracy of the model, but decrease the simulation speed. A value of 6 represents an excellent compromise between accuracy and speed for most simulations.

Gas heater: This parameter indicates to the general storage tank model whether the tank is heated with electric elements, with a gas flue, or with a combination of gas and electric. 0 = Both heater are electric, 1 = Auxiliary heater #2 is gas (setting the maximum heating rate of the first heating element to zero or nonzero dictates whether the tank also has an electric element).

Number of internal heat exchangers: It is the number of internal heat exchangers that are contained within the storage tank. For each internal heat exchanger, the user must specify 12 parameters that describe the heat exchanger.

Equal sized nodes: This parameter indicates to the general storage taank model that the tank should be divided into nodes of the same size. The number of nodes is controlled by the number of derivatives supplied. Do not change this parameter.

Uniform tank losses: This parameter indicates to the general storagee tank model that the tank will have uniform loss coefficients for each node. The number of nodes is controlled by the number of supplied derivatives. Do not change this parameter.

HX Fluid Indicator: The fluid contained in the first internal heat exchanger: 1=Water, 2=Propylene Glycol, 3=Ethylene Glycol. These fluids are contained in the internal heat exchanger and are not mixed with the storage fluid.

Fraction of glycol: It is the fraction of glycol contained in the internal heat exchanger fluid by volume. If the previous parameter is set to 1 (water), this parameter is ignored. If the previous parameter is set to propylene glycol (2), this parameter may range from 0 to 1. If the previous parameter indicates ethylene glycol (3), this parameter may range from 0.55 to 0.85.

Heat exchanger inside diameter: It is the inside diameter of the pipe comprising the internal heat exchanger. It should be a real number and it can be changed from 0 to infinity. Its unit is m.

Heat exchanger outside diameter: It is the outside diameter of the pipe comprising the internal heat exchanger.

Heat exchanger fin diameter: It is the diameter of the fins on the outside pipe surface of the internal heat exchanger. If there are no fins (a smooth tube), set this parameter equal to the previous parameter (heat exchanger outside diameter).

Total surface area of heat exchanger: It is the total outside surface area of the internal heat exchanger.

Fins per meter for heat exchanger: It is the number of fins per unit length (meter) on the outside surface of the internal heat exchanger pipe. This parameter is ignored for smooth tubes.

Heat exchanger length: It is the total length of internal heat exchanger pipe immersed within the storage tank fluid.

Heat exchanger wall conductivity: It is the conductivity of the heat exchanger wall including any applicable contact resistance. Contact resistance would be present with a double wall heat exchanger where the heat exchanger is a tube within a tube design.

Heat exchanger material conductivity: It is the thermal conductivity of the material which comprises the internal heat exchanger.

Height of heat exchanger inlet: It is the height above the bottom of the storage tank of the inlet of the internal heat exchanger.

Height of heat exchanger outlet: It is the height of the outlet of the internal heat exchanger from the tank above the bottom of the storage tank.

Height of node: The height of the specified node. The number of nodes is controlled by the number of derivatives supplied to the model.

Additional loss coefficient for node: The additional loss coefficient for the specified node. The total loss coefficient for each node will be the average loss coefficient (specified much earlier) plus this incremental loss coefficient. Incremental loss coefficients are typically used when one section of the tank is more heavily insulated than other sections or to account for thermal shorts due to pipes and fittings.

4.5.2. Vertical Cylinder Tank Inputs

Flow rate at inlet 1: It is the flow rate entering the storage tank at the first inlet.

Flow rate at outlet 1: It is the flow rate of fluid exiting the storage tank from the first outlet. One of the outlet flow rates must be specified as a constant value of -2 to indicate that the outlet flow rate will be determined from a mass balance on the constant volume storage tank.

Flow rate at inlet 2: It is the flow rate of fluid entering the storage tank at the second inlet.

Flow rate at outlet 2: It is the flow rate of fluid exiting ths storage tank from the second outlet. One of the outlet flow rates must be set to a constant value of -2 to indicate that the outlet flow rate will be determined from a mass balance on the constant volume storage tank.

Temperature at inlet 1: It is the temperature of the fluid entering the storage tank at the first inlet.

Temperature at inlet 2: It is the temperature of the fluid entering the storage tank at the second inlet.

Environment temperature: It is the temperature of the environment in which the storage tank is located.

Control signal for element 1: It is the control signal for the specified auxiliary heating element. The available power for the heating element will be this input multiplied by the maximum power for the element. If an auxiliary heater is not desired for the simulation, set this input to a constant of 0.0 or set the maximum power for the element to 0.0.

Control signal for element 2: It is the control signal for the specified auxiliary heating element. The available power for the heating element will be this input multiplied by the maximum power for the element. If an auxiliary heater is not desired for the simulation, set this input to a constant of 0.0 or set the maximum power for the element to 0.0.

Flow rate for heat exchanger: It is the flow rate through the specified internal heat exchanger.

Inlet temperature for heat exchanger: It is the temperature at the inlet of the specified internal heat exchanger.

Nusselt constant for heat exchanger: It is the natural convection coefficient between the storage fluid and the internal heat exchanger wall is modeled with an equation of the form:

$h = Nu \times \frac{k}{do}$;

Typical value for C is about 0.5 and n is usually 0.25.

Nusselt exponent for heat exchanger: It is the natural convection coefficient between the storage fluid and the internal heat exchanger wall is modeled with an equation of the form:

$h = Nu \times \frac{k}{do}$;

Typical value for C is about 0.5 and n is usually 0.25.

4.5.3. Vertical Cylinder Tank Outputs

Flow rate at inlet 1: It is the flow rate of fluid into the storage tank at inlet 1.

Flow rate at outlet 1: It is the flow rate of fluid exiting the storage tank through outlet

Flow rate at inlet 2: It is the flow rate of fluid entering the storage tank through inlet

Flow rate at outlet 2: It is the flow rate of fluid exiting the storage tank through outlet

Temperature of outlet flow 1: It is the temperature of the fluid exiting the storage tank through outlet 1.

Temperature of outlet flow 2: It is the temperature of the fluid exiting the storage tank through outlet 2.

Thermal losses: It is the rate of thermal energy loss to the environment. It includes the vented energy if a boiling condition is reached.

Energy supplied by inlet 1: It is the rate at which energy is added to the storage tank by the entrance of the fluid through inlet 1.

Energy removed by outlet 1: It is the rate at which energy is removed from the storage tank by the exiting of fluid through outlet 1.

Energy supplied by inlet 2: It is the rate at which energy is added to the storage tank by the entrance of the fluid through inlet 2.

Energy removed by outlet 2: It is the rate at which energy is removed from the storage tank by the exiting of fluid through outlet 2.

Auxiliary heating rate: It is the average rate at which power was added to the tank by BOTH auxiliary heaters.

Element 1 power: It is the average power supplied to the storage tank over the timestep by the first heating element specified in the parameter list.

Element 2 power: It is the average power over the timestep supplied to the tank by the second auxiliary heater specified in the parameter list.

Losses to gas flue: It is the rate at which energy is removed from the storage tank through losses to the gas flue (while the tank is not being charged by the gas flue).

Internal energy change: It is the change in internal energy of the tank from the beginning of the simulation.

Average tank temperature: It is the average temperature of the fluid in the storage tank over the time step.

Static pressure difference - inlet 1: It is the static pressure difference between the top of the tank and the first inlet port.

Static pressure difference - outlet 1: It is the static pressure difference between the top of the tank and the first outlet port.

Static pressure difference - inlet 2: It is the static pressure difference between the top of the tank and the second inlet port.

Static pressure difference - outlet 2: It is the static pressure difference between the top of the tank and the second outlet port.

Energy input from heat exchanger: It is the rate at which energy is added to the storage tank from the specified internal heat exchanger.

Temperature of fluid exiting heat exchanger: It is the temperature of the fluid exiting the specified internal heat exchanger.

Tank temperature at outlet of heat exchanger: It is the temperature of the storage tank at the outlet of the specified internal heat exchanger.

LMTD of heat exchanger: It is the average log mean temperature difference of the specified internal heat exchanger over the time step.

UA of heat exchanger: It is the average overall heat transfer coefficient of the specified internal heat exchanger over the time step.

Tank temperature – top: It is the temperature of the fluid at the top of the storage tank.

Tank temperature – bottom: The temperature of the fluid at the bottom of the storage tank.

Temperature of node 1+: The temperature of the specified node.

4.6. Heat Exchanger - Cross Flow - Both Fluids Unmixed / Type 5e

A zero capacitance sensible heat exchanger is modeled in various configurations. In this instance a cross flow heat exchanger with both hot (source) and cold (load) side unmixed is modeled. Given the hot and cold side inlet temperatures and flow rates, the effectiveness is calculated for a given fixed value of the overall heat transfer coefficient. In this study Type 5e is used as air to air heat recovery unit and water to air heating coil (see Figure 4.5)

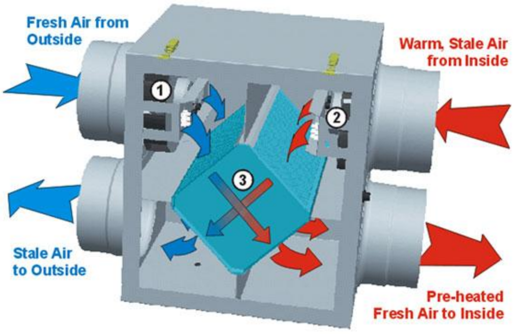
Figure 4.5 (a) shows the employed plate type heat recovery unit. As it was mentioned before, it is an zero capacitance heat exchanger. It consists of a plate type heat exchanger, two inlets for fresh and return air, and two outlet for supply air to the space and to exhaust to the outdoor environment.

4.6.1 Heat Exchanger Parameters

Cross flow mode: The general heat exchanger model may operate in one of four configuration modes. Setting this parameter to 3 indicates a cross flow arrangement. Do not change this parameter.

Specific heat of hot side fluid: The specific heat of the fluid flowing through the hot-side of the cross flow heat exchanger.

Specific heat of cold side fluid: The specific heat of the fluid flowing through the cold side of the cross flow heat exchanger.



(a) Heat Recovery Unit

(b) Heating Coil

Figure 4.5. (a) Plate type heat recovery unit, (b) Heating Coil

4.6.2. Heat Exchanger Inputs

Hot side inlet temperature: The temperature of the fluid flowing into the hot side of the cross flow heat exchanger.

Hot side flow rate: The flow rate of the fluid flowing through the hot side of the cross flow heat exchanger.

Cold side inlet temperature: The temperature of the fluid flowing into the cold side of the cross flow heat exchanger.

Cold side flow rate: The flow rate of the fluid flowing through the cold side of the cross flow heat exchanger.

Overall heat transfer coefficient of exchanger: Overall heat transfer coefficient of the cross flow heat exchanger.

4.6.3. Heat Exchanger Outputs

Hot-side outlet temperature: The temperature of the fluid leaving the hot side of the cross flow heat exchanger.

Hot-side flow rate: The flow rate of fluid exiting the hot side of the cross flow heat exchanger.

Cold-side outlet temperature: The temperature of the fluid leaving the cold side of the cross flow heat exchanger.

Cold-side flow rate: The flow rate of fluid exiting the cold side of the cross flow heat exchanger.

Heat transfer rate: The total heat transfer rate between the fluids in the cross flow heat exchanger.

Effectiveness: The effectiveness of the cross flow heat exchanger.

4.7. Auxiliary Heater / Type 6

In this study Type 6 is used as an auxiliary electrical heater (see Figure 4.6) is modeled to elevate the temperature of a flow stream using either internal control, external control or a combination of both types of control. The heater is designed to add heat to the flow stream at a user-designated rate (Q_{max}) whenever the external control input is equal to one and the heater outlet temperature is less than a user-specified maximum (T_{set}). By specifying a constant value of the control function of one and specifying a sufficiently large value of Q_{max}, this routine will perform like a domestic hot water auxiliary with internal control to maintain an outlet temperature of T_{set}. By providing a control function of zero or one from a thermostat or controller, this routine will perform like a furnace adding heat at a rate of Q_{max} but not exceeding an outlet temperature of T_{set}. In this application, a constant outlet temperature is not sought and T_{set} may be thought of as an arbitrary safety limit.

Figure 4.6. Electrical Heater

4.7.1. Auxiliary Heater Parameters

Maximum heating rate: The maximum possible energy transfer to the fluid stream. The maximum available energy transfer to the fluid stream will be the product of the maximum possible energy transfer and the conversion efficiency.

Specific heat of fluid: It is the specific heat of the fluid flowing through the auxiliary heater.

Overall loss coefficient for heater during operation: The loss coefficient (UA) from the heater during operation. During operation:

$$Q_{loss} = UA \times (T - T_{env}) + (1 - efficiency) \times Q_{max}$$

During non-operation: $Q_{loss} = 0$

Efficiency of auxiliary heater: The thermal conversion efficiency of the auxiliary heater. Typical values: Electric Heater = 1.0 ; Natural Gas = 0.79

4.7.2. Auxiliary Heater Inputs

Inlet fluid temperature: It is the temperature of the fluid entering the auxiliary heater.

Fluid mass flow rate: It is the flow rate of the fluid entering the auxiliary heater.

Control function:

Control function = 1 ---> Heater is on and providing energy to stream

Control function = 0 ---> Heater is off

The heater control function input requires either 1 or 0; proportional control signals (e.g. CF=0.53) will be interpreted as heater=off.

Set point temperature: It is the value of the temperature where the auxiliary heater will be off.

Temperature of surroundings: This data is used to determine losses.

$Q_{loss} = UA \times (T - T_{env}) + (1 - efficiency) \times Q_{max}$

4.7.3. Auxiliary Heater Outputs

Outlet fluid temperature:

If control=0 or mdot=0 or inlet temp > T_{set} then: $T_{out} = T_{in}$

Else $T_{out} = (Q_{max} \times Eff + mC_pT_{in} + UAT_{env} - \frac{UAT_{in}}{2})/(mC_p + \frac{UA}{2})$

Unless $T_{out} > T_{set}$

Then: $T_{out} = T_{set}$

Outlet fluid flow rate: Outlet flow rate is equal to inlet flow rate.

Required heating rate: The power needed to heat the fluid to the set point temperature including losses and conversion inefficiencies.

If $Q_{aux} = Q_{max}$; unless $T_{out} > T_{set}$

Then $Q_{aux} = (mC_p(T_{set} - T_{in}) + UA \times (T - T_{env}))/efficiency$

Losses from the auxiliary heater:

$Q_{loss} = UA \times (T - T_{env}) + (1 - efficiency) \times Q_{max}$

Rate of energy delivery to fluid stream: Power to fluid stream:

$Q_{fluid} = mC_p(T_{out} - T_{in})$

4.8. Differential Controller for Temperatures / Type 2b

The on/off differential controller (see Figure 4.7) generates a control function which can have a value of 1 or 0. The value of the control signal is chosen as a function of the difference between upper and lower temperatures Th and Tl, compared with two dead band temperature differences DTl and DTl. The new value of the control function depends on the value of the input control function at the previous time step. The controller is normally used with the input control signal connected to the output control signal, providing a hysteresis effect. However, control signals from different components may be used as the input control signal for this component if a more detailed form of hysteresis is desired.

For safety considerations, a high limit cut-out is included with this controller. Regardless of the dead band conditions, the control function will be set to zero if the high limit condition is exceeded.

4.8.1. Differential Controller Parameters

Number of oscillations: The number of control oscillations allowed in one time step before the controller is "Stuck" so that the calculations can be solved. This parameter should be set to an odd number so that short-term results are not biased.

High limit cut-out: The controller will set the controller to the OFF position, regardless of the dead bands, if the temperature being monitored (Input 3) exceeds the high limit cut-out. The controller will remain OFF until the monitored temperature falls below the high limit cut-out temperature.

Figure 4.7. Differential Controller

4.8.2. Differential Controller Inputs

Upper input temperature Th: Upper input temperature: The temperature difference that will be compared to the dead bands is Th (this input) minus Tl (Input 2).

Lower input temperature Tl: The temperature difference that will be compared to the dead bands is Th (Input 1) minus Tl (this input).

Monitoring temperature Tin: Temperature to monitor for high-limit cut-out checking. The controller signal will be set to OFF if this Input exceeds the high limit cut-out temperature (Parameter 4) The controller will remain OFF until this input falls below the high limit cut-out.

Input control function: The input control function is used to promote controller stability by the use of hysteresis. The control decision will be based on the dead band conditions and controller state at the previous time step (this input). In most applications, the output control signal from this component is hooked up to this input.

Upper dead band dT: A dead band is an area of a signal range or band where no action occurs. The purpose is to prevent oscillation or repeated activation-deactivation cycles . Upper dead band temperature difference is used to determine dead band for Th.

Lower dead band dT: Lower dead band temperature difference is used to determine dead band for Tl.

4.8.3. Differential Controller Outputs

Output control function: The output control function may be ON or OFF when 1 or 0 are assigned, respectively.

4.9. Forcing Function / Type 14h

In a transient simulation, it is sometimes convenient to employ a time dependent forcing function which has a behavior characterized by a repeated pattern. The pattern of the forcing function is established by a set of discrete data points indicating the value of the function at various times throughout one cycle. Linear interpolation is provided in order to generate a continuous forcing function from the discrete data. The cycle will repeat every N hours where N is the last value of time specified. While the code of Type 14 is entirely general, this version of the component uses dimensionless units so that it too can be used in a very generic manner.

4.9.1. Forcing Function Parameters

Initial value of time: The initial value of time for the function. If the cycle is to repeat, this initial value of time must be set to 0.0.

Initial value of function: The value of the function at the initial value of time.

Time at point : The value of time at the specified data point.

Value at point: The value of the function at the specified data point.

4.9.2. Differential Controller Outputs

Average value of function: The average value of the function over the timestep.

Instantaneous value of function over the timestep: The instantaneous value of the function at the end of the timestep.

4.10. Quantity Integrator / Type 24

This component integrates a series of quantities over a period of time. Each quantity integrator can have up to, but no more than 500 inputs. Type 24 is able to reset periodically throughout the simulation either after a specified number of hours or after each month of the year. With the release of TRNSYS 16, Type 24 was expanded so that the time between resets could be counted relative to the start time of the simulation or in absolute time. For example, with a 1 hour reset time, relative time resetting, and a simulation start time of 0.5, the integrator will reset at time 1.5, 2.5, 3.5, 4.5, etc. With a 1 hour reset time, absolute time resetting, and a simulation start time of 0.5, the Type24 integrator would reset at time 1.0, 2.0, 3.0, 4.0, etc. Thus the first integration period would not be a full hour.

4.10.1. Quantity Integrator Parameters

Integration period: The time interval over which the inputs are to be investigated. The outputs are reset to zero after each reset time interval. If the set time is set to a negative value, then units of months are assumed (if the reset time is set to -2, then the reset time will be two months...)

Relative or absolute start time: This parameter controls whether the integration intervals are relative or absolute 0: integrate at time intervals relative to the simulation start time,1: integrate at absolute time intervals. For example, if the simulation start time is 0.5, the simulation time step is 0.25 and the integration interval (or reset time) is 1: If this parameter is set to 0, reset will occur at 0.5, 1.5, 2.5, etc. If this parameter is set to 1, reset will occur at 1, 2, 3, etc.

4.10.2. Quantity Integrator Inputs

Input to be integrated: Leave the initial value at zero unless you wish to add a constant to the integration results. The constant added will be the initial value.

4.10.3. Quantity Integrator Outputs

Result of integration: The result of the integration of the corresponding input. Output 1will be the result of the integration of Input 1 with respect to time.

4.11. Online Plotter – With File, TRNSYS Supplied Units / Type 65a

The online graphics component is used to display selected system variables while the simulation is progressing. This component is highly recommended and widely used since it provides valuable variable information and allows users to immediately see if the System 1s not performing as desired. The selected variables will be displayed in a separate plot window on the screen. In this instance of the Type 65 online plotter, data sent to the online plotter is automatically printed, once per time step to a user defined external file. TRNSYS supplied unit descriptors (kJ/hr, kg/s, °C, etc.), if available, will be printed along with each column of data in the output file.

4.11.1. Online Plotter Parameters

Nb. of left-axis variables: The number of variables that will be plotted using the left Y-axis for scaling purposes.

Nb. of right-axis variables: The number of variables that will be plotted using the right axis for scaling purposes.

Left axis minimum: The minimum value for the left Y-axis.

Left axis maximum: The maximum value for the left Y-axis.

Right axis minimum: The minimum value for the right Y-axis.

Right axis maximum: The maximum value for the right Y-axis.

Number of plots per simulation: Number of plots per simulation. Use -1 for monthly plots.

X-axis gridpoints: The number of grid points that the X-axis (time) will be divided into.

Shut off Online w/o removing: This parameter can be used to shut off the ONLINE without removing from the assembly panel / input file, according to the following rules: -1 : don't display online >=0 : display online.

Logical Unit for output file: This parameter sets the Fortran Logical Unit (File reference number) of the output file. It is used internally by TRNSYS to refer to the file. This parameter will automatically be assigned to a unique value by the TRNSYS Studio

Output file units: This parameter controls the way variable units are printed: the value of 2 means that printed units will be the default units provided by TRNSYS.

Output file delimiter: This parameter controls the delimiter used in the output file: 0: use tabs to delimit columns,1: use spaces to delimit columns, 2: use commas to delimit columns.

4.11.2. Online Plotter Inputs

Left axis variable: The specified variable which is to be plotted using the left Y-axis for scaling purposes

Right axis variable: The specified variable which is to be plotted using the right Y-axis for scaling purposes.

CHAPTER 5

ASSIGNED VALUES TO INPUTS AND PARAMETERS

There are many parameters in the considered systems and their components. The output of the program highly depends on the input and design parameters. The definition of parameters and inputs are given in Chapter 4. In this chapter, the assigned values of parameters and inputs for three different systems are presented in the form or tables. Those tables include 4 columns indicating data name, type (constant or variable), value and unit. In this chapter, also schematic figures are given to present components input and output connections.

Technical data of some components such as Heat Recovery Unit, Heating Coil, Pump 1, 2, Supply and Return Fan are given in the Appendix A.

5.1. System 1

Weather Data (Type 109), Supply Fan (Type 3c), Electrical Heater (Type 6), Return Fan (Type 3c), Time Controller (Type 14h), Integrator (Type 24) and Online Plotter (Type 65a) are components of System 1. They are explained in this section.

5.1.1. Weather Data / Type 109

Weather data for different cities of the worlds exists in the library of TRNSYS. In this study, the weather data of Izmir is used. It contains the data files for the Typical Meteorological Year (TMY) data sets derived from the 1961-1990. The TMY2 are data sets of hourly values of solar radiation and meteorological elements for a 1-year period. The design parameters and input data are given in Table 5.1.

As it is seen from Figure 5.1, Weather Data outputs are connected to Supply Fan, Electrical Heater and Online Plotter.

Table 5.1. Design parameters and input values for Weather Data

Design Parameters			
Name	**Type**	**Value**	**Unit**
Data reader mode	Constant	2.00	-
Logical unit	Constant	30.00	-
Sky model for diffuse radiation	Constant	4.00	-
Tracking mode	Constant	1.00	-
Design Input Data			
Name	**Type**	**Value**	**Unit**
Ground reflectance	Constant	0.20	-
Slope of surface	Constant	0.00	°
Azimuth of surface	Constant	0.00	°

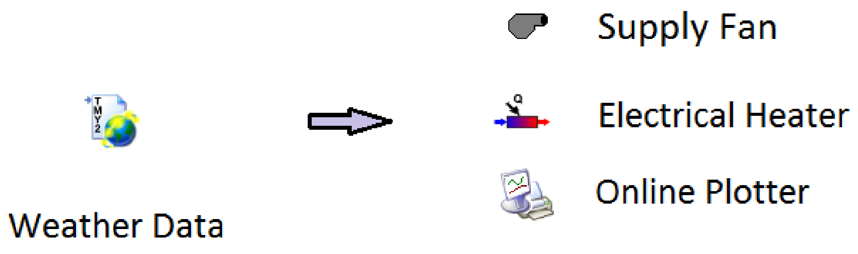


Figure 5.1. Output connections for Weather Data

5.1.2. Supply Fan / Type 3c

A single speed radial fan is selected as supply fan for this study. Its air flow rate is fixed due to system specifications and maximum power is defined according to the fan characteristic curve.

A return fan extracts the same amount of air from indoor space. Because of constant temperature and flow rate of the return air, this fan is not included in the simulation; however its electrical consumption is added to the total electrical consumption. Assigned values for parameters and input data are given in Table 5.2.

In Figure 5.2, input and output connections of Supply Fan are presented. Supply Fan takes inputs from Weather Data and Time Controller outputs and it gives its outputs to Electrical Heater and Integrator.

Table 5.2. Design parameter and input values of Supply Fan

Design Parameters			
Name	**Type**	**Value**	**Unit**
Maximum flow rate	Constant	1204.00	kg/hr
Fluid specific heat	Constant	1.00 (Air)	kJ/kg.K
Maximum power	Constant	180	W
Conversion coefficient	Constant	0.10	-
Design Input Data			
Name	**Type**	**Value**	**Unit**
Inlet fluid temperature	Variable	Connected to the Weather Data – Ambient temperature	°C

(cont. on next page)

Table 5.2 (cont.)

Inlet mass flow rate	Constant	1204.00	kg/hr
Control signal	Variable	Connected to the Time Controller – Instantaneous value of function over the time step	-

Figure 5.2. Input and output connections for Supply Fan

5.1.3. Electrical Heater / Type 6

The maximum heating rate is fixed to 100 kW to enable heating element for continues operation, except 0 signal received from Time Controller. The air flow rate through the electrical heater is constant as 1000 m³/h. The pressure drop through the electrical heater is assumed as 20 Pa and it is included to the total pressure drop for Supply Fan. Design parameters and input data are presented in Table 5.3. Electrical Heater uses Weather Data, Supply Fan and Time Controller outputs and it transfers its calculated values to Integrator and Online Plotter. These relations can be observed from Figure 5.3.

Table 5.3. Design parameters and input values of Electrical Heater

Design Parameters			
Name	**Type**	**Value**	**Unit**
Maximum heating rate	Constant	100000.00	W
Specific heat of fluid	Constant	1.00 (Air)	kJ/kg.K
Overall loss coefficient for heating during operation	Constant	0.00	kJ/hr.K
Efficiency of auxiliary heater	Constant	1.00	-
Design Input Data			
Name	**Type**	**Value**	**Unit**
Inlet fluid temperature	Variable	Connected to the Supply Fan – Outlet fluid temperature	°C
Fluid mass flow rate	Variable	Connected to the Supply Fan – Outlet flow rate	kg/hr
Control function	Variable	Connected to the Time Controller – Instantaneous value of function over the time step	-
Set point temperature	Constant	22.00	°C
Temperature of surroundings	Variable	Connected to the Weather Data – Ambient temperature	°C

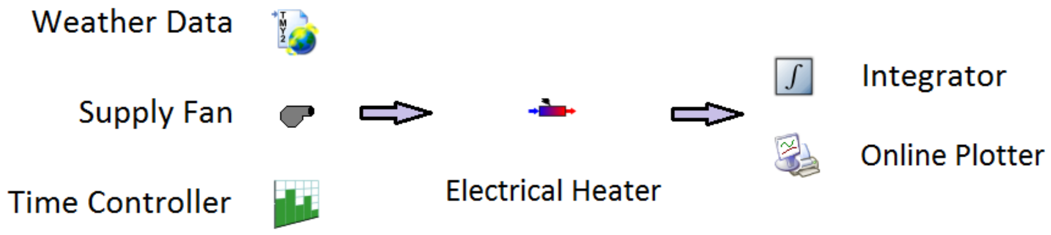


Figure 5.3. Input and output connections for Electrical Heater

5.1.4. Time Controller / Type 14h

Time Controller is an on/off signal creator and it is programmed according to user depended time intervals. Design parameters presented in Table 5.4 generates on signal between 17:00 and 24.00 and off signal between 24.00 and 17.00.

Figure 5.4 shows Time Controller data which sends its signals to Supply Fan and Electrical Heater.

Table 5.4. Design parameters of Time Controller

Design Parameters			
Name	**Type**	**Value**	**Unit**
Initial value of time	Constant	0.00	hr
Initial value of function	Constant	0.00	any
Time at point 1	Constant	17.00	hr
Value at point 1	Constant	0.00	any
Time at point 2	Constant	17.00	hr
Value at point 2	Constant	1.00	any
Time at point 3	Constant	24.00	hr
Value at point 3	Constant	1.00	any
Time at point 4	Constant	24.00	hr
Value at point 4	Constant	0.00	any

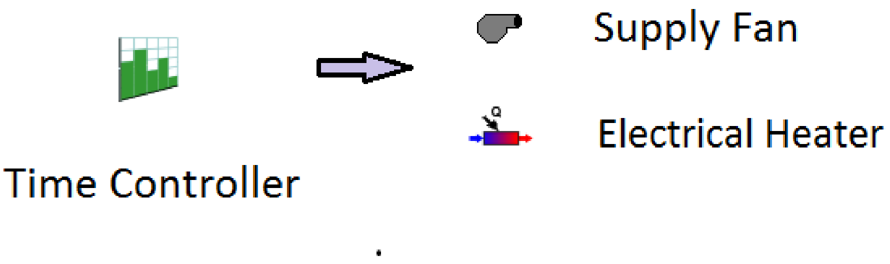


Figure 5.4. Input and output connections for Time Controller

5.1.5. Integrator / Type 24

Integrator is used to calculate its input values summation with respect to time. In System 1, it calculates total energy consumptions of Electrical Heater and Supply Fan as it is indicated in the Table 5.5. Figure 5.5 shows that Integrator takes Electrical Heater and Supply Fan outputs, integrates them and send it to Online Plotter.

Table 5.5. Design parameters and input values of Integrator

Design Parameters			
Name	**Type**	**Value**	**Unit**
Integration period	Constant	STOP	hr
Relative or absolute start time	Constant	1.00	-
Design Input Data			
Name	**Type**	**Value**	**Unit**
Input to be integrated 1	Variable	Connected to the Electrical Heater – Required heating rate	any
Input to be integrated 2	Variable	Connected to the Supply Fan – Power consumption	any

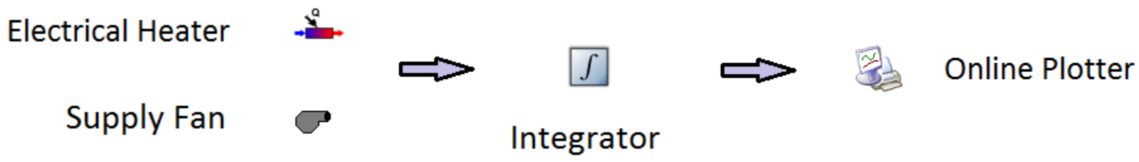


Figure 5.5. Input and output connections for Integrator

5.1.6. Online Plotter / Type 65a

Online Plotter collects data from input elements and presents them in form of graphics. As it is shown in Table 5.6, design parameters and input data determine graphic specifications and values to be plotted. In Figure 5.6 input connections for Online Plotter for System 1 are presented.

Table 5.6. Design parameters and input values of Online Plotter

Design Parameters			
Name	**Type**	**Value**	**Unit**
Number of left-axis variables	Constant	2.00	-
Number of right-axis variables	Constant	3.00	-
Left-axis minimum	Constant	-10.00	-
Left-axis maximum	Constant	100.00	-
Right-axis minimum	Constant	-100000.00	-
Right-axis maximum	Constant	100000.00	-
Number of plots per simulation	Constant	1.00	-

(cont. on next page)

Table 5.6 (cont.)

X-axis grid points	Constant	10.00	-
Shut off online w/o removing	Constant	0.00	-
Logical unit for output file			
Output file units	Constant	2.00	-
Output file delimiter	Constant	0.00	-
Design Input Data			
Name	**Type**	**Value**	**Unit**
Left axis variable 1	Variable	Electrical Heater outlet temperature	any
Left axis variable 2	Variable	Ambient temperature	any
Right axis variable 1	Variable	Electrical Heater energy consumption	any
Right axis variable 2	Variable	Electrical Heater energy consumption integration	any
Right axis variable 3	Variable	Supply Fan energy consumption integration	any

Figure 5.6. Input connections for Online Plotter

5.2. System 2

System 2 consists of Weather Data (Type 109), Heat Recovery Unit (Type 5e), Supply Fan (Type 3c), Return Fan (Type 3c), Electrical Heater (Type 6), Time Controller (Type 14h), Integrator (Type 24) and Online Plotter (Type 65a).

Heat Recovery Unit is the only new component of the System 2 compared to System 1. Other components are explained in detail in previous section. Even the type of the component is the same, assigned values to input data and parameters or input-output connections of the component may differ. For example, by adding Heat Recovery Unit pressure drop in the system will increase, hence maximum power of fan should be changed. Those differences are explained in this section. The assigned values to input data and parameters of Weather Data are the same as System 1 values. Hence, only its output connections are presented in related sections. Supply Fan, Online Plotter input data and parameters are different, so those values are explained in tables and components input and output connections are presented in the figures. Electrical Heater, Time Controller and Integrator are exactly identical with System 1's elements; therefore they are not mentioned in this section. Since Heat Recovery Unit is a new component, it is examined in details.

5.2.1. Weather Data / Type 109

In System 2, Weather Data inputs and parameters are similar to System 1's, its output data connected to Heat Recovery Unit, Electrical Heater and Online Plotter as it is seen in Figure 5.7.

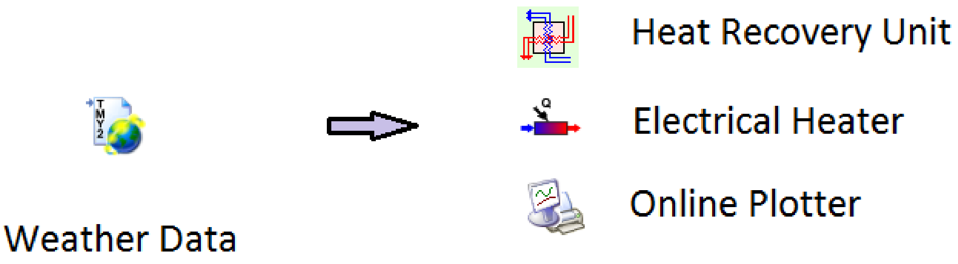


Figure 5.7. Output connections for Weather Data

5.2.2. Heat Recovery Unit / Type 5e

Heat recovery unit is a flat plate type air to air heat exchanger with cross flow arrangement. Its sizing depends on the air volume rate, its thermal performance, and pressure drop. In the present study, these values are fixed and they are not changed in the software. These values are selected based on the negotiation with heat recovery unit manufacturers. The air flow rate, efficiency and pressure drop are assigned as 1024 kg/h, 78% and 95 Pa. The pressure drop value of the selected heat recovery unit is used for selection of the supply and return fan.

In Table 5.7, Heat Recovery Unit inputs data and parameters values are listed. Heat Recovery Unit takes Weather Data and after calculations performed according to component specifications, it gives outputs data to Supply Fan and Online Plotter. These relations are presented in Figure 5.8.

Table 5.7. Design parameters and input values of Heat Recovery Unit

Design Parameters			
Name	**Type**	**Value**	**Unit**
Cross flow mode	Constant	5.00	-
Specific heat of hot side fluid	Constant	1.00 (Air)	kJ/kg.K
Specific heat of cold side fluid	Constant	1.00 (Air)	kJ/kg.K
Design Input Data			
Name	**Type**	**Value**	**Unit**
Hot side inlet temperature	Constant	22.00	°C
Hot side flow rate	Constant	1204.00	kg/hr
Cold side inlet temperature	Variable	Connected to the Weather Data – Ambient temperature	°C
Cold side flow rate	Constant	1204.00	kg/hr
Overall heat transfer coefficient	Constant	600.00	W/K

Figure 5.8. Input and output connections for Heat Recovery Unit

5.2.3. Supply Fan / Type 3c

Supply Fan of the System 2 is the same type as System 1’s Supply Fan. But its inputs and parameters are different. Because of the Heat Recovery Unit addition to the system, Supply Fan pressure drop increases. Therefore, its maximum power is also greater. Figure 5.9.

Table 5.8 shows Supply Fan design parameters and input data for System 2. Supply Fan takes input data from Heat Recovery Unit and Time Controller, and then it gives calculated data to Electrical Heater and Integrator, as it can be observed from Figure 5.9.

Table 5.8. Design parameters and input values of Supply Fan

Design Parameters			
Name	**Type**	**Value**	**Unit**
Maximum flow rate	Constant	1204.00	kg/hr
Fluid specific heat	Constant	1.00 (Air)	kJ/kg.K
Maximum power	Constant	370.00	W
Conversion coefficient	Constant	0.10	-
Design Input Data			
Name	**Type**	**Value**	**Unit**
Inlet fluid temperature	Variable	Connected to the Heat Recovery Unit – Cold-side outlet temperature	°C
Inlet mass flow rate	Variable	Connected to the Heat Recovery Unit – Cold-side flow rate	kg/hr
Control signal	Variable	Connected to the Time Controller – Instantaneous value of function over the time step	-

Figure 5.9. Input and output connections for Supply Fan

5.2.4. Online Plotter / Type 65a

Design parameters and inputs to be plotted as graphics are listed in Table 5.9 and input connections are presented in Figure 5.10.

Table 5.9. Design parameters and input values of Online Plotter.

Design Parameters			
Name	**Type**	**Value**	**Unit**
Number of left-axis variables	Constant	3.00	-
Number of right-axis variables	Constant	3.00	-
Left-axis minimum	Constant	-10.00	-
Left-axis maximum	Constant	100.00	-
Right-axis minimum	Constant	-100000.00	-
Right-axis maximum	Constant	100000.00	-

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Table 5.9 (cont.)

Number of plots per simulation	Constant	1.00	-
X-axis gridpoints	Constant	10.00	-
Shut off online w/o removing	Constant	0.00	-
Logical unit for output file	Constant	31.00	-
Output file units	Constant	2.00	-
Output file delimiter	Constant	0.00	-
Design Input Data			
Name	**Type**	**Value**	**Unit**
Left axis variable 1	Variable	Electrical Heater outlet temperature	any
Left axis variable 2	Variable	Ambient Temperature	any
Left axis variable 3	Variable	Heat Recovery Unit outlet temperature	any
Right axis variable 1	Variable	Electrical Heater energy consumption	any
Right axis variable 2	Variable	Electrical Heater energy consumption integration	any
Right axis variable 3	Variable	Supply Fan energy consumption integration	any

Figure 5.10. Input and output connections for Online Plotter.

5.3. System 3

System 3consists of Weather Data (Type 109), Solar Collector (Type 71), Storage Tank (Type 60f), Pump 1 (Type 3b), Temperature Controller (Type 2b), Pump 2 (Type 3b), Heat Recovery Unit (Type 5e), Supply Fan (Type 3c), Heating Coil (Type 5e), Return Fan (Type 3c), Electrical Heater (Type 6), Time Controller (Type 14h), Integrator (Type 24) and Online Plotter (Type 65a).

Solar Collector, Storage Tank, Pump 1, Pump 2, Temperature Controller, Heating Coil are new components of the System 3 compared to System 2. Other components are explained in detail in previous section. Even the type of the component is the same, assigned values to input data and parameters or input-output connections of the component may differ. Those differences are explained in this section. The assigned values to input data and parameters of Weather Data and Supply Fan are the same as System 2 values. Hence, only their input and output connections are presented in related sections. Electrical Heater, Integrator and Online Plotter input data and parameters are different, so those values are explained in tables and components input and output connections are presented in the figures. Heat Recovery Unit and Time Controller are exactly identical with System 1's elements; therefore they are not mentioned in this section. Since Solar Collector, Storage Tank, Pump 1, Pump 2, Temperature Controller and Heating Coil are new components, they are examined in details.

5.3.1. Weather Data / Type 109

In System 3, Weather Data inputs and parameters are similar to System 1 and 2’s, its output data connected to Solar Collector, Storage Tank, Heat Recovery Unit, Electrical Heater and Online Plotter as it is seen in Figure 5.11.

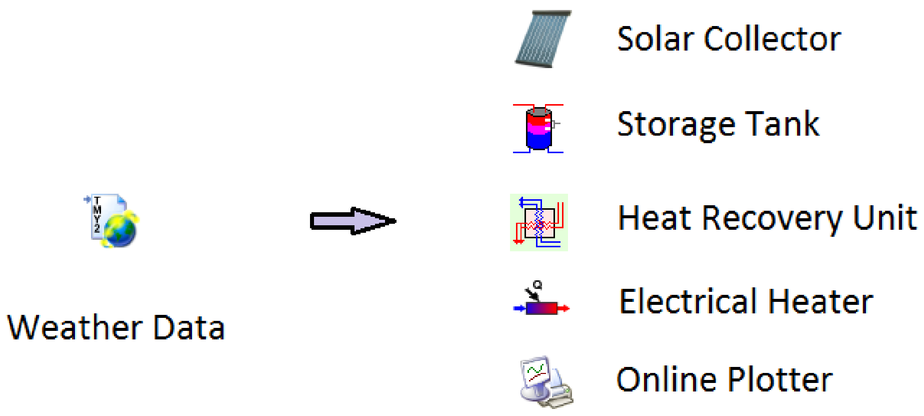

Figure 5. 11. Output connections for Weather Data

5.3.2. Solar Collector / Type 71

The present study is based on the use of solar energy and its storage. Hence, the solar collector design parameters are very important to obtain realistic results. The design parameters and input data values of the solar collector are given in Table 5.10. In this study, simulation calculations are performed for different values of solar collector area in order to investigate the Solar Collector area effect on the system energy consumption. As it is seen from Table 5.10, the studied solar collector areas are 5-10-15-30-40-50 m^2 respectively. Solar Collector takes input data from weather data and Pump 1, and then based on the given design parameters, calculation is performed. Then obtained results are assigned to the Storage Tank, Temperature Controller and Online Plotter as output data. The relation between Solar Collector, Weather Data, Pump 1, Storage Tank, Temperature Controller and Online Plotter is shown in Figure 5.12.

Table 5.10. Design parameters and input values of the Solar Collector

Design Parameters			
Name	**Type**	**Value**	**Unit**
Number in series	Constant	1.00	-
Collector area	Constant	Assigned by authors. In this study its value is between 5 to 50.	m^2
Fluid specific heat	Constant	4.19 (Water)	kJ/kg.K
Efficiency mode	Constant	1.00	-
Flow rate at test conditions	Constant	3.00	kg/hr.m^2
Intercept efficiency	Constant	0.70	-
Negative of first order efficiency coefficient	Constant	10.00	kg/hr.m^2.K
Negative of second order efficiency coefficient	Constant	0.03	kg/hr.m^2.K^2
Logical unit of file containing biaxial IAM data	Constant	32.00	-
Number of longitudinal angles for which IAMs are provided	Constant	7.00	-
Number of transverse angles for which IAMs are provided	Constant	7.00	-
Design Input Data			
Name	**Type**	**Value**	**Unit**
Inlet temperature	Variable	Connected to the Pump 1 – Outlet fluid temperature	°C
Inlet flow rate	Variable	Connected to the Pump 1 – Outlet flow rate	kg/hr

(cont. on next page)

Table 5.10 (cont.)

Ambient temperature	Variable	Connected to the Weather Data – Ambient temperature	°C
Incident radiation	Variable	Connected to the Weather Data – Total radiation on tilted surface	kJ/hr.m^2
Incident diffuse radiation	Variable	Connected to the Weather Data – Sky diffuse radiation on tilted surface	W/m^2
Solar incidence angle	Variable	Connected to the Weather Data – Angle of incidence for tilted surface	degree
Solar zenith angle	Variable	Connected to the Weather Data – Solar zenith angle	°
Solar azimuth angle	Variable	Connected to the Weather Data – Solar azimuth angle	°
Collector slope	Constant	35.00	°
Collector azimuth	Constant	0.00	°

Figure 5.12 Input and output connections for Solar Collector

5.3.3. Pump 1 / Type 3b

The Pump 1 is a single speed circulation pump. In this study, Pump1 circulates the water between Solar Collector and Storage Tank and its flow rate is assumed as 225 kg/h based on the negotiation with solar collector designers.

Pump 1 maximum power value depends on the pressure drop which should be overcome. Since the pressure drop in the solar collector changes with solar collector area, maximum power of the Pump 1 increases with solar collector area. Based on negotiations with solar collector manufactures, for 5 m² solar collector area, the pressure drop is around 5000 Pa. By increasing solar collector area, the number of mounted pump increases. As design parameter, the total maximum power of pumps is given in Table 5.11.

The assumed water flow rate and head of the pump are practical values that may be faced in application. Based on the assumed values, a pump is searched for this application and it is observed that a practical pump available in market can be selected.

As it was mentioned before, Pump 1 circulates the water between Solar Collector and Storage Tank, so it takes data from Storage Tank and Temperature Controller and it gives data to Solar Collector, Integrator and Online Plotter. These connections are schematically presented in Figure 5.13.

Table 5.11. Design parameters and input values of Pump 1

Design Parameters			
Name	**Type**	**Value**	**Unit**
Maximum flow rate	Constant	225.00	kg/hr
Fluid specific heat	Constant	4.19 (Water)	kJ/kg.K
Maximum power	Constant	27.00	W

(cont. on next page)

Table 5.11 (cont.)

Conversion coefficient	Constant	0.05	-
Power coefficient	Constant	1.00	-
Design Input Data			
Name	**Type**	**Value**	**Unit**
Inlet fluid temperature	Variable	Connected to the Storage Tank - Temperature of outlet flow 1	°C
Inlet mass flow rate	Variable	Connected to the Storage Tank – Flow rate of outlet 1	kg/hr
Control signal	Variable	Connected to the Temperature Controller – Output control function	-

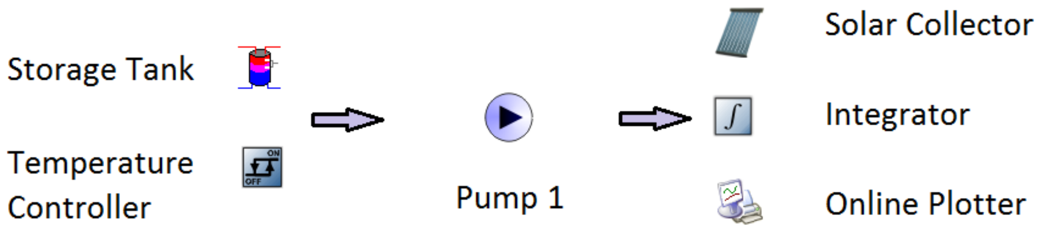

Figure 5.13. Input and output connections for Pump 1

5.3.4. Pump 2 / Type 3b

The Pump 2 is a single speed circulation pump. In this study, Pump 2 circulates the water between Storage Tank and Heating Coil. Its flow rate and maximum power are assumed as 152 kg/h and 18 W, respectively, based on the negotiation with heating coil designers.

As it was mentioned before, Pump 2 circulates the water between Storage Tank and Heating Coil, so it takes data from Heating Coil and Time Controller and it gives data to Heating Coil, Storage Tank, Integrator and Online Plotter. These connections are schematically presented in Figure 5.14. Design parameters and input data are also presented in Table 5.12.

Table 5.12. Design parameters and input values of Pump 2

Design Parameters			
Name	**Type**	**Value**	**Unit**
Maximum flow rate	Constant	152	kg/hr
Fluid specific heat	Constant	4.19 (Water)	kJ/kg.K
Maximum power	Constant	18.00	W
Conversion coefficient	Constant	0.05	-
Power coefficient	Constant	1.00	-
Design Input Data			
Name	**Type**	**Value**	**Unit**
Inlet fluid temperature	Variable	Connected to the Heating Coil – Hot-side outlet temperature	°C
Inlet mass flow rate	Variable	Connected to the Heating Coil – Hot-side outlet flow rate	kg/hr
Control signal	Variable	Connected to the Time Controller – Instantaneous value of function over the time step	-

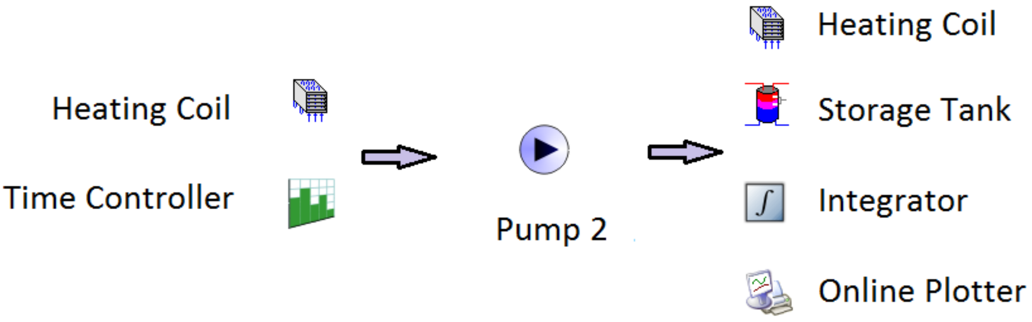

Figure 5.14. Input and output connections for Pump 2

5.3.5. Supply Fan / Type 3c

Supply Fan input data and design parameters are identical with System 2's. Similarly to System 2, Supply Fan takes input data from Heat Recovery Unit and Time Controller, and differently it gives calculated data to Heating Coil and Integrator, as it can be observed from Figure 5.15.

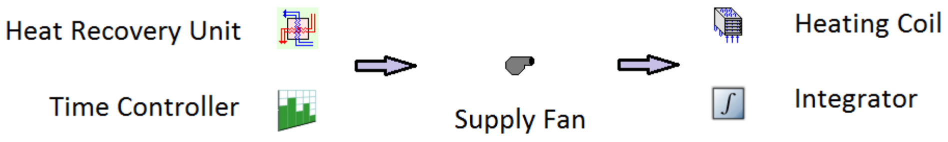

Figure 5.15. Input and output connections for Supply Fan

5.3.6 Storage Tank / Type 60f

In this study a vertical cylinder water tank is used for sensible thermal storage of the solar energy. Since the storage tank is one of the most important elements of the system, a special attention should be paid on its design parameters. Especially tank volume is a dominant factor for storage capacity. In this study, the storage tank volume is changed to investigate the storage tank volume effect on the system energy consumption. The study is performed for storage tank of 0,5-1-2-3-4-5-6-7-8 m^3.

Type 60f has optional internal heat exchangers, electrical and gas heaters. In this study those options are not taken into account and their values are assigned as zero. Storage Tank design parameters and assigned values, and input data are presented in Table 5.13.

Storage Tank input values comes from Weather Data, Solar Collector and Pump 2 connections and after component calculations it gives data to Pump 1, Temperature Controller, Heating Coil and Online Plotter as it is seen from Figure 5.16.

Table 5.13. Design parameters and input values of Storage Tank

Design Parameters			
Name	**Type**	**Value**	**Unit**
User-specified inlet positions	Constant	2.00	-
Tank volume	Constant	Assigned by authors. In this study its value is between 0,5 - 8,0	m³
Tank height	Constant	1.25	m
Tank perimeter	Constant	-1.00	m
Height of flow inlet 1	Constant	1.25	m
Height of flow outlet 1	Constant	0.00	m
Height of flow inlet 2	Constant	0.00	m
Height of flow outlet 2	Constant	1.25	m
Fluid specific heat	Constant	4.19 (Water)	kJ/kg.K
Fluid density	Constant	1000.00	kg/m³
Tank loss coefficient	Constant	0.00	kg/hr.m².K

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Table 5.13 (cont.)

Fluid thermal conductivity	Constant	2.16 (Water)	kg/hr.m.K
Destratification conductivity	Constant	0.00	kg/hr.m.K
Boiling temperature	Constant	100.00 (Water)	°C
Auxiliary heater mode	Constant	2.00	-
Height of 1st aux. heater	Constant	0.00	m
Height of 1st thermostat	Constant	0.00	m
Set point temperature for element 1	Constant	0.00	°C
Deadband for heating element 1	Constant	0.00	ΔC
Maximum heating rate of element 1	Constant	0.00	kJ/hr
Overall loss coefficient for gas flue	Constant	0.00	kJ/hr.K
Flue temperature	Constant	20.00	°C
Fraction of critical time step	Constant	6.00	-
Gas heater?	Constant	0.00	-
Number of internal heat exchangers	Constant	0.00	-
Node heights supplied	Constant	0.00	-
Additional loss coefficient’s supplied	Constant	0.00	-
HX fluid indicator	Constant	0.00	-
Fraction of glycol	Constant	0.00	-
Heat exchanger inside diameter	Constant	0.00	m

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Table 5.13 (cont.)

Heat exchanger outside diameter	Constant	0.00	m
Heat exchanger fin diameter	Constant	0.00	m
Total surface area of heat exchanger	Constant	0.00	m^2
Fins per meter for heat exchanger	Constant	0.00	-
Heat exchanger length	Constant	0.00	m
Heat exchanger wall conductivity	Constant	0.00	kJ/hr.m.K
Heat exchanger material conductivity	Constant	0.00	kJ/hr.m.K
Height of heat exchanger inlet	Constant	0.00	m
Height of heat exchanger outlet	Constant	0.00	m
Height of node	Constant	0.00	m
Additional loss coefficient for node	Constant	0.00	kJ/hr.m^2.K
Design Input Data			
Name	**Type**	**Value**	**Unit**
Flow rate at inlet 1	Variable	Connected to the Solar Collector – Outlet flow rate	kg/hr
Flow rate at outlet 1	Variable	-	kg/hr
Flow rate at inlet 2	Variable	Connected to the Pump 2 – Outlet flow rate	kg/hr
Flow rate at outlet 2	Variable	-	kg/hr

(cont. on next page)

Table 5.13 (cont.)

Temperature at inlet 1	Variable	Connected to the Solar Collector – Outlet fluid temperature	°C
Temperature at inlet 2	Variable	Connected to the Pump 2 – Outlet fluid temperature	°C
Environmental temperature	Variable	Connected to the Weather Data – Ambient temperature	°C
Control signal for element 1	Constant	0.00	-
Control signal for element 2	Constant	0.00	-
Flow rate for heat exchanger	Constant	0.00	kg/hr
Inlet temperature for heat exchanger	Constant	0.00	°C
Nusselt constant for heat exchanger	Constant	0.00	-
Nusselt exponent for heat exchanger	Constant	0.00	-

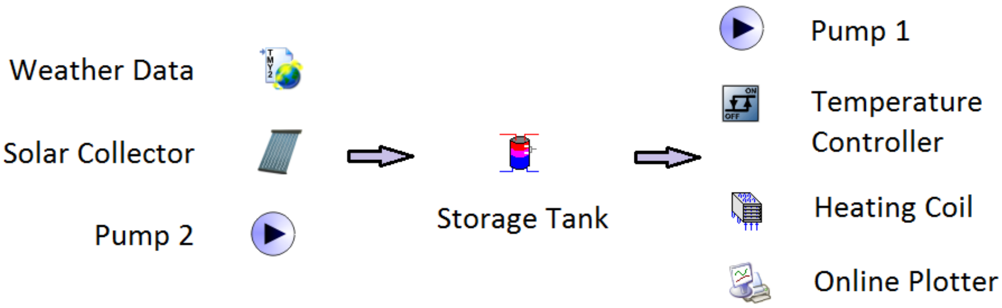

Figure 5.16. Input and output connections for Storage Tank

5.3.7. Heating Coil / Type 5e

Heating Coil is a serpentine type water to air heat exchanger with cross flow arrangement. Its sizing depends on the air and water volume rate and water pressure drop and inlet and outlet temperatures. In this study, the air flow rate is fixed as 1000 m3/h, as it was explained before. In order to fix the water flow rate and pressure drop, a Heating Coil is selected based on the average temperature values. The Heating Coil is selected for water inlet and outlet temperature as 80 and 60°C, and air inlet and outlet temperature as 10 and 30°C. These values are taken from the coil manufacturer. The calculated air and water pressure drop values by coil manufacturer are used for the selection of Supply Fan and Pump 2.

Heating Coil design parameters and input data assigned values are listed in Table 5.14. Figure 5.17 show s that Supply Fan, Storage Tank and Pump 2 gives input data of Heating Coil and Heating Coil gives calculated data to Pump 2, Electrical Heater and Online Plotter.

Table 5.14. Design parameters and input values of Heating Coil

Design Parameters			
Name	**Type**	**Value**	**Unit**
Cross flow mode	Constant	5.00	-
Specific heat of hot side fluid	Constant	4.19 (Water)	kJ/kg.K
Specific heat of cold side fluid	Constant	1.00 (Air)	kJ/kg.K
Design Input Data			
Name	**Type**	**Value**	**Unit**
Hot side inlet temperature	Variable	Connected to the Storage Tank – Temperature of outlet flow 2	°C

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Table 5.14 (cont.)

Hot side flow rate	Variable	Connected to the Pump 2 – Outlet flow rate	kg/hr
Cold side inlet temperature	Variable	Connected to the Supply Fan – Outlet fluid temperature	°C
Cold side flow rate	Variable	Connected to the Supply Fan – Outlet flow rate	kg/hr
Overall heat transfer coefficient	Constant	101.00	W/K

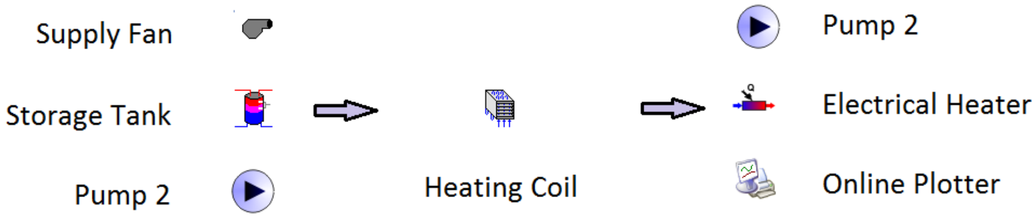

Figure 5.17. Input and output connections for Heating Coil

5.3.8. Electrical Heater / Type 6

In System 3, Electrical Heater design parameters are similar to System 1 and 2’s, but its input data is different as it is seen from Table 5.15.

In System 3, Weather Data, Heating Coil and Time Controller is connected to Electrical Heater as input data. Electrical Heater gives its output data to Integrator and Online Plotter similarly to previous systems as it is observed from Figure 5.18.

Table 5.15. Design parameters and input values of Electrical Heater

<table>
<tr><th colspan="4">Design Parameters</th></tr>
<tr><th>Name</th><th>Type</th><th>Value</th><th>Unit</th></tr>
<tr><td>Maximum heating rate</td><td>Constant</td><td>100000.00</td><td>W</td></tr>
<tr><td>Specific heat of fluid</td><td>Constant</td><td>1.00 (Air)</td><td>kJ/kg.K</td></tr>
<tr><td>Overall loss coefficient for heating during operation</td><td>Constant</td><td>0.00</td><td>kJ/hr.K</td></tr>
<tr><td>Efficiency of auxiliary heater</td><td>Constant</td><td>1.00</td><td>-</td></tr>
<tr><th colspan="4">Design Input Data</th></tr>
<tr><th>Name</th><th>Type</th><th>Value</th><th>Unit</th></tr>
<tr><td>Inlet fluid temperature</td><td>Variable</td><td>Connected to the Heating Coil – Cold-side outlet temperature</td><td>°C</td></tr>
<tr><td>Fluid mass flow rate</td><td>Variable</td><td>Connected to the Heating Coil – Cold-side flow rate</td><td>kg/hr</td></tr>
<tr><td>Control function</td><td>Variable</td><td>Connected to the Time Controller – Instantaneous value of function over the time step</td><td>-</td></tr>
<tr><td>Set point temperature</td><td>Constant</td><td>22.00</td><td>°C</td></tr>
<tr><td>Temperature of surroundings</td><td>Variable</td><td>Connected to the Weather Data – Ambient temperature</td><td>°C</td></tr>
</table>

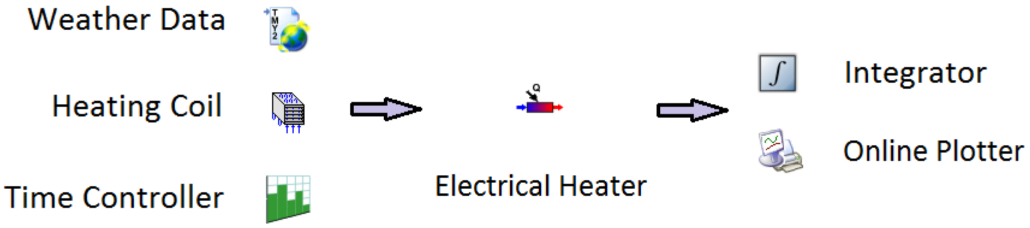

Figure 5.18. Input and output connections for Electrical Heater

5.3.9. Temperature Controller / Type 2b

This Temperature Controller compares solar collector outlet water temperature with Storage Tank outlet 1 water temperature. The water leaves from outlet 1 are received by Pump 1. The operation principle of this controller is described in Chapter 4. The design parameters and input data values of the solar collector are given in Table 5.16.

Temperature Controller takes its input data from Solar Collector, Storage Tank and itself, and then it gives its output to Pump 1 and itself again. These input and output connections for Temperature Controller are presented in Figure 5.19.

Table 5.16. Design parameters and input values of Temperature Controller

Design Parameters			
Name	**Type**	**Value**	**Unit**
Number of oscillations	Constant	5.00	-
High limit cut-out	Constant	200.00	°C

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Table 5.16 (cont.)

Design Input Data			
Name	**Type**	**Value**	**Unit**
Upper input temperature Th	Variable	Connected to the Solar Collector – Outlet temperature	°C
Lower input temperature Tl	Variable	Connected to the Storage Tank – Temperature of outlet flow 1	°C
Monitoring temperature Tin	Variable	Connected to the Storage Tank – Average tank temperature	°C
Input control function	Variable	Connected to the Temperature Controller – Output control function	-
Upper dead band dT	Constant	0.00	ΔC
Lower dead band dT	Constant	0.00	ΔC

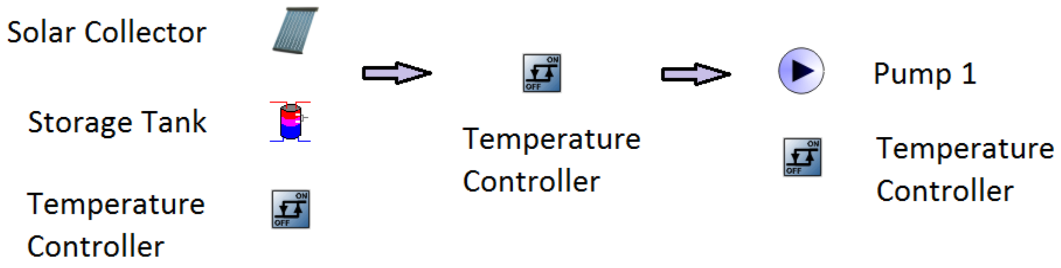

Figure 5.19. Input and output connections for Temperature Controller

5.3.10. Integrator / Type 24

Integrator of System 3 has the same design parameters with System 1 and II's but its input data is different. This Integrator performs calculations for four elements. Input data is shown in Table 5.17 and its input and output connections are presented in Figure 5.20. As it is seen, Integrator takes data from Supply Fan, Pump 1, Pump 2 and Electrical Heater. It performs calculations for those elements and then it transfers those values to Online Plotter.

Table 5.17. Design parameters and input values of Integrator

Design Parameters			
Name	**Type**	**Value**	**Unit**
Integration period	Constant	STOP	hr
Relative or absolute start time	Constant	1.00	-
Design Input Data			
Name	**Type**	**Value**	**Unit**
Input to be integrated 1	Variable	Connected to the Electrical Heater – Required heating rate	any
Input to be integrated 2	Variable	Connected to the Supply Fan – Power consumption	any
Input to be integrated 3	Variable	Connected to the Pump 1 – Power consumption	any
Input to be integrated 4	Variable	Connected to the Pump 2 – Power consumption	any

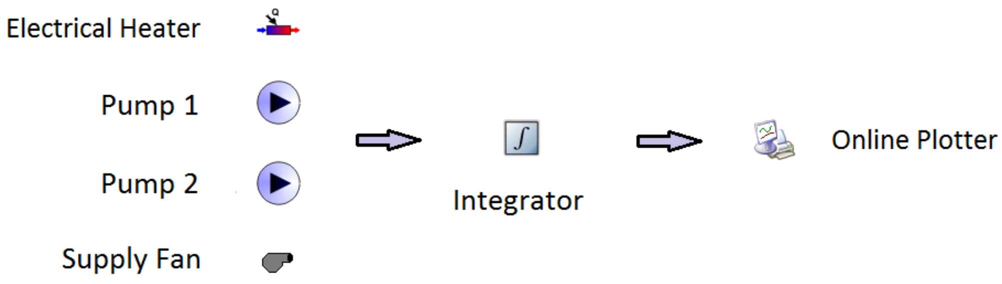

Figure 5.20. Input and output connections for Integrator

5.3.11. Online Plotter / Type 65a

Design parameters and inputs to be plotted as graphics are listed in Table 5.18 and input connections are presented in Figure 5.21.

Table 5.18. Design parameters and input values of Online Plotter.

Design Parameters			
Name	**Type**	**Value**	**Unit**
Number of left-axis variables	Constant	6.00	-
Number of right-axis variables	Constant	8.00	-
Left-axis minimum	Constant	-10.00	-
Left-axis maximum	Constant	100.00	-
Right-axis minimum	Constant	-100000.00	-
Right-axis maximum	Constant	100000.00	-
Number of plots per simulation	Constant	1.00	-
X-axis gridpoints	Constant	10.00	-
Shut off online w/o removing	Constant	0.00	-
Logical unit for output file	Constant	31.00	-
Output file units	Constant	2.00	-
Output file delimiter	Constant	0.00	-
Design Input Data			
Name	**Type**	**Value**	**Unit**
Left axis variable 1	Variable	Electrical Heater outlet temperature	any

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Table 5.18 (cont.)

Left axis variable 2	Variable	Ambient temperature	any
Left axis variable 3	Variable	Heat Recovery Unit outlet temperature	any
Left axis variable 4	Variable	Heating Coil outlet temperature	any
Left axis variable 5	Variable	Solar Collector outlet temperature	any
Left axis variable 6	Variable	Storage Tank outlet temperature	any
Right axis variable 1	Variable	Electrical Heater energy consumption	any
Right axis variable 2	Variable	Electrical Heater energy consumption integration	any
Right axis variable 3	Variable	Supply Fan energy consumption integration	any
Right axis variable 4	Variable	Supply Fan energy consumption	any
Right axis variable 5	Variable	Pump 1 energy consumption integration	any
Right axis variable 6	Variable	Pump 2 energy consumption integration	any
Right axis variable 7	Variable	Pump 1 energy consumption	any
Right axis variable 8	Variable	Pump 2 energy consumption	any

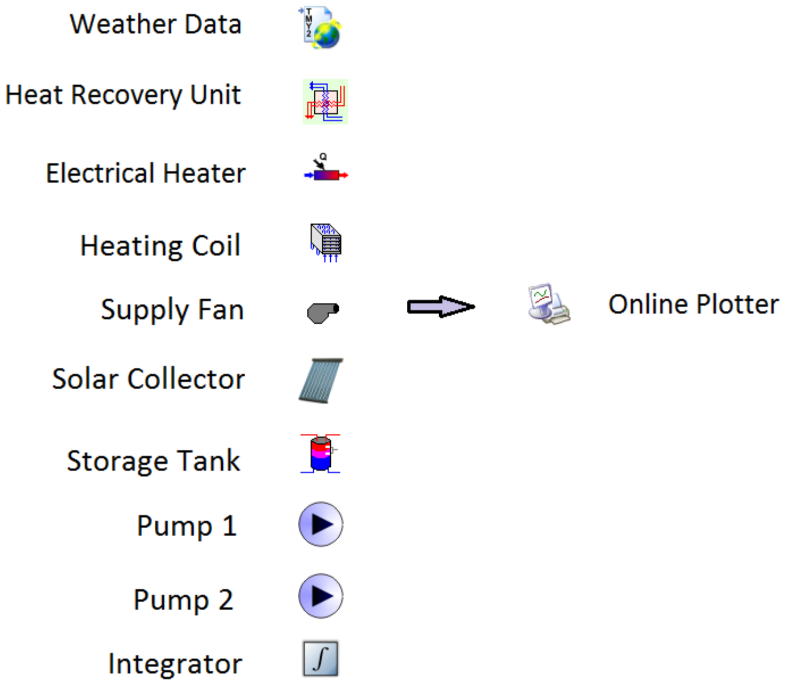

Figure 5.21. Input and output connections for Online Plotter.

CHAPTER 6

RESULTS AND DISCUSSIONS

System 1, 2 and 3 are described in Chapter 3. Information on TRNSYS software is given in Chapter 3. The input, design and output parameters to simulate System 1, 2 and 3 are explained in Chapter 4 and 5. Based on the given information in previous chapters, results from TRNSYS program are obtained and presented in this chapter for each system, separately.

In this chapter, the obtained results from TRNSYS program are presented and discussed via graphics and they are interpreted. The presented graphs are valid for whole simulation period, between 1st of November and 31th of March. However, in order to have detailed idea on variation of the presented data, some graphics are presented only for the first week of January. It should be mentioned that 10% of the fan power is assumed to be lost in all of results presented in this section. Moreover in this study the considered air mass flow rate supplied to the indoor space is low. That is why small fans are used to supply air. The selection of these fans are performed among fans exist in market. For this kind of small fans nominal power is written and variation of power with pressure drop or air flow rate is not given. In this study the nominal value of the fan power declared by manufacturer is considered.

6.1. Results of System 1

Figure 6.1 shows the system designed by TRNSYS defined components. As it is seen the system consists of Weather Data, Supply Fan, Electrical Heater, Time Controllers, Integrator and Online Plotter. The manner they are connected with each other is given in tables in Chapter 5.

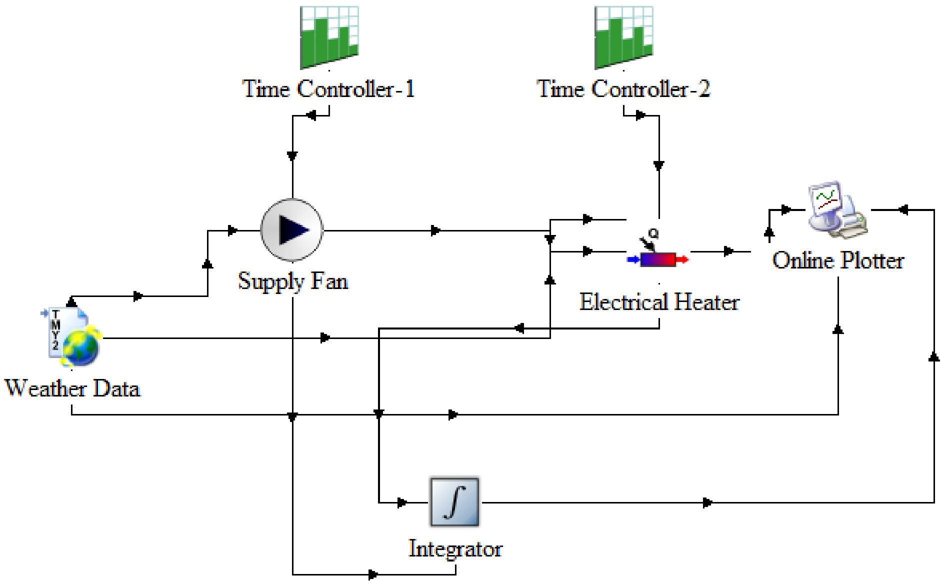

Figure 6.1. View of System 1 designed by TRNSYS defined components

Figure 6.2 shows variations of ambient temperature, air temperature at the outlet of Electrical Heater and Electrical Heater energy consumption with time. The X-axis (horizontal axis) presents time in hourly time steps. The left vertical axis presents temperature values in °C unit and right axis presents the power consumption of the Electrical Heater in kJ/h unit. It is drawn for the first week of the January. The variation of ambient air temperature with time is drawn by dark blue color while the change of air temperature at the outlet of Electrical Heater with time is shown by red color. The hourly variation of Electrical Heater energy consumption with time is shown by dark pink color. The figure is drawn to show the relation between ambient temperature, Electrical Heater outlet air temperature and Electrical Heater energy consumption in detail. The ambient temperature decreases during the night period while it increases by time during the day. As seen from the dark pink line, indicating energy consumption of the Electrical Heater, it works only between 17.00 and 24.00 since it is controlled by Time Controller. The energy consumption is small at 17:00 however its consumption increases towards the night due to the decrease of ambient temperature.

Electrical Heater air temperature, showing by red color, appears between 17:00 to 24:00 since not only Supply Fan but also Electrical Heater does not operate out of this period. As seen, at 17:00, the Electrical Heater starts to operate and air temperature at Electrical Heater outlet increases to 22°C. The supply air temperature remains constant between 17:00 to 24:00. At 24:00, Supply Fan and Electrical Heater are switched off and the system does not work.

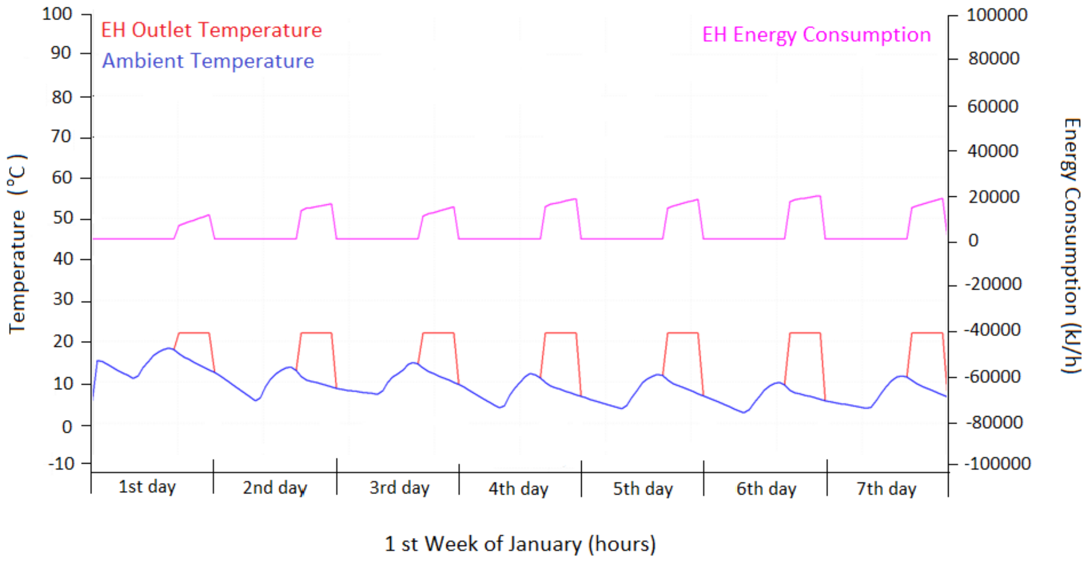

Figure 6.2. The change of Ambient, Electrical Heater outlet air temperatures and Electrical Heater energy consumption with time for the period of January first week for System 1

Figure 6.3 is the same with Figure 6.2, however it is drawn for the period of 7 days starting 9th day of November. The variations of ambient temperature, Electrical Heater outlet temperature and energy consumption of Electrical Heater are the same with Figure 6.2. However, the interesting point of this figure is Electrical Heater outlet temperature at the second day. The ambient temperature is above 22°C for this day and that is why electrical heater does not operate between 17:00 and 19:00. By increasing of time, the ambient temperature decreases and Electrical Heater starts to operate at 19:00.

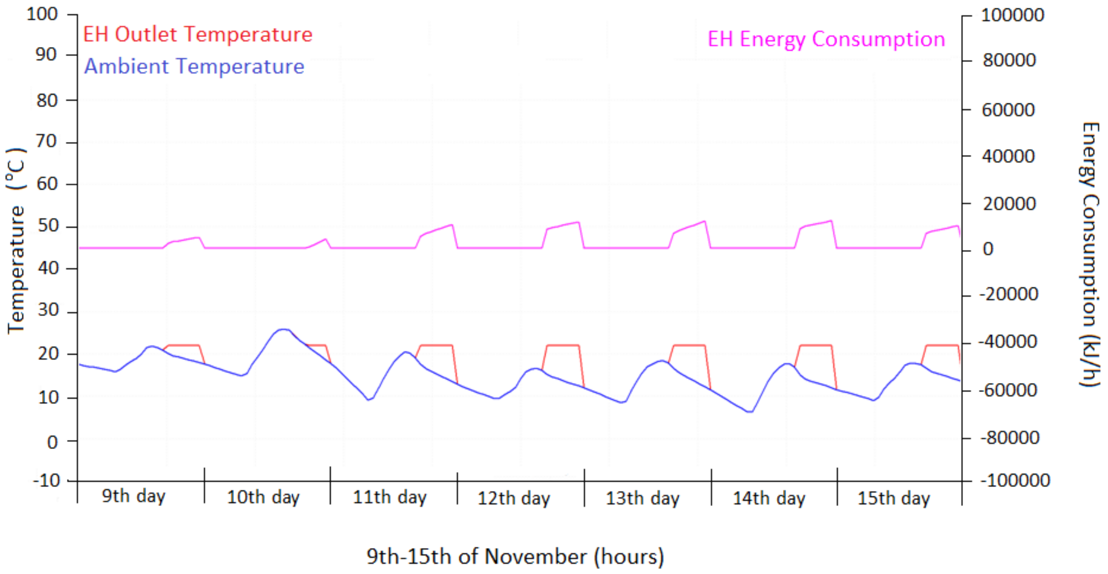

Figure 6.3. The change of Ambient, Electrical Heater outlet air temperatures and Electrical Heater energy consumption with time for the period of 7 days starting 9th day of November for System 1

Figure 6.4 shows the results of simulation for the period between 1st of November and 31th of March. The time changes from 7296 to 10920, which is totally 3624 hours. The same colors for ambient temperature, Electrical Heater outlet temperature and Electrical Heater energy consumption are valid also for this figure. As it is seen from Figure 6.4 the ambient temperature of Izmir is generally above 0°C even during the nights of winter period. During off period of the system, red lines shows that Electrical Heater outlet temperature becomes equal to ambient temperature as it is expected. Since the set point temperature of Electrical Heater H is fixed to 22°C, Electrical Heater outlet temperature is usually 22°C during the operating period. Based on the fluctuations of ambient temperature, the energy consumption of Electrical Heater can change from day to day, considerably.

From integration of Electrical Heater energy consumption, the Electrical Heater energy consumption of System 1 can be calculated. Electrical Heater energy consumption during whole simulation period is 13745 MJ. However, the energy consumption of the Supply and Exhaust Fan should be added to this value. The power of the Supply and Exhaust Fan is assumed as 180 W. The integration of this power consumption for the whole operating period yields totally 1370 MJ for Supply and Returns Fans. Therefore, the total energy consumption of System 1 is 15115 MJ.

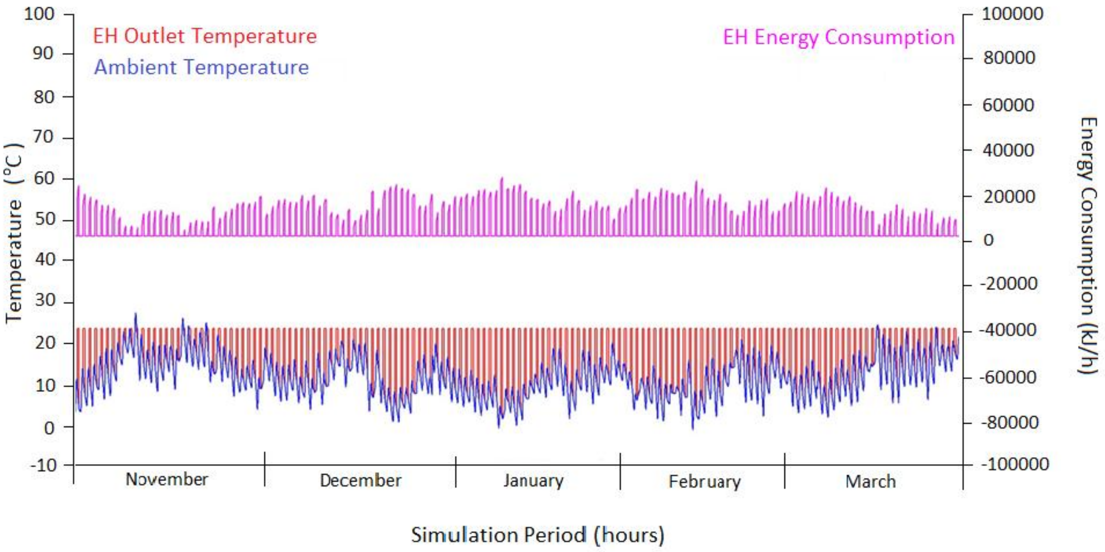

Figure 6.4. The change of Ambient, Electrical Heater outlet air temperatures and Electrical Heater energy consumption with time for the period between 1st of November and 31th of March for System 1

6.2. Results of System 2

Figure 6.5 shows the system designed by TRNSYS defined components. As it is seen the system consists of Weather Data, Heat Recovery Unit, Supply Fan, Electrical Heater, Time Controllers, Integrator and Online Plotter. The manner they are connected with each other is given in tables in Chapter 5.

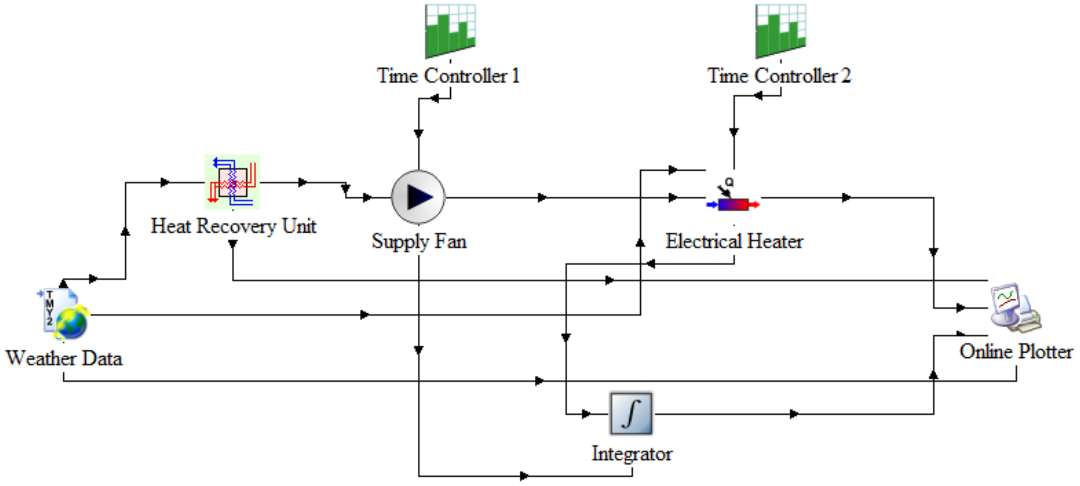

Figure 6.5. View of System 2 designed by TRNSYS defined components

Figure 6.6 shows variations of ambient temperature, air temperature at the outlet of Heat Recovery Unit, Electrical Heater and Electrical Heater energy consumption with time. The parameters of X-axis, left and right vertical axis are in the same with Figure 6.2 of System 1. It is also drawn for the first week of the January. The variation of ambient air temperature with time is drawn by dark blue color while the change of air temperature at the outlet of Heat Recovery Unit and Electrical Heater are dark pink and red, respectively. The hourly variation of Electrical Heater energy consumption with time is shown by yellow color. The figure is drawn to show the relation between ambient temperature, Heat Recovery Unit and Electrical Heater outlet air temperature and Electrical Heater energy consumption in detail. The ambient temperature behavior, Electrical Heater temperature set point and working periods are exactly the same with System 1. This means that, the set point of Electrical Heater is 22°C and system operates between 17:00 and 24:00. The energy consumption is small at 17:00 however its consumption increases towards the night due to the decrease of ambient temperature. This is the reason of positive slope observed in yellow line (power of Electrical Heater), during working periods. The behavior of the dark pink colored line, showing the air temperature at the outlet of Heat Recovery Unit, is the typical result of the heat recovery process. Heat Recovery Unit's inlet air at the ambient temperature approaches to return air temperature before it enters to Electrical Heater. The outlet air temperature of

Electrical Heater, showing by red color, appears between 17:00 to 24:00 according to its working period. The air temperature at the outlet of Electrical Heater remains constant at 22°C while the system operates.

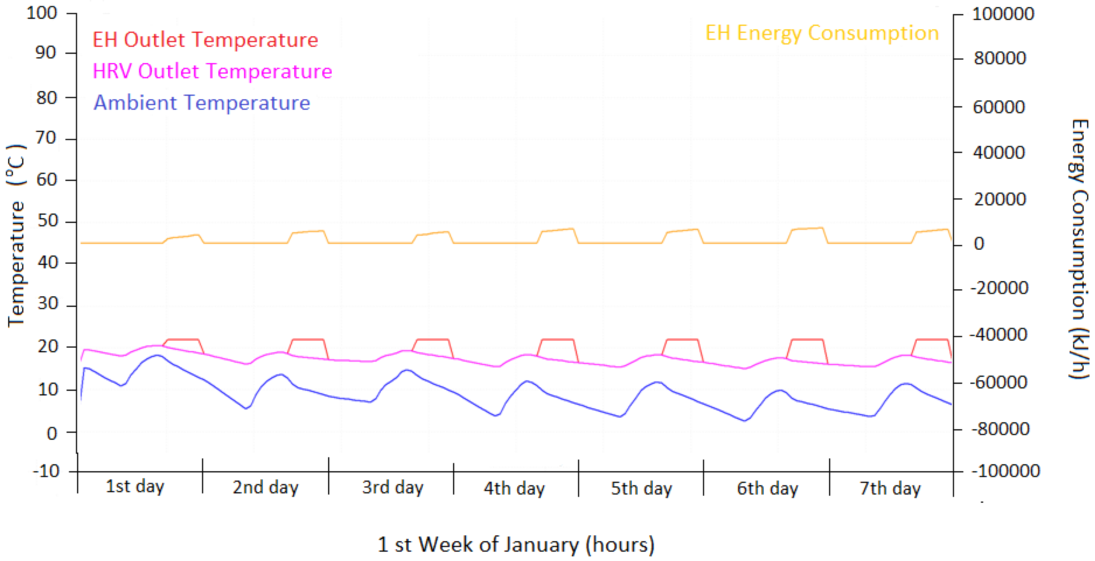

Figure 6.6. The change of Ambient, Heat Recovery Unit, Electrical Heater outlet air temperatures and Electrical Heater energy consumption with time for the period of January first week for System 2.

The parameter and units of axis of Figure 6.7 is the same with those of Figure 6.6, however it is drawn for the period of 7 days starting 9th day of November. The presented values are the same with Figure 6.6. However, the interesting point of this figure is Heat Recovery Unit and Electrical Heater outlet temperature at the second day. Since the ambient temperature for this day is above 22°C, which is also return air temperature, Heat Recovery Unit operates in order to decrease its outlet temperature. Similar to System 1, Electrical Heater does not operate between 17:00 and 19:00 since outlet temperature of Heat Recovery Unit is above the required supply temperature. By increasing of time, the ambient temperature decreases and Electrical Heater starts to operate at 19:00. That is why, no electrical consumption is observed for the period of between 17:00 and 19:00.

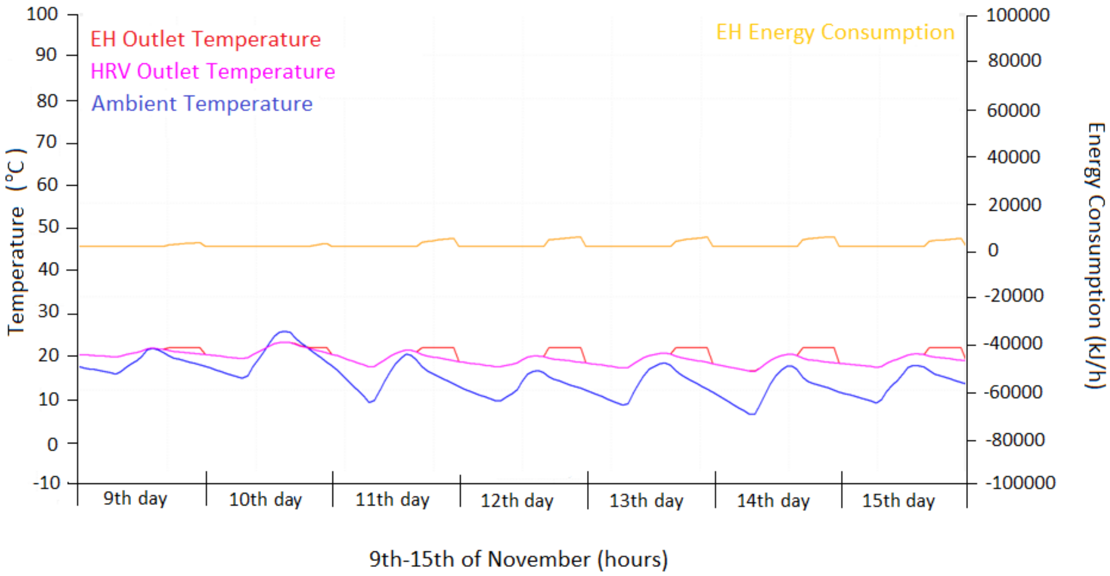

Figure 6.7. The change of Ambient, Heat Recovery Unit, Electrical Heater outlet air temperatures and Electrical Heater energy consumption with time for the period of 7 days starting 9th day of November for System 2.

Figure 6.8 shows the results of simulation for the period between 1^{st} of November and 31^{th} of March. The time changes from 7296 to 10920, which is totally 3624 hours. The same colors for ambient temperature, Heat Recovery Unit and Electrical Heater outlet temperature and Electrical Heater energy consumption, used in Figure 6.6 and Figure 6.7, are valid also for this figure. During off period of the system, dark pink and red lines shows that Heat Recovery Unit and Electrical Heater outlet temperature approach to ambient temperature as it is expected. Since the set point temperature of Electrical Heater is fixed to 22°C, Electrical Heater outlet temperature is usually 22°C during the operating period. Based on the fluctuations of ambient temperature and Heat Recovery Unit outlet temperature, the energy consumption of Electrical Heater can change from day to day, considerably.

The total Electrical Heater energy consumption of System 2 from 1^{st} of November and 31^{th} of March can be calculated by integration of instantaneous Electrical Heater energy consumption. This has been performed and total energy consumption of Electrical Heater is found as 4726 MJ.

However, the energy consumption of the Supply and Exhaust Fan should be added to this value. The power of the Supply and Exhaust Fan is assumed as 370 W. Fan power increase is the result of added pressure drop of Heat Recovery Unit. The integration of this power consumption for the whole operating period yields totally 2816 MJ for Supply and Returns fans. Therefore, the total energy consumption of System 1 is 7542 MJ.

When System 2 results are compared with System 1, the total energy consumption is decreased by 50 %.

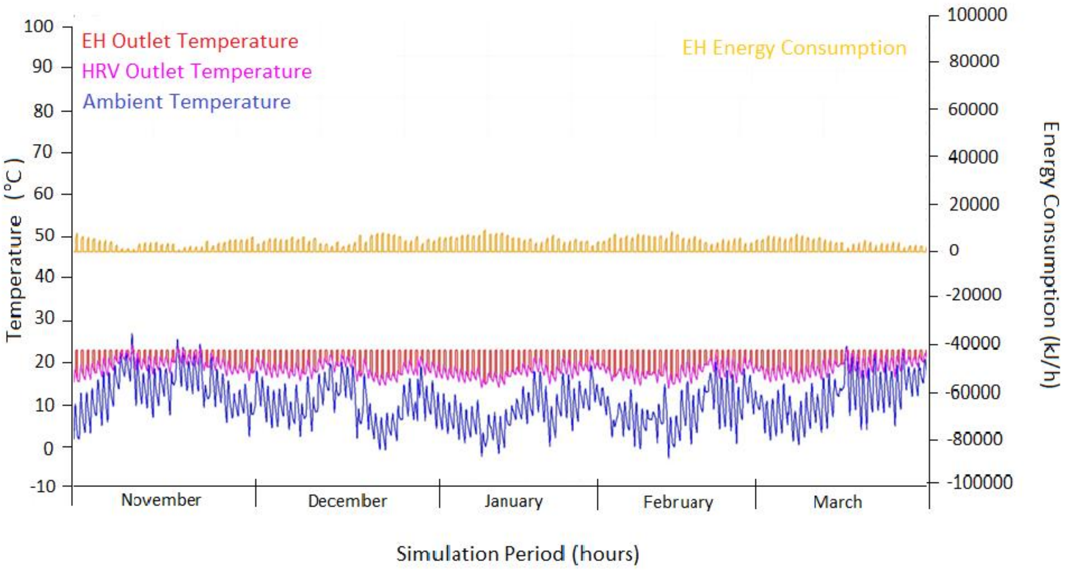

Figure 6.8. The change of Ambient, Heat Recovery Unit, Electrical Heater outlet air temperatures and Electrical Heater energy consumption with time for the period between 1st of November and 31th of March for System 2

6.3. Results of System 3

Figure 6.9 shows the system designed by TRNSYS defined components. As it is seen the system consists of Weather Data, Heat Recovery Unit, Supply Fan, Electrical Heater, Time Controllers, Solar Collector, Circulation Pumps, Storage Tank, Temperature Controller, Heating Coil, Integrator and Online Plotter. The manner they are connected with each other is given in tables in Chapter 5.

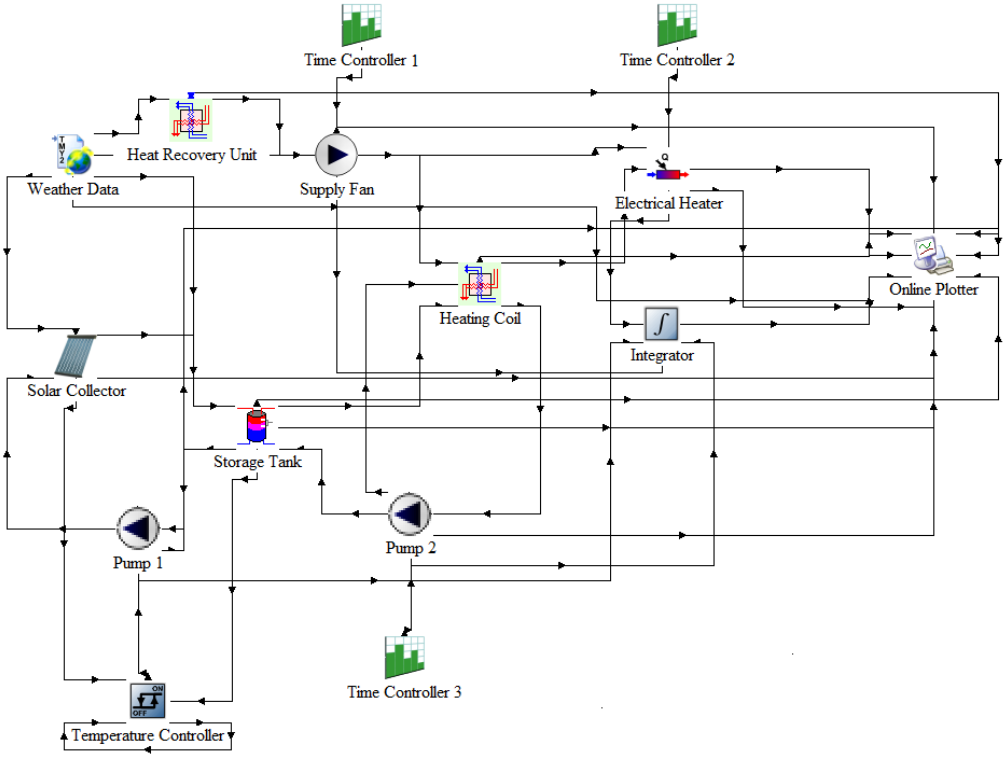

Figure 6.9. View of System 3 designed by TRNSYS defined components

The main idea of this study is to investigate an economical method for supplying fresh air at 22°C into a space during winter period. For this reason, three different systems are designed and simulated as it was mentioned before. In previous sections results of System 1 and 2 are presented. In this section; the effect of Solar Collector area and Storage Tank volume will be investigated since these two parameters are found as the most remarkable ones compared to others. After evaluation of this comparison, the System 3, with optimized values of Solar Collector area and Storage Tank volume, will be simulated and results will be presented.

6.3.1. Effect of Solar Collector Area and Storage Tank Volume on the Energy Consumption of Electrical Heater

In order to investigate the effect of Solar Collector area and Storage Tank volume on the energy consumption of Electrical Heater, 54 different cases are considered and simulations are performed by changing Solar Collector areas of 5-10-15-30-40-50 m^2 and Storage Tank volume of 0.5-1.0-2.0-3.0-4.0-5.0-6.0-7.0-8.0 m^3.

Table 6.1 shows Electrical Heater consumption (MJ) for different solar collector area and storage tank volume. The minimum electrical consumption is observed for a system with 30 m^2 and 2 m^3 storage tank volume. The maximum energy consumption is seen for a system with 5 m^2 and 8 m^3 solar collector area and storage tank volume. The variation electrical heater consumption with solar collector area and storage tank volume are also plotted and shown in Figure 6.10.

Table 6.1. SC area, ST volume and EH energy consumption values

RUN #	**Solar Collector Area**	**Storage Tank Volume**	**Electrical Heater Consumption**
	m²	**m³**	**MJ**
1	5	0.5	1475
2	5	1.0	1338
3	5	2.0	1343
4	5	3.0	1373
5	5	4.0	1408
6	5	5.0	1454
7	5	6.0	1517
8	5	7.0	1594
9	5	8.0	1675
10	10	0.5	721
11	10	1.0	521
12	10	2.0	470
13	10	3.0	476
14	10	4.0	489
15	10	5.0	506
16	10	6.0	524
17	10	7.0	542
18	10	8.0	561
19	15	0.5	487
20	15	1.0	292
21	15	2.0	221
22	15	3.0	215

(cont. on next page)

Table 6.1 (cont.)

23	15	4.0	224
24	15	5.0	240
25	15	6.0	258
26	15	7.0	278
27	15	8.0	298
28	30	0.5	292
29	30	1.0	125
30	30	2.0	75
31	30	3.0	66
32	30	4.0	79
33	30	5.0	100
34	30	6.0	122
35	30	7.0	142
36	30	8.0	161
37	40	0.5	253
38	40	1.0	97
39	40	2.0	51
40	40	3.0	44
41	40	4.0	57
42	40	5.0	75
43	40	6.0	94
44	40	7.0	113
45	40	8.0	131
46	50	0.5	233
47	50	1.0	85
48	50	2.0	39
49	50	3.0	35
50	50	4.0	46
51	50	5.0	62
52	50	6.0	79
53	50	7.0	96
54	50	8.0	113

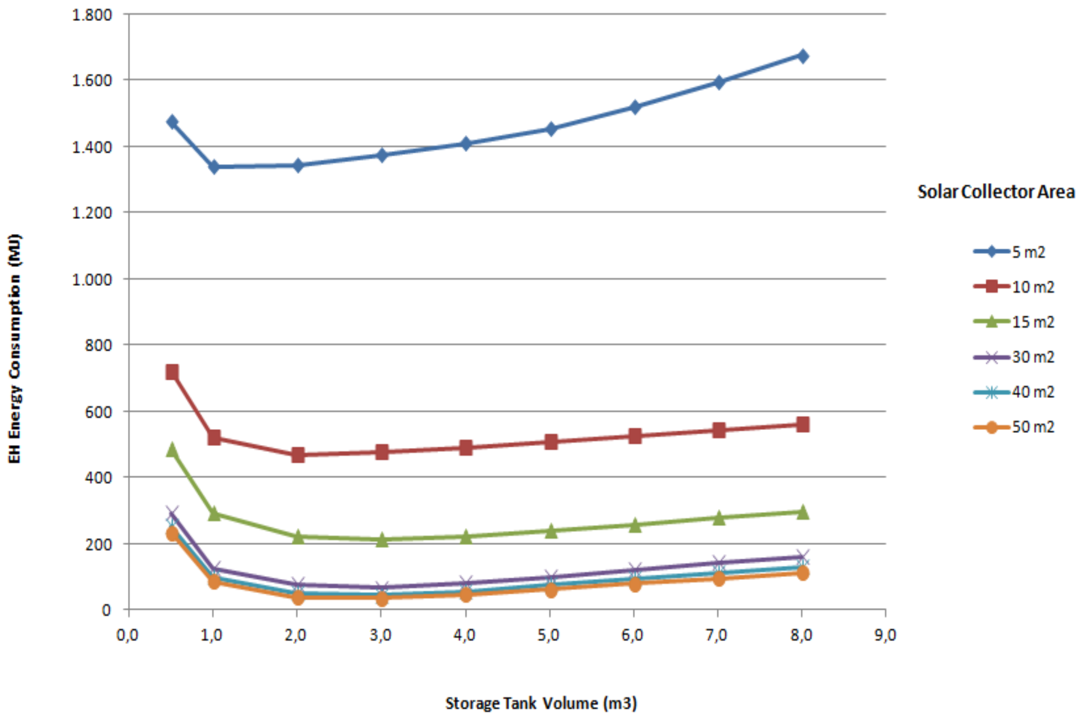

Figure 6.10. The variation of Electrical Heater energy consumption depending on Solar Collector area and Storage Tank volume

From Figure 6.10, it is clearly seen that the increase of Solar Collector area decreases the energy consumption. The decreasing rate of Elecgtrical Heater energy consumption with Solar Collector area is not the same. For small Solar Collector areas (e.g. 5 m²), the increase of Solar Collector area highly reduces Elecgtrical Heater energy consumption. For large solar Solar Collector areas (e.g. 30 m²), the increase of Solar Collector area does not change Elecgtrical Heater energy consumtions. For each Solar Collector area, there is an optimum Storage Tank volume for which the minimum Elecgtrical Heater comsumptin occurs. The optimum point of Storage Tank changes with the Solar Collector area. For a Solar Collector area of 5 m², the optimum Storage Tank volume is 1 m³, however this value increases to 3 m³ for the Solar Collector area of 40 m². The simulation results of two systems with 5 m² - 1 m³ and 30 m² - 2 m³ solar collector area and Storage Tank volume, respectively, are presented in following subsections.

6.3.1.1. Results of System with 5 m² Solar Collector Area and 1 m³ Storage Tank Volume

Figure 6.11 shows the change of ambient, Solar Collector outlet and Storage Tank outlet temperatures with time for the period of January first week. Dark blue, green and light blue lines present ambient, Solar Collector outlet and Storage Tank outlet water temperatures respectively.

With 5 m² Solar Collector area and 1 m³ Storage Tank water volume, it is seen that the solar energy increases water temperature of Solar Collector approximately 30°C compared to the ambient temperature and the temperature at Storage Tank outlet is approximately 10°C less than Solar Collector outlet temperature during the operation period. Solar Collector operates during the day when the ambient temperature is high. When the water temperature of Solar Collector becomes lower than Storage Tank temperature, Pump1 stops and Solar Collector water temperature drops to the ambient temperature. During the day, the temperature of ST increases since hot water leaves Solar Collector circulated through Storage Tank. At 17:00, Pump 2 starts to operate and heat is transferred from Storage Tank by leaving hot water from it. That is why, the temperature of Storage Tank decreases after 17:00 up to 24:00. At 24:00 Pump 2 stops and the temperature of the Storage Tank remains constant. It should be mentioned that no heat dissipation is assumed from the Storage Tank.

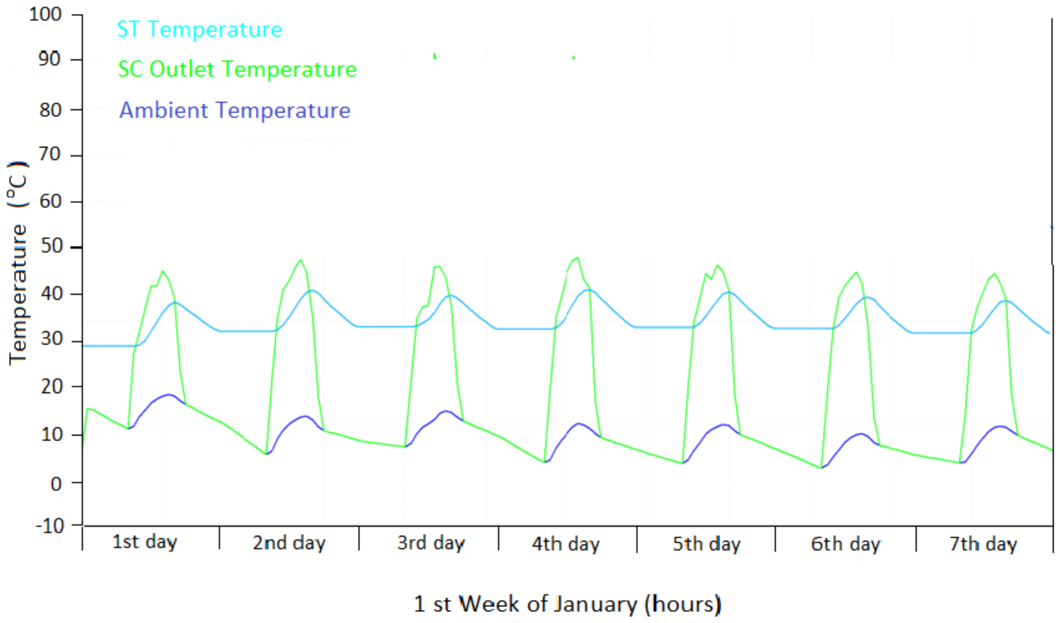

Figure 6.11. The change of ambient, Solar Collector water outlet and Storage Tank water outlet temperatures with time for the period of January first week when Solar Collector area and Storage Tank volume are 5 m² and 1 m³, respectively

Figure 6.12 shows the change of ambient, Heat Recovery Unit air outlet and Heating Coil air outlet temperatures with time for the period of January first week. Dark blue, dark pink and yellow lines present ambient, Heat Recovery Unit air outlet and Heating Coil air outlet temperatures, respectively.

With 5 m² Solar Collector area and 1 m³ Storage Tank water volume, it is seen that Heat Recovery Unit air outlet temperature is increased approximately 4°C by using Heating Coil in which the hot water of the Storage Tank is circulated. Figure 6.12 also shows the effect of Heat Recovery Unit. As seen, by using a suitable Heat Recovery Unit, the fresh air temperature can be increases considerably by using the energy of exhaust air. The rest of energy requires to increase supply temperature to 22°C is provided by the energy stored in the tank.

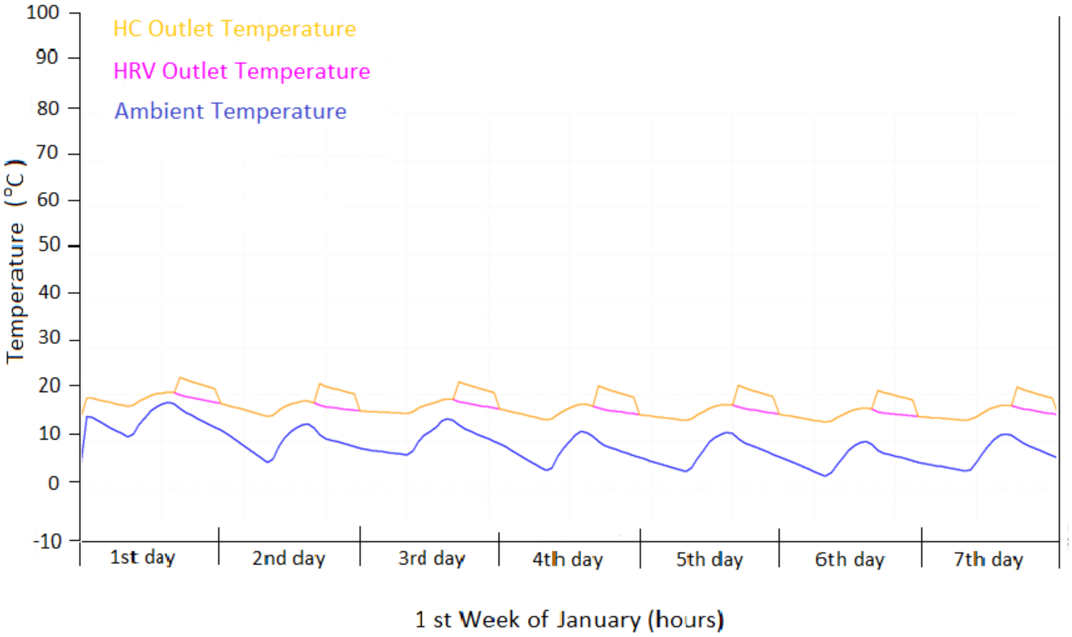

Figure 6.12. The change of Ambient, Heat Recovery Unit outlet and Heating Coil outlet temperatures with time for the period of January first week when Solar Collector area and Storage Tank volume are 5 m² and 1 m³

Figure 6.13 shows the change of ambient, Heating Coil air outlet and Electrical Heater air outlet temperatures with time for the period of January first week. Dark blue, yellow and red lines present ambient, Heating Coil outlet and Electrical Heater outlet air temperatures respectively. It is seen that Electrical Heater increases the temperature of the air leaving the Heating Coil by approximately 3°C. There is no doubt Electrical Heater operates between 17:00 and 24:00. The temperature of Heat Recovery Unit air outlet and Heating Coil outlet is the same for the period from 24:00 to 17:00.

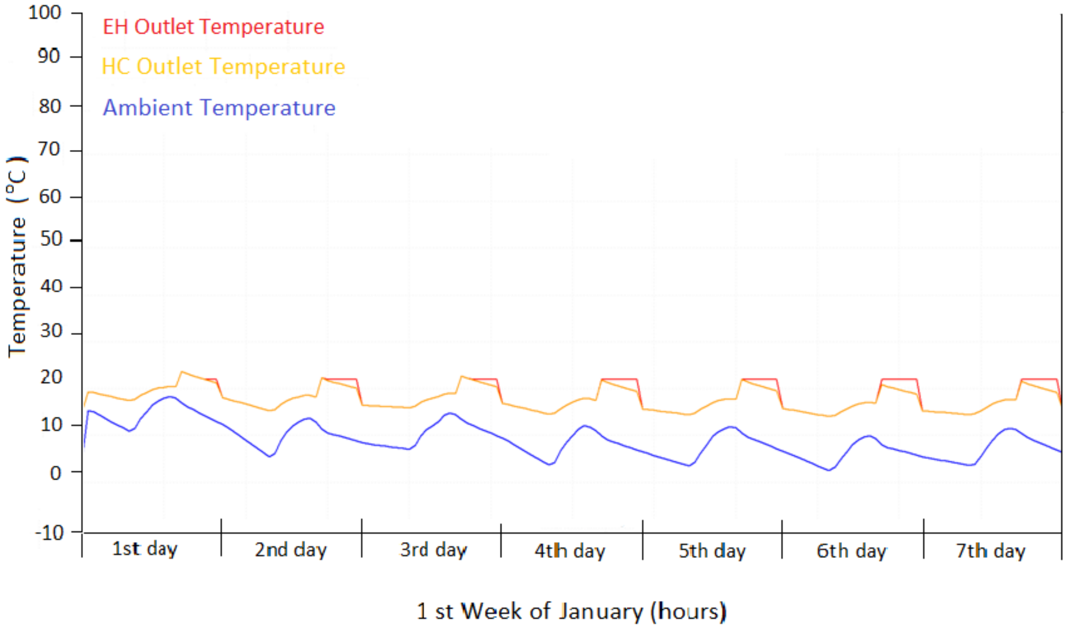

Figure 6.13. The change of ambient, Heating Coil outlet and Electrical Heater outlet air temperatures with time for the period of January first week when Solar Collector area and Storage Tank volume are 5 m^2 and 1 m^3

Figure 6.14 shows the instantaneous energy consumption (kJ/h) of Pump 1, Pump 2 and Electrical Heater. Grey, dark pink and light pink lines present the instantaneous energy consumption of Pump 1, Pump 2 and Electrical Heater, respectively. As it was mentioned, the operation hours of Pump 1 and 2 are different. Pump 1 operates according to the temperature difference between Storage Tank and Solar Collector outlet, while Pump 2 operates only between 17:00 to 24.00. By other words, Pump 2 operates only during the period when the fresh air is supplied to the indoor space. Therefore, it is observed that operation hours of Pump 2 and Electrical Heater are exactly the same as it is expected.

In this figure; it is seen that the energy consumption of Pump 2 is smaller than Pump 1 and also total energy consumption of circulation pumps are remarkably less then energy consumption of Electrical Heater.

Electrical Heater energy consumption is not identical for the all days of week. The Electrical Heater energy consumption depends on Heating Coil air outlet and ambient temperature. For the first week of January, it can be said that the instantaneous energy consumption of Electrical Heater is around 4000 kJ/h during operating periods.

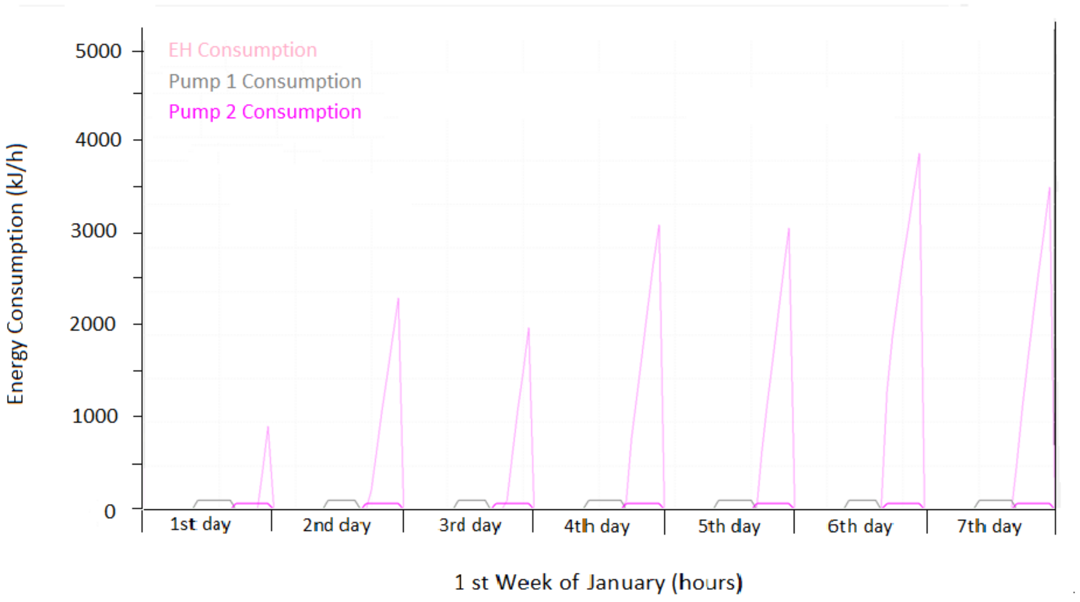

Figure 6.14. The operation status of Pump 1 and 2 and electrical heater with time for the period of January first week when Solar Collector area and Storage Tank volume are 5 m² and 1 m³

6.3.1.2. Results of System with 30 m² Solar Collector Area and 2 m³ Storage Tank Volume

In this section, results of the simulation performed for System 3 with 30 m² Solar Collector area and 2 m³ Storage Tank volume Figure 6.15 shows the change of ambient, Solar Collector outlet and Storage Tank outlet temperatures with time for the period of January first week. Dark blue, green and light blue lines present ambient, Solar Collector outlet and Storage Tank outlet water temperatures, respectively. With 30 m² Solar Collector Area and 2 m³ Storage Tank water volume, it is seen that Solar Collector water outlet temperature is increased approximately to 70°C due to the effect of solar energy. The water temperature at the Storage Tank outlet is around 60°C. The Storage Tank water outlet temperature increases during the day, and then it drops from 17:00 to 24:00. Finally it is constant during the night since no heat is transferred from the Storage Tank.

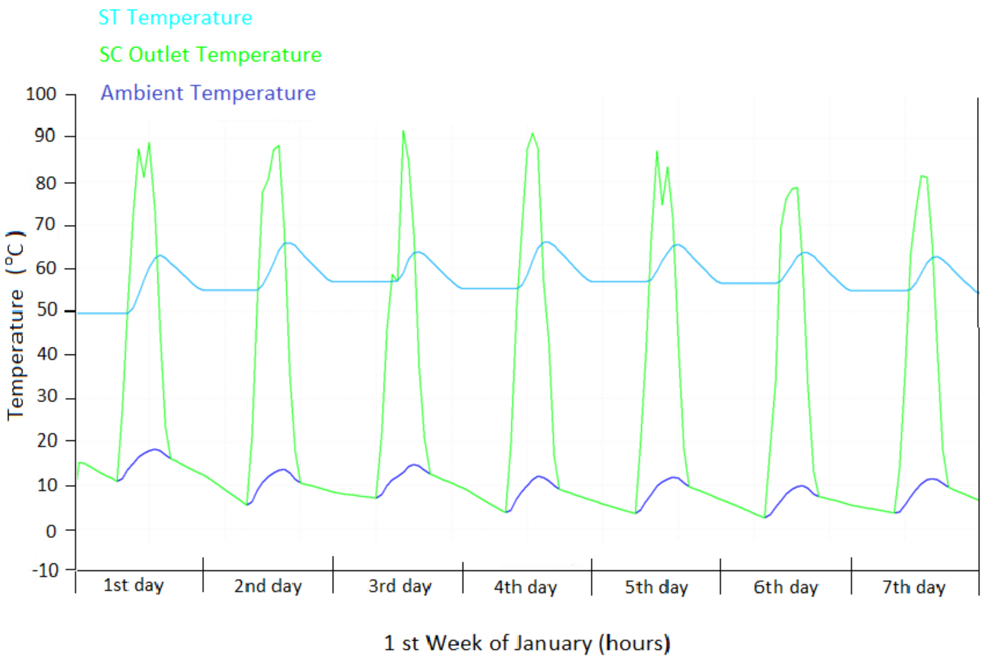

Figure 6.15. The change of ambient, Solar Collector outlet and Storage Tank outlet water temperatures with time for the period of January first week when Solar Collector area and Storage Tank volume are 30 m² and 2 m³

Figure 6.16 shows the change of ambient, Heat Recovery Unit air outlet and Heating Coil air outlet temperatures with time for the period of January first week. Dark blue, dark pink and yellow lines present ambient, Heat Recovery Unit outlet and Heating Coil outlet air temperatures, respectively.

With 30 m² Solar Collector area and 2 m³ Storage Tank water volume, it is seen that energy stored in the Storage Tank increases Heating Coil air outlet temperature approximately 7°C. The increase of Heating Coil air outlet temperature occurs during the period of 17:00 to 24:00.

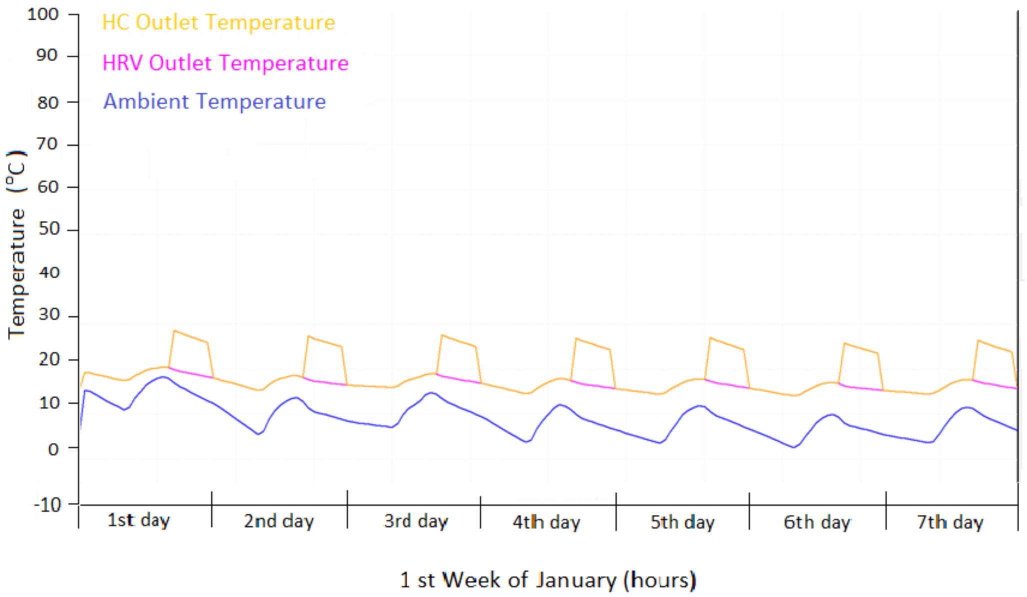

Figure 6.16. The change of ambient, Heat Recovery Unit and Heating Coil outlet air temperatures with time for the period of January first week when Solar Collector area and Storage Tank volume are 30 m² and 2 m³

Figure 6.17 shows the change of ambient, Heating Coil outlet and Electrical Heater outlet air temperatures with time for the period of January first week. Dark blue, yellow and red lines present ambient, Heating Coil outlet and Electrical Heater outlet air temperatures, respectively. It is seen that Electrical Heater operates only in first day of January, since the temperature of Heating Coil outlet is greater then set point (22°C) of Electrical Heater except the first day. This figure clearly shows the effect of solar energy stored in the tank.

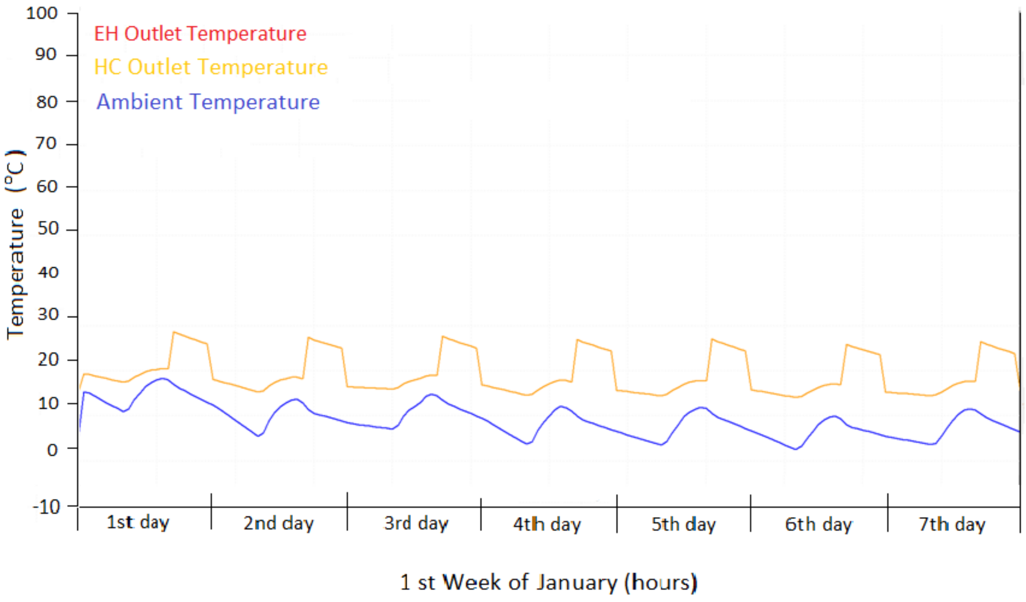

Figure 6.17. The change of ambient, Heating Coil and Electrical Heater outlet air temperatures with time for the period of January first week when Solar Collector area and Storage Tank volume are 30 m² and 2 m³

Figure 6.18 shows operation status of Pump 1, Pump 2 and Electrical Heater in terms of their energy consumptions (kJ/h). Grey, dark pink and light pink lines present operation status of Pump 1, Pump 2 and Electrical Heater respectively.

As it is mentioned before, the only period Electrical Heater operates is the first day of January and its electrical consumption is very low compared to the System with 5 m² Solar Collector area and 1 m³ Storage Tank volume. Energy consumption maximum value for this period is approximately 2000 kJ/h. It is obvious that the energy consumption is much more less and the System 3 with 30 m² Solar Collector area and 2 m³ Storage Tank volume is a convenient solution.

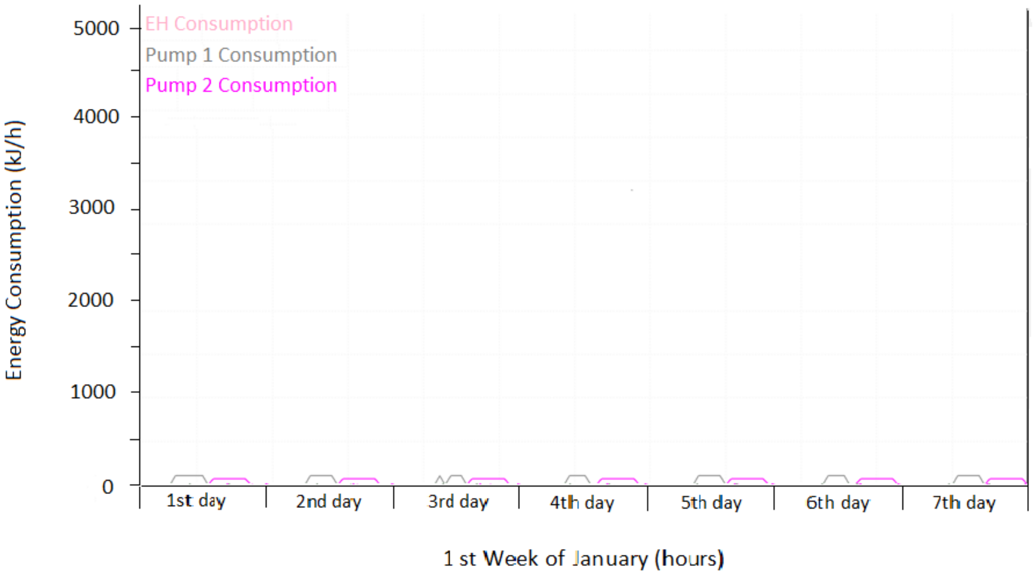

Figure 6.18. The operation status of Pump 1 and 2 and Electrical Heater with time for the period of January first week when Solar Collector area and Storage Tank volume are 30 m² and 2 m³.

Figure 6.19 shows the change of ambient, Heat Recovery Unit outlet, Heating Coil outlet and Electrical Heater outlet air temperatures with time for whole simulation period which refers between 1st of November and 31st of March. Dark blue, dark pink, yellow and red lines present ambient, Heat Recovery Unit outlet, Heating Coil outlet and Electrical Heater outlet air temperatures, respectively.

It is remarkable that Electrical Heater operates only few times during simulation period since Heating Coil outlet temperature is already greater than 22°C usually.

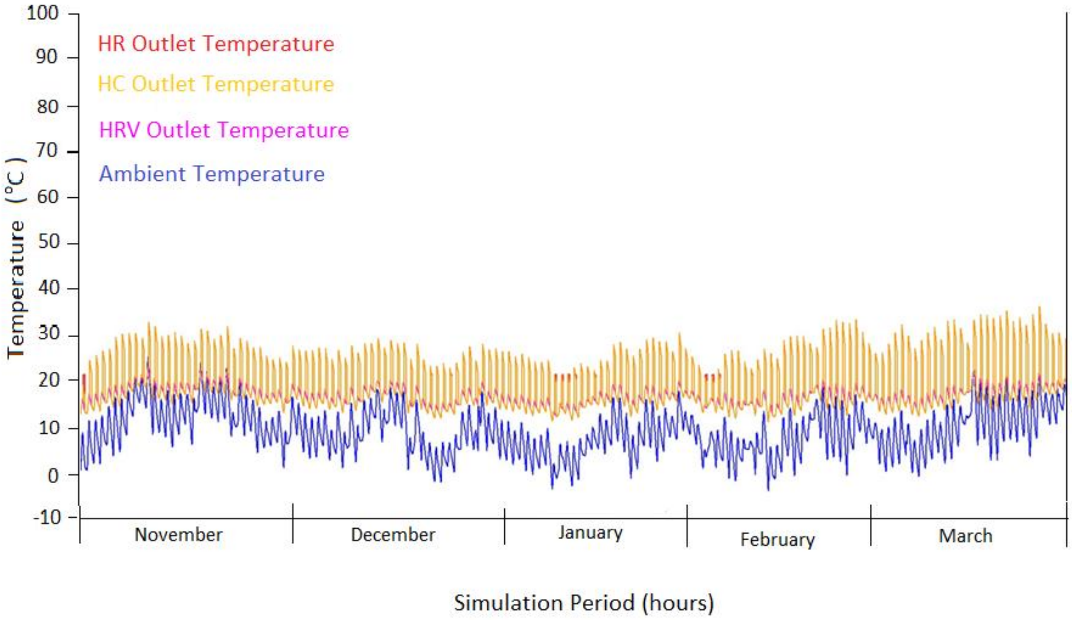

Figure 6.19. The change of ambient, Heat Recovery Unit, Heating Coil and Electrical Heater outlet air temperatures with time for the period of 1st of November and 31st of March when Solar Collector area and Storage Tank volume are 30 m² and 2 m³

As a result, among the optium volume of tanks, it is observed that the system with 5 m² Solar Collector area and 1 m³ Storage Tank water volume is the system consumes the highest energy and the system with 50 m² Solar Collector area and 3 m³ Storage Tank water volume is the one which consumes the lowest energy. But regarding the small difference of the energy consumptions between the systems of 30 and 50 m², the system with 30 m² Solar Collector area is considered as the most appropriate system for this simulation. Again, for the systems with 30 m² Solar Collector area and by regarding the small difference between energy conspumption of the system, with 2 and 3 m³ volume tank, the optimum Storage Tank is selected as 2 m³ n this study. In this case, System 3 with 30 m² Solar Collector area and 2 m³ Storage Tank volume is selected as the most convenient system for the applications described in this study.

The total Electrical Heater energy consumption of System 3 with 30m² Solar Collector area and 2 m³ Storage Tank volume from 1st of November and 31th of March can be calculated by integration of instantaneous Electrical Heater energy consumption. This has been performed and total energy consumption of Electrical Heater is found as 75 MJ.

However, the energy consumption of the Supply and Exhaust Fan should be added to this value. The power of the Supply and Exhaust Fan is assumed as 370 W. Fan power increase is the result of added pressure drop of Heat Recovery Unit. The integration of this power consumption for the whole operating period yields totally 2816 MJ for Supply and Returns fans. The power values of Pump 1 and Pump 2 are 27 W and 18 W, respectively. The integration of this power consumption for the whole operating period yields totally 132 MJ Therefore, the total energy consumption of System 3 is 3023 MJ. When System 3 results are compared with System 2, the total energy consumption is decreased by 39 %.

6.3.2. Comparison of System Results

After investigation of energy consumption results in system basis, it is meaningful to compare results of three systems in order to see the benefit of solar energy storage.

As it is mentioned before, System 1 and 2 include only Electrical Heater, Supply and Return Fan as energy consumer components, since System 3 includes also Pump 1 and 2. In Table 6.2 energy consumptions of each component of each system is shown in detail.

Table 6.2. Energy Consumptions of System's Components

System Components		**Energy Consumption (MJ)**		
		System 1	**System 2**	**System 3**
Electrical Heater	**:**	13745	4726	75
Supply Fan	**:**	685	1408	1408
Return Fan	**:**	685	1408	1408
Pump 1	**:**			64
Pump 2	**:**			68
TOTAL	**:**	**15115**	**7542**	**3023**

Figure 6.20 shows the comparison of total energy consumption of three systems. Reduce of energy consumption is remarkable. By using System 2 instead of System 1 and System 3 instead of System 1 energy consumption reduces 50% and 80%, respectively.

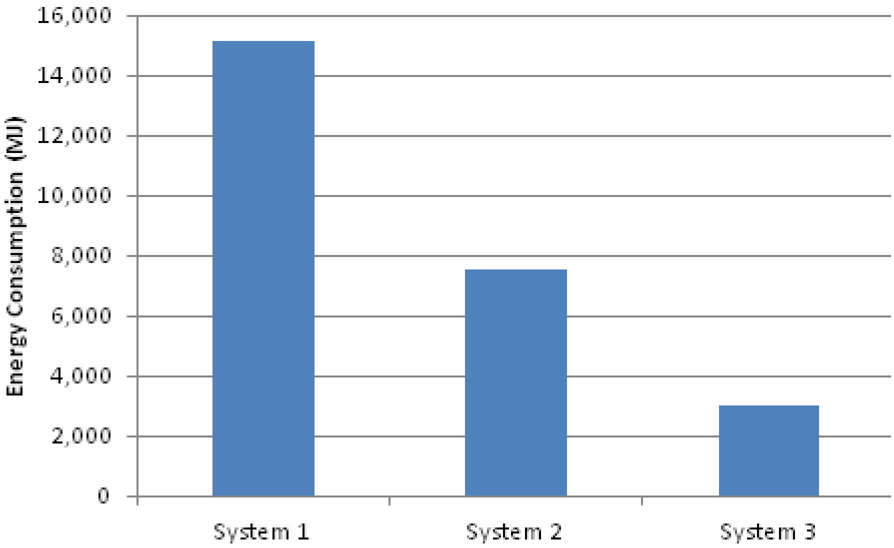

Figure 6.20. Comparison of total energy consumption of System 1, 2 and

CHAPTER 7

CONCLUSION

This study is performed in order to investigate the effect of solar thermal energy storage on energy consumption of building ventilation system. Three systems are simulated; System 1 with Electrical Heater, System 2 with Electrical Heater and Heat Recovery Unit and System 3 which is solar-assisted version of System 2. Simulation is performed for the period between 1st of November and 31th of March in hourly base. TRNSYS program was used to perform dynamic simulation. The study is performed for Izmir city. The variation of temperature at different points in the system is plotted for the aforementioned period. Based on the obtained results following remarks can be concluded:

1- As expected, the maximum energy consumptions is observed for the System 1 in which an Electrical Heater is used. The total energy consumed by Electrical Heater for the aforementioned period is 13745 MJ.

2- Comparison of System 2 energy consumption with System 1’s shows that use of Heat Recovery Unit reduces energy consumption 50%. The total energy consumption of the System 2 is 7542 MJ.

3- Comparison of .System 3 with System 2 and 1 shows that use of solar thermal energy storage reduces energy consumption 60% and 80%, respectively. The total energy consumption of the System 3 is 3023 MJ. However, the System 3 is complex and complicated system. Our observation showed that for the most days of the studied period, the Electrical Heater does not operate and just for some cold days in works.

4- A parametric study is performed to find optimum Solar Collector area and Storage Tank volume. The Solar Collector area is changed from 5 to 50 m² while the volume of Storage Tank varies between 0.5 to 8.0 m³. Our calculation showed that a system with Solar Collector area and Storage Tank volume of 50 m² and 3.0 m³, respectively, has the minimum total energy consumption. But since the energy consumption difference is very small with the system with Solar Collector area and Storage Tank volume of 30 m² and 2.0 m³, in order to optimize system dimension, system with 30 m² and 2.0 m³ Solar Collector area and Storage Tank volume is considered as System 3.

5- Most of energy consumed by System 3 is related to the electrical energy of the supply and return fans. The energy consumed by Electrical Heater is 75 MJ while the electrical energy of Supply and Return Fans, and Pumps are 2948 MJ.

6- Even for the system with Solar Collector area of 5 m² and Storage Tank volume of 2.0 m³, we observed the days for which the water temperature at the outlet of Solar Collector reaches 90°C. That is why for those a high limit cut-out value is defined to Temperature Controller adapted to the system to switch off Pump 1.

7- Solar-assisted and Heat Recovery Unit used ventilation systems may be convenient for systems with high fresh air flow rates, in order to reduce energy consumptions. For the spaces such as cinemas, theaters and shopping centers, the energy consumes for providing fresh air is considerable. The suggested system can reduce the consumed energy considerably.

For a complete feasibility study and realization of System 3, an economical analysis is needed to be performed.

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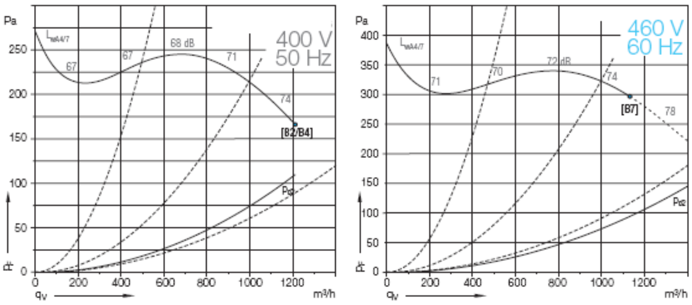
APPENDIX A

SELECTION DATA OF COMPONENTS

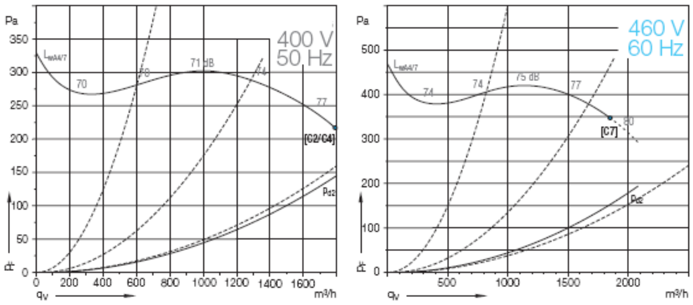
The fan characteristic curves of Supply and Return Fans taken from a company in the market are given below.



Technical Data

	Curves	Nominal motor power kW	Poles –	Motor size	Motor voltage V	Nominal frequency Hz	Connection	Nominal motor current A	Nominal motor speed 1/min	Media Temperature max. °C	Max. volume flow m³/h	Fan weight TEM 01/08 kg
	[B2]	0.18	4	63	230/400	50	Δ/Y	0.97/0.56	1350	60	1250	8/12

(a)



Technical Data

	Curves	Nominal motor power kW	Poles –	Motor size	Motor voltage V	Nominal frequency Hz	Connection	Nominal motor current A	Nominal motor speed 1/min	Media Temperature max. °C	Max. volume flow m³/h	Fan weight TEM 01/08 kg
	[C2]	0.37	4	71	230/400	50	Δ/Y	1.78/1.03	1370	60	1970	10/14

(b)

Figure A.1. Fan characteristic curves, a) Fans of System 1, b) Fans of System 2 and 3

The pump characteristic curve of Pump 1 and 2 taken from a company in the market is given below.

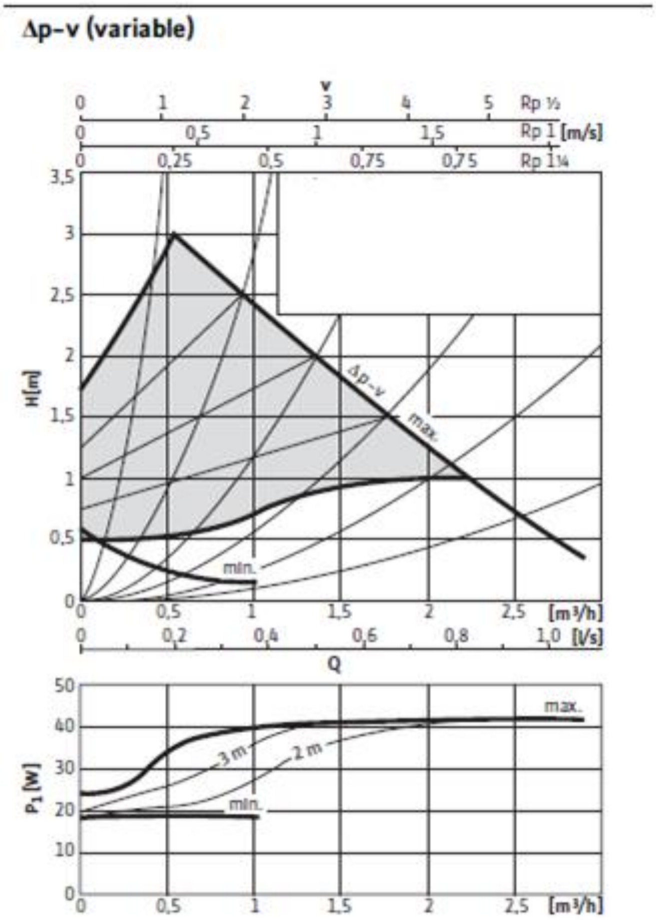
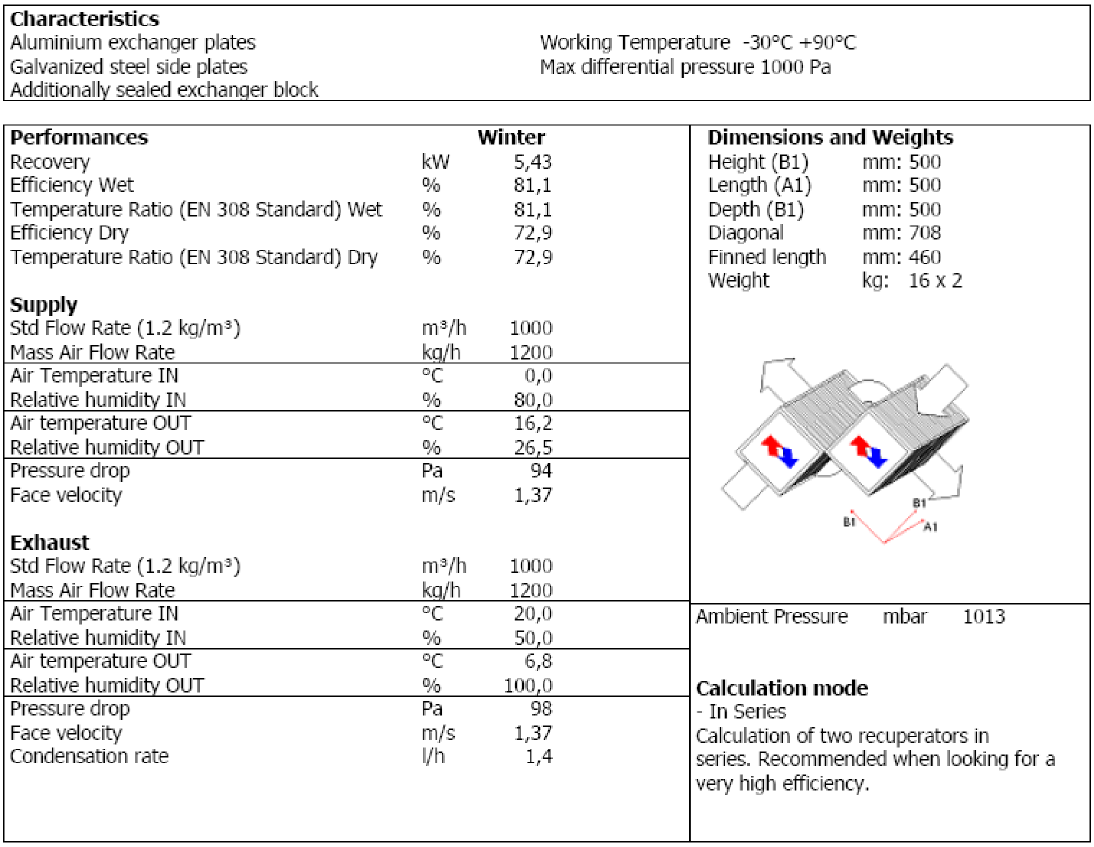


Figure A.2. Pump characteristic curve of Pump 1 and 2 of System 3

The selection data sheet of Heat Recovery Unit taken from a producer is given below.



Characteristics

Aluminium exchanger plates	Working Temperature -30°C +90°C
Galvanized steel side plates	Max differential pressure 1000 Pa
Additionally sealed exchanger block	

Performances		**Winter**
Recovery	kW	5,43
Efficiency Wet	%	81,1
Temperature Ratio (EN 308 Standard) Wet	%	81,1
Efficiency Dry	%	72,9
Temperature Ratio (EN 308 Standard) Dry	%	72,9
Supply		
Std Flow Rate (1.2 kg/m³)	m³/h	1000
Mass Air Flow Rate	kg/h	1200
Air Temperature IN	°C	0,0
Relative humidity IN	%	80,0
Air temperature OUT	°C	16,2
Relative humidity OUT	%	26,5
Pressure drop	Pa	94
Face velocity	m/s	1,37
Exhaust		
Std Flow Rate (1.2 kg/m³)	m³/h	1000
Mass Air Flow Rate	kg/h	1200
Air Temperature IN	°C	20,0
Relative humidity IN	%	50,0
Air temperature OUT	°C	6,8
Relative humidity OUT	%	100,0
Pressure drop	Pa	98
Face velocity	m/s	1,37
Condensation rate	l/h	1,4

Dimensions and Weights

Height (B1)	mm: 500
Length (A1)	mm: 500
Depth (B1)	mm: 500
Diagonal	mm: 708
Finned length	mm: 460
Weight	kg: 16 x 2

Ambient Pressure	mbar	1013

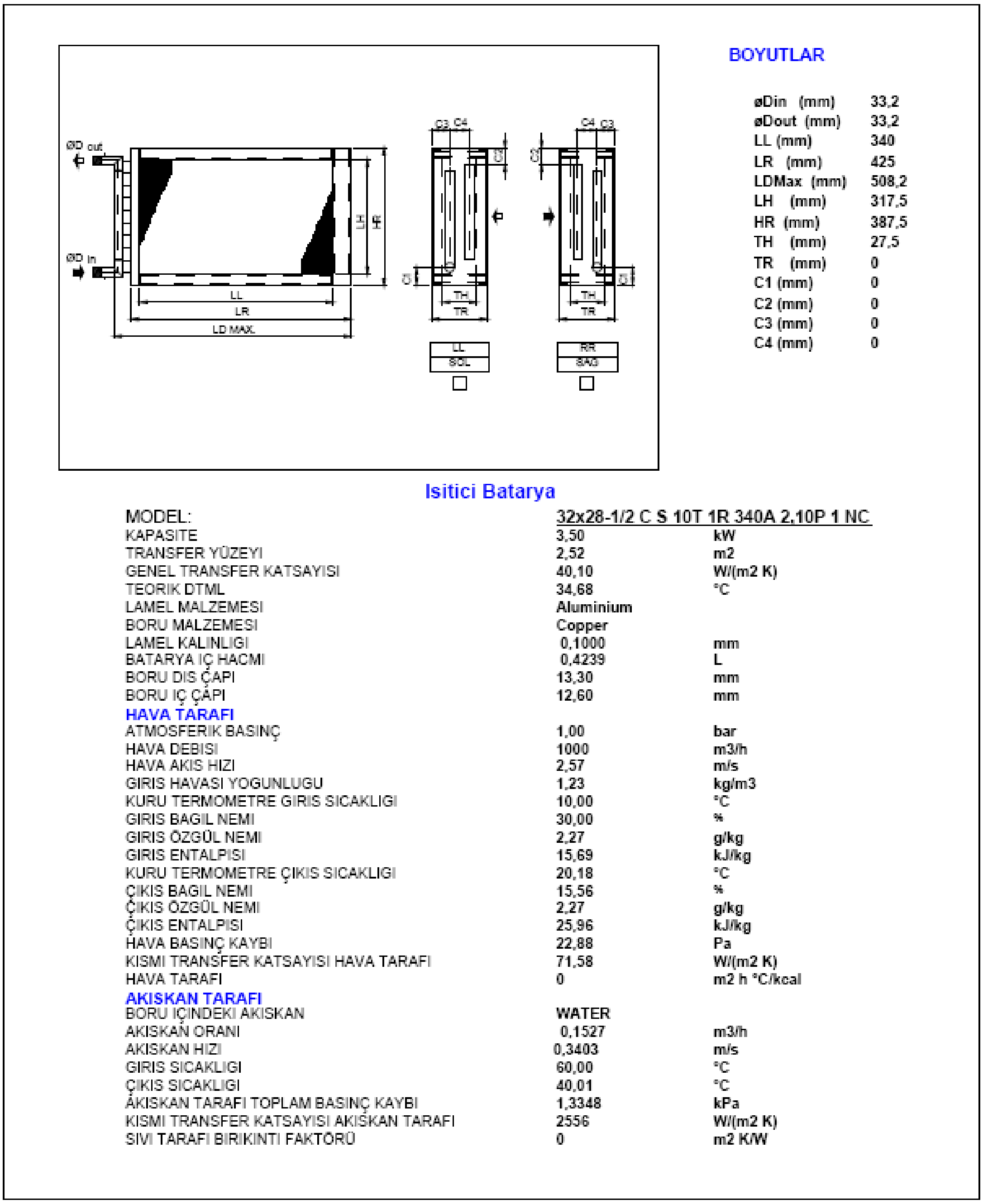
Calculation mode

- In Series

Calculation of two recuperators in series. Recommended when looking for a very high efficiency.

Figure A.3. Selection data sheet of Heat Recovery Unit of System 1 and 2

The selection data sheet of Heating Coil taken from a coil producer is given below.



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BOYUTLAR

øDin (mm)	33,2
øDout (mm)	33,2
LL (mm)	340
LR (mm)	425
LDMax (mm)	508,2
LH (mm)	317,5
HR (mm)	387,5
TH (mm)	27,5
TR (mm)	0
C1 (mm)	0
C2 (mm)	0
C3 (mm)	0
C4 (mm)	0

Isitici Batarya

MODEL:	32x28-1/2 C S 10T 1R 340A 2,10P 1 NC	
KAPASITE	3,50	kW
TRANSFER YÜZEYI	2,52	m2
GENEL TRANSFER KATSAYISI	40,10	W/(m2 K)
TEORIK DTML	34,68	°C
LAMEL MALZEMESI	Aluminium	
BORU MALZEMESI	Copper	
LAMEL KALINLIGI	0,1000	mm
BATARYA IÇ HACMI	0,4239	L
BORU DIS ÇAPI	13,30	mm
BORU IÇ ÇAPI	12,60	mm
HAVA TARAFI		
ATMOSFERIK BASINÇ	1,00	bar
HAVA DEBISI	1000	m3/h
HAVA AKIS HIZI	2,57	m/s
GIRIS HAVASI YOGUNLUGU	1,23	kg/m3
KURU TERMOMETRE GIRIS SICAKLIGI	10,00	°C
GIRIS BAGIL NEMI	30,00	%
GIRIS ÖZGÜL NEMI	2,27	g/kg
GIRIS ENTALPISI	15,69	kJ/kg
KURU TERMOMETRE ÇIKIS SICAKLIGI	20,18	°C
ÇIKIS BAGIL NEMI	15,56	%
ÇIKIS ÖZGÜL NEMI	2,27	g/kg
ÇIKIS ENTALPISI	25,96	kJ/kg
HAVA BASINÇ KAYBI	22,88	Pa
KISMI TRANSFER KATSAYISI HAVA TARAFI	71,58	W/(m2 K)
HAVA TARAFI	0	m2 h °C/kcal
AKISKAN TARAFI		
BORU IÇINDEKI AKISKAN	WATER	
AKISKAN ORANI	0,1527	m3/h
AKISKAN HIZI	0,3403	m/s
GIRIS SICAKLIGI	60,00	°C
ÇIKIS SICAKLIGI	40,01	°C
AKISKAN TARAFI TOPLAM BASINÇ KAYBI	1,3348	kPa
KISMI TRANSFER KATSAYISI AKISKAN TARAFI	2556	W/(m2 K)
SIVI TARAFI BIRIKINTI FAKTÖRÜ	0	m2 K/W

Figure A.4. Selection data sheet of Heating Coil of System 3