5.0 INTRODUCTION

After the introduction of the Kyoto Protocol in 1997 and Economics of Climate Change in 2006, there has been a strong shift towards the issues of global warming and its effect on environment. While socio-economic effects of climate change are being debated globally, the burden of ecological responsibility lies on development (i.e. industrialization & construction etc.). Hence, businesses and individuals have become increasingly aware of twin concepts of ‘sustainable building’ (green building) and carbon footprint. India has tenth largest forest coverage in the world. It is also world's fifth largest carbon emitter, accounting for 5% of global greenhouse gases, according to statistics from Indian government. Deforestation and forest degradation - through agricultural expansion, conversion to pastureland, infrastructure development, logging and fires account for nearly 20% of emissions (Indian Draft Policy 2014). The proportion of energy utilized in buildings is higher than its freight (Steemers 2003). Therefore, to reduce urban carbon emission characteristics of building energy consumption needs to be understood. Many researchers have tried to study this pattern of building energy consumption using different approaches including the engineering based methods (Heiple et al., 2008; Yamaguchi and Shimoda 2010; Jennings et al., 2014; Shimoa et al., 2007) and using the machine learning (Howard et al., 2012; Tian and Choudhary 2011; Farzana et al., 2014; Tian et al., 2014).
The adverse effect of high temperatures on human physiology and energy use in buildings has been investigated in various studies (Haines et al., 2006; Watkiss 2011; Xu et al., 2012) and deaths due to heat waves (Changnon et al., 1996; Garssen et al., 2005; Conti et al., 2005). Owing to the effect of Urban Heat Island (UHI), urban areas are more severely impacted (Sarat et al., 2006; Tan et al., 2010; Mamon et al., 2010; Emmanuel and Kruger 2012; Kolokotroi et al., 2012). As urban areas retain and release more heat to their local environment, UHI refers to the fact that temperatures in urban areas are generally higher than surrounding rural areas. This is due to increased trend towards urbanization (Angel et al., 2005 and World Urbanization Prospects 2011), design of sustainable and comfortable urban dwelling spaces is becoming more important (Toparlar et al., 2015). There is a wide range of simulation tools for accessing the building energy performance which includes MATLAB Simulink (Ochs et al., 2013) and TRNSYS 17 (Klein et al., 2011). According to this study, there are major differences between tools regarding modelling of walls, zone nodes, windows and shading, and time step of solver (fixed in TRNSYS and adaptive in MATLAB Simulink). However, study also shows good agreement in results between the two tools. Gustafsson et al., (2014) compared energy performance of three HVAC systems for renovation through dynamic simulation using MATLAB and TRNSYS.

Also, present day alternatives of energy, like nuclear energy etc. are there, but they have huge environmental threats and thus researches are still not grounded and are going on. Therefore, additional sources of energy are required, which are cheap, safe, and environmental friendly. Another concern of resources is its waste
utilization (Alkhamis et al., 2000). So, presently shift is towards the application of renewable energy alternatives for energy generation and utilization, as they are cleaner forms of energy and also are abundantly available. This study investigates the use of solar energy for household thermal usage.

Solar Energy does not belong to anybody and is, therefore, free and is the most readily and abundant available source of energy. It has been well established that Sun transmits huge amounts of heat towards earth, about 34% of which is reflected from clouds and ground and from the objects surface. It is non-polluting and aids in reducing greenhouse effect. Until 1970, some researches were done in said field to harness it but were more academic because of problems in its use i.e. how to convert low-grade solar energy into high-grade energy, how to store solar energy for its intermittency and instability and how to use collected solar energy efficiently. But, after dramatic rise in oil prices in the 1970s, several countries began to formulate extensive research and development programme to exploit solar energy. So, it becomes important for India also to jump in as India is having a high diurnal swings, receives solar energy equivalent to over 5000 trillion kW/year, which is far more than total energy consumption of the country (Solar Energy).

The growing population of Indian has caused its cities to expand and with major burden being shared by metro cities. Therefore, in order to incorporate enormous growth and with limited land to build houses, vertical expansions in the form of buildings have come up. Buildings no matter residential or commercial are enormous consumers of energy. People are now days spending, on an average of about 90% of their life time, indoors (US-EPA 2012). Thus increasing energy
demand from building sector, which is about 40% of total energy consumption and 36% of total CO$_2$ emissions, half of these accounts go for heating ventilation and air conditioning (HVAC) systems (Hajdukiewicz et al., 2013; European Union 2012; Lombard et al., 2008). Huge amount of research has been done on proper installation and utilization of household HVAC systems.

Fasiuddin and Budaiwi (2011) in their works clearly emphasized regarding selection of proper HVAC systems. They showed that energy savings of 30% can be made by proper selection of HVAC systems. Rasouli et al., (2013) studied techniques of recovery of ventilation (Energy recovery ventilators) for improved economy to generate better comfort conditions using TRNSYS Simulations. Conceicao and Lucio (2010) developed numerical software that simulates building thermal behavior with complex topology in transient conditions and used in the study of kindergarten thermal response and occupants’ thermal comfort and air quality in Mediterranean conditions. Sameti and Kasaeian (2015) proposed a model for combined solar heating and radiative cooling and developed a MATLAB code to simulate combined space heating and cooling of a small building in Louisville, Kentucky. Another work carried out by authors Tao et al., (2013) presented heating performance and energy distribution of a system with combination of ground-source heat pump and solar collector or a solar assisted ground-source heat pump system (SAGSHPS) by calculations and experiments.

Building materials, as basic as, water and concrete have also a vital role to play in maintaining comfort inside the building. Concrete with other masonry products by virtue of high capacity for heat storage, moderate conductance, and high
emissivity prove to be one of ideal building materials. Hence, heat is transferred deep into a material for storage and due to the high emissivity; it absorbs more radiation. Hence use of proper sizing concrete can prove to be one of the most effective materials to manage diurnal energy flow (Olesen 2012), making study well for building application. Also, notion of water as effective thermal mass holds importance because it has high potential for heat storage (i.e. high heat capacity) and it can be effective in diurnal thermal management schemes. Primarily water has no structural purpose, so to exploit its dynamic properties; one can incorporate pipes in the concrete of floor and extract benefits of thermal mass (Haglund and Rathman, 1996). Sourbrnon et al., (2013) had used MATLAB based optimization toolbox “YALMIP” and TRNSYS to study Model Predictive Control (MPC) controller to find energy cost savings potential of concrete core activation (CCA). They concluded that MPC is able to realize an electricity consumption reduction of over 15%, while keeping the operative temperature within thermal comfort band and not taking prediction errors into account. Dynamic simulations were performed on TRNSYS to evaluate performance of various technologies for cooling by (Salvalai et al., 2013). Again, Chargui et al., (2013) investigated coupling of heat pump and cooling tower using TRNSYS. Chargui and Sammouda (2014) used TRNSYS to study effect of incidence solar radiation in all directions during winter season in residential house coupled with a heat pump system. Tashtoush et al., (2015) designed solar collector subsystem components and evaluated performance of solar ejector cooling system using R134a refrigerant. A dynamic hourly simulation of a 7 kW solar constant pressure mixing ejector cooling system (SECS) components was carried out, using TRNSYS. Also, performance of solar collector and overall system
performance were investigated and ejector sub-system was modeled with EES software.

All these researches point towards proper utilization of renewable energy because of exponential consumption and scarcity of conventional energy sources. Space heating hence becomes an essential feature of building which ensures thermal comfort of inhabitant. The building as the largest consumer of energy is spending most of the utilized energy over HVAC systems and thus becomes prime area of interest for research. The presented study is an effort to introduce solar energy as a tool for space heating, considering two different conditions viz.

**CASE 1:** There are many places where electricity distribution is not wholesome and/or is not present. These are particularly those regions which are far flung and beyond normal reach. As transportation facility is also scarce, the inhabitants living conditions become more adverse. Winters make conditions more adverse as everything is badly impacted. Owing to such facts a condition was exclusively chosen for locations where people are locked up in their shelters for the long winter months as adverse climatic conditions in these locations prove to be lethal. Attempts to facilitate comfortable living in such locations and to take care of availability of hot water so that it can be used to ensure comfortable living of dwellers is investigated. The simulation for checking for feasibility of using solar radiations to get hot water was carried out. The problem solving incorporated the heliothermal application for solar thermal collector.

**CASE 2:** As an extension of previous case, district heating concept is utilized at a local level inside the building using solar energy, for New Delhi region in India.
Different fluids are analyzed for a typical pipe material at different depths of their respective installation.

5.1 SYSTEM DESCRIPTION

5.1.1 CASE 1

Ethylene Glycol was used as a liquid which was heated up with solar collector having an area of 2 m$^2$. This heated liquid exchanged heat with water in heat exchanger which was load liquid with the starting temperature of 6°C. To maintain simplicity of problem we have studied whole system considering assumption that liquid in the circuit are not replenished at any point of time. To get a better understanding of problem further we only simulated problem for a time period of ten hours beginning from 08:00 a.m. to 06:00 p.m. The schematic of the problem is as shown in Fig. 5.1.

![Schematic Circuit Diagram](image)

**Fig 5.1:** Schematic Circuit Diagram

A pump sends in the absorbent fluid to solar collector so that it can get heated up. This fluid in turn after getting heated up in solar collector moves on to heat exchanger where it transfers heat to the absorbate fluid. The absorbate fluid forms
working fluid of second cycle. The movement of this fluid inside cycle is by virtue of hydraulic energy imparted by another hydraulic pump. In this circuit, water is stored inside a storage tank with variable losses. This storage tank can be assumed as an arrangement very similar to the heating arrangement that is incorporated inside the human shelters. Also since the demand of chilled water varies directly to the sun's position with respect to that time, tank can also be formulated as an element which is a part of some vapour absorption cycle which extracts low grade thermal energy to provide refrigeration (primarily involved in chillers). There are plotters inside this software patch which can be linked to the various elements. These plotters primarily collect information from different element and plot a temporal graph. The graph plots a number of variables of same graph opposite to time variables which give relative information of different parameters. Also there are two sides (left and right) of vertical axis on which variables can be plotted. The main components of TRNSYS model is the solar collector. Additional components of a model include: pipe duct, hot water cylinder with 2 inlets and 2 outlets, Type 2b differential temperature controller, Type 114 variable speed pump, and heat exchanger.

5.1.2 CASE 2

The system shown in Fig. 5.2 is simulated for climatic conditions of the New Delhi, India. The solar collector module having an area of 2 m² has been tested for flow rate of 40 kg/hr. The intercept efficiency, efficiency slope and efficiency curvature are 0.80, 13 KJ/hr.m.K, and 0.05 KJ/hr.m.K. The module takes the values of different radiations namely incident radiation, total horizontal radiation, and horizontal diffuse radiation. After that, it also requires ground reflectance, incidence
angle and collector slope for internal numerical calculations. It receives temperature and flow-rate from source side pump and delivers heated fluid to a zero capacitance sensible heat exchanger (source side). The effectiveness of this constant effectiveness heat exchanger is assumed to be 0.6. Notably it doesn't uses overall heat transfer coefficient as in this version efficiency is constant over the time-step. The maximum possible heat transfer is calculated on the basis of minimum capacity rate fluid and cold side and hot side inlet temperatures. The flow rate on both side of heat exchanger is 10 kg/hr. The heated liquid received from solar collector heats up the water in the secondary circuit. The heated water in the secondary circuit passes through diverter. An added feature with diverter enables it to bypass circuit of the installed pipes and go directly to the mixer if the required temperature is not reached. It checks temperature of fluid coming out of the heat exchanger and generates a value of 0 or 1 depending on logic that temperature is below or above 30°C. The diverter splits the single inlet liquid according to the specified value (between 0 & 1) into two liquid outlet streams. If control signal is 1, then whole of the water flows through the system of underground pipe structures and if the control signal is 0 then it simply goes to mixer. The 10 m buried pipe has inner diameter of 0.027 m and outer diameter of 0.0334 m. The density, thermal conductivity, specific heat and viscosity of the fluid is taken to be 1000 kg/m³, 0.609 W/m.K, 4.19 kJ/kg.K and 0.00089 N.s/m² respectively. Similarly density and specific heat of concrete are taken to be 2400 kg/m³ and 0.92 kJ.K/kg. Both circuits run forcibly with the help of pumps having same characteristics except the fact they provide hydraulic energy to different liquids. Both pumps have a rated flow rate of 10 kg/hr and of rated power 2684 kJ/hr.
To make a comparative and extensive study different parameters have been varied. The variations are listed below:

- The fluid in primary circuit (Glycol, Ethyl Alcohol and Water)
- The pipe material for buried pipes is Aluminum (Al)
- The depth of buried pipes.

Fig 5.2: Schematic Circuit Diagram

5.2 COMPONENT DESCRIPTION

5.2.1 SOLAR COLLECTOR

This component theoretically models thermal performance of a Flat-Plate Quadratic Efficiency Solar Collector. The fluid temperature may be an inlet, average, or outlet temperature. The model assumes that efficiency vs. ΔT/I_T curve can be modeled as a quadratic equation. Corrections are applied to slope, intercept, and curvature parameters to account for presence of a heat exchanger, identical collectors in series, and flow rates other than those at test conditions.
This is useful for considering non-optically symmetric collectors such as evacuated tubes, etc. A general equation for solar thermal collector efficiency can be obtained from the (TRNSYS 17) as:

\[
\eta = \frac{Q_u}{A_{IT}} = \frac{\dot{m}C_{pf}(T_o-T_i)}{A_{IT}} = F_R(\tau\alpha)_n - F_R\frac{U_L(T_i-T_a)}{I_T}
\] (5.1)

The loss coefficient \(U_L\) is not exactly constant, so a better expression is obtained by taking into account a linear dependency of \(U_L\) versus \((T_i-T_a)\):

\[
\eta = \frac{Q_u}{A_{IT}} = F_R(\tau\alpha)_n - F_R\frac{U_L(T_i-T_a)}{I_T} - F_R\frac{U_L(T_i-T_a)^2}{I_T}
\] (5.2)

Equations 5.2 can be rewritten as:

\[
\eta = a_0 - a_1 \frac{\Delta T}{I_T} - a_2 \frac{(\Delta T)^2}{I_T}
\] (5.3)

This is a general solar collector thermal efficiency equation. The thermal efficiency is defined by three parameters: \(a_0\), \(a_1\) and \(a_2\). These three parameters are available for collectors tested according to ASHRAE standards and rated by SRCC, as well as for collectors tested according to the recent European Standards on solar collectors (TRNSYS 17).

In Equations 5.3, \(\Delta T\) is equal to \((T_i-T_a)\). Also, collector test reports sometimes provide efficiency curve using a different temperature difference:

\[
\Delta T = \begin{cases} 
\Delta T_i = T_i - T_a \\
\Delta T_{av} = T_{av} - T_a \\
\Delta T_o = T_o - T_a 
\end{cases}
\] (5.4)

The first formulation is usually preferred in US, while second one is used in most European documents. Equation 5.2 can use any of those definitions of temperature difference and user can specify the \(a_0\), \(a_1\) and \(a_2\) coefficients using any
of the definitions. If coefficients are given in terms of average or outlet temperature, correction factors are applied. Those correction factors have been derived for linear efficiency curves (Equation 5.1), so Equation 5.2 must first be converted to that form by performing some manipulations. A modified first-order collector efficiency coefficient is defined:

\[ U_{\text{L}}' = U_{\text{L}} + U_{\text{L}} \left( \frac{T_i - T_a}{T} \right) \]  

Which gives

\[ \eta = \frac{Q_u}{A_{\text{IT}}} = F_R (\tau \alpha)_n - F_R U_{\text{L}}' (T_i - T_a) / I_T \]  

The correction factors are then given by (TRNSYS 17):

\[ F_R (\tau \alpha) = F_{\text{av}} (\tau \alpha)_n \left( \frac{m_{\text{test} C_{\text{pf}}}}{m_{\text{test} C_{\text{pf}} + F_{\text{av}} U_{\text{L}}'}} \right) \]  

\[ F_R U_{\text{L}} = F_{\text{o}} U_{\text{L}} \left( \frac{m_{\text{test} C_{\text{pf}}}}{m_{\text{test} C_{\text{pf}} + F_{\text{o}} U_{\text{L}}'}} \right) \]

5.2.2 PUMP

Type 114 models a single (constant) speed pump that is able to maintain a constant fluid outlet mass flow rate. Both pressure drop effects and pump’s starting and stopping characteristics not modeled in the study. As with most pumps and fans in TRNSYS, Type 114 takes mass flow rate as an input but ignores value except in order to perform mass balance checks. Type 114 sets downstream flow rate based on its rated flow rate parameter and current value of its control signal Input. If pump is determined to be off due to its control signal being set less than 0.5, pump mass flow rate, power drawn, energy transferred from pump to ambient and energy
transferred from the pump to fluid stream are all set to zero. The temperature of fluid exiting pump under OFF condition is set to temperature of fluid at the pump inlet. If, however, pump is determined to be ON (control signal greater than or equal to 0.5) then mass flow rate of fluid exiting pump and power drawn by pump are set to respective rated conditions specified in model’s parameter list. The overall efficiency of pump and efficiency of the pump motor are used to calculate efficiency of pumping process as:

\[ \eta_{\text{pumping}} = \frac{\eta_{\text{overall}}}{\eta_{\text{motor}}} \]  

(5.9)

The power required at the pump shaft (excluding motor efficiency effects may then be calculated as

\[ \dot{P}_{\text{shaft}} = \dot{P}_{\text{rated}} \eta_{\text{motor}} \]  

(5.10)

Energy transferred from pump motor to fluid stream can be calculated as:

\[ \dot{Q}_{\text{fluid}} = \dot{P}_{\text{shaft}} (1 - \eta_{\text{pumping}}) + (\dot{P} - \dot{P}_{\text{shaft}}) f_{\text{motorloss}} \]  

(5.11)

In which \( \eta_{\text{pumping}} \) is pumping process efficiency and \( f_{\text{motorloss}} \) is a value between 0 and 1 that determines whether the pump motor inefficiencies cause a temperature rise in fluid stream that passes through pump or whether they cause a temperature rise in ambient air surrounding the pump. Through use of \( f_{\text{motorloss}} \) fraction, user can specify effectively whether pump has an inline motor, in which case all waste heat would impact fluid stream temperature and \( f_{\text{motorloss}} \) would have a value of 1, or whether pump motor is housed outside of fluid stream such that it’s waste heat impacts the ambient and \( f_{\text{motorloss}} \) would have a value of 0.

The energy transferred from the pump motor to ambient is given by
\[
\dot{Q}_a = \dot{P}_{\text{rated}}(1 - \eta_{\text{motor}})(1 - f_{\text{motorloss}})
\]  

(5.12)

The temperature of fluid exiting the pump can now be calculated as

\[
T_o = T_i + \frac{\dot{Q}_{\text{fluid}}}{m_{\text{fluid}}}
\]  

(5.13)

Type 114 does not model pump starting and stopping characteristics. As soon as control signal indicates that the pump should be ON, the outlet flow of fluid jumps to its rated condition. The reasoning is that time constants with which pumps react to control signal change, is shorter than typical time steps used in hydronic simulations. Type114 also operates as many pump and fan models do in TRNSYS. That is to say that they ignore fluid mass flow rate provided as an input to model except so as to perform a mass balance on pump. Therefore care must be taken in specifying fluid loops with multiple pumps that inlet mass flow rates greater than rated mass flow rate for a given pump are not specified. The total number of time steps during which fluid inlet mass flow rate for Type114 is not equal to its outlet flow rate is reported to list file at end of each simulation.

5.2.3 CONTROLLER

There are two basic methods for controlling transient simulations of solar energy systems or components: energy rate control and temperature level control. The controller used here is designed primarily for implementing temperature level control. Type 2 is most frequently used to control fluid flow through solar collector loop.

Temperature level control in TRNSYS relies on a control function, \( \gamma \), which is typically constrained to \([\gamma_{\text{min}}; \gamma_{\text{max}}]\). Two types of temperature level control are
commonly used: continuous (e.g. proportional) control and discrete (On/Off) control.

In continuous control, \( \gamma \) can take any value from \( \gamma_{\text{min}} \) to \( \gamma_{\text{max}} \). In On/Off control, either \( \gamma = 0 \) or \( \gamma = 1 \).

This controller generates a control function \( \gamma_o \) that can have values of 0 or 1. The value of \( \gamma_o \) is chosen as a function of difference between upper and lower temperatures, \( T_H \) and \( T_L \), compared with two dead band temperature differences, \( \Delta T_H \) and \( \Delta T_L \). The new value of \( \gamma_o \) is dependent on whether \( \gamma_i = 0 \) or 1. The controller is normally used with \( \gamma_o \) connected to \( \gamma_i \) giving a hysteresis effect. For safety considerations, a high limit cut-out is included with this controller. Regardless of dead band conditions, control function will be set to zero if the high limit condition is exceeded.

Mathematically, control function is expressed as follows:

If the controller was previously ON

If \( \gamma_i = 1 \) and \( \Delta T_L \leq (T_H-T_L) \), \( \gamma_O = 1 \)

If \( \gamma_i = 1 \) and \( \Delta T_L > (T_H-T_L) \), \( \gamma_O = 0 \) \hspace{1cm} (5.14)

If the controller was previously OFF

If \( \gamma_i = 0 \) and \( \Delta T_H \leq (T_H-T_L) \), \( \gamma_O = 1 \)

If \( \gamma_i = 0 \) and \( \Delta T_H > (T_H-T_L) \), \( \gamma_O = 0 \) \hspace{1cm} (5.15)

However, control function is set to zero, regardless of upper and lower dead band conditions, if \( T_{IN} > T_{MAX} \). This situation is often encountered in domestic hot
water systems where the pump is not allowed to run if the tank temperature is above some prescribed limit, Fig. 5.3.

![Fig 5.3: Controller Function](image)

### 5.2.4 TANK

This component models a fully-mixed tank with a constant cross-sectional area that contains a variable quantity of fluid. In its simplest form, a single flow enters from a hot source and a single flow stream exits to a load as illustrated in Fig 5.4 (a). Since incoming and outgoing flows need not be equal, level of fluid in tank can vary. The level is allowed to vary between user specified high and low level limits. If lower limit is reached, load flow necessary to maintain this level is output rather than desired load flow. If volume of fluid exceeds upper limit, then excess flow necessary to keep the tank at upper limit is set as an output. There are two modes for handling excess flow when upper limit is reached. In mode 1, excess flow mixes with contents of the tank to simulate a recirculation flow stream as illustrated in Fig 5.4 (b). In this case, temperature of excess flow stream is the temperature of contents of tank. In mode 2, excess incoming fluid stream is diverted from tank as
illustrated in Fig 5.4 (c). The temperature of diverted stream is equal to that of incoming flow stream.

\[ \dot{m}_h, T_h \rightarrow i_n, T \rightarrow i_r, T \rightarrow \dot{m}_h, T_h \]

**Fig 5.4:** Variable Volume Tank Configurations

The variable volume tank is modeled as a fully-mixed variable mass of water. The two differential equations describing rate of change of mass and internal energy are:

\[ \frac{dM}{dt} = m_i - m_o \]  
\[ C_{pf} \frac{dT}{dt} = m_i C_p T_h - m_o C_p T - (UA) \Delta T + T_{envir} \]

The net flow into tank, \( m_1 \), is \( m_h \) in Mode 1 and \( (m_h - m_i) \) in Mode 2. The net flow leaving the tank is \( (m_s - m_r) \) in Mode 1 and \( m_s \) in Mode 2.

The solutions of equation 5.16 for final and average mass for a given time step are:

\[ M_T = M_0 + \Delta t \]  
\[ m = \frac{M_T + M_0 + \Delta t}{2} \]

Simultaneous solution of equations 5.16 and 5.17 for final and average fluid temperatures for a time step gives
\[ T_p = \frac{a}{b} + \left( \frac{T_p - \Delta t}{\Delta t} - \frac{a}{b} \right) \left( 1 + \frac{c\Delta t}{M_p - \Delta t} \right)^{-\frac{b}{c}} \]  

\[ \bar{T} = \frac{a}{b} + \frac{M_{p-\Delta t}(T_{p-\Delta t} - \frac{a}{b})}{(c-b)\Delta t} \left\{ \left( 1 + \frac{c\Delta t}{M_{p-\Delta t}} \right)^{1-b/c} - 1 \right\} \]  

Where, \( a = m_i T_i + \frac{(UA)_t T_{envir}}{C_{pf}} \); \( b = m_i + \frac{(UA)_t}{C_{pf}} \), and \( c = m_i - m_o \)

The change in internal energy, difference in enthalpies per unit time between outgoing and incoming flow streams, and energy loss rate are calculated as:

\[ \Delta U = C_{pf}(M_p T_p - M_i T_i) \]  

\[ \Delta H = m_i C_{pf} T_h - m_o C_{pf} \bar{T} \]  

\[ \dot{Q}_{envir} = (UA)_t (\bar{T} - T_{envir}) \]  

The overall conductance for heat loss from tank, \((UA)_t\), is calculated based upon average wetted and dry areas for current time step and user specified wet and dry loss coefficients.

5.2.5 EQUATIONS STATEMENT

The EQUATIONS statement allows variables to be defined as algebraic functions of constants, previously defined variables, and outputs from TRNSYS components. These variables can then be used in place of numbers in TRNSYS input file to represent inputs to components; numerical values of parameters; and initial values of inputs and time-dependent variables. The capabilities of EQUATIONS statement overlap but greatly exceed those of CONSTANTS statements.
Variable names defined by an EQUATIONS or CONSTANTS statement may be used in place of numerical values or the unit number, output number combinations which follow INPUTS statement. Variables used as INPUTS are evaluated each time one of their constituent quantities changes. Variables used in place of numerical values for parameters, or initial values of inputs and time-dependent quantities are evaluated once at the start of simulation and therefore should not refer to TIME or to component outputs.

Important: Equations that vary with time should not be used as initial values or as parameters since equation will be calculated only once at the beginning of simulation.

5.2.6 HEAT EXCHANGER WITH CONSTANT EFFECTIVENESS

A zero capacitance sensible heat exchanger is modeled as either constant or user-provided effectiveness device that is independent of system configuration. The maximum possible heat transfer rate is calculated based on minimum capacity rate fluid and cold side and hot side fluid inlet temperatures. The concept of an overall heat transfer coefficient for heat exchanger is not used. Type 91 relies on an effectiveness minimum capacitance approach to modelling a heat exchanger. Under this assumption, user is asked to provide the heat exchanger’s effectiveness and inlet conditions. The model then determines whether the cold (load) or the hot (source) side is minimum capacitance side and calculates heat transfer based on Equation 5.31. The heat exchanger outlet conditions are then computed using Equation 5.32
and 5.33. The capacitance of each side of heat exchanger is calculated according to following four equations as:

\[ C_c = \dot{m}_c C_{pc} \] (5.25)

\[ C_h = \dot{m}_h C_{ph} \] (5.26)

\[ C_{\text{max}} = \text{maximum value of } C_h \text{ and } C_c \] (5.27)

\[ C_{\text{min}} = \text{minimum value of } C_h \text{ and } C_c \] (5.28)

A schematic of the heat exchanger is shown in the Fig. 5.5

The following expressions are used to determine maximum possible amount of heat transfer at a given time step.

If \( C_{\text{min}} = C_h \), \( \dot{Q}_{\text{max}} = C_h (T_{hi} - T_{ci}) \) (5.29)

If \( C_{\text{min}} = C_c \), \( \dot{Q}_{\text{min}} = C_c (T_{hi} - T_{ci}) \) (5.30)

The actual heat transfer then depends upon user specified effectiveness.

\[ Q_T = \varepsilon Q_{\text{max}} \] (5.31)

Lastly, heat exchanger outlet conditions are calculated for two flow streams.
\[ T_{ho} = T_{hi} - \left( \frac{Q_T}{C_h} \right) \] (5.32)

\[ T_{co} = T_{ci} + \left( \frac{Q_T}{C_c} \right) \] (5.33)

### 5.2.7 FLOW DIVERTER AND MIXER

The use of pipe or duct ‘tee-pieces’, mixers, and diverters, which are subject to external control, is often necessary in thermal systems. This component has ten modes of operation. Modes 1 through 5 are normally used for fluids with only one important property, such as temperature. Modes 6 through 10 are for fluids, such as moist air, with two important properties, such as temperature and humidity. Modes 1 and 6 simulate the function of a tee-piece that completely mixes two inlet streams of same fluid at different temperatures and or humidity as shown in Fig 5.6. Modes 2 and 7 simulate the operation of a flow diverter with one inlet which is proportionally split between two possible outlets, depending on the value of \( \gamma \), an Input control function as shown in Fig 5.7.

\[ T_o = \frac{m_1 T_1 + m_2 T_2}{m_1 + m_2} \] (5.34)

\[ \omega_o = \frac{m_2 \omega_1 + m_2 \omega_2}{m_1 + m_2} \text{ (Mode 6)} \] (5.35)

\[ m_o = m_1 + m_2 \] (5.36)

![Fig 5.6: T - Piece Function](image-url)
\[
T_1 = T_i \quad (5.37)
\]
\[
\omega_1 = \omega_i \text{ (Mode 7)} \quad (5.38)
\]
\[
m_1 = m_i (1 - \gamma) \quad (5.39)
\]
\[
T_2 = T_i \quad (5.40)
\]
\[
\omega_2 = \omega_i \text{ (Mode 7)} \quad (5.41)
\]
\[
m_1 = m_i \gamma \quad (5.42)
\]

**Fig 5.7**: Flow Diverter Function

### 5.2.8 BURIED HOIZONTAL PIPES

This subroutine models a pipe buried beneath the ground surface. The buried pipe is surrounded by a 3-dimensional finite difference conduction network in order to calculate heat build-up in the soil.

### 5.2.9 WEATHER FILE

This component serves purpose of reading data at regular time intervals from an external weather data file, interpolating data at time steps of less than one hour, and making it available to other TRNSYS components. The model also calculates several useful terms including mains water temperature, effective sky temperature, and heating and cooling season forcing functions.
This component reads weather data files in various formats like, Typical Meteorological Year (TMY) format, Typical Meteorological Year Version 2 (TMY2) format, Typical Meteorological Year Version 3 (TMY3) format, International Weather for Energy Calculations (IWEC) format, Canadian Weather for Energy Calculations (CWEC) format, Energy + format, Meteonorm files for TRNSYS and German 2004 and 2010 TRY formats.

5.2.10 ONLINE GRAPHICAL PLOTTER WITH OUTPUT FILE

The online graphics component is used to display selected system variables while 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 is not performing as desired. The selected variables will be displayed in a separate plot window on screen. In this instance of Type65 online plotter, data sent to online plotter is automatically printed, once per time step to a user defined external file. Unit descriptors (kJ/hr, kg/s, °C, etc.) are NOT printed to the output file. Here the plotter 65a differs as TRNSYS supplied unit descriptors (kJ/hr, kg/s, °C, etc.), if available, will be printed along with each column of data in an output file.

5.3 RESULTS AND DISCUSSION

5.3.1 CASE 1

The simulation results thus obtained Fig 5.8 depicts transient behavior of temperature and heat transfer rates for heat exchanger employed in Fig 5.1. It is seen from Fig 5.8 that source temperature drops from an initial value of 65°C once heat
transfer to load starts. The module takes values of different radiations namely incident radiation, total horizontal radiation, and horizontal diffuse radiation. It also requires ground reflectance, incidence angle and collector slope for internal numerical calculations. It receives temperature and flow-rate from source side pump and delivers heated fluid to a zero capacitance sensible heat exchanger (source side). The source temperature rises as day passes, which corresponds to increasing trend of days temperature towards middle of the day, which further reduces towards the end as day sets. This is because of increased solar radiation, during that part of simulation time. The load temperature reaches to desired temperature of 60 °C typically from 1400 hours to 1800 hours during simulation time. Further, it is also observed that heat transfer rate of load remains constant throughout simulation cycle and source heat transfer follows expected trend. This shows that transient behavior is beneficial for user as well as the designer so that such system can be made more efficient both at operational and designer level.

![Graph showing temperature changes over simulation time](image)
Fig 5.8: Transient behavior of (a) temperature and (b) heat transfer rate for varying source and load conditions.

Fig 5.8 shows that temperature at inlet to collector is taken as constant; corresponding outlet temperature of collector initially is around 20°C due to heat storage in collector and use of insulating materials for solar collector. The outlet temperature drops to 5°C and this is due to fact that there is time delay in process of radiative heat transfer from sun to fluid in collector. The temperature then gradually starts increasing and attains a peak value of around 70°C at 1400 hours followed by a sudden drop to 35°C which is attributed to drop in radiation received between 1400 hours to 1500 hours at specified location. The trend further increases and again attains approximate peak value at 1600 hours and then gradually reduces to 10°C at 1800 hours. The behavior is attributed to chosen design and input conditions for a typical location.
Fig 5.9: Transient behavior of (a) temperature and (b & c) heat transfer rate for varying solar radiations and mass flow-rate.
The heat transfer rates shows nothing between 0800 hours to 1000 hours as level of radiation is low and there is no appreciable heat transfer during that period. As incident radiation level increases, heat transfer rate also increases along with the collector’s outlet temperature.

Further, influence of mass flow rate on heat transfer rate is also shown in the Fig. 5.9. It can be seen that there is no mass flow rate between 1000 hours to 1100 hours and 1500 hours to 1800 hours respectively. However energy from the sun is being stored as per thermal capacity of water. Also role of controller is also important that it is not allowing fluid with lesser heat to flow through heat exchanger by controlling the pumping action. This is further ensuring safety of equipment.

5.3.2 CASE 2

The system consists of two circuits; primary circuit and secondary circuit, as shown in Fig. 5.2. A medium is required to carry energy in primary circuit and to transfer it to secondary circuit through heat exchanger.

Solar collectors provide a hot medium; pump circulates it through heat exchanger and back to solar collector. The hot medium from heat exchanger is then after transferred to diverter, which diverts the flow of hot medium to pipes or to mixer from where it is then sent to load side pump which pumps it back to heat exchanger where it again gets heated and is sent back to secondary circuit.

The proposed simulation study highlights possible thermal active building system that can be employed in a residential building. The present system has been analyzed for heating a room by using a typical configuration of floor buried pipe
along with different fluids. The results obtained revealed that such system is feasible for achieving comfort conditions using solar energy thereby reducing climate change effects because of conventional heating. Based on investigations for primary as well as secondary circuits in Fig. 5.2, it is observed that optimum tilt angle for a solar collector maximizes system annual solar fraction and further maximum energy gain is influenced by tilt angle. The present investigation involves use of flat plate collector for system which as a typical useful energy and solar fraction. Further, as collector efficiency is a function of overall heat loss coefficient, flat plate collector shows less heat gain due to losses by internal convection and conduction thereby providing less thermal insulation and therefore requires a proper angle for useful energy gain. The area of solar collectors has a great effect on the useful energy gained and solar fraction. As area increases, energy gained and annual solar fraction increases therefore, it is a fact that larger collector areas provide larger amounts of thermal energy to drive the heating system. Further, outlet temperature increase is less dependent on larger solar collector because of increased flow rate with increase in collector area. The outlet temperature from a solar collector increase as collector area and amount of flow rate also increase, which maximizes energy gain. Flat Plate solar collector of area 2 m$^2$ and a flow rate of 40 kg/hr was found to be very suitable for modeled heating cycle, since it can achieve an adequate driving temperature.
Fig 5.10: Variation of fluid outlet temperature from heat exchanger for Aluminum pipe

Fig 5.11: Average fluid temperature inside buried pipe for Aluminum pipe

Fig 5.10 and Fig 5.11 shows variation of heat exchanger outlet temperature and average temperature of fluid inside buried pipes with simulation time. The
simulation cycle has been plotted for an increment of every half hour for evaluating dynamic behavior of system. Figure 5.10, shows time fraction per day for different outlet temperature ranges from a heat exchanger. The time fraction is half-hourly occurrences of outlet temperature from heat exchanger during the day. The temperature below 40°C are high, and this is due to sunrise and sunset time, and temperature of 66°C (water) will increase with an increase in solar collector area during the day. In addition, time fraction of 2m² collector area for temperature of 66°C is found for consistent time which is considered enough for operation of system.

From Figure 5.10, it is observed that maximum heat exchanger outlet temperature is of the order of 66°C for water and 52°C for glycol. However, temperature of ethylene glycol is 56 °C. The difference of temperature is attributed to the thermal capacity of each fluid. From the figures, it is also observed that variation of temperatures start between the 32 to 41 hours of simulation time with the maximum values at the 35 hours. This is due to the fact that solar radiation is the highest at time for a typical weather under study. Results revealed that thermal properties have a big influence on the heat loss calculations. Further, it is also observed that variation of these three parameters with time is not influenced by choice of pipe material of buried pipe as these parameters are only being influenced by heat exchanger specification and weather chosen for study. The collector flow rate is considered an important parameter of system performance as it controls fluid temperature inside collector. Raising fluid temperature inside collector above boiling point may cause pipe damage if fluid pressure is not at saturated level. This
factor influences collector flow rate thus eliminating excessive rise of temperature to undesirable point. The performance of system was computed in the form of desired outlet temperature for different working fluids for which results are shown in Fig 5.10 and 5.11. Further, flow rate influences outlet temperature which affects performance of system. The 40 kg/hr collector flow rate maintains outlet temperature at a desired level for collector area for optimum performance of system.

![Thermal Loss from Pipe (kJ/hr)](image)

**Fig 5.12:** Variation of thermal losses inside Aluminum pipe

It has been shown that the 2m² of flat plate collector with a flow rate of 40 kg/hr is required to run proposed heating system for which a number of simulations is carried out to study performance for given period. It has been observed that time fraction of temperature around 60°C is for sufficient period which indicates that system can run by solar energy by using flat plate collector and without any input from conventional energy. The performance of heating system being driven by solar energy strongly depends upon the climate, i.e. ambient conditions and solar
radiation. In addition, overall system performance depends on outlet temperature and thermal losses as detailed in Fig 5.12.

Fig 5.12 shows variation of thermal losses for aluminum pipe against time for three different fluids i.e. Ethyl Alcohol, Glycol and water. Figure also shows that thermal losses are maximum for water as a fluid in all the cases as water is having low thermal energy storage capacity as compared to other two fluids. In all cases, influence of thermal capacity of material is neglected.

Fig 5.13: Variation of piping heat losses for Aluminum pipe

Similarly Fig. 5.13, show variation of piping heat losses for aluminum pipe against time for the three different fluids i.e. Ethyl Alcohol, Glycol and water. The results are similar to thermal losses. Figure shows that thermal losses are maximum for water as a fluid in all cases as water is having low thermal energy storage capacity as compared to other two fluids. In all cases influence of thermal capacity of material is neglected.
5.4 CONCLUSION

5.4.1 CASE 1

The utility/possibility of employing heliothermal application in remote areas of Jammu and Kashmir, state in India, for which the weather data is simulated for a typical application, was analyzed. These applications are certainly required because conventional energy supply is very erratic and unreliable due to unprecedented weather conditions during colder months. Further such systems also reduce the electrical energy consumption and further dependence on gas for hot water and space heating application. The system was analyzed using TRNSYS software, and main results of simulation shows that a lot of energy can be extracted from such application and output temperature and maximum heat transfer rate could be achieved as desired. It is further concluded that such systems need to be optimized on the basis of operational parameters for better results. The application of improved materials and better insulating materials will assist in increasing efficiency further.

On basis of analysis, it is concluded that solar energy can be made efficient and cost efficient by proper design and operating procedures they should be widely used for a suitable building application.

5.4.2 CASE 2

In this study effort is to introduce concept of space heating inside the building using solar energy in New Delhi region in India. Here analysis is extended to variation of fluid types for a typical pipe material at different depths of buried pipes. Also, variation of primary circuit fluid has also been simulated. It has been observed that time fraction of temperature around 60°C is for sufficient period which indicates
that system can run by solar energy by using flat plate collector and without any input from conventional energy. The performance of heating system being driven by solar energy strongly depends upon climate, i.e. ambient conditions and solar radiation.

In addition, overall system performance depends on the outlet temperature and thermal losses. Based on investigations for primary as well as secondary circuits, it is observed that optimum tilt angle for a solar collector maximizes system annual solar fraction and further maximum energy gain is influenced by tilt angle. Flat Plate solar collector of area 2 m² and a flow rate of 40 kg/hr were found to be very suitable for the modeled heating cycle, since it can achieve an adequate driving temperature.

Results revealed that variation of these parameters with time is not influenced by choice of buried pipe material as these parameters are only being influenced by heat exchanger specification and weather chosen for study. The influence of weather can be easily quantified from results. Further, thermal losses are maximum for water as it is having low thermal energy storage capacity as compared to other two fluids. Results revealed that thermal properties have a big influence on heat loss calculations. However, thermal conductivity of the soil surrounding pipe is difficult to estimate because of inhomogeneous and unknown soil composition and moisture content. Using pipes of dissimilar dimensions and different materials to obtain more flexible capacity will also lead to energy savings that requires further evaluation.