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Research Paper

Design of central solar heating with underground seasonal storage in Australia

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Abstract: Simulation of a central solar heating system with seasonal storage has done by using TRNSYS to predict thermal performances and economic aspects. The location of the simulated site is at Glenroy, Melbourne, a southern part of Australia (latitude: 37º 42´ S, longitude: 144º 5´ E, altitude: 97 m.). The meteorological conditions data are prepared by Meteonorm, based on 10 years of measurements. The central solar heating system consist of solar collector, a well-insulated underground seasonal thermal storage tank with heater, fan coil unit that installed in the heating zone and two single speed pump. In the daytime, water from the underground storage tank will feed pass through the solar collector, collecting energy and return to underground storage tank, that will keep the water temperature gradually goes up. In the winter time, and when the indoor house temperature is below 21 ºC, the warm water from the underground storage tank will feed into the house. The heating coil, install in the house, will work as heat exchanger so that energy from water could transfer to an air space in the house to keep the indoor temperature above 21 ºC and the residents may feel comfortable. The sizing of the underground storage tank and also the auxiliary heater capacity are limited by its initial cost and availability, so it will be set as selected parameters. After that, the area of solar collector, initial water temperature would selected by the simulation. The simulation result has shown that, the underground storage tank suitable for this application is around 50 m3 with 5m2 solar collector area. The initial water temperature in the staring of January should be at 50 ºC. The solar factor for this application is 0.76. The economical analysis has shown that the Internal Rate of Return (IRR) of this investment when compare with widely used natural gas heater is around 8.5% that seems to be very economically and favorably.

Keywords: solar heating, underground storage, seasonal storage

Introduction

The main energy consumption in Australia in the winter time is the residential heating. When we take a look at Australia we can detect certain trends that relate to the consumption of energy. According to data from the World Resources Institute, the total commercial energy consumed in 1993 was 3.92 EJ. This was a major increase of 99% from 1973. We can also look at the total energy consumed in 1993 and the projected energy consumed in 2014. If the projected data are correct there will be a 55% (5.698 EJ) in the energy consumed from 1993 to 2014. Recent energy consumption has been on the order of 1 EJ per year. It is expected to reach nearly 10 EJ per year within the next 15 years. Reduction of energy consumption was promoted by Australian Government for a long time. One of the most effective solutions is to use the alternative energy. Solar energy, an abundant, clean and safe source, is an attractive substitute for conventional fuels for passive and active heating applications. During the day, excess solar heat is collected for short or long term storage, and it is recovered at night in order to satisfy the heating needs of greenhouses. Efficient and economical heat storage is the main factor in utilization of solar energy for daily used purposes. Solar thermal energy seasonal storage system is the appropriate alternative way for Australia cause of the meteorological conditions.

Thermal storage systems in buildings act as energy buffers which balance the periodic thermal demands and supplies. Systems can be designed to cope with the diurnal (24 hours), intermediate (several days) or even seasonal thermal energy fluctuations. Thermal energy storage is made practical by the large heat capacity of water. One metric ton of water, just one cubic meter, can store 334 MJ. Appropriate applications of thermal storage systems can significantly reduce the thermal energy consumption as well as improve the comfort conditions of the indoor environment.

In Germany, since 1995, eight central solar heating plants with seasonal heat storage have been built within the governmental Research and Development program "Solarthermie-2000" (Schmidt et al., 2004). In Turkey, annual periodic performance of a solar assisted groundcoupled heat pump space heating system with seasonal energy storage in a hemispherical surface tank is investigated using analytical and computational methods (Ramyutus and Unsal, 2000). Moreover, thermal performance and economic feasibility of central solar heating system with seasonal storage under four climatically different Turkey locations are studied based on a finite element analysis and finite element code ANSYSTM (Ucar and Inalli, 2005). As in Korea, a central solar heating plant with seasonal storage is simulated using TRNSYS to predict thermal performances and economic aspects (Chung el al.,1998). As mentioned above, central solar heating system with seasonal heat storage has studied by many researchers in many countries. This work shows the feasibility and suitableness of this system in Australia.

System Layout and Control

The central solar heating system that studied was shown in Fig 1. The system consist a set of solar collector, a well-insulated underground seasonal thermal storage tank with heater, fan coil unit that installed in the heating zone and two single speed pump.

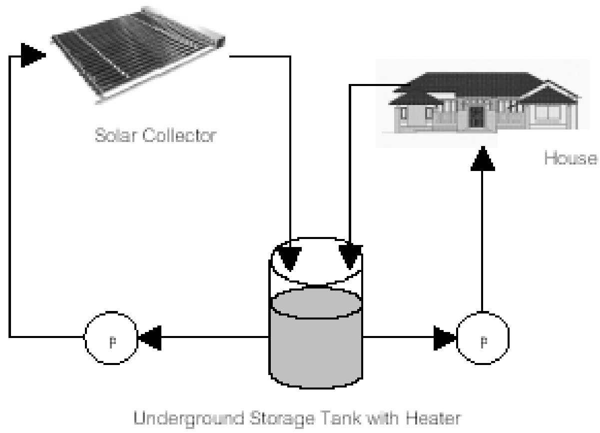

Figure 1 Layout of the central solar heating system with cylindrical seasonal thermal storage.

In the daytime, 8.00 am – 4.00 pm daily, the controller set would operate a single speed pump, and then the water from the underground storage tank will feed pass through the solar collector, collecting energy and then return to underground storage tank. This recharge process not only maintains the energy of the system but also keeps the water temperature gradually goes up. In the winter time, around middle of May to the middle of August, and when the house temperature is below 21 ºC, the controller will operate another single speed pump, and then the warm water from the underground storage tank will feed into the house. The heating coil, install in the house, will work as heat exchanger so that energy from water could transfer to an air space in the house to keep the indoor temperature above 21 ºC and the residents may feel comfortable (recommended by ASHRAE standard).

Methodology and Simulation Tool

The central solar system with seasonal storage tank were setup as a model in simulation program TRNSYS, a well-known and widely used system simulation program of transient thermal process. This program has high ability to develop the central solar heating system. It provides libraries of subroutines such as solar collectors, water tanks, pumps, pipes, valves and controller. Users can write their own subroutine components to respond their particular need. The system layout (as shown in Fig 1.) is reproduced by assembling the corresponding the TRNSYS components. The simulation time step should be short enough to reproduce the variation of the thermal process, 1 hour for each time step was found to be suitable for this simulation. The system design was defined by all the parameters for each component. Initial and boundary conditions are determined respectively by the initial values of the component variables and by the dynamics of meteorological conditions. The components, selected in this study, are listed as follows:

- The TYPE1b quadratic efficiency solar thermal collectors: This component models the thermal performance of a flat-plate solar collector. The solar collector array may consist of collectors connected in series and in parallel.
- The TYPE 38 plug-flow storage tank: This component models the behavior of a temperature stratified storage tank using variable size segments of fluid. The size of segments is governed by the simulation time step, the magnitude of collector and load flow rates, heat losses and auxiliary input. The main advantage over fixed node simulation techniques is that temperature stratification can be modeled with small segments in the temperature gradient zone without the need to use small simulation time steps to obtain a good solution.

- The TYPE 52b cooling and heating coil rectangular fin: This component models the performance of a cooling and heating coil using the effectiveness model outlined by Braun. The user must specify the geometry of the cooling and heating coil and air duct. The continuous flat plate fins are specified. Either a simple or detailed level of analysis may be chosen by the user. The level of detail determines the method used in modeling a coil operating under partially wet and dry conditions.
- The TYPE 3b single speed pump: This pump model computes a mass flow rate using a variable control function and a fixed maximum flow capacity. 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.
- The TYPE 14h forcing functions: 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.

The reliability of all selected components was well tested by TRNSYS and global user.
Normally, the sizing of the underground storage tank will be limited by its initial cost that should not be over than 50 m3 for 4 people family. The auxiliary heater capacity, easy available, should not be over than 5000 W. After that, the area of solar collector, initial water temperature will be selected by the simulation.
The main thermal characteristics of the studied system were shown in Table 1.

Table 1 Main thermal characteristics of main components of the system.

Solar Thermal Collector		
area (series)	5	$m.^2$
orientation	North	
incident angle	45	degree
specific flow rate	100	kg./hr.
Plug-flow underground storage tank		
tank volume	50	$m.^3$
thermal conductivity	1.5	kJ./(hr.m.K.)
overall heat loss coef.	5	kJ./(hr. K.)
max. heating rate	5	kW.
auxiliary thermostat temp.	50	°C
Heating coil rectangular fin		
specific flow rate	50	kg./hr.
no. of HX row	7	
no. of tube in each row	4	
outside tube diameter	0.025	m.
inside tube diameter	0.020	m.
tube spacing	0.350	m.
tube thermal conductivity	500	kJ./(hr.m.K.)
fin thickness	0.010	m.
fin spacing	0.100	m.
number of fin in coil	25	
fin thermal conductivity	700	kJ./(hr.m.K.)

Energy in and out from each components of the system was calculated both instantaneous and summary values to check the energy balance.

Weather Condition and Heat Load

The location of the simulated site is at Glenroy, Melbourne, Australia (latitude: 37º 42′ S, longitude: 144º 5′ E, altitude: 97 m.). The meteorological conditions data are prepared by Meteonorm, based on 10 years of measurements. Hourly values of the meteorological and radiation data are used in the simulation. The annual heat load is the annual energy used of the 148 m^2 single floor house. The number of people lived in this house was set to 4 people with normally Australian activities. Some heat generated equipments such as lights and computers were studied. Infiltration of both living and attic zones were also set as inputs too.

Simulation Results

From the simulation, the initial temperature from the starting of January that suitable to this study is 50.0 ºC, with solar collector area 5.0 m^2. Reheating the water via solar collector in the daytime every day can rise up its temperature to 56.5 ºC in the middle of May. In the winter time, whenever the indoor house temperature is below than 21.0 ºC, the heating system will be operated to keep the indoor temperature above 21.0 ºC. This will make the water temperature goes down to 40.6 ºC. The auxiliary heater in storage tank, controlled by its thermostat, will start automatically, couple with reheating the water via solar collector every daytime. After this period, the water will reheat without heating the house, so that its temperature can raise up to 50.0 ºC in the end of year. Fig. 2 (at the end) has shown the simulation result of water temperature in underground storage tank, indoor house temperature and auxiliary energy consumption in the winter time for the selected parameters. The simulation values of the energy for each component have shown in Table 2.

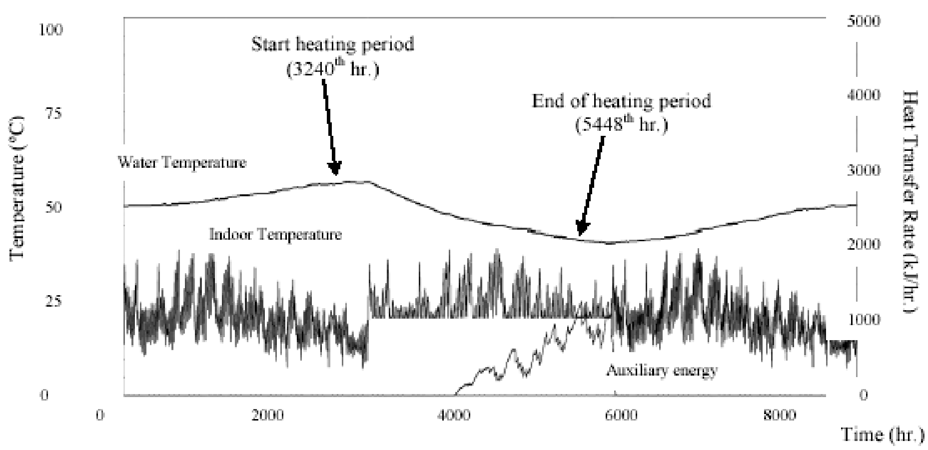

Figure 2 The simulation result by TRNSYS

Table 2 The simulation values of the energy for each component (units in GJ).

Whole year house heating load required	14.04
Energy supplied to the tank from the collector	15.46
Auxiliary energy from heater	1.81
Overall tank losses	0.90
Energy store in the tank	0.78
Energy supplied to the house from the tank	10.64

The energy balance of the system should be expressed as:

Energy supplied to the tank from the collector + Auxiliary energy from heater = Tank losses + Energy stored in the tank + Heating load --(1)

By substitute the simulation value from Table 2.in Equation (1)., the energy balanced has shown the whole year 8.9% error. This error should be an effect of accumulation error in each interval time step from each calculation.

The solar fraction of the system should be expressed as:

Solar fraction = Energy supplied to the house from the tank / Heating load --------------------------------(2)
Varying the solar collector area was done in this study, which the effect of changing solar collector area on solar fraction has shown in Fig 3. The solar fraction of the selected collector area, 5 m2, is around 0.76.

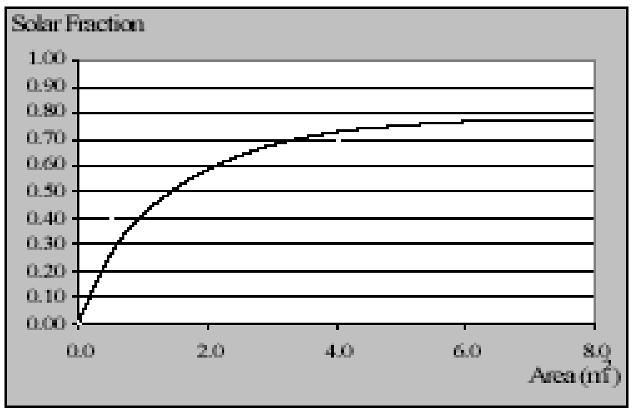

Figure 3 The optimization of solar fraction and solar collector area.

The energy that can be saved by this central solar heating system should be expressed as:

Saved energy = Energy supplied to the house from the tank - Auxiliary energy from heate---------(3)

By substitute the simulation value from Table 2, the energy that can be saved by this system is around 8.83 GJ per year. This can lead to be the saving for natural gas fuel cost that normally used as energy source of Australian housed heater around 80 AUS$ a year.

Economic Analysis

The Internal Rate of Return (IRR) is the index in this economical analysis. It is the discount rate that results in a net present value of zero for a series of future cash flows. It is one of the Discount Cash Flow (DCF) approach to valuation and investing just as Net Present Value (NPV). Both IRR and NPV are widely used to decide which investments to undertake and which investments not to make. NPV show the stream of future cash flow discounted back to the present by some percentage that represents the minimum desired rate of return. The formulae to find IRR should be express as:

$$NPV = \sum_{n=1}^{N}\left(\frac{NCF_n}{(1+i)^n}\right) - TIC = 0 \quad \text{-------------------------}(4)$$

Or

$$TIC = \sum_{n=1}^{N}\left(\frac{NCF_n}{(1+i)^n}\right) \quad \text{--------------------------------}(5)$$

where
TIC is the initial investment at the present value (AUS$),
i is the internal rate of return,
N is the number of years for operating life of the system (years),
NCF_n is the net cash flow at the year n^{th} that be energy cost saving compare with the natural gas heating system (AUS$).
The estimation this investment when compared with natural gas heater system could be found by substitute the economical value in the Equation (4) or (5). The discount rate of the progress was set to be 9% a year (7% for MLR interest and 2% for inflation in Australia) when the cash flow reduce 1% a year for maintenance cost. With trial and error the values of internal rate of return (IRR) until getting the net present value (NPV) of zero. An equation will give us that the internal rate of return (IRR) of 8.5%.

Conclusion

The simulation result has shown that, from the selected parameters: underground storage tank volume 50 m3, auxiliary heating energy 5000 W., the solar collector area suitable for this application is 5 m2. The initial water temperature in the staring of January should be at 50.0 ºC which will increase up to 56.5 ºC when recharge daily via solar collector (without house heating load). In the winter time, warm water from underground storage tank will be used in house heating application that its temperature will drop to around 40.6 ºC. The water temperature will be warm up back to around 50.0 ºC at the end of the year. The solar factor for this application will be 0.76. The economical analysis has shown that the Internal Rate of Return (IRR) of this investment when compare with widely used natural gas heater is around 8.5% that seems to be very economical and favorable to use in the single house family in Australia.

References

1. Chung, M., Park, J. and Yoon H. (1998). Simulation of a central solar heating system with seasonal storage in Korea. **Solar Energy**, 64/4-6, 163-178.
2. Ramyutus, M. and Unsal, M. (2000). Analysis of solar aided heat pump systems with seasonal thermal energy storage in surface tank. **Energy,** 25/12, 1231-1243.
3. Schmidt, T., Mangold, D. and Muller-Steinhagen, H. (2004). Central solar heating plants with seasonal storage in Germany. **Solar Energy,** 76/1-3, 165-174.
4. Ucar, A. and Inalli, M. (2005). Thermal and economical analysis of a central solar heating system with underground seasonal storage in Turkey. **Renewable Energy,** 30/7, 1005-1019.