Study on solar space heating for intermittently occupied buildings

Guoqing Yu

Department of Building Environment and Equipment Engineering
University of Shanghai for Science and Technology
Shanghai 200093, China
guoqing.yu@163.com

Hui Yang

Guangdong Jirong engineering Co. Ltd

Room 201, No. 228 Jiangchang road,

Shanghai, 200436, China
mrhuiyang@163.com

ABSTRACT

Today lots of research and application of solar heating are focused on continuously occupied buildings, such as residential buildings. This paper studies solar heating for intermittently occupied buildings such as offices, classrooms, workshops which generally are unoccupied during nights and weekends. If we stop space heating during nights, energy for space heating will be reduced. In the paper, a simple building is assumed and a solar assisted space heating system is designed for it. Hourly simulations during the whole winter are conducted under various conditions, such as different building envelopes, different control strategies and so on. The results show that whether stopping heating during nights in solar heating buildings can save conventional auxiliary energy compared to continuous heating depends on the control strategies and types of envelopes.

1. INTRODUCTION

Solar assisted heating is one important way to reduce energy used for space heating. Today lots of research and application of solar heating are focused on residential buildings. This paper will focus on solar heating for buildings such as offices, classrooms, workshops which generally are unoccupied during nights and weekends. If we stop space heating during nights and weekends, a certain portion of energy will be saved. This paper call this is time scheduled heating.

However, it is not so simple to use time scheduled heating. If we stop heating during nights, can the room temperature drop below zero and encounter the risk of freezing? How much energy will be saved by time scheduled heating? How to reduce the fluctuation of the room temperature during daytime?

In the paper, a typical office room is assumed and a solar heating systems is designed for it. The performance of time scheduled solar heating will be studied by hourly simulations during a whole winter.

2. THE RESEARCH OBJECTS

2.1 Description of the Office

The office is a typical section in the middle of the building, which is assumed to be located in Beijing. Its size and shape is shown in Fig.1,

Length of south/north face: 10 m

Length of west/east face: 10 m

Height: 3.3m

Window: in south and north face respectively, $9m^2$

The north and south walls are exposed to ambient, its east wall, west wall, ceiling and floor are adjacent to the internal zone of same temperature as the room in question.

The exterior walls are made of 50 mm insulation with 200 mm heavyweight concrete. The separation walls, floors and ceilings are made of 200 mm heavyweiht concrete.

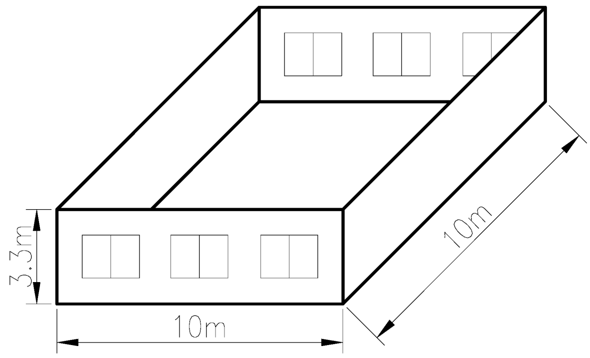

Fig.1 Shape and size of the office

2.2 The Schematic of the Solar Space Heating System

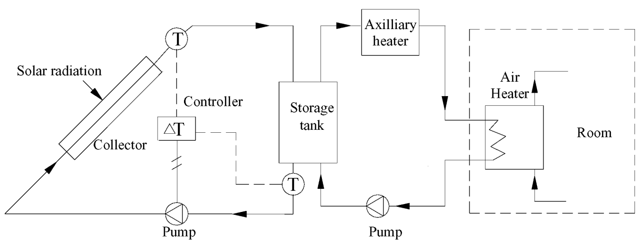

Fig.2 Schematic of a space heating system

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A solar space heating system is designed for a large office. The schematic of the solar heating system is shown in Fig. 2. It includes a heat source (solar collectors), two pumps, an air heater (radiator, or water-air heater), a thermal storage tank and the load (an office room).

In typical continuous space heating systems, the load pumps run continuous with constant flow rates. In the time-scheduled space heating system discussed in this paper. Typically, it is in operation during daytime and is stopped during nights. Several operating strategies are used and discussed in the following sections.

2.3 The Main Components of the System

(1) Collectors: Flat collectors are employed in the system. Total aperture area is 20 m^2. The collectors are positioned east-west and oriented to due south. The slope of collectors is 40^o, the same as the local latitude.

(2) Storage tank: The volume of the tank is $2.0m^3$ in these cases.

(3) Auxiliary heater: When the solar power is not enough, an auxiliary heater is required to heat the supply hot water to required tmperature if the inlet temperature is less than the required temperature, which is varied during the whole winter in order to keep room temperature near 18^oC.

3 ROOM MODELS

The room model is essential for the simulation, so it will be described here in brief. The room model includes walls, windows, roofs/ceilings, doors, and floors. The heat transfer from and within the zone are formulated in a matrix and solved in different ways for different type of envelopes. The mathematical description is as follows[1].

3.1 Exterior Wall

The instantaneous heat flux entering or leaving the zone for an exterior wall can be modeled according to the following transfer function relationship.

$$q_i = \sum_{h=0} b_{h,i} T_{sa,i,h} - \sum_{h=0} c_{h,i} T_{eq,i,h} - \sum_{h=1} d_{h,i} q_{i,h} \quad (1)$$

The coefficients b_h , c_h and d_h are transfer function coefficients for current and previous values of the solid-air temperature ($T_{sa,i}$), equivalent zone temperature ($T_{eq,i}$), and heat flux, q_i. A value of h equal to zero represents the current time interval, h equal to one is the previous hour and so on. The solid-air temperature, $T_{sa,i}$, is the temperature of the outdoor air which, in the absence of all radiation exchanges, would give the same heats transfer at the outside surface as actually occurs. The heat capacity the walls was considered in this model.

3.2 Window

The solar energy passing through the window is the product of the incident solar radiation and the transmittance provided as an input. The thermal conduction through the window from the ambient is given as

$$Q_i = A_i U_{g,o,i}(T_a - T_{eq,i}) \qquad (2)$$

3.3 Radiative Gains

Radiation gains to each surface in the room originate from lights, people, and solar radiation entering windows. Solar radiation passing through windows is assumed to be diffusely reflected.

3.4 Internal Space

An energy balance on the zone air plus any furnishings considered as a lumped system yields

$$Cap\frac{T_{ZF} - T_{ZI}}{\Delta t} = \sum_{j=1}^{N} h_{c,j} A_j (T_{s,j} - T_Z) + Q_{\inf 1} + Q_{\text{int}} \qquad (3)$$

T_{ZI}, T_{ZF}: Room temperature at the initial and final point of a time step;

Cap: Capacitance of Room air and furniture;

The first term of right side of the equation refers to heat transfer between room air and inner surface of a wall, partition, etc. The second term refers to heat gain by infiltration. The third term refers to heat input by air heaters.

4. SIMULATION AND DISCUSSIONS

In order to study the characteristics and performance of solar space heating systems, hourly simulations are conducted on the basic case described in the above section. The hourly data during winter of typical meteorological year (TMY) comes from [2]. The heating season includes November, December, January and February.

4.1 Continuous heating

Case1 is the standard case and continuous heating is used in it, the system is described in the above section and the space heating runs continuously even during nights. In order to keep the room temperature near 18°C, the supply water temperature has to be varied during the whole winter, as shown in Fig.3.

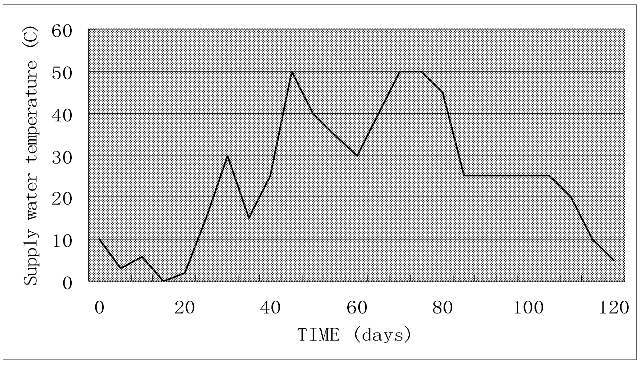

Fig.3 The supply water temperature during winter

The average daily (for 24 hours) room temperature during the whole winter is 16 °C and the average daytime (for 10 working hours) room temperature is 17.9 °C.

Some indices of performance are outlined in Table 1. The solar fraction is really high and it is due to the good solar resources in Beijing. It is worth noting that the passive solar heat gain through the south windows play an important role in the heating to the office in addition to the active solar heating.

Table 1: Key indices for the cases in question

Cases	**Qload**	**Qaux**	**Qsolar**	η	*f*	E_{pump}	T_{24h}	$T_{daytime}$
	GJ	GJ	GJ	%	%	kwh	°C	°C
Case1	12.20	4.42	7.78	25.5	63.8	10.1	16	17.9
Case2	5.10	0.91	4.19	18.0	82.2	4.20	13.1	13.9
Case4	10.78	4.49	6.29	22.5	58.3	5.46	16	17.6

Case5	11.5	3.78	7.47	24.9	65.0	9.28	15.4	18.0
Case6	12.10	4.40	7.70	25.4	63.6	9.90	14.7	18.7
Case7	9.23	3.49	5.74	21.4	62.2	5.36	14.3	18.0

Note:

Qload: Heat supplied to the room

Qaux: Heat produced by auxilliary heater

Qsolar: Useful heat supplied to Load

η : Average collector efficiency during the whole heating season

f : Solar fraction for the whole heating season

T_{24h}: Room temperature of the whole day, 24 hours

$T_{daytime}$: Room temperature during daytime.

E_{pump}: Electricity consumed by load pump

4.2 Using Time Scheduled Heating

In Case2, time scheduled heating is used, heating starts from 8:00 to 18:00 and stops during unoccupied hours. The average room temperature during the whole winter dropped to 13.1°C and the average daytime room temperature is reduced to 13.9°C in this cases. It can not meet the requirement for comfort. The main indices are listed in Table1 for case2.

It is impossible to keep the room temperature as high as continuous heating if we solely stop space heating during nights and do not change all the other things. Therefore we have to take some measures to compensate for reduction of heat input resulting from no space heating during nights. There are several ways to deal with this.

(1) Case 3: Start heating before occupation

In this case, space heating begins several hours before occupation and the others remains the same as Case2. The room temperature variation during daytime is mitigated than case2. The average daily and daytime room temperature raised by about 0.2 °C and 0.3°C respectively when starting heating 1 hour in advance, as shown in Fig.4. It can not meet the requirement for comfort even when starting heating 7 hours before occupation.

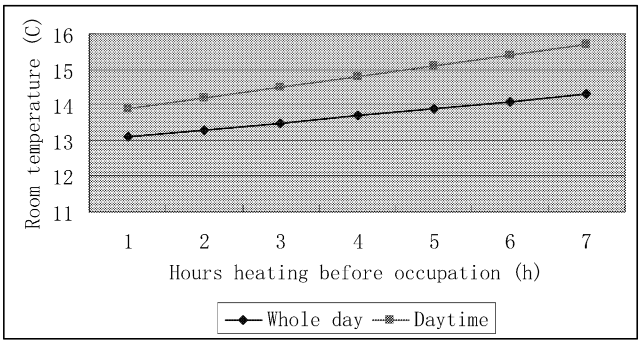

Fig. 4 Room average temperature in a whole winter when heating before occupation

(1) Case 4: Start heating before occupation and raising supply water temperature

By several trials, we find the daily average temperature can keep stable by raising supply water temperature than continuous heating by 20°C in addition to starting heating 3 hours in advance. The room temperature fluctuates widely than continuous heating, but the fluctuation during daytime is adequately acceptable. The average daily and daytime room temperature during the whole winter is 16 °C and 17.6 °C respectively. It can meet the requirement for comfort.

The indices are listed in Table 1, they indicate that the heat load is really reduced but the auxilliary heat is increased. This means that this case will not save convectional auxiliary heat but use a little more. However the pumping energy consumption will be reduced greatly due to stopping heating during nights.

(3) Case5: Increasing heat transfer area and flowrate

In this case, both the heat transfer area and flowrate are increased by 70% compared to case2 and it starts heating 3 hours ahead of working hour, the others are kept unchanged. The average daily and daytime room temperature during the whole winter is 15.4°C and 18.0°C respectively. It can meet the requirement for comfort. From table 1, we find that both the heat load and auxilliary heat are reduced. This means that it really can save energy.

4.3 Using Time Scheduled Heating to Rooms of Light Weight Walls

We also studied the effects of using time scheduled heating to rooms of light-weight walls. In cases 6 and 7, the exterior walls are made of 50 mm insulation plus 100 mm light weight concrete blocks, which are only one sixth of the heavy weight concrete in weight but its thermal resistance are larger than the former. The separation walls, floors and ceilings are made of 100 mm light-weight concrete.

Case6 employs continuous heating and case 7 using time scheduled heating companied with heating 3 hours before occupation. The room temperature fluctuates widely than Case1, but the fluctuation during daytime is acceptable. The average daily and daytime room temperature during the whole winter in Case6 is 14.7 °C and 18.7 °C respectively, the value of them in Case7 is 14.3 °C and 18.0 °C respectively. The profiles of room temperature during the first week of January are shown in Fig.5.

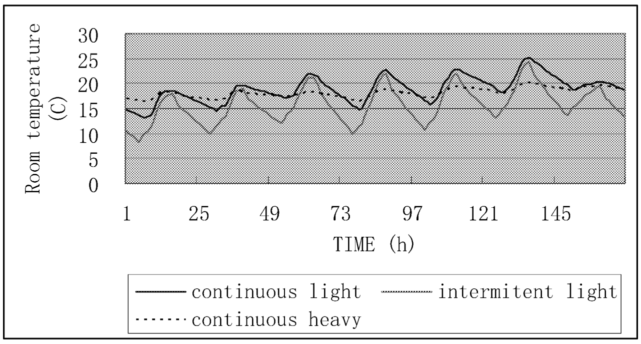

Fig. 5 Room temperature variation for three modes

4.4 Effects of Volume of storage tanks

As well known, the storage volume is important for the performance of solar heating systems. This paper studies the effect of tank volume on the total auxiliary heat of three cases:

Case1: heavy envelope and continuous heating

Case5: heavy envelope and time scheduled heating

Case7: light envelope and time scheduled heating

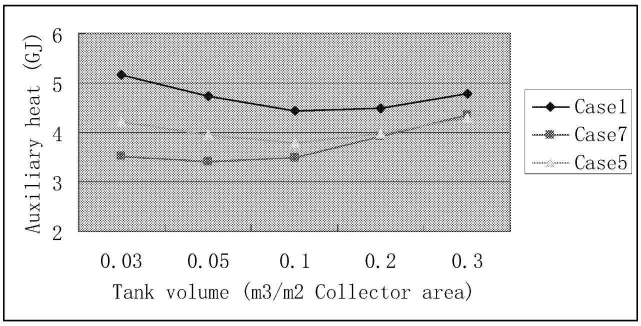

Fig. 6 Effects of Volume of storage tanks

The results are shown in Fig.6. It indicates that the optimum volume of tank is near $0.1m^3/(m^2$.collector area) both for heavy envelope regardless of continuous heating or time scheduled heating, and that the optimum volume of tank are near $0.05m^3/(m^2$.collector area) for light envelope and time scheduled heating, i.e. smaller than that for heavy envelopes.

5. CONCLUSIONS

(1) The room temperature variation usually larger when using time scheduled heating than continuous heating. It is hard to meet the

requirement of room temperature for comfort by using time scheduled heating simply with starting heating before occupation.

(2) Using time scheduled heating can reduce the total heat load compared to continuous heating whether for rooms of heavy or light weight envelopes.

(3) Whether time scheduled heating in solar space heating can save conventional auxilliary heat energy compared to continuous heating depends on the control strategies and types of envelopes.

1) When companied with raised supply water temperature, it uses more conventional auxilliary heat for heavy weight buildings. However it will reduce auxiliary heat for light weight buildings.

2) When using more heat transfer area and higher flowrate, it can save auxilliary heat energy for either heavy or light weight buildings.

6. ACKNOWLEDGEMENTS

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6. REFERENCES

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