

Simulation Results of Active Solar Shading Louvres Collector for an Office Building Energy Supply

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Abstract: Shading louvres offer maintenance-free, aesthetically pleasing protection from solar gains, which can cause visual and thermal discomfort in addition to unnecessary increase in building energy demands. In most office buildings there is an increasing demand for heating in winter and cooling in summer. The conventional passive louvres could be converted to active louvres, and used to convert the incident solar radiation to a useful energy. In this way, the shading louvres could be used to supply useful energy that could offset the building thermal and cooling loads.

This paper presents results of a study carried out to evaluate the benefit of employing shading louvres to serve as active solar collectors for the purpose of energy provision in office buildings. A solar louvre collector system has been designed for use in an office building and simulated dynamically using TRNSYS^[1] simulation software. The results have shown a significant reduction in the building energy consumption, when solar shading louvres are used as solar energy collectors, compared to the case of a building without active louvres.

NOMENCLATURE

η_{col} Collector efficiency;
 COP Coefficient of performance;
 k Coefficient of heat transfer [$W/m^2 \cdot ^\circ K$];
 g' solar heat gain coefficient;
 $\dot{m}$ Mass flow rate [kg/h];
 T Temperatures [$^\circ C$];
 F_{av} Heat removal factor, based on the average temperature;
 U_c Cover-absorber heat transfer coefficient [$W/m^2 \cdot ^\circ K$];
 $X_m = (T_{av} - T_a) / I$ [$m^2 \cdot ^\circ K/W$];
 I Solar radiation on the plane of the collector [W/m^2];
 F_{av} Heat removal factor, based on the average temperature (T_{av});
 $(\tau_c \alpha_p)$ Transmittance-absorptance product;

$$\eta_{col} = F_{av}(\tau_c \alpha_p) - F_{av} U_c \frac{(T_{av} - T_a)}{I} \quad (1)$$

The solar louvre collector was tested under controlled environment to characterise its optical and thermal performance, and the following linear performance curve was obtained^[2]:

$$\eta_{col} = 0.87 - 4.0 X_m \quad (2)$$

i.e., $F_{av}(\tau_c \alpha_p) = 0.87$, and $F_{av} U_c = 4.0 W/m^2 \cdot ^\circ K$.

The efficiency η_{col} could be calculated using the parametric model given in equation^[2].

The building under consideration is located in Winterthur, Switzerland (Latitude $47^\circ N$ 30, and Longitude $8^\circ E$ 43). The 5-storey building is oriented southwards, and the solar louvre collectors were simulated on the south-façade of the second floor. The overall dimension of the floor is ($55.40 m \times 7.10 m \times 2.76 m$). The floor is divided into offices of different sizes, separated by internal wall-partitions. The facade has apertures made of 39 single-pane windows ($k = 2.8 W/m^2 \cdot ^\circ K$, $g' = 0.75$), integrated in the south wall, with a total glass surface area of $78.7 m^2$, which is approximately 40% of the outer wall surface. The described office-floor was simulated for 30 louvres in line, cascaded horizontally above the glazing, with either 5 or 7 rows.

Heating and cooling were simulated using under floor heating coil and colds ceiling arrangement, respectively.

Heat loads for user attitude assumptions were made, as listed in Table 1.

1. INTRODUCTION

The design and conversion of the shading louvres used in this study has been the subject of other work^[2]. Schematic of the solar louvre collector, used in this study, is shown in Figure 1. The louvre collector has an elliptical cross-section of an aspect ratio approximately equal to 6. The collector utilises water as a working fluid in a direct-flow (fin-on-tube) configuration.

Equations relating the performance of the solar louvre collector can be derived in a similar manner to those used for flat plate collectors, and thus the efficiency of the louvre collector can be given by the following equation, see ref.^[3]:

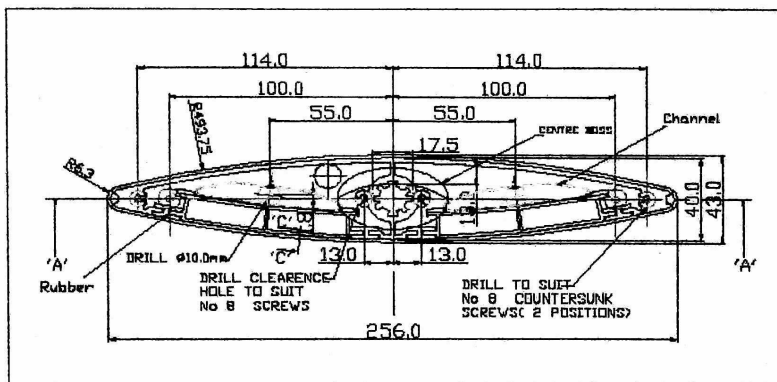


Figure1: A schematic of the solar louvre collector

Table 1: Internal heat loads estimation of the office floor.

Loads	Amount	Specific and Max heat load [W]	Power-on or people in time, automatic controls
Staff.	20	65 W/clerk, Max. 1300 W	Mon – Fri: No. of staff: 7:00 – 8:00: 5 8:00 – 17:00: 20 17:00 – 18:00: 10 18:00 – 19:00: 5
Computers	20	230 W/pc, Max. 4600 W	Mon – Fri: pc's online: 7:00 – 8:00: 8 8:00 – 17:00: 20 17:00 – 18:00: 8 18:00 – 7:00: 4
Lighting	91	13 W/m ² , Max. 5100 W	Mon – Fri: Percentage lit: 7:00 – 9:00: 50% 9:00 – 17:00: 20% 17:00–19:00: 100%
Heating	1 system ¹	Unlimited, depending on boundary and automatic control conditions.	Heating, if internal temperature $T_i < T_r$: Mon–Fri, 8:00–20:00: $T_r = 21.5\text{ }^{\circ}\text{C}$ Else: $T_r = 18\text{ }^{\circ}\text{C}$
Cooling	1 system ²	Unlimited, depending on boundary conditions	Every day: $T_i > 26^{\circ}\text{C}$: Activated

System¹: Under floor heating, **System²:** Chilled Ceiling/cold slaps

2. THE MODEL

It was assumed, that the whole surface area of the solar louvre acts as a collector.

Calculations were performed for five different cases, with 5 or 7 rows of solar louvres, two different window types (the present windows (old), and proposed windows (new)), and two different sizes of window areas (actual area = 78 m², and the proposed area = 109 m²). These are as shown in Table 2.

For simplicity, it was assumed that the cooling water for the chiller could be held at constant temperature (25°C for Winterthur), using a cooling tower. Details of the main components of the system are as described below:

The total surface area of the solar louvre collector considered for simulation (7 rows of 30 louvres) is 56.7 m². The collectors are simulated using TRNSYS-type 1b, and the collector efficiency curve given in equation (2).

Table2: Cases used in simulation

Louvre number	Window Type	Window Size
7	$k = 2.8 \text{ W/m}^2 \cdot ^\circ\text{K}$, $g' = 0.75$ (old)	78 m^2
7	$k = 1.1 \text{ W/m}^2 \cdot ^\circ\text{K}$, $g' = 0.60$ (new)	78 m^2
7	$k = 2.8 \text{ W/m}^2 \cdot ^\circ\text{K}$, $g' = 0.75$ (old)	109 m^2
7	$k = 1.1 \text{ W/m}^2 \cdot ^\circ\text{K}$, $g' = 0.60$ (new)	109 m^2
5	$k = 2.8 \text{ W/m}^2 \cdot ^\circ\text{K}$, $g' = 0.75$ (old)	78 m^2

The chiller used in this simulation (NAK) is manufactured by GBU GmbH [5].

The solar collector is connected to a stratified fluid storage tank (TRNSYS-type 4b, water storage medium of volume 1000l and height 2.4m), located inside the building. The tank heat loss coefficient is estimated at $0.2 \text{ kJ/h m}^2 \cdot ^\circ\text{K}$. For simplification, only one storage tank is assumed for both direct solar heating and solar cooling (heat supply to the adsorption chiller).

The fluid flow rate between collector and tank is assumed constant at 4082 kg/h , and is controlled by a differential controller, with a dead-band temperature difference of 2°C . Heat losses from water pipes are neglected.

Solar heating was simulated assuming that the thermal energy given by the temperature difference between the water temperatures inside the tank (temperature to heat source) and the room temperature can be used for heating. The return flow temperature is set to be equal to the room temperature, which, for example, can be maintained by the floor heating system. The heating is controlled by the mass flow rate of the hot water into the heating units in the office floor, with an upper-limit of 1000 kg/h .

NAK closed cycle chillers have low operating temperatures, starting at approximately 55°C . The temperature of the chilled water was set at 8°C . Using the collector working fluid; the upper temperature is limited to 100°C .

A closed cycle efficiency curve based on the operating temperature (tank temperature to the heat source) is used. A constant cooling temperature of 25°C was assumed (lower cooling temperatures will improve the performance of the system).

The coefficient of performance COP is calculated using the fluid temperature $T_{hot/top}$ of the heat source

at the op of the hot water tank. Following the data catalogue from GBU GmbH [5], the COP is given by:

$$COP = 0.02 T_{hot/top} - 0.45 \quad (3)$$

For temperature range $55^\circ\text{C} < T_{hot/top} < 85^\circ\text{C}$, value of COP in equation (3) varies between 0.56 and 0.62.

A stratified fluid storage tank (TRNSYS-type 4b, water storage medium of volume 2500 l, height 1.8 m and tank loss coefficient of $0.2 \text{ kJ/hm}^2 \cdot ^\circ\text{K}$) was used for the cold water, and is located inside the building. The fluid temperatures at the top and bottom of the tank are $T_{cold/top}$ and $T_{cold/bottom}$ respectively.

The return flow temperature T_{back} to the tank is set at 12°C below $T_{hot/top}$, and according to the manufacturer data, the maximum temperature differences should not exceed 13°C . The fluid flow rate between chiller and hot water tank is assumed as $\dot{m}_{hot} = 1720 \text{ kg/h}$. At this flow rate, a refrigeration capacity of approximately 12 kW could be produced, depending on the actual COP -value. The refrigeration capacity is big enough to cover maximum demands for this floor in conjunction with the coldwater storage tank.

Regulation is controlled by the hot water tank temperature (activated only for temperature above 55°C) and by the coldwater tank temperature (activated, if the tank temperature at the top is above 12°C).

The fluid flow rate $\dot{m}_{cold} \text{ kg/h}$ between the chiller and the cold-water tank is calculated using the definition of COP (neglecting heat capacity variations), by:

$$\dot{m}_{cold} = \dot{m}_{hot} COP \frac{T_{hot/top} - T_{back}}{T_{cold/top} - 8^\circ\text{C}} \quad (4)$$

The cold-water flow rate given by equation (4) is limited to a maximum flow rate of 2500 kg/h . The cooling inside the office floor is simulated by taking water from the bottom of the coldwater storage tank. The return flow temperature is set to be equal to the room temperature, which could be maintained by the cooled ceiling. The mass flow rate to the cooling units/slaps in the office is 1000 kg/hr and the flow is activated during the periods of cooling process, and/or as long as the temperature inside the coldwater storage tank is below room temperature.

The indoor ventilation is based on the ASHRAE 62-1989, "Ventilation for acceptable Indoor Air Quality", which is estimated at $20 \text{ cubic foot per minute per person}$ (i.e. $33.98 \text{ m}^3/\text{hour/person}$).

3. MODELLING VERIFICATION

The annual energy consumption values for the office floor are shown in Figure 2, for the 4 cases with 7 rows of solar louvres. The window size and the terms "old" for the existing window type and "new" for the new window type are shown. The predicted results for the energy demand for heating and cooling, based on measurements (rhombus plotting mark), simulation results (triangle plotting mark) for the existing building situation, and simulation results for the 4 different situations are also shown. Percentage values show, for each calculation, the contribution of the solar energy to the specific energy demand.

Results of simulation for the existing building without solar louvres match quite well the known (measured) total building energy demand. This is an indication that results of the simulation are reasonable accurate.

4. RESULTS & DISCUSSIONS

Results presented in this paper are only representative graphs to show the difference that solar louvre collectors could make to the building heating and cooling energy demands. The annual heating and cooling demands results presented in Figure 2, show that aperture sizes and type of glazing has a significant effect on the total energy demand - more profound for glazing.

The results also show that, the total heating and cooling energy demands are lower for the new window type compared to the existing situation.

Energy balance of the system in comparison to the building heating and cooling energy demands for a period of one week in October is presented in Figure 3. This chosen week depicts both the need for heating and cooling, and would reflect the general pattern of the system energy balance.

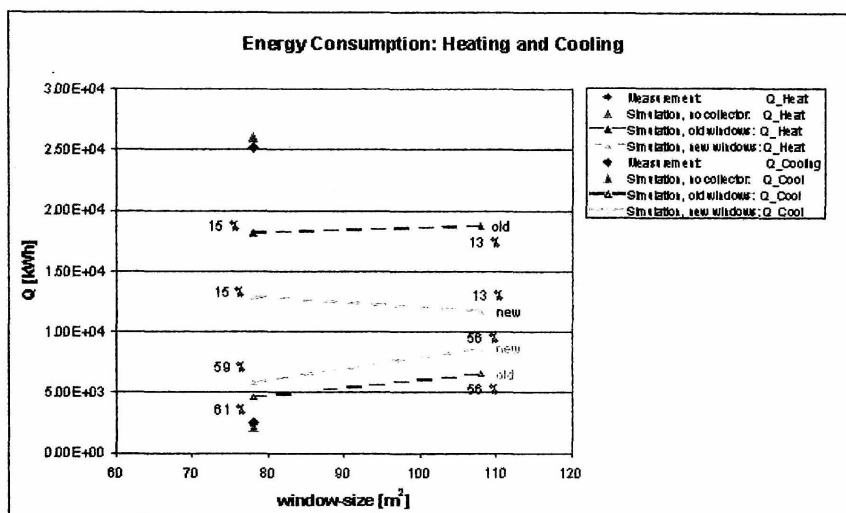


Figure 2: Comparison of simulation and measurement results of the annual heating and cooling demands for the existing building case and for the 4 cases with 7 rows of solar louvre collectors.

The temperature of the hot water storage tank was maintained above 60 °C most of the week. It worth noting that, cooling was required only during days with high solar radiation level, namely, 16th, 20th and 21st of October (See Figure 3). On the 16th of October the collector outlet temperature as well as the storage tank temperature were relatively low, (in vicinity of 60 °C), and so the cooling system was not able to provide the cooling load. The offices room

temperature was maintained steadily throughout the week at about 10 °C above the ambient temperature, regardless of the variation in solar radiation level (See Figure 5).

The maximum value of COP achieved by the system is 0.3, corresponding to storage tank temperature of 65°C and collector outlet temperature of approximately 75 °C (Figure 5).

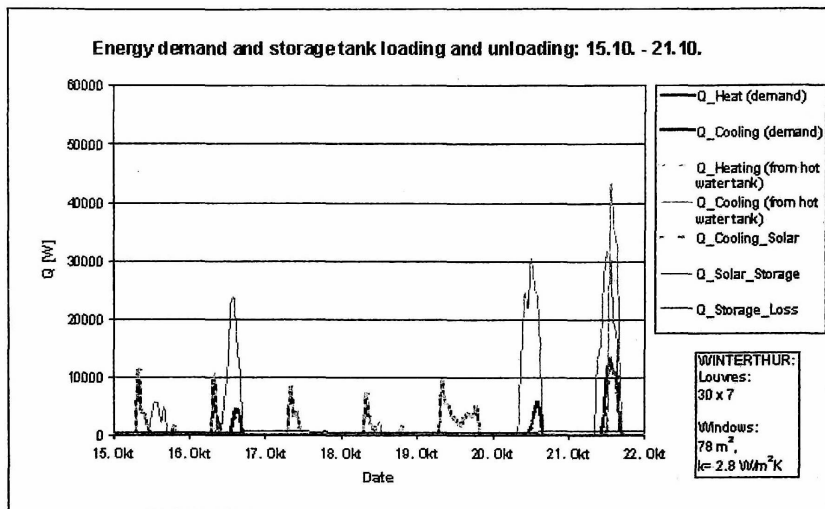


Figure 3: Daily variation of the system energy balance.

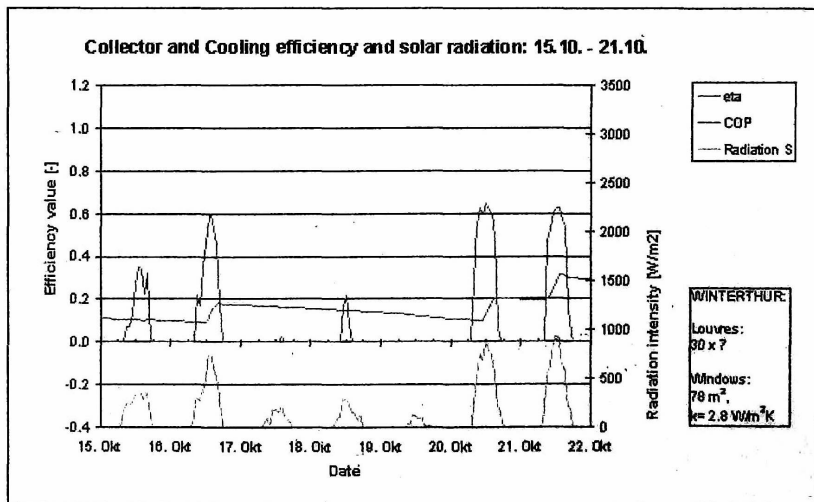


Figure 4: Daily variation of the collector efficiency, coefficient of performance of the cooling system and the solar radiation in the plane of the collector

It can be seen that, during this week of October, the system was able to provide all the heating demand of the building, and part of the cooling load. In one

occasion the system was able to meet the cooling load as well, i.e., on October 21st, when there was sufficient solar radiation (See Figure 4).

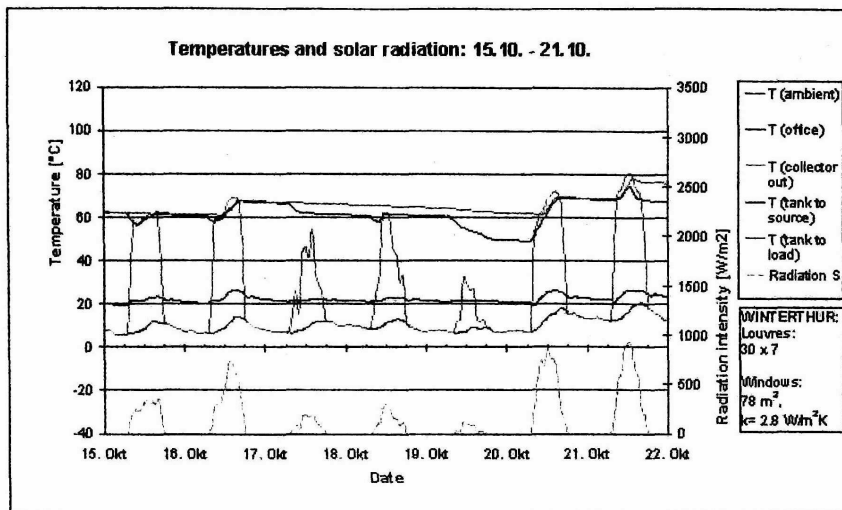


Figure 5: Daily variation of temperatures of the different components of the system and the solar radiation in the plane of the collector

5. CONCLUSION & RECOMMENDATIONS

In addition to the fact that shading louvres are able to reduce cooling load of some buildings during hot summer months, this study concludes that, further benefits could be realised by utilising the extended surface area of the louvres for useful solar energy collection. The solar energy collected from these louvres can be used directly to supply building heat load, during cold winter months, as well as powering cooling system, e.g., absorption/adsorption chillers. Results of the simulation have shown, solar louvre collectors are able to provide a significant proportional of the building energy load (heating and cooling), even at very low solar radiation level conditions.

Although, the simulation was performed for a given louvre design, other design considerations (optimise louvre design, louvre tilt angle and using diverse tank sizes, tank insulations, flow rates and input temperatures control) are possible to optimise and improve the performance of the louvre collector as well the whole system.

Results of the simulations indicate that for the given building, by optimising the collector size and efficiency, more than 15% of the heating demand,

and more than 60% of the cooling demand could be met by solar energy, provided that a super-insulated storage tank is used for the solar cooling sub-process. In practise, the percentage of covering the energy demands by solar energy will be more a question of cost rather than a question of scientific or physical limitations.

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