EXPLOITATION OF SOLAR GREENHOUSE IN VENTILATION SYSTEM OF BUILDING

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ABSTRACT

The paper deals with on-site measurements of energy benefits resulting from exploitation of a solar greenhouse, which was created in the attic under the southward-oriented glazed roof for pre-heating of the ventilating air. This conception of the solar energy utilisation is used in the residential complex of the senior citizen home in Svitavy, 60 km north of Brno. Based on the data collected with the use of an automation monitoring system during the heating season 2001–2002, the main characteristics of the investigated solar greenhouse operation were established. The maximum temperatures exceed 20°C on sunny winter days, with temperature difference between outdoor and inner temperature approx. 25 K, and so the preheated air can be used directly for warm-air heating. Resulting benefits are dependent on the time and way of operation. Nevertheless, experience of other similar applications (e.g. solar energy facades, see Jaros et al., 2004) shows, that the annual energy savings up to 10 % of the total heat consumption of the building can be reached this way.

KEYWORDS

solar energy, building ventilation, energy savings

INTRODUCTION

Low energy consumption is one of the major objectives of new projects as well as of retrofitting of the existing buildings. In situation, when thermal losses of well-insulated buildings are quite low, the energy consumption of ventilation starts to play an important role. Among other possibilities, the utilisation of solar energy can be used for its decreasing.

Solar greenhouses represent one of the low-cost options of solar energy utilisation, which can be used both in newly built as well as in retrofitted buildings. Collected heat can be employed in different ways. The proposed paper deals with the exploitation of a solar greenhouse for pre-heating of ventilating air, which is sucked into the ventilation system of a building.

DESCRIPTION OF THE BUILDING

This conception of the solar energy utilisation is used in the residential complex of the senior citizen home in Svitavy, 60 km north of Brno (Fig.1). The complex consists of five apartment buildings with 115 apartments. Wide exploitation of principles of a “solar architecture” in the design resulted in a considerable decrease in the energy consumption. Moreover, two active solar systems, which exploit the solar energy collected in the solar greenhouse, were used here. Besides the above-mentioned pre-heating of ventilating air used in three smaller

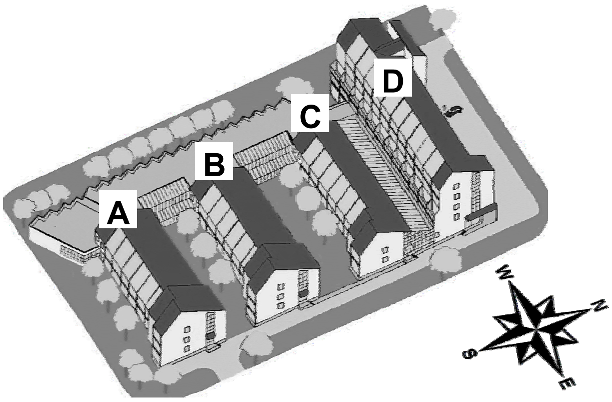

Figure 1. Schematic view of the residential complex in Svitavy.

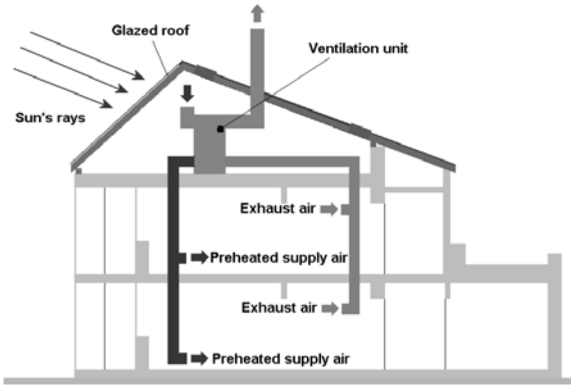

Figure 2. Scheme of ventilating system in buildings "A", "B", "C".

buildings (in Fig.1 labeled "A", "B", "C"), the solar greenhouse acts as a heat source for air-water heat pumps used for hot water preparing in main building of the complex (labeled "D").

The solar greenhouses were created in attics under the southward-oriented glazed roofs. Floors of the attics are covered with concrete blocks in order to ensure better heat storage. Outdoor air enters the attics through the slots located on the bottom side of the roofs. Preheated air is supplied to the rooms through the ventilation system with heat recovery (Fig.2). In summer season, the ventilation system is set on a suction of cold outdoor air.

Our investigations were carried out with the aim to establish the thermal conditions in the solar greenhouse under different weather circumstances and estimate the energy savings resulting from its exploitation. For this purpose, a data acquisition system has been installed in the attic of the southern building ("A"). A hot wire anemometer was used to measure the air temperature and velocity in the ventilation system inlet. Thermocouples were used for measuring the temperature of the air and the surrounding surfaces (roof, floor, glazing). Weather conditions, like air temperature, wind speed and direction, as well as solar irradiation, were also monitored. The location of the sensors is shown in Fig.3. The data were stored with the time step of one minute.

EVALUATION OF MEASURED DATA

Based on the data collected during the heating season 2001–2002, the main characteristics of the investigated solar greenhouse operation were established. Because the temperature conditions in the solar greenhouse depend particularly on the solar radiation intensity (SRI), the evaluated days have been sorted out according to the prevailing type of the solar radiation (direct or diffusive) into three categories: sunny, somewhat cloudy, and cloudy days (Fig.4).

Temperature Conditions in the Solar Greenhouse

As far as the energy savings are concerned, the conditions in winter and transitional seasons (spring, autumn), when the preheated air is sucked, are crucial. As it can be seen from Fig.5, the maximum air temperatures in the greenhouse exceed 20 °C on sunny winter days, with temperature difference between outdoor and inner temperature approx. 25 K. On sunny days in spring and autumn, the temperatures are still higher. In such a situation, the preheated air can be used directly for warm-air heating. On the other hand, the average temperature difference between outdoor and inner temperature is only 5–7 K on cloudy days (Fig.6).

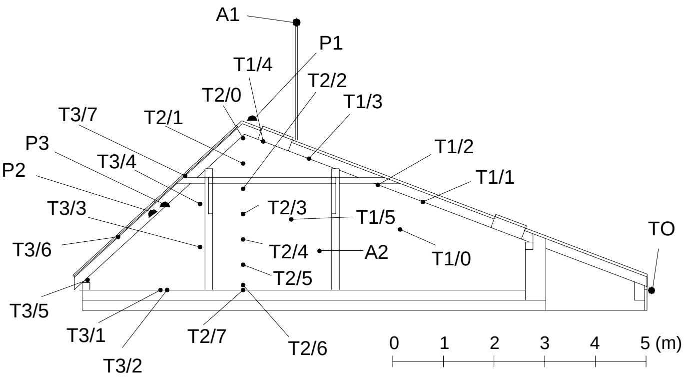

Figure 3. Location of sensors in the solar greenhouse.

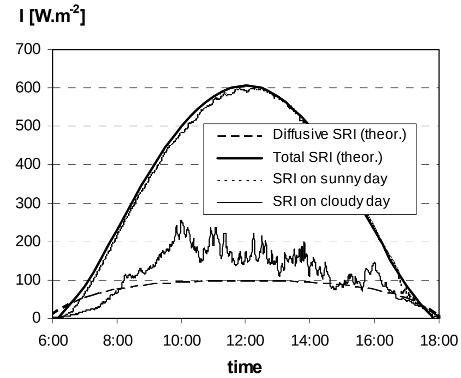

Figure 4. SRI on sunny and cloudy day (March 14 and 25, 2002).

The temperature field in the greenhouse is not homogeneous – temperature stratification (i.e. increasing of the temperature along the height of the greenhouse) arises in most cases (see Fig.7). Temperature differences in the space depend again on the solar radiation intensity, and so they reach 5–6 K on sunny days (this result is in good agreement with the outcomes of the numerical modeling, see Charvat et al., 2001), while in cloudy days and at night only 1–2 K, respectively. Considerable decrease in the inner air temperatures is evident after turning on the ventilation (Fig.5, 7). This is caused by a penetration of cold outdoor air into the attic, which was also forecast by numerical models (Jaros et al., 2002).

Assessment of Energy Savings

The energy savings resulting from the exploitation of the solar greenhouse were considered as a heat that would be necessary for heating of the air from the outdoor temperature to the temperature in the ventilation inlet:

$$Q = \dot{m} \cdot c_p \cdot (t_i - t_o) \cdot \tau = \dot{V} \cdot \rho \cdot c_p \cdot (t_i - t_o) \cdot \tau \qquad (1)$$

where $\dot{m}$, $\dot{V}$ – mass and volumetric flow rate of air, t_i, t_o – air temperature in the ventilation inlet and outdoor temperature, c_p, ρ – specific heat and density of air, τ – time of operation.

Fig.7 shows that the air temperature in the inlet duct, when the ventilation is off, is higher than in the attic. After the ventilation is turned on, the sucked air reaches the same temperature as the surrounding air in the corresponding height (250 cm). Next decreasing of both temperatures is caused by suction of cold outdoor air into the attic (as mentioned above).

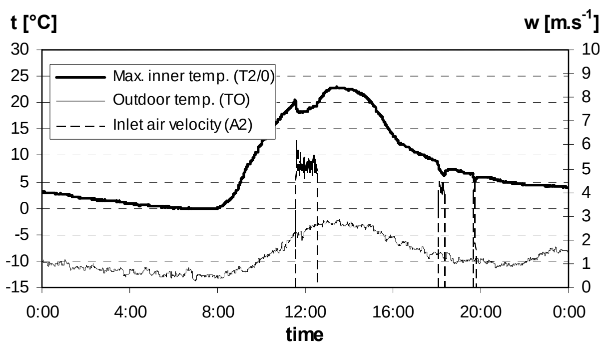

Figure 5. Air temperatures in the solar greenhouse on sunny winter day (December 9, 2001).

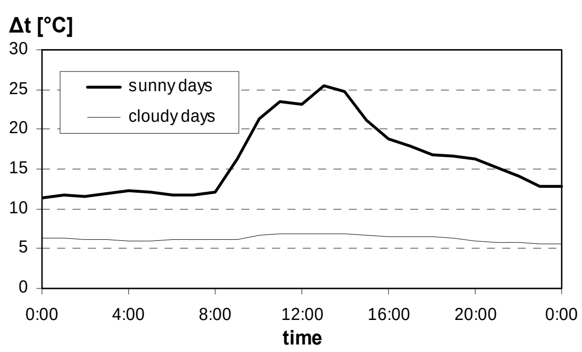

Figure 6. Average difference between outdoor and maximum inner temperature in winter days.

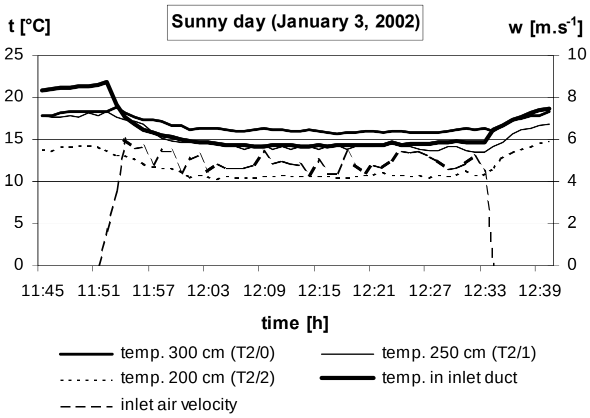

Figure 7. Air temperatures in the inlet duct and its surroundings on sunny winter day.

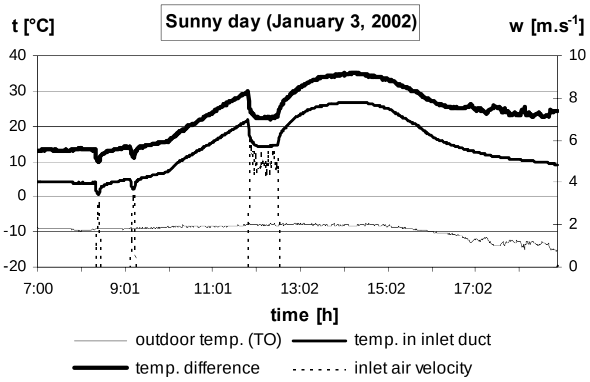

Figure 8. Day course of air temperatures in the ventilation system on sunny winter day.

The temperature difference $t_i - t_o$, which is crucial for the amount of energy savings (see Eqn.1), therefore decreases too, but it is still high enough on sunny days (Fig.8).

The assessment of the energy savings is complicated by the fact that the time of operation, which substantially affects the savings, was not the same every day. Typically, the ventilation is turned on centrally twice for half an hour during sunny days, but only for a short time (or not at all) on cloudy winter days.

The evaluation of the annual energy savings was based on the assumption that January is the coldest month, while February vs. December and March vs. November have approximately the same temperatures. Therefore, the day values of the energy savings in the characteristic days of these three periods (always three days with sunny, somewhat cloudy and cloudy weather) were evaluated according to Eqn.1. Next, one-minute values of the energy savings, which are more convenient for the comparison of particular types of the day (they are not dependent on the time of operation), were determined (Tab.1). Monthly energy savings were then estimated from the average day values of the energy savings and the number of days with a certain type of weather in the given month (Tab.2).

TABLE 1
One-minute energy savings in characteristic days during heating season 2001–2002

Sunny days					
Date	q [kJ.min^{-1}]	Date	q [kJ.min^{-1}]	Date	q [kJ.min^{-1}]
3.1.2002	833,88	3.2.2002	480,5	6.3.2002	655,77
23.1.2002	489,94	15.2.2002	844,45	9.3.2002	506,34
29.1.2002	293,13	19.2.2002	693,71	11.3.2002	549,09
Mean value	538,98	Mean value	672,89	Mean value	570,40
Somewhat-cloudy days					
2.1.2002	114,64	1.2.2002	390,25	3.3.2002	576,79
20.1.2002	177,15	14.2.2002	772,19	7.3.2002	250,42
25.1.2002	247,33	28.2.2002	382,67	10.3.2002	401,49
Mean value	179,71	Mean value	515,04	Mean value	409,57
Cloudy days					
1.1.2002	31,15	7.2.2002	210,58	2.3.2002	246,02
9.1.2002	279,87	13.2.2002	179,36	22.11.2001	114,17
24.1.2002	105,95	25.2.2002	145,15	29.11.2001	189,18
Mean value	138,99	Mean value	178,36	Mean value	183,12

TABLE 2
Assessment of energy savings resulting from the solar greenhouse exploitation in heating season 2001–2002

Month	**Clear days**		**Somewhat cloudy days**		**Cloudy days**		**Monthly savings**
	#	Ø *ΔQ* [MJ]	#	Ø *ΔQ* [MJ]	#	Ø *ΔQ* [MJ]	*ΔQ* [MJ]
11/01	1	60,23	4	45,01	25	10,35	499,0
12/01	6	41,37	6	5,46	19	1,63	312,0
1/02	4	41,37	6	5,46	21	1,63	232,5
2/02	6	69,54	12	49,18	10	8,37	1091,1
3/02	13	60,23	11	45,01	7	10,35	1350,6
Total	30	–	39	–	82	–	3485,2

CONCLUSION

The obtained outcomes reveal that the solar greenhouse represents a possibility of exploiting the solar energy for the energy savings in ventilation, which can be applied in newly built as well as in retrofitted buildings. Resulting benefits naturally depend on the time and way of operation. Nevertheless, experience of other similar applications (e.g. solar energy facades, see Jaros et al., 2004) shows that the annual energy savings up to 10 % of total heat consumption of the building can be reached this way.

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