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PARAMETRIC ANALYSIS OF SOLAR COMBISYSTEMS WITH FACADE COLLECTORS IN LARGE RESIDENTIAL BUILDINGS

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ABSTRACT

A solar combisystem for domestic hot water production and space heating with solar collectors directly integrated into the facade was investigated through parametric analysis for a block of flats. The residential buildings were considered in three variants with different energy performance levels: old structure building (represented by the envelope thermal resistance $R = 1$ m²K/W), present thermal quality of constructions (represented with *U*-values required by legislation) and level expected for future (*U*-values recommended by legislation, heat recovery of ventilation).

For the analysis, the reference flat of the residential building was modeled in TRNSYS with climate database for Prague (TMY). Influence of solar collector area to achieved solar fraction (savings factor) was investigated in all residential building variants. The impact of solar collector coverage of the envelope on indoor environment (winter heat gains, summer cooling loads) was analyzed.

Keywords: facade collectors, building integration, solar combisystem

INTRODUCTION

The energy consumption for space heating in the European Union represents 57 % in the residential sector where one of the most effective savings can be achieved by insulation improvements of the building envelope [1]. Following the trend towards low energy buildings means improving the thermal heat resistance of the building envelope and providing the remaining energy demand with renewable energy. The use of solar thermal collectors for domestic hot water production and space heating is one possibility which is also promoted by the European strategy. Moreover, the strategy aims towards the 'Solar Active House' (heating and cooling demand is covered to 100 % by solar thermal energy) where high potentials for solar combisystems (domestic hot water production and space heating) are offered to meet this demand [2]. To cover such a high energy demand large collector areas are needed where collector integration into the building envelope provides not only available area but also technical advantages (lower heat loss of collectors, passive heat gains in winter) and new aesthetical and architectural possibilities. Integration of solar collectors into the building envelope represents a transition from the concept of envelope considered as heat loss to an advanced multifunctional envelope being both, building construction and source of renewable heat (energy active envelope) at the same time. Constructional building integration of solar collectors, meaning replacing the building envelope construction by the solar collector, seems to be a challenging issue but crucible for future developments and the spreading of solar technologies.

In preceding studies [3-6] solar DHW systems and combisystems with envelope integrated flat-plate collectors have been investigated from the point of system performance (solar gains, solar fraction, stagnation level) and building behavior (winter heat gains, summer loads). Extensive parametric simulation analysis of solar combisystems presented in the paper has been performed to take solar flat-plate collectors with integration into facades with different grade of characteristic insulation level into consideration.

MODEL DESCRIPTION

Parametric analysis has targeted the energetic behavior of solar combisystems for domestic hot water and space heating in a residential building with standard atmospheric flat-plate collectors directly integrated (no air gap) into the facade.

The analysis for the solar collector considers three different levels of insulation (thermal heat resistance of 1 m²K/W, 3 m²K/W and 6 m²K/W). The efficiency curves obtained from the mathematical model KOLEKTOR 2.2 [7] are used as input for parametric studies with the Transient System Simulation Program (TRNSYS) [8].

In TRNSYS studio, the solar system model is built and connected with the multizone building model (thermal interconnection between the collector and building envelope; *Fig. 1*). The solar combisystem for domestic hot water production and heating of the building is modeled for a flat in a block of flats (BF), distinguished through the energy performance level defined by characteristic envelope insulation level ($R = 1$ m²K/W, insulation level of old structure building in Czech Republic; $R = 3$ m²K/W, present thermal quality of construction and $R = 6$ m²K/W, recommenced level of insulation for buildings in the Czech Republic).

For parametric analyses, the solar collector area A_C to the building envelope area A_e is varied from 1 to 100 % of envelope coverage (collector envelope ratio).

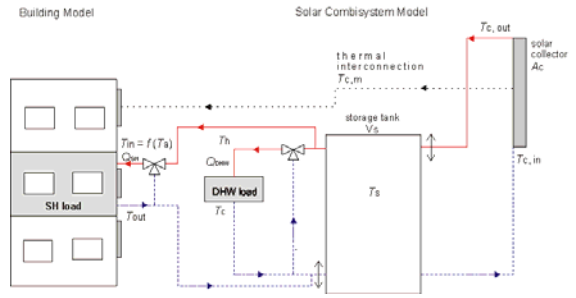

Fig. 1 – Solar combisystem model layout (DHW circuit and space heating circuit) with thermal interconnection between the solar collector and building envelope

The solar combisystem model is based on compact integrated central heat storage tank ($V_s = 500$ l) with ideal stratification (variable inlets) with two heating circuits (DHW and space heating). Two auxiliary heaters are applied; one as output for the DHW load ($Q_{a\text{-DHW}}$) and the second auxiliary heater for the space heating load ($Q_{a\text{-SH}}$). Simulations are carried out for a heating system with typical nominal operation temperature of 55/45 °C and heating exponent n = 1.3 (radiator); supply temperature control is provided according to the ambient temperature t_a (equithermal control).

Simulations were carried out for a typical meteorological year (TMY) in Prague, Czech Republic. An overview about the main parameters is given in *Tab.1*.

Tab. 1 – Main parameters of the simulation model

V_s [l]	500		
A_C [m²]	1 to 20		
Q_{DHW} [l/day]	120		
Space heating	55/45°C, n=1.3, equitherm. control		
Heated floor area [m²]	80		
	R1	*R3*	*R6*
Heat resistance of building envelope [m²K/W]	1	3	6
Space heating demand Q_{SH} [kWh/m²a]	85.2	47.2	8.2
Space cooling demand Q_{SC} [kWh/m²a]	4.6	8.0	26.2

Principal observed parameters for the building performance were winter heat gains Δq_{sh} and summer cooling loads Δq_{sc} induced by collectors integrated into the envelope. For the solar system performance, solar fraction f and specific stagnation time b_{st} have been evaluated.

RESULTS

Solar combisystem performance

Computer simulation analyses for a solar combisystem with atmospheric flat-plate collectors integrated into the façade of a block of flats distinguished through the energy performance level of the building have been performed. *Fig. 2* shows the performance characteristics of the investigated solar combisystem expressed by means of system solar fraction f and specific stagnation time b_{st} dependent on collector area A_c as variable parameter.

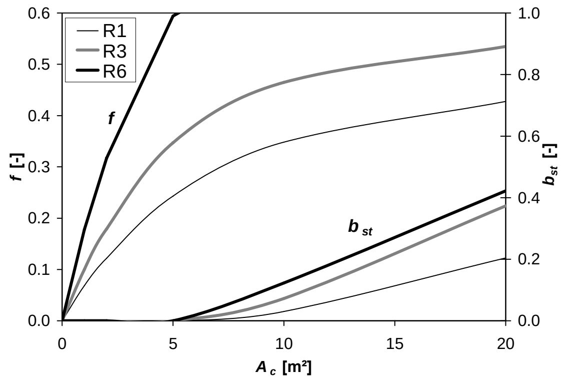

Fig. 2 – Solar combisystem performance characteristics with integration into the facade of three different types of insulation levels

As illustrated in figure 3 the performance of the solar combisystem (solar fraction f) generally increases with the increase of thermal resistance of the building envelope due to decrease of collector losses on the back side and therefore achieving higher collector efficiency. To achieve the same solar fraction with less insulation (low heat resistance of building envelope) the collector area has to be increased but thus again is coupled with increase in stagnation time due to an unutilizable summer irradiation peak. However, considering typical design parameters where a solar fraction f of 0.3 should be achieved not stagnation problems occur in the case of the building with recommended level of insulation ($R = 6$ m²K/W) and the building with present thermal quality of construction ($R = 3$ m²K/W).

Impact on building performance

The influence of building integrated solar collectors on indoor environment and building performance has been evaluated. Specific winter heat gains and summer cooling loads have been obtained from annual space heating demand $Q_{SH,Ac}$ and space cooling demand $Q_{SC,Ac}$ of the investigated building with envelope direct integrated collectors compared to the reference case without collector integration ($Q_{SH,ref}$, $Q_{SC,ref}$):

$$\Delta q_{sh} = \frac{Q_{SH,ref} - Q_{SH,A_C}}{A_C} \left[\frac{kWh}{m^2}\right] \qquad (1)$$

The characteristics of specific heat gains Δq_{sh} and cooling loads Δq_{sc} are plotted in dependence on collector-facade coverage area ratio A_C/A_e for atmospheric solar collectors integrated into building envelope (façade) with different energy performance level of the building (*Fig. 3* and *Fig. 4*).

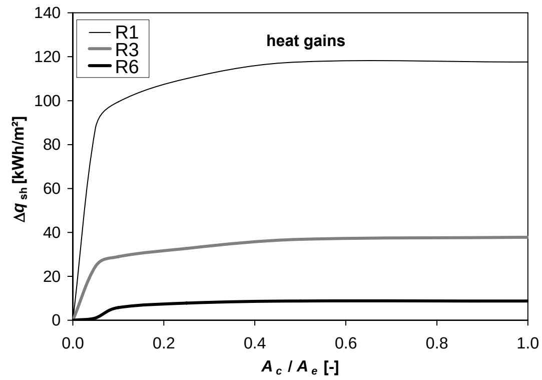

Fig. 3 – Collector induced specific heat gains to building due to integration of atmospheric collectors into facade of different building structures distinguished through the heat resistance of the building envelope (R1, R3, R6)

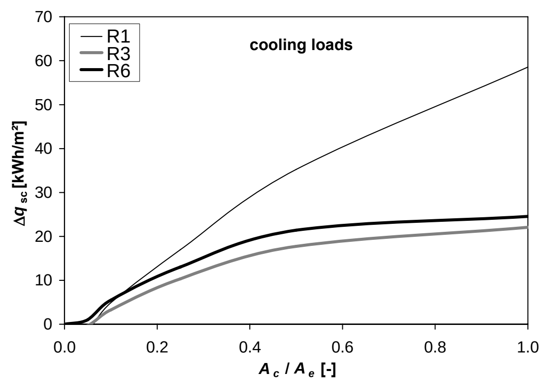

Fig. 4 – Collector induced specific cooling loads to building due to integration of atmospheric collectors into facade of different building structures distinguished through the heat resistance of the building envelope (R1, R3, R6)

Heat gains from the collectors integrated into the façade achieve during the heating season, depending on the level of insulation, between 4 to 8 % of the heating demand for a façade coverage factor of 0.25 (A_C = 5 m²). During the summer period the impact of the collector to the building environment in general is lower than during winter. Covering ¼ of the façade with collectors results in collector induced specific heat gains of up to 110 kWh/m² for the poorest insulation level and a collector induced specific cooling load of 17 kWh/m² (for R1) during summer. To make the influences of solar collectors integrated into facades with different insulation levels more clear, *Fig. 5* and *Fig. 6* illustrate specific heat gains and cooling loads for a given solar fraction of $f = 0.3$. Integrating a solar collector into a façade with good thermal resistance (here R = 6 W/m²K) leads to a large improvement of the collector performance, hence, smaller collector area is needed to achieve the same solar fraction than with collectors integrated into a poorly insulated façade (R = 6 W/m²K).

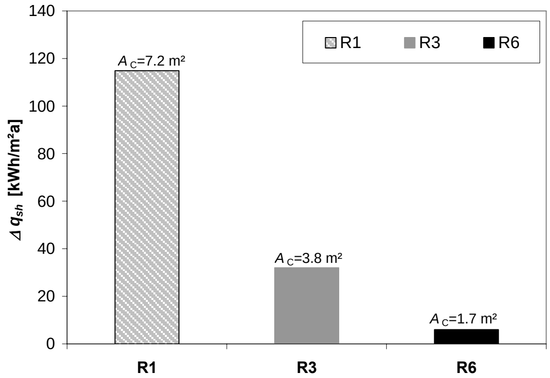

Fig. 5 – Collector induced specific heat gains to building due to facade integration for a given solar fraction (f = 0.3) and required collector area Ac to achieve this fraction

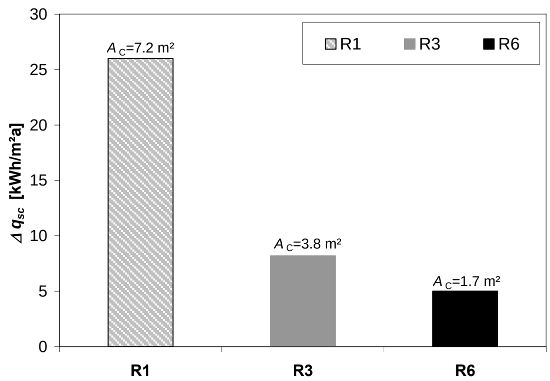

Fig. 6 – Collector induced specific heat gains to building due to facade integration for a given solar fraction (f = 0.3) and required collector area Ac to achieve this fraction

DISCUSSION

Parametric simulation analyses of a solar combisystem for domestic hot water production and space heating of a flat in a block of flats equipped with atmospheric solar flat-plate collectors integrated into the façade has been performed. Different residential buildings distinguished through their energy performance level (old structure building, R = 1 m²K/W; present thermal quality of constructions, R = 3 m²K/W and level expected for future, R = 6 m²K/W) were considered. Through variation of the collector area the impact of collector integration on the indoor environment (winter heat gains, summer cooling loads) was analyzed.

Direct integration of solar collectors thermally coupled to a well insulated façade in higher performance compared to façade collectors integrated into a façade with low thermal resistance. Due to the vertical position of the collector stagnation risks are reduced to a minimum and occur only for large collector areas. Integration into facades with recommended insulation levels reduces the collector area significantly compared to integration into old constructions, e.g. achieving a solar fraction of 0.3 requires only ¼ collector area for the façade with a thermal heat resistance of $R = 6$ W/m²K compared to integration into $R1$.

The influence of building integrated solar collectors on the indoor environment and building performance has been evaluated by means of specific heat gains in winter and cooling loads in summer both induced by heat flow from solar collectors into the building interior. The simulations make clear that high insulation levels of building envelopes serve as thermal protection; hence, the influence of solar thermal collector integration into the building envelope does not bring large problems for summer overheating even for total façade coverage and brings very low heat gains in winter.

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ABBREVATIONS

A_C solar collector area [m²]
b_{st} specific stagnation time [-]
f solar fraction [-]
Q_{SC} space cooling demand [kWh/a]
Q_{SH} space heating demand [kWh/a]
R Heat resistance of building envelope [m²K/W]
V_S storage tank volume [l]
Δq_{sc} specific cooling loads [kWh/m²]
Δq_{sh} specific heat gains [kWh/m²]