SOLAR COMBISYSTEMS WITH BUILDING-INTEGRATED EVACUATED FLAT-PLATE COLLECTORS

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ABSTRACT

Solar combisystems with building-integrated atmospheric and subatmospheric (evacuated) solar collectors have been investigated. Standard efficiency curves for investigated solar collectors were derived from software tool KOLEKTOR 2.2 for flat-plate collector heat transfer calculations. Combisystems performance characteristics (solar fraction, specific stagnation time) and influence on building indoor environment (winter heat gains, summer heat loads) are analysed through TRNSYS simulations. Three types of solar collectors (atmospheric, evacuated to 1 kPa, vacuum with 0.1 Pa) and three types of collector-building configuration (separate installation, roof integration, facade integration) were compared.

1. INTRODUCTION

Progressing tendency in low-energy and passive housing has increased the demand for solar combisystems for domestic hot water (DHW) and space heating (SH). These systems represent general effort to achieve higher solar coverage of energy supply in building sector but also meet the problems with frequent stagnation in summer season due to large collector area installed. Together with the low energy housing an interest for solar collector integration into building envelope had arisen to meet not only the technical advantages (lower heat loss of collectors, passive heat gains in winter) but even aesthetical and architectural demands. Moreover, the integration of solar collectors into building envelope instead of separate installation represents transition from the concept of envelope considered as a heat loss to envelope being a heat source (energy active envelope) which actually means a step further to solar energy active building defined in [1].
Solar DHW systems and combisystems with building-integrated spectrally selective atmospheric collectors were studied in detail from the point of system performance (solar gains, solar fraction, stagnation levels) and building behaviour (winter heat gains, summer overheating) in [2, 3]. Solar collectors with a low heat loss (high quality flat-plate or vacuum tube collectors) are often applied to combisystems due to higher temperatures in the solar combisystem storage tanks expected by designers. Since the vacuum tube collectors are not very feasible for envelope integration, the possibility for reduction of flat-plate collector front heat loss by evacuation or use of advanced materials (aerogel) is sought. Such low front heat loss collectors can be operated at elevated operation temperatures without considerable decrease in efficiency. Application of subatmospheric flat-plate collectors with moderate vacuum (less than 10 kPa, already available on the market for decades) or high vacuum (less than 1 Pa, not commercially available yet) for combisystems and their integration into building envelope is analysed in the paper.

2. EVACUATED FLAT-PLATE COLLECTORS

Application of single cover glazing to flat-plate atmospheric solar collectors results in relatively high heat loss through the front cover. The share of front heat loss for standard collector with spectrally selective absorber achieves approx. 65-80 % of total collector heat loss (for $t_m - t_a = 50$ K). Front heat loss coefficient U_f [W/m^2.K] is dependent on the heat transfer rate from absorber to inner surface of glazing (radiation, gas conduction and convection in the collector front air gap), heat transfer through glazing itself and heat transfer from outer surface of glazing to ambient environment (radiation, wind convection). While radiation heat transfer can be eliminated to minimum by means of high quality selective coatings, the convection and conduction heat transfer through the air gap is critical to front heat loss. There are several ways how to reduce the air convection and conduction heat transfer through the gap e.g. by means of multiple glazing layers, convection supressing devices or use of nanoporous materials (aerogels). However, all these variants cause a decrease of optical efficiency and their application is suitable rather to high-temperature process heat applications. An alternative to these measures is a sufficient decrease of pressure in the gap (evacuation), use of low conductivity gases (Kr, Ar) or a combination of both [4, 5]. In this paper we have studied only solar flat-plate collectors with front gap filled with air at atmospheric and subatmospheric pressures.

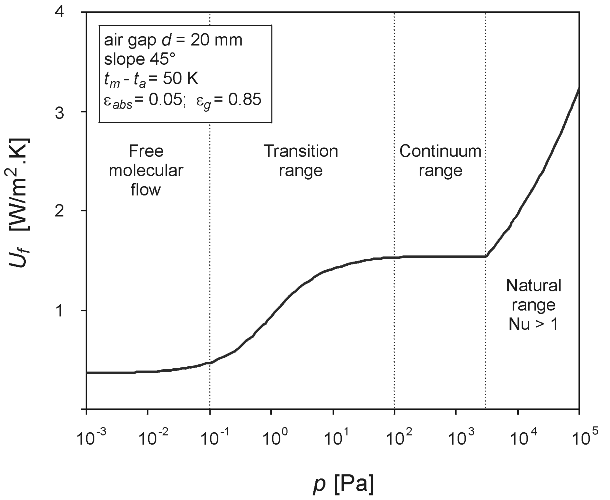

Fig. 1: Collector front heat loss coefficient U_f in dependence on pressure p in the air gap

The decrease of pressure in the air gap to values between 10^3 ad 10^4 (moderate vacuum) reduces the convective heat transfer to minimum (value of Nusselt number drops to 1), air heat conduction is unaffected by pressure and remains fully developed (see Fig. 1). Air can be treated as homogenous medium in continuum regime. Mean free path of molecules l_m = 0.8 to 8 μm is much shorter than characteristic size of the air gap (thickness d = 20 mm). Further decrease of pressure increases of l_m and molecules travel freely between the absorber surface and internal surface of glazing. In this transition regime, the number of air-air and air-surface collisions becomes equal which results in reduction of air heat conduction. Evacuation to pressure under 0.1 Pa (high vacuum) elongates the mean free path of the molecules to order of air gap thickness (l_m = 80 mm) and air molecules collide only with the boundary surfaces. Air occurs in free molecular flow regime and its thermal conductivity drops to zero and heat transfer between absorber and glazing is realised practically only by radiation. Although high vacuum technology is not easily feasible due to sealing problems, demanding pumping and valve technology and economic aspects and there is no commercially available flat-plate solar collector utilizing the high vacuum technology on the market yet, we have used these collectors for comparison as extreme case for integration into envelope.

The performance of subatmospheric solar collectors has been analysed in the software tool KOLEKTOR 2.2 for heat transfer calculations for flat-plate collector geometries with respect to envelope integration. Original atmospheric FPC model [5] has been extended to subatmospheric conditions. Fig. 2 shows the standard efficiency curves for flat-plate collectors with different level of pressure inside the front air gap (A-atmospheric, E-evacuated to 1 kPa, V-vacuum with 0.1 Pa) and type of collector-envelope configuration (S-separate, R-roof integration, F-facade integration). The thermal resistance of the envelope was considered 6 m^2K/W. Efficiency curves for roof and facade integration differ in the case of atmospheric collectors due to convection heat transfer reduction with higher slope of air gap in contrast to evacuated and vacuum collectors which have the convection heat transfer in the air gap eliminated completely.

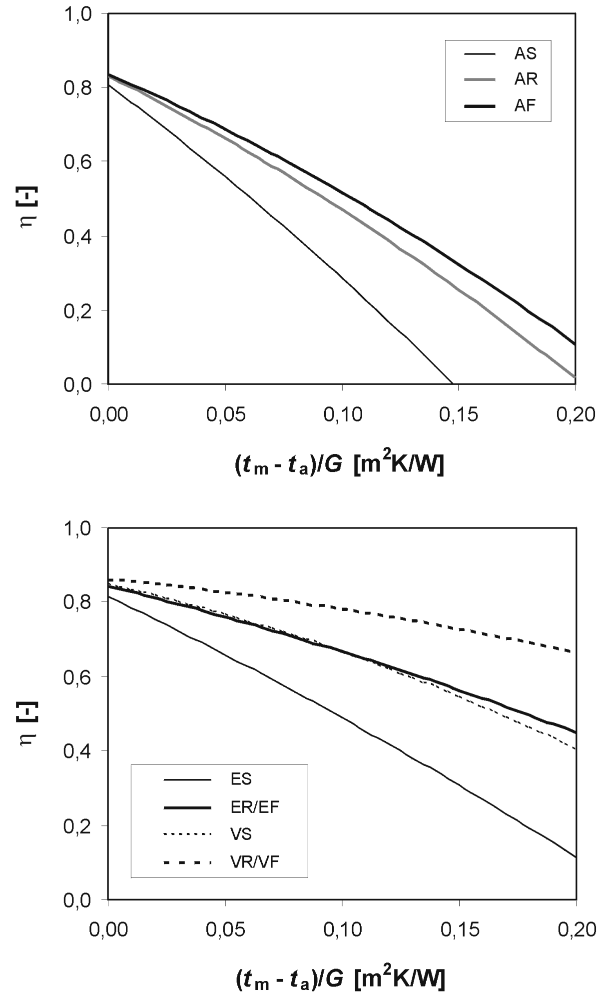

Fig. 2: Efficiency curves of investigated atmospheric (A), evacuated (E) and vacuum (V) flat-plate collectors

3. SOLAR COMBISYSTEM-BUILDING MODEL

Energetic behaviour of solar combisystems with envelope-integrated (roof, facade) solar collectors with different rate of front heat loss (atmospheric, subatmospheric) has been investigated through a computer simulation. Simulations were aimed to compare the performance of solar combisystems with presented types of collectors and to obtain information on the influence of collectors on building performance (winter gains and summer loads). Computer simulations were performed with Transient System Simulation Program (TRNSYS [4]). The simulation model is composed from solar combisystem model and multizone building model with thermal interconnection between collector and envelope as described in more detail in [2]. South roof and facade of the building have equal net area (42 m^2) and both are divided into two surfaces, one of the surfaces has been coupled to collector absorber (absorber temperature is identical with temperature of outer insulation layer). Splitting the envelope (roof, facade) into two surfaces allows varying the solar collector area A_c to envelope area A_e ratio (coverage factor) for parametric analysis.

Solar combisystem model is based on compact integrated central heat storage tank (1200 l) with ideal stratification (variable inlets) with two heating circuits (DHW and space heating). Two auxiliary heaters were applied, first to output for DHW load ($Q_{a\text{-}dhw}$) and second for space heating ($Q_{a\text{-}sh}$). Schematic diagram of the solar combisystem model is shown in Fig. 3. Nominal heating system temperature difference was set to 55/45 °C with supply temperature control according to ambient temperature t_a.

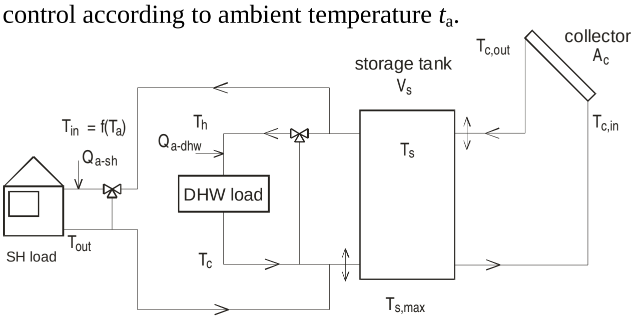

Fig. 3: Solar combisystem model layout

Considered building has a light-weight envelope based on mineral wool insulation with *U*-values typical for low-energy housing (R = 6 m^{2}K/W). The volume of the building is 550 m^3 and heated floor area is 150 m^2. The constant ventilation rate 0.3 ACH with heat recovery (75 %) has been considered in winter and without heat recovery in summer. Proper shading has been applied for summer to exclude the excessing heat load caused by windows. The base case of the building considers the separate installation of solar collectors and its annual heating demand Q_{sh} is 6880 kWh/a (45 kWh/m^2.a) while annual space cooling demand Q_{sc} is negligible (2 kWh/a). Daily average DHW load 200 l/day (heated from 12 °C to 55 °C) in the building results in annual DHW heating demand Q_{dhw} = 3710 kWh/a.

Principal observed parameters for the building performance were winter heat gains and summer heat loads caused by collector integrated into envelope. For the solar system performance, solar fraction *f* and specific stagnation time b_{st}.

4. RESULTS

Computer simulation analysis for solar combisystems with solar collectors with different rate of evacuation and different type of collector-building configuration has been performed and a number of result sets were obtained.

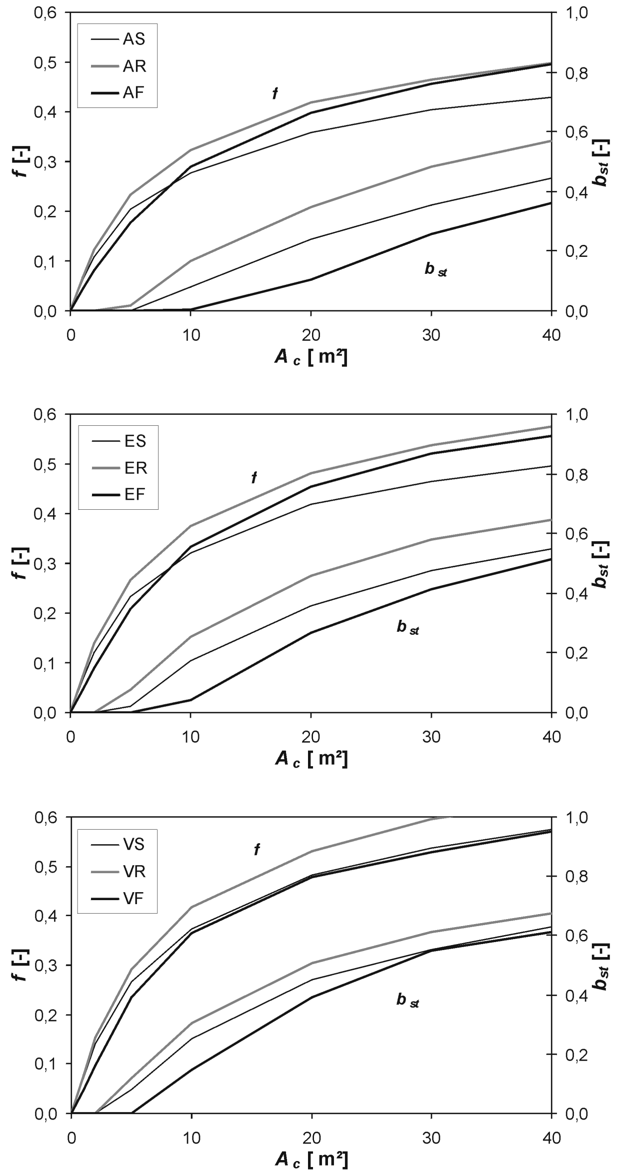

Fig. 4: Solar combisystem performance characteristics with different solar collector types and configurations

Fig. 4 shows the performance characteristics of solar combisystem for different design parameters (collector area A_c as variable parameter). The graphs are plotted in the same scale to easily compare the solar fraction *f* and specific stagnation time b_{st} for different collector types. Integration of all investigated solar collector types into building envelope (roof, facade) results in higher performance of solar combisystem (higher solar fraction) in the range of usual collector areas (> 8 m^2). In the case of facade integration with standard combisystem collector area 10 m^2, the stagnation conditions are completely eliminated for atmospheric and evacuated collectors and reduced to minimum values for vacuum collectors in comparison with roof integration or separate installation.
Low pressure in the collector air gap results in better performance of collector and whole combisystem. Evacuated collectors show about 5 % higher solar fraction, vacuum collectors about 10 % higher values (both facade and roof integration) at 10 m^2 of collector area in standard combisystem case compared to atmospheric collectors.

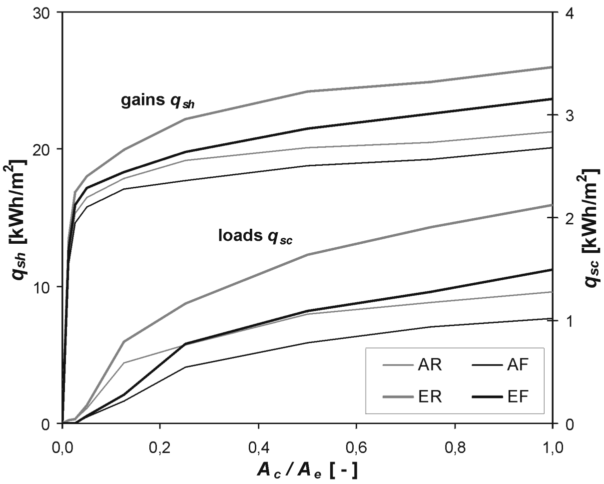

Fig. 5: Collector induced specific gains and loads to building due to integration

Influence of building-integrated solar collectors on indoor environment and building performance has been evaluated. Specific winter heat gains and summer heat loads were obtained from annual space heating demand Q_{sh} and space cooling demand Q_{sc} of integrated cases compared to base case and reduced by collector area A_c. The characteristics of specific gains and loads are plotted in dependence on collector-envelope (roof, facade) coverage area ratio A_c / A_e (see Fig. 5).
Due to high heat resistance of the envelope (low-energy house) the influence of solar collector integration does not bring large problems for summer overheating. In the most extreme case (vacuum roof integrated collector, 40 m^2), the heat load is less than 150 kWh/season. Heat gains from envelope integrated solar collectors to building during the heating season achieve about 3 to 4 % of heating demand for combisystem with 10 m^2 collector area (with no respect to type of collector integration and quality of collector) and 12 to 20 % of heating demand (proportionally from atmospheric to vacuum collectors) for extreme collector area 40 m^2.

5. CONCLUSION

Simulation analysis of flat-plate solar collector types with different rate of air gap evacuation (atmospheric, evacuated, vacuum) and collector-building configuration (separate installation, roof integration, facade integration) has proved the advantage of building integration of solar collectors in the case of solar combisystems for low-energy houses compared to separate instalations. Integration generally results in higher solar fractions achieved, integration into facade reduces stagnation periods to minimum. Use of evacuated and vacuum flat-plate solar collectors further increases the solar fraction of standard solar combisystems by 5 % and 10 % respectively.

6. ACKNOWLEDGMENTS

The research work has been supported by a Marie Curie Early Stage Research Training of the European Community's 6th Framework Programme under the contract MEST-CT-2005-020498: SOLNET and research project Environmental Engineering MSM 6840770011.

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