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THERMAL ANALYSIS AND APPLICATION OF ROLL BOND SOLAR ABSORBERS FOR HEATING AND COOLING IN RESIDENTIAL BUILDINGS

TOPLOTNA ANALIZA IN UPORABA ROLL BOND SONČNIH ABSORBERJEV ZA OGREVANJE IN HLAJENJE HIŠ

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Keywords: Roll bond technology, STAF panel, solar technology, heat pump

Abstract

The use of renewable energy sources will have to be increased significantly over the coming decades. The potential of solar energy in Slovenia represents the largest share of renewable energy sources. This article shows the use of roll bond solar absorbers for the heating and cooling of houses. For this purpose, we performed a numerical simulation of solar absorbers and theoretical calculations.

Povzetek

Izrabo obnovljivih virov energije bo potrebno v prihodnjih desetletjih izdatno povečati. Potencial sončne energije predstavlja v Sloveniji največji delež med obnovljivimi viri energije. Predstavljen članek prikazuje uporabo roll bond sončnih absorberjev za ogrevanje in hlajenje hiš. V ta namen smo izvedli numerično simulacijo sončnih absorberjev in teoretične izračune.

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1 INTRODUCTION

The effects of global warming are a crucial issue. The combination of renewable energy sources (RES) and the use of alternative energy technology, such as heat pumps and hydrogen technology, could solve major ecological problems. In Central Europe, the energy demand for heating and cooling in residential buildings is clearly higher than, for example, for the generation of electricity or energy for trucking. In this paper, a new solar thermal absorber has been analysed, which is produced by using the so-called "roll bond" technology. This study contains three core parts: the description of the production process of solar thermal absorbers, an analysis of the thermal behaviour for one selected absorber geometry, and the application in the heating and cooling systems of residential buildings. The focus lies on the determination of the energy efficiency by combining this solar thermal absorber with heat pumps and biomass or geothermal systems in Central Europe.

1.1 Production of solar roll bond absorbers

The roll bond technology enables the production of very flat heat exchanger geometries. It is also possible to use such heat exchangers for solar absorbers in different applications, e.g., a solar collector, photovoltaic thermal hybrid solar collectors, a thermodynamic panel and as an absorber for façade panels. Two different types of roll bond heat exchanger geometries can be used for these applications. The first type is a double-sided inflated plate made of aluminium. The second type is a one-sided inflated plate made of aluminium and an aluminium zirconium alloy combination.

The initial material for the production of roll bond plates is two aluminium strips in coils. This is followed by several production processes, including straightening and brushing before the required fluid pipe system for the absorber is printed on the bottom strip by means of serigraphy. Both strips are preheated up to 300 °C and bonded together under pressure in a heated rolling mill. The bonded strip has to be cooled down before it can be cut into plates with the requested dimensions at the end of the production line. Fig. 1 shows a schematic of the roll-bond process. The plates are put into a furnace for annealing, which is required before the inflation of the fluid pipes. After the annealing process, the fluid pipes are inflated using air at a pressure between 100 to 140 bar. Fig. 2 shows a schematic presentation of annealing the plates and the inflation process. The final steps in the production process are the shearing and brazing of connection tubes on the heat exchanger as well as the leakage tests.

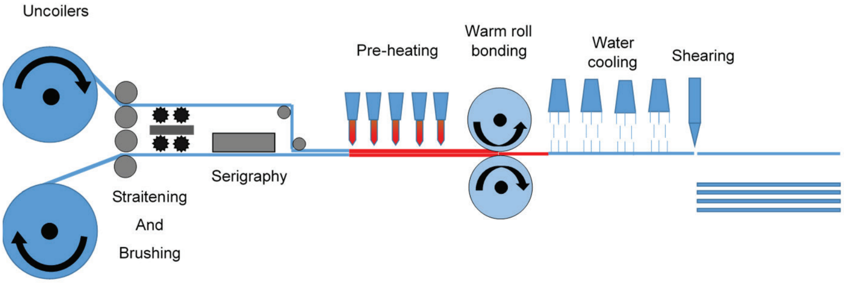

Figure 1: *Schematic of the roll-bond process*

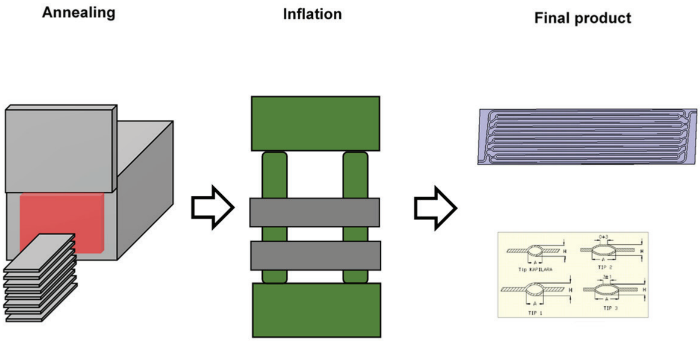

Figure 2: *Schematic of the plates annealing and the inflation process*

2 INTRODUCTION OF THE SOLAR THERMAL ACTIVATED FAÇADE (STAF) PANEL

Conventional sandwich panels offer an inexpensive and simple solution to form thermal envelopes for industrial buildings. They are pre-fabricated façade elements of which millions of square metres are produced and mounted every year. A sandwich panel consists of both an interior and an exterior metal sheet with thermal insulation between them. The central concept of the Interreg project “ABS-Network SIAT 125” *[1]* is the thermal activation of a conventional sandwich panel in which solar radiation is transformed into thermal energy. Therefore, the so-called “solar thermal activated façade (STAF)” panel has integrated fluid pipes at the exterior as well as at the interior metal sheet. Fig. 3 shows the basic design of an STAF panel with its formed aluminium sheets (absorbers) by using roll-bonding technology (as described above).

Depending on the application and seasonal influences, fluid flowing through the pipes enables the thermal use of solar energy (energy harvesting) on the exterior surface. In addition, the fluid can manage the thermal conditioning (heating and cooling) of the rooms on the interior surface (working principle is shown in Fig. 4). The insulator located between the absorber plates represents the thermal building envelope and should keep heat losses as low as possible. Due to this sophisticated modification of sandwich panels, the field of application can be extended to office buildings, public buildings, residential buildings, etc.

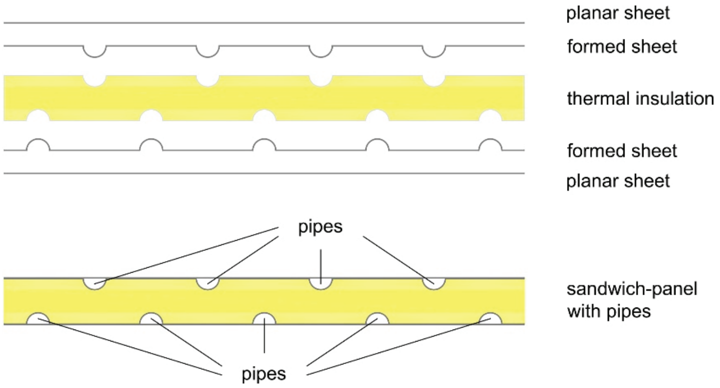

Figure 3: *Illustration of the basic design of the STAF panel*

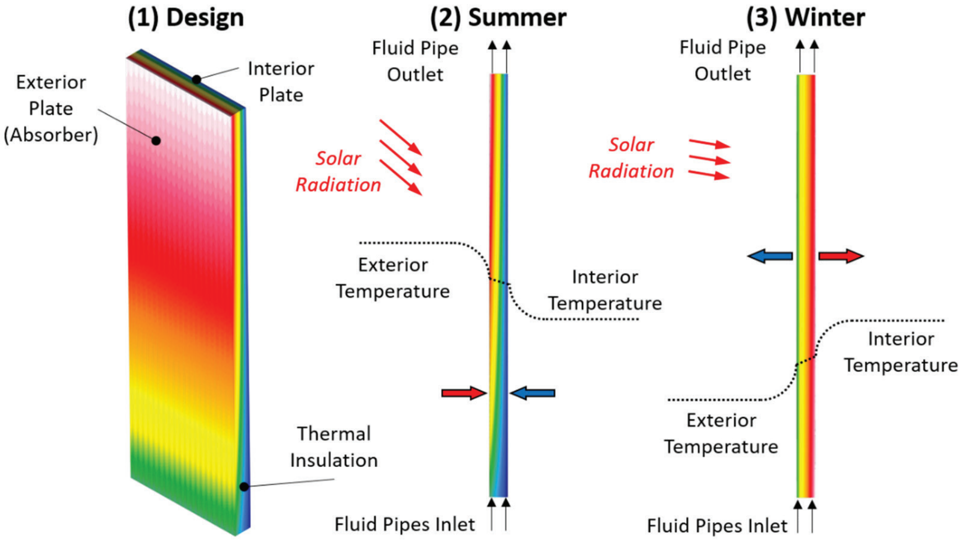

Figure 4: *Illustration of the design and the working principle of the STAF panel*

3 THERMAL ANALYSIS OF THE STAF PANEL (CFD SIMULATION)

With the help of Computational Fluid Dynamics *[2]* (CFD) method, a thermal analysis was performed at the Graz University of Technology to understand the heat transfer mechanism and to improve the efficiency of the absorber plate. This numerical simulation method enables calculating a broad range of different scenarios because geometrical and operative parameters can easily be varied.

In this study, the thermal performance of the exterior plate of a 3.5 × 1.0 m STAF panel was analysed by using a CFD software package from ANSYS Fluent *[3].* The simulation method was developed and validated in the course of the research project UNAB *[4].* Because the absorber plate dimension is yet limited to 1.75 × 0.5 m by the production plant of Talum d.d., four plates with the same fluid pipe geometry are interconnected to fulfil the required absorber dimensions for the STAF panel (shown in Fig. 5). In the simulation, aluminium is used as absorber material (with a density of 2700 kg/m^3, a specific heat of 896 J/kgK, and a thermal conductivity of 201 W/mK). Furthermore, the simulation considers a thermal insulation with a thickness of 0.15 m, which is made of polyurethane (with a density of 40 kg/m^3, a specific heat of 1400 J/kgK, a thermal conductivity of 0.025 W/mK), and an interior aluminium plate. At the interior surface of the interior plate, an interior room temperature of 20 $^\circ C$ and a heat transfer coefficient of 5 W/m^2K is assumed in the simulation. The sides of the STAF panel are determined to be symmetrical; the bottom and top surface are defined as an adiabatic wall. The panel's exterior absorber plate has two inlets at the bottom (1st absorber) where the fluid is introduced to the pipe network. (the fluid pipe profile used is illustrated in Fig. 5). In this simulation, a mixture of 70 $Vol\%$ water and 30 $Vol\%$ glycol is used to prevent freezing of the fluid at temperatures below 0 °C (with a density of 1035 kg/m^3, a specific heat of 3617 J/kgK and a thermal conductivity of 0.5 W/mK). The fluid flows upwards through the 1st absorber, enters the 2nd absorber, and leaves the absorber at the top of the STAF panel.

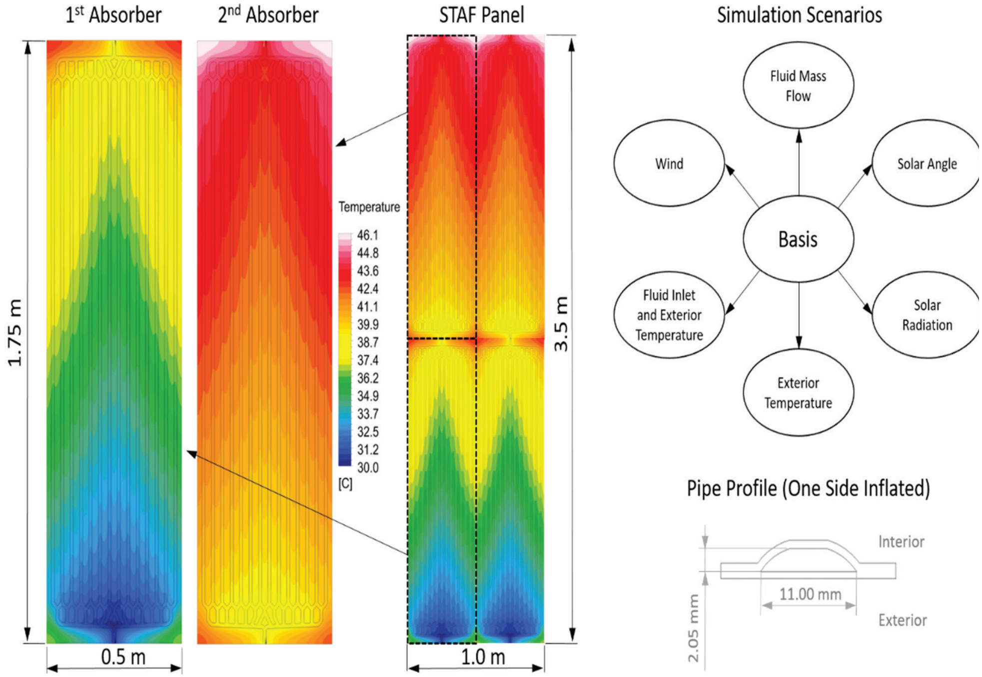

Figure 5: *Temperature contours of the exterior surface of (1) the absorber plates, (2) the STAF panel, (3) simulation scenarios, (4) fluid pipe profile*

The remaining thermal boundary conditions have been varied in a parameter analysis. In the initial scenario (basic scenario), the exterior temperature (T_{ext}) amount of 30 $°C$ and the exterior heat transfer coefficient (representing more or less the influence of the average wind speed over a year in Graz, Austria) is 25 W/m^2K. Furthermore, solar radiation of 1000 W/m^2 and a solar angle of 45° are assumed. The water-glycol mixture is introduced with a volume flow rate ($\dot{V}_F$) of 100 l/h per inlet and at an temperature ($T_{F,in}$) of 30 $°C$. The varying parameter are illustrated in the schematic of the simulation scenarios in Fig. 5; all scenarios are summarized in Table I. Additionally, the table contains the computed fluid temperature ($T_{F,out}$) at the outlet positions of the absorber's pipework as well as the calculated thermal output ($\dot{Q}_{STAF}$) and efficiency (η_{STAF}) of the whole STAF panel according to the following equations ((3.1) and (3.2)).

$$\dot{Q}_{STAF} = \dot{m}_F \cdot c_{p,F} \cdot \left(T_{F,out} - T_{F,in}\right) \tag{3.1}$$

$$\eta_{STAF} = \frac{I_{Sol} \cdot A_{STAF}}{\dot{Q}_{STAF}} \tag{3.2}$$

In the basic scenario, a fluid outlet temperature of 43.3 $°C$ was achieved, resulting in a thermal output of 1379.7 W and an efficiency of 0.394. If the mass flow increased up to 200 l/h, the fluid outlet temperature was 4.9 K lower. Although the fluid outlet temperature was lower, the efficiency was significantly higher because the heat losses to the environment have decreased. At a mass flow of 50 l/h, the fluid outlet temperature is 4.9 $°C$ higher than in the basis scenario, resulting in a lower efficiency. In the CFD simulation, the simultaneous reduction of the exterior and the fluid inlet temperatures leads to a lower fluid outlet temperature while the efficiency was slightly increased. Compared to the basis scenario, the fluid outlet temperature was 6.6 $°C$ lower when the solar radiation was reduced from 1000 to 500 W/m^2; the efficiency was almost equal. When the fluid inlet temperature was reduced while the exterior temperature was constant at 30 $°C$, the absorber is more efficient than reducing both the inlet and exterior temperatures. In this case, the exterior temperature was amplifying the heating effect. Furthermore, the heat transfer effect of the absorber is strongly influenced by the wind. For a heat transfer coefficient of 5 W/mK^2, which represents less wind, the fluid outlet temperature was 4.9 K higher than in the basic scenario. For a heat transfer coefficient of 100 W/m^2K, the fluid outlet temperature was 7.4 K lower than in the basic scenario. Finally, the influence of the solar angle was analysed. For a flat solar angle of 20°, the fluid outlet temperature was 4.3 K higher, while it was 5.3 K lower at a steep solar angle of 65°.

Table 1: *Results from CFD simulation scenarios*

Simulation scenario	$\dot{V}_F$	T_{ext}	$T_{F,in}$	$T_{F,out}$	$\dot{Q}_{STAF}$	η_{STAF}
	$[l/h]$	$[°C]$	$[°C]$	$[°C]$	$[W]$	$[-]$
Basic scenario	100	30	30	43.3	1379.7	0.394
Volume flow rate of 200 l/h per inlet	200	30	30	38.4	1742.6	0.498
Volume flow rate of 50 l/h per inlet	50	30	30	48.1	943.0	0.269
Exterior and fluid inlet temperature of 20 °C	100	20	20	33.4	1393.3	0.398
Exterior and fluid inlet temperature of 10 °C	100	10	10	23.5	1407.8	0.402
Exterior and fluid inlet temperature of 0 °C	100	0	0	13.7	1421.3	0.406
Exterior and fluid inlet temperature of -10 °C	100	-10	-10	3.8	1436.9	0.411
Solar radiation of 500 W/m²	100	30	30	36.7	691.4	0.395
Fluid inlet temperature of 20 °C	100	30	20	39.5	2027.5	0.579
Fluid inlet temperature of 10 °C	100	30	10	35.7	2670.1	0.763
Fluid inlet temperature of 0 °C	100	30	0	31.8	3309.5	0.946
Fluid inlet temperature of -10 °C	100	30	-10	28.0	3945.8	1.127
Exterior heat transfer coefficient of 5 W/m²K	100	30	30	48.2	1892.3	0.541
Exterior heat transfer coefficient of 100 W/m²K	100	30	30	35.9	615.5	0.176
Solar angle of 65°	100	30	30	37.9	824.5	0.236
Solar angle of 20°	100	30	30	47.6	1829.9	0.523

4 APPLICATION OF THE STAF PANEL (CASE STUDY)

The purpose of installing STAF panels on buildings is to save as much as possible in the consumption of already used primary energy sources for space and domestic hot water heating and thus contribute to lower greenhouse gas emissions. Buildings with integrated STAF panels are approaching the status of low-carbon (energy-efficient) buildings, which affects the outcome in obtaining an energy certificate. With the installation of STAF panels, we are approaching the standards that reflect EU objectives, which are always higher regarding the policy of obtaining permits for new buildings. By installing a modified version of STAF panels for the thermal improvement of an existing building, it is necessary to emphasize the construction work is not significant, the architecture remains almost the same, which means that substantial construction work in the renovation is not required, since the panels are installed on the outside of the wall (façade), following which the thermal insulation of the building is improved. It is also essential to use a renewable energy source (solar energy) for heating, which is fairly energy efficient for use in Central Europe and elsewhere.

STAF panels, which can also be installed on the outer wall of a building have some decisive advantages. The use of solar radiation, of course, also depends on the installation of solar panels according to the cardinal orientation and the slope of the panels (different values for different areas in the world). In Central Europe, if the panel is installed, for example, on the southern vertical wall of the building, about 30% of solar radiation is lost compared to the optimal slope. Solar collectors are usually installed on the roofs of building, as the greatest amount of sun rays reaches them due to the slope, and due to the reduced influence of surrounding buildings, that could cast a shadow on the collectors. Precisely because it is a “too favourable” position for the installation of panels, in summer, problems with overheating of panels may occur and, consequently, lower efficiency and damage to panel components *[4].*

STAF panels can be used as additional heat generators to the existing heating system with the production of heat for space heating and domestic water. For example, imagine a residential house built in the vicinity of the municipality of Krško, Slovenia, with the maximum heating power to heat this building (12 kW). Depending on the annual load of the heating plant, the necessary energy for the heating of the residential building including sanitary water preparation is 36,580 kWh per year *[5].* For the energy analysis of the application of solar panels for heating of residential buildings, the STAF panels were combined with a heat pump system (Fig. 6). For the determination of the solar radiation, the number of effective hours for the Krško region, Slovenia were calculated. According to the solar calculator from the solar electricity handbook *[6]*, the effective number of solar hours is 1,224. The principle idea behind the STAF panels is to cover the majority the heat demand in the summer and the highest share in the winter. Table 2 shows the amount of energy that is obtained from the STAF panels and with a heat pump if the STAF panels cover 30%, 50%, or 80% of the energy demand for heating. Figure 7 shows the price for heating and the minimal required number of installed STAF panels dependant on solar coverage with STAF panels.

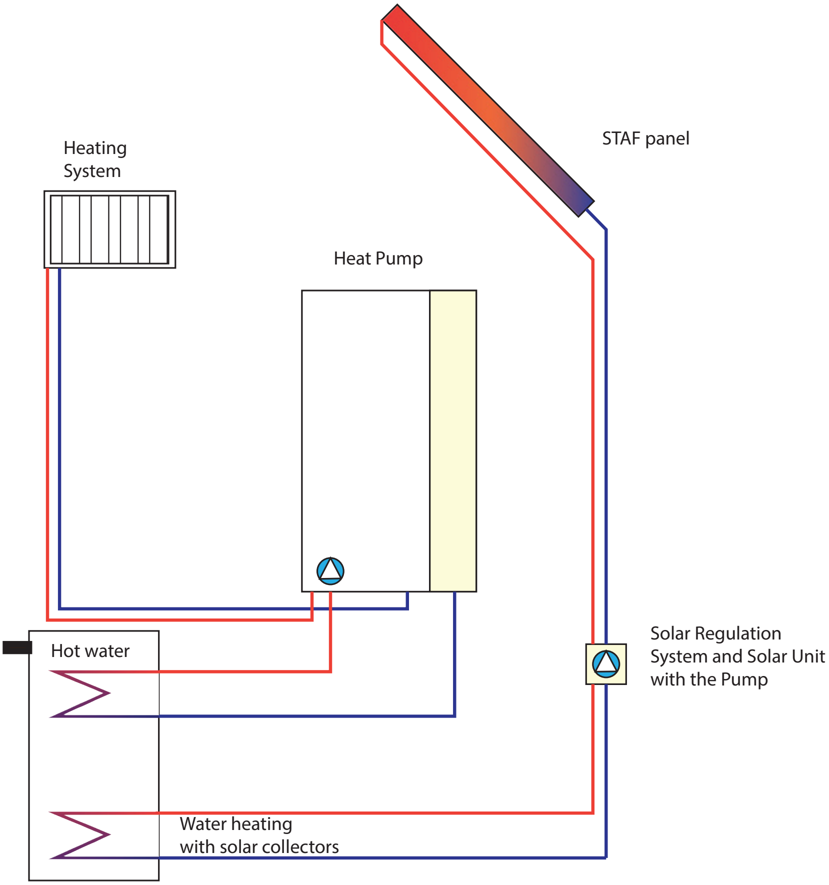

Figure 6: *Hydraulic schematic of a heat pump cycle for heating of a family house with integrated STAF panel*

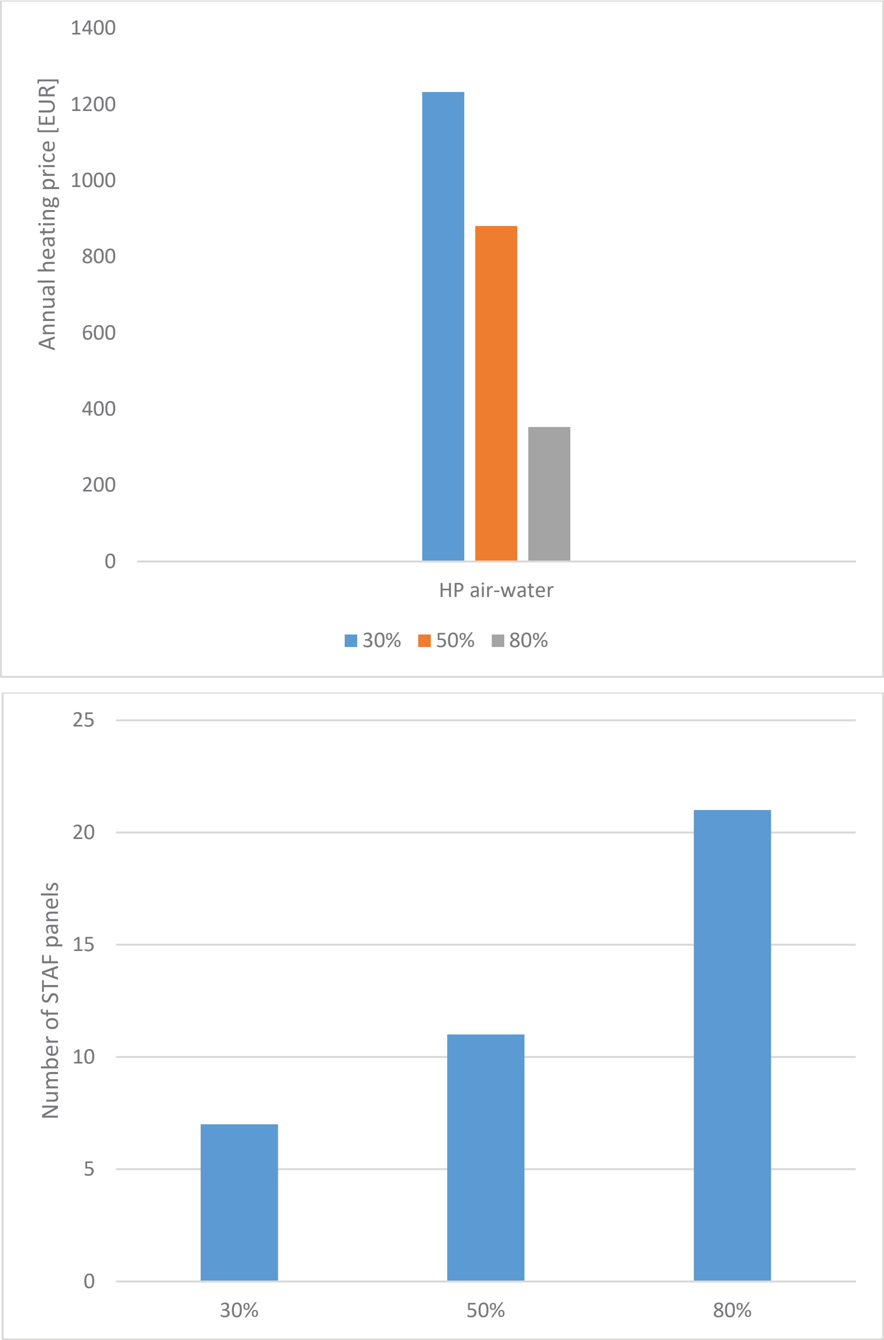

Figure 7: *Heating price depending on the energy demand of a family house and the minimal number of required STAF panels*

Table 2: *Use of solar energy (STAF panels) for heating of a family house*

:	30% use of solar energy	50% use of solar energy	80% use of solar energy
STAF panels	10974 kWh	18290 kWh	29264 kWh
Heat pump (HP)	25606 kWh	18290 kWh	7316 kWh

5 CONCLUSION AND OUTLOOK

In this article, we have shown the possible application of STAF panels with heat pump technology. The results show that an application of STAF panels is very interesting from thermodynamic, ecologic, as well as economic perspectives.

Multiple CFD simulations were performed to analyse the thermal behaviour and determine the thermal output of STAF panels. In the simulations, a water-glycol mixture was heated inside an STAF panel with the dimensions of 3.5 × 1.0 × 0.15 m up to 48.2 °C. The maximal thermal output was approximately 3.9 kW. The exterior temperature and the wind have a powerful impact on the thermal behaviour and output. When the ambient temperature is higher than the average surface temperature of the exterior absorber plate, the fluid is additionally heated. Unfortunately, the absorber's heat loss increases as the ambient temperature decreases. The heat loss at low ambient temperatures can be reduced by installing a glass cover for the absorber.

In the course of the project "ABS-Network SIAT 125" *[1]*, further thermal and structural analysis of the STAF panel will be performed to optimize the whole construction and improve the thermal output. Additionally, outdoor tests will be performed at the Graz University of Technology to compare the thermal behaviour of the most promising STAF panel absorber geometries under real climate conditions.

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