# AKTIVA – DESIGN AND INTEGRATION OF BUILDING OUTER SURFACES FOR MULTI-FUNCTIONAL SPACE HEATING AND COOLING APPLICATIONS

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**ABSTRACT**

In modern highly-insulated buildings the summer operation is getting more important and comfort cooling of buildings becomes increasingly an issue, in particular for office buildings. Free cooling during night-time by convection and radiation of an activated outer surface such as an absorber or collector has rarely been considered in practical operation for Swiss climate conditions, yet, but has shown interesting potentials in recent studies. An even more beneficial operation, though, would be to use the same outer surface also for space heating in winter operation, for instance as a heat source for a heat pump, as well as in summer operation for DHW heating. Thus, the objective of the project is the optimisation of properties of outer building surfaces for both heating and cooling operation, e.g. regarding the selectivity of the outer surface. Furthermore, adapted options for the system integration into a hydronic system are investigated by simulations. The results of the simulations are compared to lab measurements.

As first step the properties of an unglazed collector with different degrees of selective coating and different inclination angles have been lab-tested. In parallel, a collector model based on the data sheet parameters has been implemented in Matlab-Simulink and compared to the lab test data with good agreement. Subsequently, the unglazed collector has been integrated into a system simulation model consisting of a heat pump or chiller, respectively, a source storage connected to the collector for the winter heat pump operation as well as a direct connection of the collector to the differently oriented building zones for summer cooling. The building zones are equipped with thermally-activated building systems (TABS), which are often applied in office buildings and offer favourable conditions for low temperature heating and high temperature free-cooling operation.

Simulation results show a high degree of coverage for the Zurich average year weather data according to SIA 2028 for both operation modes. For single office use based on SIA 2024 loads, degree of coverage of winter source energy is about 75% corresponding to an SPF of the heat pump around 4. In summer cooling mode, about 90% of the cooling energy can be covered by free cooling. Results vary depending on the selectivity and inclination, so based on the requirements parameters can be optimised for heating or cooling. An integration of the source storage in cooling mode increases the degree of coverage up to 10%, in particular in adverse conditions like high selectivity of the collector or warm summer climate like Lugano warm year. As result of the project recommendation on the design, integration and control of outer surfaces for multi-functional operation in different applications will be concluded and verified by lab measurements of enhanced prototypes.

*Keywords: Renewable heating, free cooling, unglazed solar collector, multi-functional façade, heat pump*

## INTRODUCTION

New buildings in Switzerland have U-values around 0.2 W/($m^2$K) and are therefore well insulated. The internal loads, however, tend to increase. As a result, comfort cooling in office buildings becomes increasingly an issue, but should not lead to excessing electricity use for cooling in summer. Different free-cooling techniques have established as cooling options mainly in office buildings, though. By direct use of environmental heat sinks like the ground or outside air they offer an energy-efficient way to increase the cooling performance, since the sole energy expense is the circulation of the fluid. However, each passive cooling technology has its specific limitations. Space cooling by radiation or night-time convection of an activated outer building surfaces has yet rarely be considered or validated in practical operations for Swiss climate conditions, despite promising potentials [1]. A further synergy exists when the same system is used for space heating operation in winter or domestic hot water production (DHW) in summer, as well.

Thus, the objective of the project AKTIVA is the optimisation of properties of the outer building elements, which could be designed as absorbers or collectors, for multi-functional application, e.g. regarding the selectivity and inclination angle. As result, renewable heating and cooling fraction as well as design and applications ranges of the system are evaluated.

## METHODS

Within the project AKTIVA system simulations based on lab-measurement of the component characteristics are accomplished. On the one hand, lab-measurements of the characteristics of the outer surface are performed at the University of Applied Sciences Northwestern Switzerland in Muttenz. On the other hand, the HSR University of Applied Sciences Rapperswil is modelling and simulating the system with an integrated multi-functional absorber using the simulation environment Matlab-Simulink with the CARNOT Toolbox [2]. The industrial project partner Energie Solaire SA in Sierre, which produces unglazed absorbers for different applications, supports the project with the absorbers and know-how.

### Lab-Measurements

Three unglazed collectors of the industrial partner Energie Solaire SA with different selective coatings ($\varepsilon = 0.15$, $\varepsilon = 0.3$, $\varepsilon = 0.9$) were measured regarding their heating and cooling capacity. The collectors are connected to a hydraulic system which emulates respectively simulates different operating conditions. In a first step, the cooling potential during the night was investigated, which depends on the ambient temperature (convection) as well as the sky temperature (radiation). Furthermore, the impact of different inclination angles was examined regarding the cooling and heating capacity, since a small inclination is better for cooling whereas higher inclination angles typical for façade integration has advantages in heating.

### Collector Modelling

In order to evaluate the outer surface performance over the year-round operation a model of the unglazed collector has been implemented based on the model-approach of Stegmann et. al [3], which depends on the results of the European collector test standard EN 12975 [4]. The model includes the effects of direct and diffuse solar radiation, heat emission as well as condensation due to sky- and ambient temperatures. Subsequently, the simulated data of the collector model were validated with measurement data of the unglazed lab-collector.

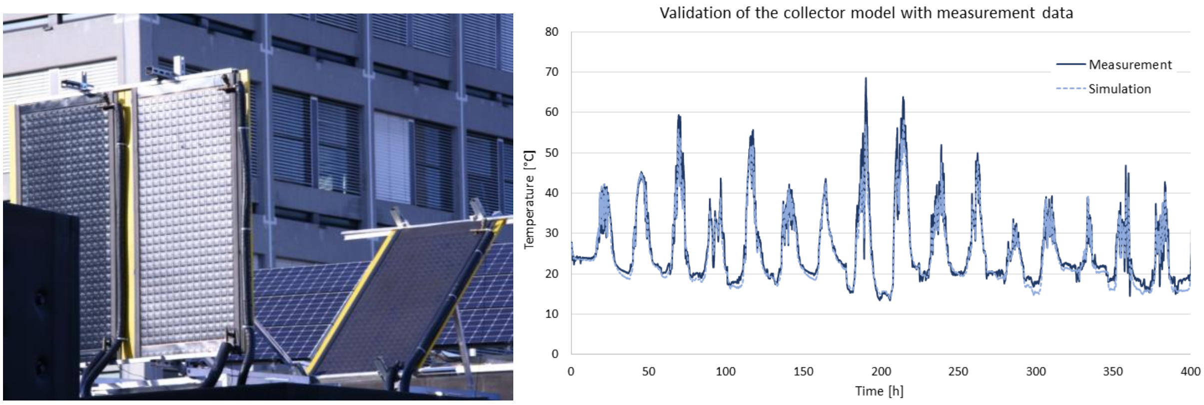


*Figure 2: Experimental setup of the unglazed absorbers with different selectivity and inclination (left) and comparison of measured and simulated data of the outlet-temperature of the non-selective collector of ε = 0.9 (right).*

Figure 2 shows good agreement of measured and simulated data. Only small deviations in the range of up to 3 K occur in particular situations.

**System Simulations**

After validation the collector model was integrated into an adapted hydraulic system to evaluate the components and system key figures. Therefore, the model was coupled with a heat pump, source storage and a heating and a cooling load. By this integration, the operation modes heating with collector source, direct heating from the collector, simultaneous heating and cooling with the heat pump, active cooling with the heat pump and recooling with the collector as well as free-cooling with the collector can be covered. Figure 3 shows the system integration.

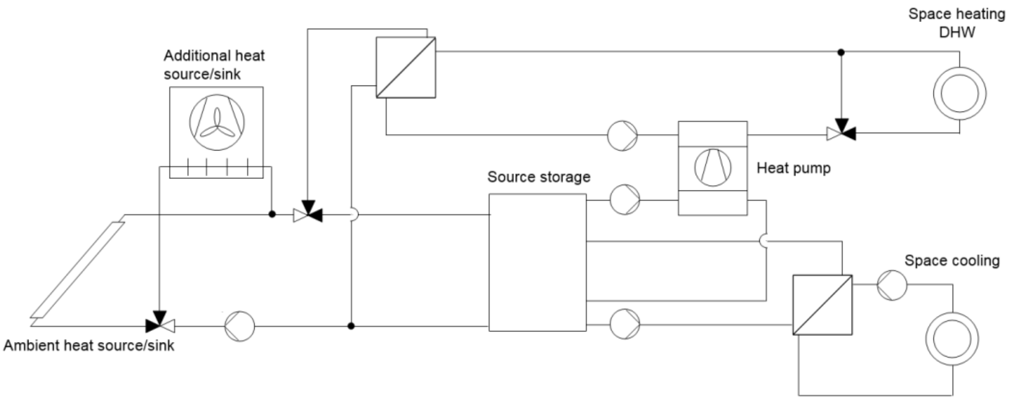


*Figure 3: Hydraulic system integration to simulate and evaluate the cooling and heating potential of multi-functional component use*

The emission system in the room zones are TABS of 30 cm concrete with core activation resulting in maximum supply temperature of 29 °C in the heating mode. During winter period, the collector is connected to the storage and serves as a heat source for the heat pump. In summer period, however, the collector can be directly connected to the TABS, or as variant can be connected parallel to the source storage, and cooling is covered from the storage. The heat pump can be used as a backup chiller. Winter heating operation covers the period of October-March, while summer cooling takes place in the period of April – September.

## RESULTS

### Simulation results for multi-functional use of collector and source storage

Figure 5 summarises performance results as uniform metric "degree of coverage" of the collector for both space heating and cooling mode. The components in the hydronic integration are chosen in that way that each component can be used for both space heating and space cooling mode. However, the requirements for the components are partly opposite for the two operation modes, implying optimisation potentials of component parameters and design depending on the prevalent loads.

The heating and cooling loads are assumed for two single office zones with façades in north and south direction and a glazing fraction of 60%. Weather conditions are Zurich Meteoschweiz average year and Lugano warm year according to SIA Merkblatt 2028 [5]. Data for the internal loads are taken of SIA Merkblatt 2024 [6]. The collector design corresponds to 0.33 $m^2_{coll.}/m^2_{ERA}$. A brine-storage with 10 $l/m^2_{ERA}$ is integrated as source storage. Resulting room temperatures correspond to the temperature requirement according to the SIA 180 [7].

Four cases have been simulated in order to evaluate the heating and cooling potential for the extreme characteristics of the collector operation, considering the inclination and emission coefficient. The inclination varies between 5° and 90°, which corresponds to collectors on a flat roof or façade-integrated collectors. The emission coefficient varies between 0.1 and 0.9 for a selective collector and non-selective collector, respectively. Figure 5 left shows the degree of coverage for the collector either as a free-cooling system or as source for the heat pump in all four cases. All cases are considered without storage use in cooling mode and with the collector as only heat source in heating mode.

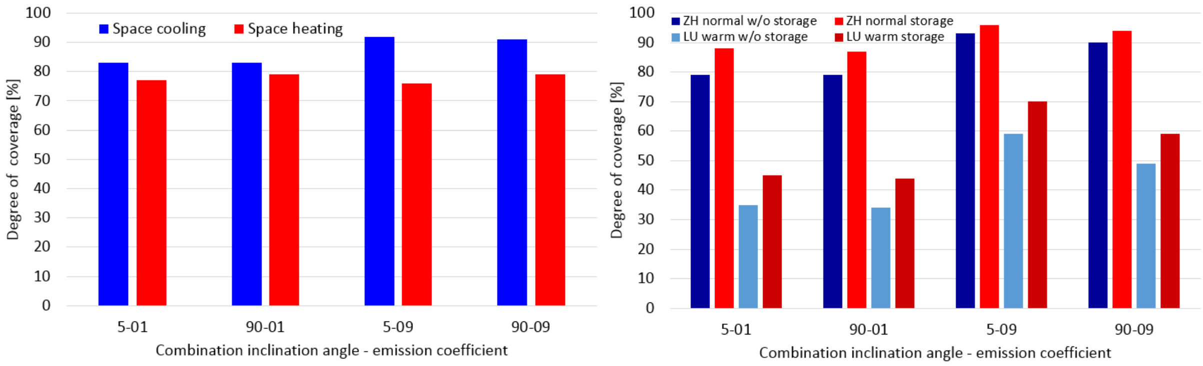


*Figure 5: Degree of coverage for a multi-functional collector use by inclination and emission coefficient (left) and free-cooling fraction with multi-functional use of source storage (right)*

The degree of coverage during space heating mode can be recalculated as the seasonal performance factor (SPF) of the heat pump. A fraction of source energy of 75% (i.e. 25% compressor energy) corresponds to an SPF of 4. The relatively high SPF-values are a result of the favourably low supply temperature for TABS. During cooling mode, the degree of coverage represents the fraction of free-cooling on the totally used cooling energy. The missing fraction has to be supplied by an active back-up of the heat pump in chiller mode. Due to small temperature difference in the operation of the unglazed collectors as heat pump source, the emission coefficient has a lower influence to the degree of coverage and differences between the selective and non-selective collectors are small. However, the effect on the cooling performance is higher even though the ambient temperatures during the night are relatively low in Zurich with a temperature below 15° C in 85% of all night hours.

Thus, the inclination has a relatively small influence to the cooling power in this case, since the convective heat rejection still reaches high shares.

Multi-functional use of the source storage both in heating and cooling mode is evaluated in Figure 5 right. It can be seen that the increase of the degree of coverage by free-cooling depends on the situation. For limited surface characteristic, i.e. low emission coefficient, or adverse ambient conditions, i.e. hot summer climate of Lugano warm year, the storage use in cooling operation can increase the degree of coverage by about 10%. However, with favourable conditions in Zurich average summer climate and good surface properties of an emission coefficient of 0.9 and 5° inclination, differences decrease to about 3%.

**Design aspects**

Parameter variations have been accomplished to evaluate the dependency of SPF in winter heating and degree of coverage in summer cooling mode, respectively. Figure 6 left shows the impact of the collector design on the SPF for two extremes of inclination/emission of 5°/0.9 (cooling optimised) and 90°/0.1 (heating optimised). For increasing collector area the performance increases digressively. Both designs reach good SPF values above 4, even with low collector areas of 0.1 $m^2_{coll.}/m^2_{ERA}$. By the selective coating and good inclination, though, the SPF can be increased by about 0.5, up to absolute values above 5. In cooling mode, characteristic is vice versa. For cooling optimised designs the free-cooling fraction can be increased by 0.15 and more up to values above 90% for the same inclination angle of 5°. This is even the case in moderate night-time temperature in the Swiss middle land of Zurich normal summer with about 85% of night-time temperatures below 15 °C allowing higher convective shares. In the hotter climates of southern Switzerland, differences are even more pronounced due to limited convective losses.

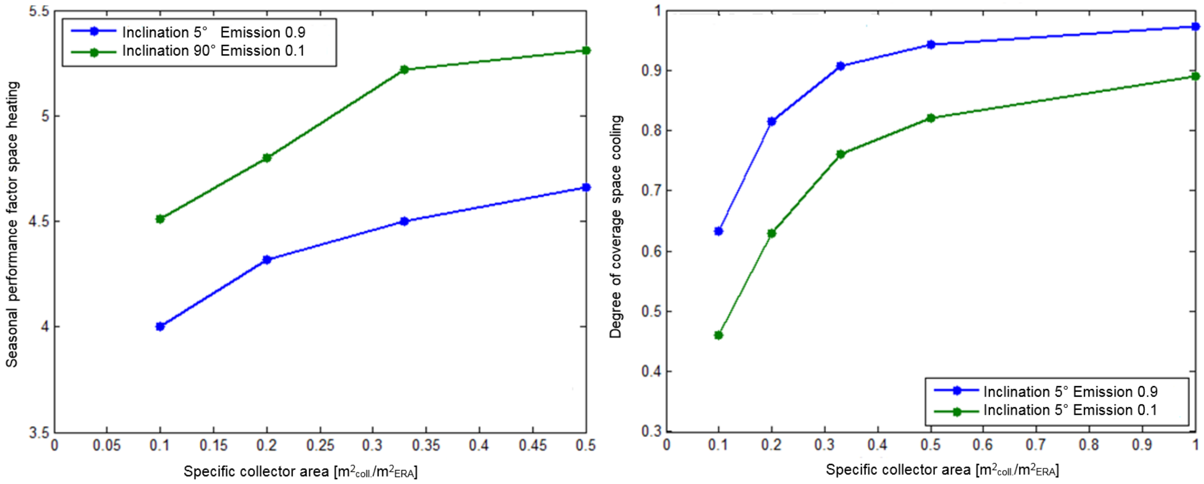


*Figure 6: Seasonal performance factor and degree of coverage of multi-functional collector for different combinations of inclination and emission in Zurich Meteoschweiz average year.*

## CONCLUSION

A multi-functional system configuration based on the core components heat pump and solar collector has been lab-tested, modelled and simulated for different characteristic of the collector surface. The system integration is done in a way that all system components are suited for multi-functional use for space heating and cooling. In both operation modes, high degree of coverage is confirmed by the simulation. However, depending on the prevalent load situation an optimisation of the characteristic can be accomplished.

A further use of the source storage as cold storage for the cooling mode can increase the degree of coverage of passive cooling operation by further 10% in particular in more restrictive boundary conditions of higher night-time temperatures or limited properties of the surface regarding cooling operation.

Also the design has an impact, since larger collector areas increase both, source conditions for the heating operation and free-cooling shares.

In unfavourable weather conditions, though, the operation limits of the components, e.g. the lower temperature limit of the heat pump, may require an additional source or back-up systems. On the other hand, in favourable conditions, a direct solar space heating operation and DHW heating in transitional periods is probable, but has not been investigated, yet.

Further investigations and potentials are seen in control optimisations and design depending on different load conditions, since the yield of environmental energy in both space heating and cooling is strongly linked to the temperature levels of the surface. Thus, if operational temperatures can be enhanced by the control of the system, an enhanced degree of coverage is expected. Further simulation will be carried out to evaluate these impacts.

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