CLIMA 2016 - proceedings of the 12th REHVA World Congress

volume 3

Heiselberg, Per Kvols

Publication date:
2016

Document Version
Publisher's PDF, also known as Version of record

Activated building surfaces for space heating and cooling

Carsten Wemhoener[#1], Raphael Schweizer[#2], Andreas Mueller[*3], Thomas Afjei[*4]

[#]*Institute of Energy Technology, HSR University of Applied Sciences Rapperswil*
Oberseestrasse 10, CH-8640 Rapperswil, Switzerland

[1]carsten.wemhoener@hsr.ch

[2]raphael.schweizer@hsr.ch

[*]*Institute of Energy in Building, University of Applied Sciences Northwestern Switzerland*
St. Jakobs-Strasse 84, CH-4132 Muttenz, Switzerland

[3]andreas.mueller@fhnw.ch

[4]thomas.afjei@fhnw.ch

Abstract

Increasing internal loads and outdoor temperatures raise the need for comfort cooling, in particular in office buildings. A free-cooling method hardly considered is the heat rejection by activated components of the building envelope. An even more advantageous application is the heating and cooling operation with the same component. However, requirements for the surface properties may be different, resulting in optimisation potential depending on the prevailing load situation.

Therefore, a model has been developed and validated based on test rig measurements of absorbers with different selective coating. Subsequently, the model has been integrated in a system configuration suited for multifunctional operation consisting of a source storage, a heat pump and thermally activated building systems in the room zones.

Space heating capacities up to 600 W/m^2 are reached with good solar irradiation and selective coating. At low radiation, the absorber is operated as heat exchanger to the ambient air. Solar fractions of about 75-80% are reached as heat source corresponding to an overall seasonal performance factor of 4-5 for the heat pump and solar combination depending on absorber properties.

Cooling capacity ranges from 70 W/m^2 (selective) to 150 W/m^2 (non-selective) in clear sky nights and about 90% of the cooling demand can be covered in free-cooling operation with Zurich Meteoschweiz normal weather data.

Selective properties of the surface are less important as source energy for heat pump heating and for cooling in moderate nights. However, non-selective properties are important for radiation losses in hot summer nights, while selective coating increases the performance by direct solar heating.

Keywords – free-cooling; heat pump; unglazed solar collector; multifunctional system; renewable heating

1. Introduction

Reasons for increasing cooling need, in particular in office buildings, are manifold, among them better insulation of buildings, increased comfort requirements in high performance buildings, increasing internal load due to more electrical equipment in use, large glazing fractions as well as last but not least the trend to rising outdoor temperatures by climate change. Therefore, comfort cooling becomes a necessity in many cases, in particular in office buildings. However, cooling loads can be covered efficiently by free-cooling methods, which have been increasingly introduced. Different free-cooling methods like ground-coupled free-cooling or nighttime ventilation exist, but all have their particular limitations, like the energy balance of the ground for free-cooling by borehole heat exchangers and an adequate air exchange and sufficiently low outdoor temperatures for nighttime ventilation.

A passive cooling method seldom considered despite potentials is the nighttime heat rejection by activated components of the building envelope, which can act as heat exchanger to the ambient and radiator to the sky. This method gets even more beneficial, when the same activated surface can be used for heating purpose, as well. However, favorable properties for the space heating and cooling operation are not necessarily the same. Indeed, while losses of the surface are to be maximized for space cooling, they shall be minimize for heating purpose. On the other hand, heating occurs in wintertime at low sun angles, leading to higher inclination angles for optimized surface yields, while in cooling mode, radiation to the night sky is maximized at high view factors at low inclination of the surface. Thus, optimisation potentials exist depending on the prevailing load situation. Therefore, in the project AKTIVA, capacity of unglazed solar collectors are evaluated by test rig measurements for both space heating and cooling application. Based on the measurements, a model of the unglazed absorber is developed and integrated in a system configuration. System simulations are performed in order to evaluate key characteristics of the system performance in both space heating and cooling mode.

2. Lab testing of solar absorbers

Lab testing has been performed at the Energy Research Lab (ERL) of the Institute of Energy in Building of the University of Applied Sciences Northwestern Switzerland in Muttenz. Fig. 1 shows installed absorbers on the roof of the lab.

Three unglazed solar absorbers with different degree of selective coating with emission coefficients of $\varepsilon=0.15$ (selective coating), $\varepsilon=0.3$ (faint selective) and $\varepsilon=0.9$ (non-selective) have been installed on the roof of the ERL. Tests have been performed at different weather conditions and with different inclination angles.

Fig. 1 Installed absorbers on the roof of the Energy Research Lab (right)

Fig. 2 shows the test results on 23-24 Sept. 2013 at constant absorber inlet temperature of 25°C, which had good solar irradiation conditions during the day followed by a clear sky in the beginning of the night. As expected the selective absorber reaches the highest capacity for space heating operation during daytime of about 600 W/m^2 at maximum. The non-selective absorber only reaches about 500 W/m^2, thus for the space heating operation, the selective absorber has advantages of higher capacities.

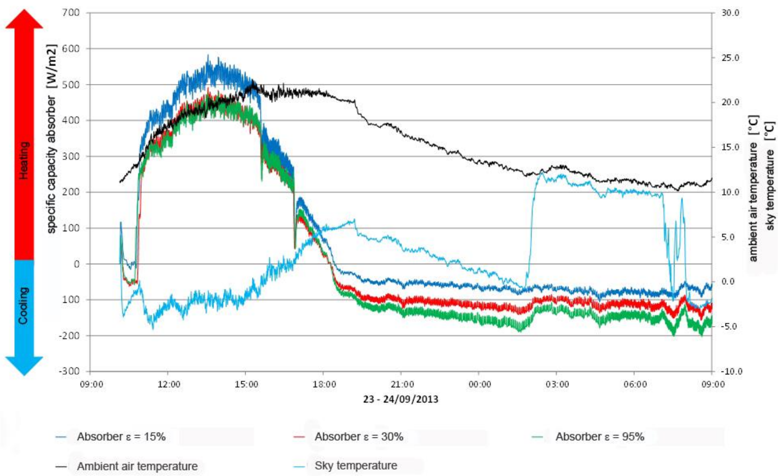

Fig. 2 Measurement results at good solar irradiation at daytime and clear sky at nighttime of the three differently selective coated absorber

In clear nights, though, the (fictive) sky temperature, which has been recalculated by longwave radiation measurements with a pyrgeometer, is significantly lower than the ambient air temperature, in the first nighttime hours by about 15 K. Therefore, even if the absorber temperature is in the range of the ambient temperature, the absorber can reject heat by radiation to the night sky.

In the space cooling operation, the favorable property of the absorber is hence a high emission coefficient by non-selective characteristic, which is opposite to the space heating mode. At good radiative characteristics of the non-selective absorber to the night sky results in a cooling capacity of -200 W/m^2 for the non-selective absorber, while the capacity of selective absorber is below 100 W/m^2.

However, at about 2 a.m., clouds come up, which is illustrated in Fig. 2 by the instantaneous rise of the sky temperature to almost the level of the ambient air temperature. Consequently, the cooling capacity of the three absorber are approaching each other and the selectivity is of minor importance, since the radiation exchange with the sky is now limited by the reflexion of the clouds, expressed by a higher sky temperature due to a higher emission coefficient of the sky. The decrease of the cooling capacity of the three collectors is most prevalent for the non-selective collector, while the selective collectors is hardly affected by the rising sky temperature.

3. Validation of absorber model

Based on the test results of the test rig measurements a model of the absorber has been implemented in the simulation tool Matlab-Simulink.

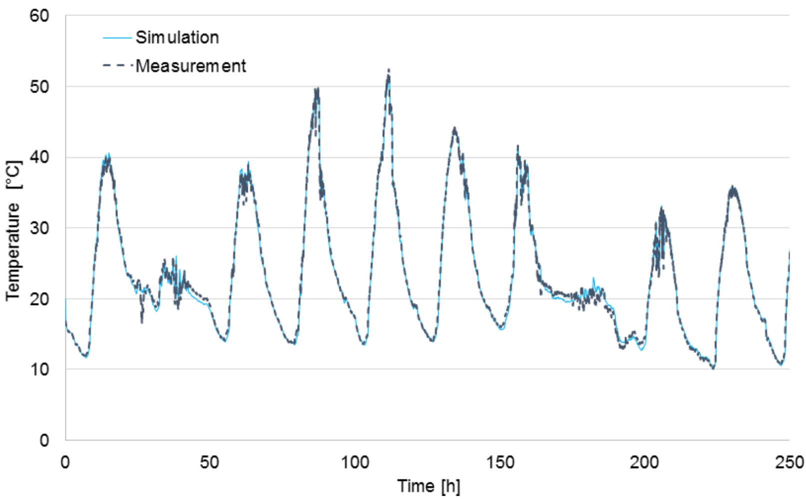

Fig. 3 Validation of the model with test rig data for the faint selective absorber of ε=0.3

The model is based on the model described in the collector test standard EN 12975 [1]. However, the normally identified coefficients from the collector testing have been replaced by physical expressions as described in Stegmann et al. [2] for PV/T collectors.

After the implementation of the model, it has been validated for the different absorber types with the test rig data. Fig. 3 shows the comparison for the simulation of the faint selective collector which confirms the good agreement of the absorber model and the measured data.

4. System integration

After modeling the absorber is integrated in a system model which is compose of components that can be used for multifunctional operation. The system configuration comprises a storage tank, a heat pump as well as thermally activated building systems as emission system in the room zones. All components can be used both in space heating and space cooling mode. In space heating mode, the absorber is used as solar heat source for the heat pump. The storage is integrated as source storage for the source of the heat pump. With solar radiation, the source fluid is heated by solar energy. In times of low solar irradiation the absorber is used as outdoor heat exchanger in order to extract heat from the ambient air. In order to prevent frosting, a water-glycol mix of 40% has been used in the simulation. As alternative, also an ice storage could be used as source storage. Fig. 4 shows the principle of the system integration in dedicated space heating mode with the absorber source as a heat source of a heat pump. In times of high solar radiation when outlet temperatures of the absorber are higher the supply temperature required by the TABS system, also a direct solar heating can be applied by bypassing the storage and the heat pump with the heat exchanger.

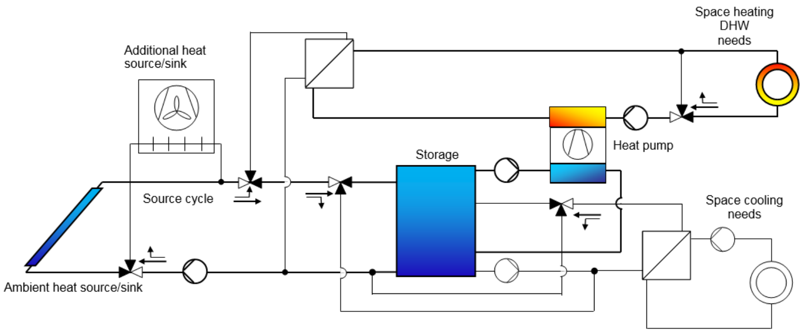

Fig. 4 Principle of the system integration, depicted in dedicated space heating mode with a solar absorber source and heat pump heating

In space cooling mode, the solar absorber is used for nighttime heat rejection in free-cooling mode, which can be directly coupled to the TABS. By recooling the TABS and the building structure in the room zones at nighttime, the cooling loads for the next day can be covered. Thus, the TABS are used as cold storage to transfer the nighttime cooling energy to the daytime use.

The storage can be integrated as cold storage in the cooling operation, which helps to overcome adverse weather conditions in the night. In case of insufficient cooling energy by the solar absorber, the heat pump can be applied as back-up chiller. Thereby, the heat extraction at the heat pump evaporator is used to cool down the storage, while the storage is used for cooling down the room zones. The condenser heat will be preferably used for DHW operation, or, in case of the no heat demand, is rejected at the higher temperature level to the ambient by the solar collector.

As further back-up system, an additional heat source, which can also be used as additional heat sink can be integrated in parallel into the system configuration. For space heating, also a back-up heater could be integrated instead.

5. Performance results in space heating mode

The lab test results give instantaneous capacity values, which, however, cannot reflect the long term performance due to the dependence on changing weather conditions. Therefore, seasonal simulations for the space heating and cooling operation have been accomplished with the validated model.

Simulations have been performed for two room zones in north and south orientation with single office use according the Swiss standard SIA 2024 [3] for the weather data of Zurich Meteoschweiz average year according to the Swiss standard SIA 2028 [4]. As extreme weather for the space cooling mode a warm summer of Lugano warm year according to SIA 2028 has been used. The room zones are equipped TABS in the middle of the 30 cm concrete ceiling in a pipe distance of 0.2 m.

The design of the absorber is 0.33 m^2_{abs}/m^2_{ERA}, where the index abs denotes the absorber aperture area and the index ERA denotes the energy reference area. This corresponds to a three storey office building with entirely covered roof area by the absorber. The tested absorber types can be used as roof material. The storage design corresponds to 5 l/m^2_{ERA}.

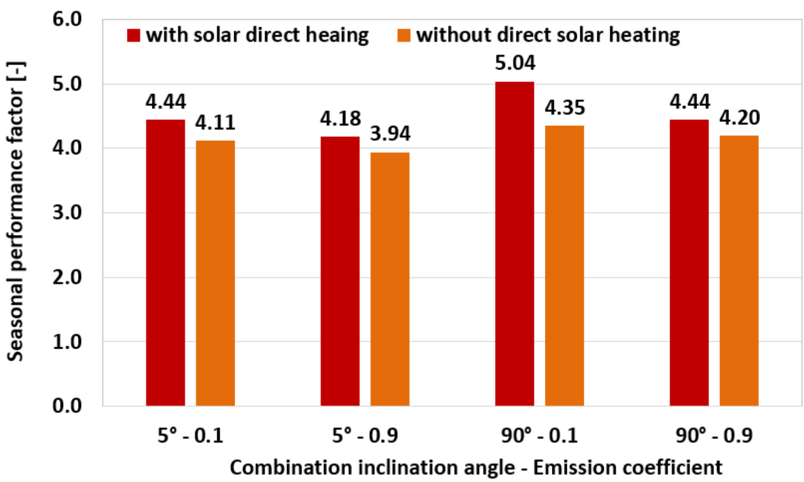

Fig. 5 Seasonal performance factor in space heating mode for extreme values of the absorber properties emission coefficient and inclination angle with and without direct solar heating

Fig. 5 shows the seasonal performance factor (SPF) in space heating mode for extreme combinations of the emission coefficient of 0.1 (selective) to 0.9 (non-selective) and the inclination angle of 5° (flat roof) to 90° (façade integration).

For the results the option of a direct solar heating has been considered only in one case to evaluate if the hydronic extra expense is justified. Without solar heating seasonal performance factors are in the range between 3.94 at adverse properties for the heating mode, and 4.35 for favorable properties (high inclination, selective coating). These values are in the range of ground-coupled heat pumps Recalculated to the heat source fraction, a degree of coverage of the solar energy is in the range of 75%-80%.

With the direct solar heating option, the SPF increases up to about 5, which makes up a difference of 0.7 to the SPF without direct solar heating for favorable properties.

Since the direct solar heating option depends on temperature levels higher than the required supply temperature for the TABS, it is clear that good properties of the absorber are needed to reach these required higher temperatures. Thus, the difference decreases with adverse properties to 0.25. Thus, it depends on absorber properties, if the hydronic expense seems justified.

6. Performance results in space cooling mode

Fig. 6 illustrates the configuration for space cooling operation with optional integration of the storage, where the absorber is used to reject the heat by radiation to the sky and by radiation and convection to the ambient air.

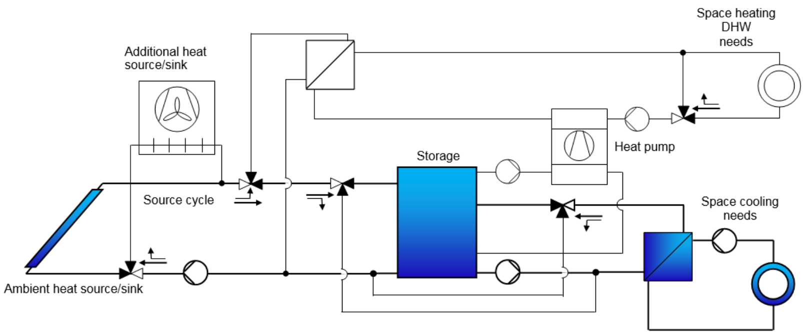

Fig. 6 System integration in space cooling mode with optional integration of the storage

The storage can be used if cooling loads of the room zone are lower than the free-cooling potential by nighttime cooling. The degree of coverage in free cooling operation for the different absorber properties is depicted in Fig. 7 with and without storage integration. In moderate summer climate of Zurich Meteoschweiz, high degree of coverage of above 90% for good absorber properties, i.e. high emission coefficient of the non-selective absorber and low inclination for better view factor to the sky.

For rather adverse properties, still above 80% of the cooling needs can be covered by free-cooling. For these properties, the inclination angle is no longer of importance, since the radiative fraction is low due to the low emission coefficient of 0.1. In general, the properties are of minor importance in moderate climate, since the convective fraction of the heat rejection is still high due to lower ambient nighttime temperature.

In Zurich Meteoschweiz, for instance, 85% of the nighttime hours are below 15°C. Regarding the storage integration, the increase of the degree of coverage is limited to about 3% with good properties, and about 5% in rather adverse properties in moderate climate.

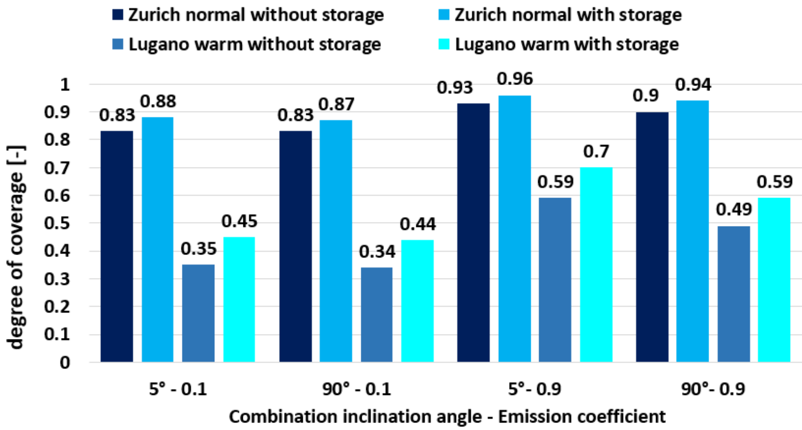

Fig. 7 System integration in dedicated space cooling mode with optional integration of the storage als cold storage

As comparison the extreme summer climate of Lugano warm year is included in the figure, as well. The degree of coverage notably decreases to about 60% with good absorber properties and to about 35% with rather adverse. Thus, the radiative fraction is more important than in moderate summer climate, since the potential for convective heat rejection is limited. Due to the more restricted potential for free cooling in warm summer nights, the storage integrations yields a higher increase of the degree of coverage, since nights with adverse weather conditions can be supplied by buffered cooling energy from the storage. Thus, the increase of degree of coverage with integrated storage is in the range of 10%.

Fig. 8 shows the seasonal performance factor in the cooling mode, which is combined of the electro-thermal amplification of the free-cooling mode, which only needs auxiliary energy for the pumping of the cooling fluid, and the EER of the back-up cooling by the heat pump in chiller mode. At favorable weather conditions and good absorber properties leading to high free-cooling degree of coverage, high performance factors of about 33 result, which is a typical range of free cooling applications. With decreasing free-cooling share and more back-up cooling, the performance factors decrease, however, even in extreme summer climate of Lugano warm, values above 8 are reached. Comparing the performance factors, it becomes clear that the emission coefficient has the higher impact on the performance than the inclination angle. If Zurich weather conditions are consider, the change of inclination angle from good to bad conditions reduces the SPF 33 to 26, while for changing emission coefficient, the value decreases to 15.

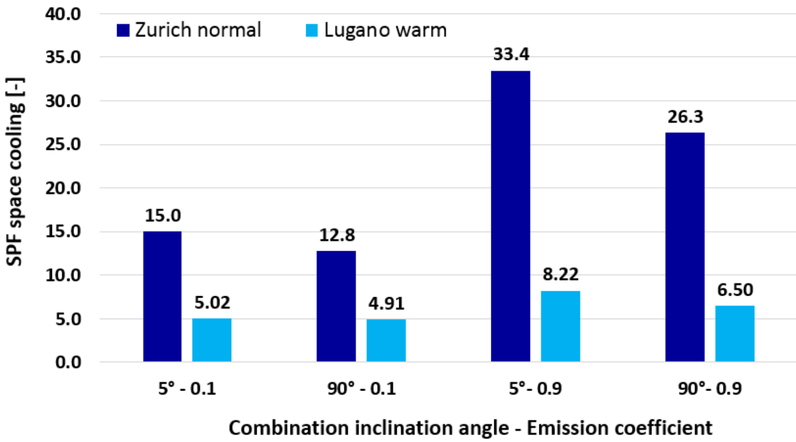

Fig. 8 Seasonal performance factor in cooling mode for different absorber properties and different different weather conditions

Moreover, the SPF illustrates that even if the same degree of coverage is reached, as for the emission coefficient of 0.1 in Zurich weather, the SPF is lower, since longer running times of the pump is needed due to the reduced cooling capacity of the absorber.

First economic estimations for the space cooling operation mode have been made and compared to a cooling operation by a ground borehole heat exchanger. The collector cost, when it is used as roof material, is about 300 €/m^2 which results in investment cost of 4000–7500 €/kW$_c$, with an estimated average cooling capacity in the range of 40-75 W/m^2. If ground borehole heat exchanger cost is set to 60-90 €/m and average cooling capacity of 15-30 W/ is assumed based on [5], the investment cost for the cooling operation would be 2000–6000 €/kW$_c$, which means, that the investment cost is in a similar range. However, for a better assessment, also the other operation modes would have to be considered.

7. Discussion and conclusions

Based on test rig measurements of absorbers with different properties a simulation model of the absorber is developed and validated. The model is integrated in a system configuration suitable for multifunctional operation in space heating and cooling in order to evaluate the key characteristics of degree of coverage and seasonal performance factors for the operation modes.

In space heating operation for buildings up to three storey, i.e. an absorber size of 0.33 m$^2_{abs}$/m$^2_{ERA}$, seasonal performance factors of the heat pump operation with the only source energy of the solar absorber reaches values in the range of 4 without direct solar heating, which corresponds to typical values of ground-source heat pumps. With direct solar heating SPF of up to 5 can be reached. Selective properties are of minor importance for the absorber operation as heat source, since the absorber operation temperature is close to the ambient temperature, and thus, losses to the ambiance are low. However, in order to increase direct solar heating, which significantly improves the SPF of the space heating operation, selective properties are essential in order to reach the necessary temperature level.

In space cooling operation, high degrees of coverage in the range of 80% to above 90% are reached. In moderate climate also the non-selective properties are not so predominant, since there is still potential for heat rejection by convection. In extreme summer climate, though, with higher nighttime temperatures, the radiation fractions and thereby the impact of the non-selective properties are more important. The impact of the non-selective properties is also visible in the SPF of the cooling operation, which is significantly decreased from 33 to 15 with a change from non-selective to selective properties.

Summarizing, both in space heating and cooling operation high performance values are achieved with the absorber as only heat source and sink, respectively. However, based on the prevailing load situation, optimization potentials exist regarding the properties of the absorber.

Acknowledgment

The study is a Swiss contribution to the IEA HPT Annex 40 on heat pump concepts for nearly Zero Energy Buildings. Information on the Annex 40 is found on the project website http://www.annex40.net. The support and funding of the project by the Swiss Federal Office of Energy SFOE both for the Annex 40 and the project AKTIVA is highly acknowledged.

References

[1] EN 12975-2. *Thermal solar systems and components – part 2: test methods*, European standardisation committee, 2011

[2] M.Stegmann, E. Bertram, G. Rockendorf, S. Janßen: *Modell eines unverglasten photovoltaisch-thermischen Kollektors basierend auf genormten Prüfverfahren*, 22. Solarthermisches Symposium, Kloster Banz, 2012

[3] SIA 2024. *Standard use conditions for the energy and building technology*, Swiss society of engineer and architects, Zurich, 2006.

[4] SIA 2028. *Climate data for Building physics, Energy- and Building Technologies*, Swiss society of engineers and architects, Zurich, 2010

[5] Huber, A., Dott, R., Afjei, Th. *Heating and Cooling with ground-coupled borehole heat exchanger*, final report of SFOE research project, , Zurich, 2010