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Evaluation of solar heat source and sink in multi-functional heat pump operation

Carsten Wemhoener^{a*}, Simon Buesser^a, Roman Schwarz^{ab}, Lukas Rominger^a

^aHSR University of Applied Sciences Rapperswil, Oberseestrasse 10, CH-8640 Rapperswil, Switzerland

^bBasler und Hofmann AG, Forchstrasse 395, CH-8032 Zürich

Abstract

With increasing heat pump use, heat sources gain importance. For high performance, the heat source should deliver high temperature levels. Compared to outdoor air solar installations like unglazed collector or photovoltaic/thermal installations can extract energy from the ambient air, but also yield higher temperatures at solar irradiation.

To overcome cost barriers compared to cheaper outside air heat pumps, a multi-functional operation for direct solar space heating/domestic hot water (DHW) generation at high solar irradiation has advantages. During nighttime, also space cooling by heat rejection to the colder ambient temperatures/night sky can be provided which increases performance of the overall system by multi-functional integration.

Test rig measurement of solar components as heat sink are evaluated and seasonal performance calculations are performed by simulation. Results indicate that in particular in buildings with higher space cooling and DHW shares, solar components can yield higher overall seasonal performance factors than outdoor-air heat pumps. Night cooling capacities can be enhanced by an evaporation on the collector, which also enables to vary surface properties to adapt to DHW production during daytime and space cooling during nighttime.

Keywords: Solar heat source, evaporative cooling, nZEB, multifunctional heat pump design

1. Introduction

Currently, residential buildings are seldom cooled actively in central European countries like Switzerland, while in office buildings, there is already a cooling demand due to higher internal gains. However, recent studies indicate, that due to increasing outdoor air temperatures, rising number of electric devices and higher comfort requirements, also residential cooling demands will increase notably until the mid of the 21st century.

In [1] an increase of the cooling demand in residential buildings in Switzerland of 300% to 700% for the reference year of 2060 has been evaluated by simulations, see Fig. 1. Since buildings have a long life cycle, it is thus important to consider changing boundary conditions already in the planning phase. In addition to purely passive measures regarding the design of the building envelope, efficient cooling processes must also be developed in order to maintain comfort conditions, but limit the electrical expenditure for the cooling function.

Free cooling methods have already been introduced, but mainly in non-residential buildings. In residential buildings free cooling methods are often limited to nighttime ventilation or ground-coupled free cooling when a ground-coupled heat pump is used as heat generator. A possibility of free cooling in residential buildings, which is not much applied so far, is the heat dissipation by activated outer surfaces of the building envelope, e.g. those installed with solar thermal components. These components, which are designed to generate heat, can also reject heat to the ambience during nighttime operation, under the condition that there is a good thermal connection to the ambience.

* Corresponding author. Tel.: +41 55 222 43 25
E-mail address: carsten.wemhoener@hsr.ch

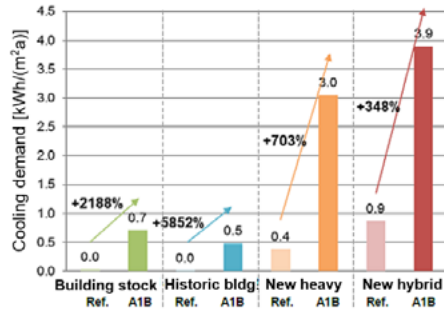


Fig. 1. Longterm development of residential cooling demands in Switzerland to the reference year 2060 [1]

In addition to pure heat dissipation to the outside air by convection, heat dissipation by infrared radiosity to the ambience and particularly to the sky is used, since a cloudless night sky has a significant lower equivalent sky temperature that is up to 20 K colder than the outdoor air temperature.

Fig. 2 shows the cooling mechanisms that can be used for nighttime cooling on the outer surfaces of buildings. The heat emission is especially favourable for uncovered solar components, which are in direct contact to the ambience. An increase in the cooling capacity of these components can be achieved by an additional evaporative cooling, if the surface of the components is wetted with water. In order to have a sustainable water source, reuse of decentralized treated grey- and wastewater is investigated as water for wetting the absorber.

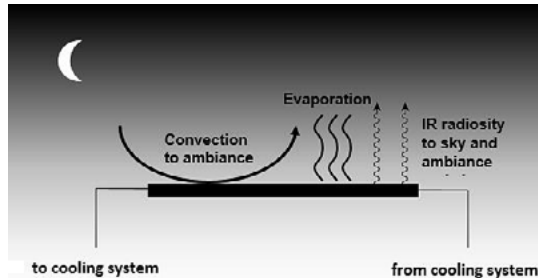


Fig. 2. Different cooling mechanisms on building outer surfaces

2. Simulation case study

In order to evaluate the feasibility of free cooling by the outer building surfaces, simulation studies were carried out for residential and office buildings. The simulations for residential buildings were carried out for a single- and multi-family house. For both types of buildings, energy-efficient new buildings have been considered that meet the requirements of the Swiss building directive MuKEN 2014 [5]. Summarizing, the following building cases were considered in the simulation study:

- Single family building as low energy (according to Swiss label MINERGIE) and passive house level (according to the Swiss label MINERGIE-P)
- Multi family building as low energy (according to Swiss label MINERGIE) and passive house level (according to the Swiss label MINERGIE-P)
- Office building according to the future Swiss building directive MuKEN 2014

The varied building parameters are given in chap. 2.1. In this publication, the investigations of the residential buildings, in particular in single-family buildings, are presented. Results for the office buildings examined show that high free cooling fractions of 80% to almost 100% can be achieved for Zurich Meteoschweiz weather station according to the Swiss guideline SIA 2028 [2] and boundary conditions of use according to SIA 2024 [3], depending on comfort requirements and properties of the outer building surface. This means, that active cooling by a chiller can be significantly reduced to back-up operation for the cases of adverse weather conditions with high nighttime temperatures.

Since typical nighttime air temperatures in Zurich Meteoschweiz weather are in the range of 15 °C, there is a good potential for cooling by outer surfaces, and the mentioned high fractions of 80 – 100% can be reached.

2.1 Building parameters

The single-family house has an energy reference area of 200 m². The U-value of the outer walls with U_{AW} of 0.17 W/(m²K) corresponds to the requirements of the Swiss building directive MuKEn 2014. The window fraction of 40% is evenly distributed across all façade orientations. The windows are triple glazed with an U_w -value of 1.0 W/(m²K) and a low fraction of the frame of only 10%. The g-value of 0.5 is in the typical range for triple glazing. For shading, variants are calculated that reflect the user behavior.

With optimal shading, from 200 W/m² irradiance and a room temperature of 23.5 °C, the total energy transmission is reduced to a g-value of 0.1. Irradiance of 400 W/m² and 600 W/m² are considered as variants for non-optimal shading and 1000 W/m² as unshaded case. For the hot water consumption, 150 l or 37.5 l/person with a used temperature of 55 °C were kept constantly throughout the year, which corresponds to an energy consumption of 2900 kWh or 14.5 kWh/(m²yr) used energy for the hot water demand.

The multi-family building has five stories with a total of 10 flats. The total energy reference area is 1500 m². The U-value of the outer walls is with a U-value of 0.185 W/(m²K) just above the limit value according to MuKEn 2014 and the U-value of the triple-glazed window with a frame proportion of 10% with U_w of 1.2 W/(m²K) is also slightly higher than the requirement for single building components. The g-value is 0.5, which is reduced to 0.14 when shading is activated. Shading is controlled dependent on the façade orientation. The activation of the shading of 200/400/600 W/m² irradiance on the façade is also varied in order to model different user behavior. The occupancy of the flats with 5 persons or one person area of 30 m²/person is higher than in a single-family house with a person specific area of 50 m²/person. Hot water consumption is assumed to be a slightly lower consumption of 30 l/person inline with the standards for multi-family buildings at a hot water temperature of 55 °C.

The residential buildings are equipped with mechanical ventilation and heat recovery, which has a thermal efficiency of 80%. In summer mode, heat recovery is reduced to 10% for modelling a summer bypass. The residential buildings are also both equipped with floor heating, which corresponds with 0.1 m pipe spacing to a rather large dimensioned floor heating, which enables low flow temperatures and thus creates favourable conditions for renewable energy use. The floor heating serves as emission system for both heating and free cooling operation.

2.2 System configuration

The building technology consists of a solar absorber, which is connected to a water-glycol source storage tank and serves as the only heat source for the heat pump. The heat pump operates in both heating and hot water mode. If the temperature level of the solar absorber is high enough, the hot water generation can also be switched-over to the absorber and be carried out directly with the solar absorber. In this study a selective absorber is considered, which can reach the hot water temperatures in summer operation due to the reduced radiative losses at higher temperatures. Furthermore, both a buffer tank for heating operation and the hot water tank are integrated. In cooling mode, the source storage is used as a cold storage. Then the absorber circuit is operated during the night for heat losses to the ambience in order to cool down the storage tank. When charging the storage tank with the heat extracted from the building by the floor heating, the comfort limit of a floor surface temperature of at least 19 °C must be considered. Table 1 summarizes the parameters of the single-family and multi-family house.

Table 1. Building and system parameters for the single-and multi-family building

Building and system parameters	Single-family house	Multi-family house
Residents/People	4	50
Window fraction	40%	40%
Energy reference area (ERA) [m ²]	200	1500
Annual heating demand [kWh/(m ² _{ERA} yr)]	25	15
Annual hot water demand [kWh/(m ² _{ERA} yr)]	14.5	19.5
Annual cooling demand [kWh/(m ² _{ERA} yr)]	4-6	4-6
Absorber area [m ² _{ABS}]	11-18	71-178

The hot water demand of the multi-family building exceeds the heating energy demand due to a low space heating demand of 15 kWh/(m²yr) on average among the flat, ranging from 9.3 kWh/(m²yr) of a flat on the third floor in south orientation to 27.4 kWh/(m²yr) of a flat in north orientation on the top floor. The low space heating demand is due to the lower area-to-volume ratio of the multi-family house.

In addition, the multi-family house has a higher occupancy with 30 m²/person, which increases the hot water requirements and also lowers the space heating needs due to about two-thirds higher internal gains compared to the single-family house. However, the loads for equipment and lighting remain the same. The cooling requirement is with an average of 4 kWh/(m²yr) still moderate and ranges from 2.6 to 4.8 kWh/(m²yr) among the flats. It is slightly lower than for a single-family house, partly for similar reasons as for heating, e.g. due to the smaller outer surface area compared to the energy reference area and also due to slightly lower window area per energy reference area. In Switzerland, the energy reference area comprises all treated areas for heating or cooling of the building storeys as gross area, i.e. including the insulation layer thickness.

3. Results of the feasibility study

In the following results for the single family house are presented in more detail. Results on the multi-family house are discussed in more detail in [7] and are shortly summarised in chapter 3.3.

3.1 Energies and seasonal performance factors single-family house

For the single family house, the following variants are considered:

- Variation of collector area 10.7 m² (6 absorbers) and 17.8 m² (10 absorbers)
- Variation of activation of the shading of 200/400/600 W/m². Moreover, an unshaded case (activation at 1000 W/m²) is considered.
- Variation building envelope according to the Swiss low energy and ultra-low energy house labels MINERGIE®- and MINERGIE-P® [4]
- Variation of weather boundary conditions Zurich Meteoschweiz normal and warm data set

The MINERGIE®-single family house has shading of 200 W/m² and an effective space heating demand including the ventilation heat recovery of 26.1 kWh/(m²yr). The DHW demand is 14.6 kWh/(m²yr) and the space cooling demand is by the good shading moderate with a 4 kWh/(m²yr). With a MINERGIE-P®-building envelope the space heating demand decreases to 17.1 kWh/(m²yr) and the space cooling demand increases to 4.8 kWh/(m²yr). Thereby, the space heating demand approaches the DHW demand. Despite the moderate space cooling demands at optimal shading the cooling demand surpasses on single days the DHW demand in the summer months of June - August, where peaks in the cooling demand are observed.

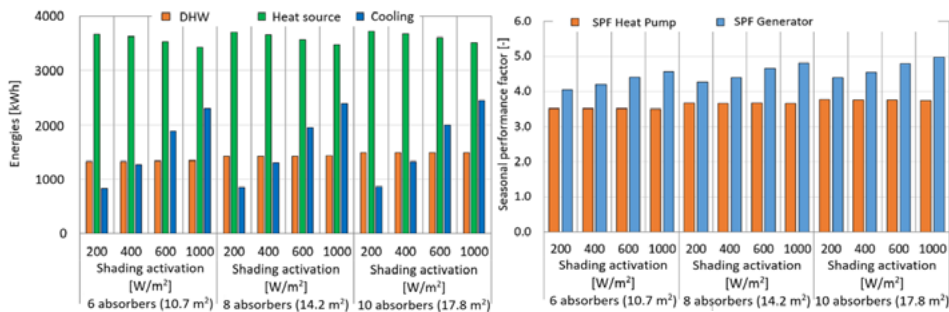


Fig. 3. Collector yield of different operation modes (left) and seasonal performance factor of the heat pump and overall (right)

Even without solar thermal DHW production, which reduces the heat pump operation in summer time, to cover the cooling demand only in simultaneous operation with the heat pump in DHW operation would be difficult. Fig. 3 left shows the collector yield for the different collector areas at variation of the shading activation of 200 W/m² to 1000 W/m² (unshaded). The space heating operation is not affected by the higher solar gains in the case of lower shading. The DHW yield is only dependent on the absorber area, and is independent of the shading. At lower absorber area the solar DHW fraction is about ca. 40%, at higher absorber areas it increases to ca. 46%. In the summer months, it is about 75-90%.

The yield of the absorber in the space cooling operation, though, is directly correlated to the shading of the building, since the space cooling loads increase with reduced shading of the building. In the unshaded case, the absorber yield in cooling is about 3 times of the space cooling energy with optimal shading. In Fig. 3 right, the performance factors of the heat pump and the overall performance factor of all generators is contrasted. As expected the shading affects the performance factors of the heat pump only slightly. The performance factor in space heating operation is almost 4, in DHW operation almost 3, which corresponds to an overall performance of 3.5-3.8.

At higher absorber area, the performance factor increases due to higher source temperatures in space heating and DHW operation by about 0.1-0.2, leading to an overall performance of 3.8.

For the ultra low energy building (MINERGIE-P building), which is not depicted, the required yield in space heating is reduced by 25%. The solar fraction corresponds to the low energy single family house (MINERGIE building). The absorber yield in cooling operation corresponds at optimal shading to the low energy house, in the unshaded case, it increases by 15%.

With smaller absorber areas and lower outside temperature with little solar irradiation, problems with the lower operation limit of the heat pump may occur, which may require an emergency heating or a second heat source, which, however, has not been modelled. At larger absorber areas, the source temperature level in the source storage increases, and thereby also the performance factor of the heat pump, which mitigates problems with the lower temperature limit of the heat pump.

For the consideration of the overall seasonal performance factor of the heat pump and the direct solar and free cooling operation, the seasonal performance of the generator (SPF_{gen}), which is depicted in Fig. 3 right. The SPF_{gen} describes the overall efficiency with the application of multiple generators and relates the thermal energy to the electricity input. In this case the condenser heat and the direct solar thermal yield of the collector is related to the electricity for the heat pump and the collector pump. Pumping energy for the source energy of the heat pump, the DHW production and free cooling is taken into account. For all operation modes, values up to around 5 can be obtained for the SPF_{gen} , which is by 0.6-0.8 higher than the SPF_{HP} , as shown in Fig. 3 left.

3.2 Thermal comfort single family house

The comfort evaluation is depicted uniformly for an absorber area of 17.8 m². The comfort is evaluated by the operative temperature according to the requirement of the SIA 180 [6] for air-conditioned buildings, even though the building is not actively conditioned, but just free cooling is applied. The impact of the humidity is not evaluated, since with free cooling operation, the relative humidity cannot be affected. As the winter room temperatures are well in the comfort range of SIA 180 (temperature band 20.5 °C to 24.5 °C), the summer comfort only is depicted in the following. Here, the operation of the shading as well as the free cooling operation is decisive.

Fig. 4 shows the room temperatures in the summer season of mid of April until the end of September without shading (Fig. 4 left) and with optimal shading (Fig.4 right), with and without free cooling operation in both figures. Without shading, a maximum temperature in the range of 33 °C is reached. By a free cooling operation without shading, the temperature can be limited to a maximum of 28 °C. However, thereby, single comfort violation also occur with free cooling, as the comfort limit is set to 26.5 °C in the standard SIA 180., see also Fig. 5. By an optimal shading without free cooling, maximum temperatures are limited to 29 °C.

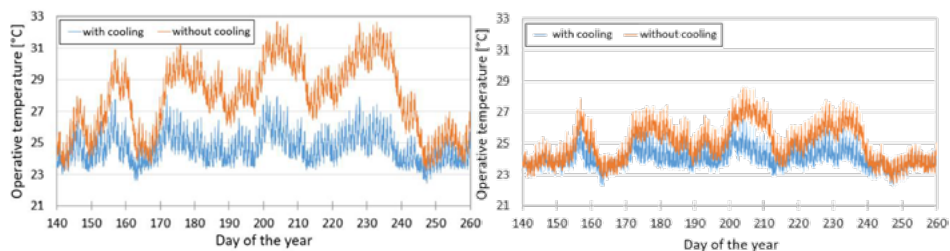


Fig. 4. Room temperatures in the summer without shading (left) and with optimal shading (right) with and without free cooling

With optimal shading starting with irradiation values of 200 W/m² and free cooling operation the temperatures stay in the comfort range. In Fig. 5 the hourly averaged room temperatures are depicted in the comfort range of SIA 180 for the annual period based on the moving average of the last 48 h of the ambient temperature.

In winter operation the temperature are well in the comfort range with temperatures of 22-23 °C, which are often measured in monitoring projects.

In Fig. 5 left the room temperatures with optimal shading and no free cooling operation are depicted. The 340 overheating hours outside the comfort range mainly occur in summer operation. In Fig. 5 middle the room temperatures without shading, but with free cooling are depicted. The overheating hours are reduced to 260 with about 150 hours occurring in the mid-season and about 110 hours in the summer. The overheating hours in the mid-season indicate optimisation potentials in the control, as the capacity of the collector at colder outdoor condition should be sufficient. Free cooling allows to reduce significantly the number of overheating hours that occur during summer time. Fig. 5 right shows the comfort range at optimal shading and free cooling operation.

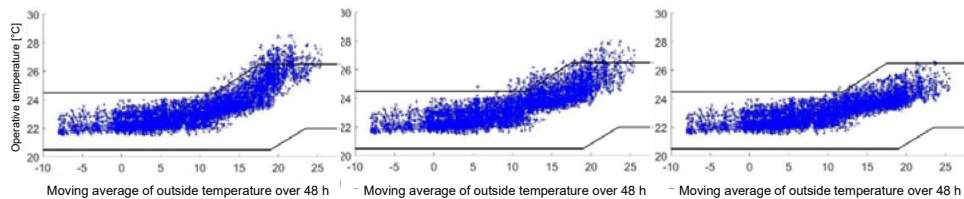


Fig. 5. Room temperature with shading and without free cooling (left) and without shading but with free cooling (middle) as well as with optimal shading and free cooling (right)

No overheating occurs anymore and there is even a reserve until the comfort boundary is reached. Thus, the free cooling operation can compensate a non-optimal shading within limits. But a shading cannot be entirely replace with the considered design of the free cooling system, in particular at high outdoor temperatures.

3.3 Summary of results of the multi-family house

For the multi-family building similar indicators are evaluated as for the single family building. The main results are summarised below. However, the energy demands and system efficiencies are affected by the specific building parameters and load. For instance, the multi-family building has a more compact building envelope with a lower surface-to-volume ratio paired with a higher occupancy of 30 m²/person and thereby higher internal gains. This lowers the space heating demand to an average of 15 kWh/(m²·yr). Nevertheless, depending on the location in north or south orientation, the space heating demand varies among the flats. But, due to the higher occupancy, the specific DHW demand increases to 19.7 kWh/(m²·yr) and has a higher impact on the overall performance. Cooling demand is thereby considered the same as in the single family house. The same variations as for the single family house are considered.

The seasonal performance factor of the heat pump in the multi-family house is in the range of 4.5–4.9 depending on the collector area. For larger collector area the source temperature for the space heating operation increases. In the DHW operation the average SPF is 2.8, with a moderate increase of 0.1 with larger collector areas, as due to the direct solar fraction, the heat pump is producing the water at higher temperature levels. Meanwhile, the higher impact of the DHW operation the performance factor increases by 0.2-0.3 with larger collector area leading to performance factor of the heat pump SPF_{HP} in the range of 3.5–3.8.

The solar fraction increases with doubled collector area only moderately from 33% to 40%. The moderate increase is due to the limited DHW storage volume. With an extension of the storage size, the solar fraction could be increased up to 50%. The overall performance factor including heat pump, direct solar fraction and the free cooling operation SPF_{gen} yields higher performance values in the range of 4.5–5.0. Thereby, also the shading has an impact, since with reduced shading the cooling demand and the free cooling fraction increases.

Also the thermal comfort shows the same tendencies as in the single family building, but the difference between shading-only and free cooling operation becomes more distinct. The thermal comfort in winter can be maintained quite well. For a collector area of 107 m², optimal shading and no free cooling, about 1000 overheating hours are observed, so shading-only is not sufficient. With free cooling operation overheating hours can be limited to 100, and violations of the comfort range are mainly in the mid-season and may be further reduced with optimised control. With a combination of optimal shading and free cooling operation the comfort range can be maintained the whole summer with temperatures up to 26 °C, and still holding a little reserve regarding the comfort limit. For warmer boundary conditions of a warm summer some overheating hours result even with optimised shading and free cooling. An additional active cooling by the heat pump would have to be applied to entirely stay in the comfort range.

4. Test rig results for the space cooling operation

In order to further characterise the space cooling operation with test rig results, measurement have been performed on a selectively coated unglazed solar collector on the accredited test rig of the HSR Institute SPF, which is the national test centre of Switzerland for solar thermal collector. Fig. 6 left shows the unglazed solar collector on the test rig and Fig. 6 right depicts a sketch of the measurement system including a legend of the measurement points. In order to determine the capacity of the absorber in free cooling mode, the inlet and outlet temperatures of the absorber fluid are measured. With the measured volume flow the enthalpy change on the fluid side and thereby the cooling capacity can be evaluated. The fluid is a water-glycol mixture.

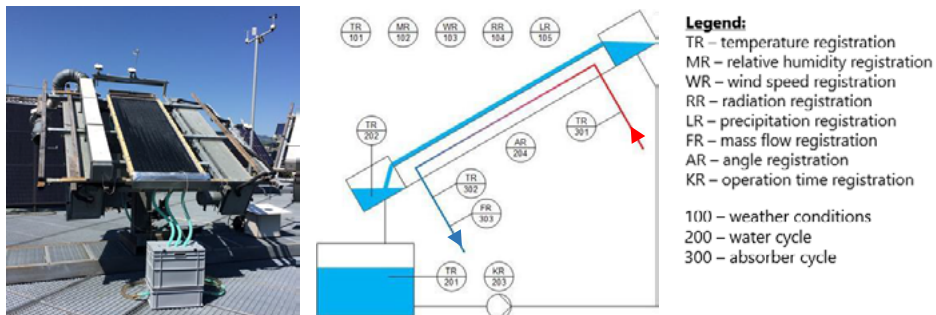


Fig. 6. Unglazed solar collector on the test rig (left) and sketch of the test rig with measurement points including the legend of the measurement points (right)

Additionally, the weather boundary conditions of the short wave solar irradiation, the downward long wave radiation, the ambient temperature and relative humidity as well as the wind speed and precipitation are measured in order to characterize the impact on the cooling capacity. As expenditure for the free cooling operations the electricity input to the pump is measured. For the operation of the system, continuous and cyclic operation can be run. During continuous operation, the absorber surface is continuously wetted by a water film running down on the absorber surface. In cyclic operation, the film is only continued for 10 seconds every 2 minutes, which saves pump electricity.

In the following figures, the cooling capacity for different weather boundary conditions is depicted. Fig. 7 left shows the temperatures linked to the nighttime absorber operation in cooling mode. The inlet and outlet temperature are decisive for the evaluation of the cooling capacity. The inlet temperature is kept constant at about 20 °C. By the high volume flow rate of 200 l/h, the temperature difference between inlet and outlet is limited to 2 K. With a lower mass flow rate, the temperature difference can be increased, but the capacity is reduced, since the average temperature difference to the ambient is decreased. Thus, as in space heating, a lower mass flow decreases the outlet temperature, but also the cooling capacity. The temperature of the tank characterizes the temperature of the water film on the absorber. In this case, a night with a moderate ambient temperature and a clear sky is depicted. This can be seen at the temperature difference to the (fictive) sky temperature that characterizes the long wave radiation exchange between the absorber and the sky.

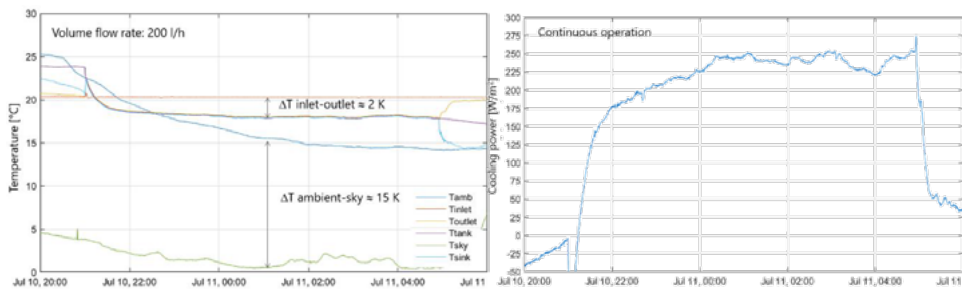


Fig. 7. Temperatures (left) and cooling capacity (right) of the unglazed solar collector on the test rig at favourable nighttime ambient conditions with clear sky and moderate ambient temperature

Since the water vapour in the atmosphere absorbs long wave radiation and reemits it as long wave downward radiation, a clear sky is a more favourable weather condition than a cloudy sky and the sky temperature reaches values up to 20 K lower than the ambient air temperature.

Fig. 7 right depicts the cooling capacity of the absorber. At favourable conditions a cooling capacity in the range of 250 W/m² is reached. Until about 10 p.m., the ambient temperature is still higher than the average absorber temperature, which limits the cooling capacity. Nevertheless, even at warmer ambient temperatures, a cooling capacity by radiation and evaporation surpasses the convective gains by the ambient temperature. During the night, the cooling capacity is increased with the decrease of the ambient temperature, which is in line with the decrease of temperatures from the building as well as the inlet temperature to the collector in real operation.

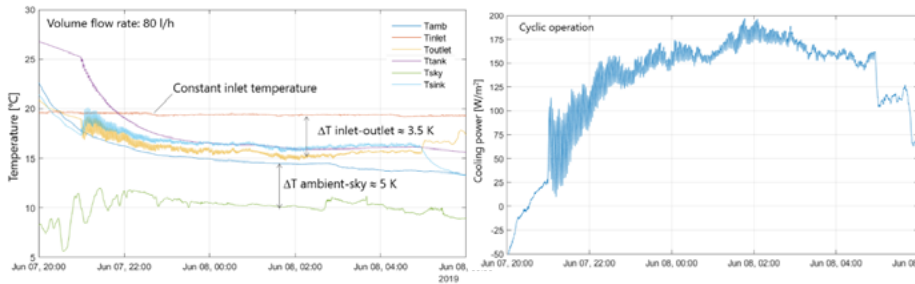


Fig. 8. Temperatures (left) and cooling capacity (right) of the unglazed solar collector on the test rig at moderate nighttime ambient conditions with cloudy sky and moderate ambient temperature

Fig. 8 depicts a cyclic operation with cloudy sky conditions and a lower mass flow rate of 80 l/h, which is the nominal mass flow of the collector at heating conditions. In this case, the temperature difference between the ambient and the sky temperature decreases to only 5 K, which is due to a higher long wave downward radiation from the sky. Despite the lower cooling capacity, which is depicted in Fig. 8 right, a temperature difference for 3.5 K over the absorber is reached due to the lower mass flow rate.

The cooling capacity is not constant due to the cyclic operation. The water on the collector surface is partly evaporating, which has also influence on the radiation properties, since the collector has a selective coating. If water is on the collector, the long-wave emissivity in the infrared spectrum ϵ_{IR} is defined by the water to values around $\epsilon_{IR}=0.95$. However, if the water is evaporated, the emissivity changes to the one of the selective coating, which has an emissivity around $\epsilon_{IR}=0.15$. Thus, the evaporative and radiative cooling capacity is reduce at dry parts of the collector surface, which leads to a decrease of the cooling capacity in cyclic operation. In the beginning of the night, the water for the wetting of the absorber is still warm, which leads to the higher swing in the temperatures. The swing is successively reduced down to differences of about 20 W/m². This effect of the selective coating is depicted in Fig. 9. In this case, the inlet temperature to the collector is adapted to the ambient temperature. Until about 1:30 am the collector is wetted. Then, the water film is stopped for two hours until 3:30 am, and the collector is drying completely. In the drying process cooling capacity successively decreases, and for the dry collector, the cooling capacity is strongly decreased from initially 125 W/m² before the drying process down to values around 10 W/m² after complete drying of the collector surface.

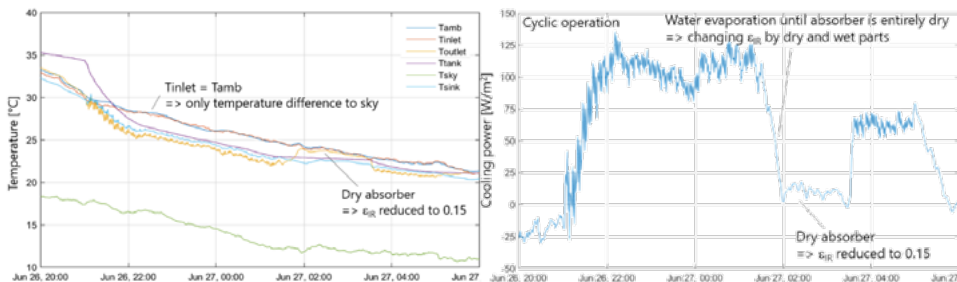


Fig. 9. Temperature difference for wet and dry absorber (left) and respective cooling capacity (right)

At the test rig, there is also the option to switch-on artificial wind in the range of wind speed of 1-3 m/s. The ventilator is located directly along the long side of the absorber and shown as a white box in Fig. 6. As the wind changes both the convective and evaporation heat transfer coefficients, a significant increase of the cooling capacity is measured with artificial wind. Fig. 10 left depicts the temperatures and Fig. 10 right the cooling capacity at clear sky conditions and artificial wind of 3 m/s. A cooling capacity up to 450 W/m² is measured at ambient temperature of 13 °C and a temperature difference to the sky of 15 K.

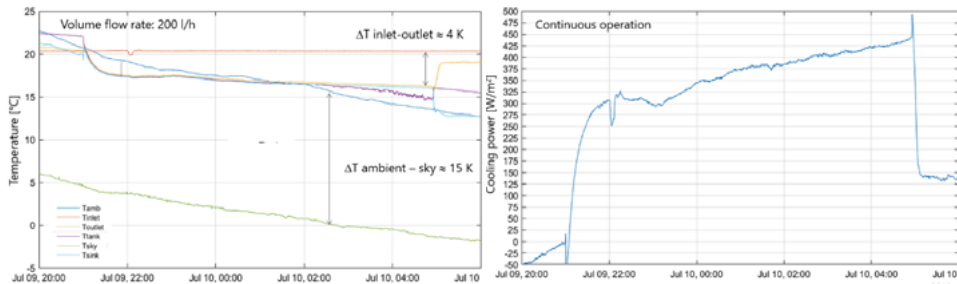


Fig. 10. Temperatures (left) and cooling capacity (right) with 3 m/s artificial wind on the absorber surface at clear sky conditions

5. Conclusion and Outlook

Result of a feasibility study for different building types and heat pump systems with solar heat source confirm a good performance of the heat pump in space heating and DHW operation with an overall SPF in the range of 3.5 – 3.8. By direct solar operation in DHW mode during the summer with higher solar irradiation values, the DHW performance can be increased above the pure heat pump operation to values above 4. Moreover, the unglazed solar collector can also be used for the integration of the free cooling operation during nighttime, where the collector rejects heat by convection, radiation and evaporation, if the collector surface is wetted. Besides the evaporative cooling effect by wetting the collector surface, also radiative properties can be changed in case of a selective coating of the collector. Thereby, a selective coating helps to reach higher temperature in the DHW operation during daytime due to a reduction of the radiative losses, while it enhances radiation losses due to the high emissivity of water up to 95% in nighttime of the free cooling operation. The overall performance including the free cooling operation can reach overall SPF values above 5 in low energy buildings depending on the space cooling and DHW loads.

For the feasibility study, however, only limited test data including the evaporative cooling were available. Therefore, test rig measurements have been carried out at the accredited test rig of the national Swiss solar test center for solar thermal systems at the HSR Rapperswil, which confirm good specific cooling capacities in the range of 100 – 300 W/m² depending on the ambient conditions, which are even higher than the values used in the feasibility study. Wind on the collector surface enhances the convective and evaporative heat transfer to the ambience and values up to 450 W/m² have been measured at a wind speed of 3 m/s at the collector surface. However, in summer, low wind speeds at night are predominant, thus the potential for higher cooling capacities by wind is limited.

In the frame of the project, also the application of treated greywater as water source for the space cooling operation is investigated in collaboration with the Institute of Ecopreneurship of the University of Applied Sciences Northwestern Switzerland FHNW in the frame of the Swiss Competence Centre for Energy Research, Efficiency of Industrial Processes (SCCER-EIP). First results indicate that fouling and scaling on the collector surface can be effectively avoided by the water treatment in a decentral membrane bioreactor (MBR) water treatment process, and cooling capacities are not affected. Also, bacteria growth meets the requirements for evaporative cooling, so treated wastewater can be a sustainable water source for the evaporative free cooling. Experiments and respective simulation studies will be carried on in order to further characterize the process and free cooling potentials.

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