Alternative cooling systems for nearly zero-energy buildings

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Abstract

The paper deals with the issue of nearly zero-energy buildings from the point of view of energy use for heating and cooling. Consumption of heat can be reduced very effectively today by using a good insulation of the building envelope, by effective use of solar gains or by installing heat recovery units into ventilation systems. The problem occurs with the reduction of energy consumption for cooling. To illustrate the possible solutions of alternative cooling systems were created two case studies of absorption solar cooling and adsorption solar cooling using seasonal heat storage below the building and the primary energy use by those systems was evaluated.

Keywords: alternative cooling, solar cooling, simulation

1. Introduction

In the context of nearly zero energy buildings is not difficult to reduce energy consumption for heating because of good building envelope thermal insulation, usage of effective heat recovery units in ventilation systems, usage of suitable heat sources (eg. heat pumps) and good orientation of glazed surfaces for maximizing of solar gains in winter. These facts however very often lead to overheating of buildings in the summer because of poor shading of glazed surfaces, poor building constructions thermal capacity and high internal heat gains.

Maximum reduction of energy demand for cooling is therefore a necessary step before designing a cooling system. This can be achieved especially by effective shading of glazed surfaces during high intensity of solar radiation. Another possible way of cooling demand reduction is nocturnal ventilation when external air temperature is lower than indoor air temperature, so buildings can be precooled during the night. Direct or indirect adiabatic cooling and free cooling can be useful as well.

2. Alternative cooling systems and cooling load reduction

Lower energy demand for cooling can be covered by cold source with lower cooling capacity and it is offering usage of alternative cold sources in combination with the high temperature cooling elements, which leads to minimizing energy consumption for cooling.

One of possible solutions can be for example absorption or adsorption cooling, which uses absorption or adsorption chiller as cold source. Both cooling units operates on the principle of sorption cycle where the refrigerant vapour is absorbed by so called absorbent and then expelled by heating up to a high temperature into the condenser. In condenser is the heat removed by cooling water and the refrigerant continues through the expansion valve into the evaporator. The refrigerant removes heat from chilled water and evaporates again. Compared to standard compression cooling, sorption cooling doesn't consume electric energy for compressor operation but only heat energy and electrical energy for circulation pumps.

Disadvantages of those cooling systems are a need of heat source providing high temperature of heating water and a need of condenser cooling. Consequently, sorption cooling systems are suitable for example for buildings with high production of waste heat from technological processes or for buildings with district heating etc.

Special application of sorption cooling is solar cooling system where the heat for cooling unit operation is provided by solar thermal collectors however it is necessary to use appropriate type and amount of collectors to achieve sufficient temperature of heating water.

3. Case study 1 – UCEEB Experimental Building, Buštěhrad (Czech Republic)

Absorption solar cooling systems aren't currently a standard solution for cooling of buildings, they are rather exceptional applications. Reasons are mostly operational-economic character. The main aim of this case study was to design absorption cooling system for the Experimental Building of University Centre of Energy Efficient Buildings (UCEEB), CTU in Buštěhrad (Czech Republic) and to optimize individual components in the terms of operating efficiency.

3.1 Input data

The building has four floors and a basement. In the east part are offices, west part is residential and in the centre of the building is the atrium. Main entrance to the building is from south side. The building was divided to seven zones for the purposes of thermal loads calculation (Figure 1 and 2). Flats and offices are divided to south and north part. Whole atrium is a separate zone, as well as basement and roof extension.

Heat load of building was determined from simulation in TRNSYS software using Meteonorm climate data for Prague with 15 minute time step. It was assumed that external blinds installed on building will be automatically closed when incident solar radiation exceeds 300 W/m^2. There has also been considered nocturnal ventilation when the interior temperature was higher than 24 °C and external temperature was lower than 18 °C. Nocturnal ventilation was interrupted when interior temperature falls below 20,5 °C. Air exchange ratio was 1 h^{-1} during nocturnal ventilation.

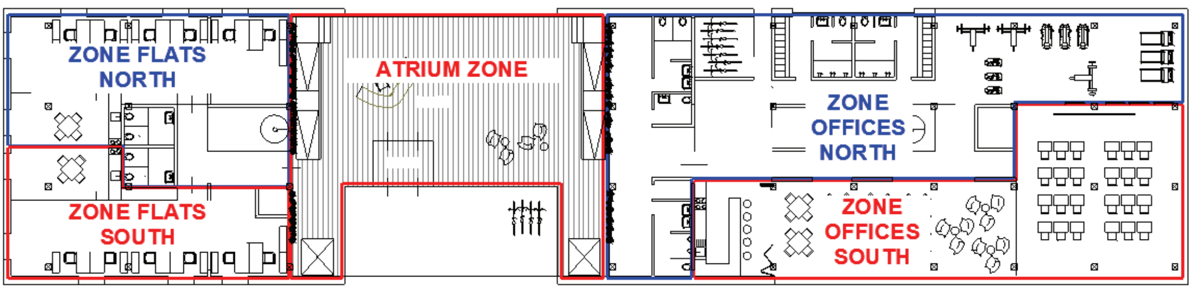

Figure 1. Typical floor plan and zones location.

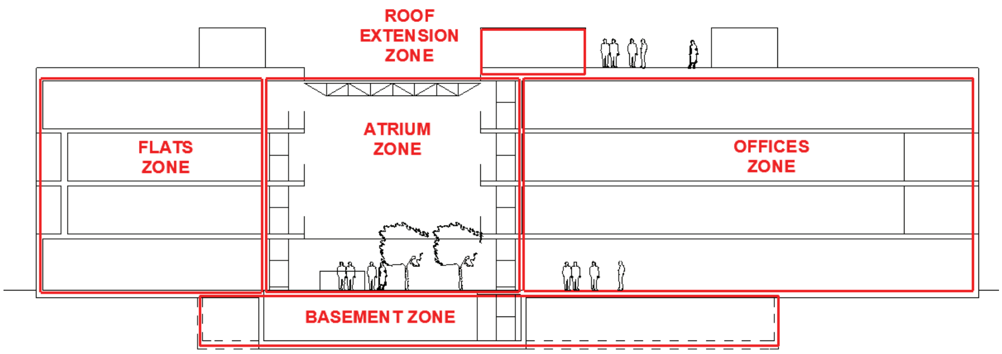

Figure 2. Building section and zones location.

Cooling was designed just for offices, other zones was not cooled. Final heat loads are shown on Figure 3. Maximum heat load is 24,45 kW and energy demand for cooling is 5431 kWh/year.

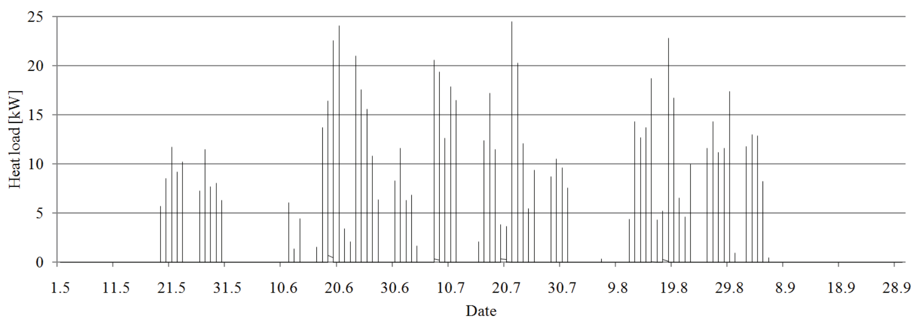

Figure 3. Heat loads in the period from 1st May to 1st October.

3.2 Design of absorption solar cooling system

For the design of individual parts of the absorption solar cooling system was created a dynamic model in TRNSYS simulation software. This model demonstrates possible form of absorption solar cooling system.

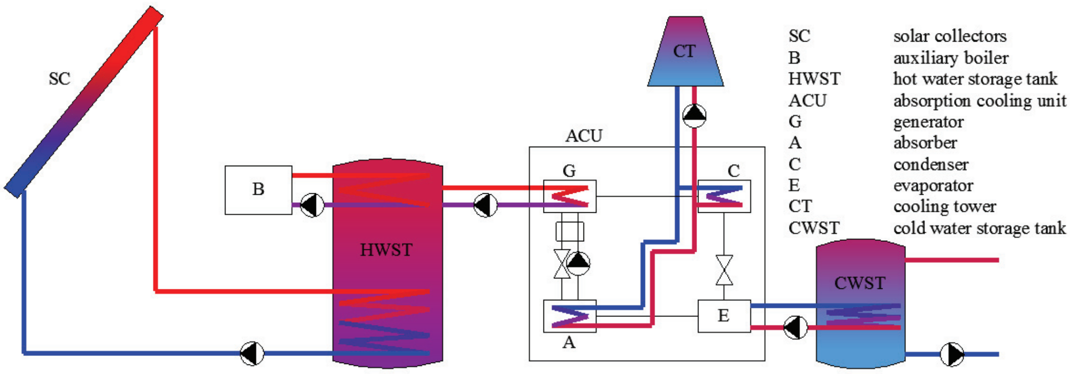

Figure 4. Absorption solar cooling system scheme [1].

3.2.1 Absorption cooling unit

As a cold source was used absorption cooling unit YAZAKI WFC-SC5 with cooling capacity of 17,6 kW (heating water temperature 88 °C, cooling water temperature 31 °C, chilled water temperature 7 °C). Actual capacity was calculated for every simulation time step according to actual temperatures and flowrates.

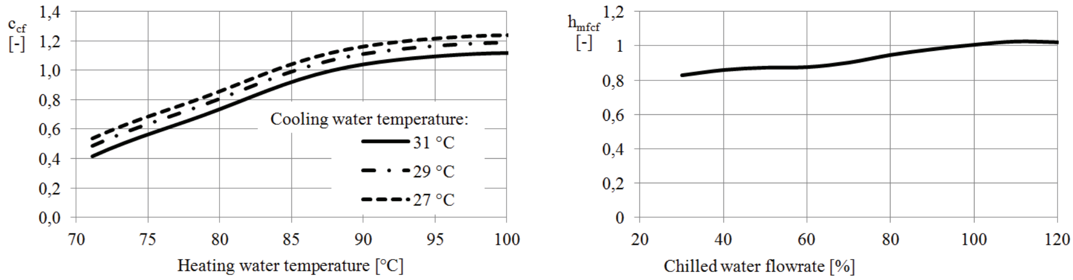

Figure 5. Performance characteristics of absorption cooling unit YAZAKI WFC-SC5 [2].

This cold source doesn't provide wide range of power control, so it is necessary to accumulate produced cold to cover consumptions peaks. Size of storage tank can be easily determined from difference between production and consumption of cold. Maximum difference is 21,91 kW which equals to the storage tank size of 3,71 m^3 at a temperature gradient of chilled water 6 K.

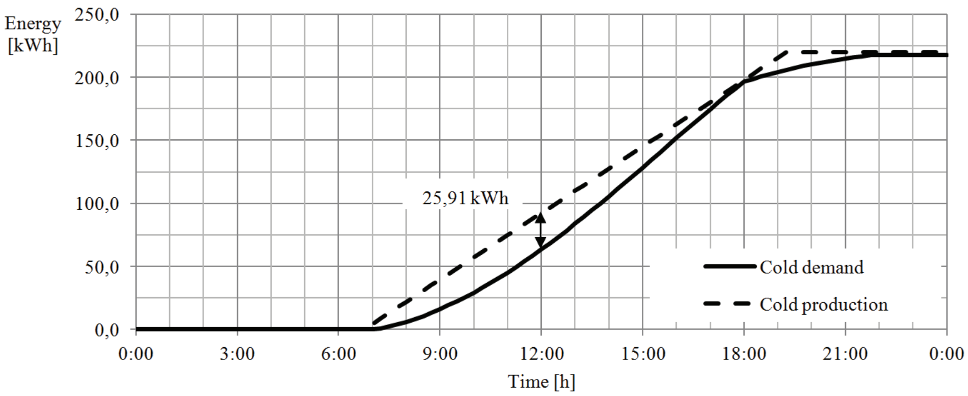

Figure 6. Determination of cold water storage tank volume from the difference between production and consumption of cold.

3.2.2 Solar thermal collectors

Primary heat source for absorption cooling unit were solar thermal collectors. It is necessary to use collectors with high output temperature for maximum efficiency of cooling unit. Theoretical heat demand for production 5431 kWh of cold was 7815 kWh of heat, estimated heat losses were 2500 kWh. Estimated heat demand was 10315 kWh/year. In the model were used solar thermal collectors THERMICS 30 HTH.

Simulation shows that solar gains generated by 23 pieces of solar thermal collectors in the period from 1st May to 1st October was 6207 kWh. Heat losses in distribution system were 1528 kWh. Total useful solar gains therefore were 4679 kWh. Remaining energy (1920 kWh) was generated by auxiliary gas heater.

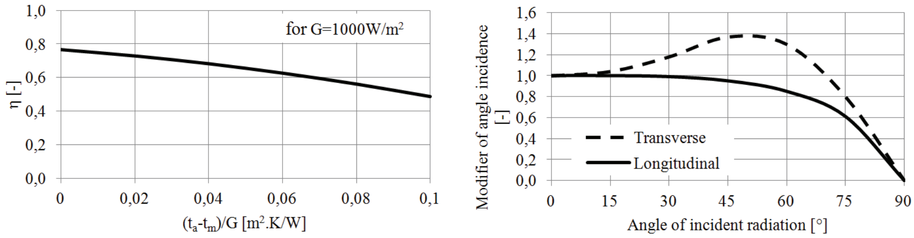

Figure 7. Efficiency curve (left) and optical characteristics (right) of solar thermal collectors THERMICS 30 DTH [3].

3.2.3 Condenser and absorber recooling

Condenser and absorber of absorption cooling unit have to be cooled. Cooling water is usually prepared in cooling tower according to the needs of cooling unit. In the cooling tower are not cooled just heat loads of the building but also heating energy used in generator of absorption cooling unit. In the simulation was used a cooling tower with temperature gradient of cooling water 30/35 °C and flowrate of 11 m^3/h.

3.2.4 Cold distribution

Chilled water outlet temperature is from 10 to 12 °C which is relatively high temperature compared to standard compression cooling system. For this temperature is ideal to use high temperature cooling elements (radiant cooled ceilings). It should be considered the minimum surface temperature to prevent condensation.

3.3 Final parameters of the system

Table 1. Final parameters of the designed absorption solar cooling system.

Absorption cooling unit YAZAKI WFC-SC5		
Chilled water circuit:	Cooling capacity	17,6 kW
	Flowrate	3,3 m3/h
	Temperature gradient	12,5/7 °C
Heating water circuit:	Heating capacity	25,1 kW
	Flowrate	5,2 m3/h
	Temperature gradient	88/73 °C
Cooling water circuit:	Cooling capacity	42,7 kW
	Flowrate	11,0 m3/h
	Temperature gradient	31/35 °C
Chilled water storage tank		
Storage tank volume:		3,7 m3
Surface heat flux:		4,38 W/K
Heating water storage tank		
Storage tank volume:		2,2 m3
Surface heat flux:		2,79 W/K
Solar thermal vacuum tube collectors THERMICS 30 HTH		
Amount:		23 ks
Total area:		96,3 m2
Total aperture area:		55,9 m2

Absorption solar cooling is a system which uses heat and electricity for cold production. The system efficiency can be easily expressed for example by energy efficiency ratio (EER) which represents ratio between produced cold and consumed energy. Following table shows partial calculated energy consumptions for production of 5470 kWh of cold. Total electrical input was 976 W, auxiliary heater was a gas boiler. The ratio of produced cold and consumed electricity is 15,27; the ratio of produced cold and consumed heat is 0,83. Partial delivered energy, total primary energy and non-renewable primary energy is shown in following table.

Table 2. Partial delivered energy, total primary energy and non-renewable primary energy.

Energy carriers	**Partial delivered energy**	**Total primary energy factor**	**Non-renewable primary energy factor**	**Total primary energy**	**Non-renewable primary energy**
	[kWh/rok]	[-]	[-]	[kWh/rok]	[kWh/rok]
Ambient energy	4679	1,0	0,0	4679	0
Gas	1920	1,1	1,1	2112	2112
Electricity	179	3,2	3,0	573	537
Total	6778			7364	2649

Absorption solar cooling is one of many alternatives to a compressor cooling systems, which can reduce the energy consumption of buildings in the terms of current trends and in the terms of delivered/bought energy. Its use is particularly beneficial for buildings with high production of waste heat (eg. industrial buildings) and also for buildings with high consumption of hot water (eg. hotels) where you can use the condensation heat from the refrigeration unit to preheat domestic hot water.

4. Case study 2 – Energy Centre, Pinkafeld (Austria)

Aim of this study was to design adsorption solar cooling system with seasonal heat accumulation to the ground under the building. The building, Energy Centre Pinkafeld (Austria), is two story building without basement designated as research facility for HVAC systems. On the first floor are simulation rooms, library and facility room. On the second floor are offices and archives. Glazed surfaces are situated mostly on the south, east and west facade for maximization of heat gains during winter. Atrium is ventilated naturally, so heat load during summer isn't considered for this space.

4.1 Input data

In the simulation external blinds were closed during summer when incident solar radiation was higher than 300 W/m^2. Nocturnal ventilation was performed when internal temperature was higher than 24 °C and external temperature was lower than 18 °C. Air exchange ratio was 1 h^{-1}.

Building was divided to three main zones for simulation purposes. First zone was eastern part with facility and archives, second zone was atrium and third zone was western part with simulation rooms and offices.

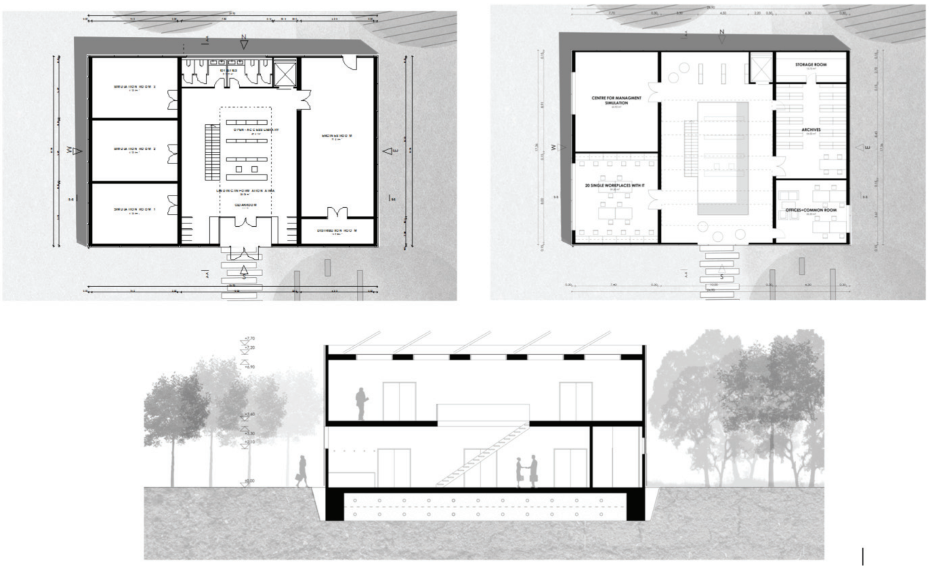

FIgure 8. First floor plan (left), second floor plan (right) and building section (down).

Maximum heat load during summer was 12,9 kW and energy demand for cooling was 5801 kWh/year. Maximum heat losses during winter was 6,9 kW and energy demand for heating was 10043 kWh/year.

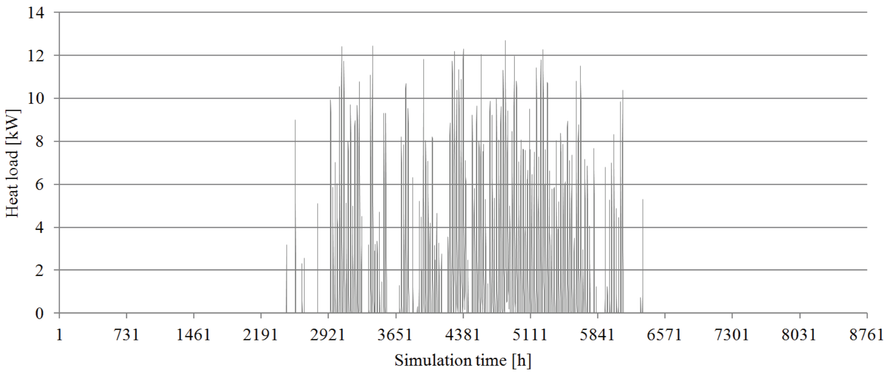

Figure 9. Heat load during whole year.

Simulation for design of the whole system was created in TRNSYS software and Meteonorm climate data for Vienna with 15 minute time step were used.

4.2 Design of adsorption solar cooling system with seasonal thermal energy accumulation to the ground under the building

HVAC systems design was based on seasonal accumulation of heat energy to the ground under the building. Waste heat from adsorption cooling unit was stored to the ground during summer and reused for heating by heat pump during winter. Heat pump was also used for heating up domestic hot water during the whole year. Heat source for adsorption cooling unit were solar thermal vacuum tube collectors. System scheme is shown on Figure 10.

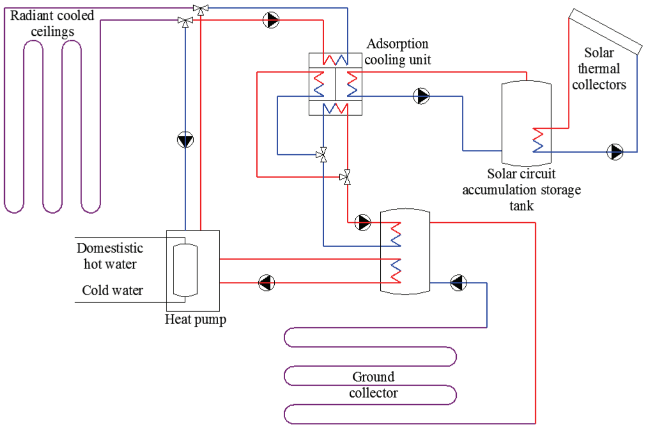

Figure 10. Scheme of adsorption solar cooling system with seasonal accumulation to the ground.

4.2.1 Adsorption cooling unit

In the simulation was used adsorption cooling unit INVENSOR LTC 09 as a cold source with cooling capacity of 9 kW (heating water temperature 72 °C, cooling water temperature 27 °C, chilled water temperature 14,5 °C). Cooling capacity was recalculated for every time step of simulation according to performance characteristics provided by the manufacturer.

This cold source has low cooling capacity, so it is necessary to accumulate produced cold to cover consumptions peaks. Ceiling constructions were designed as concrete slabs and they are ideal for cold accumulation and sharing cold to the interior. Disadvantage is slow reaction to a boundary conditions change.

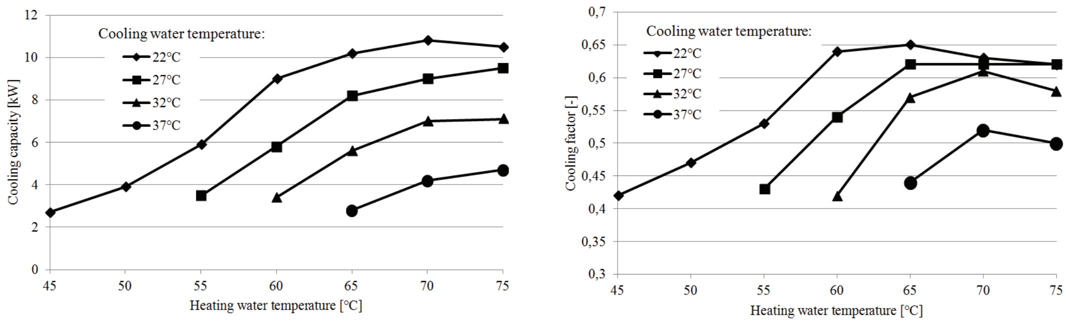

Figure 11. Cooling capacity (left) and cooling factor (right) according to temperatures of heating and cooling water [4].

4.2.2 Heat pump

Heat source for heating of the building in the winter was heat pump Stiebel Eltron WPC 04 with built in 175 l domestic hot water storage tank and with heating capacity of 4,77 kW in B0/W35 and COP 4,52.

Heating capacity was recalculated for every time step of the simulation according to performance characteristics provided by the manufacturer.

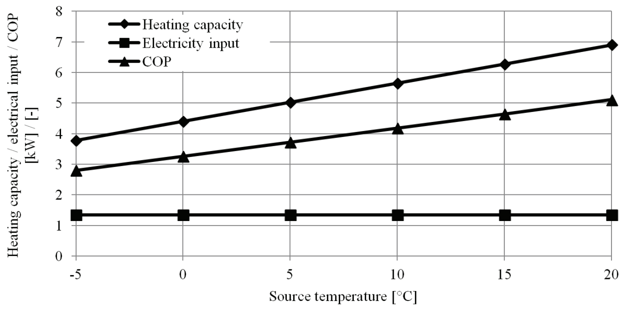

Figure 12. Heating capacity, electrical input and COP according to temperature of heat source [5].

4.2.3 Solar thermal collectors

Heat source for adsorption cooling unit were solar thermal vacuum tube collectors THERMICS 30DTH (Figure 7.). In the simulation were used 25 pieces of thermal collectors.

Ideal temperature of heating water was determined from efficiency curve of solar collectors and from efficiency curve of adsorption cooling unit. The most efficient temperature of heating water is between 90 and 95 °C but considering useful solar gains is better to use lower temperature around 60 or 65 °C. Solar collector's efficiency will be higher and it leads to the reduction of total aperture area.

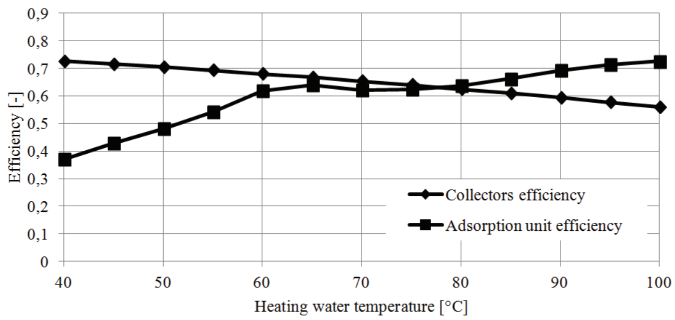

Figure 12. Determination of ideal heating water temperature from efficiency curves of solar collectors and absorption cooling unit.

4.2.4 Ground collector

Large amount of heat is rejected to the ground from condenser of adsorption cooling unit during summer. For a more detailed analysis of heat flux in the ground was created simplified model of ground collector. Model calculates with variable temperature of surrounding ground during the year and with variable temperature of ground collector. Heat loses of ground collector were calculated from heat transfer through foundations and through the bottom of collector to the surrounding ground. Heat loses were 169 W/K. More accurate model of energy distribution in the whole volume of ground collector wasn't aim of this simulation.

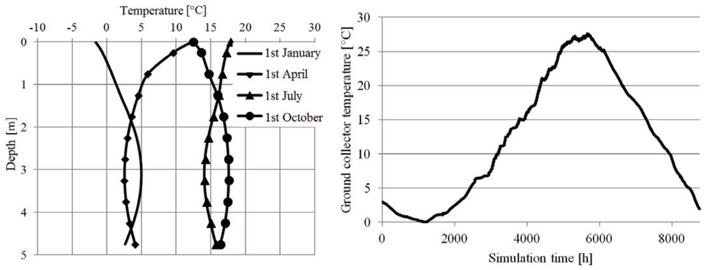

Figure 13. Ground temperatures during the year according to depth (left) and average temperatures of ground storage mass during the year (right).

4.3 Final parameters of the system

Table 3. Final parameters of the designed adsorption solar cooling system with seasonal heat accumulation to the ground under the building.

Adsorption cooling unit InvenSor LTC 09		
Chilled water circuit:	Cooling capacity	9 kW
	Flowrate	2,3 m3/h
	Temperature gradient	18/14,5 °C
Heating water circuit:	Heating capacity	14,8 kW
	Flowrate	2,2 m3/h
	Temperature gradient	72/66 °C
Cooling water circuit:	Cooling capacity	23,8 kW
	Flowrate	4,5 m3/h
	Temperature gradient	27/31,5 °C
Heat pump Stibel Eltron WPC4		
Heating power in B0/W35:		4,77
Coefficient of performance in B0/W35:		4,52
Solar vacuum tube collectors THERMICS 30 HTH		
Amount:		25
Total area:		104,6 m2
Total aperture area:		60,8 m2
Solar circuit storage tank		
Storage tank volume:		3,0 m3
Storage tank heat flux:		3,2 W/K
Chilled water storage tank		
Storage tank volume:		3,7 m3
Storage tank heat flux:		4,4 W/K
Heating water storage tank		
Storage tank volume:		2,2 m3
Storage tank heat flux:		2,8 W/K
Ground storage		
Storage tank volume:		375 m3
Storage tank heat flux:		169 W/K

Following table summarize partial calculated energy consumptions for production of 5801 kWh of cold. Total electrical input was 380 W. The ratio of produced cold and consumed electricity is 14,8; the ratio of produced cold and consumed heat is 0,64. Partial delivered energy, total primary energy and non-renewable primary energy is shown in following table.

Tab.4 Partial delivered energy, total primary energy and non-renewable primary energy.

Energy carriers	**Partial delivered energy**	**Total primary energy factor**	**Non-renewable primary energy factor**	**Total primary energy**	**Non-renewable primary energy**
	[kWh/rok]	[-]	[-]	[kWh/rok]	[kWh/rok]
Ambient energy	9027	1,0	0,0	9027	0
Electricity	392	3,2	3,0	1254	1176
Total	9419			10281	1176

Adsorption solar cooling is one of possible alternatives for reduction of non-renewable primary energy consumption. Question is prise of this system. Using a large number of solar thermal vacuum tube collectors increase purchase cost of the system. Compared to standard compression cooling device will be this system much more expensive and payback time will be longer than lifetime of the system. Using this system is currently more a matter of prestige for the buildings assessment like BREEAM or LEED methodology.

5. Conclusion

Solved case studies are showing potential of alternative systems in terms of energy consumption reduction and usage of renewable energy sources. Next step will be economical evaluation of those systems compared to standard compression cooling system. Detailed calculation of purchase and operating cost is necessary for future progress in solar cooling systems.

8. References

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10. Biography

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