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The SolabCool®, cooling of dwellings and small offices by using waste or solar heat

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Abstract

This article describes the development of the SolabCool®. The SolabCool® is an air-conditioning unit for one family dwellings and or small offices. It is based on solar or waste heat driven adsorption cooling. The process is intermittent, so 2 tanks with silica gel at reduced pressures are used. To make the machine cost-effective and easy to use, two completely new valves were developed, patented and implemented, in combination with an advanced control unit. A pilot manufacturing plant is in operation since end of 2013. The first modules were produced and tested. The maximum so-called cold factor for the SolabCool® is 0.55. The cold factor is rather stable at a large variety of operation conditions, i.e. climate conditions. This is a very good result compared to other semi-intermittent air-conditioners. Demonstration in the market in The Netherlands started in 2014. The design freeze of the SolabCool® is carried out in the summer of 2014 and the pilot production will start.

Peer-review by the scientific conference committee of SHC 2014 under responsibility of PSE AG

Keywords: adsorption cooling; silica gel; solar cooling; waste heat driven cooling

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1. Introduction

The energy performance of new buildings is becoming that good that, even in the Northern climate zones, little heat is needed for space heating. Moreover, in 2020 the EU legislation will go in the direction of near zero energy buildings. At the same time, these well insulated houses and offices suffer a growing chance of overheating during summer. End-users are demanding more and more comfort in their dwellings. For this reason, air conditioning in dwellings will become more or less a standard, even in the colder climates of Northern Europe. Of course, at the same time the air conditioners applied, should fit in the goals of nearly-zero energy buildings legislation and targets.

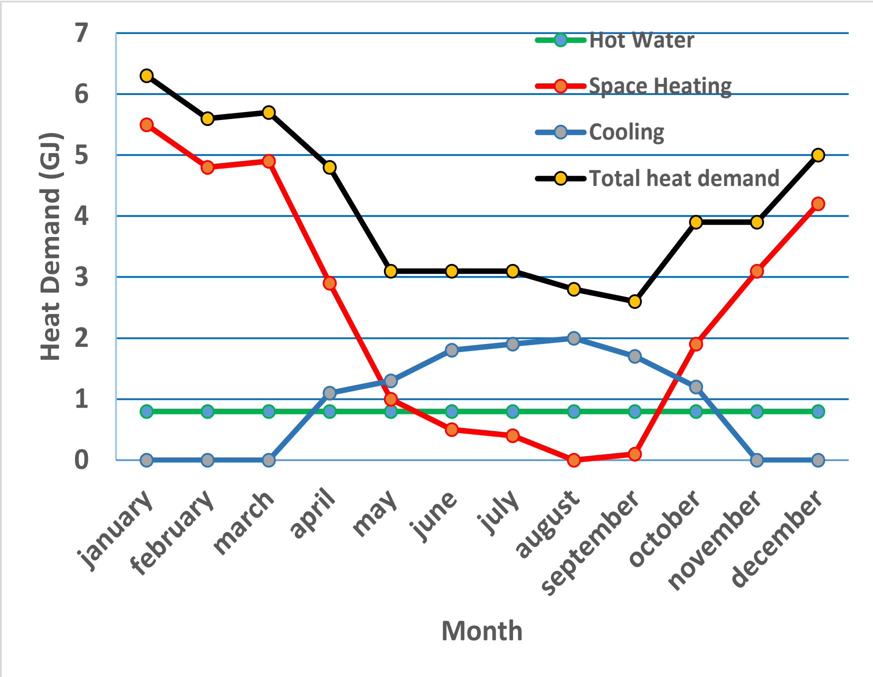

Fig. 1. Heat demand per month for district heating in The Netherlands.

In summer time the only heat demand in dwellings is hot tap water. Consequently, in districts with a district heating systems this leads to low demand of (waste) heat in summer time. At the same time the waste heat supply from, for instance, cogeneration units is in summertime equal or even somewhat higher in this period. For economic and environmental reasons it would be very beneficial if the surplus of waste heat from district heating systems could have another application. Producing cold with heat would be a very interested option. Also solar heat will become more and more an interesting option for cooling in summer. Cooling is needed at the moment solar energy is largely available. Adsorption cooling systems can make use of this heat to produce cold. In figure 1 the energy demand for district heating over the year is given, for The Netherlands.

2. Technology development

Already for many years a Dutch SME company, De Beijer RTB, is working in the field of chemical energy storage. For this reason the technology basis for applied development of adsorption energy storage systems is well developed. In combination with the Dutch research institute TNO and the Technical University of Eindhoven (TU/e) the basic scientific knowhow and technical knowhow is available for further development of a silica gel based energy storage system.

Within the KIC-Innoenergy [1] an innovation project dealing with the further development of adsorption based energy system is approved and financed. This project started in 2011 and will end in 2015.

The goal is to develop a market ready silica gel – water adsorption cooling system using waste heat as energy source. Moreover, the system efficiency, size, life time and the complete price of the system should be accepted by the market. The development of a pilot plant is part of this project.

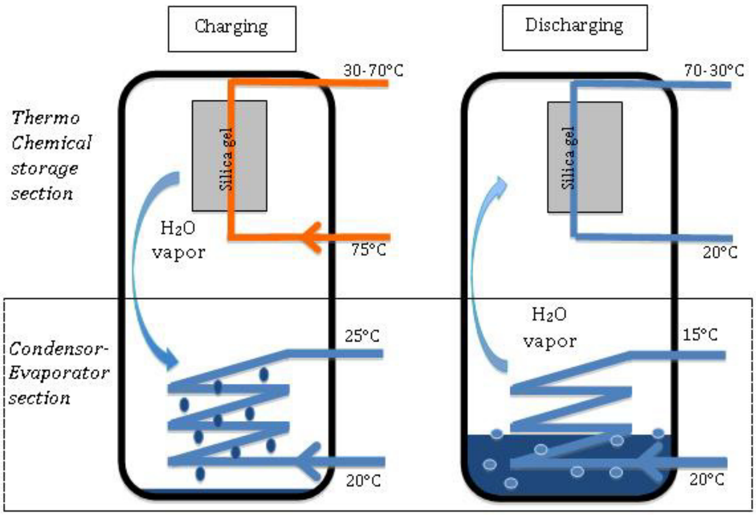

Fig.2. SolabCool® principle of cooling with heat

The working principle of the SolabCool® system is depicted in figure 2. In figure 3 the scheme is given.

In the figure the two intermittent stages are presented. The SolabCool® consists of two SolabCool Modules and the SolabControl. The SolabCool Modules are the vessels in which the alternating adsorption/desorption and condensation/evaporation processes take place.

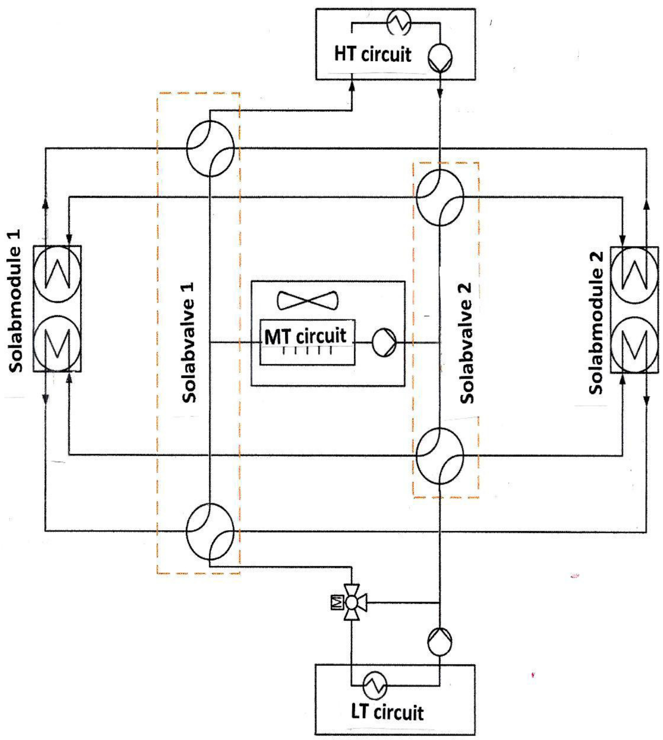

Fig. 3. Scheme of the SolabCool

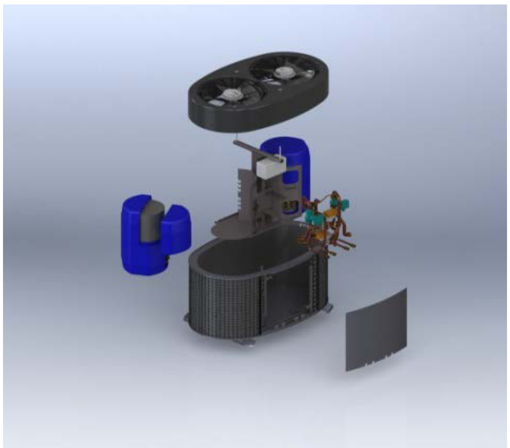

Fig. 4. Exploded view of the SolabCool®

The SolabControl contains a switching system with two 4-way valves, which alternately connect the HT(high temperature) and MT (medium temperature) circuits to each of the modules. The vessels are under low pressure and filled with a certain quantity of water. With the use of excess or free heat from a process at a temperature level above

65°C, cooling can be produced with a reasonable efficiency (COP of cooling around 0.5 – 0.6) at a temperature level of 18 to 21°C. Cooling at a lower temperature would quickly lower the efficiency to an undesirable level. The heating capacity from the high temperature source, driving the desorption process and the production of the cooling capacity, has to be expelled efficiently at a temperature level of around 30°C (absorption and condensation heat). Ideally, this low temperature residual heat should be used for another process, like swimming pool heating or pre-heating domestic hot water. While one is loading by using the waste heat, the other tank is discharging and cold water or air is produced in the evaporator. The loading/unloading process takes about 7.5 minutes. So after about 7.5 minutes, the reverse process takes place in the tanks. To switch between the loading and discharging stage a dedicated 8-way valve with control unit and strategy is developed and implemented.

The heart of the system is the heat exchanger packed with silica gel. The technology for making this heat exchanger with silica gel, the right recipe for the silica gel and the newly developed valves are the core elements of the IP of the SolabCool bv. In figure 4 the exploded view of the production prototype is given.

3. Test results

In December 2013 the first produced prototype of the SolabCool® from the pre-pilot plant was tested at the test rig of TNO [2]. Since there are no standard tests yet for this kind of machines, the test procedure was specially developed for the SolabCool®. A series of test conditions was proposed by De Beijer RTB and tested. The tests have been performed by a temperature of the high temperature circuit of 65, 72 and 81 ^{0}C. The medium temperature circuit with 27, 33 and 36 ^{0}C and the low temperature circuit of 15, 18 and 21 ^{0}C.

This has led to 15 different test conditions for the SolabCool®.

The temperatures stated are the temperatures which are controlled by the test rigs. Because of the intermittent functioning of the SolabCool®, switching between the two SolabCool Modules every few minutes, and the gradual change in the amount of energy transferred in the modules a stable control of the temperature of the cooling water produced by the SolabCool® was not possible. In figure 5 this can be seen. The switching takes place every 7.5 minutes and the temperature profiles show that the heat transfer is not constant in this period.

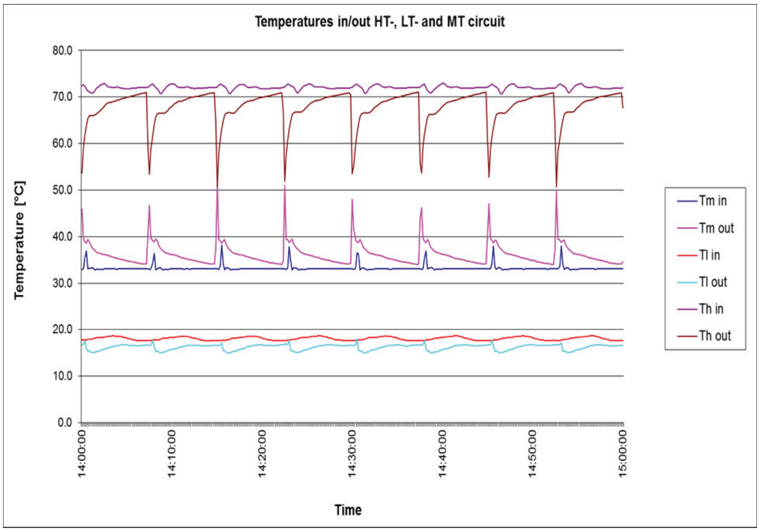

Fig. 5. For the test conditions, 72-18-33, the temperatures of the SolabCool are presented.

In future commercial SolabCool® systems the delivery temperature of the cooling water can be controlled by the heat rejection temperature (MT circuit).

Testing the SolabCool® is not straight forward. The switching of the HT- and MT flow between the modules, in this case around every 7.5 minutes, interrupts the various flows for some time and the restart is at a different temperature level. Also the LT flow is interrupted for some time. The flow- and temperature controls in the three test rigs need their time to re-stabilize. For large scale testing, or more frequent testing, it would be advisable to use a different test-rig set up than the ones used for vapor-compression heat pump development and testing.

In figure 5 the temperatures of the system is presented. In this figure the intermittent character of the SolabCool® can be seen. During switching of the 8 way valve the process is reversed and start all over again.
These test results are presented in table 1.

Table 1: Test results

Test condition Ht-Lt-Mt	Qth HT [kJ/h]	Qth-LT [kJ/h]	Qth MT [kJ/h]	Electric consumption [Watt]	Cooling capacity [kW]	COP cooling [--]	LT circuit In - out [°C]
72-21-27	29854	16361	44770	19	4.545	0.548	21.0 - 17.1
72-21-36	16842	6860	22274	18	1.906	0.407	21.0 - 19.4
72-21-33	20774	10128	29416	18	2.813	0.488	21.0 - 18.6
72-18-33	18023	7306	24143	19	2.029	0.405	18.1 - 16.3
72-18-27	27107	13628	39333	18	3.786	0.503	18.0 - 14.8
72-15-27	22944	10281	32049	19	2.856	0.448	15.0 - 12.5
72-15-30	18987	7471	25343	19	2.075	0.394	15.0 - 13.2
81-15-30	22680	9418	30710	19	2.616	0.415	15.0 - 12.7
80-15-27	26579	11862	36680	19	3.295	0.446	15.0 - 12.2
81-18-33	22689	9565	30355	19	2.657	0.422	17.9 - 15.7
81-21-33	25171	12400	35815	19	3.444	0.493	20.9 - 18.0
81-21-36	21113	8953	28341	19	2.487	0.424	21.0 - 18.8
78-21-27	31881	17677	47599	19	4.910	0.554	21.0 - 16.8
65-21-27	25261	13796	37788	19	3.832	0.546	21.0 - 17.7
65-18-27	22401	11068	32476	19	3.075	0.494	18.0 - 15.3

In the last column the average temperatures of the cooling water, cooled by the evaporator of the SolabCool®, are given. The power related to this temperature difference and the flow gives the cooling capacity for cooling the building. For the SolabCool as designed the cooling power is in the range of 3-4 kW, sufficient for room air conditioning.
These results were achieved with water flows of 1.0 m^3/h for the HT- and LT circuit and 2.0 m^3/h for the MT circuit.

By making a simple energy balance for each test condition, Qth HT + Qth LT = Qth MT, it was found that between 3 and 6% heat energy was unaccounted for. This can be explained as to be the heat loss of the SolabCool® unit to the surrounding air. The 6% heat loss level does occur at the high temperature heat source tests, the 3% heat loss level occurs during the low temperature heat source tests. This prototype SolabCool® did not have any thermal insulation on the piping or the vessels at all. It can be expected that with proper insulation the efficiency will improve.

The cooling efficiencies ($COP_{cooling}$) in these test results have been calculated only from the thermal energy flows of the HT circuit and the LT circuit, without taking any electric energy consumption into account.

In figure 6 the refrigeration factor ($COP_{cooling}$) is given as function of the temperature difference between the absorber and evaporator. A factor of 0.55 is close to the design value of 0.6. The refrigeration factor depends on this temperature difference and decrease with the increase of the temperature difference between absorber and evaporator. The rather flat gradient in this graph shows that the cooling factor is just slight affected by the different operation conditions. So this is a fairly good result.

Further Improvement of the performance can be reached by better packing of the silica gel in the heat exchanger and partly immersion of the heat exchanger in the lower part of the vessel. During research at the TU/e [3} the functioning of the heat exchanger is studied with among other a camera mounted in the storage tank. This, to visualize the evaporation and condensing process for the lower heat exchangers.

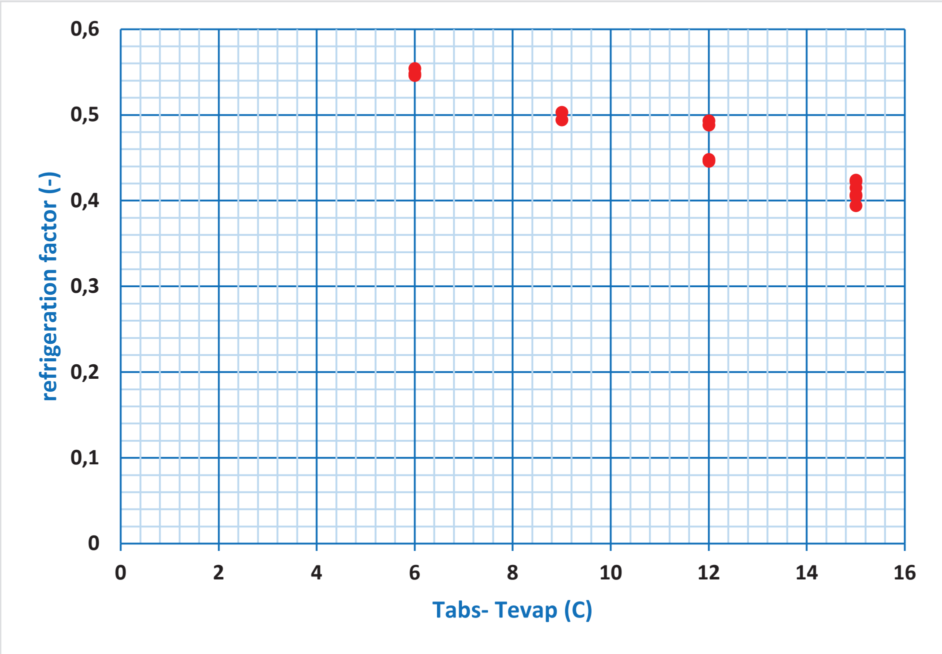

Fig. 6. The so-called refrigeration factor of the SolabCool

Fig. 7. Droplets on the evaporation/condensing heat exchanger

4. Application and system integration

The SolabCool® is being demonstrated at field tests as single stage system in a one family dwelling and as a cascade system of 4 SolabCool® units in a small office. On the website of SolabCool® bv [5] the various system layouts can be seen. The results of these field test will become available at the end of 2014. The first results are promising with respect to the performance and durability of the systems. In April 2014 [4] the design freeze of the SolabCool® was reached. This is the blue print for the pilot production of the system.

In this article the focus of the SolabCool® is on waste heat form district heating systems. Since the operating temperature is in the order of 60 °C, also a good performance solar collector can be used for generating the needed heat for the SolabCool®. Therefore chances for the SolabCool® are not only seen in the market of Northern Europe but also in Mid and Southern Europe, United States and China. There is a high demand for cooling and solar energy is widely available.

5. Industrialization

In September 2013 the pilot plant was opened in Duiven, The Netherlands. Here the next steps are carried out, in order to come to a stable production process with quality control system resulting in high quality systems.

An important aspect of the SolabCool® is the vacuum technology of the system. A test rack for the quality control of the vacuum is an important aspect of the production process. The core of the production process is besides the vacuum technology, the process of making the heat exchangers which are filled with silica gel on the outside. Stability, good quality of the silica gel is necessary for a well performing product.

Up scaling of the production is foreseen for 2015.

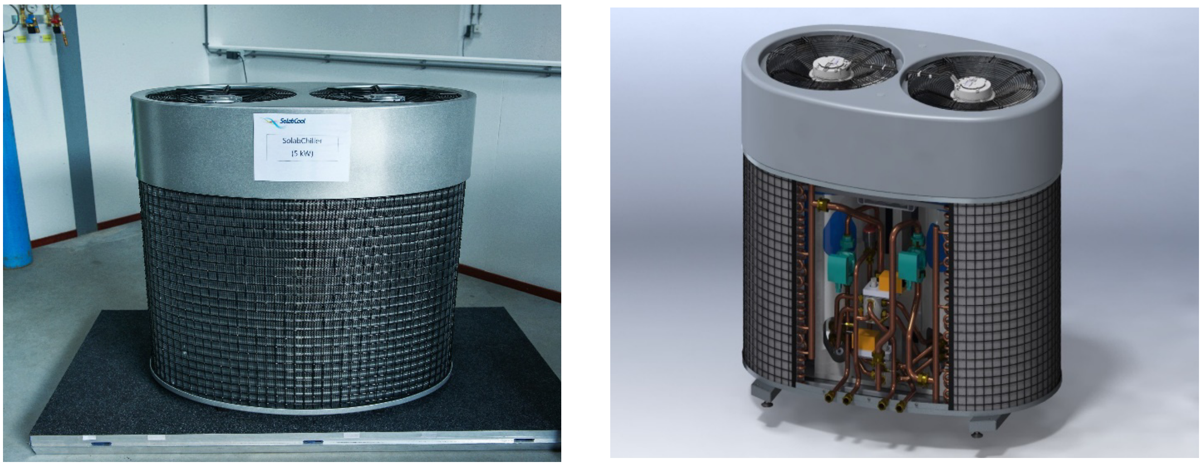

Fig. 8. A and b the SolabCool® as manufactured

6. Conclusions

The SolabCool® is an air-conditioning unit for one family dwellings and or small offices. The system is heat driven. Heat from for instance district heating enables a better performance for the district heating system in summer time. But also other sources of waste heat or solar heat can be used. The SolabCool® system consist of 2 tanks. The process is intermittent, so 2 tanks with silica gel at reduced pressures are used. To make the machine cost-effective and easy to use, two completely new valves were developed and implemented, in combination with a control unit. A first prototype from the pre-production was tested at TNO end 2013. For this kind of intermittent adsorption system no standard testing method is yet available. The tests in the laboratory were carried out under various testing temperatures. The so-called refrigeration factor is 0.55 and decreases slightly with the increase of the temperature difference between the evaporator and condenser. This is a very good result. Optimization of the system will make a refrigeration factor of 0.6 possible. A pre-pilot manufacturing plant is in operation since end of 2013. Demonstration in the market in The Netherlands started in 2014. The design freeze of the SolabCool® was reached in the summer of 2014. The pilot production of a commercial SolabCool system will start early 2015. The first SolabCool market introduction will be in Europe.

Acknowledgements

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References

[1] KIC InnoEnergy, The innovation project Energy storage as necessary part of Energy balance Buildings and Districts.
[2] Schiphouwer, H, TNO report TNO 2014 R10213 Testing the performance of the SolabPump cooling unit, 2014, Confidential.
[3] Rindt, C, Ouwerkerk, H Energy Technology Group TU Eindhoven, various reporting to the KIC Storage project, confidential, June 2014.
[4] Vos, M and De Beijer H. Design Freeze of SolabCool, project number: 50.800 SolabCool, 50.305 KIC InnoEnergy, De Beijer RTB B.V Duiven April 2014, Confidential.
[5] www.solabcool.com