# The SolabCool®, Breakthrough in (waste) heat driven cooling technology to compete with vapor compression systems

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**Abstract**

The growing prosperity of the world population in combination with climate change mitigation measures as Near Zero Energy Buildings causes an increase in the cooling demand. A significant growth of the cooling demand will take place in warmer climates, such as South Europe, Latin America and South Asia. Furthermore, the cooling demand in moderate climates will also have a significant growth due to the need for more comfort and the rising outdoor temperatures. These climates are challenging for full adoption of adsorption chillers. Adsorption chillers are activated by adding heat to the adsorption material. This heat can be delivered by solar thermal energy and or waste heat (for instance district heating in summer time). This paper describes the ongoing technology development of the adsorption reactor and evaporator/condenser as well as the reduced production costs. These developments combined have led to a price competitive compact adsorption chiller from the company SolabCool B.V. This chiller delivers about 8 kW of environmentally friendly cooling power in moderate climates. For the warmer climates this cooling output is based on this development now at least 5 kW.

*Keywords: adsorption cooling, silica gel, solar cooling, waste-heat driven cooling*

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## 1 Introduction

An important aspect in the policy for $CO_2$ reduction is energy reduction in the built environment. Therefore building regulations are becoming stricter, resulting in the direction towards energy neutral or even energy positive buildings in the near future. Today, the energy performance of new dwellings and renovated buildings must be better and better, resulting in Near Zero Energy Buildings. Even for the Northern climate zones, little heat is needed for space heating, but consequently, these well insulated houses will suffer overheating during the summer. Furthermore, the end-users are demanding a higher level of comfort also in their dwellings. Also for this reason, cooling is almost a requirement and therefore introduced in dwellings, even in the colder climates of Northern Europe.

Next, the growing prosperity of the world population in combination with climate change causes an increasing cooling demand. In 2010 it is estimated that the total global heating and cooling demand will be responsible for at least 12 % of the carbon dioxide ($CO_2$) emission from the total $CO_2$ emission to foresee in the energy requirements. As a consequence of climate change and better building regulations, the energy use for heating will decrease, where the energy use for cooling will increase rapidly, with the strongest expected growth in South Asia (Isaac and Vuuren ,2009; Eisentraut and Brown , 2014). This cooling demand can easily be answered by the well-known compression cooling machines. However, these cooling machines use coolants which have a Global Warming Potential (GWP). Moreover, due to the peak load of electricity usage of the cooling machines during the (hot) day a higher probability of net instability is foreseen. Currently the hydrofluorocarbons coolants are rapidly phased out, due to their high GWP. These coolants are replaced by natural coolants, such as $CO_2$, ammonia and propane. However, these coolants have still a GWP of at least 1 (Bivens, 2000). To decrease the impact of cooling on global warming, a coolant with zero GWP is necessary, e.g. water. An adsorption chiller uses water as coolant fluid and uses heat as energy source for driving the adsorption cycle. The heat needed for making the cooling can be produced by solar energy and or is waste heat.

During summer time the need for heat in the build environment is reduced to hot tap water. In the case of


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district heating systems this leads to low demand of (waste) heat in summer time. The waste heat from cogeneration units of electricity is in the summertime widely available. For economic and environmental reasons, it would be very beneficial if the waste heat from district heating systems could have another application during the summer time. Cooling with waste heat would be a very interesting option. Adsorption cooling systems can make use of this waste heat (or solar heat in the situation no district heating system is available).

In figure 1 the energy demand for district heating over the year is given, for The Netherlands. In The Netherlands over 400.000 dwellings are connected to district heating. For Europe the number of buildings connected to district heating is much higher. District heating is seen as good option for effective use of energy (for instance by using waste heat of industrial processes) and therefor lowering the $CO_2$ emissions and for this reason the market growing. Therefore, an attractive market will be opened for cooling systems working on the waste heat from district heating systems.

Furthermore, cooling is needed during warmer periods where the solar irradiation can be quite intensive. In most countries with a high demand for cooling, also the solar irradiation will be high. Therefore, the use of thermal solar energy technologies for producing heat will be in these locations very beneficial for cooling with heat. The here above-mentioned analysis shows that producing cooling with heat can be very effective for both the environment and the costs.

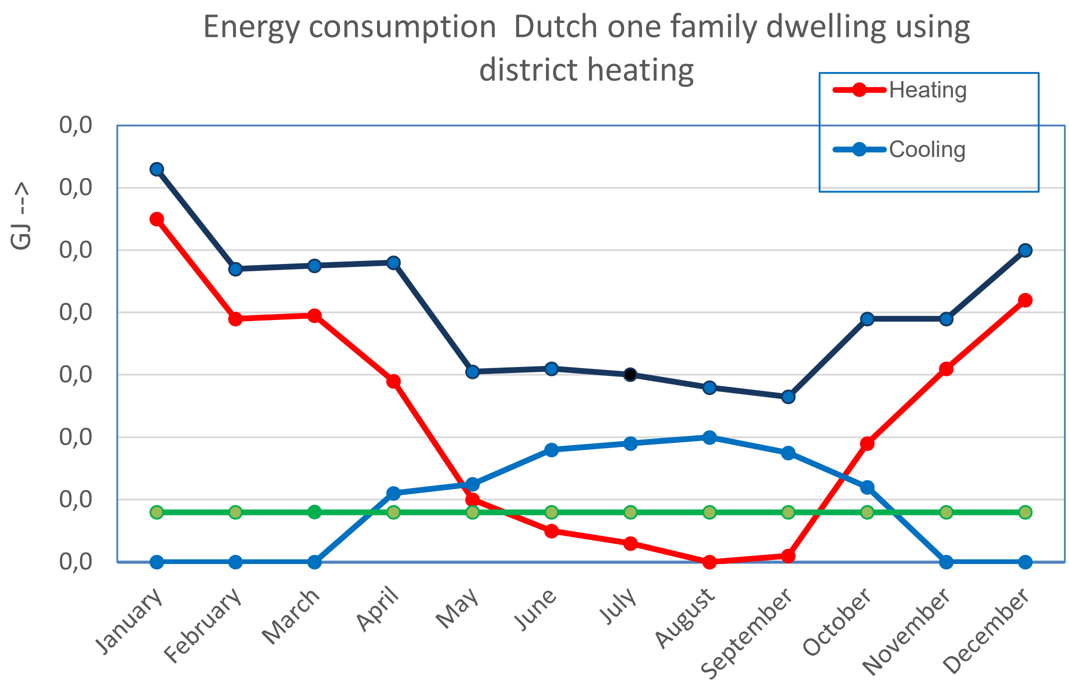


**Fig. 1.: Heat demand per month for district heating in The Netherlands**

## 2 The adsorption technology

Adsorption chillers, such as the SolabCool® uses water as coolant fluid. In the SolabCool® chiller water is evaporated under low pressure conditions in order to provide useful cooling for the use in the built environment. In figure 2 the working process of the SolabCool® chiller is displayed. The chiller works with an intermittent cycle of charging and discharging and is thereby equipped, in order to provide continuous cooling, with 2 modules. The modules are under low pressure (typically lower than 10kPa) and filled with a of the vessel. While one tank is loading by using the (waste) heat, the other tank is discharging whereby cooling is produced by the evaporation process in the evaporator. The loading/unloading process typically takes about 15 minutes. So, after about 15 minutes, the reverse process takes place in the tanks.

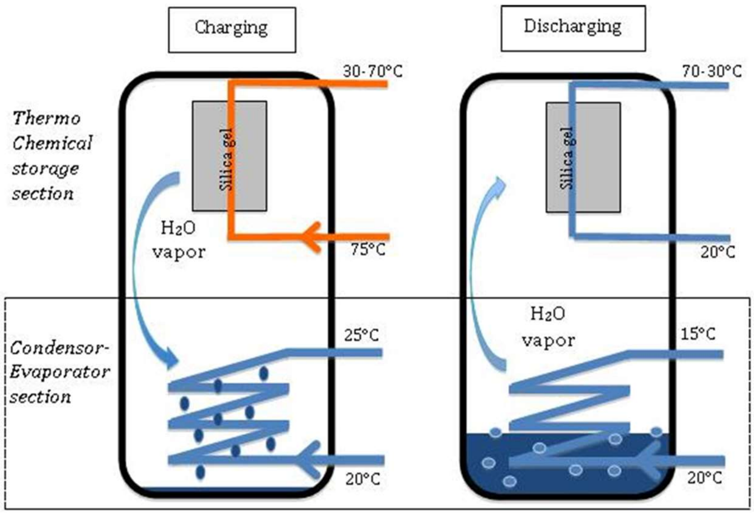


**Fig.2: SolabCool® principle of cooling with heat**

The discharging process delivers the final cooling power by evaporation of water. The evaporated water is adsorbed into the silica-gel, this is an exothermic process and the environment is used to extract the heat of adsorption. The other module is thermally regenerated (>60°C) by evaporating the water out of the silica-gel with e.g. low cost waste heat or solar energy.

For minimizing the external thermal heat losses and efficient hydraulic switching between the loading and discharging module a dedicated compact eight-way valve is developed by SolabCool B.V.(See figure 3).

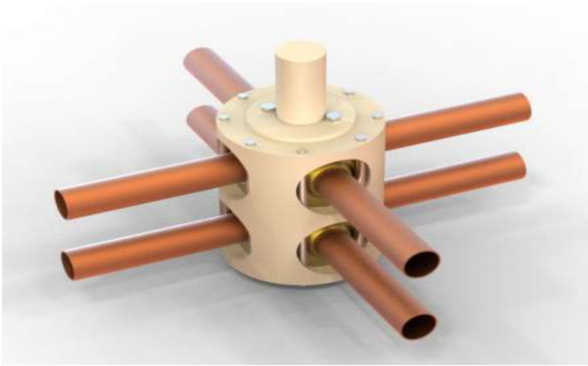

**Fig.3: The dedicated eight way valve**

For optimizing the functioning of the adsorption chiller a dedicated control unit was developed. The so-called SolabControl contains a hydraulic switching system with two 4-way valves, which alternately connect the HT flow (high temperature for regenerating the silica gel), MT flow (medium temperature to get rid of the heat of adsorption and condensation) and LT flow (to deliver the desired cold water) circuits to each of the modules.

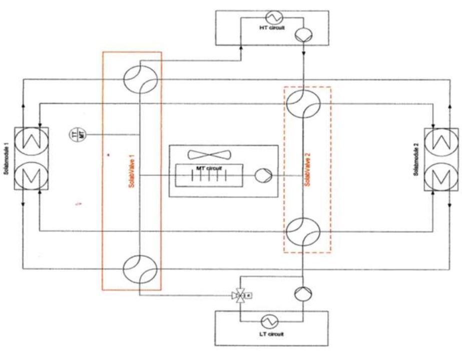

**Fig.4: The solabcontrol unit**

With the use of excess or free heat from a process at a temperature level above 60°C, cooling can be produced with a reasonable efficiency at a temperature level of 18 to 21°C. In the next chapter the testing results for the first generation of the SolabCool® is presented and discussed.

Due to the fact that the adsorption process is thermally driven, the performance of adsorption chillers lowers with increasing outdoor temperature. Another issue for the massive deployment of adsorption chillers in warmer climates is to become price and performance competitive with compression cooling machines.

## 3 First Test Results

A protype of the first generation of the SolabCool® from the pre-pilot plant was tested at the test rig of TNO (Schiphouwer, 2014). Since there are no standard tests yet for this kind of machines, the test procedure was specially developed for the SolabCool®. A series of 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®.

Testing the SolabCool® is not straight forward. In the test report (Schiphouwer, 2014) the test set-up, procedure and the detailed results are described.

The cooling efficiencies (Refrigeration factor) were calculated from the thermal energy flows of the high temperature circuit and the low temperature circuit, without taking any electric energy consumption into account. In figure 5 the measured refrigeration factor is given as function of the temperature difference between the absorber and evaporator. The measured factor of 0.55 was close to the design value of 0.6.

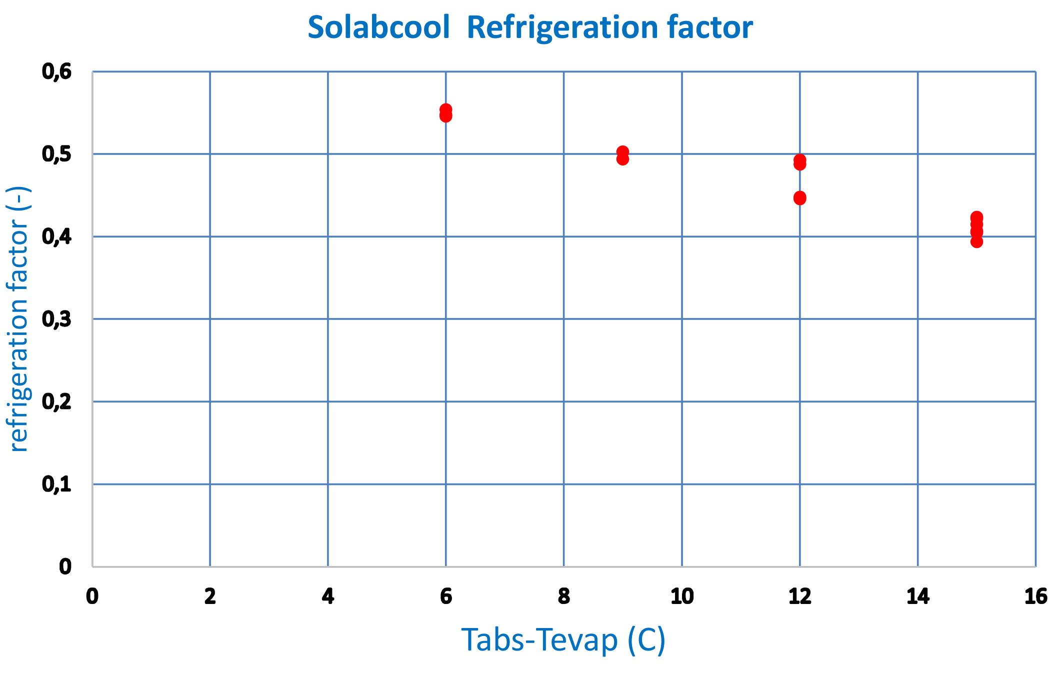


**Fig. 5: The so-called refrigeration factor of the SolabCool®**

It was shown that 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 Technical University of Eindhoven by Rindt et al. (2014) the functioning of the heat exchanger is studied with among other a camera mounted in the storage tank under low pressure. This, to visualize the evaporation and condensing process for the lower heat exchangers.

**Fig. 6: Droplets on the evaporation/condensing heat exchanger**

Based on the analysis of both the test results, a series of improvements in the design and manufacturing were suggested. The design and construction of the evaporator/condenser was adapted by applying a dedicated coating. The fixation of the silica gel at the heat exchanger was improved by using special means for getting the silica gel well packed and in a higher density in the heat exchanger. In the recent period these improvements have been further elaborated by the Dutch SME company in their production process in order to achieve a higher power output and a lower cost price.

## 4 Adsorption technology development

For multiple years a Dutch SME company is heavily active in doing research, development & demonstrating the possibilities of thermochemical energy storage devices. Challenges which are found in the development of thermochemical energy storage devices are comparable for the development of adsorption technologies. Therefore, the same company developed the SolabCool® technology. Adsorption cooling technologies has nowadays not reached its full potential. Multiple challenges such as cooling performances in warm climates, product costs & market adoption strategies are still in a premature phase. Within the KIC-Innoenergy an innovation project was carried out in the period 2011 to 2015. After completion of this project the Solabcool® as product was ready to be manufactured. However, the cooling market required more cooling capacity for the same volume of the system. For this reason, the development of a higher performance of the Solabcool® continued. The goal is to develop a market ready adsorption cooling system with the working principle based on adsorption and using waste heat as energy source with a capacity of 8 kW and with dimensions which are the same as the first system.

Current product prices are 4 times higher than desired which lowers the rate of market adoption. In the following sections the technological development for increasing the performance of the SolabCool® chiller in warmer climates, such as South Asia and reducing the price per kW is presented. Both developments lead to an affordable, competitive and environmentally friendly cooling. 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. The goal is to develop a market ready compact adsorption cooling system with the working principle based on.

**Optimization of the adsorbent reactor**

Since the heart of the adsorption technology is working in a low pressure environment, the transport of thermal energy towards and from the adsorbent is only due to conduction. Adsorption materials, like Silica-gel, have a low thermal conductivity in the range of 0.2 – 0.6 [W/mk]. In order to maximize the reactor power, the heat of adsorption has to be extracted as efficient as possible. Therefore, the amount of thermal contact resistances and conductivity characteristics are directly determining the overall performance and COP of the adsorption system. Based on these limitations SolabCool® developed a new adsorbent coating methodology to maximize the contact area between the adsorption material and the heat exchanger (see figure 7). In order to sustain the desired capacity high coverage densities were achieved up to 500 grams of adsorption material per square meter of heat exchanger surface. By this new adsorbent coating technology, the specific cooling power tripled with respect to a packed-bed configuration.

**Fig. 7: Coated adsorption reactor**

**Optimizing of low pressure evaporation & condensation processes**

The evaporation and condensation process under low pressure conditions is a phenomenon that is currently highly investigated by multiple studies (Giraud F. et al. 2015), but is key in order to maximize the cooling potential and increase the overall COP. The condensation process in a low pressure environment is more sensible for the presence of non-condensable gasses. These undesired gasses can block the condensing surface area around the condenser during charging. Trough withdrawing in the evacuation process all the non-condensable gasses and enhancing the condensation surface, the condensation performance increases with at least 10%. In the compact adsorption cooling system the condenser heat exchanger also functions as evaporator during the discharging process. The condensate from the charging process is evaporated at a temperature of at least 20°C and provides thereby a return temperature of 10°C till 18°C which can be used for all different types of cooling purposes. Research has been performed by SolabCool B.V. in order to improve the dynamics of low pressure evaporation (< 2kPa). Multiple tests and research results in a unique heat exchanger design whereby the process of bubble growth in small optimized non disturbed cavities and extracting these bubbles from the surface area is enhanced. This results in an increase in evaporation of 16%. By combining the test results of enhanced condensation and evaporation a unique new heat exchanger design was developed which leads to significant higher cooling powers.

**System design improvements**

With a new unique heat exchanger which improves the condensation and evaporation under low pressure conditions (<2kPa) the first prototypes have been made. Figure 8 shows the first compact prototype where 8kW of cooling power was achieved (COP of 0.6) while driving the system with 70°C and using a dry cooler with a MT circuit return temperature of 27°C. In warmer climates the return temperature of the dry cooler is typically higher since the environmental temperature is higher than (northern) European climates. This reduces the cooling power to 5kW. The left product is a stand-alone SolabChiller which contains two adsorption modules and an integrated dry cooler in order to get rid of the heat of condensation and adsorption. The product on the right is the SolabPump which can be placed inside buildings. This product is used to couple multiple SolabPumps in order to scale up the cooling output. In case of the SolabPump the dry cooler is externally placed.


**Fig. 8: SolabChiller (left) and a SolabPump (right).**

## 5 Market prospects & industrialization

The current developments lead to an increased cooling power output by combining the improved adsorption reactor and evaporator/condenser. For a large number of adsorption chiller applied in the built environment a price reduction per kW is necessary. The technology developments have led to a more economical production process for the SolabCool® chiller. The sales price of the Solabcool® per kW cooling for The Netherlands came down from €1900/kW in 2017 to €1150 kW in 2019. This new improved production process leads to a price/performance ratio, which is close to be competitive with compression cooling systems (about €800/kW). The technical developments lead to a cooling power output of at least 5 kW in for adsorption chiller challenging climates, such as South Europe, Latin America, South Asia. Combined is the SolabCool® chiller able to deliver environmentally friendly cooling for the cooling market in warmer climates against competitive costs.

Since the operating temperature of the Solabcool® is in the order of 60 °C, a good performing solar collector can be used for generating the needed heat for driving this cooling system. 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.

**Application and system integration**

The SolabCool® is being demonstrated at field tests as single stage system in a one family dwelling (see figure 9) and as a cascade system of 4 SolabCool® units in a small office. During these tests the hot water was consumed from the local district heating system which temperature was kept at 70°C. Inside the family dwelling the cold water was distributed through the conventional radiator system and was easily integrated. By adding a four-way valve between the hot water system and the SolabChiller, the software switches the system to provide cooling or heating.


**Fig. 9: SolabChiller placed near a family dwelling**

**Industrialization**

In September 2013 the first pilot plant of the SolabCool® was opened in Duiven, The Netherlands. Here the first steps where made for the setup of a complete and efficient production process. This year (2019) the production process will start for the second generation SolabCool® products equipped with higher performances. Also upscaling of the production process is foreseen in order to deliver also products outside Europe.

## 6 Conclusion & Outlook

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. A first prototype from the pre-production was tested. 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 was a very good result which also showed ways to improve the efficiency and capacity. Results found in literature and by experimental research on the performance of the evaporator/condenser and the adsorption reactor have resulted in an improved cooling power output. The production process for these components have led to a strong decrease of the production cost. These developments combined resulting in a second generation of SolabCool® Chiller, which is price competitive with compression cooling, environmentally friendly and is able to deliver at least 5 kW of cooling power in for adsorption chiller challenging climates, such as South Europe, Latin America, South Asia. In the near future the production process and upscaling of the second improved generation adsorption chillers is foreseen.

## 7 Acknowledgements

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