Technical Evaluation of Solar Desiccant Evaporative Cooling with Solar Absorption and Traditional Compression Systems

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ABSTRACT

The use of heat produced by solar thermal collectors is an interesting option for thermal driven air conditioning process. Three technologies are commercially available: absorption, adsorption and desiccant cooling systems. This paper is focused on solar desiccant cooling and solar absorption systems. The aim of the study is to assess energetic and comfort performances of these solar cooling systems integrated in an office building. Solar systems are positioned in reference to standard air conditioning equipments (compression and variable refrigerant equipments).For that purpose, the link between solar air conditioning system and building is predominant. Therefore the modelling takes place in a dynamic thermal building simulation software, CA-SIS developed by EDF R&D to get global results. The article presents main results of assessments regarding the energetic and economic balances and the thermal comfort of the occupants.

KEYWORDS

solar cooling, desiccant cooling, comparison, dynamic annual simulation

INTRODUCTION

Since air conditioning demand is growing and CO2 emissions are to be limited, there is a great interest in conditioning buildings in a more environment-friendly way.

The fact that the highest cooling loads occur in time when high solar radiations are available – during the day and during the year – motivates the study and the development of solar air conditioning. At the present time there are three types of solar air-conditioning technologies commercially available : absorption, adsorption and solid desiccant cooling systems.

This paper is mainly focused on solid desiccant cooling systems. The aim of the study is to assess the performance of this type of system into an office building. Desiccant evaporative cooling technology principally leans on the usage of water and of his potential one of phase change to cool the supply air in the building. Figure 1 and Figure 2 shows a schematic installation of the solar desiccant cooling system and the air evolution in the psychometric chart. In order to maximize the effect of the latent heat of vaporization of water, the ventilated air flow is first of all dried out in a "desiccant wheel" [A→B].

It is next cooled in a sensible heat exchanger (recuperation wheel) [B→C] and at last cooled down adiabatically [C→D] trough a humidifier.

The functioning of such a system necessitates a regeneration air flow (air extracts from the building) that allows (after being cooled down adiabatically [E→F] in a humidifier) to cool the air of the process in the recuperation wheel [F→G]. The last operation is to regenerate the desiccant material [H→I] after having been heated [G→H]. The regeneration heat could be taken from solar collectors and back-up energy, via storage tank. The required low temperatures are comprised between 50 and 70°C and so, liquid flat plate collectors could be used.

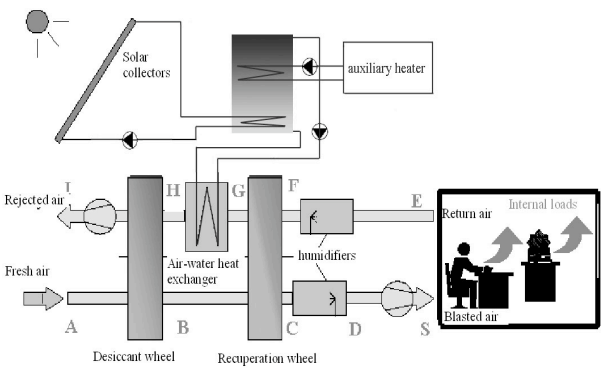

Figure 1 : Diagram of an installation of desiccant cooling

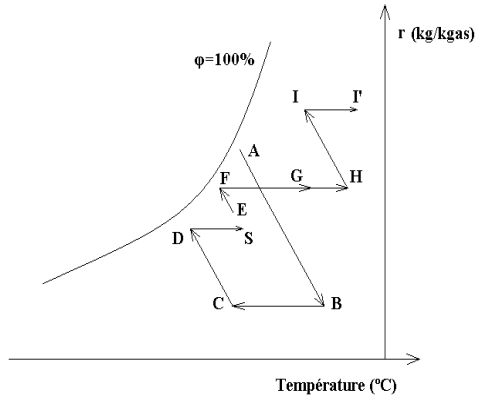

Figure 2 : Cycle's psychrometric representation

SIMULATIONS AND DESIGN

Modelling

Simulations have been conducted with CA-SIS, a dynamic thermal building simulation software developed by EDF R&D (French Electric Company). Desiccant wheel model (Stabat, 2002) consists of an analogy with a rotary sensible heat exchanger. The principle of this algorithm is to use the equations defined by the « analogy » model two times : the first one calculates the model's specific parameters (i.e. UA the conductance and MN the desiccant mass multiplied by the sped rotation) with a functioning point provided by the manufacturers; Then the model allows expressing the wheel outputs conditions : ambient, regeneration temperature and humidity.

BUILDINGS AND SYSTEMS

Buildings' Description

Systems are integrated into a typical office building in a Parisian climate, with a net area of 1000 m². The building has been modeling in two different configurations :

- The first one is in accordance with the French thermal regulation [RT2000, 2000] regarding the overall heat transfert coefficient. Heating and cooling loads (set point temperature 24°C) represent respectively 53,4 kWh/an.m^2 and 24.2 kWh/an.m^2.
- The second one is build in a « High Energetic Performance » way (HEP), which means that the overall heat transfert coefficient is 20% lower than the regulation's requirement, with external insulation and high-performance windows.

Attention has also been paid to the fittings and the lighting in order to cut back their power consumption and their heat rejection by 25%.
The set point for the reference system is 24°C, which is the temperature normally recorded in the office building. The set point for the solar cooling systems (absorption and DEC) is 27°C, which corresponds with the thermal comfort limit.

Systems' Description

Four systems have been studied ; see Table 1 for their description.

Table 1 : Chart of the four systems studied.

Solution for cool production	Auxiliary heater & heater for winter	Heat and cool emission	Heat collector
Compression unit **(Reference system)**	Gas-fired boiler	Fancoils	None
VRV units	VRV units	Fancoils	None
Absorption unit	Gas-fired boiler	Fancoils	Evacuated Tube collectors (108m2)
Desiccant air handling unit	Gas-fired boiler	Air ventilation	Flat plate collectors (130m2)

RESULTS

Comfort indicators

As mentioned before, comfort indicators are very important to be studied with desiccant cooling systems.

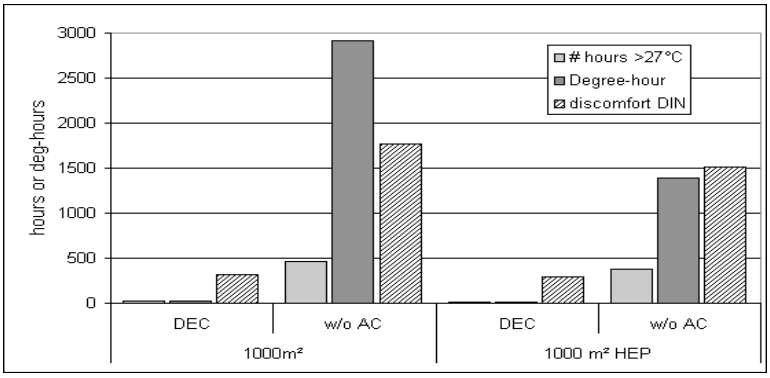

Figure 3 : Discomfort chart

Energetic performance indicators

The Solar Fraction Cooling. is the ratio between the solar useful heat and the global regeneration heat provided to the desiccant wheel.

$$SFC = \frac{Q_{TOT\,regen} - Q_{boiler}}{Q_{TOT\,regen}} \qquad (1)$$

The Coefficient of Performance is actually a thermal COP, which is the ratio between the air handling unit's cool production and the heat provided by the solar subsystem, including the back-up heater. This criterion characterizes the thermal efficiency of the unit. A constant COP of 0.7 was choosen for absorption.

$$COP_t = \sum_{AHU_{ON}} \frac{h_A - h_S}{h_H - h_G} \quad (2)$$

The thermal COP cannot establish the global efficiency. For that purpose we used energetic efficiency which is the ratio between the cooling production and the final energy used for the air conditioning. The Primary Energetic EFficiency is the same ratio, but with final energy converted into primary energy

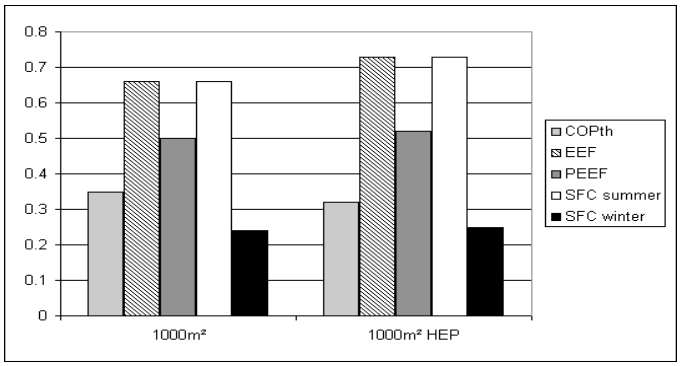

Figure 4 : Energetic Performance indicators

The Figure 5 shows the global energetic consumptions for both solutions. The primary energetic consumption is shown at figure 6. The ratio to convert electricity into primary energy is 2.58.

The global CO_2 emission of the building, expressed in kilograms per year per squared-meters is shown at figure 6. We applied French environment agency figures for the emissions calculations. (ADEME, 2005)

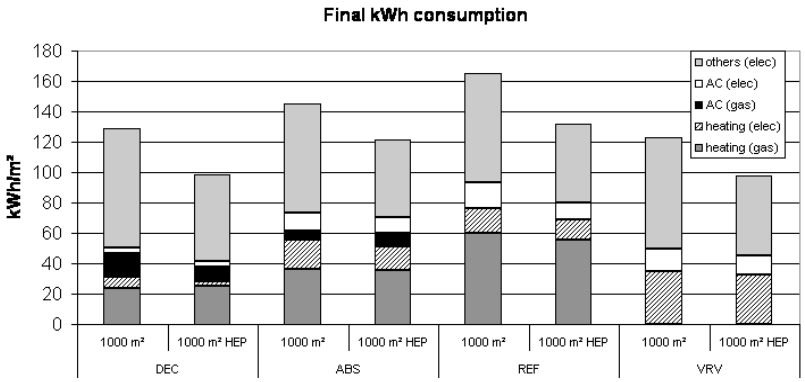

Figure 5 : Final Energy consumption

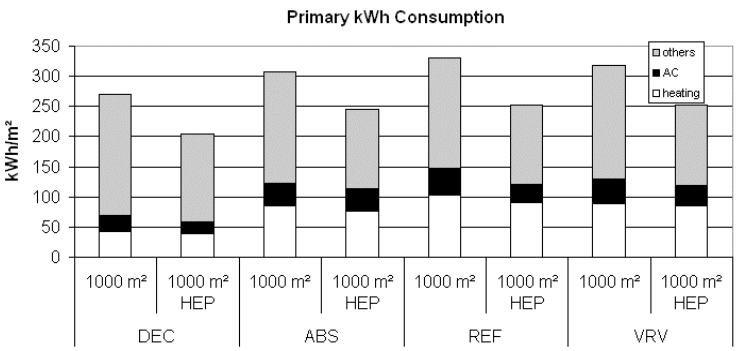

Figure 6 : Primary Energy consumption

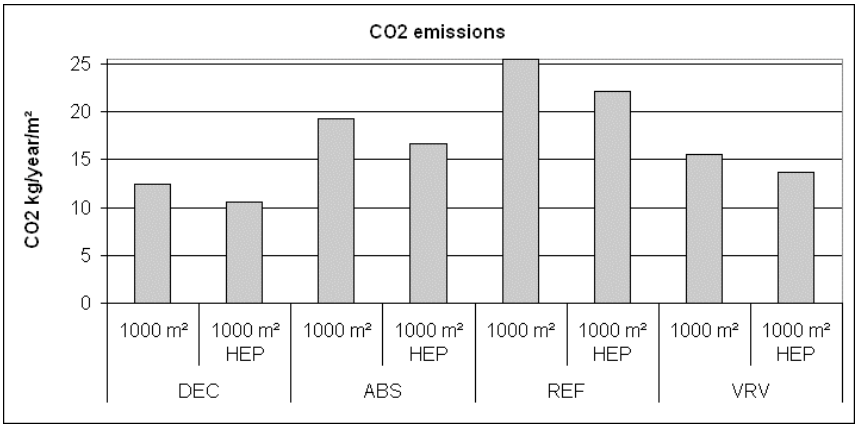

Figure 7 : CO_2 emission

DISCUSSION

Thermal Comfort

The Office building defined clearly needs air-conditioning, with almost 500 hours above 27°C and almost 3000 degree-hours for the standard version. There is also more than 1500 hours outside the thermal comfort zone defined by (DIN, 1946(II)). For more than 1000 hours, it is the humidity that exceeds the limits.
The indoor temperatures in the HEP building still exceed 27°C, but the intensity of the over-heating is reduced, as the degree-hours indicator is divided by two. This version still needs an air-conditioning system, but the cooling loads will be reduced.
When desiccant cooling is applied, the set point is only exceeded for few hours, and the degree-hours indicator tends toward zero. There is no difference between the two buildings' versions. From a temperature point of view, the comfort in the buildings is well guaranteed. Concerning the DIN comfort zone, there is still 300 hours with humidity outside the zone. These results show that the desiccant cooling unit used in this modelling could not deal with all of the latent loads. The impact of the humidity on performance of the DEC system has to be studied more precisely.

Energetic Performance

The thermal COP of the desiccant cooling is about 0.3-0.35, which is quite low compared to another study (SACE 2, 2003) with an annual COP of almost 0.6. This is due to the beginning phase of the desiccant cooling with a low COP. In this study, because of the one hour time step, the regulation could not be very sophisticated : the indirect evaporative mode used when the cooling loads are not very high could not be used. This leads to lower the annual COP.
The SFC is around 0.7 for both version.This is above the ratio of 0.4 recommended to save primary energy (Henning, 2001). The solar fraction in winter is lower, around 0.25, this is due to the fall of the heat production of the collectors in winter, especially with flat-plate collectors.
Within regards to energy consumption, we see that the final energy consumption is reduced by 20% beetween the standard and the HEP building in the reference system (compression equipment). For absorption, the global reduction is around 10%, and 20% for desiccant cooling. That reduction also takes into account the drop of cooling loads due to the higher set point in the normal compression option.

The DEC has the lowest primary energy consumption , with a drop of 20% compared with the reference on the year. The primary energy consumption of the absorption system is 5 % lower. This small decrease can be explained by a high electric consumption of the auxiliaries, notably the cooling tower. The VRV primary energy consumption is the same with the reference. This is due to the COP of the VRV units that is close to the conversion ratio beetween final and primary energy.
Within regards to the heating consumption, we see a drop of 17% between absorption and reference. This is due to the solar energy used in winter. For DEC, the reduction is about 50%. In addition to the solar energy the energy recovery wheel is useful in winter to preheat fresh air flow, which is quite important for meeting rooms.
The DEC has the lowest CO_2 emission, with 12.5 kg/year/m², a drop of 50 % compared with the reference. It represents 12.5 tons of $C0_2$ saved by year. For absorption, 5 to 6 tons of $C0_2$ are saved, and for the VRV solution, 8 to 10 tons are saved. The drop between reference and VRV emissions is due to the way electricity is produced in France.

CONCLUSION

In the paper several aspects of solar air conditioning have been discussed. The reduction of cooling loads of the building is an important step towards efficiency energy in buildings and the increase of solar factor and thus the competency of solar air conditioning systems. Results showed that these technologies are feasible from an energetic point of view, the primary energy consumption being reduced from 20% for DEC and 5% for absorption. The economic study carrid out was not presented in this paper, but substantial savings can be realized. However, within regards to investments costs the payback is not guaranteed for the moment.
The study shows that the modelling of the absorption can be improved with a better chiller model, that is to say a variable COP and a better optimization of auxiliaries' consumption. For desiccant cooling system, the improvement will be focused on a better modelling of the indoor humidity and an improved rcontrols strategy (free cooling, indirect humification, etc.) with a shorter time step. These are the future developments of our work.

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