AIR COOLING POWERED BY FAÇADE INTEGRATED COLOURED OPAQUE SOLAR THERMAL PANELS

I. Mack[1]; S. Mertin[2]; V. Hody - Le Caër[2]; A. Schüler[2]; Y. Ducommun[1];

1: SwissINSO SA, EPFL – PSE (Parc Scientific), Bâtiment D, Av. J.-D. Colladon, CH-1015 Lausanne, Switzerland

2: Solar Energy and Building Physics Laboratory, EPFL-ENAC-IIC-LESO-PB, Station 18, CH-1015 Lausanne, Switzerland

ABSTRACT

Air conditioning is an important part in building services world-wide in both commercial and residential buildings. With the general attempt to reduce the usage of fossil fuels and increase the usage of green solutions, the market for solar air conditioning is growing rapidly.

Solar air conditioning combines solar thermal absorbers to transfer solar radiation into heat with heat-driven cooling technologies. Common heat-driven cooling technologies are absorption and adsorption chillers using heat to produce cold by a thermodynamic cycle.

However, solar thermal collectors are currently limited to roof applications, as their black surface with its tubing is not aesthetic. This limits the potential amount of possible heat gain, which could be used for solar air cooling or heating.

By using the Klymaa™ opaque coloured solar thermal collectors of SwissINSO, the solar coverage for air cooling and/or heating can be significantly increased, as they are aesthetically integrated into the façade. SwissINSO's coloured collectors use a cover glass with a thin coating developed by the Solar Energy and Building Physics Laboratory (LESO-PB) of the Ecole Polytechnique Fédérale de Lausanne (EPFL). The coating is a multilayer system deposited by magnetron sputtering on solar float glass. The solar transmittance τ_e of these coatings is high to assure a maximum efficiency of heat absorption by the black absorber behind the coloured cover glass. The absorber can be flat-plate or vacuum tubes, depending on the needs for the air conditioning, as the cover glass is opaque.

INTRODUCTION

Air conditioning in the commercial as well as in the residential building sector is nowadays becoming standard. The cooling power is generally provided by electrical-driven compressor cooling equipments with huge energy consumption, leading to an increased power demand during summer. This means in turn that the emission of greenhouse gasses increases, due to this energy demand, which contribute to climatic changes [1].

There is thus a desperate need to supplement or even better, to replace, the use of fossil energies by renewable energies to generate the power needed to control the temperature of public or commercial buildings, large residential complexes, educational institutions or hospitals. From the renewable energies - wind, sun, water or biogas - the solution of choice is the use of solar energy. Solar energy has the great advantage that the solar gains and the cooling loads of buildings occur at more or less the same time [1]. Furthermore, it can also be used for heating of the building as well as for providing the necessary domestic hot water.

The incoming solar radiation can be transformed by different processes into cold air to provide cooling for buildings. One possibility is the conversion to electricity by photovoltaic cells and the usage of a classical electrical-driven compressor cooling equipment. This concept is not highly considered, as the maximum use of photovoltaic is achieved by feeding the obtained electricity into the public grid [2,3]. The other possibility is to convert the solar radiation into heat by using solar thermal collectors, and to run thermal-driven chillers for providing the desired cooling [4].

Solar thermal collectors typically consist of a metallic absorber sheet, which is covered with a black optical selective coating, converting the incoming solar radiation into heat by absorption. However, the visibility of the unaesthetic inside of the thermal panels (tubes, corrugations of the metal sheet, etc.) has limited their acceptance as integrated elements of the building's envelope. "Integration" in conventional architecture is often considered synonymous to "invisible" [5].

Due to their unpleasant visual aspect, solar thermal collectors have been until now considered as technical components to be hidden and are confined to roof-top applications, where they are less visible and have less impact on the architectural design [6]. As a consequence, the surface available for collecting solar energy is very limited in most cases, and therefore the solar gain available to be used for the thermal control of a building is very low.

A solution to overcome this difficulty of aesthetic architectural integration is to use the Klymaa™ opaque coloured solar thermal collectors of SwissINSO. They use a front face cover glass with a thin coating developed by the Solar Energy and Building Physics Laboratory (LESO-PB) of the Ecole Polytechnique Fédérale de Lausanne (EPFL) [7-9]. The coloured collectors and their application for solar air cooling will be presented in this paper.

Coloured Collectors

SwissINSO's approach for the integration of the Klymaa™ solar thermal collectors is illustrated in Figure 1, which schematically shows a thermal solar collector with a coloured coating applied to the inner surface of the covering glass pane. This coating reflects only a very small part of the visible light giving the coloured impression of the collector [7,8]. The main part of the solar radiation passes the coating and is absorbed by the thermal absorber mounted behind the glass. The necessary spectral-reflection band needed for the coloured

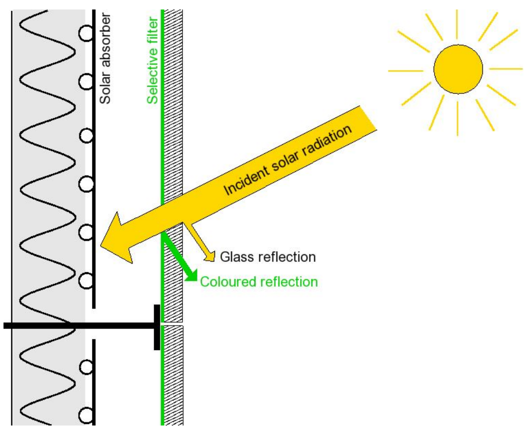

Figure 1: Principle of the SwissINSO coloured solar thermal panel indicating that most of the solar radiation is transmitted through the coating and only a few percent are reflected.

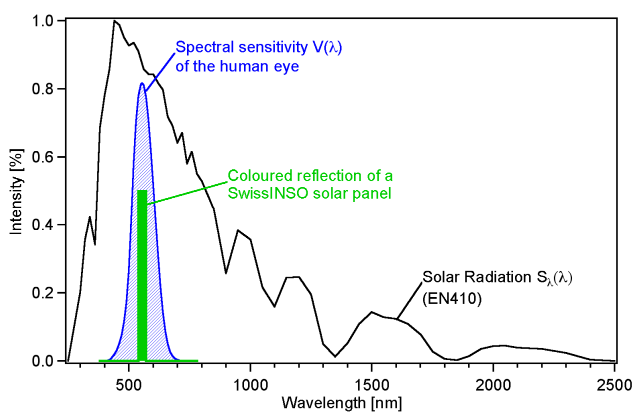

Figure 2: Showing the spectral distribution of the solar radiation in comparison to the spectral sensitivity of the human eye and the coloured reflection of a SwissINSO solar panel.

impression is very narrow compared to the spectral distribution of the incoming solar radiation, as can be seen in Figure 2 [10]. In this figure also the spectral sensitivity of the human eye is shown. This shows only a very small part of the solar spectrum is used for the coloured appearance of the collector, whereas most of the solar energy is transmitted through the glass.

The coloured coating is combined with a diffusing treatment on the outer surface of the cover glass to further enhance the amount of energy transmitted to the absorber. In combination with this surface treatment the energetic losses compared to a standard glass covered absorber are only a few percent [8]. The advantage of the coloured cover glass in comparison to a coloured absorber is that the function of optical selectivity and coloured reflection are separated, giving more freedom to coating optimisation [7].

The current development towards new colours and new materials for coloured coatings will be presented in another contribution of this conference [11].

SOLAR CURTAIN WALL SOLUTION

The overall aesthetics of the building's envelop can be kept uniform by SwissINSO's coloured solar thermal collectors. On the surfaces of a building exposed to solar radiation, the Klymaa™ solar collectors are installed as spandrel areas. Whereas in areas with low or no sun exposure, the cladding panels use the same coloured opaque glass not mounted on solar collectors but used simply as conventional glazed spandrels with isolation material behind them. This provides a homogeneous façade from the aesthetic point of view and on the same time the investment costs are kept low, as only the solar active parts of the façade are equipped with a solar thermal collector.

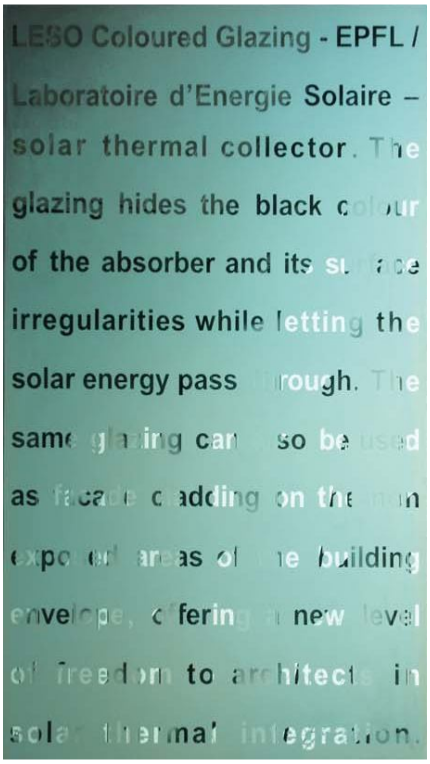

Figure 3: Klymaa™ coloured opaque solar thermal panel of SwissINSO. Design: Munari-Probst

The configuration of the solar thermal collector can be adapted to the usage of the gained heat as well as to climatic conditions. For the solar collector in the SwissINSO's coloured panels it is possible to use flat-plate, evacuated tube as well as CPC (Compound Parabolic Concentrator) collectors [12-14]. The type of collector used is always adapted to the needs of each building, as a function of usage of the gained energy, climatic conditions, window to wall ratio or building usage. An advantage of evacuated tube collectors is that the solar gain can be increased by turning the individual tubes in such a way, that the absorber fines in each tube are optimal orientated towards the incidence angle of the solar radiation [15].

Besides providing the uniformity of the building envelope, the Klymaa™ solution renders the exact curtain wall expression sought by the architect, because the glass panes can be produced in colour shades and patterns designed to custom specifications. An example is shown in Figure 3.

SOLAR AIR COOLING

Air conditioning is the process of treating air to control simultaneously its temperature, humidity, distribution and cleanliness. Since cooling loads and solar gain occur at more or less the same time, it seems logical to use solar energy for cooling purposes. Solar cooling systems consist of the following main components: The solar collectors (flat-plate, evacuated tubes or CPC), a heat buffer storage, the heat distribution system, the thermally driven chiller, an optional cold storage, a cooling tower to remove auxiliary heat from the system, the air conditioning system, and a backup system.

In the following section only the thermally driven chillers, the cooling towers and the back-up heat source are described, as the collectors have already been described in the previous.

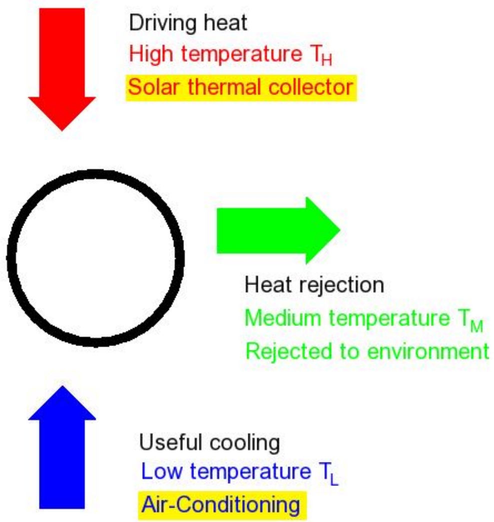

Figure 4: Schematic drawing of the energy flows and the temperature levels in a thermally driven chiller.

Chillers consume energy to transfer heat from a low temperature source to a sink at medium temperature. The necessary energy to run the chillers can be gained by SwissINSOs coloured solar thermal collectors by transferring solar radiation into heat. The principle and the different temperature levels are shown in Figure 4 for thermal-driven chillers.

Thermally driven chillers using the chemical process of absorption consist of two chemical components, one of them serving as sorbent and the other as refrigerant [2]. Absorption cycles are based on the fact that the boiling point of a mixture is higher than the corresponding boiling point of the pure liquid. The different operational steps of such systems are well documented and not described here [3].

An alternative to absorption is the physical process of adsorption, where the liquid sorbent is replaced by a highly porous solid adsorber. To obtain a quasi continuous operation with adsorption cycles it is necessary to have at least two compartments working parallel [3]. The advantages of those systems are, their simple mechanical construction and their very low electrical consumption, as no internal solution pump is required [1].

The operation temperature of the different chilling system as well as the desired temperature for the cooling system influence on one hand the chiller choice, and on the other the collector type [4,16]. The collector efficiency of flat-plate and evacuated tube over the generated temperature is shown in Figure 5. Furthermore, the working areas of the different sorption technologies are indicated, showing that it is crucial to choose the correct combination for a efficient cooling system. For absorption and adsorption systems it is therefore possible to use flat-plate, evacuated tube collectors and CPCs.

To complete the chilling system, a cooling tower is needed to remove extra heat at medium temperature. Hereby two possibilities exist; The open-circuit system, with direct contact between the primary cooling water and air, and the closed-circuit system, with only indirect contact between the two media across a heat-exchanger wall. Both systems use latent heat transfer where the coolant, which has to be water, is cooled by evaporating about 2-3 % of itself [3]. This is a very efficient method of cooling, but it is accompanied with significant water consumption. Therefore in areas of low water availability it is advisable to use closed-

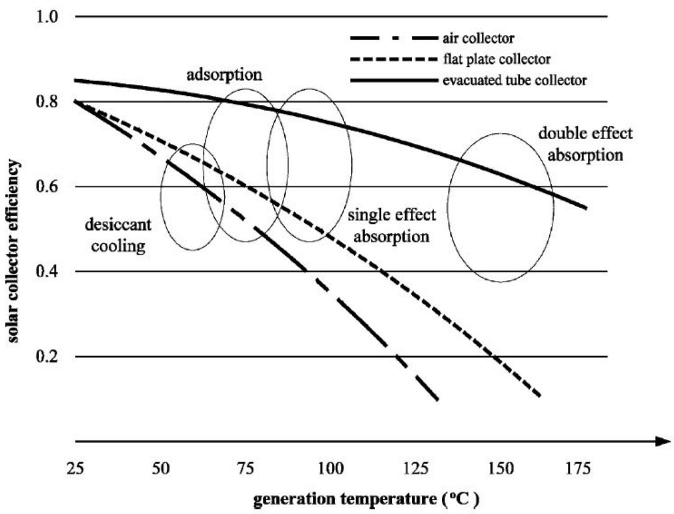

Figure 5: Possible combination of solar thermal and sorption refrigeration technologies (Source [16]*).*

circuits in combination with dry-air coolers which transfer just sensible heat and no water to the ambient air [3].

Additionally, back-up heaters are needed to assure that air conditioning is also provided at times when the solar energy is not sufficient (cloudy days, night time or exceptional internal loads).

CONCLUSIONS

Solar cooling is a clean, energy thrifty and sustainable solution for air conditioning of urban buildings. The demand of renewable energy sources for air conditioning is sharply increasing and the necessity to find sustainable solutions is becoming more and more important. To benefit from the available solar coverage for solar air conditioning, it is necessary to have a sufficient amount of collectors to gather the necessary solar energy and transform it into cold.

The Klymaa™ coloured solar thermal panels of SwissINSO provide the opportunity to aesthetically integrate solar thermal collectors into façades, thus offering much larger active surfaces for solar energy collection. This provides the possibility to increase the potential heat gain, which can be used for air conditioning or heating of the building. To provide the best solar coverage for each building it is necessary to adjust the components of the solar system to the building's character and to the occupants' behavioural pattern. The flexibility of SwissINSO's collector to use flat-plate, evacuated tube or CPC collectors is a large step towards this adjustment.

ACKNOWLEDGMENTS

The authors are grateful to Christian Roecker and Dr. Maria Cristina Munari-Probst for their support and good collaboration.

REFERENCES

[1] M. Delorme, R. Six, D. Mugnier, J.-Y. Quinette, N. Richler, E. Wiemken, H.-M. Henning, T. Tsoutsos, E. Korma, G. Dall'O, P. Fragnito, L. Piterà, P. Oliveira, J. Barroso, J. Ramòn-Lòpez, and S. Torre-Enciso, *Solar air conditioning*, 2004.

[2] H.-M. Henning, "Solar assisted air conditioning of buildings – an overview," *Applied Thermal Engineering*, vol. 27, Jul. 2007, pp. 1734-1749.

[3] H.-M. Henning, ed., *Solar-Assisted Air-Conditioning in Buildings: A Handbook for Planners*, Springer, 2007.

[4] A. Papadopoulos, "Perspectives of solar cooling in view of the developments in the air-conditioning sector," *Renewable and Sustainable Energy Reviews*, vol. 7, Oct. 2003, pp. 419-438.

[5] W. Weiss, ed., *Solar Heating Systems for Houses - A Design Handbook for Solar Combisystems*, James & James (Science Publisher) Ltd, 2003.

[6] M. Munari Probst and C. Roecker, "Towards an improved architectural quality of building integrated solar thermal systems (BIST)," *Solar Energy*, vol. 81, Sep. 2007, pp. 1104-1116.

[7] A. Schüler, C. Roecker, J.-L. Scartezzini, J. Boudaden, I.R. Videnovic, R.-C. Ho, and P. Oelhafen, "On the feasibility of colored glazed thermal solar collectors based on thin film interference filters," *Solar Energy Materials and Solar Cells*, vol. 84, Oct. 2004, pp. 241-254.

[8] A. Schüler, J. Boudaden, P. Oelhafen, E. de Chambrier, C. Roecker, and J.-L. Scartezzini, "Thin film multilayer design types for colored glazed thermal solar collectors," *Solar Energy Materials and Solar Cells*, vol. 89, Nov. 2005, pp. 219-231.

[9] A. Schüler, D. Dutta, E. de Chambrier, C. Roecker, G. de Temmerman, P. Oelhafen, and J.-L. Scartezzini, "Sol–gel deposition and optical characterization of multilayered SiO2/Ti1−xSixO2 coatings on solar collector glasses," *Solar Energy Materials and Solar Cells*, vol. 90, Nov. 2006, pp. 2894-2907.

[10] A. Schüler, C. Roecker, J. Boudaden, P. Oelhafen, and J.-L. Scartezzini, "Potential of quarterwave interference stacks for colored thermal solar collectors," *Solar Energy*, vol. 79, Aug. 2005, pp. 122-130.

[11] S. Mertin, V. Hody - Le Caër, M. Joly, J.-L. Scartezzini, and A. Schüler, "Coloured Coatings for Glazing of Active Solar Thermal Facades by Reactive Magnetron Sputtering," *CISBAT 2011*, 2011.

[12] E. Zambolin and D. Del Col, "Experimental analysis of thermal performance of flat plate and evacuated tube solar collectors in stationary standard and daily conditions," *Solar Energy*, vol. 84, Aug. 2010, pp. 1382-1396.

[13] C. Tîba and N. Fraidenraich, "Optical and thermal optimization of stationary non-evacuated CPC solar concentrator with fully illuminated wedge receivers," *Renewable Energy*, vol. 36, Sep. 2011, pp. 2547-2553.

[14] N. Fraidenraich, C. Tiba, B.B. Brandão, and O.C. Vilela, "Analytic solutions for the geometric and optical properties of stationary compound parabolic concentrators with fully illuminated inverted V receiver," *Solar Energy*, vol. 82, Feb. 2008, pp. 132-143.

[15] M. Munari Probst, "Architectural Integration and Design of Solar Thermal Systems," Ecole Polytechnique Federale de Lausanne, 2009.

[16] H.-M. Henning, "Air Conditioning with Solar Energy," *SERVITEC 2000*, Barcelona: 2000.