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Breathing building: A decentralized façade-integrated solar air-conditioning system

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A decentralized adaptive solar air-conditioning system is presented, which contains usual air-conditioning equipment and a new module, designed with a honeycomb structure, containing phase change material for latent thermal cold and hot energy storage. Heat recovery devices are responsible for higher system efficiency. A low-cost configuration and a multi-function deluxe version are presented, where in the second case a (magnetic) heat pump, a (magnetic) cooling device and an evaporative apparatus are added. Whereas the simple configuration is of medium cost and shows a good energy saving potential, the deluxe version is more expensive, but, on the other hand, is designed to show a higher energy saving potential. It is also expected to yield exquisite indoor hygienic and climatic conditions.

1. INTRODUCTION

In previous times in its housings a building façade usually had a high thermal capacity and by this showed a large cold and heat storage capacity and could improve the indoor climate positively by large phase shifts of the temperature of one to several days and by substantial temperature amplitude reductions.

With the development of large and high buildings, centralized air-conditioning systems were developed, which, by a centralization of the air handling processes in a central unit, can be more economic, if the buildings are compact and the rooms that require air conditioning are laying not too far apart. Most content in standard air-conditioning handbooks focuses on this main type of system (ASHRAE, 2013, Schramek et al., 2008).

Already before, but especially from the 1960's – with the occurrence of cheaper construction of domestic houses and office buildings with a fast response on internal sources and outdoor weather changes – a tremendously high number of (cheap) air-conditioners were installed, containing each an entire small air-conditioning system mounted to or integrated into the building façade (see Figure 1).

Energy consumption was not much considered, and these units were/are very energy consuming. Then in the last decade, big efforts were undertaken, especially in Germany, to develop high-quality and energy-saving decentralized air-conditioning systems. An example is the 535-feet-tall Post Tower, the tallest office building in the German Federal State of North Rhine-Westphalia. It contains floor units, taking fresh air from the space between the building and a covering glass façade. The air is then individually conditioned and blown into the back laying office rooms (see Figure 2).

The parallel researches and developments of passive and active solar energy devices and systems, as e.g. photovoltaics, thermal opaque, semi-transparent or translucent façade systems, double skin façades, mechanically ventilated solar façades, etc., and those of modern decentralized air-conditioning today are merging together. Examples of utilizing passive solar thermal energy, for example by applying the technology of phase change materials, has been studied and reviewed (see e.g. Mehling and Cabeza, 2008).

The authors of the present article have also strongly contributed to this development with some new ideas as a solar heating and storage façade (Manz et al., 1992), a translucent heating and day-lighting façade (Manz et al., 1997) and another application, which is a system lowering and phase shifting the temperature profiles in Minergie® houses by the application of phase change material storages (see Muriset et al., 2009, 2010). A direct continuation of these system ideas and the work of the Swiss research group is the modern decentralized façade-integrated solar air-conditioning system presented in this article (for more scientific and technical information consult Noume, 2010).

Depending on the geometry and other parameters of the building, architects, building and air-conditioning engineers, etc. must take at the very beginning of a building design process the decision, based on criteria of economy, energy consumption, esthetics of the façade, etc., between the two basic alternatives, which are the centralized and the decentralized air-conditioning system. Important help in such a decision process, for example, may come from comprehensive studies with comparisons

Figure 1. *Split systems are façade air-conditioning systems with a condenser each mounted externally to the room for which they are active. Reference: Split System, 2014.*

Figure 2. *The 163 m tall German Post Tower is equipped with a very modern decentralized air conditioning system. Reference: Post Tower, 2014.*

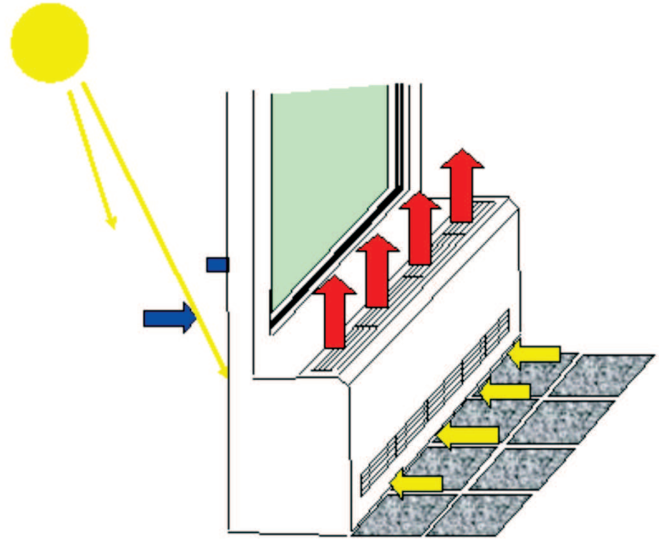

Figure 3. *The solar assisted façade system is mounted into convector-type housing underneath a window with a shading device.*

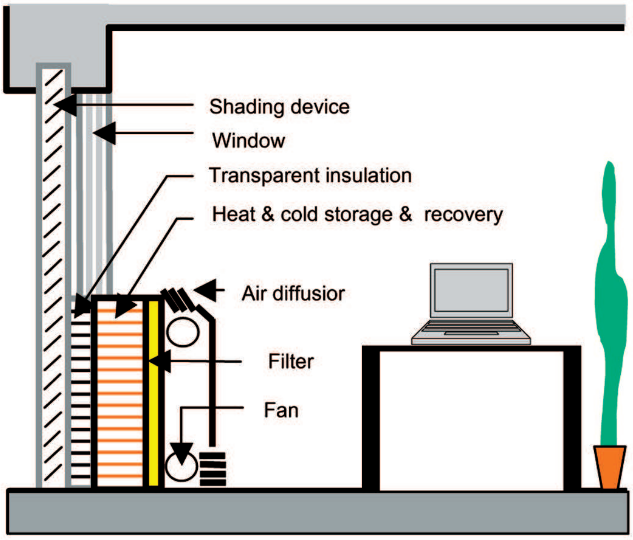

Figure 4. *In this figure a cross section of the decentralized air-conditioning system is presented.*

between the two alternatives and some listings of advantages and disadvantages of the two variants. Such have been published by Franzke et al., 2003 and Bhatia, 2012.

2. THE DECENTRALIZED SYSTEM

2.1 The basic system

The new designed decentralized façade system is an automatically controlled adaptive (“intelligent”) façade system (see e.g. Figures 3 and 4), which is capable of monitoring the internal and external climatic conditions and reacting in an appropriate energy saving manner also by utilizing solar energy. A comfortable indoor environment is provided which follows a high hygienic standard and shows a low-energy demand. This is obtained by a controlled acceptance or refusal of outdoor free energy, respectively by storing it from night to day time or vice versa. With these functions the system shows a low impact on the environment.

The system was designed in the context of a Master diploma work (see Noume, 2010) in two different versions, namely a (simple) low-cost configuration (see Chapt. 2.2) and a (deluxe) multi-function configuration (see Chapt. 2.3).

2.2 The low-cost configuration

The low-cost system contains standard energy-collecting and saving materials and devices as high-quality glazing, transparent insulation and a new type of honeycomb packaging of phase change material for thermal energy storage purposes. Furthermore, (mechanical) ventilation equipment is present, as fans, filters, heat recovery devices and air distribution grids for the inlet and outlet of the air (all these components are shown in Figure 5). The operation characteristics are described in Chapt. 3 for a winter and summer period.

2.3 The multi-function configuration

The multi-function configuration system is a full façade-integrated air-conditioning system (see Figure 6). It also has all the solar collecting features. Furthermore, it contains hot and cold recovery devices. The additional equipment contains an air/liquid heat exchanger for additional heating (HHEX) and for cooling purposes (CHEX), which is combined with a water condensation unit. In a very future-oriented window module heating and cooling may be realized by the application of the magnetic heating and cooling technology (see e.g. Tishin and Spichkin, 2003, Yu et al., 2010, Egolf et al., 2014). But one has to be aware that this technology is just at the entrance to heating and refrigeration markets, but has not yet been established.

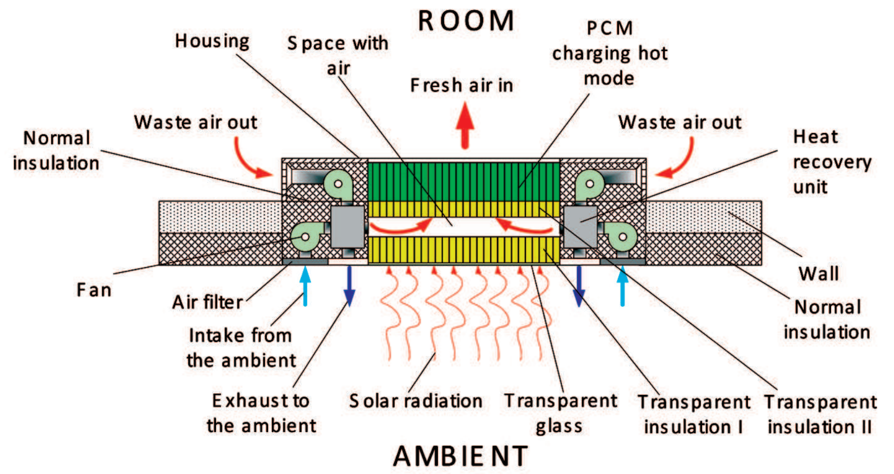

Figure 5. *The low-cost configuration system is shown in a cross section. It contains only basic ventilation equipment with the exception of a specially developed honeycomb phase change material storage device which is translucent for visible radiation (from Ref. Noume, 2010).*

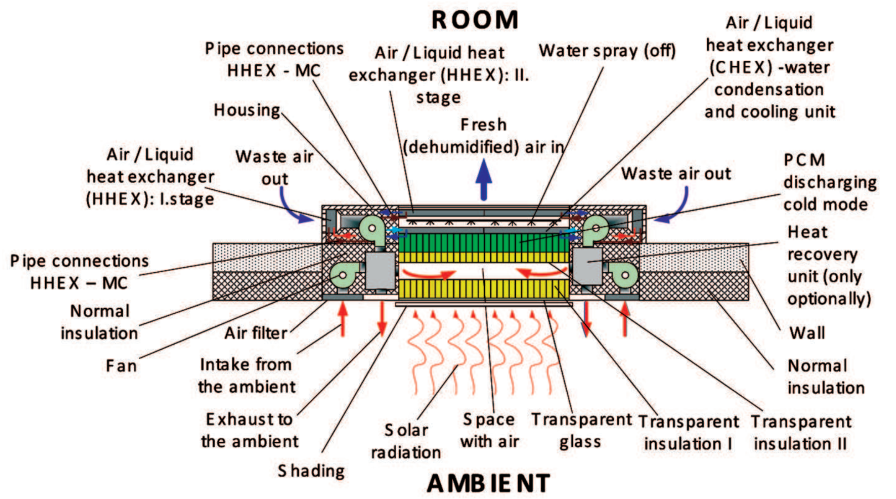

Figure 6. *The multi-function decentralized air-conditioning system is a module with a larger number of built-in apparatuses than contained in the simple low-cost configuration. It additionally contains heating, cooling and water spraying or water vaporization equipment (Ref. Noume, 2010).*

Table 1. *The table shows nine different operation modes, which have been evaluated corresponding to different times of the season and day time.*

Operation	Season		
	Winter	Spring & Autumn	Summer
Sunny-day	X	X	X
Cloudy-day	X	X	X
Night-time	X	X	X

3. OPERATION CONDITIONS

Nine different operation conditions have been chosen for a system operation evaluation (see Table 1). This article is too short for a deep and detailed discussion of all of them. But they can be found in the final report of (Noume, 2010). Important is to state that it is taken advantage of many newest developments of building physics (e.g. passive or active night cooling), solar energy technology (e.g. new glazings, transparent insulation, translucent elements, chess–board pattern packaging of PCM in honeycomb structures, photovoltaics), refrigeration (e.g. magnetic heating and cooling, desiccative cooling) and air conditioning (e.g. by forced convection, by displacement ventilation, etc.). Instead of a lengthy and detailed description of all operation conditions, in the following two sections only two illustrative examples are given.

Figure 7, for example, presents a heating mode during a sunny winter day. The shading device is open if no occupants are in the office; otherwise it covers the window to avoid dazzling by bright sun light. But the decentralized air-conditioning device under-

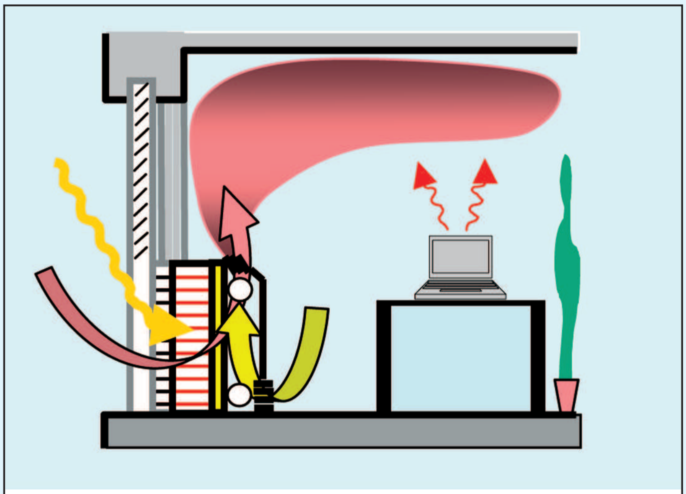

Figure 7. *On a sunny winter day mixed convection is the adequate ventilation method.*

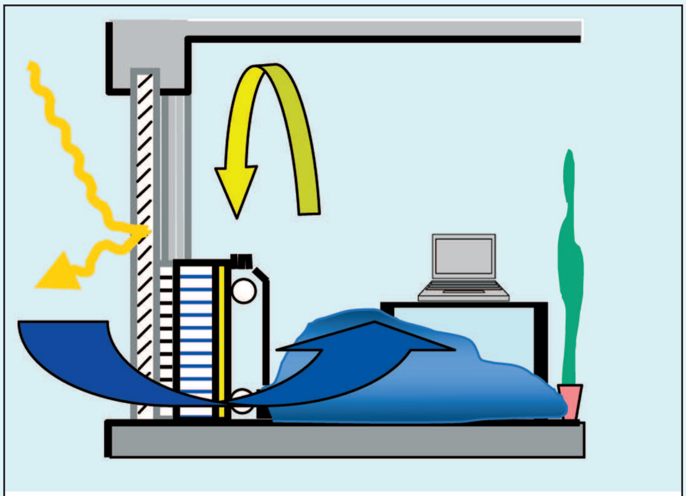

Figure 8. *On a sunny summer day displacement ventilation is applied.*

neath the window is fully opened and solar radiation enters through a transparent insulation, that avoids too high heat transfer losses, directly into the honeycomb storage module, where direct transmission and absorption of solar energy and transport of heat by air flow leads to a solid-liquid phase transition of phase change material in the filled cells and a thermal energy storage for the inlet air during daytime. In the empty cells air crosses and makes the necessary heat transfer to the cells, which are filled with PCM. If there is a net heat storage capacity in the evening available for a heating at night time, the system takes advantage of this. The air conditioning in this operation mode is mixed convection (see e.g. Awbi, 1995), where air is taken from outside and mixed with indoor air and then blown through the upper diffusor grid into the room by turbulent convection flow. If heat exchangers are also present, the described mechanisms are only responsible for a preheating of the air. Good insulation and glazing properties together with high internal sources as given by persons, computers, etc., (in Southern countries) may make it avoidable to install additional heat exchangers for heating purposes.

Figure 8, for example, presents a cooling mode during a sunny summer day. Active night cooling is applied, that means by forced convection colder air is blown into the storage device where by phase change “cold thermal energy” is stored. Furthermore, all the thermal masses in the back-lying room are cooled down at night as much as possible. At day time the shades are fully closed, but as they are no barriers to an air flow, a reduced amount of air is entering the room from outside. The incoming air is cooled by the thermal honeycomb storage device and by this is cooler than the air in the building’s room. This condition allows operating the system in the displacement ventilation mode (see e.g. Skistad, 1994). Then air is creeping along the floor and fills a lowest layer in the room by cool air. A person in this “lake” of cool air initiates by its elevated temperature a natural convection flow, which brings fresh air into its respiration zone. It is clear that in this operation mode clean floor conditions are required, as it is usually the case in well-maintained office rooms.

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