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# Active and passive cooling methods for dwellings: A review

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ABSTRACT

In this document a review of three active as well as ten passive cooling methods suitable for residential buildings is carried out. The review firstly addresses how the various technologies cool the space according to the terms of the building heat balance, under what technical conditions they might be applied, and what their energy needs are. Secondly, what scientific analysis has been carried out and what the major findings are. Thirdly, what their economic and technical feasibility of use at the stage of implementation and operation within a dwelling are. Then, either with the reviewed studies or with a simulation modelling, an assessment of temperature drop of each cooling method within a standard-size dwelling is carried out. Also, a comparison of initial investment, energy consumption, maintenance, retrofitting and required space is done. Thereafter, with this information, a decision-making program is developed in order to find out the most suitable cooling method of this dwelling in each case study according to the climate, status (new or existing), and the affordability. With that, and taking the Mexican housing sector as case study, it is found that building color, shading system, night ventilation, controlled ventilation, roof coating and eco-evaporative cooling are the most suitable passive methods for an extensive use in this country.

## 1. Introduction

The current energy situation in the world is characterized by the depletion of energy resources and increases of their costs and environmental impacts, while increases of demands are also presented. The Intergovernmental Panel on Climate Change (IPCC), the International Energy Agency (IEA) and British Petroleum (BP) classify the energy consuming sectors in the world by transport, industry, agriculture and buildings [1–3]. The Working Group III of the IPCC considers the building sector (commercial, public and residential) as the second largest energy consuming sector only behind industry. In 2010, the building sector consumed around 120 EJ [4], 24% of the total world consumption [1], and the IPCC expects its share of the total growing in the future.

In terms of energy-related greenhouse gas (GHG) emissions, the building sector currently has the third largest emissions, with an associated $CO_2$ factor of 84.5 $kgCO_2$ per GJ consumed at final stage [4]. If the primary energy consumption in the building sector maintains growing while increasing activities such as the use of air-conditioning (AC) and refrigerators with GHG refrigerants and low-efficient firewood stoves, its GHG emissions will be the second largest share of the total only behind the industry sector [4] from 8.6 billion ton $CO_2$ in 2004 to 11.1 and 14.3 billion tons by 2020 and 2030, respectively [4].

As it is seen, the energy consumption embraced to buildings and its related GHG emissions are a very important target in order to counter global climate change [5]. Three main measures to achieve this countering are set up by the IPCC: the efficiency of use of the final energy consumption, the switch to low-carbon fuels including the use of renewable energy sources, and controlling the emissions of non-$CO_2$ GHG such as $CH_4$ and $N_2O$ [4].

As part of the final energy consumption, the energy use in buildings may generally be attributed to three main activities: electric appliances (lighting, food storage and preparation, entertainment, etc.), domestic water heating, and space cooling & heating. Space cooling is typically supplied by electrical devices, where the electricity demand in the world for this is significant [4] (11.4% of the U.S. electricity consumption in 2010 [4,6] and 3.3% of the EU-15 consumption [4,6] was used for cooling). Furthermore, 27 out of the 50 largest metropolitan areas in the world are located on developing countries under warm or hot climates [5] where there is an increasing need for cooling. Electrically driven AC units are usually applied to achieve thermal comfort. Nonetheless, this comes with a high energy demand. In developing countries, AC may account for more than half of the electricity consumption of a single dwelling [5]. With electricity generation being

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**Nomenclature**

$\rho \cdot c_p \cdot V \cdot \frac{dT}{dt} =$ Heat gain/loss on a certain volume airzone within a certain period of time [J/s]
$E_{Int} =$ Internal heat gains, including solar direct gains [J/s]
$E_{Conv} =$ Heat gain/loss through the envelope [J/s]
$E_{Vent} =$ Heat gain/loss due to controlled and uncontrolled ventilation [J/s]
$E_{AC} =$ Heat gain/loss due to mechanical systems [J/s]

predominantly fossil-based [1,2], the increasing usage of AC will increase the GHG emissions and the depletion of oil and natural gas, particularly [1,2], therefore driving up their costs and hindering economic growth [1,2].

Electrical AC, however, is not the only means of ensuring a favorable indoor climate. This article focuses on the energy demand for space cooling in dwellings, reviewing potential ways of reaching acceptable indoor climatic conditions by using low-energy cooling technologies compared to high-energy cooling systems such as AC. Then, based on the assessment, a decision-making program is developed and applied on the residential building stock of Mexico, a country located mainly under warm conditions. Furthermore, by using this program, the article presents an assessment of the feasibility of implementation of the different cooling technologies in a Mexican setting in terms of climate, affordability and retrofitting. With this, it is expected to have a clearer perspective of an extensive use of passive cooling techniques within residential buildings not only in Mexico, but in all territories when it is necessary to achieve thermal comfort and save energy.

## 2. Building energy balance

In order to establish the assessing terms of the cooling performance of the different methods, the building energy balance is firstly stated. On this, it is considered that the indoor temperature is well-mixed within a certain thermal zone [7]:

$$\rho \cdot c_p \cdot V \cdot \frac{dT}{dt} = E_{Int} + E_{Conv} + E_{Vent} + E_{AC} \tag{1}$$

In Eq. (1) is established that the heat transfer through the building can be carried out by four means: internal heat gains ($E_{Int}$); heat transfer through the envelope ($E_{Conv}$); heat exchange between the indoor and the outdoor air ($E_{Vent}$); and mechanical heat transfer ($E_{AC}$). Although the means of transportation towards the air zone could be different, internal heat gains are generally transferred by radiation, the heat through the envelope is transported by conduction, and the indoor air is heated or cooled by convection [7]. Furthermore, if the building is considered as free-running, $E_{AC}$ is neglected.

$E_{Int}$, $E_{Conv}$ and $E_{Vent}$ could be carried out onto different paths. For instance, heat transfer between indoor and outdoor air can be through natural ventilation or infiltration [7,8]; internal heat gains can be from occupants, radiating devices and direct solar gains [7,8] (see Fig. 1).

Thereby, in order to understand the operation of the methods, the following section is classified into the terms of the building heat balance.

## 3. Review of the cooling methods

### 3.1. Active cooling methods

Active cooling methods are defined by Lechner as "mechanical equipment to satisfy the needs [of cooling within a building] not provided by nature" [9]. Active methods use electricity and heat as power source, mainly [9]. The most used in the residential sector are three: fans, evaporative coolers and heat pumps (compression and absorption cooling machines) [9].

#### 3.1.1. Heat transfer between indoor and outdoor air

*3.1.1.1. Fans.* A fan is an electrical motor that rotates three or four blades at a constant spinning speed. With this rotation, changes of pressure around the blades occur therefore airflow is produced [10]. The airflow cools the surfaces through forced convection heat transfer [8]; while on people the cooling is also through evapotranspiration, where there is a heat exchange between the air in motion and the sweat drops of the human skin, which change of stage from liquid to gas [8,10] thus absorbing and removing latent heat from the skin.

The conditions to use fans are wide. They can achieve acceptable comfort levels in hot climates such as the surveyed in the hot dry climate of Phoenix, USA [11] and more moderate conditions such as San Francisco, USA [12].

Scientific analyses have found that comfort levels are higher in mild climates such as Los Angeles, USA and hot humid such as Miami, USA, than in hot dry ones such as Baghdad, Iraq. Research has also found that above 35 °C the fan airflow directly to human body can produce dehydration or heat exhaustion [13,14].

Depending on features such as size, spinning velocity and position (ceiling, table, pedestal etc.) the energy consumption of fans is usually ranged between 50 and 185 W to supply up to approximately 220 $m^3$ of air per hour for a built area of around 120 $m^2$ [15]. A 185 W fan is capable to provoke a human sensation of decrease up to 5 °C of the indoor temperature in a 120 $m^2$ building depending on the humidity [15]. Nevertheless, there are fans that can be either under or over this range [15].

Regarding the feasibility of use, due to the levels of comfort that they can achieve and their relatively low prices – 10 to 250 € approx. [16], fans seem as a good option for the broad use of building cooling in the residential sector. Nonetheless, one must take account of this extensive use would entail a growing global energy cooling demand.

*3.1.1.2. Evaporative coolers.* Evaporative coolers use water evaporation to cool the air. Just as the airflow of fans cools the human body by the evaporation of sweat drops, the evaporative cooler drives absorption of energy (sensible heat) to evaporate purposed-induced water drops [17]. The building cooling could be applied by using an electrical device that absorbs air at a given temperature from outdoors, dropping this air temperature through the water evaporation and provide cool humid air into the building [18]. Furthermore, evaporative cooling can be divided

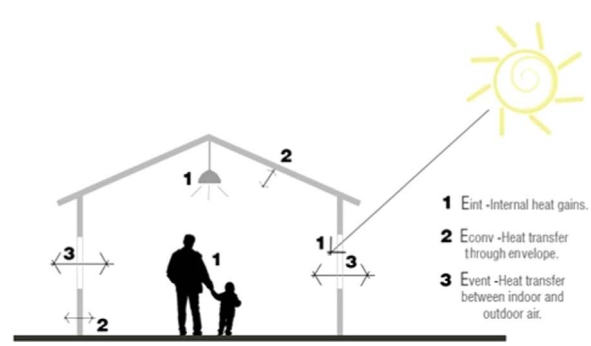


**Fig. 1.** Heat-flow paths within a free-running building.

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