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The influence of an estimated energy saving due to natural ventilation on the Mexican energy system

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ABSTRACT

This article shows the impacts of the extensive use of NV (natural ventilation) in the Mexican residential sector on the Mexican energy system. By integrating a thermal-airflow simulation programme with an energy systems analysis model, the impact on the Mexican energy system of replacing air conditioning, in particular, with natural ventilation to cool residential buildings is determined. It is shown that when, as in Mexico, there is a relatively simple connection between supply and electricity demand, NV creates savings which could be used to reduce either the fossil-fuel-based generation and mitigate CO_2 emissions, or the use of water reservoirs and hydro generation during a dry season.

1. Introduction

ECD (Electric cooling demand) in residential and commercial buildings is high throughout the world [1,2], accounting for 11.4% of total U.S. electricity consumption in 2010 [3] and 3.3% of consumption in the EU-15 [4,5]. Moreover, 38 of the 50 largest metropolitan areas in the world are in developing countries, and 27 of the 38 are located in warm to hot climates [1]; thus their buildings need to be cooled lest their occupants suffer comfort and/or health issues. Active cooling methods such as AC (air conditioning) and fans are often claimed to be the only means to achieve thermal comfort – especially during the warm season. These technologies, however, can be very energy-consuming. As Ekwall [6] has shown, in developing countries residential AC alone might account for more than half of the residential electricity usage and this can only be expected to increase as economic conditions improve. Further, given the reliance of developing nations on fossil-fuel-based generation [7], any such increase will only strain oil and natural-gas resources, in particular [5], thus driving up their costs and hindering economic growth [8].

In addition, active cooling methods increase GHG (greenhouse gas) emissions [9,10] as long as electricity generation is fossil-fuel-based. GHG encompass a group of gasses, all of which enhance the greenhouse effect, and although the main gas in terms of anthropogenically enhanced greenhouse effect is carbon dioxide, originating mainly from fossil energy use, refrigerants leaking from AC systems are also potent GHG [11].

A reduction of GHG emissions is thus necessary in order to counter global warming [12]. Hence, measures to mitigate the emissions have been carried out worldwide. For instance, the European Commission aims to reduce EU GHG emissions by 20% compared with 1990 levels by 2020 [13]. Of the total EU CO_2 emissions, energy use from buildings contributes about 35%, and out of this share, about 77% is residential buildings [13]. In Mexico, 8% of the total GHG emissions originate in the residential sector [14].

The residential sector is therefore an important target for CO_2 emission reduction through energy saving. The literature addresses residential energy saving and CO_2 emission reduction from three main perspectives – through systems analyses with focus on a switch to low carbon fuels [15–18], from a conversion system optimisation perspective [19–28] and finally with a focus on the end-use demand efficiency [29–33].

Addressing the third perspective, under the right environmental conditions, buildings with controlled NV (natural ventilation) can

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be one of the ways to obtain thermal comfort while maintaining low levels of energy consumption thus saving energy [34–43].

In order to assess the benefits of using NV in a country-wide scenario, it is necessary to estimate its potential energy saving. This article makes this assessment by establishing common cases of dwellings identified by building design, outdoor conditions and occupants' behaviour, running simulations of their indoor temperature and finding an aggregate AC consumption for the sector with and without NV. An analysis of the influence of this saving on the Mexican energy system is then carried out.

The principal contributions of this paper are therefore the assessment of the extensive use of a relatively low-cost cooling technology under warm conditions and the impacts on the energy system performance. These impacts consist mainly in energy and environmental benefits in a country-wide scenario by replacing fossil-fuel-based generation with a clean technology, thus reducing direct energy production and indirect CO_2 emissions.

In this context, another contribution is as the method is suitable for warm conditions countries, the assessment can be applied not only on Mexico (which is presented as case study), but on any country with such conditions. This is as long as the main characteristics of both its building stock (construction materials, occupancy, typical meteorological year, etc.) and energy system (installed capacities by energy source, production and demand distributions, etc.) are given, as the assessment method requests. With these characteristics the assessment can be carried out and a proper energy strategy can be planned, therefore environmental benefits can be achieved.

2. Methodology

The simulation of alternative scenarios is done using the programme EnergyPlus [44] with a model that uses a set of deterministic (not stochastic) inputs [45]. This set is divided into three main groups: occupants' behaviour, building design and outdoor conditions. The following data are the main inputs in the simulation:

Occupants' behaviour

- Number and schedule of occupants
- Use of electric devices
- Opening of windows and solar shading operation
- Temperature set-point

Building design

- Construction materials
- Building shape and orientation
- Openings' size, shape and orientation
- Surroundings
  - Adjacent constructions and trees
- HVAC systems
  - AC
  - Fans
  - Heating systems

Outdoor conditions

- Outdoor temperature
- Relative humidity
- Wind speed and direction

The estimated energy saving is given by the difference between the ECD without NV – validated with data from the literature – and the ECD with NV.

2.1. Assessment of the energy saving potential due to NV

The assessment method includes using an AC system with varying cooling load. The thermal energy balance in the zone air (building) is given by Eq. (1) assuming that the indoor temperature is well mixed. The energy stored in the building is equal to the sum of the convective heat from the surfaces (E_{Conv}), the internal heat loads (E_{Int}), the heat transfer due to air-conditioning (E_{AC}) and the heat transfer due to NV (E_{Vent}) [35]:

$$\rho c_p V \frac{dT}{dt} = E_{Conv} + E_{Int} + E_{AC} + E_{Vent}. \quad (1)$$

To estimate the energy saving potential, the AC demand without NV must be calculated. Thus, E_{Vent} in Eq. (1) is left out as well as the energy stored ($\rho c_p V dT/dt$) since the indoor temperature is considered constant over time due to the use of AC. Also, E_{Conv} is set as the model of convective heat transfer. E_{AC} is thus solved from Eq. (1) as follows:

$$E_{AC} = -\sum_{i=1}^{n} h_{Conv} A_i (T_i - T_{Set-Point}) - E_{Int}. \quad (2)$$

E_{AC} is calculated in Eq. (2) by using the given scheduled internal loads, the solar heat gains and the respective convective heat transfer calculated in each time step using EnergyPlus. This calculation sets a constant temperature set-point.

For calculating the electricity demand, an average COP (coefficient of performance), i.e. the ratio of the cooling provided over the electricity consumed, of the AC system is given [35]:

$$COP = \frac{|E_{AC}|}{|D_{AC}|}. \quad (3)$$

Therefore, D_{AC} can be estimated as

$$D_{AC} = \frac{-\sum_{i=1}^{n} h_{Conv} A_i (T_i - T_{Set-Point}) - E_{Int}}{COP}. \quad (4)$$

The ECD may be determined as the aggregate of D_{AC} over a given period of time.

When NV is applied, the scheduling of the openings is optimised by EnergyPlus to reach the comfort temperature in each time step in which case E_{AC} is set to zero. When it is not possible to apply NV, it is assumed that the AC system is switched on and the energy rate of the AC using NV is given by Eq. (5):

$$E_{AC-Vent} = \rho c_p V \frac{dT}{dt} - E_{Conv} - E_{Int} - E_{Vent}. \quad (5)$$

$E_{AC-Vent}$ is estimated in each scenario with Eq. (5) by using its respective internal loads in each time step. Since the EnergyPlus couples the airflow balance and the thermal balance of the building, the stored energy, the convective heat transfer from the zone surfaces and E_{Vent} are given as outputs at every time step.

AC saving exists when $E_{AC-Vent}$ is less than $E_{AC.}$ The estimated hourly electricity saving is thus given by the difference between the AC demand without NV and the demand using NV:

$$E_{Sav} = E_{AC} - E_{AC-Vent}. \quad (6)$$

Therefore, the electricity saving could be calculated during n hours as:

$$EnSav = \sum_{h=1}^{n} \frac{E_{Sav,h}}{COP} \forall E_{Sav,h} > 0. \quad (7)$$