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Control strategies for Energy Recovery Ventilators in the South of Europe for residential nZEB—Quantitative analysis of the air conditioning demand

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ABSTRACT

Mechanical ventilation systems are essential for ensuring the indoor quality of air in nZEB (nearly Zero Energy Buildings) with a high level of airtightness. In cold countries, it has already been demonstrated that Heat Recovery Ventilators (HRV) recovering the sensible energy from air ventilation are needed to achieve the energy demand goals for nZEB set by Passivhaus. In tropical areas with hot temperatures and high relative humidity in the ambient air, the necessity of recovering latent and sensible energy with Energy Recovery Ventilators (ERV) has also been demonstrated. However, in warm climates with medium relative humidity levels, for example in cities located on the Mediterranean coast, the evaluation of the effectiveness of an EVR for residential buildings has to be analyzed and optimized.

This article establishes the effectiveness of several control strategies for ventilation air systems including ERV with the aim of optimizing the air conditioning energy demand of dwellings located in several cities in the South of Europe. Possible control strategies have been analyzed to minimize the undesirable operation of ERVs which could otherwise increase the air conditioning energy demand for winter and summer seasons. The impact of the latent effectiveness and the effect of free-cooling on the air conditioning energy demand is also studied.

1. Introduction

As a consequence of the European Directive 2010/31 [1] regulating energy demand in the building sector, new buildings will have to be nearly zero energy buildings (nZEB) from 2020 (from 2018 in the case of new public buildings). The maximum air conditioning energy demand set by the Passivhaus standard [2], a reference for the definition of nZEB, has been used in this article.

The first obvious action to achieve desired energy demands is to improve the building envelope to reduce thermal losses. The second is to reduce air infiltrations by increasing the airtightness of buildings. However, the reduction of air infiltration means that there is not enough fresh air to guarantee the indoor air quality for occupants. Therefore the inclusion of mechanical ventilation systems becomes mandatory for residential buildings. Hence, ventilation air becomes an important source of energy loss for nZEB.

Guillén-Lambea et al. [3] show that ventilation thermal loads account for almost the total thermal loads for residential nZEB located in mild climates and conclude that only buildings located in the hottest cities (of which there are few in the Mediterranean area) are capable of fulfilling the air conditioning demand of nZEB without a Heat Recovery Ventilator (HRV).

Depending on the climate area, the latent load could represent a significant fraction of the total thermal load in air conditioning systems. The energy recovery ventilator (ERV) is an exchanger made of a permeable medium that transfers both moisture and heat from one air stream to another. Suitable permeable materials include cellulose, polymers, and other synthetic membranes [4]. Zhang [5] states that cooling and dehumidifying fresh ventilation air constitutes 20–40% of the total energy load for air conditioning in hot and humid regions. An enthalpy/membrane energy exchanger has been experimentally investigated [6] and the study shows that including an ERV in the mechanical ventilation system instead of a conventional HVAC system reduces the total energy consumption

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by 8% in tropical climates (Kuala Lumpur) and by 4% in a moderate climate (Sydney). Zhang et al. [7] developed a theoretical thermodynamic model that includes a membrane-based energy exchanger air dehumidification system. Their results show that using a membrane energy exchanger provides energy savings of up to 33% for a commercial building situated in a humid region in China.

Several researchers have looked at control strategies in order to achieve the highest possible performance of ERVs. Rasouli et al. [8,9] investigate the energy savings achieved with the use of an optimized control system for the ERV by performing simulations using TRNSYS of an office building in four North American cities. They find that an ERV not properly controlled may increase the cooling demand, but conclude that an ERV can save energy by up to 10% for an office building in Chicago and 15% in Miami using an optimal control strategy, compared with the use of an HRV only. Liu et al. [10] simulate an apartment in five cities in China demonstrating that the ERV is an effective energy saving method in some of them, but conclude that an ERV is better for non-residential buildings that need more fresh air.

Although membrane ERVs are available on the market, they continue to raise some unanswered questions. For example, what is the performance of these units working under real conditions in real houses, and how does this compare with the performance measured in the laboratory? More importantly, are these products suitable for recovering the humidity in residential buildings located in warm and medium humid climates in the south of Europe?

The present study is focused on the Mediterranean area, where warm climate conditions with medium humidity could justify the use of energy recovery systems as opposed to heat recovery systems alone. For this purpose, a dwelling for a family of four people situated in a block of houses has been modeled in TRNSYS [11]. The model has been validated with monitored values obtained from a real nZEB house. Simulations have been done for different control strategies of the energy recovery system in order to define the maximum recovery energy from ventilation air for each location. The paper's aim is to propose an optimal control for the ERV to minimize the air conditioning energy demand for areas with mild winters and warm and medium-humid summers, characteristic of the Mediterranean area. Additionally, simulations have been performed to check the influence of the latent effectiveness of the ERV and the effect of the free-cooling on the total air conditioning energy demand.

2. Computational model

2.1. Software

A computational model has been developed using TRNSYS [12] software to simulate the energy demand for heating and cooling the selected residential housing. A TRNSYS project is typically set up by connecting components graphically in the Simulation Studio. TRNSYS components are referred to as Types. The building model is known as Type56 [13] and is used in this study to simulate the dwelling. The heat exchanger is simulated using the Type667 [14].

TRNSYS also interfaces with various other simulation packages. In our TRNSYS model, the Engineering Equation Solver (EES) is called using Type 66 [15] in order to control the by-pass of the ERV depending on the temperature, humidity and enthalpy of the air streams. EES [16] is a non-linear equation solver that has been used to solve sets of equations to control the operating mode of the ERV, simulating several operating strategies.

The simulations provide the sensible energy demand for heating and cooling and the latent demand for dehumidification and humidification throughout one year on an hourly basis for several cities located in different countries.

Table 1
Building enclosure technical parameters.

Building enclosure	Total Area (m^2)	Transmittance U ($W/(m^2K)$)
External Walls	North:15.7 South:18.2 East:20.0 West:6.8	0.34
Floor	81.15	0.26
Roof	81.15	0.26
Windows	North:8.4 South:10.8 East:0.0 West:0.0	1.40

Airtightness n_{50} = 0.60 ACH (maximum infiltration level stated by Passivhaus, Ceiling height 2.5 m.

2.2. Dwelling description

The dwelling is taken from a real project built in Spain. This dwelling has been selected as it is a typical dwelling for a family of four persons in the south of Europe. The apartment is located on the top floor of a building of 4 floors. This dwelling has previously been used in a study of the annual envelope energy losses in buildings [17] and in a study comparing the ventilation flow rates in residential buildings imposed by the regulations of some countries [3]. The building area and enclosure technical parameters are indicated in Table 1. The envelope transmittance values are those recommended by Passivhaus [18] for Southern Europe.

2.3. Air ventilation system

The air ventilation system layout is represented in Fig. 1. The air discharged from the most contaminated rooms (kitchen, bathroom and toilet) never comes into contact with the fresh air entering the dwelling, therefore issues related to air purification and bacterial contamination may not arise. The ERV system also includes a filter for the incoming air flow in order to guarantee the air quality and a second filter for the exhaust air to protect the ERV. The air flow distribution (%) for each room is indicated in Fig. 1. The percentages are those recommended by a company which currently develops and commercializes the ERV, based on the occupation and the air volume of the rooms. The energy supplied to the two ventilators for the proposed system will be 0.29 Wh/m^3. (Data supplied by Zehnder Group Iberica IC S.A).

The ventilation air flow is a significant parameter for the energy demand in a nZEB dwelling. The minimum air flow rate recommended or imposed in the regulations of some countries is detailed in a previous article [3]. The Passivhaus standard establishes a value between 30 m^3/h and 32 m^3/h per person (for residential use) [2]. Taking into account that the simulated dwelling is suitable for a family of 4, the total air ventilation rate considered in the model is 120m^3/h. The air ventilation flow will be constant throughout the year, except that an extra ventilation flow is added during five hours of high occupation assumed at the weekend when the air ventilation flow will be 240m^3/h.

2.4. Internal loads

The internal loads consist of sensible and latent heat transfers due to occupants, appliances and lighting. The lighting load is only sensible. The model includes sensible and latent loads due to occupation, and the nominal load is calculated by considering four people in the house: 1 person in the kitchen, 1 person in the main bedroom and 2 people in the living room. The heat generation according to different degrees of activity follows the values detailed in the ISO 7730: 2005 [19]. The nominal values applied to the model are shown in Table 2.