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Energy saving potential and repercussions on indoor air quality of demand controlled residential ventilation strategies

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ABSTRACT

Ventilation is ambiguously related to the energy saving rationale originating from the mitigation of global warming, the reaching of peak oil or health concerns related to fossil fuel burning. Since it makes up for about half of the energy consumption in well-insulated buildings, it is an attractive target for energy saving measures. However, simply reducing ventilation rates has unwanted repercussions on the indoor air quality. Two main strategies have been developed to reconcile these seemingly opposing interests: heat recovery and demand control ventilation. This paper focuses on the energy saving potential of demand controlled mechanical exhaust ventilation in residences and on the influence such systems may have on the indoor air quality to which the occupants of the dwellings are exposed. The conclusions are based on simulations done with a multi-zone airflow model of a detached house that is statistically representative for the average Belgian dwelling. Four approaches to demand based control are tested and reported. Within the paper exposure to carbon dioxide and to a tracer gas are used as indicators for indoor air quality. Both energy demand and exposures are reported and compared to the results for a standard, building code compliant, exhaust system, operating at continuous flow rates. The sensitivity of the control strategies to environmental and user variations is tested using Monte-Carlo techniques. Under the conditions that were applied, reductions on the ventilation heat loss of 25–60% are found, depending on the chosen control strategy (with the exclusion of adventitious ventilation and infiltration).

1. Introduction

Advances in several disciplines of knowledge such as the growing understanding of global warming (IPCC, 2007) and its effects on our environment, the increasing evidence of the limited nature of our major energy supply and the large cost, both economical and human, of air pollution related illnesses are dramatically altering the goals of innovations in building technology. The focus is shifted towards 'green' or sustainable buildings, seeking concepts that allow to maintain or even further increase the comfort level that we are accustomed to, while significantly reducing the associated energy use in every aspect of human life.

In a moderate climate, hygiene ventilation is responsible for about half or more of the energy expenditure in well insulated dwellings, while the energy use in buildings itself takes up about 40% of the energy use in the EU. Consequently, this field represents a massive gross energy saving potential. Simply reducing ventilation rates, however, will deteriorate the indoor air quality and therefore sort unwanted effects such as an increase in the incidence of respiratory illness [1,2] and loss of productivity [3].

Two main strategies exist in contemporary building practice that allow to reconcile these opposing interests, namely the use of heat recovery units and the implementation of demand controlled ventilation. Heat recovery ventilation is widely spread in cold climates and its merits are discussed extensively in literature (e.g. [4]).

However, in the moderate climate zone of western Europe, especially in the Netherlands, France, the UK and Belgium, with about 2500–3000 heating degree days [5,6], the payback time for investments in heat recovery ventilation are long, especially in buildings with relatively low air change rates such as dwellings. Due to its competitive price setting as well as due to reports in popular media and scientific literature about possible health risks associated with heat recovery systems [7] simple mechanical exhaust ventilation dominates the residential ventilation market [8,9] in this region. In light of this exhaust ventilation tradition, home owners tend to prefer demand controlled exhaust ventilation over heat recovery systems to comply with tightening energy performance legislation. However, little information is available in

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literature on the performance that can be achieved with different approaches to demand controlled exhaust ventilation. This paper presents performance and sensitivity results that can be used to understand and design appropriate residential demand controlled exhaust ventilation.

1.1. Background

Available literature on demand controlled systems is mainly focussed on two aspects: single-zone, large air change rate situations [10–13] on one hand and on optimal setpoint or control algorithm development [14,15] on the other. Although few papers focus on the residential context [16], time use reports indicating that 70% of our time is spent at home and 50% of that time is spent alone [17] clearly show the potential for demand control in dwellings.

In contrast to the dedicated air handling systems for large spaces such as open plan offices, conference halls and theatres, fresh air supply and exhaust in residential ventilation are usually decoupled in space. Fresh air is introduced in the living room and bedrooms whereas polluted air is extracted from the dwelling in 'wet' spaces such as kitchen, toilet and bathroom. Transfer devices in doors allow air to flow from the dry spaces to the wet spaces through hallways and staircases. This particular configuration requires a performance assessment on a multi-zone (system) level in order to account for inter zone interaction.

In addition to that, the rating of the indoor environment is a complex, multi-layered problem [18]. The long list of indoor air quality performance indicators for residential ventilation systems proposed in the EN 15665 standard [19] clearly demonstrates that no consensus exists on how to rate ventilation system performance. Nonetheless, the choice of performance criterion has a large influence on assessment results [20].

Residential ventilation systems are usually bought as a complete package with a set of standard components and are therefore far less tailor made than large HVAC systems. In a competitive market, reliable performance assessment and evaluation of these ventilation systems is essential, although the operating conditions (building geometry, wind conditions) can vary largely between dwellings and occupancy is susceptible to change over the lifetime of an installation.

1.2. Scope

This paper focuses on the energy saving potential of four demand control strategies for mechanical exhaust ventilation in residences on a system level and with their repercussions on the indoor air quality to which the occupants of the dwellings are exposed. This is in accordance with the dominant market trend in the moderate climate zone of Western Europe. The robustness of the performance of these control strategies is assessed by sensitivity analysis based on Monte-Carlo techniques.

2. Modeling

The results presented in this paper are based on airflow simulations. These were executed in the multi-zone airflow simulation package Contam [21]. The validation of multi-zone ventilation models against e.g. tracer gas measurements is well documented in literature [22–25]. Multi-zone simulation models typically assume well-mixed air in every room (simulated as a single node in the model). As a result, these models are not suited for detailed analysis of the distribution of contaminants in a single room. However, this is not the scope of this paper. In contrast to a typical office setting, no specific occupied zone can be defined in a residential setting. To assess the energy use related to hygiene ventilation, only the bulk fresh airflow in the building is relevant. As Contam is a ventilation model only, it cannot calculate transient room or duct temperatures. Therefore, for simplicity, the temperature inside the building and all ducts has been set to 18 °C, the inside temperature fixed by the Belgian EPBD calculation procedure, which corresponds to the average temperature measured in Belgian dwellings [26]. The effect of this assumption has been discussed by Steeman [27]. In this section, the implementation of the building geometry in the model will be discussed first, followed by an overview of the used performance assessment parameters. Finally the selected demand control strategies will be presented.

2.1. Building model

The geometry used in the model is based on a detached house that is statistically representative for the average Belgian dwelling. It has been designed for and used in several previous research projects [28–32] and is currently used to assess the performance of residential ventilation systems in the EPBD framework in Belgium [33]. Table 1 lists the dimensions (m^2) of the spaces in the building model. Fig. 1a and b show the plan of the ground floor and 1st floor of the dwelling, respectively.

The airflow in this dwelling has been modelled through the introduction of system components and leakage.

Overall airtightness, characterized by the v_{50} value, is modelled by means of cracks in the roof and wall surface. The v_{50} value is the ratio of the air leakage rate at 50 Pa pressure difference and the building envelope heat loss area. According to observations by Bossaer [26], the specific leakage rate through roof and walls has a 2/3 ratio, which has been implemented in the model. Each wall is fitted with two cracks, one at 1/4 of its height and the second one at 3/4. The internal doors are simulated with additional cracks in the walls. For the indoor walls, a fixed specific leakage value is assumed. This methodology is in agreement with guidelines given in EN 15242 [34]. In the results presented, a specific air leakage (v_{50}) of 3 m/h is used, representing the best quartile of measured airtightness values in a measurement campaign in Flanders in the late 90's [26]. A recent measurement campaign [35], along with results from other countries [36], shows a tendency towards this level of airtightness in newly built dwellings.

A mechanical exhaust ventilation system is implemented according to the requirements of the Belgian residential ventilation standard [37]. This standard imposes design flow rates for the main system components in an exhaust system. In general, the required flow rates are 3.6 $m^3/h/m^2$ of floor area, with minimum values for wet spaces such as kitchen and bathrooms. The resulting design flow rates are also listed in Table 1. The non-mechanically driven

Table 1
Floor area (m^2) and design supply/extraction airflow rate (m^3/h) of the spaces in the building model.

Ground floor	Area	Supply	Exhaust
Living room	35.7	128.4	
Office	8	28.9	
Kitchen	10.2		50
Service room	7.7		50
Toilet	1.7		25
Hallway	28.1		
1st floor			
Bedroom 1	17	61.1	
Bedroom 2	18.2	65.6	
Bedroom 3	18.3	65.8	
Bathroom	8		50
Hallway	28.1		