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Heat recovery ventilation operation traded off against natural and simple exhaust ventilation in Europe by primary energy factor, carbon dioxide emission, household consumer price and exergy

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ABSTRACT

Indoor air pollution has a negative impact on human health, comfort and productivity. Emissions, however, are often related to essential functions of the indoor environment and cannot be eliminated with source control. Ventilation is then used to dilute these pollutants to acceptable concentrations.

Due to recent crises in the energy markets and the subsequent quest for higher efficiency in energy use, heat recovery ventilation has gained capstone status in sustainable building concepts. However, along with a reduction of ventilation heat loss, operating a heat recovery unit increases the pressure drop and fan power consumption in the system. These aspects are rarely traded off against each other and even more scarcely for a broad range of operating conditions. This paper addresses this trade-off based on primary energy, carbon dioxide emission, household consumer energy price and exergy frameworks for the different climates in Europe.

The results presented here demonstrate that, for the moderate climate region of middle Europe, natural ventilation, simple exhaust mechanical ventilation and heat recovery ventilation have no clear advantage over each other as far as operating energy is concerned. Realistically low specific fan power will make heat recovery ventilation advantageous in virtually all tested conditions.

1. Introduction

Over the last decades, researchers from a broad range of fields have abundantly demonstrated the impact of indoor air pollution on human health [1], comfort [2–4] and productivity [5,6]. As people spend about 90% of the time indoors [7,8], the minimization of these effects is essential. The issue has been prioritized by WHO [9]. Although source control is the most effective and straightforward way to reduce exposure to harmful pollutants, some emissions are related to the very function of the building, such as housing the occupants in residences. The sources related to these essential functions cannot be eliminated. Therefore, the pollutant concentrations are diluted by ventilation.

With continuing stress on energy prices and overwhelming scientific consensus about the climate impact of fossil fuel depletion [10], the last decades also brought about a focus on energy efficiency. In the EU, space heating accounts for about 26% of all final energy consumption [11,12]. Since infiltration, adventitious and intended ventilation combined represent about 50% of the total heat loss in well insulated buildings, this focus has resulted in an improved airtightness of newly built construction and an increased implementation of controlled ventilation flow rates.

Heat recovery ventilation has, after its successful introduction in the Scandinavian market, gradually attained a capstone status among energy efficient ventilation strategies. 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 [13] however, simple mechanical exhaust ventilation dominates the residential ventilation market [14,15] in the moderate climate zone of western Europe, such as the Netherlands, France, the UK and Belgium, while the Southern regions of Europe tend to rely on natural ventilation. Since optimization studies [16] have demonstrated that the optimal performance of appropriately sized balanced mechanical ventilation without heat recovery, simple exhaust mechanical ventilation and natural ventilation is equal with regard to both heat loss and mean exposure to pollutants, no a priori towards one of them can be assumed.

Balanced mechanical ventilation, on the other hand, has the advantage over the other system approaches that air to air heat exchangers can be added to the concept to achieve heat recovery between supply and exhaust air, thus considerably reducing ventilation heat losses. Nevertheless heat recovery ventilation operation is faced with a trade-off: an increased pressure drop due to the narrow passages in the heat exchanger unit for heat recovery

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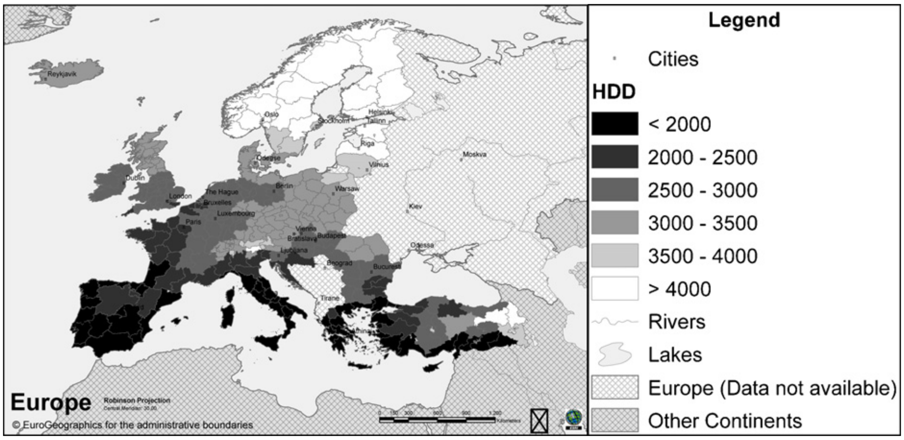

Fig. 1. HDD in the EU [34].

ventilation companions the decrease in heat loss due to that same heat recovery. The increased pressure drop will in turn lead to a higher electric energy use for the fan, while the reduced heat loss will lower the space heating load. The balance between both is, beside by system characteristics, strongly affected by climate and by the conversion factor used to compare electricity consumption to fossil fuel consumption. Simple exhaust ventilation has the disadvantage that no broadly available technology allows for heat recovery on it, while it still needs electricity for fan operation. Nonetheless, it provides more stable flow conditions than natural ventilation and some of the energy in the exhaust air can be recovered by the implementation of heat pump technology for domestic hot water production or for low temperature heating systems [17–19].

Although numerous papers discuss the performance of heat recovery ventilation [20,21], the sensitivity of this performance to variations in climatic conditions [22–27] or the impact of simple exhaust mechanical ventilation and natural ventilation on the indoor environment [28,29], they are rarely traded off against each other. Dodoo [30], however, presented an analysis of their respective merits in a very specific context with district heating. Nevertheless, the number of climatic conditions considered is always rather limited.

Therefore, in this paper, we investigate the tradeoff between heat recovery and increased electricity load for the operating phase of heat recovery ventilation for the different climates in Europe by using a set of possible conversion factors for electricity, based on primary energy, carbon dioxide emission, operating cost and exergy frameworks respectively. In the first section of the paper, the tradeoff is studied using fixed assumptions for the relevant system characteristics and boundary conditions. The sensitivity of the results with regard to these assumptions is then treated in the discussion section.

2. Methods

The frameworks used to trade off heat loss and electricity consumption all have their specific limitations. When considering carbon dioxide emissions, for example, nuclear power is a positive contributor to emission reductions. This, however, completely neglects all other considerations regarding safety and waste management that are associated with that particular technology. Using 4 different frameworks allows to grasp more than one of these facets, but is still incomplete and should be supplemented with additional information.

The results presented only consider the operating energy under different trade-off conditions. It has to be stressed that the method proposed is not suited for the prediction of actual performance of a specific implementation of a system, but is merely focused on demonstrating the distribution and variability of the potential for heat recovery ventilation. The potentials, demonstrated in the figures shown in the results section, are valuable resources for fixing stimulus policies and during conceptual design phases. A more complete feasibility assessment for a specific project should be based on precise system characteristics and climate data and should include investment costs, building specific elements such as acoustic nuisance, draft risk or the need to filter contaminated outdoor air and additional operating costs such as maintenance and component replacement (e.g. fans and filters!).

The assessment of heat recovery ventilation made in this paper only takes in to account the intended ventilation. The ventilation systems are all assumed to run at a constant rate, all year long. This is a valid assumption since, although occupants tend to open windows during summer [31], thus increasing the total air flow rate, the system is rarely shut down. The ability to shut the system down is even forbidden in some ventilation standards [32]. For all of the coefficients used, averaged values should be handled with care.

2.1. Climate and recovered heat

To characterize the different climate conditions, the heating degree day [33] data from Eurostat [34] is used (Fig. 1). The data was averaged over a 10 year period from 2000 to 2009.

This data conforms to the NUTS 2 level as defined by Eurostat [35] which corresponds to a subnational, regional scale for EU Member States, Norway, Turkey, Croatia, Switzerland, Liechtenstein and Iceland. For some regions the data is available on NUTS 3 (city) scale. The data was used in its finest geographical form available.

In accordance with the Eurostat definition of heating degree days (HDD) [36], which assumes a heating threshold of 15 °C and an indoor temperature of 18 °C, the number of heating degree days for any given day is defined as 18 °C minus the daily mean temperature, whenever that daily mean temperature is below 15 °C. The daily mean temperature is defined as the mathematical average of the minimum and maximum temperature of that day. Based on this definition, the average number of HDD for the EU is 3000. The distribution of HDD within the EU is shown in Fig. 1.

The total heat recovered annually by a heat recovery unit (HRU) is calculated from the heat content of the ventilation air:

$$Q_{\mathrm{HR}} = \int_a \rho \cdot c \cdot \varepsilon \cdot g(t) \quad \Delta T(t) \quad dt$$