Energy and Buildings 128 (2016) 384–393

Contents lists available at ScienceDirect

Energy and Buildings

journal homepage: www.elsevier.com/locate/enbuild

Evaluation of the potential energy recovery for ventilation air in dwellings in the South of Europe

Silvia Guillén-Lambea [a,b,*], Beatriz Rodríguez-Soria [a], José M. Marín [b]

[a] University Center of Defense, Ctra. Huesca, s/n, 50090, Zaragoza, Spain
[b] Aragón Institute of Engineering Research (I3A), Thermal Engineering and Energy Systems Group, University of Zaragoza, Torres Quevedo Building, C/Maria de Luna 3, 50018 Zaragoza, Spain

ARTICLE INFO

Article history:
Received 28 September 2015
Received in revised form 26 May 2016
Accepted 5 July 2016
Available online 6 July 2016

Keywords:
Ventilation
South of Europe climatic area
Residential dwellings
Energy recovery strategies

ABSTRACT

Heat recovery in ventilation systems for dwellings in cold and mild climates is needed in order to meet the requirements of nearly zero-energy buildings (nZEB) in terms of energy demand. These requirements can be met without heat recovery systems in only a few European areas with warm climates. The energy recovery potential for warm Mediterranean cities located in the south of Europe has not been investigated in sufficient depth. This article proposes a new methodology to analyze the climate data using the psychrometric chart to determine in which cases it is of interest to recover heat only or to recover the latent energy. The study covers several cities in southern Europe and the results are compared with northern European cities in terms of recovery strategies. The result demonstrates the necessity to establish different energy recovery strategies in cities located in similar latitudes. The appropriate strategy can be established with the climate data analysis methodology proposed. In some cities, the convenience of recovering latent energy to meet nZEB energy requirements has been demonstrated.

1. Introduction

The current worldwide concern for reducing energy consumption is reflected by the new standards, laws, norms, policies and regulations published around the world.

As Pérez-Lombard [1] pointed out, the energy consumption of buildings represents 37% of the total final energy consumption of the European Union and the residential sector is responsible for 70% of this building energy consumption.

To regulate energy consumption in the building sector, the EU published the 2010/31/EU European Directive [2] requiring that all new buildings constructed in the EU from 2020 onwards (and all new public buildings starting in 2018) should be nearly zero-energy buildings (nZEB).

The heating and cooling demands for residential buildings are regulated all over the world. The strategies aimed at reducing the air conditioning demand are to increase thermal insulation and improve the air tightness of the building envelope. Both parameters have been shown to have the greatest impact on the improvement of heating and cooling demands. In buildings with high thermal insulation and air tightness, a third parameter has been identified as the most critical for energy demand: the energy losses due to ventilation. Roulet et al. [3] state that a minimum of 50% of energy losses are due to ventilation.

Heat recovery is widely implemented in northern and central European countries and is a requirement for the Passivhaus standard. The constructive methodology Passivhaus, developed in Germany by the Passivhaus-Institut Darmstadt [4], has spread throughout Europe as a reference for the drafting of regulatory changes aimed at adapting buildings to nZEB [5].

Several works have demonstrated that heat recovery is a necessity for severe climatic conditions (in north and central Europe). Fehrm et al. [6] conclude that heat recovery can reduce the primary energy consumption by a minimum of 20% for Germany and Sweden.

The current heat exchangers mounted on ventilation systems have a sensible efficiency in the range 65–95% (depending on the airflow rate and pressure drop of the system). Passivhaus requires a minimum of 75% for heat exchanger efficiency [7] for nominal working conditions.

With the aim of reducing the air-conditioning demand even further, energy recovery systems which recover not only the sensible energy also the latent energy have been studied in depth during recent decades. This is mainly because, depending on the climate conditions, the latent load constitutes a large fraction of the total

* Corresponding author at: University Center of Defense, Ctra. Huesca, s/n, 50090, Zaragoza, Spain.
E-mail address: sguillen@unizar.es (S. Guillén-Lambea).

http://dx.doi.org/10.1016/j.enbuild.2016.07.011
0378-7788/

thermal load in the HVAC system [8]. In one research article [9], an energy analysis shows that enthalpy heat exchangers (latent and sensible) reduced the total energy consumption by 8% compared to conventional air conditioning systems in tropical climates and by 4% in a moderate climate. In a study of a building in four American cities, Rasouli et al. [10] demonstrate that by using energy recovery the reduction in the annual heating energy consumption could reach 40%, which is 5% higher than the heat recovery, and estimate a 20% reduction in the cooling energy consumption if the ERV is well controlled.

Current heat exchangers for ventilation systems have a latent effectiveness in the range 55–60% [11] which is lower than the effectiveness of sensible heat exchangers.

The selection of the optimal recovery system is further complicated because the use of membrane-based materials to transfer both moisture and heat simultaneously could have the disadvantage of lower thermal conductivity compared to the well-known plate heat exchangers.

The present study focuses on the south of Europe, where warm and high humidity climate conditions could justify the use of energy recovery systems rather than heat-only recovery systems.

For this purpose, an in-depth analysis of the climatic data for cities located in humid areas (all around the Mediterranean coast) has been carried out. From this analysis, different psychrometric chart regions have been defined in order to evaluate the maximum energy recovery from ventilation systems and, finally, an optimized strategy in terms of sensible heat recovery or latent energy recovery is proposed.

The objective of this research is to indicate the advisability of choosing a heat or an energy recovery device depending on the potential energy to be recovered, as well as to identify some critical areas where the latent and sensible energy should be recovered to comply with the Spanish, European and nZEB regulations concerning the energy demand in buildings.

2. Background: sensible and latent loads due to ventilation air flow

The air flow supply to a dwelling at the outside temperature and humidity is equal to the air flow leaving the dwelling under indoor conditions, in cases where the ventilation system is balanced. This thermal load due to the ventilation air flow is an important energy demand (heating or cooling demand depending on the ambient conditions). The total energy which has to be added to the ventilation air flow for the air conditioning system can be calculated using Eq. (1).

$$E = \dot{m}_{vent} \cdot (h_{out} - h_{in})\, t \tag{1}$$

Where

E is the total energy demand due to the ventilation air (kJ)

$\dot{m}_{ven}$ is the mass flow of ventilation dry air (kg $_{\text{dry-air}}$/h)

h_{out} is the enthalpy of the outside air (kJ/kg $_{\text{dry-air}}$)

h_{in} is the enthalpy of the internal air (kJ/kg $_{\text{dry-air}}$)

t is the system working time (h)

From the enthalpy definition Eq. (2).

$$h = C_{pair} \cdot T + w\left(C_f + C_{pv}T\right) \tag{2}$$

Where

C_{pair} is the dry air specific heat capacity at constant pressure (1.006 kJ/kg K)

C_f is the water heat vaporization at 0 °C (2501 kJ/kg)

C_{pv} is the water vapor heat capacity (1.86 kJ/kg K)

Substituting Eq. (2) in Eq. (1) gives Eq. (3)

$$E = \dot{m}_{vent} \cdot \left[\left(C_{pair} + C_{pv} \cdot w_{in}\right)(T_{out} - T_{in}) + \left(C_f + C_{pv}T_{out}\right)(w_{out} - w_{in})\right] \cdot t \tag{3}$$

Where

T_{out} is the outside air temperature (°C)

T_{in} is the inside air temperature (°C)

w_{out} is the outside air specific humidity (kg/kg$_{\text{dry-air}}$)

w_{in} is the inside air specific humidity (kg/kg$_{\text{dry-air}}$)

There is a sensible thermal load due to the temperature change and a latent thermal load due to the change of humidity. These values correspond to the two terms in Eq. (3), resulting in Eq. (4) and Eq. (5), respectively.

$$Q_s = \dot{m}_{vent} \cdot \left(C_{pair} + C_{pv} \cdot w_{in}\right)(T_{out} - T_{in}) \cong \dot{m}_{vent} \cdot C_{pair}\,(T_{out} - T_{in}) \cdot t \tag{4}$$

$$Q_l = \dot{m}_{sup} \cdot \left(C_f + C_{pv}T_{out}\right)(w_{out} - w_{in}) \cdot t \cong \dot{m}_{vent} \cdot C_f\,(w_{out} - w_{in}) \cdot t \tag{5}$$

Where

Q_s is the sensible energy demand due to the ventilation air (kJ)

Q_l is the latent energy demand due to the ventilation air (kJ)

2.1. Heat recovery ventilators (HRV)

The HRV includes in the system a heat exchanger used to heat the outside air before supplying it to the dwelling, transferring the heat from the inside air before expelling it outside. During summer the outside air is cooled by the same process. These heat exchangers only transfer the sensible energy between the two air streams. The energy transferred is the energy recovered by the ventilation air before being supplied to the dwelling.

Heat recovery depends on the heat exchanger sensible efficiency and can be calculated using Eq. (6).

$$Q_{s,rec} = \varepsilon_{sens} \cdot C_{min} \cdot \left(T_{sup,in} - T_{exh,in}\right) \cdot t \tag{6}$$

Where

$Q_{s,rec}$ is the sensible energy recovered (kJ)

C_{min} is the minimum capacitance of the air stream, which is the lesser product of the mass flow rate and specific heat for each of the two streams (supply and exhaust)

$T_{exh,in}$ is the exhaust air temperature at the inlet of the heat exchanger, which is the dwelling temperature (°C)

$T_{sup,in}$ is the supply air temperature at the inlet of the heat exchanger, which is the outside temperature (°C)

ε_{sens} is the sensible effectiveness of the heat exchanger (–) defined by Eq. (7), supposing that $Cmin = C_{sup} = Cexh$

$$\varepsilon_{sens} = \frac{\left(T_{exh,in} - T_{exh,out}\right)}{\left(T_{sup,in} - T_{exh,in}\right)} \tag{7}$$

Where

$T_{exh,out}$ is the temperature of the exhaust air after passing through the heat exchanger (°C)

An extensive review of heat exchanger technologies for building applications can be found in the research article [11].

2.2. Energy recovery ventilators (ERV)

The ERV includes in the system a heat exchanger where an amount of air from the outside crossing the heat exchanger is separated by a permeable membrane from the exhaust air that allows not only heat to transfer from one stream to the other but moisture to transfer as well. Heat recovery depends on the heat exchanger sensible effectiveness and can be calculated using Eq. (6). The