Evaluation of the potential Energy Recovery for ventilation air in dwellings in the South of Europe.

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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 paper 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.

Keywords

Ventilation; South of Europe climatic area; Residential dwellings, Energy recovery strategies

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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 thermal load in the HVAC system [8]. In one research paper [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 paper 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.

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

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 $_{dry\text{-}air}$ /h)
h_{out} is the enthalpy of the outside air (kJ/kg $_{dry\text{-}air}$)
h_{in} is the enthalpy of the internal air (kJ/ kg $_{dry\text{-}air}$)
t is the system working time (h)

From the enthalpy definition eq. 2.

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

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 0ºC (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

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

Where
T_{out} is the outside air temperature (ºC)
T_{in} is the inside air temperature (ºC)
w_{out} is the outside air specific humidity (kg/kg$_{dry\text{-}air}$)
w_{in} is the inside air specific humidity (kg/kg$_{dry\text{-}air}$)

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 equation 3, resulting in eq. 4 and eq.5, respectively.

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

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

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.

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

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 (ºC)

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

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

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

Where

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

An extensive review of heat exchanger technologies for building applications can be found in the paper [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 moisture recovery depends on the latent effectiveness which can be calculated using eq.8.

$$Q_{l,rec} = \varepsilon_{lat} \cdot G \cdot (w_{sup,in} - w_{exh,in}) \cdot t \quad (8)$$

Where

$Q_{l,rec}$ is the latent energy recovered (kJ)

$w_{exh,int}$ is the outside air specific humidity (kg/kg$_{dry-air}$)

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

$$G \equiv \dot{m}_{vent} C_f$$

ε_{lat} is the latent effectiveness of the heat exchanger (-) defined by eq.9.

$$\varepsilon_{lat} = \frac{(w_{exh,in} - w_{exh,out})}{(w_{sup,in} - w_{exh,in})} \quad (9)$$

Energy recovery ventilators recover the total energy (sensible+latent) following eq.10.

$$Q_{TOT,rec} = Q_{s,rec} + Q_{l,rec} = \varepsilon_{sens} \cdot Q_s + \varepsilon_{lat} \cdot Q_l \quad (10)$$

The total recovered energy depends on two parameters: the potential energy which can be recovered and the heat exchanger sensible and latent effectiveness. This paper focuses on calculating the potential energy to be recovered depending on the climate parameters and proposing an optimized strategy to recover sensible or latent energy, or both, or to by-pass the heat exchanger depending on the climatic data.

The second parameter depends on the heat exchanger technology. An extensive review of membrane heat exchanger technologies for air conditioning systems can be found in [12]. Values for the sensible efficiency of current heat exchangers for ventilation systems vary from 65% to 95% depending on the air temperatures and air flow rates. The heat exchanger effectiveness for latent energy is lower, current values being around 55-60% [11].

Other factors which affect the heat exchanger latent and sensible effectiveness depending on the heat exchanger itself have not been considered, such as the air flow leakage between the two circuits.

3. Methodology

In this section, firstly the comfort parameters are analyzed and selected due to their high impact on the energy demand. Secondly, a psychrometric chart is divided into regions depending on the ambient air temperature and humidity in order to establish a recovery strategy. Finally, the climate data treatment is presented.

3.1. Comfort parameters

The air conditioning system in a dwelling should maintain the inside air conditions within the comfort interval. The temperature and humidity set values differ depending on the country's regulations [5]. For Spain, the norms indicate a room temperature set at 21°C for heating and 25°C for cooling and a relative humidity of 60% in summer and 40% in winter. However, the trend for energy demand optimization is to increase this comfort interval. The Passivhauss standard recommends for nZEB a set of 20ºC-26ºC, although for winter nights the temperature could be reduced to 19ºC. For humidity, the comfort values are between 30% and 60%.

The values selected for this study are 20-26ºC and 30-60%. The selected intervals are very conservative. If the interval is reduced, the potential energy to be recovered will increase.

3.2. Analysis of the psychrometric chart

For ventilation systems without energy recovery, the outside air is introduced into the dwelling at the outside conditions. The air temperature and humidity hourly data are available from climate data files. Depending on these values, the outside air is located in different chart regions on the psychrometric chart (Figure 1). The climatic data analyzed are taken from the Meteonorm meteorological database on an hourly basis [13]. Depending on the location, the ventilation air energy demand of the air conditioning system will be sensible, latent or both. Under some conditions the air will not need to be conditioned before entering the dwelling. First, the amount of energy required for the ventilation air must be determined. In addition, it is highly advisable to assess the amount of heat, the humidification and the dehumidification energy required in order to decide whether heat recovery will be needed or whether latent energy recovery is also required. For this purpose, the psychrometric chart has been divided into several regions for the analysis of the energy demand for the ventilation air depending on the humidity and temperature (Figure 1).

Figure 1. Psychrometric chart regions.

Depending on the region where the hourly values for the outside air temperature and humidity are on the psychrometric chart, their hourly energy demand should be treated as follows:

<u>REGION A</u>

The outdoor conditions for region A are mostly registered during cool and dry winter days. The outdoor air entering the dwelling through the ventilation system should be heated to at least 20ºC (sensible energy demand from the heating system) and humidified to 30% RH. This air flow (point a, Figure 1) should be treated at least to reach point 1.

It is very important to identify whether there is any registered value during the summer in this region, because during the summer season the heating is not working and the ventilation air should be used to cool the dwelling. However, the humidification always needs to be carried out.

<u>REGION B</u>

When the outside air is located in this region during the winter season (point b, Figure 1), only sensible heat has to be added to the air in order to reach the low set point temperature. The treated air will reach the comfort area at the comfort humidity, so latent energy is not needed.

For the summer season, no sensible heat has to be added to the air, but if the RH is higher than 60% the air should be dehumidified. The final absolute humidity (w) has to be calculated to obtain the latent energy demand applying eq. 5, using eq.11:

$$w(T) = 0.623 \cdot \frac{RH \cdot P_V(T)}{P_{atm} - RH \cdot P_V(T)} \quad (11)$$

where P_{atm} is the atmospheric pressure and P_v (T) is the vapor pressure saturation which can be calculated using the Antoine equation (Eq. 12). This is a simple 3-parameter fit to experimental vapor pressures measured over a restricted temperature range:

$$logP = A - \frac{B}{T+C} \qquad \text{(P in bar)} \quad (12)$$

where A, B, and C are "Antoine coefficients" that vary from substance to substance [14]. For water and a temperature range of 0ºC to 100ºC these values are A=5.11564; B=1687.537 and C=230.17.
T is the air temperature (ºC).

REGIONS C AND D

The air should be heated and dehumidified before reaching the dwelling in the winter season and only dehumidified in the summer season. The air humidity has to reach point 2 on Figure 1 for the winter season but has to reach the 60% RH curve for the summer season. In this case the final absolute humidity (w) has to be calculated depending on the temperature using eq.11.

REGION E

The outside air temperature is located within the comfort interval, therefore only latent energy has to be added to dehumidify the air. The air should reach 60% relative humidity (RH) (point e, Figure 1). The final absolute humidity (w) has to be calculated using eq.11 and eq. 12.

REGION F

The air should be cooled to 26ºC and dehumidified to 60% RH before reaching the dwelling in the summer season (point f, Figure 1). Accordingly, sensible and latent energy has to be added to the ventilation air to reach the comfort area. For winter season, if the humidity is higher than 60% RH, the air should be dehumidified.

REGION G

When the outside air conditions are located in this region, for the summer season, the cooling system has to reduce the air temperature in order to reach the high set point temperature. The cooled air will reach the dwelling at a relative humidity within the comfort area, hence there is no latent energy demand.

REGION H

The registered values for outdoor conditions in the H region are registered during summer days. For warm and humid climates, no points located in this region are expected because such outside air conditions are rare for Mediterranean climates.
The outdoor air entering the dwelling through the ventilation system should be cooled to at least 26ºC and humidified to 30% RH. This air flow should be treated to reach point 4 on Figure 1. Latent and sensible energy is required.

REGION I

The outside air has a dry temperature within the comfort interval, so only latent energy has been added to humidify the air. The air should reach 30% relative humidity and the absolute humidity should be calculated using equations 11 and 12, in the same way as the points in region E.

REGION J

The points in region J are within the comfort interval, therefore the ventilation air does not need to be treated. If there is an ERV on the ventilation system, the air should by-pass the heat exchanger.

3.3. Climate data treatment.

Representative cities from humid and hot zones in the south of Europe and from cold areas in central Europe have been selected for the purposes of comparison. Figure 2 shows the cities under study.

Figure 2. Representative cities selected.

The climate data for each city has been classified first depending on the air dry temperature. The temperature range has been divided into intervals of 1ºC. The number of hours registered for each interval has been counted.

For the interval T< -7ºC all the registered data with dry temperatures below -7ºC are counted, and for the interval T>41ºC the registered hours with a temperature above 41ºC are grouped.

The frequency of each interval temperature (n) is the total number of hours for which the air dry temperature is within a range. The frequency has been divided into summer frequency (n_{summer}) and winter frequency (n_{winter}) because the control strategy applied may be different. For example, for the interval 17ºC to 18ºC, there are some registered data during the winter season where the ventilation air should be heated but there are also some data registered during the summer season (cool summer nights or mornings). During these hours the ventilation air does not need treatment but must enter the dwelling at ambient conditions (used to cool down the house during the hot Mediterranean summers: free cooling).

The dry temperature for each interval is the arithmetic average of the dry temperatures registered in the corresponding interval (T_{med}). The relative humidity (RH_{med}) and the absolute humidity (w_{abs}) are the arithmetic average of the humidity values registered for each interval.

Figure 3 shows the frequencies for the temperature intervals for Alicante (Spain) as an example. The values are represented separately for summer and for winter as the strategy differs. The sections are colored dark grey for winter and light grey for summer.

Figure 3. Frequencies for temperature intervals on the psychrometric chart sections for Alicante.

The time value t for equations 4 and 5 depending on the air conditions of the region on the psychrometric chart are as follows:

- For A region $t=n=n_{winter}$ as $n_{summer}=0$, because the outside air is not at these conditions during any summer hours.
- For B region, $t=n_{winter}$ for sensible heat (equation 4). No latent energy is demanded during winter. However, during the summer season the air has to be dehumidified in case RH>60%, then $t=n_{summer}$ if RH>60%.
- For C and D regions, $t=n_{winter}$ for sensible heat (equation 4). However, t= n for latent energy (equation 5). The latent energy is calculated separately for summer and winter, as the final absolute humidity is not the same.
- For E region t =n for equation 5. No sensible heat is required by the ventilation air.
- For F region $t=n_{summer}$ for sensible heat and latent heat (eq. 4 and eq.5). If there is any winter hour in this region and the HR is higher than 60%, the air will be dehumidified and $t=n_{summer}+n_{winter}$ (only hours with RH>60%).

In the Passivhaus standard, the ventilation rate must be the minimum necessary to ensure the hygiene of the interior rooms, considering this value to be between 30 m^3/h and 32 m^3/h per person (for residential use) [7]. It also recommends regulating the exchange rate depending on the activity. Ventilation must be mechanically controlled via a heat exchanger to avoid introducing the outside air temperature. The use of heat recovery systems in the ventilation circuit is required by the Passivhaus standard. Houses built under this standard have an average heating demand lower than 15 kWh/m^2 a year and a cooling demand lower than 15 kWh/m^2 a year.

The energy demand has been calculated for a continuous ventilation air flow of 120 m^3/h. This is the recommended air flow in the Passivhaus standard for a typical European family of 4 people.

4. Results and discussion.

For Alicante the sensible demand is 68% and the latent demand is 32% of the total energy demand occasioned by the dwelling ventilation. Assuming a dwelling of 80 m^2 (the typical size for an apartment of 4 people) and a ventilation air flow of 120 m^3/h, the energy demand due to ventilation is 20.8 kWh/m^2 for sensible energy (20.3 kWh/m^2 for heating and 0.5 kWh/m^2 for cooling) and 9.8 kWh/m^2 for the latent energy (99.7% is dehumidification). The dehumidification demand is 8.3 kWh/m^2 during summer and 1.5 kWh/m^2 during winter.
The heating demand due to the dwelling ventilation flow (21.8 kWh/m^2) does not meet the maximum heating demand indicated by the Passivhaus standard (15 kWh/m^2) as a reference for the nZEB definition, therefore sensible heat should be recovered. The cooling demand due to the dwelling ventilation flow (8.8 kWh/m^2), however, still leaves room for other demands. Therefore it seems that the cooling demand requirement indicated by the Passivhaus standard could be met (15 kWh/m^2).
Table 1 shows the heating and cooling demands allowed by Spanish regulations depending on the climatic zone for a dwelling of 80 m^2. Alicante is located in the B4 Spanish climatic zone. Taking into account that the minimum ventilation flow rate imposed by Spanish regulations [15] is 172.8 m3/h, the energy demand due to ventilation is 30.0 kWh/m^2 for sensible energy (29.3 kWh/m^2 for heating and 0.7 kWh/m^2 for cooling) and 14.1 kWh/m^2 for the latent energy. The dehumidification demand is 12.0 kWh/m^2 during summer and 2.1 kWh/m^2 during winter. The heating demand due to ventilation air (31.4 kWh/m^2) does not meet the maximum heating demand established in the current Spanish regulations. The cooling demand due to the dwelling ventilation flow (12.7 kWh/m^2) meets the requirements indicated by the current Spanish regulations. However, it leaves little scope for other demands, and therefore it seems that the cooling demand requirement will barely be fulfilled without an energy recovery system.

Spanish regulation DB-HE1 [16]

Winter Climate Zone	**Heating demand (KWh/m^{2}year)**
α/A/B	15.0
C	32.3
D	51.7
E	77.0
Summer Climate Zone	**Cooling demand (KWh/m^{2}year)**
1/2/3	15.0
4	20.0

Table 1. Heating and cooling demands allowed by current Spanish regulations depending on the climatic zone.

Calculations have been done for the cities selected. Figure 4 shows the percentage of sensible and latent demand due to the ventilation air.

Figure 4. Sensible and latent energy demand due to ventilation air for each city.

Las Palmas de Gran Canaria and Santa Cruz de Tenerife, both located in the Canary Islands, have a latent demand higher than the sensible demand. Almeria and Murcia are the Mediterranean cities which have more than 40% of latent energy demand. For Valencia, Palma, Barcelona and Alicante, all of them located on the Spanish Mediterranean coast, the latent energy demand due to ventilation air is between 20% and 40% of the total energy demand. For Gerona and Nice, cities located at the north of the Mediterranean sea, the latent energy represents less than 20% of the total energy. The latent energy for those cities is at the same level as for continental cities such as Madrid or Berlin.
Figure 5 represents the percentage of hours of the year for the different outside air conditions in the psychrometric regions. Region A is important for cold cities such as Berlin and Ávila, one of the coldest Spanish cities (winter climatic zone E). No frequencies for warm Mediterranean cities appear in this

region. Region B has the highest frequency of almost all the studied cities except those in the Canary Islands. The next step should be to determine if the frequency is during winter (only sensible energy can be recovered) or during summer, as the strategy differs. The cities located in the Canary Islands have the highest frequencies in region E where only latent energy can be recovered. It is interesting to see that region J, which is the comfort area, has the highest frequencies for cold cities (Berlin and Avila) and for Málaga as a warm city. However, the frequencies occur during summer for the former and mostly during winter for the latter.

Figure 5. Percentage of the hours of the year for ambient conditions in the psychrometric regions.

For a quick interpretation of the results, Fig. 6 shows the frequencies for each region distinguished by season, as the recovery strategies are different. The sections are colored dark grey for winter and light grey for summer. In Figure 6, the localization of the climate data for 4 cities with very different climatic data reflects the results obtained regarding the percentage of the sensible versus latent energy in the ventilation air.

Santa Cruz de Tenerife, which has 46% sensible energy demand versus 54% latent energy demand, has the highest frequency of ambient conditions located in region E (45% of the time over the year) where only latent energy demand occurs. Murcia, with 59% sensible energy demand, has the highest frequency in region B (45% of the time over the year) while Barcelona with 53% of the time in region B, consequently their percentage of sensible energy is increased till 73%. Berlin, where the latent energy demand is very low (14%), has no frequency of ambient conditions located in region E. Its highest frequencies are located in regions B and A. The result for region A indicates that the latent energy in Berlin is due to humidification, in contrast to the other cities where the latent energy is due to dehumidification.

Figure 6. Frequencies for temperature intervals on the psychrometric chart sections for 4 cities.

Figure 7 represents the number of hours during a year when ventilation air requires energy from the air conditioning system as follows:

Time Sens (h) is the number of hours that the air conditioning system will transfer only heat to the ventilation air.

Time Lat (h) is the number of hours that the air conditioning system will need to dehumidify or humidify the air to reach the comfort area.

Time Both (h) is the number of hours that the air conditioning system will transfer heat and humidity.

Time By-pass is the number of hours that no treatment is needed, and the ventilation air should by-pass the energy recovery unit.

In cases where a heat exchanger is placed on the ventilation system, Fig.7 shows the time that the heat exchanger will work recovering the energy. This result will help to select the appropriate kind of heat exchanger. It is worth noting that for all the cities the period of time for transferring both heat and humidity simultaneously is not the longest. Most of the time, either heat recovery or humidity recovery is needed, but not at the same time. This result indicates that the best configuration seems to be having both heat exchangers working in parallel.

If the level of latent energy is significant, as for example in Murcia, the optimised configuration proposed will be a heat exchanger with a sensible core and a latent core which can work in dual mode for the period of time when sensible and latent energy can be recovered simultaneously.

Figure 7. Frequency of the energy demand of the ventilation air.

To be able to make a choice of the most appropriate energy recovery system for each city, frequencies of the energy demand should be analysed together with the potential energy to be recovered. Table 2 shows the ventilation air energy demand for an apartment of $80m^2$. The energy has been calculated with a ventilation air flow of $30m^3/h$ per person for 4 people living in the dwelling. This is the minimum air flow recommended per person by Passivhaus. The results can be compared to the Passivhauss standard where the heating demand should be lower than 15 kWh/m^2 a year and the cooling demand lower than 15 kWh/m^2 a year.

CLIMATIC ZONE/CITY	ENERGY DEMAND DUE TO VENTILATION AIR (kWh/m^{2}year)					
	Winter			Summer		
	QHEATING (Sensible)	QHUM+QDEHUM (Latent)	QTOTAL	QCOOLING (Sensible)	QHUM (Latent)	QTOTAL
ALICANTE	20.37	1.50	**21.88**	0.47	8.31	**8.78**
A4_ALMERIA	14.00	1.90	**15.90**	1.22	9.38	**10.60**
AVILA	35.99	1.39	**37.38**	0.75	0.18	**0.93**
C2_BARCELONA	20.29	2.15	**22.45**	0.43	5.34	**5.77**
BILBAO	25.23	1.11	**26.34**	0.17	2.91	**3.08**
GERONA	27.38	1.16	**28.54**	0.69	2.08	**2.76**
LAS PALMAS DE GRAN CANARIA	4.79	12.35	**17.14**	0.16	7.61	**7.77**
D3_MADRID	21.86	2.17	**24.04**	0.95	4.13	**5.08**
A3_MALAGA	15.61	0.35	**15.97**	1.16	0.81	**1.97**
MURCIA	18.59	4.29	**22.88**	0.55	9.15	**9.70**
PALMA DE MALLORCA	21.86	2.43	**24.29**	0.95	5.49	**6.44**
SANTA CRUZ DE TENERIFE	4.01	3.80	**7.82**	0.60	1.57	**2.17**
B4_SEVILLA	17.28	0.54	**17.82**	3.25	1.95	**5.19**
B3_VALENCIA	19.37	1.64	**21.01**	0.92	4.94	**5.86**
BERLIN	43.50	4.32	**47.82**	0.11	2.85	**2.97**
NICE	22.97	1.35	**24.32**	0.16	3.67	**3.82**

Table 2. Ventilation air **E**nergy demand (kWh/m^{2}y) for a dwelling of 80m^2.

As previously mentioned, Roulet et al. [3] state that at least 50% of energy losses are due to ventilation, which means the values obtained should not exceed 7.5 kWh/m^2 a year to avoid energy recovery from the ventilation system. The grey cells in Table 2 indicate when the energy recovery will be mandatory for meeting the energy consumption for nZEB dwellings, and if the energy recovered should be latent or sensible.

5. Conclusions

Energy demand due to ventilation air in dwellings has become a very significant issue. It has already been demonstrated that heat recovery from ventilation air is a necessity in severe climatic conditions in order to meet the energy demand levels required for nZEB dwellings. Based on an in-depth analysis of the climatic data for several cities located in mild and warm climates in the south of Europe, this paper proposes a methodology for evaluating the advisability of recovering the sensible, the latent or both energies from the ventilation air. The methodology calculates only real demands, identifying the season of the year for outside air conditions in order to make the appropriate decision as regards conditioning the ventilation air.

The south of Spain has a high energy demand due to the latent energy needed to condition the ventilation air in dwellings. More than 40% of the energy demand is due to the latent loads which represent a high potential for energy recovery systems instead of heat recovery systems. Cities located mid way down the Spanish Mediterranean coast have a latent energy demand due to ventilation air of between 20% and 40% of the total energy demand. However, the latent energy for cities located at the north of the Mediterranean sea represents less than 20% of the total energy. The latent energy for those cities is at the same level as that of continental cities such as Madrid or Berlin.

For the winter season, only the cities located in the Canary Islands have significant potential for latent energy recovery. Only in Santa Cruz de Tenerife is the use of a latent energy exchanger mandatory to reach nZEB energy demand levels. However, in this case a sensible heat exchanger does not seem to be necessary.

For the rest of the cities under study, the recovery of latent energy is very low compared to sensible heat. Nevertheless, in the summer dwellings in cities located at the south of the Mediterranean coast such as Alicante, Murcia or Almeria, should preferably use a latent recovery system rather than a sensible heat exchanger. The sensible recovery system should be mandatory for those cities to reach nZEB heating demand values during winter, while the latent heat exchanger is highly recommended but not a necessity during summer. It is concluded that a membrane-based recovery system seems not to be the best choice as both transfers occur at the same time. Besides, the thermal efficiency could be penalized compared with traditional heat exchangers.

Given the disparity of strategies needed depending on the climate data for Europe, energy maps need to be drawn showing the potential latent energy that could be recovered.

Moreover, the demands for latent and sensible energy do not arise at the same time, and this has an influence on the kind of recovery system appropriate for each climate condition. The choice of the recovery system is decisive. Most current research is focused on developing new materials with the capability of transferring both moisture and heat simultaneously. However, this solution may not be the most suitable for mild and warm climates where the need to recover heat or transfer moisture does not occur at the same time for most of the year.

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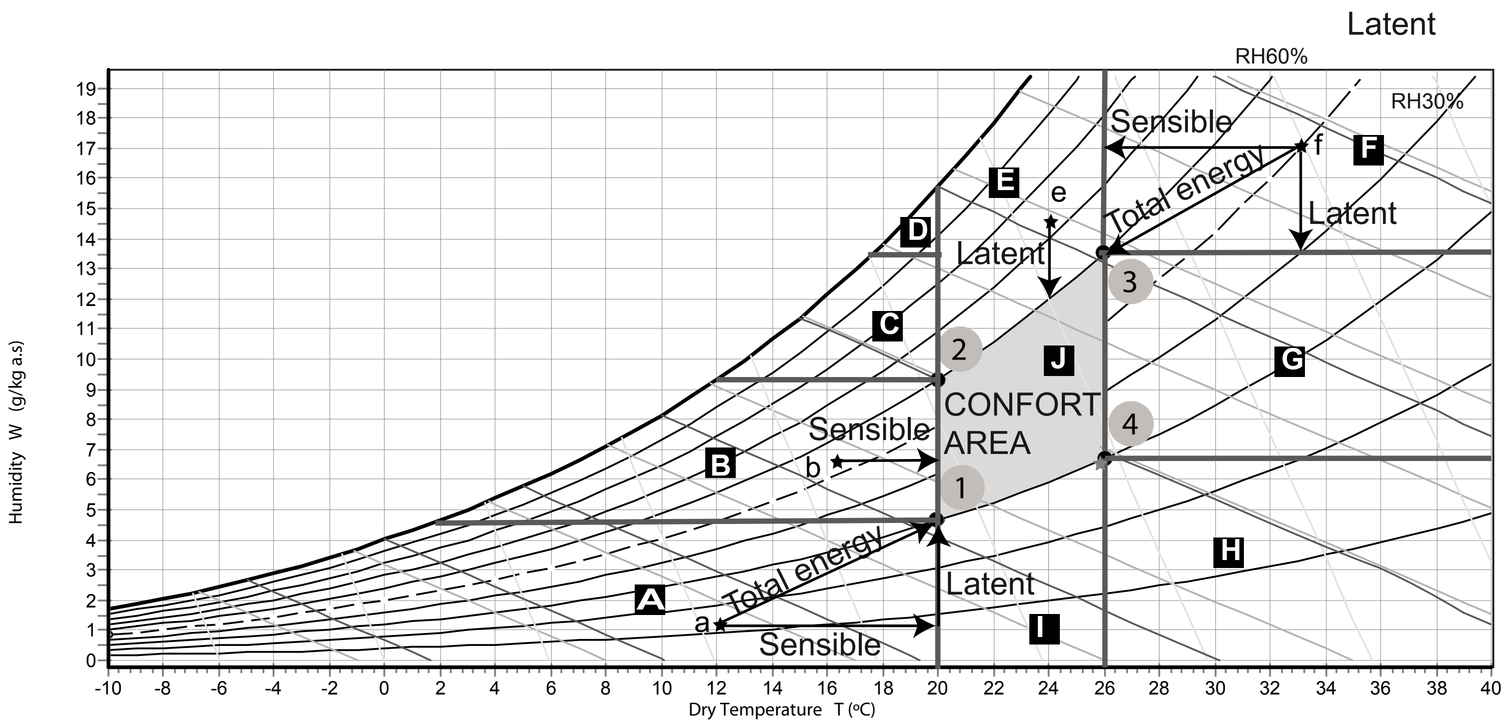
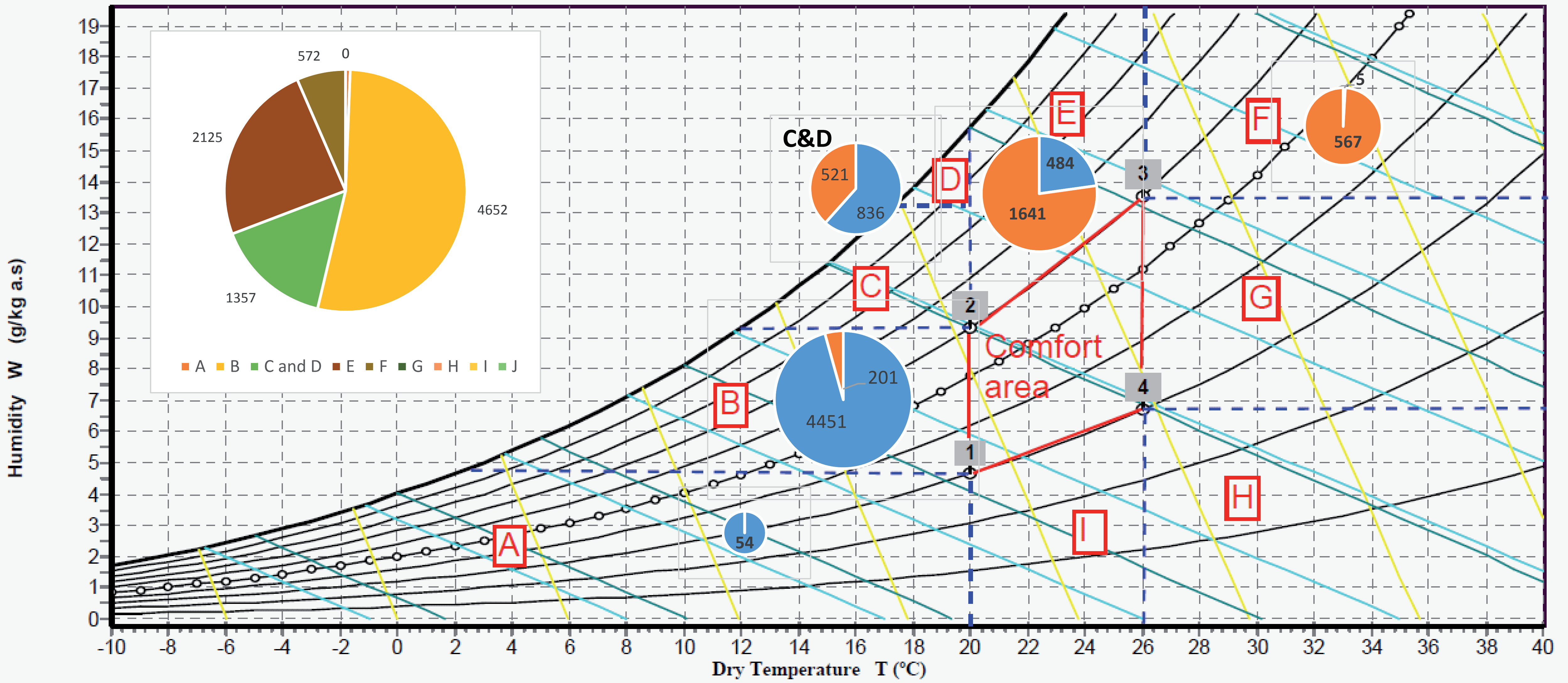
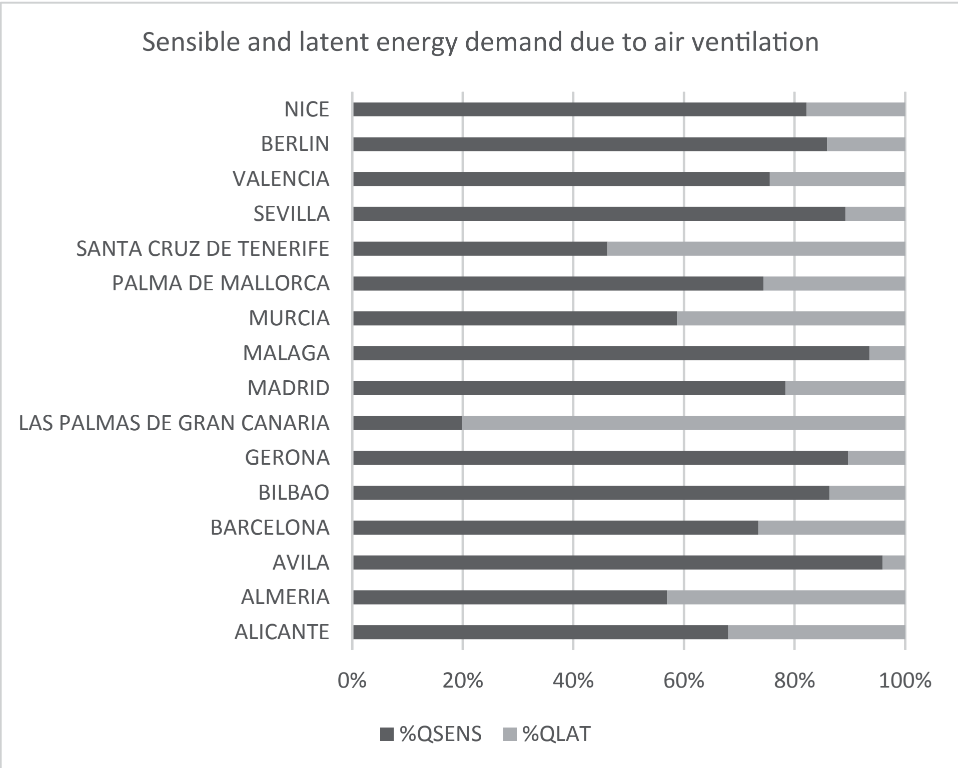

Latent
RH60%
RH30%
Sensible
Total energy
Latent
Latent
Sensible
CONFORT
AREA
Total energy
Latent
Sensible
A
B
C
D
E
F
G
H
I
J
1
2
3
4
a
b
e
f
Humidity W (g/kg a.s)
Dry Temperature T (ºC)

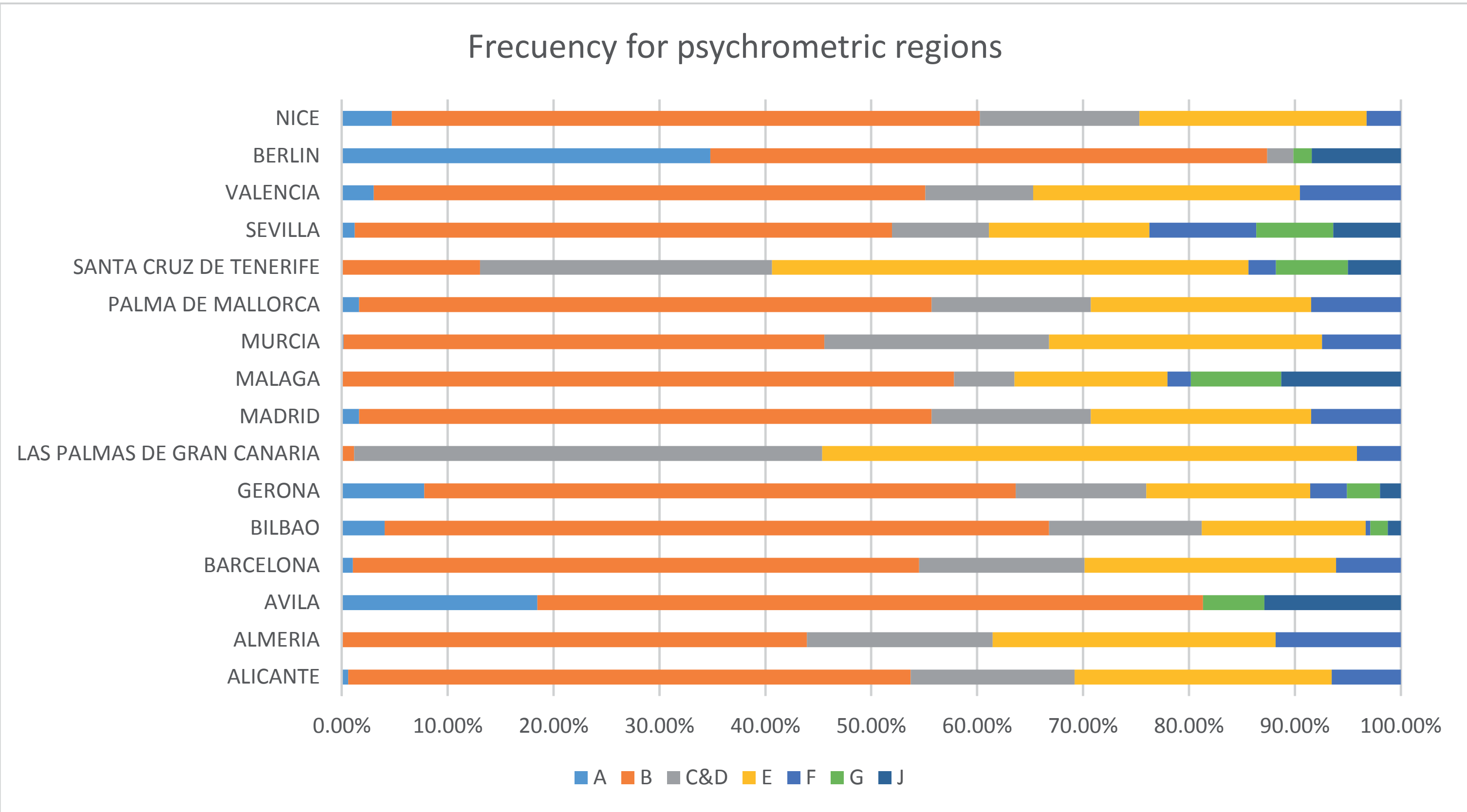

Berlin
Bilbao
Nice
Gerona
Ávila
Barcelona
Madrid
Palma de Mallorca
Valencia
Sevilla
Alicante
Málaga
Murcia
Almería
Santa Cruz de Tenerife
Las Palmas de Gran Canaria



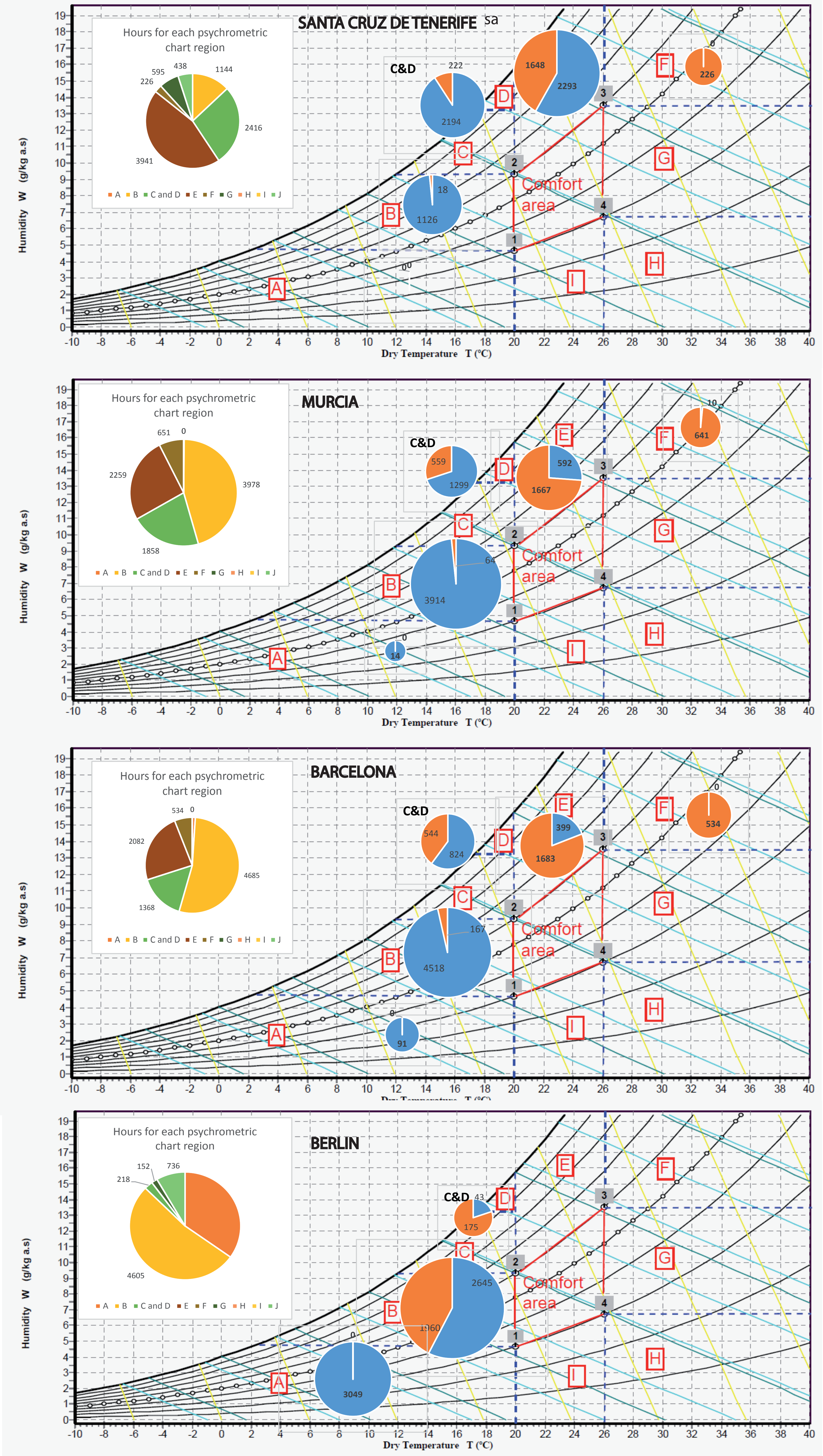
Humidity W (g/kg a.s)
Dry Temperature T (°C)
572
0
2125
4652
1357
A B C and D E F G H I J
C&D
521
836
484
1641
567
201
4451
54
A
B
C
D
E
F
G
H
I
1
2
3
4
5
Comfort area



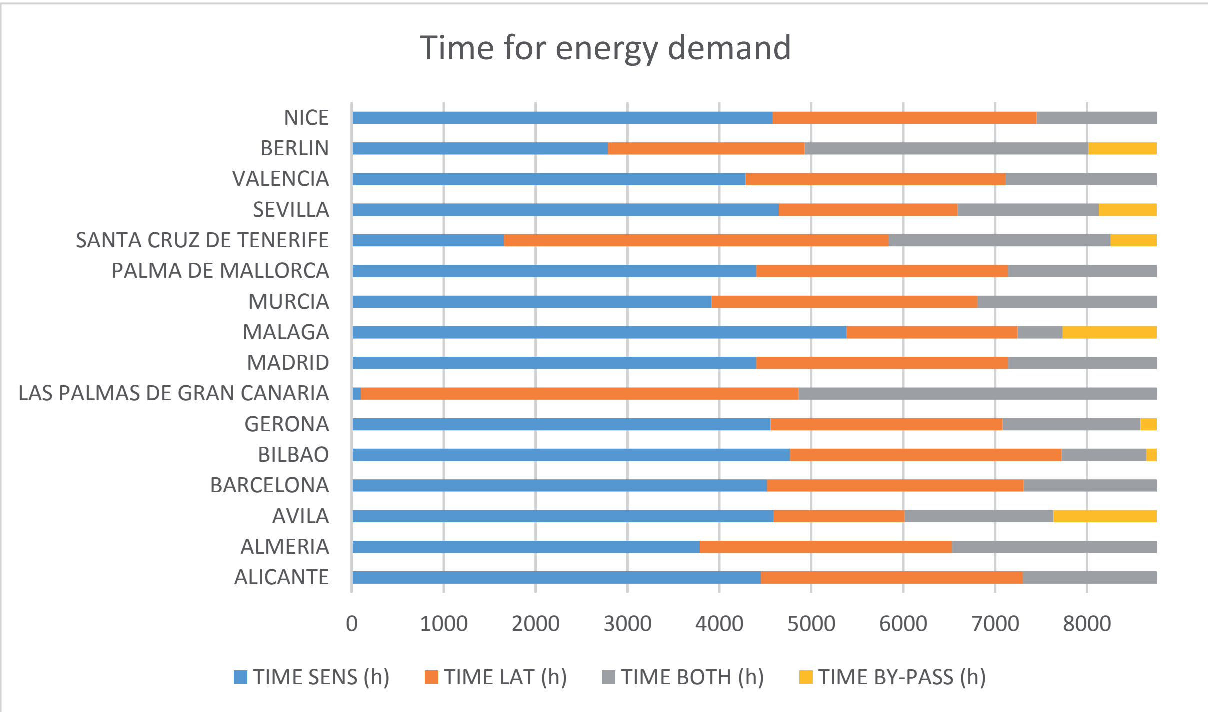
Sensible and latent energy demand due to air ventilation
NICE
BERLIN
VALENCIA
SEVILLA
SANTA CRUZ DE TENERIFE
PALMA DE MALLORCA
MURCIA
MALAGA
MADRID
LAS PALMAS DE GRAN CANARIA
GERONA
BILBAO
BARCELONA
AVILA
ALMERIA
ALICANTE
0%
20%
40%
60%
80%
100%
%QSENS
%QLAT



Frecuency for psychrometric regions
NICE
BERLIN
VALENCIA
SEVILLA
SANTA CRUZ DE TENERIFE
PALMA DE MALLORCA
MURCIA
MALAGA
MADRID
LAS PALMAS DE GRAN CANARIA
GERONA
BILBAO
BARCELONA
AVILA
ALMERIA
ALICANTE
0.00%
10.00%
20.00%
30.00%
40.00%
50.00%
60.00%
70.00%
80.00%
90.00%
100.00%
A
B
C&D
E
F
G
J



SANTA CRUZ DE TENERIFE
Hours for each psychrometric chart region
A B C and D E F G H I J
C&D
Comfort area
Humidity W (g/kg a.s)
Dry Temperature T (°C)
MURCIA
Hours for each psychrometric chart region
A B C and D E F G H I J
C&D
Comfort area
Humidity W (g/kg a.s)
Dry Temperature T (°C)
BARCELONA
Hours for each psychrometric chart region
A B C and D E F G H I J
C&D
Comfort area
Humidity W (g/kg a.s)
BERLIN
Hours for each psychrometric chart region
A B C and D E F G H I J
C&D
Comfort area
Humidity W (g/kg a.s)
Dry Temperature T (°C)



Time for energy demand
NICE
BERLIN
VALENCIA
SEVILLA
SANTA CRUZ DE TENERIFE
PALMA DE MALLORCA
MURCIA
MALAGA
MADRID
LAS PALMAS DE GRAN CANARIA
GERONA
BILBAO
BARCELONA
AVILA
ALMERIA
ALICANTE
0
1000
2000
3000
4000
5000
6000
7000
8000
TIME SENS (h)
TIME LAT (h)
TIME BOTH (h)
TIME BY-PASS (h)