Environmental and Climate Technologies
2025, vol. 29, no. 1, pp. 1058–1072
https://doi.org/10.2478/rtuect-2025-0071
https://content.sciendo.com

RIGA TECHNICAL UNIVERSITY

Cost-Benefit Analysis of Heat Recovery and Humidity-Controlled Ventilation in Spanish Apartments

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Received 11.04.2025; accepted 10.12.2025

Abstract **– Heat recovery ventilation (HRV) systems are increasingly recognized across Europe as a practical solution to enhance indoor air quality while reducing energy losses in residential buildings. They are frequently mandatory in contemporary building regulations and sustainability certification frameworks. In southern European contexts such as Spain, new housing developments often incorporate HRV systems, which are not explicitly required but might be required indirectly to comply with energy consumption limitations in building codes in the colder regions. The cost-effectiveness of these installations is strongly influenced by both local climate conditions and required ventilation rates. This research assesses the financial feasibility of mechanical heat recovery ventilation specifically in Spanish apartment buildings, accounting for the country's varied climatic regions. Using regional climate data, the study calculates potential energy savings linked to HRV and compares them to baseline heating costs using a Levelized Cost of Energy (LCOE) approach, which incorporates initial installation expenses, recurring operating costs, and probable energy price fluctuations. The potential of demand-controlled ventilation is also addressed, in the form of humidity-controlled ventilation. The findings suggest that HRV systems can be economically acceptable in Spain's colder inland regions and in houses with more airflow demand, presenting acceptable LCOE and payback periods. However, in the more temperate coastal areas, these systems often fail to break even, highlighting the critical importance of climate-specific considerations. Beyond economic factors, this paper comments on other benefits of HRV, such as enhancing indoor thermal comfort in winter, filtration, and potentially lowering total energy demand. Future research should include thorough life-cycle cost evaluations.**

Keywords **– Energy efficiency; Energy Policy; Heat Recovery Ventilation; LCOE (Levelized Cost of Energy); Mechanical Ventilation; nZEB (Nearly Zero Energy Building); Payback Period; Thermal Comfort.**

1. INTRODUCTION

Over the last few decades, improvements in building envelopes have been driven by regulatory change aimed at reducing total energy demand. In Spain, the 2013 and 2019 code updates [1] have played a decisive role in enhancing insulation and, by extension, in lowering the need for heating and, somewhat, cooling. However, as the building envelope becomes

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more efficient, ventilation-related thermal demand grows in relative importance within the overall energy balance of buildings. As a result, ventilation systems and, particularly, heat recovery ventilation (HRV), have gained attention as part of the broader conversation on energy efficiency and indoor air quality (IAQ).

1.1. Regulatory Evolution and Market Trends for Heat Recovery Ventilation

In Spain, the residential ventilation sector represents an estimated annual market of around 30 million euros, according to reports by the Spanish Association of Air-Conditioning Equipment Manufacturers (AFEC) [2]. While this figure amounts to only about 2 % of the overall turnover in the national HVAC sector, it has grown by approximately 33 % since 2021. Despite this trend, relatively little detailed information is available on the breakdown of different ventilation solutions in the Spanish residential market. Indeed, there are no consolidated data that fully capture how much of the market is occupied by heat recovery systems versus single-flow or other more conventional ventilation methods.

Some official recommendations, along with voluntary green certifications, have promoted the use of mechanical ventilation with heat recovery. In Spain, while the national building code (Código Técnico de la Edificación, CTE) does not explicitly require HRV, it indirectly encourages it in colder climates. Spain's Long-Term Strategy for Energy Renovations (ERESEE 2020) [3], which includes one preparatory report authored by the Spanish Technical Association for HVAC and Refrigeration (ATECYR) [4], advocated using heat recovery systems in energy retrofits for climate zones D and E. This recommendation was carried forward to the final version of the national strategy document.

Under Passivhaus certification, which is the most widely known certification scheme in Spain, HRV is not only quasi-mandatory but also a pivotal component of both the overall economic strategy and the HVAC concept [5]. In fact, the standard typically sets a ventilation rate of 30 m^3/h per person, a figure tied to the design goal of restricting the maximum heat load to 10 W/m^2 [6].

In contrast, the approach taken by the Spanish national building code (CTE) relies on the number and type of habitable rooms, leading to airflow rates of around 20 to 30 m^3/h per person if we assume the maximum possible occupancy in an apartment. Because actual occupancy is statistically quite lower in real operation, many constant-flow systems end up delivering per-person ventilation rates that exceed this figure. At least this would be the case with constant flow systems, without any regulation. In practice, it is common to install two- or three-speed control knobs in individual systems.

A window into real-world trends can be seen in public housing projects in the Basque Country. In a non-exhaustive, non-representative sample of 48 developments built between 2012 and 2024 available to us, 81 % had HRV systems. However, it remains unclear how faithfully building code specifications are replicated in actual installations regarding flow rates and balancing. There is however, a persistent gap between what is theoretically projected and what is ultimately constructed, including the possibility that true operational airflow, and thus the associated energy consumption, can differ significantly from the values assumed in design documents based on simulations.

Moreover, changes in Spanish regulations introduced 2017 significantly lowered the required ventilation flow rates by 25 % to 42 % (and up to 48 % for single-bedroom apartments). As pointed out in previous analyses [7], if minimum ventilation volumes are reduced, the relative cost-effectiveness of HRV systems could be lower, particularly in warmer regions where energy savings from heat recovery are less pronounced. This article evaluates this aspect with current prices, following the regulatory conditions in force.

1.2. Saving Energy with Heat Recovery Ventilation

Heat recovery ventilation (HRV) works by transferring thermal energy from extracted indoor air to incoming fresh air, reducing overall heat losses, but real-world factors often complicate the energy savings it promises. Rodríguez Trejo [7] investigated the trade-off between maintaining adequate IAQ and achieving energy efficiency in the existing housing stock. By focusing on amortization calculations for HRV units with high efficiency, the study introduced a concept of scheduling reduced ventilation (down to 0.2 h^{-1}) for 10 hours a day, about 41.7 % of the time. At the energy prices in 2015, it emerged that in half of the locations studied, the upfront investment in HRV would never break even. In the other half, the payback period ranged between 20 and 29 years, which closely approaches the typical service life of the equipment itself. It has to be noted that this study was done before the minimum flow-rate reductions of 2017.

Insights from broader European projects shed further light on the real-world performance of HRV. Pecceu and Caillou [8] measured the efficiency of 16 HRV systems under operational conditions, finding actual efficiencies in the 70–90 % range. They identified several causes of suboptimal performance compared to laboratory values, including imbalances in supply and exhaust airflows, duct leakage, and thermal bridging within the ventilation unit. In the United Kingdom, White *et al*. [9] undertook a performance comparison between predicted and measured efficiencies in a residential retrofit project, discovering that poor installation quality and imbalanced airflows significantly undermined system effectiveness. Corrective actions such as better duct insulation and sealing boosted efficiency from 76 % to about 90 %, though they still noted some residual, unexplained heat loss.

Incorrect or suboptimal unit placement, as documented in [10], [11] can hinder the ability to do free-cooling or produce unexpected behaviour. At the same time, discussions around Passivhaus implementation in climates with mild winters and moderate summers question whether HRV is essential; if not, capital costs could be cut down significantly [12], [13].

1.3. Saving Energy with Demand-Controlled Ventilation

The 2017 update of the CTE DB-HS3 document, which regulates residential ventilation, the standard, introduced an alternative CO_2-based goal that allows designers to avoid using the required ventilation flow rates if two conditions are met: first, that average yearly CO_2 concentration is lower than 900 ppm and, second, that the annual cumulative hours during which CO_2 exceeds 1600 ppm is less than 500 000 ppm·h.

The push toward finer control of ventilation in residential buildings has brought new interest in demand-controlled ventilation (DCV), which adjusts airflow in response to real-time indicators like CO_2 levels, relative humidity (RH), or direct occupancy sensing. Studies from as far back as 2004 in Swedish multifamily dwellings indicated that combining CO_2 and RH-based DCV could reduce the energy demand for ventilation by over 50 %, whereas occupancy-based control alone yielded savings of around 20 % [14].

The increasing ability to monitor and manage large amounts of data has opened a new field for DCV in the residential sector, sometimes labelled as smart ventilation. Smith and Kolarik [15] simulated a room-based DCV for renovated apartments, integrating a manifold of fans and a three-way exhaust damper. The proposed system used CO_2 and temperature sensors for dry rooms and humidity-based control for wet rooms, achieving a 74 % reduction in fan electrical consumption compared to a constant air-volume system. A real-world development of said concept in a refurbishment of Danish apartments achieved over 60 % fan energy savings, but its impact on heating or cooling is not available [16]. A proof of concept of automated gradual opening of windows in coordination with variable speed fans was presented in [17].

Humidity-based control (often referred to as hygro-regulation in Spain and France) is one of the most widespread DCV solutions in certain European markets. Although using RH as a proxy for human presence is imperfect (some studies have shown only a weak correlation between humidity and CO_2 levels [10]) humidity sensing can be adequate for adjusting airflow in response to moisture generation, preventing excessive dryness, and avoiding mold risks. As a result, humidity-based systems often balance acceptable IAQ with reduced airflow in periods of low occupancy or minimal moisture production, thereby contributing to energy savings. Their lower cost and simpler technology requirements, compared to more sophisticate CO_2-based or occupancy-sensor systems, explain why humidity-based DCV has gained traction in several countries.

2. METHODOLOGY

To evaluate the energy associated with the different ventilation systems mentioned, three alternatives with ventilation rates according to CTE DB-HS 3 were considered, with five apartment typologies, in 104 locations in all 50 provinces of Spain. The considered apartment types and the ventilation rates are shown in Table 1. The table also includes a comparison of ventilation rates in the previous version of CTE DB-HS 3.

TABLE 1. MINIMUM AIRFLOW REQUIREMENTS IN THE SPANISH NATIONAL BUILDING CODE

Ref. occupancy	**Apartment type**	**CTE-DB HS3** 2009–2017		**CTE-DB HS3** 2017-today	
2 p.	Studio ap.	96.4 m^3/h	26.8 L/s	50.4 m^3/h	14.0 L/s
2 p.	1 bedroom, 1 bathroom	96.4 m^3/h	26.8 L/s	50.4 m^3/h	14.0 L/s
3 p.	2 bedrooms, 1 bathroom	111.6 m^3/h	31.0 L/s	86.4 m^3/h	24.0 L/s
4 p.	2 bedrooms, 2 bathrooms	115.2 m^3/h	32.0 L/s	86.4 m^3/h	24.0 L/s
6 p.	3 bedrooms, 2 bathrooms	172.8 m^3/h	48.0 L/s	118.8 m^3/h	33.0 L/s

2.1. Calculation of Energy Demand Due to Ventilation

The total energy demand attributed to ventilation was divided into two components: thermal energy needed to heat the incoming outdoor air (ventilation heat losses), and the electricity consumption required to operate the mechanical ventilation system. All calculations were made under standard occupancy conditions, assuming continuous operation and following the design assumptions of the Spanish regulation.

2.1.1. Heating demand due to ventilation

To calculate the heating demand due to regulatory ventilation, three procedures were used. First, dynamic simulations were carried out using the official climate files from the national building code, considering the heating season from October to April. Second, the same simulations were repeated with TMYx climate data from the 2004–2018 period for six cities, each representing one of the CTE climate zones. Finally, heating demand was calculated using a method based on heating degree-days for 104 meteorological stations, aiming to achieve higher spatial granularity in the results. The dynamic simulations, performed with officially recognized software for code compliance-oriented simulation [18], which uses the

EnergyPlus calculation engine – served to validate the results obtained with the static degree-day-based method.

These calculations were repeated to compare three scenarios. First, as a baseline scenario, a so-called *auto-regulating* ventilation system was considered, that is, single-flow mechanical exhaust ventilation with constant flow rate and fixed air inlets in windows. The *hygroregulable* or humidity-based DCV scenario was simulated following the procedure outlined in the current officially recognized technical documents (DIT) from the Eduardo Torroja Institute of Construction Science [19]–[21]. These DITs are approved as valid alternative solutions for all building projects in Spain. For hygroregulated ventilation, the method defined in these documents essentially consists of applying a reduction factor to the equivalent average airflow, depending on housing typology and climate zone. None of the available DITs include climate zone α (Canary Islands), so this system could not be evaluated for that region.

To calculate the heating demand in the HRV case, the declared recovery efficiency provided by manufacturers was used for each apartment's ventilation flowrate. In this case, several units were considered, and an average value was taken, ranging from 86 % to 91 % total heat recovery efficiency. It is important to note that the Spanish building code only accounts for the declared efficiency in the ErP datasheets, without estimating additional losses due to ductwork, leakage, or system imbalance, which can be significant in real installations. It can be considered that this paper makes an optimistic estimation of HRV system efficiency.

2.1.2. Estimation of fan electrical consumption

The estimation of fan electricity consumption assumed that the selected equipment operates within reasonable conditions and not at its nominal maximum flow, which would significantly increase power demand. The absorbed power at the working point was calculated according to the regulatory procedure established in [18], which is based on the ErP technical datasheets in compliance with the Ecodesign Directive [22].

2.2. Cost-Effectiveness Analysis

The economic assessment is based on a Levelized Cost of Energy (LCOE) approach. This allows comparing systems with different lifespans, investment costs, and energy savings by expressing the net cost per unit of energy saved, both heating and electrical. This allows us to compare the cost of preventing said energy loss with the cost of heating. Results are presented per climatic zone and apartment type, allowing spatial comparison across Spain.

The installation costs for the evaluated systems were estimated to be 710–1015 € for the exhaust only reference system; 820–1330 € per unit for the DCV and 3260–3790 € per unit in the case of mechanical HRV, all taxes and levies included. Although there is significant variability in both equipment and installation costs depending on the purchasing power and profile of the economic agents involved (e.g., end users versus construction companies), this can be considered a conservative pricing estimate. A yearly maintenance cost of 40 € was estimated for single flux systems and 100 € for double flux HRV, including filter replacement.

The energy prices used correspond to the annual average of the most recent year for which data are available from Eurostat. Again, all taxes and levies are included, and fixed costs are also incorporated into the €/kWh, following the Eurostat methodology. To compare final energy consumption costs, and to calculate payback times, two alternative heating systems were considered: natural gas boilers, with an average system efficiency of 85 %, and air-source heat pumps with a coefficient of performance between 3.0 and 3.5, depending on the climatic zone assigned according to the provisional classification from the SHARES Tool, which in Spain distinguishes between average and cool zones.

2.3. Limitations

The method described in this section only focuses on individual mechanical ventilation units. While centralized HRV systems are often more cost-effective, they present other challenges due to their shared nature between multiple dwellings. The variety in scenarios is much harder to model in standardized conditions. Additionally, the analysis is limited to the extended heating season, from October to April, and does not account for potential summer savings or discomfort. Finally, the study inherits the limitations of the regulatory calculation procedures and the climate data used which are tailored for code compliance and not necessarily suited for detailed energy design.

3. RESULTS

This section presents the results of the analysis, which is later discussed in the following sections. Tables A1 and A3 in the Annex contain the case-by-case energy demand associated with ventilation in all climate zones, when calculated according to the official CTE climatic zones. Tables A2 and A4 in the Annex show how that demand is split into heating demand and fan electrical consumption in the case of the 3-bedroom, 2-bathroom typology.

Table 2 summarizes the calculated energy demands attributable to ventilation, in kWh per unit of area, assuming typical apartment sizes, which are relatively small.

TABLE 2. ENERGY DEMAND ASSOCIATED TO CTE VENTILATION

Climate zone	**Mechanical, simple-flux** (constant air volume)		**Humidity-based DCV** (Hygro type B)		**Heat Recovery Ventilation**	
α	7–9	kWh/m^2	n.a.		3–4	kWh/m^2
A	12–16	kWh/m^2	15–21	kWh/m^2	3–5	kWh/m^2
B	13–19	kWh/m^2	16–21	kWh/m^2	4–6	kWh/m^2
C	17–25	kWh/m^2	16–22	kWh/m^2	4–6	kWh/m^2
D	22–32	kWh/m^2	17–24	kWh/m^2	4–7	kWh/m^2
E	26–39	kWh/m^2	18–25	kWh/m^2	5–8	kWh/m^2

Notes: Heating season only. October 1 to April 30 (5064 h). Considered reference surfaces: studio apartment, 35 m^2; 1 bedroom + 1 bathroom, 48 m^2; 2 bedroom + 1 bathroom, 60 m^2; 2 bedroom + 2 bathroom, 65 m^2; 3 bedroom + 2 bathroom, 75 m^2.

As shown in Table 2, humidity-controlled ventilation (DCV) achieves variable energy savings between approximately 5 % and 60 % compared to constant airflow systems, depending on climate zone and apartment typology. Meanwhile, HRV systems consistently deliver energy savings between 60 % and 85 %, with an average reduction of around 75 % when excluding the climatic zone α. Table 3 provides an economic interpretation of these energy savings through the LCOE for 15-, 20-, and 25-year periods.

TABLE 3. AVERAGE LCOE FOR CTE OFFICIAL CLIMATES

Climate zone	Humidity-based DCV						Heat Recovery Ventilation					
	LCOE-15		LCOE-20		LCOE-25		LCOE-15		LCOE-20		LCOE-25	
α	n.a.		n.a.		n.a.		1.002	€/kWh	0.848	€/kWh	0.756	€/kWh
A	net loss		net loss		net loss		0.476	€/kWh	0.403	€/kWh	0.359	€/kWh
B	0.218	€/kWh	0.174	€/kWh	0.147	€/kWh	0.391	€/kWh	0.331	€/kWh	0.295	€/kWh
C	0.085	€/kWh	0.068	€/kWh	0.057	€/kWh	0.292	€/kWh	0.247	€/kWh	0.220	€/kWh
D	0.044	€/kWh	0.035	€/kWh	0.030	€/kWh	0.218	€/kWh	0.185	€/kWh	0.164	€/kWh
E	0.029	€/kWh	0.023	€/kWh	0.019	€/kWh	0.180	€/kWh	0.152	€/kWh	0.136	€/kWh

Note: This table contains the average cost of saving ventilation-related energy October through April (5064 h), considering the official climates in the Spanish national building code. Results for climatic zone B only include LCOE for typologies with net energy savings.

Fig. 1 shows the distribution and variability of LCOE values for humidity-based DCV and HRV systems across climatic zones and apartment typologies graphically, while Table 4 reports payback periods for both ventilation solutions. The high sensitivity of economic feasibility to climate and apartment size can be noted. On the next page, Figures 2a and 2b exemplify the geographical distribution for payback time for a 3-bedroom apartment, considering both heating systems.

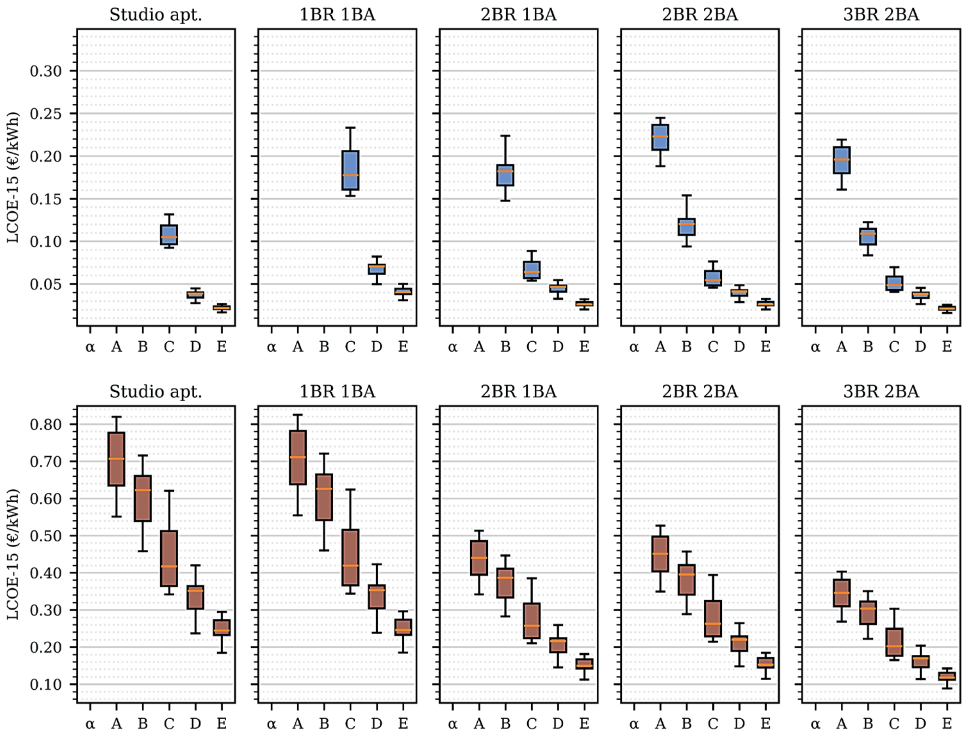

Fig. 1. LCOE for a 15-year period for humidity-based demand-controlled ventilation (top) and mechanical ventilation with heat recovery (bottom). Note that not only LCOE, but also the amount of energy or heating demand saved is different for both systems.

TABLE 4. PAYBACK TIME ACCORDING TO TYPOLOGY AND CLIMATIC ZONE

Climate zone	**Humidity-based DCV**					**Heat Recovery Ventilation**				
	Studio a.	**1BR**	**2BR**	**2BR**	**3BR**	**Studio a.**	**1BR**	**2BR**	**2BR**	**3BR**
Characteristic payback time (official climates and simulation)										
α	n.a.	n.a.	n.a.	n.a.	n.a.	never	never	never	never	never
A	never	never	never	never	never	never	never	never	never	never
B	never	never	never	> 100 y	41 y	never	never	never	never	never
C	51 y	never	14 y	11 y	9 y	never	never	never	never	never
D	6 y	11 y	7 y	6 y	5 y	never	never	> 100 y	> 100 y	41 y
E	3 y	7 y	4 y	4 y	3 y	never	never	49 y	51 y	26 y
Payback time range for 104 weather stations, grouped by climatic zone										
α	n.a.	n.a.	n.a.	n.a.	n.a.	never	never	never	never	never
A	never	never	never	41–95 y	29–74 y	never	never	never	never	never
B	never	never	26–48 y	15–43 y	13–35 y	never	never	never	never	never
C	14–30 y	27–80 y	8–18 y	7–14 y	6–13 y	never	never	never	never	never
D	4–13 y	7–16 y	5–15 y	4–13 y	4–12 y	never	never	> 32 y	> 33 y	> 20 y
E	2–5 y	4–10 y	2–6 y	2–6 y	2–5 y	> 41 y	> 42 y	15–65 y	15–62 y	11–30 y

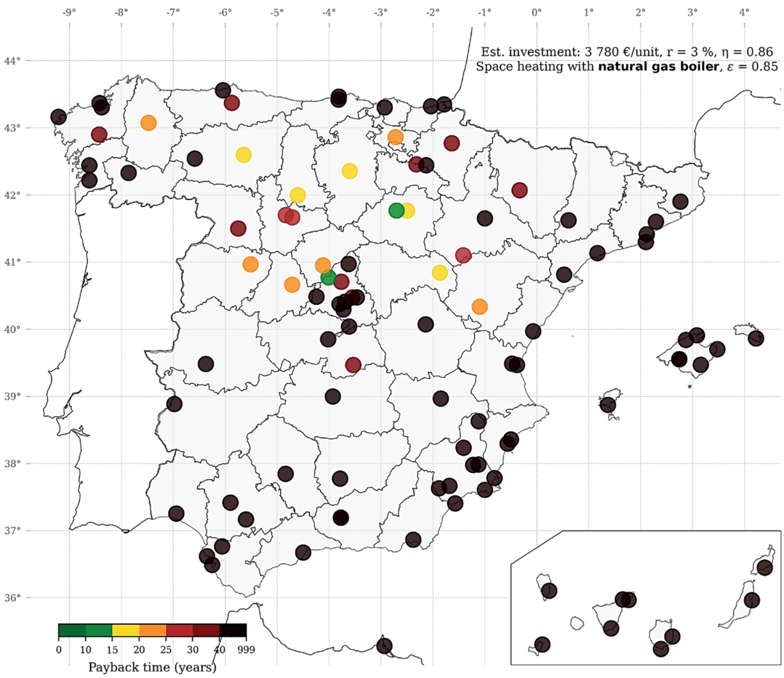

Fig. 2a. Payback time for the 3-bedroom, 2-bathroom apartment, considering a natural gas boiler for heating.

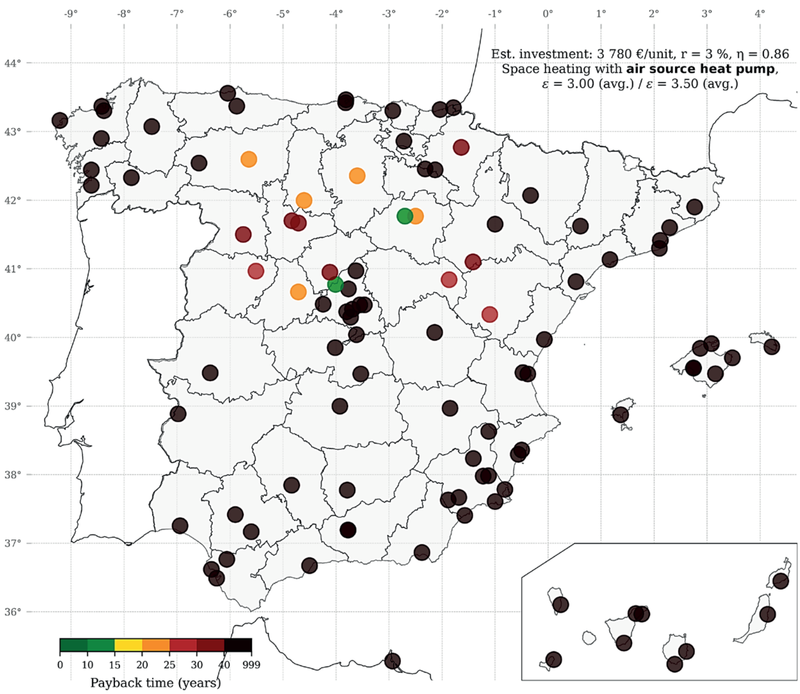

Fig. 2b. Payback time for the 3-bedroom, 2-bathroom apartment, considering an air-source heat pump for heating.

4. Discussion

Constant-flow mechanical exhaust ventilation creates significant heating demands that escalates quickly in colder climates. Humidity-based DCV presents variable outcomes across climates. While substantial energy savings are achievable, especially in colder zones, they can range widely from about 5 % to as much as 60 %. In warmer and coastal climates (zones A and B), the introduction of these systems may even slightly increase energy demands in smaller typologies, due to intermittent increases in airflow driven by humidity.

The HRV systems consistently demonstrate a pronounced reduction in ventilation-related heating demand, regardless of climate, in relative terms. The results indicate average reductions in the range of 60–85 % compared to constant-flow systems. This, however, matters very little when there is not much energy to be saved. LCOE for HRV easily exceeds 1.00 €/kWh in climate α over a 15-year span and remains higher than 0.20 €/kWh even in colder areas. DCV displays negative or negligible savings in warm climates but can become very competitive in zones D and E, especially for dwellings with high reference airflow.

The payback times shown in Table 4 reinforce that DCV can pay for itself in under 10 years in the coldest zones (D, E), particularly in larger apartments. HRV systems, however, often fail to break even in milder climates unless service life exceeds well beyond 20 years. This does not mean that there is no significant energy savings. For instance, a 3-bedroom, 2-bathroom unit in zone E can reduce from 2900 kWh down to 590 kWh of ventilation demand but still shows a payback longer than the typical service year of the units.

Fan consumption, while modest, can lessen part of the thermal benefit, especially if real-world performance deviates from nominal recovery efficiencies or if balancing issues occur. Overall, the data confirm that colder climates and higher design flow rates yield the most favourable outcomes for both DCV and HRV, but at very different energy saving potentials and cost. DCV, as currently regulated, has a limit in the amount of heating demand it can save, but does so in a very cost-effective manner. In milder areas, the incremental reduction in heating demand is too small to justify the extra capital and maintenance costs unless the goal extends beyond simple economic return (improved filtration, for instance).

5. CONCLUSION

The economic and energy-performance analysis reveal that climate decisively influences the cost-effectiveness and even feasibility of ventilation solutions in Spain. Milder climates inherently yield lower ventilation-driven heating demands, limiting the achievable savings from mechanical heat recovery ventilation (HRV). Although HRV consistently reduces ventilation heating needs by 60–85 %, resulting at least in theory in absolute annual savings of around 250–3000 kWh per apartment, the associated installation and maintenance costs remain relatively constant across regions. Consequently, HRV rarely proves economically attractive in most Spanish climates under medium-term financial criteria, despite its significant contribution to energy efficiency goals and its benevolent treatment in the national building code. Humidity-controlled ventilation (DCV) emerges as a cost-effective alternative, particularly for colder climates or apartments with higher ventilation needs, offering much more attractive payback periods, but less absolute energy saving potential. Finally, given the current price range of HRV systems, alternative investments, such as photovoltaic (PV) installations, may deliver substantially higher economic and environmental returns across much of the Iberian Peninsula. Future research should further explore the combined impact of photovoltaic systems combined with air-source heat pumps, a synergy rapidly becoming dominant in Spain’s residential sector due to ongoing electrification and mandatory renewable contributions to domestic hot water (DHW) production.

ACKNOWLEDGEMENT

This research work is part of Jorge Otaegi’s Doctoral Dissertation, funded by the University of the Basque Country UPV/EHU under grant number PIF 21/235. This research is also part of Markel Arbulu’s Doctoral Thesis, funded by the Basque Government, with grant number PRE_2023_2_0007. The work conducing to this publication was supported by the Department of Housing and Urban Agenda of the Basque Government, and its dissemination and publication was partially aided by the Department of Architecture of the University of the Basque Country UPV/EHU.

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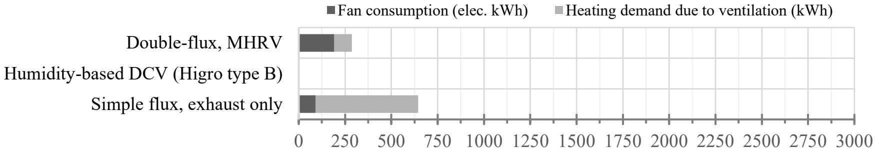
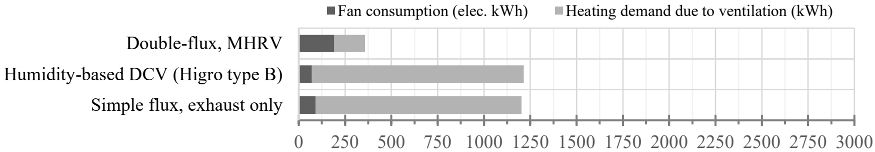
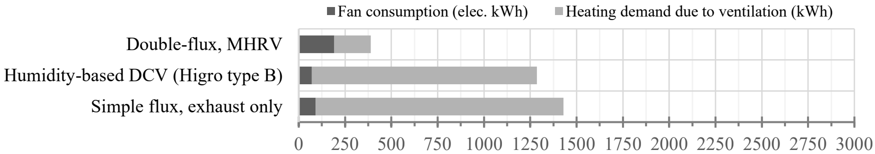
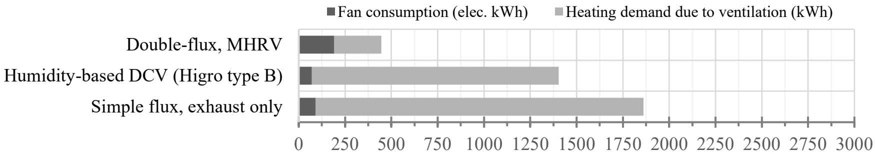
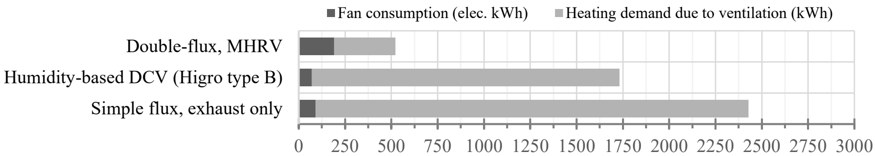
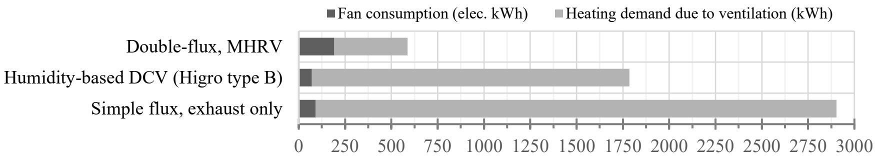
ANNEX

TABLE A1. ENERGY DEMAND DUE TO NATIONAL BUILDING CODE VENTILATION (CTE DB-HS 3) BASED ON THE OFFICIAL WINTER (HEATING SEASON) CLIMATE CLASSIFICATION

Climate zone		**Mechanical, simple-flux** (constant air volume)		**Humidity-based DCV** (Hygro type B)		**Heat Recovery Ventilation**	
α	Studio apartment	325	kWh	n.a.		125	kWh
	1 bedroom, 1 bathroom	350	kWh	n.a.		130	kWh
	2 bedroom, 1 bathroom	535	kWh	n.a.		215	kWh
	2 bedroom, 2 bathroom	540	kWh	n.a.		225	kWh
	3 bedroom, 2 bathroom	645	kWh	n.a.		285	kWh
A	Studio apartment	550	kWh	720	kWh	140	kWh
	1 bedroom, 1 bathroom	560	kWh	775	kWh	150	kWh
	2 bedroom, 1 bathroom	910	kWh	1065	kWh	250	kWh
	2 bedroom, 2 bathroom	920	kWh	990	kWh	260	kWh
	3 bedroom, 2 bathroom	1200	kWh	1215	kWh	360	kWh
B	Studio apartment	645	kWh	740	kWh	150	kWh
	1 bedroom, 1 bathroom	655	kWh	765	kWh	160	kWh
	2 bedroom, 1 bathroom	1075	kWh	1080	kWh	265	kWh
	2 bedroom, 2 bathroom	1080	kWh	1000	kWh	275	kWh
	3 bedroom, 2 bathroom	1430	kWh	1285	kWh	390	kWh
C	Studio apartment	820	kWh	775	kWh	165	kWh
	1 bedroom, 1 bathroom	825	kWh	775	kWh	175	kWh
	2 bedroom, 1 bathroom	1375	kWh	1125	kWh	300	kWh
	2 bedroom, 2 bathroom	1380	kWh	1030	kWh	310	kWh
	3 bedroom, 2 bathroom	1860	kWh	1400	kWh	445	kWh
D	Studio apartment	1060	kWh	830	kWh	185	kWh
	1 bedroom, 1 bathroom	1060	kWh	800	kWh	195	kWh
	2 bedroom, 1 bathroom	1785	kWh	1325	kWh	340	kWh
	2 bedroom, 2 bathroom	1790	kWh	1220	kWh	350	kWh
	3 bedroom, 2 bathroom	2430	kWh	1730	kWh	525	kWh
E	Studio apartment	1260	kWh	880	kWh	205	kWh
	1 bedroom, 1 bathroom	1260	kWh	840	kWh	215	kWh
	2 bedroom, 1 bathroom	2125	kWh	1390	kWh	380	kWh
	2 bedroom, 2 bathroom	2130	kWh	1330	kWh	390	kWh
	3 bedroom, 2 bathroom	2900	kWh	1335	kWh	590	kWh

Notes: October 1 to April 30 (5064 h). Simulation under regulatory conditions using approved software. Results show heating demand caused by ventilation losses and include an estimation of fan electrical consumption.

TABLE A2. SPLIT OF ENERGY DEMAND LINKED TO BUILDING CODE VENTILATION (CTE DB-HS 3) FOR A 3-BEDROOM, 2-BATHROOM APARTMENT (CTE WINTER CLIMATE CLASSIFICATION)

Climate zone	
α	
A	
B	
C	
D	
E	

Notes: October 1 to April 30 (5064 h). Simulation under regulatory conditions using approved software.

TABLE A3. ENERGY DEMAND DUE TO NATIONAL BUILDING CODE VENTILATION (CTE DB-HS 3) BASED ON TMYX CLIMATES (2004–2018) FOR SIX CITIES

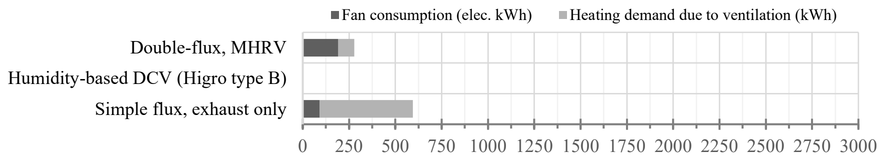
Climate (city)		**Mechanical, simple-flux** (constant air volume)		**Humidity-based DCV** (Hygro type B)		**Heat Recovery Ventilation**	
Sta. Cruz de Tenerife	Studio apartment	305	kWh	n.a.		120	kWh
	1 bedroom, 1 bathroom	330	kWh	n.a.		170	kWh
	2 bedroom, 1 bathroom	500	kWh	n.a.		210	kWh
	2 bedroom, 2 bathroom	500	kWh	n.a.		220	kWh
	3 bedroom, 2 bathroom	595	kWh	n.a.		280	kWh
Málaga	Studio apartment	515	kWh	675	kWh	140	kWh
	1 bedroom, 1 bathroom	520	kWh	730	kWh	195	kWh
	2 bedroom, 1 bathroom	855	kWh	1005	kWh	245	kWh
	2 bedroom, 2 bathroom	860	kWh	870	kWh	255	kWh
	3 bedroom, 2 bathroom	1125	kWh	935	kWh	345	kWh
Valencia	Studio apartment	670	kWh	765	kWh	150	kWh
	1 bedroom, 1 bathroom	675	kWh	790	kWh	215	kWh
	2 bedroom, 1 bathroom	1115	kWh	1120	kWh	270	kWh
	2 bedroom, 2 bathroom	1120	kWh	1035	kWh	280	kWh
	3 bedroom, 2 bathroom	1490	kWh	1030	kWh	395	kWh
Bilbao	Studio apartment	745	kWh	710	kWh	160	kWh
	1 bedroom, 1 bathroom	750	kWh	710	kWh	225	kWh
	2 bedroom, 1 bathroom	1250	kWh	1025	kWh	285	kWh
	2 bedroom, 2 bathroom	1255	kWh	950	kWh	295	kWh
	3 bedroom, 2 bathroom	1690	kWh	945	kWh	420	kWh
San Sebastián	Studio apartment	795	kWh	630	kWh	165	kWh
	1 bedroom, 1 bathroom	795	kWh	615	kWh	235	kWh
	2 bedroom, 1 bathroom	1335	kWh	1010	kWh	290	kWh
	2 bedroom, 2 bathroom	1340	kWh	940	kWh	300	kWh
	3 bedroom, 2 bathroom	1810	kWh	930	kWh	435	kWh
Burgos	Studio apartment	1140	kWh	795	kWh	195	kWh
	1 bedroom, 1 bathroom	1140	kWh	755	kWh	280	kWh
	2 bedroom, 1 bathroom	1920	kWh	1250	kWh	355	kWh
	2 bedroom, 2 bathroom	1925	kWh	1210	kWh	365	kWh
	3 bedroom, 2 bathroom	2625	kWh	1205	kWh	550	kWh

Notes: October 1 to April 30 (5064 h). Simulation under regulatory conditions using approved software, but using TMYx climate files from the 2004–2018 period. Results show heating demand caused by ventilation losses and include an estimation of fan electrical consumption.

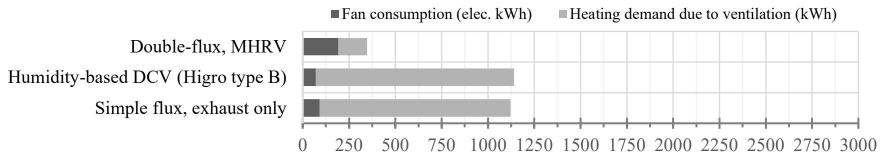
TABLE A4. SPLIT OF ENERGY DEMAND LINKED TO BUILDING CODE VENTILATION (CTE DB-HS 3) FOR A 3-BEDROOM, 2-BATHROOM APARTMENT (TMYX FOR SIX CITIES)

Climate (city)

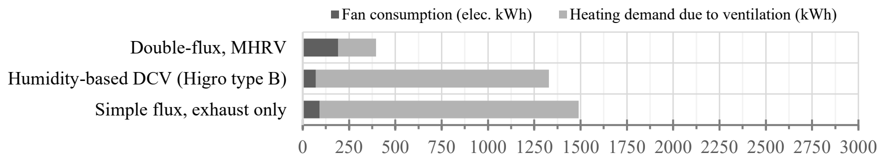
Sta. Cruz de Tenerife



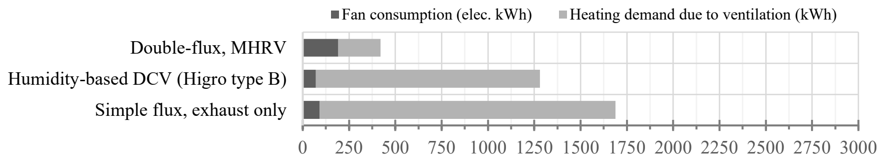
Málaga



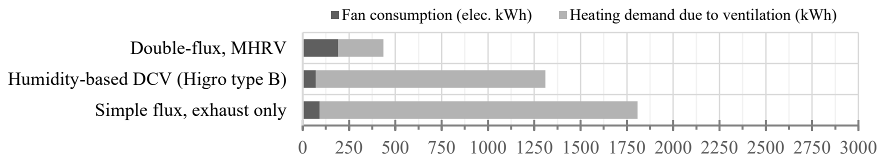
Valencia



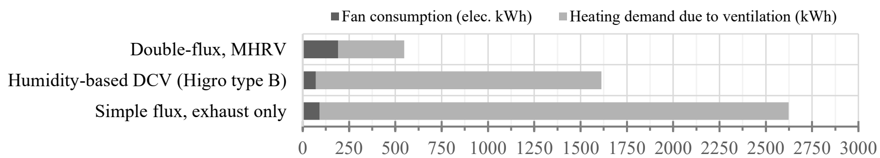
Bilbao



San Sebastián



Burgos



Notes: October 1 to April 30 (5064 h). Simulation under regulatory conditions using approved software but using TMYx climate files from the 2004–2018 period.