Evaluating the environmental adaptability of a nearly zero energy retrofitting strategy designed for Dutch housing stock to a Mediterranean climate.

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Abstract

Users' behaviour and indoor climate are two leading aspects that must be taken into account if we want the retrofitting of the housing stock to contribute to CO_2 reduction, comfort improvement and reduction of living costs. The integrated facade module evaluated in this paper, which constitutes an approach to zero energy renovation, includes a preliminary study for the identification of target occupants and their characteristics and requirements that will guide the design decisions. The proposed strategy primarily focuses on the case of social rental multi-family housing stock in the Netherlands, but should provide insights in the application of the concept in Europe. This paper presents the analysis of the adaptability of this solution to the Mediterranean climate, taking into account the specific characteristics of the occupants of this climatic zone.

The results showed an improved performance of building after the application of the evaluated solution in southern Spain, but with lower savings on the energy demand than in the Netherlands, so the economic investment should be reduced in this case. Also, the inclusion in the solution of some variables, such as the forced night-time ventilation for passive cooling and the insulation thickness reduction, were tested and proved to be an optimisation of its performance in the Mediterranean climate. Overall, the study concluded that the proposed refurbishment strategy has the potential to be implemented in different climates, particularly if certain modification in the facade operation are considered.

Keywords: social housing stock; building retrofitting; user patterns; energy performance; building simulation.

Nomenclature	
PPD	Predicted percentage of dissatisfied [%]
Tco	Optimum comfort temperature [ºC]
Text, ref	Mean outdoor dry bulb temperature [ºC]
ACH	Air changes per hour
PMV	Predicted mean vote

1. Introduction

In recent decades, the energy efficiency of the building sector has become a common goal for all European countries [1], highlighting the retrofitting of the existing residential building stock in order to turn it into a ‘nearly zero energy consumption stock’. In Europe there is an important amount of housing estates built during the post-war period. In the cases of the Netherlands and Spain, the existing housing stock built during this period accounts for 33% [2] and 46% [3] respectively of total one. In both cases, social housing represents a significant portion of the residential building stock.

This part of housing stock is in need for energy retrofitting because at the time of construction energy-performance related building regulations were very limited or non-existing [4-6], and hence, it mostly does not have any specific thermal insulation measure in its envelope. Furthermore, only 5% of the multi-family, social houses built before 1980 in southern Spain have centralised heating system, and 13% have individual one [3]. This data shows that in southern Spain a considerable number of dwellings does not have the proper specifications to reach current standards of indoor thermal comfort conditions. This situation, in addition to the low energy performance of its envelope and financial constraints of many households, increases the risk of fuel poverty [7]. For this large part of the housing stock, the main aim of the retrofitting should focus on the improvement of the indoor thermal comfort conditions of the dwellings instead of on energy saving alone [8], without raising of the living costs.

While there are evident differences between the Dutch and southern Spanish climate, important similarities between their housing stock have been found. This differences and similarities were the main reason to focus this analysis on those countries. Among these similarities standouts: the representativeness of the low-rise multi-family residential buildings with a linear typology with two dwellings per floor and the predominance of two leaves of brick constructive system [9, 10]. However, in the case of the Netherlands the percentage of glass on the facade is quite higher than in southern Spain. Also some others differences were found due to the severity of the Dutch climate, regarding the national regulations for the insulation exigencies and the comfort ranges [11, 12].

Analysing the energy performance of building retrofitting measures has been the subject of several studies in the scientific literature. Some of them evaluate the energy saving potential of the existing residential stock [13-17] or develop a decision support tool able to detect the cost-optimal retrofitting solution for a building category [18-20]. Also another researches are focused on the evaluation, in a particular case study, of the energy performance of retrofitting measures such as the envelope insulation improvement (including windows substitution) [21, 22], the inclusion of heat recovery systems in mechanical ventilation [23], or a deep renovation [24].

The retrofitting solution which is evaluated in this paper (an integrated facade module) was initially developed for the case of social rental multi-family housing stock in the Netherlands. The following blend of characteristics make the solution stands out among others already mentioned:

- It is a retrofitting strategy that integrates in the envelope of the building the mechanical ventilation and energy generation systems.
- It is a retrofitting strategy that takes into account the influence of occupants' behaviour in the design of the solution, to reduce the uncertainties related to energy savings and payback periods [25, 26].
- It is a prefabricated façade module, which make it a good solution for mass implementation and minimum user disturbance.

Taking as a starting point the constructive compatibility of the proposed integrated facade module (due to the similarities found between the Dutch and southern Spanish housing stock), the main aim of this research is to compare its performance in two different climates: Rotterdam (Netherlands) and Seville (southern Spain). The main originality of this research consists on the evaluation of the influence of several real user profiles on the energy performance of the retrofitting solution, instead of just applicate standardised or particular profiles. The results show the great influence of the users' behaviour on the energy saving potential of the proposed strategy. As a second step, the optimisation of the performance of the proposed integrated facade module for the warmer climate is also evaluated.

2. Methodology

In order to carry out an environmental assessment of the proposed integrated facade module, energy models that incorporate that retrofitting strategy were developed and located in the Netherlands and southern Spain. Also different real user profiles were applied to the models in order to evaluate its influence on the energy performance of the retrofitting solution. These energy models take as their starting point the energy model of an existing dwelling placed in Seville in its original condition, previously described and calibrated by an annual monitoring of the environmental and energetic variables [7]. The results of the energy and environmental performance assessment, regarding both demand and comfort, are obtained from a comparative analysis between the pre- and post-renovated models.

After analysing the results of this environmental assessment, a second phase of the study was developed. It consists on the modification of different variables (such as forced night-time ventilation, insulation thickness and airtightness) in the energy models, in order to evaluate it effect on the energy performance of the retrofitting solution. The final aim is to find ways to optimise the energy reduction and reduce the investment of the proposed integrated facade module in both climates (Figure 1).

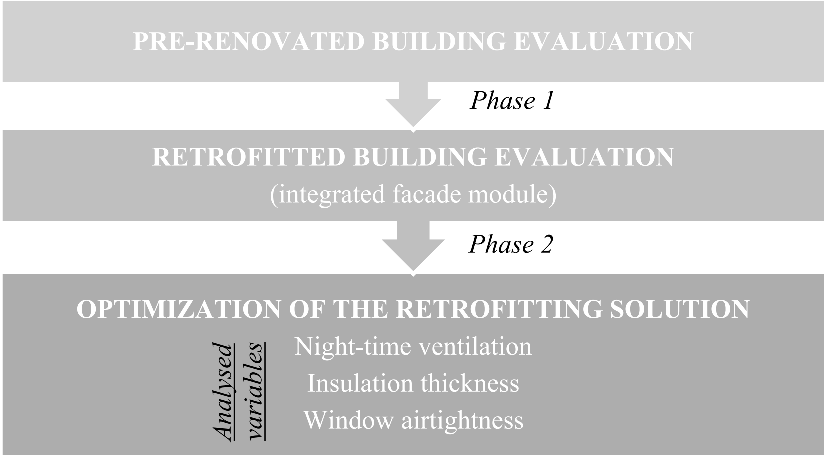


Figure 1. Methodology scheme.

The software used was Design Builder version 4.7.0.027 [27], whose Energy Plus simulation engine enabled the authors to obtain precise data on annual, monthly, and hourly demands, as well as indoor temperature values. The energy model recreates the whole dwelling as a single thermal zone. This model also includes its boundary conditions, in terms of heat transfer and shading. The climate data used for the energy simulation were taken from the EnergyPlus database [28], generated by Seville and Amsterdam Schiphol (50 km from Rotterdam) weather stations. The constructive definition of the envelope (Section 2.1 for the retrofitted models and 2.2. for the pre-renovated ones), user profiles and occupancy patterns (Section 2.3) were also included in the models generation.

2.1. The integrated facade module

The proposed integrated facade module arises from a research project developed in the TU Delft, as part of the European BTA-Flagship Program of the Climate KIC [29]. The main aims of this solution are to reach zero on the meter dwellings and to limit the nuisance for the occupants. The retrofitting strategy (Figure 2) consists on a pre-fabricated building envelope that can be installed in a short period of time, including: insulation sandwich panels to increase the thermal resistance; windows replacement; mechanical ventilation pipes integration (with a heat recovery system); energy generation through PV panels installed on the roof; and also heating and cooling systems depending on the situation [30].

The installation sequence of this retrofitting strategy on an existing building starts with the attachment of the substructure to the existing structure (slab). The second phase is the attachment of the central panel for the opaque facade and the panels including the windows to the substructure. The ventilation pipes and the windows will be integrated to the panels in the factory. The external cladding can or cannot be prefabricated, depending on the material choice. Some finishing will probably be required on site, depending of the cladding material selection.

The installation of the panels can be done by two people, with the support of cranes to lift and place the panels.

Furthermore, the challenge of this solution consists in taking into account the influence of different user profiles and occupants' behaviour in the performance of the building in order to eliminate the uncertainties between the expected and the actual energy savings. This is a great advantage over most of proposals that only aimed at a standard occupancy [31].

Table 1 summarise the main thermal and technical characteristics of the envelope and the building services provided by the integrated facade module.

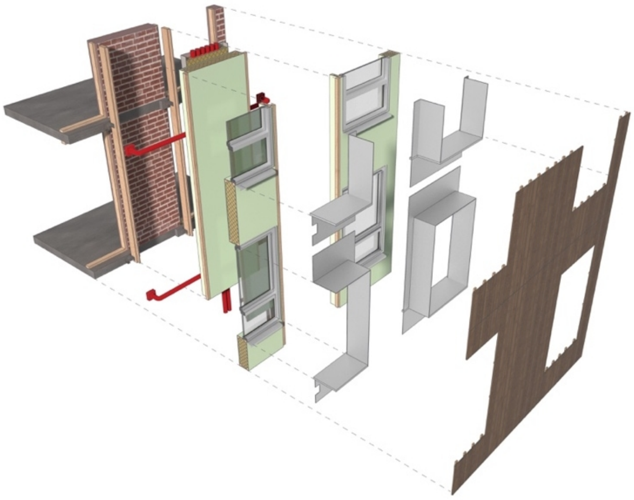


Figure 2. Exploded view of the façade module components ©2ndSkin, TU Delft.

Table 1. Main characteristics of the integrated facade module developed for the Dutch housing stock.

Parameters		**Value**	**Unit**
Mechanical ventilation with heat recovery		7	l/s*person
U-Value	Roof	0.22	W/m^{2}K
	Facade	0.15	W/m^{2}K
	Glazing	0.80	W/m^{2}K
	Window frames	0.80	W/m^{2}K
	Ground floor	0.29	W/m^{2}K
Airtightness		0.4	l/s*m^2
Facade depth		30	cm
Solar protection		Roller solar screen	

2.2. Case studies

In general terms, the target group for this research are the tenement apartment blocks massively built in the post-war period not only in the Netherlands and Spain, but also throughout Europe. Table 2 summarises the main characteristics of the Dutch and southern Spanish building stock. Initially, the proposed integrated facade module was designed for a reference building located in Rotterdam (table 3), which was selected as the most common type in the area of investigation while having typical characteristics found in the building stock analysis [29]. This building (Figure 3a) is characterised as a mid-rise apartment block with central staircase, two apartments per floor, and massive brick wall with cavity and no insulation.

Figure 3. Case studies. 3a. Rotterdam building (left). 3b. Seville building (right).

Table 2. Main characteristics of the Dutch and southern Spanish building stock.

		Netherlands [9, 11]	**Southern Spain** [10, 12]
Post-war dwellings in building stock		33%	46%
First thermal comfort regulation (year)		1975	1979
Morphological typology	Lineal	34%	44%
	Others	66%	56%
Predominant pre-renovated constructive systems		2 leaves of brick	2 leaves of brick
		1 leaf of prefabricated wall and 1 leaf of brick	1 leaf of brick
% glazing on facade		42	19
Facade U-value exigency (W/m²K)		0.22	1.25 – 0.55
Comfort standard	Winter	20 - 24 ºC	17 - 20 ºC
	Summer	23 – 26 ºC	25 - 27 ºC

Table 3. Annual standard climate values, period 1981 – 2010.

	Rotterdam [32]	**Seville** [33]
Elevation (in meters above sea-level)	4	34
Latitude	51º 57’ 00’’ N	37º 25’ 0’’ N
Longitude	4º 26’ 00’’ E	5º 52’ 45’’ W
Average temperature (ºC)	10.4	19.2
Average maximum daily temperature (ºC)	14.0	25.4
Average minimum daily temperature (ºC)	6.4	13.0
Average relative humidity (%)	83.1	59
Average rainfall (mm)	855.6	539
Average nº days of rainfall ≥ 1 mm	132	50.5
Average hours of sunlight	1624	2917

Table 4. Main typological and constructive characteristics of the case studies.

	Rotterdam case study	**Seville case study**
Tenure type	Tenants	Owners
Year of construction	1965-1974	1964
Typology	Apartment block; central staircase; two apartments per floor	Apartment block; central staircase; two apartments per floor
Nr. stores	4 (no elevator)	5 (no elevator)
Roof	Gravel, concrete (15 cm). (U-value = 2.5 W/m^2K)	Tile, coal dust and roof structure (20 cm). (U-value = 1.72 W/m^2K)
Facade	Brick (8 cm), air cavity and prefabricated wall (11 cm). (U-value = 1.7 W/m^2K)	Brick (11 cm), air cavity and brick (4 cm). (U-value = 1.53 W/m^2K) *Under windows just brick (11 cm). (U-value = 2.91 W/m^2K)
Window frame	Wooden (U-value = 2.2 W/m^2K)	Aluminium (U-value = 5.7 W/m^2K)
Glazing	Double (U-value = 4.3 W/m^2K)	Single (U-value = 7.7 W/m^2K)
Solar protection	None	Blinds

This research aims at evaluating the effect of the proposed facade retrofitting solution, which was designed for the Northern European Climate, on a building located in southern Spain (Mediterranean climate). Table 3 compares the climate characteristics. To be able to identify the effect of the climate differences, a building located in Seville, with very similar typological and constructive characteristics to the Rotterdam reference building, has been selected [7]. As already mentioned, this typology is also well-represented within the southern Spanish housing stock (table 2). It is a multi-family building of social housing built in the 60's (Figure 3b), with two apartments per floor of 58 m^2 each, and massive brick wall with cavity and no insulation.

Table 4 shows the similarities between the main typological and constructive characteristics of both case studies. As usual in southern Spain, the case study has only local cooling and heating systems (in two of the three bedroom), with a sporadic use of them. This research focuses on the energy behaviour assessment of a representative dwelling located in an intermediate floor of the building.

2.3. User profiles and occupancy patterns for energy simulations

In a previous research phase, an intensive user analysis was carried out in parallel to the technical design of the retrofitting solution, in order to feed back the users preferences in the design and to reduce the pre-bound effect [31]. When real consumptions are much lower than estimated ones, usually because users spend far less time in the dwellings than the time established by the standardised use patterns, it is called pre-bound effect [26].

As a result of that user analysis, eight Dutch user profiles were developed based on a statistical evaluation of the WoON dataset 2012 [34] (table 5). This research made use of those Dutch user profiles and its occupancy patterns in the models developed for the energy simulations. The effect of these patterns is evaluated in Rotterdam and Seville, in order to analyse and differentiate the influence of the users' behaviour and the location in the energy performance of the solution.

Given that there is no a statistical dataset about energy use preferences in Spain, four representative profiles of social housing users were set up according to the analisys developed in a previous research [7]. This user profiles are based on the cross-referenced of qualitative data obtained from user surveys and quantitative data measured in some dwellings in this climate (temperature, CO_2 concentration and electric consumption). These profiles represent four use-intensity levels of the thermal conditioning systems (table 6):

- High intensity: standardised pattern, based on the Spanish regulation [12] but far from the real situation of social housing in southern Spain.
- Medium intensity: nuclear family pattern.

- Low intensity: 2 adults pattern.
- Null intensity: 1 senior pattern, which are the users in fuel poverty. This pattern is not contemplated in the case of Netherlands.

Table 5. Winter Dutch user profiles and occupancy patterns [31].

User Profile	**Occupancy**	**Temperature**	**Night-time ventilation**
1 Senior	Mon-Wed 1p 0-23h; Thu 1p 15-12h 0p 12-15h; Fri 1p 18-9h 0p 9-18h; Sat-Sun 1p 23-6h 0p 6-23h	24ºC 18-23h; 20ºC 23-18h	NO
2 Seniors	Mon-Thu 2p 0-23h; Fri 2p 18-9h 0p 9-18h; Sat 2p 23-9h 0p 9-23h; Sun 2p 23-6h 0p 6-23h	23ºC 18-23h; 19ºC 23-18h	NO
1 Adult	Mon-Tues 1p 0-23h; Wed 1p 15-9h 0p 9-15h; Thu 1p 18-9h 0p 9-18h; Fri-Sat 1p 23-6h 0p 6-23h; Sun 0p 0-23h	17ºC 18-23h; 10ºC 23-18h	NO
2 Adults	Mon-Wed 2p 0-23h; Thu-Fri 2p 18-9h 0p 9-18h; Sat-Sun 2p 23-6h 0p 6-23h	20ºC 18-23h; 15ºC 23-18h	NO
3 Adults	Mon-Wed 3p 0-23h; Thu 3p 15-9h 0p 9-15h; Fri 3p 18-9h 0p 9-18h; Sat-Sun 3p 23-6h 0p 6-23h	20ºC 18-23h; 17ºC 23-18h	NO
Single-parent	Mon-Tues 3p 0-23h; Wed 3p 15-12h 0p 12-15h; Thu 3p 15-9h 0p 9-15h; Fri 3p 18-9h 0p 9-18h; Sat-Sun 3p 23-6h 0p 6-23h	20ºC 18-23h; 15ºC 23-18h	NO
Nuclear family	Mon-Wed 3p 0-23h; Thu 3p 15-9h 0p 9-15h; Fri 3p 18-9h 0p 9-18h; Sat 3p 18-6h 0p 6-18h; Sun 3p 23-6h 0p 6-23h	20ºC 18-23h; 18ºC 23-18h	NO
Standardised	Mon-Wed 3p 0-23h; Thu 3p 15-9h 0p 9-15h; Fri 3p 18-9h 0p 9-18h; Sat 3p 18-6h 0p 6-18h; Sun 3p 23-6h 0p 6-23h	*Living room:* 21ºC 7-23h; 15ºC 23-7h *Bedrooms:* 18ºC 7-16h; 15ºC 16-7h	NO

Table 6. Winter southern Spanish user profiles and occupancy patterns [7].

User Profiles	**Presence**	**Temperature**	**HVAC**	**Night-time ventilation**
1 Senior	Mon-Fri 1p 17-10h 0p 10-17h; Sat-Sun 1p 0-23h	NO use	*Living room:* NO *Bedrooms:* NO	NO
2 Adults	Mon-Fri 2p 21-8h 1p 8-12h 0p 12-21h; Sat-Sun 2p 0-23h	20ºC 21-23h	*Living room:* NO *Bedrooms:* YES	NO
Nuclear family	Mon-Fri 4p 21-8h 1p 8-14h 2p 14-21h; Sat-Sun 4p 21-10h 2p 10-21h	21ºC 21-23h; 21ºC 7-9h	*Living room:* YES *Bedrooms:* YES	NO
Standardised	Mon-Fri 4p 0-8h 1p 8-16h 2p 16-0h; Sat-Sun 4p 0-23h	17ºC 0-8h; 20ºC 8-0h	*Living room:* YES *Bedrooms:* YES	NO

Table 7. Summer southern Spanish user profiles and occupancy patterns.

User Profiles	**Presence**	**Temperature**	**HVAC**	**Night-time ventilation**
1 Senior	Mon-Fri 1p 17-10h 0p 10-17h; Sat-Sun 1p 0-23h	NO use	*Living room:* NO *Bedrooms:* NO	4 ach 21-11h
2 Adults	Mon-Fri 2p 21-8h 1p 8-12h 0p 12-21h; Sat-Sun 2p 0-23h	26ºC 21-23h; 26ºC 15-18h	*Living room:* NO *Bedrooms:* YES	4 ach 0-11h
Nuclear family	Mon-Fri 4p 21-8h 1p 8-14h 2p 14-21h; Sat-Sun 4p 21-10h 2p 10-21h	26ºC 21-23h; 26ºC 15-18h	*Living room:* YES *Bedrooms:* YES	4 ach 0-9h
Standardised	Mon-Fri 4p 0-8h 1p 8-16h 2p 16-0h; Sat-Sun 4p 0-23h	27ºC 0-8h; 25ºC 15-0h	*Living room:* YES *Bedrooms:* YES	4 ach 0-9h

In this last intensity pattern, the building's performance after the facade module application was evaluated in terms of indoor temperature and not of energy demand, due to the absence of energy consumption for heating and cooling. In order to evaluate if the indoor conditions are adequate, two comfort temperature bands were defined as a good reference for the analysis of the results. When assessing the quality of thermal environments, the main international standards of comfort refer to Fanger studies [35], which defined two main indices: the Predicted Mean Vote (PMV) and the Predicted Percentage of Dissatisfied (PPD). This methodology has been incorporated in the standard EN ISO 7730 [36], in which the first temperature comfort band of this research is based. The following conditions were set:

- Category of thermal environment: B (which means a PPD < 10%).
- Metabolic rate: 1.2 met.
- Clothing level: 1.0 clo (winter); 0.3 clo (summer).

There are also several studies considering that, when analysing comfort in buildings with no active HVAC systems, adaptive standards are more reliable than the standard PMV index [37-39]. This is mainly because in this kind of buildings users can modify their clothing insulation or open and close windows depending on the outdoor conditions, so that is very difficult to predict and set these variables. For this particular conditions, the ASHRAE Standard-55 described an optional method for determining acceptable thermal conditions [40], in which the second temperature comfort band of this research is based. This methodology applies only to spaces where the occupants are engaged in near-sedentary physical activities, with metabolic rates ranging from 1.0 to 1.3 met. Also accounts for people's clothing adaptation and local thermal discomfort effects in typical buildings, so it is not necessary to address these factors when using this option. This method stablishes an optimum comfort temperature (Equation 1) and two acceptability ranges. In this research, the acceptability range corresponding to 90% of satisfied occupants (which means a PPD < 10% and is defined by a temperature interval of ± 2.5 ºC) was applied.

$$Tco = 0.31 \times Text{,}ref + 17.8 \qquad (1)$$

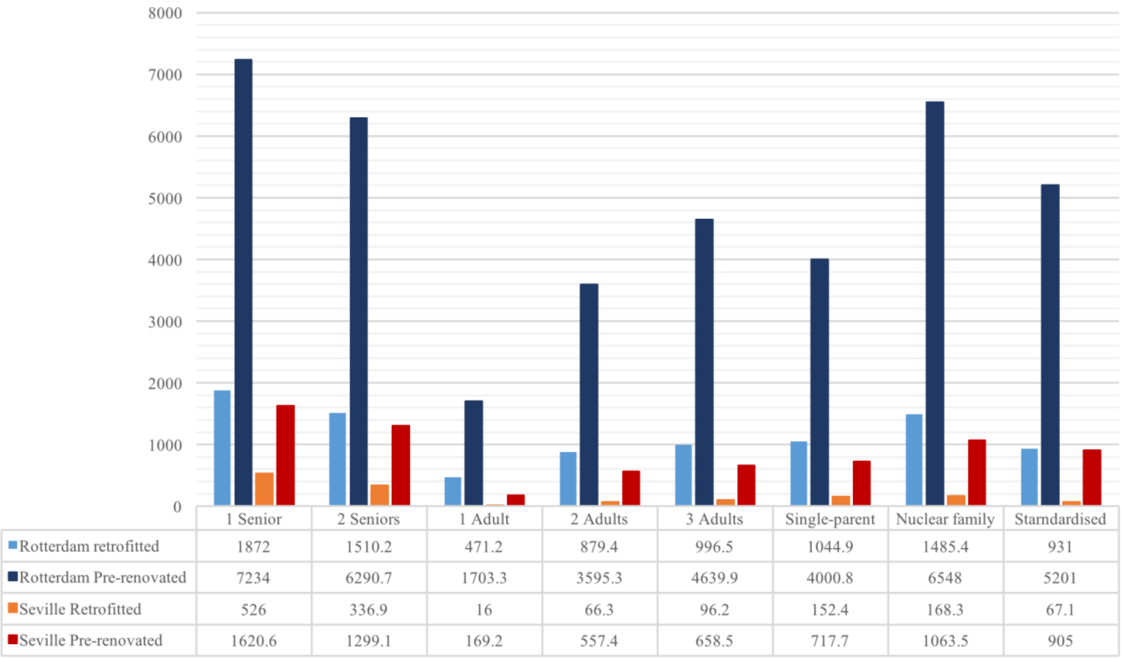
For the evaluation of the retrofitting solution during the summer period, the user profiles maintain the same occupancy pattern, but the set-point temperature and the use of the ventilation vary (table 7). In the Netherlands, no user profile contemplates the use of cooling systems, as they are not common in the residential sector. In this case, the building's performance after the integrated facade module application is evaluated in terms of comfort and not demand. The night-time ventilation defined in Table 7 refers to the habit of users opening the windows during the night, in order to dissipate the heat accumulated inside during the day. To include night-time ventilation in the energy models, a 4 ACH rate of 'Natural Ventilation' has been associated to the dwelling, activating it during the established schedule.

3. Results

3.1. Winter analysis: heating demand and comfort conditions

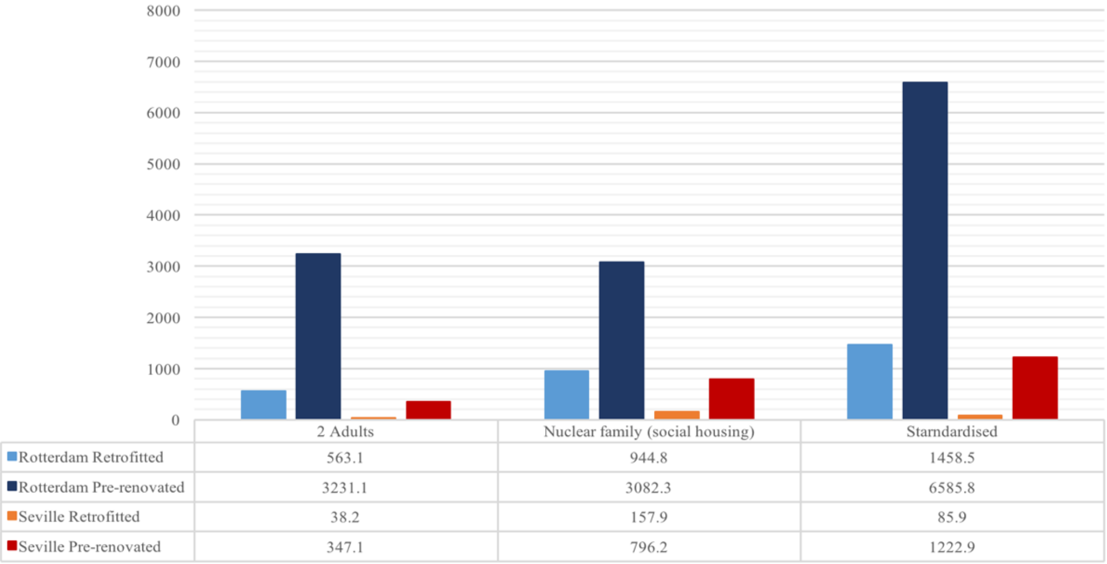
The first step of this research is a heating demand analysis of the case study comparing the results of the pre-renovated dwelling and the one incorporating the proposed integrated facade module. Both energy models were located in Rotterdam and Seville and also simulated applying the user profiles defined in the section 2.3 for the Netherlands (Figure 4) and southern Spain (Figure 5). In the case of the southern Spanish patterns, the demand of '1 senior' was not analysed because it does not contemplate the use of heating systems.

As expected, the results show higher heating demands when we locate the model in Rotterdam than in Seville. The retrofitting solution means very important savings in heating demand in both cases. In Rotterdam, all the user profiles result in savings between 70 and 80%. Also in Seville, savings between 70 and 90% are achieved. Even though the percentage of the savings in Seville and Rotterdam are similar, net energy savings are lower in Seville due to the low heating demands because its warmer climate. For example, with the Dutch standardised user profile, the annual energy save in Rotterdam is around 4300 kWh while in Seville is around 800 kWh (Figure 4). Similar differences are found when analysing different user profiles in the same location. For example, in Rotterdam, with the highest intensity profile ('1 senior') the annual energy save is around 5400 kWh while with the lowest intensity profile ('1 adult') is around 1200 kWh (Figure 4).



	1 Senior	2 Seniors	1 Adult	2 Adults	3 Adults	Single-parent	Nuclear family	Starndardised
🟦 Rotterdam retrofitted	1872	1510.2	471.2	879.4	996.5	1044.9	1485.4	931
🟦 Rotterdam Pre-renovated	7234	6290.7	1703.3	3595.3	4639.9	4000.8	6548	5201
🟧 Seville Retrofitted	526	336.9	16	66.3	96.2	152.4	168.3	67.1
🟥 Seville Pre-renovated	1620.6	1299.1	169.2	557.4	658.5	717.7	1063.5	905

Figure 4. Heating demand (kWh/year). Dutch user profiles.



	2 Adults	Nuclear family (social housing)	Starndardised
🟦 Rotterdam Retrofitted	563.1	944.8	1458.5
🟦 Rotterdam Pre-renovated	3231.1	3082.3	6585.8
🟧 Seville Retrofitted	38.2	157.9	85.9
🟥 Seville Pre-renovated	347.1	796.2	1222.9

Figure 5. Heating demand (kWh/year). Southern Spanish user profiles.

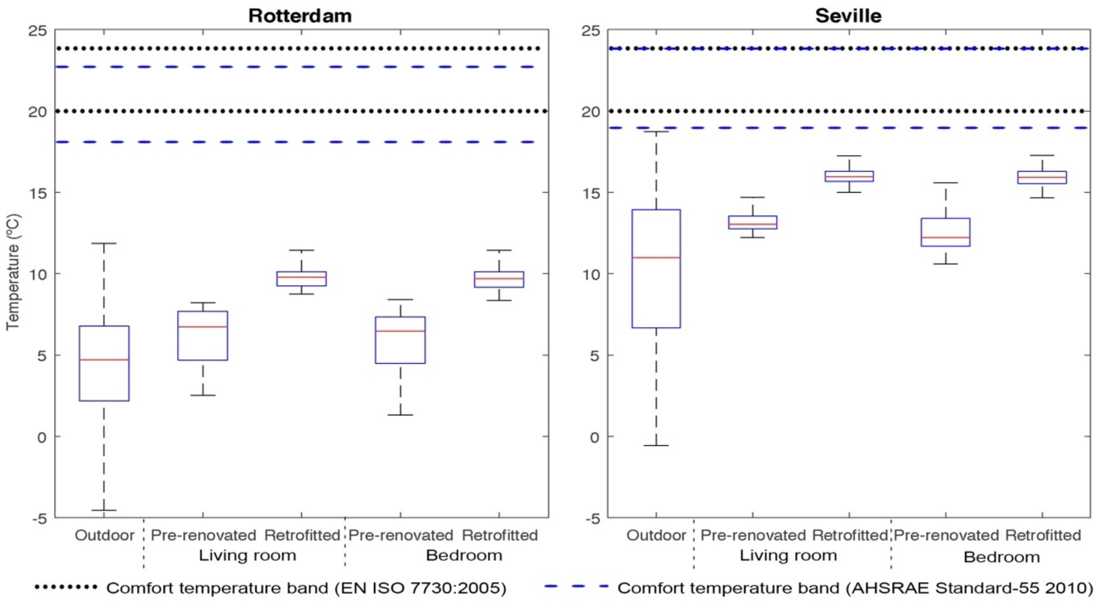


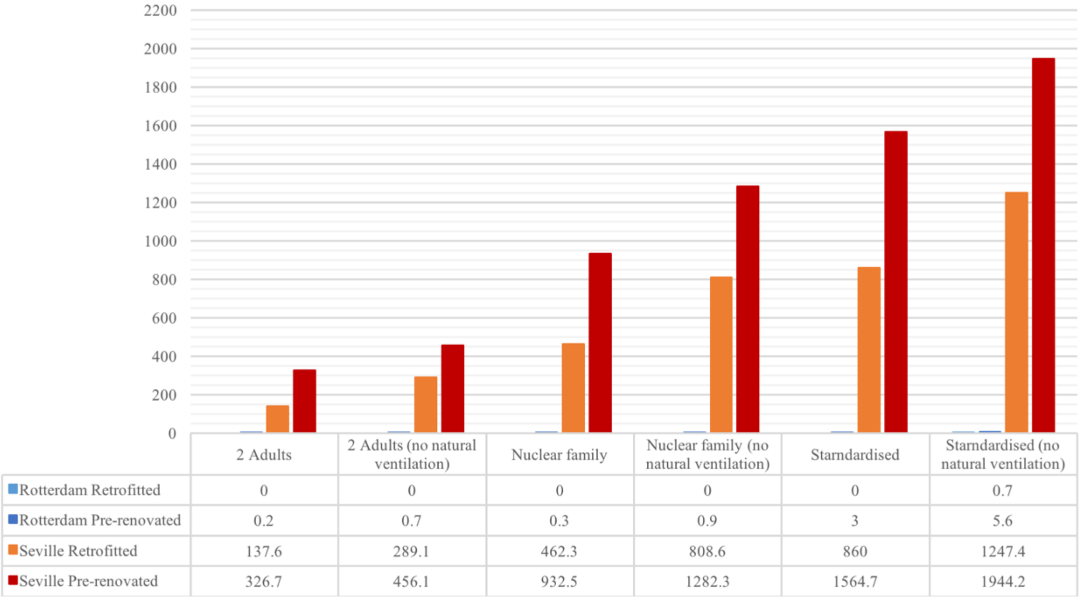
Figure 6. Temperature evolution (January). Spanish 1 senior (no additional heating used).

To evaluate the building's performance after the retrofitting solution application for the southern Spanish user profile with no any heating equipment ('1 senior'), the indoor temperature evolution was analysed developing a free-running simulation during the month of January. The results show that the retrofitting solution results in an internal temperature increase of up to 6 °C in Rotterdam and up to 5 °C in Seville (Figure 6). The lower the outdoor temperatures are, the higher the impact on indoor temperature produced by the insulating effect of the proposed integrated facade module.

Without using any heating system, the average indoor temperature in the retrofitted case study would be around 10 ºC in Rotterdam and 16 ºC in Seville. Despite the good performance of the building after applying the retrofitting solution regarding improved the indoor temperature, the thermal comfort conditions established by the EN ISO 7730 and the ASHRAE-55 Standard are not reached. In the case of Seville, with a warmer climate, the retrofitted dwelling gets closer to the comfort temperature band, but still without reaching it.

3.2. Summer analysis: cooling demand and comfort conditions

To develop a cooling demand analysis, the same process described in the previous section for the heating demand was used. Energy models were simulated applying the user profiles defined for social housing in southern Spain (Table 7), since in the Netherlands the use of cooling systems in residential sector is not common. These profiles include the use of natural night-time ventilation for passive cooling, as it is a majority action in these location. Nevertheless, there are other users that do not ventilate during the nights, that is why the building's performance after the facade module application was also evaluated in this case.



	2 Adults	2 Adults (no natural ventilation)	Nuclear family	Nuclear family (no natural ventilation)	Starndardised	Starndardised (no natural ventilation)
🟦 Rotterdam Retrofitted	0	0	0	0	0	0.7
🟦 Rotterdam Pre-renovated	0.2	0.7	0.3	0.9	3	5.6
🟧 Seville Retrofitted	137.6	289.1	462.3	808.6	860	1247.4
🟥 Seville Pre-renovated	326.7	456.1	932.5	1282.3	1564.7	1944.2

Figure 7. Cooling demand (kWh/year). Southern Spanish user profiles.

As expected due to its high temperatures during summer, the results show the largest cooling demand when we locate the model in Seville, while when we do in Rotterdam the cooling demand is almost zero (Figure 7). If the user does not contemplate the night-time ventilation, the cooling demand increases by around 30%. In Seville, the renovation facade module results in important savings in the cooling demand (50% in the user profiles with night-time ventilation and around 35% in the user profiles without it). Meaningful differences are found in net energy savings when analysing different user profiles in Seville. For example, with the highest intensity profile (‘Standardised’) the annual energy save is around 700 kWh while with the lowest intensity profile (‘2 adults’) is around 200 kWh (Figure 7).

Assuming that the users originally did not ventilate the dwelling on their own and that the ventilation system included into the retrofitting solution force the night-time ventilation, we could associate to it a cooling demand savings of up to 70%. Therefore, in order to optimise the proposed integrated facade module, at least in the case of southern Spain, its ventilation system should ensure night-time air renewal for passive cooling, preventing excessive heat accumulation.

For the evaluation of the building’s performance after the application of the retrofitting solution when cooling equipment is not used, the indoor temperature evolution was analysed with a free-running simulation during the month of August. The user profiles with the minimum (Spanish ‘1 senior’) and the maximum intensity of use and occupation (Dutch ‘Nuclear family’) were selected. The results show that the retrofitting solution decreases the indoor temperature maximum 2 °C both in Rotterdam and in Seville, coinciding with the maximum outdoor temperature. However, the insulation effect fades away when the outdoor temperature decreases, causing even increases of the indoor temperature due to heat accumulation in some punctual cases.

Without cooling system, the average indoor temperature in the Dutch case study (both before and after being retrofitted) would be between 19 ºC (‘1 senior’, Figure 8) and 20 ºC (‘Nuclear family’, Figure 9) and between 28 ºC (‘1senior’, Figure 8) and 29 ºC (‘Nuclear family’, Figure 9) in Seville. In the case of Rotterdam, the indoor temperature never exceeds the upper limits of the comfort conditions established by the EN ISO 7730 and the ASHRAE-55 Standard. In the case of Seville, the retrofitting solution leads to a decrease of more than 20% of hours of discomfort (according to the ASHRAE-55) both with the Spanish ‘1 senior’ user and the Dutch

‘Nuclear family’. However, still after the retrofitting, the results show a high percentage of hours of discomfort: 35% (‘1 senior’) and 57% (‘nuclear family’). During the summer, a higher occupation means worse indoor conditions, but the same effect of the proposed retrofitting solution.

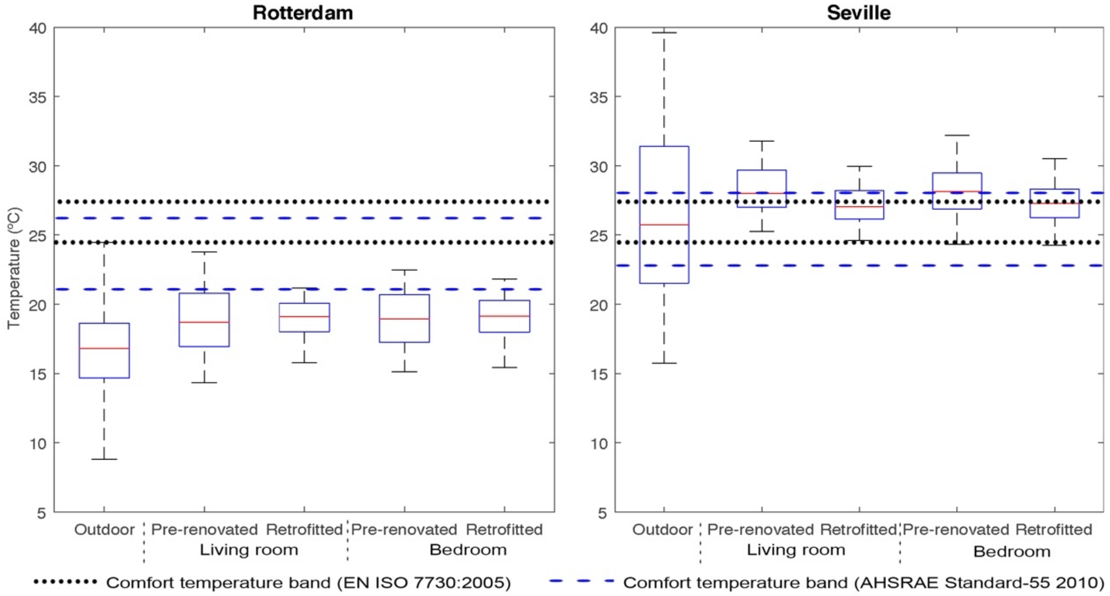


Figure 8. Temperature evolution (August). Spanish 1 senior.

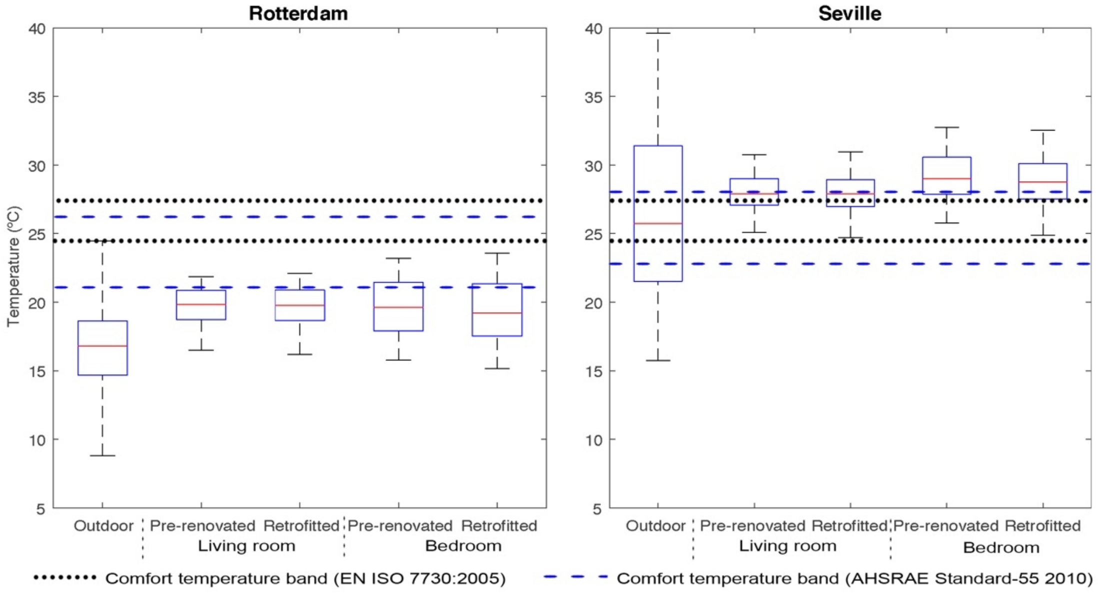


Figure 9. Temperature evolution (August). Dutch nuclear family.

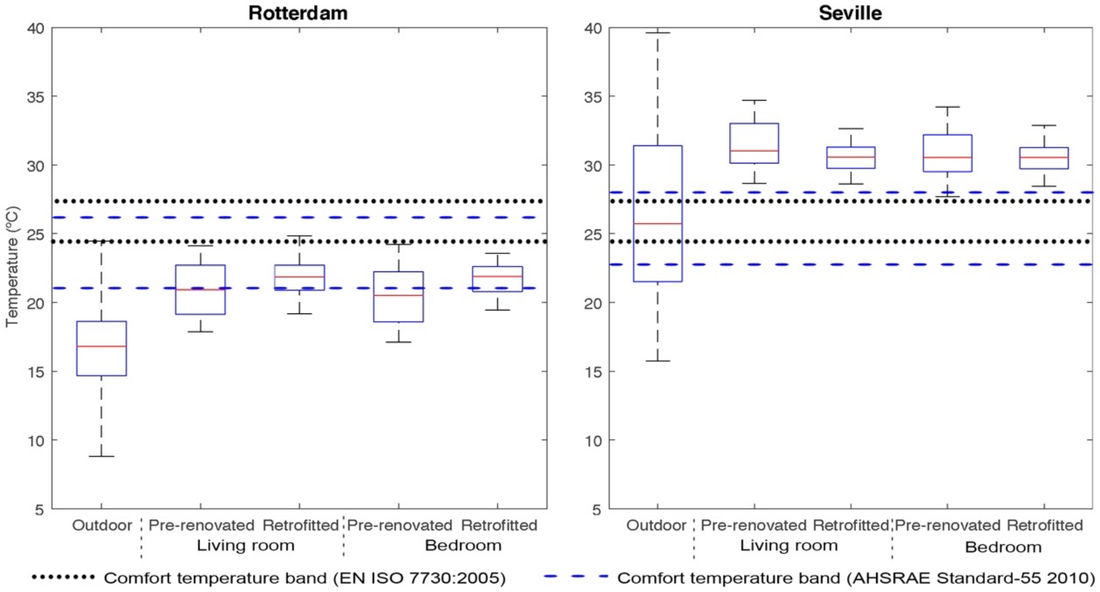


Figure 10. Temperature evolution (August). Nuclear family with no night-time ventilation.

As it was done in the cooling demand analysis, the building's performance after the facade module application was also evaluated using a free-running simulation in the case of users who do not ventilate during the nights. Figures 10 shows the temperature evolution for the user profile with maximum intensity of use (Dutch 'Nuclear family').

It is observed that when removing the night-time ventilation function, indoor temperature increases in both locations, reaching an average indoor temperature in the retrofitted case study of around 22 ºC in Rotterdam and 31 ºC in Seville (Figure 10). Despite the increase of the indoor temperature, the model located in Rotterdam still does not exceed the upper limits of thermal comfort. However, for the model located in Seville, the absence of ventilation during nights means that 100% of the hours fall within discomfort temperature, even after the renovation. This results make evident that the proposed retrofitting solution for southern Spain climate, should ensure night-time air renewal for passive cooling preventing an excessive heat accumulation.

3.3. Annual analysis

After analysing the retrofitted building's energy performance separately during both winter and summer season, its annual behaviour was evaluated. Also, in the second phase of the research, the variables described in figure 1 are introduced to the models in order to show how the retrofitting solution could be optimised according to the location. For this analysis, the results for the user profile with intermediate demand from both the Netherlands and southern Spain (Dutch '3 adults' and Spanish 'Nuclear Family') are shown.

Table 8 shows a compilation of the results obtained in the previous sections from the models with the average user profile for the location of Rotterdam and Seville. As it can be observed, the annual percentage of savings is lower in the southern Spanish user profile, since the performance of the proposed integrated facade module is lower during the summer. As far as the total demand savings in absolute value are concerned, the saving of the model located in Rotterdam with the average Dutch user profile is 3.3 times higher than in the one located in Seville with the average southern Spanish user profile. This comparison makes evident that in the case of southern Spain it would be essential to reduce the economic investment of the retrofitting solution, because the annual demand savings are much lower than in the Netherlands and the payback time would be decompensated.

Table 8. Compilation of the demands and savings due to the retrofitting.

		Pre-renovated				
User Profile	**Location**	**Heating demand**	**Cooling demand**	**Cooling (no night vent.)**	**Total demand**	**Total (no night vent.)**
3 Adults	Rotterdam	4639.9	-	-	4639.9	-
Nuclear family	Seville	796.2	932.5	1282.3	1728.7	2078.5

		Retrofitted					**Savings (Pre-renovated → retrofitted)**			
User Profile	**Location**	**Heating demand**	**Cooling demand**	**Cooling (no night vent.)**	**Total demand**	**Total (no night vent.)**	**(%)**	**(kWh)**	**No night vent. (%)**	**No night**
3 Adults	Rotterdam	996.5	-	-	996.5	-	78.5	3643.4	-	-
Nuclear family	Seville	157.9	462.3	808.6	620.2	966.5	64.1	1108.5	53.5	1112

In order to identify how the performance of the proposed integrated facade module can be optimised, the effect on the energy demand of another two variables added to the forced night-time ventilation were analysed. The two characteristics of the facade module with the most influence on the thermal energy demand were selected: insulation thickness and airtightness [41].

Originally, the designed solution has an insulation thickness of 20 cm, which results in a considerably higher thermal conductivity coefficient U-value compared to Spanish requirements [12]. The Spanish regulation establishes a U-value requirement of 1 W/m²K for the Seville climatic zone, while the proposed integrated facade module provides a U-value of 0.15 W/m²K. Therefore, the performance of the same solution but with an insulation thickness of 10 cm was evaluated, thereby increasing the U-value of the facade to 0.28 W/m²K, still far below the Spanish requirements.

The results show that by reducing the insulation level both the heating and cooling demand increase in all cases (table 9). But it is important to analyse this demand increase in absolute value, because while in the model located in Rotterdam with the average Dutch user profile this increase is 190.3 kWh per year, in the model located in Seville with the average southern Spanish user profile is only 75.6 kWh per year.

The investment cost of wall insulation is set equal to 7.5 €/m^2 per each 10 cm of thickness [42]. So in this case, the reduction of the insulation level would save 270 €/dwelling in the initial investment cost of the retrofitting. The actual cost of electricity use in Spain is 0.22 € /kWh [43], so reducing the insulation level would make tenants pay 6.65 € more per year in the case of Seville. The payback period in this case is more than 40 years, so for southern Spain it is not worth investing in 20 cm insulation thickness because 10 cm is enough. A more detailed economic study is outside the scope of this article.

Also, the originally designed solution has an airtightness of 0.65 ACH, while ASHRAE-119 Standard [44] establishes that a dwelling with a normalized leakage (NL) greater or equal to 0.4 ACH is permeable enough to not require additional mechanical ventilation systems in mild and medium climates. Therefore, taking into account that the proposed solution includes a mechanical ventilation system that ensure a good air quality, the performance of the same window solution but with an airtightness of 0.4 ACH was evaluated.

The results show that by increasing the airtightness of the solution both the heating and cooling demand decrease in all cases (except the cooling demand when night-time ventilation is not considered, due to that this sealing excess causes heat accumulation) (table 10). This airtightness improvement means a decrease of the total demand of 485.5 kWh per year in the model located in Rotterdam with the average Dutch user profile and 164.4 kWh per year in the model located in Seville with the average southern Spanish user profile.

Table 9. Compilation of the demands and savings due to the insulation thickness variation.

		Facade module less insulation: U = 0.28 W/m^{2}K (10 cm insulation)					**Savings (Original facade module U = 0.15 W/m^{2}K → less insulation)**			
User Profile	**Location**	**Heating demand**	**Cooling demand**	**Cooling (no night vent.)**	**Total demand**	**Total (no night vent.)**	**(%)**	**(kWh)**	**No night vent. (%)**	**No night vent. (kWh)**
3 Adults	Rotterdam	1186.8	-	-	1186.8	1186.8	-19.1	-190.3	-	-
Nuclear family	Seville	211.9	483.9	821.4	695.8	1033.3	-12.2	-75.6	-6.9	-67

Table 10. Compilation of the demands and savings due to the airtightness.

		Facade module more airtight: 0.4 ACH					**Savings (Original facade module: 0.65 ACH → more airtight)**			
User Profile	**Location**	**Heating demand**	**Cooling demand**	**Cooling (no night vent.)**	**Total demand**	**Total (no night vent.)**	**(%)**	**(kWh)**	**No night vent. (%)**	**No night vent. (kWh)**
3 Adults	Rotterdam	511	-	-	511	-	48.7	485.5	-	-
Nuclear family	Seville	8.9	446.9	849.6	455.8	858.5	26.5	164.4	11.2	108

3.4. Total energy performance

In this section we integrate the results of the energy simulations, together with an estimation of energy demand for hot water, domestic appliances and artificial lighting. Furthermore the renewable energy generation that would be necessary to achieve nearly zero energy consumption is calculated. In the case of the Netherlands, the estimation of energy demand for hot water, appliances and artificial lighting was obtained from calculations based on Dutch regulations and on the statistical profiles established from the WoON dataset [45]. In the case of southern Spain, the estimation of energy demand for hot water was calculated from the demand established by the Spanish regulations [12] and for the appliances and artificial lighting it was based on the statistical data obtained in the SECH-SPAHOUSEC project [46]. The necessary PV panels to cover the renewable energy generation according to the building characteristics were calculated with the PVsyst 6.4.9. software [47].

Table 11 shows the results obtained from the model with the average Dutch user profile ('3 adults') located in Rotterdam and the model with the average southern Spanish user profile ('Nuclear family') located in Seville. As it can be observed, the total demand is a 13.4% lower in Seville than in Rotterdam. When this is added to a highest solar radiation in southern Spain than in the Netherlands, it translates into a need of a half of the PV panels surface in the model located in Seville with respect to the one located in Rotterdam. As a result, the possibility of reaching the nZEB in the model located in Seville is in the building itself, whereas in the model placed in Rotterdam an extra surface to install more PV panels would be required, since the case study building has a roof area around 150 m^2. This aspect significantly reduces the economical investment of the proposed integrated facade module in southern Spain with respect to the Netherlands.

Table 11. Compilation of the demands and necessary PV area, to cover the demand.

User Profile	**Location**	**Heating**	**Cooling**	**Hot water**	**Appliances**	**Total**	**m² PV (per dwelling)**	**m² PV (building)**
3 Adults	Rotterdam	996.5	0	1680.8	3222	5899.3	35	350
Nuclear family	Seville	157.9	462.3	1430	3060	5110.2	17	170

4. Conclusions

The paper presented a study that compared the resulting energy performance and optimisation potential of an integrated facade renovation module with different climates and user profiles. Relevant typology similarities have been detected between the Dutch and the southern Spanish housing stock, which makes possible the analysis of the adaptability of the proposed integrated facade module (originally designed for the Dutch stock) to the southern Spanish climate. Also important constructive similarities have been found, which shows that at least initially the proposed solution can be built over the Spanish buildings envelope.

After the retrofitting solution performance analysis (both in terms of demand and thermal comfort), the following conclusions have been drawn:

- The proposed solution achieves heating demand savings between 70 and 90% in both Rotterdam and Seville models, and increases of the indoor temperature up to 6 ºC in Rotterdam and 5 ºC in Seville when the house is free-running during the winter.
- Even though the percentage of the savings in Seville and Rotterdam are similar, the same does not happen when we analyse net energy savings. A difference of 3500 kWh is found between the heating demand reduction due to the retrofitting in Rotterdam and Seville (for the Dutch user profile with intermediate demand). Something similar happen when we analyse the influence of the user profile in net energy savings. A

difference up to 4200 kWh is found between the highest and lowest intensity Dutch user profile.

- The proposed solution achieves cooling demand savings around 50% in Seville (with night-time ventilation) and decreases of the indoor temperature up to 1ºC when the house is free-running during the summer. If it is considered that the original user did not ventilate during the night and the facade module forces it, cooling demand savings of up to 65% are obtained in Seville and decreases of the indoor temperature up to 5 °C when the house is free-running. Thus, to optimize the originally proposed solution in the case of southern Spain the ventilation system should ensure night-time air renewal for passive cooling.
- As the cooling demand in the pre- and post-retrofitted models in Rotterdam is almost zero, a difference of 470 kWh is found between the cooling demand saving in Rotterdam and Seville (for the southern Spanish user profile with intermediate demand). Also a difference up to 500 kWh is found between the highest and lowest intensity southern Spanish user profile.
- The proposed solution works properly in southern Spain, but annual heating and cooling demand savings in absolute value are 3.3 times lower than in the Netherlands (for a user with intermediate use intensity). In southern Spain the economic investment of the facade module should be reduced.
- If the insulation thickness of the proposed solution is reduced from 20 to 10 cm, heating and cooling demand increase. But in absolute value, this increase in Seville is only 75.6 kWh per year. It is not worth investing in double insulation thickness because its payback period would take more than 40 years.
- If we reduce the air permeability of the proposed solution from 0.65 to 0.4 ACH, heating and cooling demand decrease. In absolute value, this decrease is 485.5 kWh per year in Rotterdam and 164.4 kWh per year in Seville. It is worth investing in the

airtightness improvement (ensuring a good indoor air quality) because an important improvement in savings would be obtained.

- When the building is retrofitted total demand is a 13.4% lower in Seville than in Rotterdam. Due also to a highest solar radiation, in Seville the PV panels surface necessity is half than in Rotterdam. This means an important reduction of the economical investment to reach the nZEB in southern Spain with respect to the Netherlands.

These results demonstrate a high influence of the user profile in the heating and cooling demand saving, at the same level of importance that the location of the case study. Because of that, all the retrofitting analysis should take into account real user profiles and not just the standardised ones.

The next step of this research should be a more detailed economic analysis of the energy savings and investment. The results on energy savings optimisation can support the financial feasibility analysis. Moreover, the renovation of the building stock has social implications as the residents are involved and need to accept the proposed interventions. As such the social acceptance in southern Spain of the proposed integrated facade module should be evaluated. Finally, the analysis of the political barriers to self-consumption and energy production would be important to propose strategies to increase the renovation rates and support the european decarbonisation goals.

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