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Dissemination Level		
PU	Public	X
PP	Restricted to other programme participants (including the Commission Services)	
RE	Restricted to a group specified by the consortium (including the Commission Services)	
CO	Confidential, only for members of the consortium (including the Commission Services)	

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1 Introduction

The present document constitutes Deliverable 8.2 “Performance assessment of the 3 demo buildings” in the framework of the EASEE project.
This deliverable reports about the activities carried out within Work Package 8, and specifically within Task 8.3 “Performance monitoring and evaluation towards targets”. As reported in the DoW; Task 8.3 has the following expectations:

“The main issues to be assessed at this stage are the final energy performance (U-value of the opaque envelope) with respect to expected target as well as the safety of the components during installation, operation and maintenance. The performance assessment, before and after the installation phase, will be carried out coupling the infrared thermo vision technique with the heat flow meter method to acquire quantitative data of real thermal transmittances of the building envelope in a quasi-steady state condition for demo buildings in Madrid. Four seasons monitoring will be performed for Gdansk and Milan demo buildings through sensors installation, in order to have data useful for the validation of the panels performances. Other data related to the specific boundary conditions (e.g. external temperatures, particular weather events, etc) will be collected during demonstration activities in order to compare real and predicted performances. Also the durability and the behavior of the expected insulating options will be assessed, collecting temperature and humidity data from sensors installed on different parts of the envelope. The work will be carried out jointly by IES and POLIMI. CIMMES will also give a support to the monitoring supervision.”

With respect to the above Task description, the following clarifications are provided:

- Due to the difficulties encountered in the manufacturing process of the panels for the external retrofitting a four seasons monitoring was not possible. Nevertheless, the monitoring of the winter season before and after the retrofitting intervention have been guaranteed for each of the demo buildings. This has enabled the comparison of performances before and after the retrofitting in the worst conditions possible.
- Descriptions of the retrofitting interventions per each demo building are provided within Deliverable 8.1 “EASEE solutions applied to demo buildings”. In this deliverable, the external retrofitting through the EASEE panels will be taken into account (with exception of the cavity retrofitted at the Spanish demo building and a room under the roof in the Polish demo building).
- Separate section has been dedicated to main results from monitoring campaign performed at Lavrion demo building in Greece (see Chapter 5).

The document has been mainly structured into 5 sections according to the related impacts evaluated, respectively:

- Chapter 2 related to **energetic impacts** for each demo building (energy performances evaluation and related energy savings in terms of building consumptions)
- Chapter 3 related to **economic impacts** for each demo building (in terms of cost effectiveness during the life cycle of the building)
- Chapter 4 related to **indirect industrial impacts** for each demo building (i.e. savings in terms of installation timing and workforce, waste reduction, CO_2 emissions, burden minimization)
- Chapter 5 provides **main results from the monitoring campaign** performed at Lavrion small scale demo buildings where innovative solutions for cavity wall retrofitting were installed and tested
- Chapter 6 draws the **conclusions.**

2 Energetic impacts

2.1 Goal and scope and key indicators

This section describes the evaluation of the energetic impacts related to the application of the EASEE retrofit solutions to the three demo buildings. This evaluation has been done both through simulations carried out using the Retrofitting Planner and the VE software and through empirical models based on measured values and real savings. Three main indicators have been selected to show the final energetic impacts of the proposed technical solutions:

1. **Energy performance**: to evaluate the energy performance, the difference in U-value (W/m^2K) before and after the retrofitting of each demo building has been chosen. The U-value was evaluated through different methods including empirical methods and simulations, as explained in the sections below.
2. **Energy consumption:** the reduction of energy consumption per year in kWh/y before and after the retrofitting has been chosen as an indicator to evaluate the energetic impacts. The percentage of expected energy savings has been calculated through the Retrofitting Planner (VE software) and when possible the actual savings were also obtained from the energy bills.
3. **Thermal comfort:** thermal comfort was also considered as an indicator of the energetic impact of the EASEE solution. Different air, radiant and dry temperatures has been estimated through the VE software as well as the standard ISO comfort indices Predicted Mean Vote (PMV) and Percentage of People Dissatisfied (PPD). The software inherently solves for air temp, mean radiant temp, humidity during the thermal analysis. Air velocity, metabolic rate and clothing level are all user inputs for comfort. For the analysis, the following comfort parameters were assumed:
    - Clothing Level = 0.69
    - Activity Level = 90
    - Air Speed = 0.1 m/s

   The PMV index predicts the mean response of a larger group of people according the ASHRAE thermal sensation scale:
    - +3 - Hot
    - +2 - Warm
    - +1 - Slightly warm
    - 0 - Neutral
    - -1 - Slightly cool
    - -2 - Cool
    - -3 - Cold

2.2 Main output per demo building

2.2.1 Italian demo building

	
• Multi-storey multi-owner building in Cinisello Balsamo (Milan) • Age of construction: 70s • Owner: Local Social Housing Agency (ALER)	Retrofitting of the entire building through the installation of 186 EASEE panels of different textures, colors and sizes.

2.2.1.1 Energy performance evaluation

Comparison of U value empirically evaluated through the data from static calculation validated by mean of monitoring systems

Transmittance has been calculated through static calculation both before and after retrofitting intervention.
Figure 1 below provides the stratigraphy of the Italian demo building before retrofitting and Table 1 summarizes the thermal properties of the materials considered in the calculation.

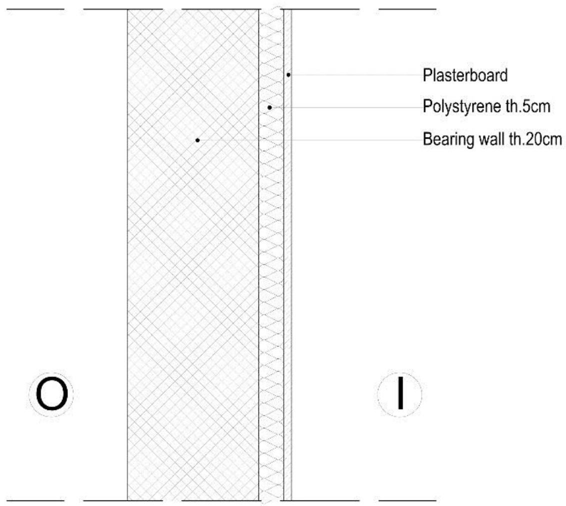


Figure 1: Stratigraphic detail before the retrofitting

Table 1: Thermal properties of the materials

Cat	Material description	Thickness (m)	Thermal resistance (m^2 k/W)	Res. factor	Equivalent thickness of air (m)
	External surface		0,04		
CLS	Concrete for external walls not-guarded, density 2400	0,20	0,0927	150,00	30,00
ISO	Polystyrene	0,05	0,9259	1,00	0,05
VAR	Plasterboard sheets	0,0125	0,0595	8,00	0,10
	Internal surface		0,13		

The table below provides the calculation of the thermal transmittance before retrofitting used as benchmarking value, corresponding to 0,812 W/m^2K.

Table 2: Thermal transmittance calculation of the stratigraphy before retrofitting

Structure name	Stratigraphy 1
Location	Milan (MI)
Structure type	Walls
Number of layers	3
Total thickness	0,2625m
Total thermal resistance	1,2481 (m^2K)/W
Total thermal transmittance	0,8012 W/(m^2K)

After retrofitting through the EASEE panels, the stratigraphy of the wall is presented in Figure 2 while results of the transmittance calculated is provided in Table 3 and corresponds to 0,2377 W/(m^2K).

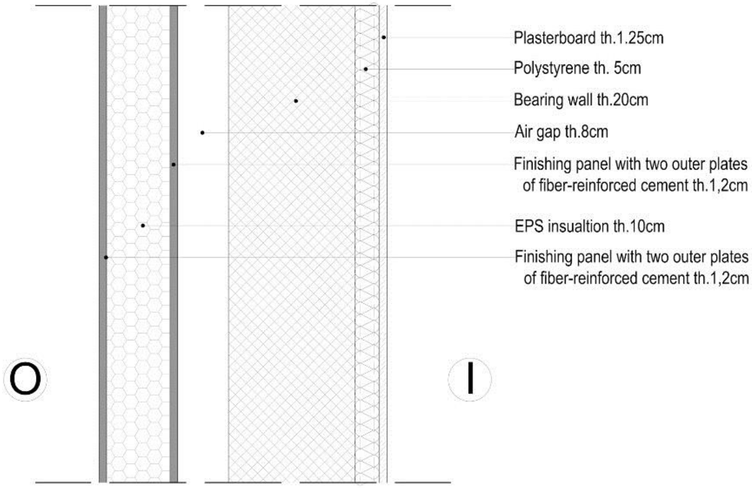


Figure 2: Stratigraphic detail after the retrofitting

Table 3: Thermal properties of the materials

Cat	Material description	Thickness (m)	Thermal resistance (m^2 k/W)	Resistance factor	Equivalent thickness of air (m)
	External surface		0,04		
FIN	Fiber-reinforced panel	0,012	0,0343	5,00	0,06
EPS	EPS insulation	0,10	2,7778	40,00	4,00
FIN	Fiber-reinforced panel	0,012	0,0343	5,00	0,06
ARI	Air gap	0,08	0,112	1,00	0,08
CLS	Concrete for external walls not-guarded, density 2400	0,20	0,0927	150,00	30,00
ISO	Polistyrene	0,05	0,9259	1,00	0,05
VAR	Plasterboard sheets	0,0125	0,0595	8,00	0,10
	Internal surface		0,13		

Table 4: Thermal transmittance calculation of the stratigraphy after retrofitting

Structure name	Stratigraphy 2
Location	Milano (MI)
Structure type	Pareti
Number of layers	7
Total thickness	0,4665 m
Total thermal resistance	4,2065 (m^2K)/W
Total thermal transmittance	0,2377 W/(m^2K)

As described in D8.1 “EASEE solutions applied to demo buildings”, a dedicated monitoring campaign has been performed in situ through the installation of sensors. The data recorded by the sensors have been automatically transmitted by wi-fi connection to a server at Politecnico di Milano and checked and tabulated in order to calculate the thermal transmittance and validate the results previously obtained.
During the data re-processing some periods of black out of the system were identified, due to lack or loss of connection between data logger and server. These periods can be noticed in the graphs reported below.
In particular, taking into consideration the data collected, the thermal transmittance of the shell was calculated. According to the UNI EN 1934: 2000 and ISO 9869: 1994, 72 hours is the minimum

range of time for making the tests. It has been taken between 29 and 31 January 2014. The range of time between two take-over of data was 10 minutes, according to regulation, in this specific case it was equal to 6 minutes. The method used is called the method of the 'progressive averages'.
First the calculation of the conductance C has been carried out, by means of the following formula:

$$C = \frac{\sum Qi}{\sum (Tsij - Tsej)}$$

where:

- Q: thermal flow through the element [W];
- T_{si}: inner surface temperature [K];
- T_{se}: outer surface temperature [K];
- j: j-th performed measurement.

The values related to the conductance to be obtained were:

- Global conductance at every step of the trial period;
- Conductance average during tested period;
- Progressive conductance average that was calculated by dividing the sum of the j-th moments and the number of moments themselves.

The asymptotic value is reliable only if:

- The heat content of the element is the same at the beginning and at the end of the test;
- It's avoided direct solar radiation over the thermal flow meter;
- The thermal conductance is constant during the test.

The U value of the vertical wall of the pre-retrofitting configuration is shown in Figure 3 while Figure 4 shows the values measured after the retrofitting phase.
Considering the existing wall, the asymptotic conductance obtained was 0,968 W / mK.
As known, the conductance is the opposite of the resistance of the shell. By using the usual values of resistance laminar surface internal and external equal to R_{se}=0.04 W/m^{2}K e R_{si}=0.13 W/m^{2}K, it was then possible to calculate the value of the transmittance U, by using the following formula:

$$U = \frac{1}{Rsi + \sum Rj + Rse}$$

The graph in Figure 3 shows the value of the global transmittance step by step, the average transmittance and the value of the transmittance obtained by using the progressive average. The transmittance was 0.827 W / m^{2}K.

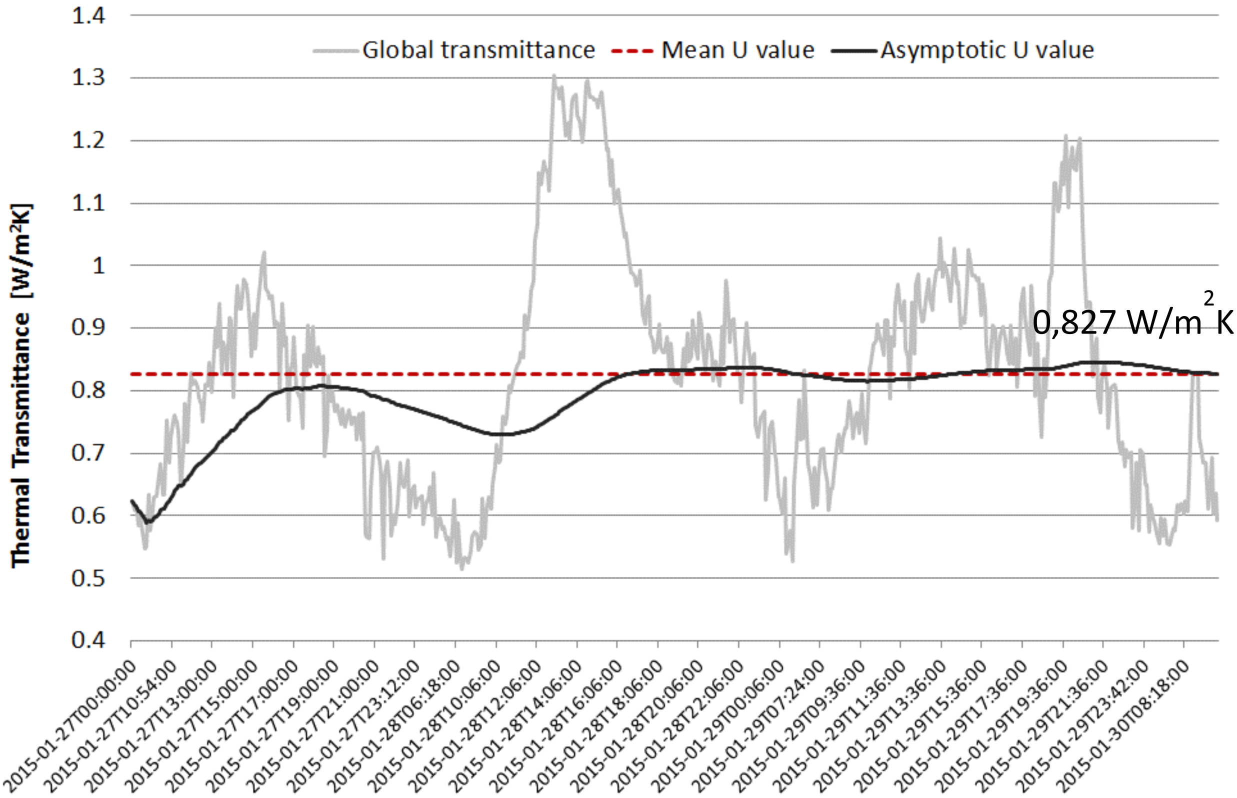


Figure 3: Asymptotic transmittance of the vertical wall pre-retrofitting (27 January to 30 January)

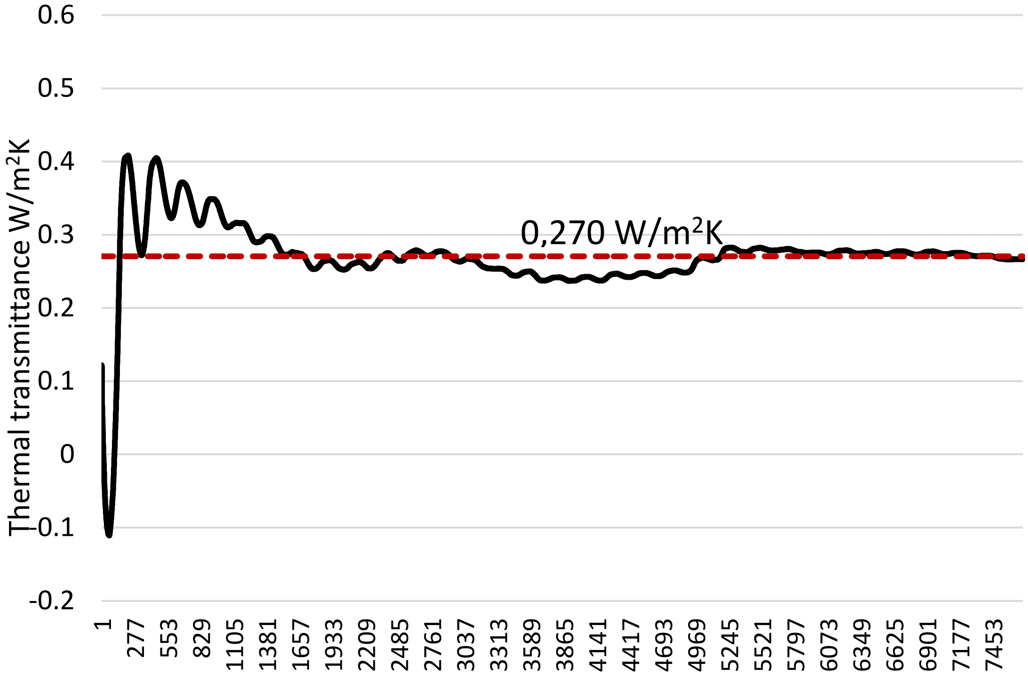


Figure 4: Asymptotic transmittance of the vertical wall after retrofitting (10 November to 22 December)

The asymptotic conductance obtained with the new wall configuration was equal to 0,303 W / mK. The related transmittance was equal to 0.270 W / m^{2}K. The thermal transmittance reduction between before-after retrofitting is equal to 67.35%, this means reduced energy consumption and higher thermal comfort.

Thermographic survey campaign

Hereafter a comparison of thermographic survey campaign on Italian demo building before and after the retrofitting with the outer EASEE solution is presented.
In particular the final thermographic survey campaign of the Italian demo building was performed with the aim to:

- Verify the final thermal behaviour of the outer envelope (both panels and joints);
- Compare the thermal behaviour of the outer envelope, before and after the EASEE retrofitting, (e.g., removal of thermal bridges);
- Verify the thermal homogeneity of the outer envelope.

The first initial survey was performed on 6th February, 2014 (ambient condition T_{out}=11°C and RH=56,4%), while the final campaign was performed on 18th February 2016 in a sunny day (outer temperature T_{out}=9,8°C and relative humidity RH=66,5%).
The area analysed to verify the final thermal behaviour of the outer envelope and comparing it with respect to the behaviour before the intervention is presented in Figure 5 below. This area was chosen since a significant thermal bridge characterized this portion of the façade before the retrofitting with the EASEE solution (Figure 6).

Figure 5: Area analysed to verify the thermal behaviour of the outer envelope

In particular, thermal profiles before the retrofitting (Figure 7, Figure 8, Figure 9) highlight the thermal bridges in beside columns (Figure 7, Figure 8) and beams (Figure 9) of the building concrete structure frame. The same area after the EASEE retrofitting presents a more homogeneous thermal behaviour (Figure 10). Some minor thermal losses are still visible along the joints. However, the incidence of these areas is reduced and can be considered acceptable. In fact, as identified in Figure 13, the area, which cover both panels and joints, presents a uniform density of temperatures. No significant spikes in the graph are identified (Figure 14) highlighting an homogenous behaviour of the outer envelope for the area 1, and an higher DT equal to 4°C is identified in the area 2 which cover panels with different colours and consequently also with different emissivity (Figure 15).

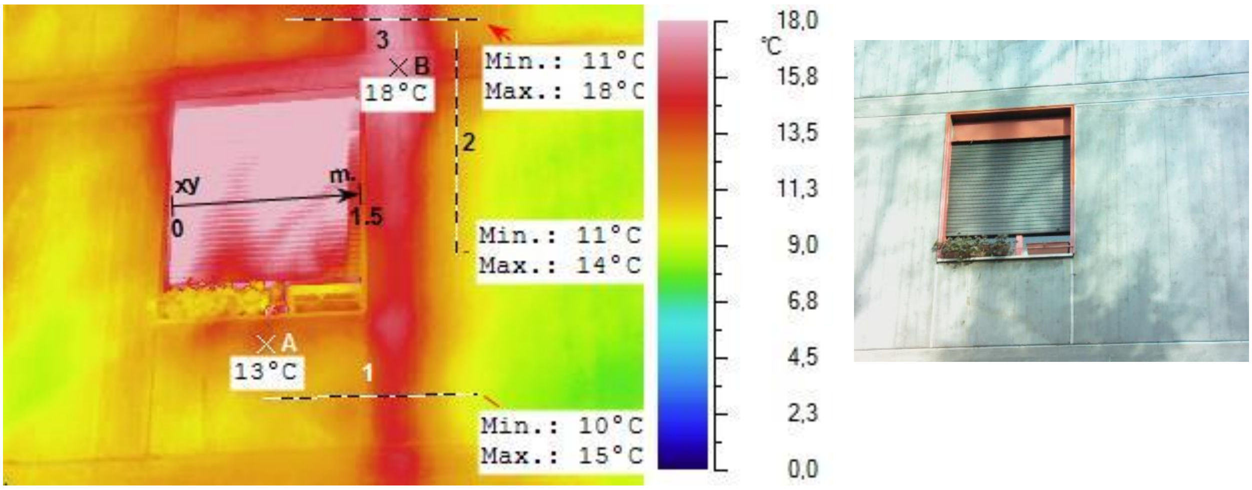


Figure 6: Area analyzed before the EASEE retrofitting: thermographic image and analyzed profiles

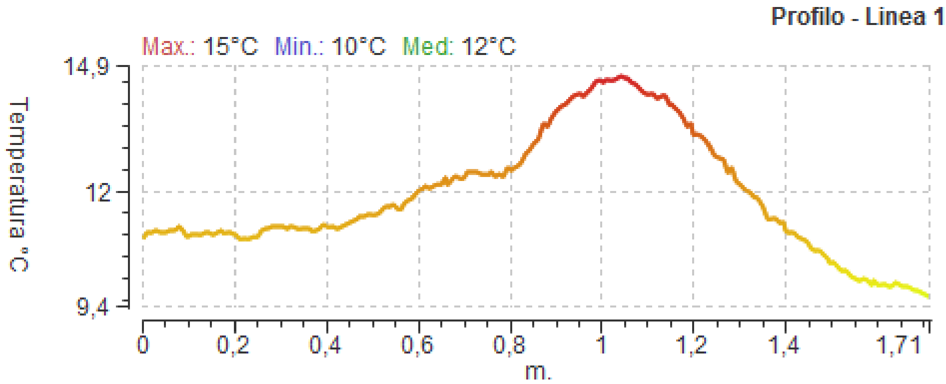


Figure 7: Thermal behaviour along the profile 1

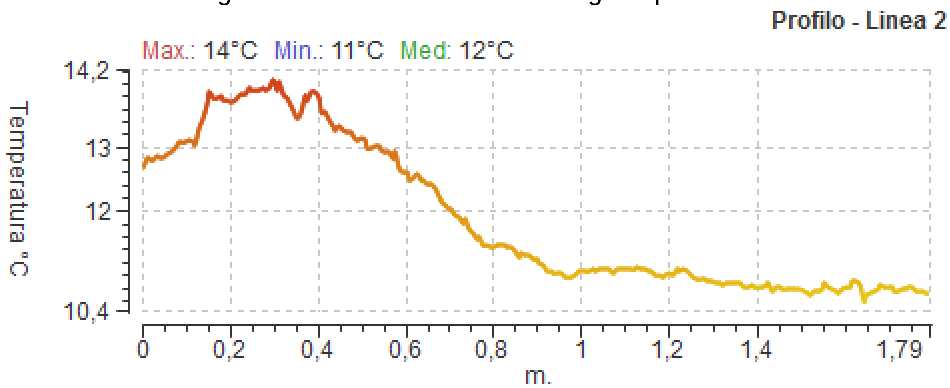


Figure 8: Thermal behaviour along the profile 2

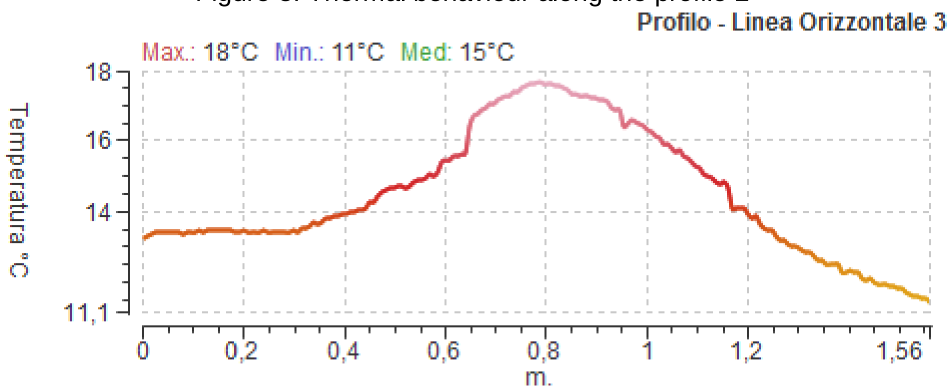


Figure 9: Thermal behaviour along the profile 3

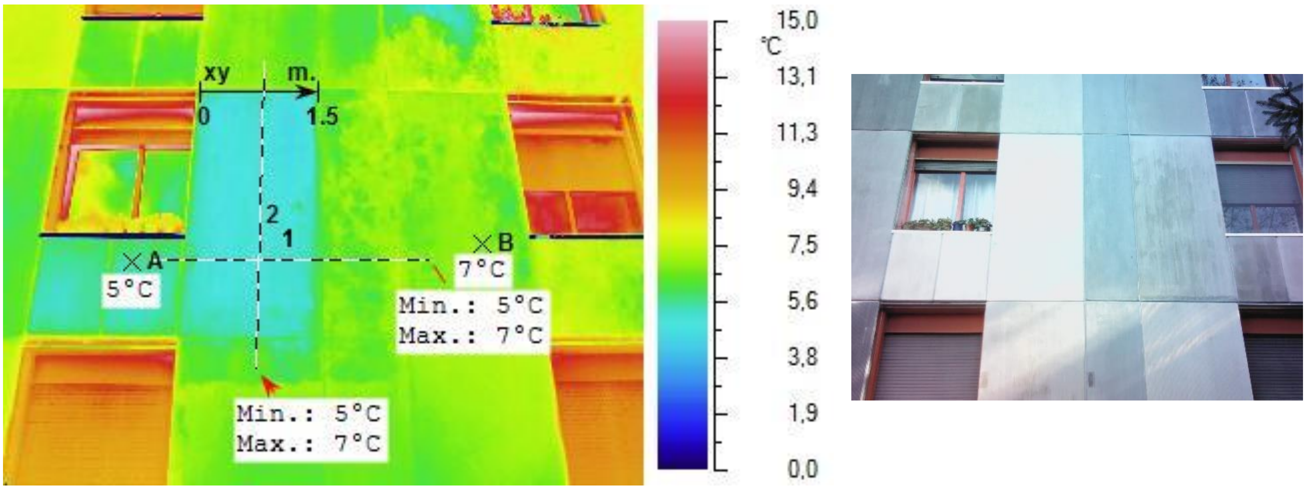


Figure 10: Area analyzed after the EASEE retrofitting: thermographic image and analyzed profiles

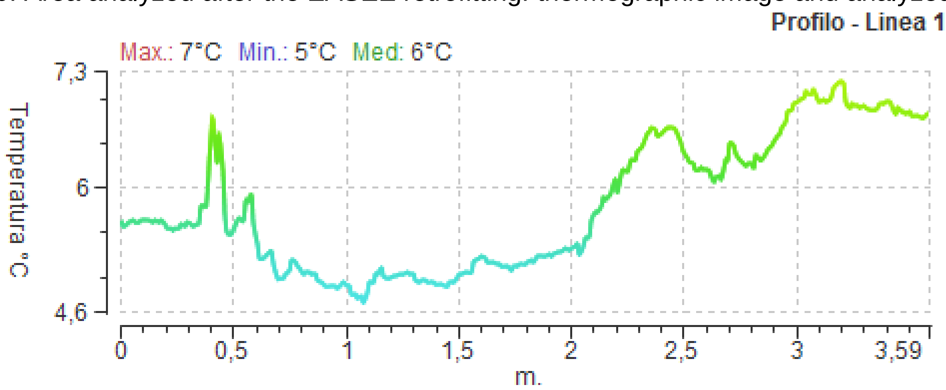


Figure 11: Thermal behaviour along the profile 1

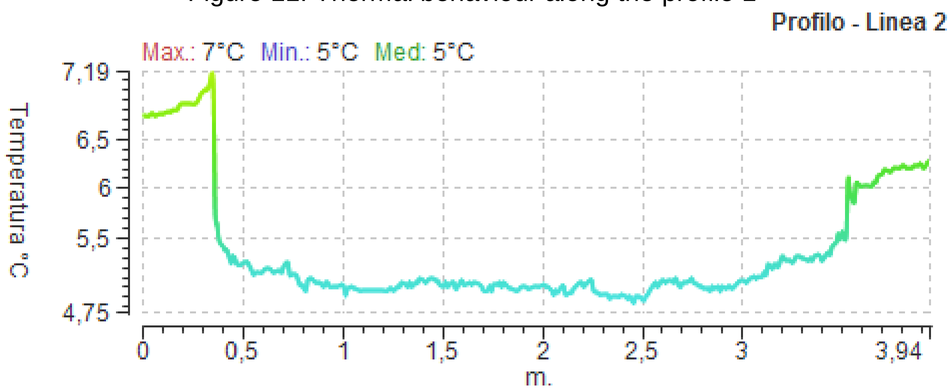


Figure 12: Thermal behaviour along the profile 2

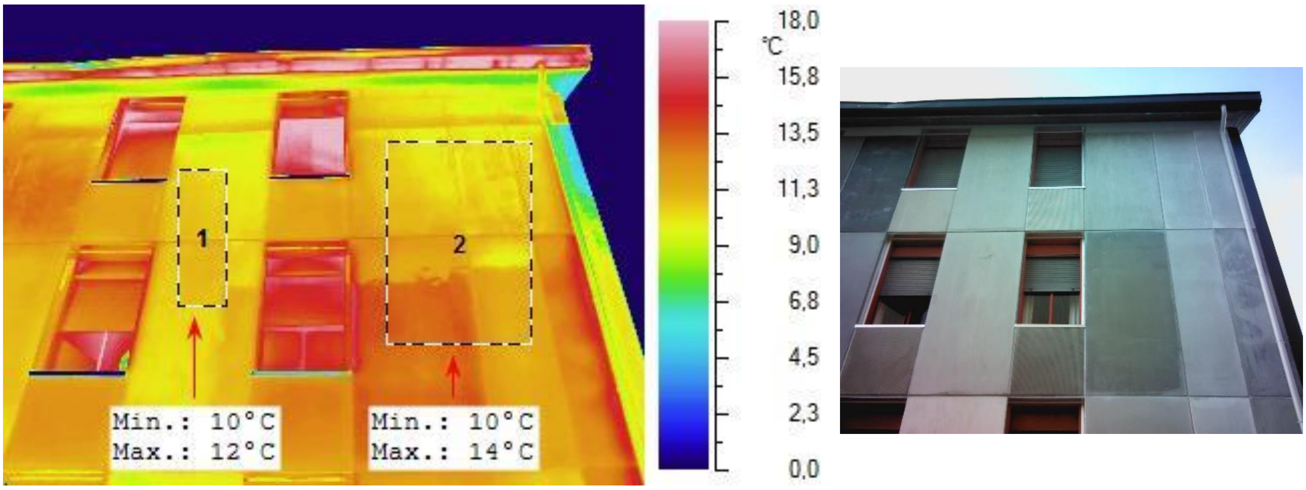


Figure 13: Area analyzed after the EASEE retrofitting: thermographic image and analyzed area

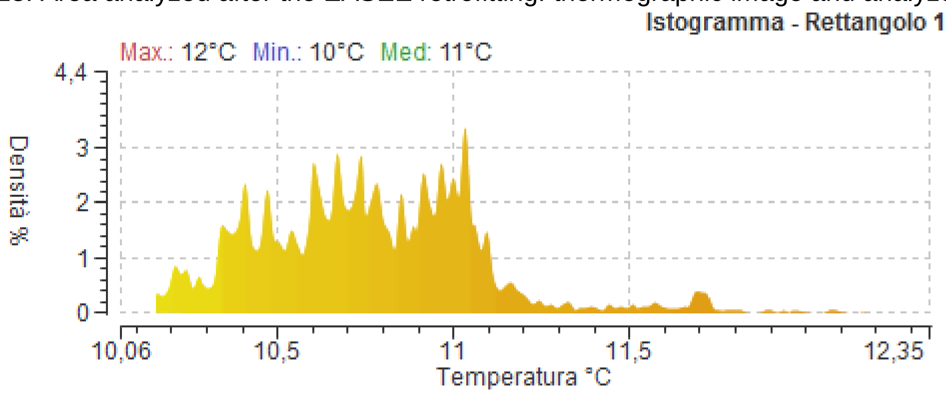


Figure 14: Thermal behavior in the area 1

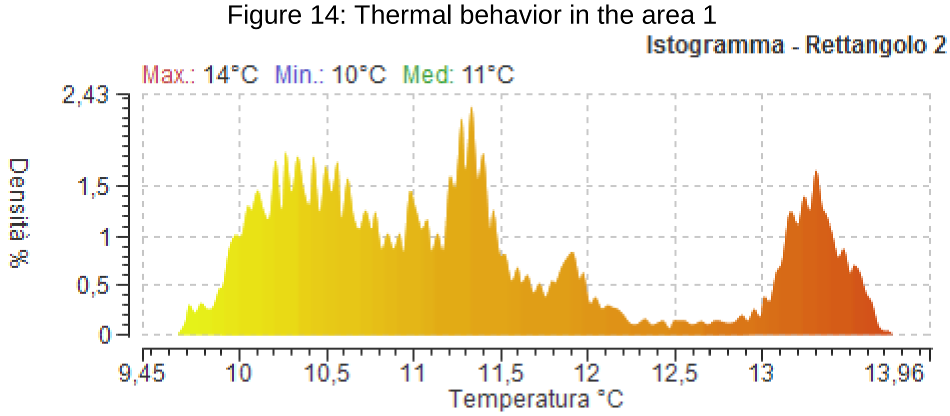


Figure 15: Thermal behavior in the area 2

2.2.1.2 Energy consumption evaluation through Retrofitting Planner

Three sets of simulations have been carried out on the Italian demo building consisting of a baseline run and a run with the EASEE Retrofit Panel Solution applied. The baseline model was calibrated using survey data to align with the energy utility figures received for the site and the EASEE solution that was applied. The EASEE construction database was used to assign constructions to the other elements of the building envelope.

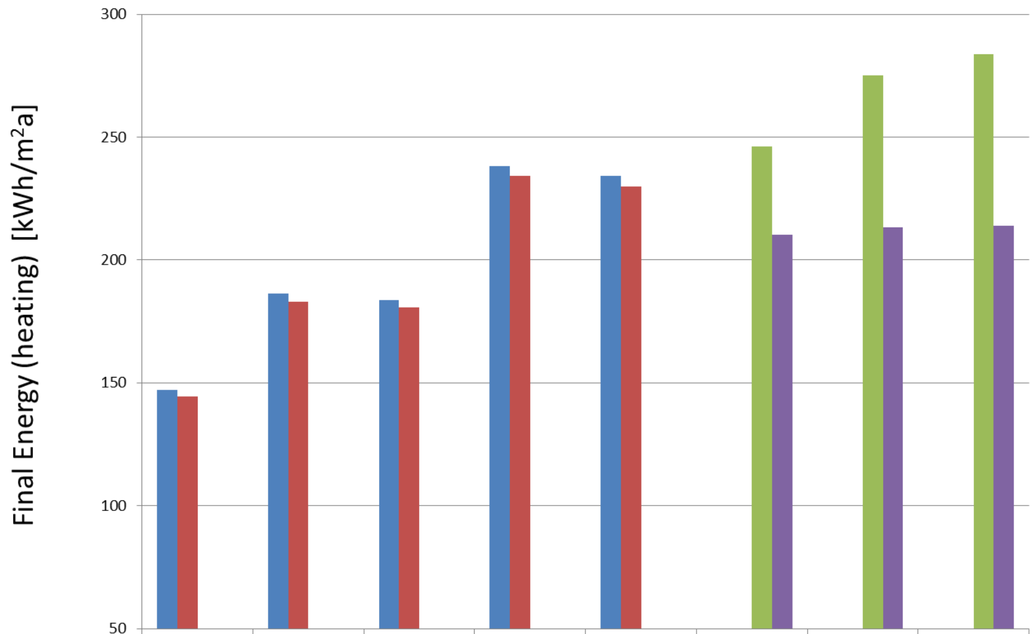
- For set 1 the external wall construction was assigned from the EASEE Construction Database. The EASEE construction database was created using data on historical u-values standards. The database currently contains 396 options for 6 different locations (UK, Germany, Italy, France, Spain and Poland). This database of constructions allows the user to quickly make realistic construction base on location and period when survey data is not available.
- For set 2 the baseline was ran with the external wall construction calculated in the VE
- For set 3 the U-Value metered/calculated for the demo building was applied.

Lifecycle costing data is inherent throughout all construction and solution set ups and a 60 year life cycle cost analysis has also been carried out for the test sites.

The main assumptions throughout the analysis are:

- Values from the NCM's standard data sets are used for modelling variables such as set points, variation profiles, internal gains and air exchanges were additional data has not been received. NCM stands for the National Calculation Method which is used throughout the UK and Ireland for the EPBD (Energy Performance of Buildings Directive).
- Material properties (i.e. thermal conductivity, density) were assumed where final documentation detailing constructions was not available
- Where occupant survey was not received for the entire building, the information which was obtained from submitted surveys from that building were applied to the entire building.

Figure 16 below shows the total heating energy for the building.



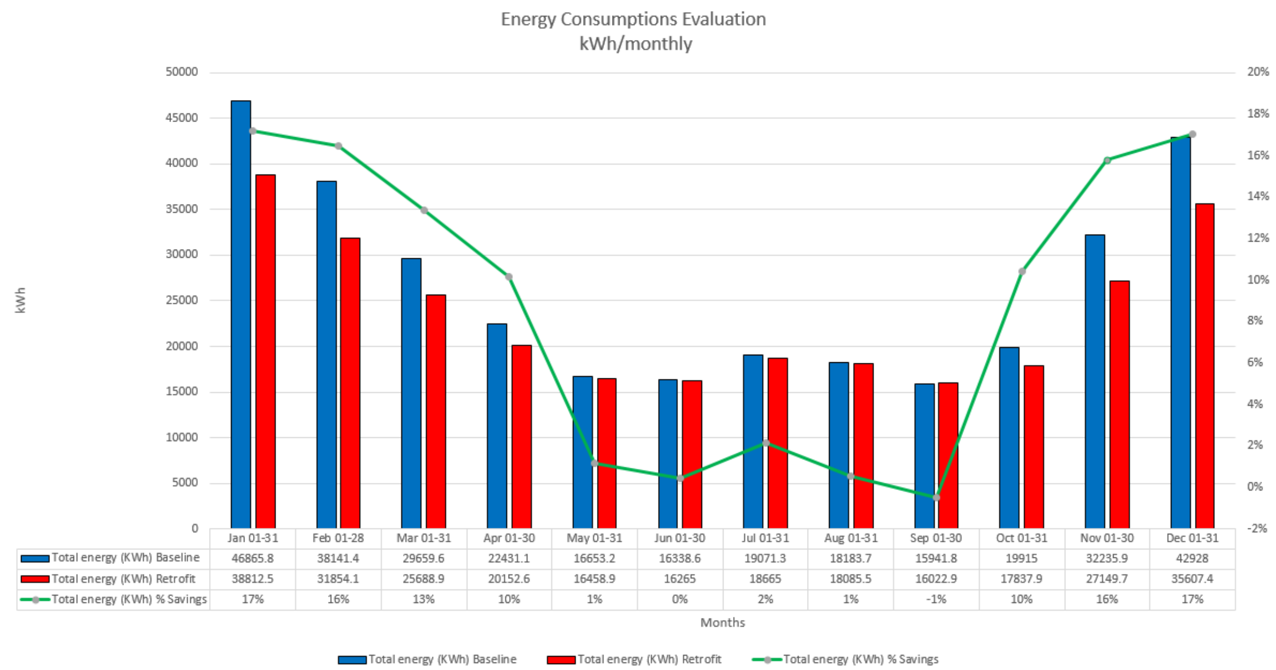
	2009/2010	2010/2011	2011/2012	2012/2013	2013/2014	EASEE Database U-Value	VE Calculated U-Value	Surveyed U-Value
Totale Energy (Heating) 18	147.03	186.2	183.73	238.35	234.09	0	0	0
Total Energy (Heating) 20	144.49	182.98	180.55	234.24	230.04	0	0	0
Total Energy (Heating) Base Simulated	0	0	0	0	0	246.2562523	274.9575048	283.7348014
Total Energy (Heating) Solution Simulated	0	0	0	0	0	210.393	213.3696	213.9966858

Figure 16: Energetic Impacts for the Italian demo building through Retrofitting Planner

The metered data is represented by the blue and red columns; the two sets of metered data (blue and red) are referred to the two twin buildings in the area of Cinisello Balsamo that ALER was monitoring, but only red ones refer to the actual building that was retrofitted. Even though there is data from the five previous years, focus is given to the two periods of 2012/2013 and 2013/2014 as they are the most recent and are more likely to represent the current occupants who completed the survey and therefore the current energy usage of the building.
The results presented above represent the total heating energy for the building for the three sets of simulations run, as previously described. The green bar is the baseline situation (before retrofitting) and the purple one is the simulation after the retrofitting with the EASEE panels.

1. **Simulation set 1**: The EASEE Database construction assigned was the heavy weight Italian 1955-75 wall construction with a U-Value of 1.2 W/m^{2}K. Baseline results are 3.21% greater than the metered results. Applying the EASEE panel solution to the test site building with this configuration provides a 14.6% reduction in energy use across the year or 35.8 kWh/m^2 per annum.
2. **Simulation set 2:** The construction U-value for this configuration was calculated in the VE. Material properties had to be assumed from the VE material database. The U-value of the construction 1.93 W/m^{2}K. Baseline results are 13.3% greater than the metered results. Applying the EASEE panel solution to the test site building with this configuration provides a 22.4% reduction in energy use across the year or 61.6 kWh/m^2 per annum.
3. **Simulation set 3:** The construction U-value for this configuration was calculated in the VE. Material properties had to be assumed from the VE material database. The U-value of the construction 2.184 W/m^{2}K. Baseline results are 15.99% greater than the metered results. Applying the EASEE panel solution to the test site building with this configuration provides a 25.6% reduction in energy use across the year or 69.7 kWh/m^2 per annum.

The simulation of heating energy for the baseline situation in Simulation set 1 is more similar to the actual metered value, and thus this set has been considered as the most realistic one. In view of this, the savings in heating energy predicted by the simulations due to the installation of the EASEE panels are about 14.6%. If this is kept over one year, the expected energy savings estimated through Retrofitting Planner are equal to 35,765 kWh/y corresponding to a reduction of 11% for the whole year (see Figure 17 below).



	Jan 01-31	Feb 01-28	Mar 01-31	Apr 01-30	May 01-31	Jun 01-30	Jul 01-31	Aug 01-31	Sep 01-30	Oct 01-31	Nov 01-30	Dec 01-31
Total energy (KWh) Baseline	46865.8	38141.4	29659.6	22431.1	16653.2	16338.6	19071.3	18183.7	15941.8	19915	32235.9	42928
Total energy (KWh) Retrofit	38812.5	31854.1	25688.9	20152.6	16458.9	16265	18665	18085.5	16022.9	17837.9	27149.7	35607.4
Total energy (KWh) % Savings	17%	16%	13%	10%	1%	0%	2%	1%	-1%	10%	16%	17%

Figure 17: Energy consumption evaluation from January to December.

The corresponding economic savings are described in section 3.2.1 later on.

2.2.1.3 Thermal comfort evaluation

The impact on thermal comfort of the retrofitting through the EASEE external prefabricated panels has been evaluate again through the IES VE software by simulating the air temperature, mean radiant temperature and dry resultant temperature before and after the intervention. The results are shown below.

Air Temperature

For the entire building, as can be seen in Figure 18 (Baseline, Retrofit) the air temperature has increased showing the improvement in the thermal performance of the building envelope from the retrofit solution. The minimum air temperature value has been improved from 12.3°C to 13.4°C. The maximum air temperature has slightly decreased from 28.2°C to 27.9°C. While the mean air temperature for the entire building has increase from19.4°C to 19.7°C.

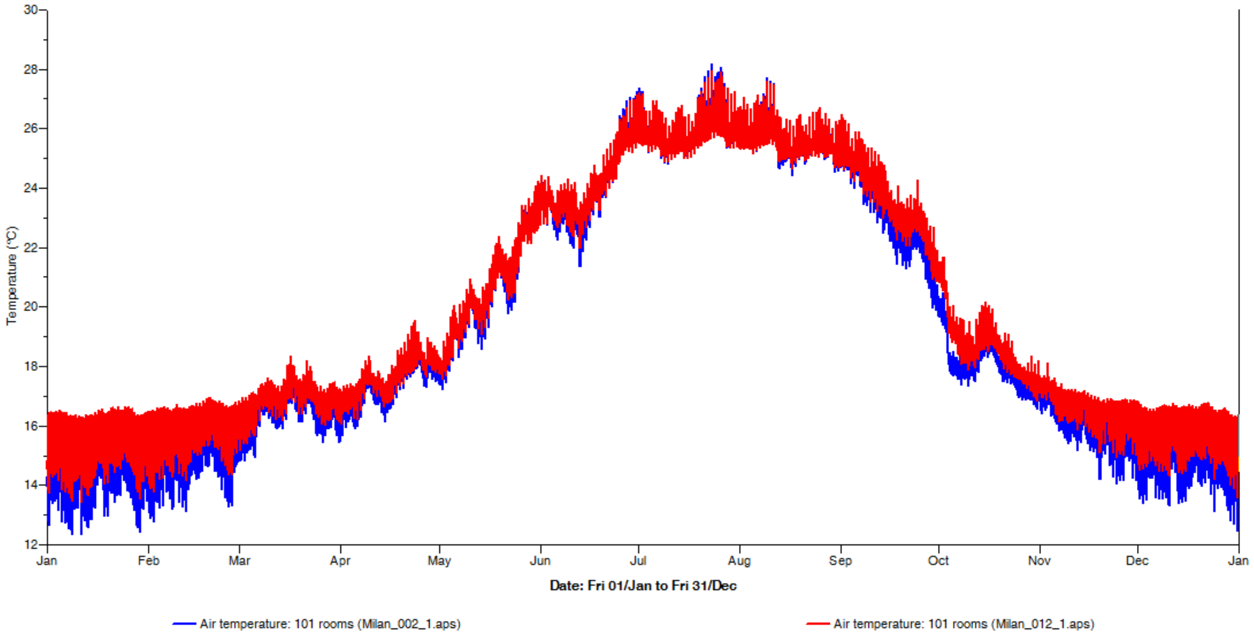


Figure 18: Air Temperature for the whole Italian Demo Building (Baseline, Retrofit)

The change in air temperature for the entire building can be seen in the range test below which shows the amount of hours the air temperature was in a particular temperature range for the entire building.

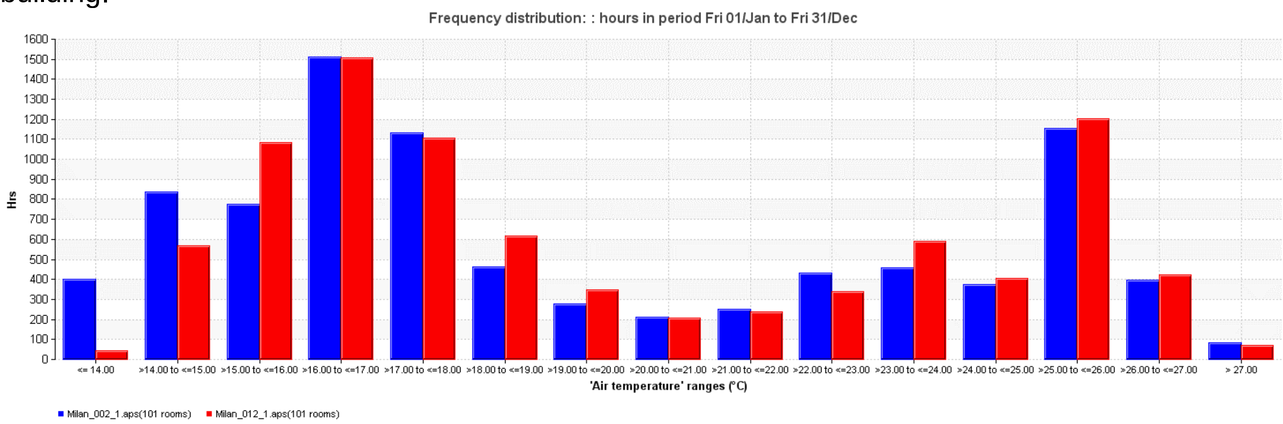


Figure 19: Amount of hours the air temperature was in a particular temperature range for the entire building

An example of the improvement air temperature from retrofitting can be seen in the chart below which displays the combined air temperature in Apartment 1 (Baseline, Retrofit, Heating Setpoint) on January 4th, when the worst case external temperature occurs.

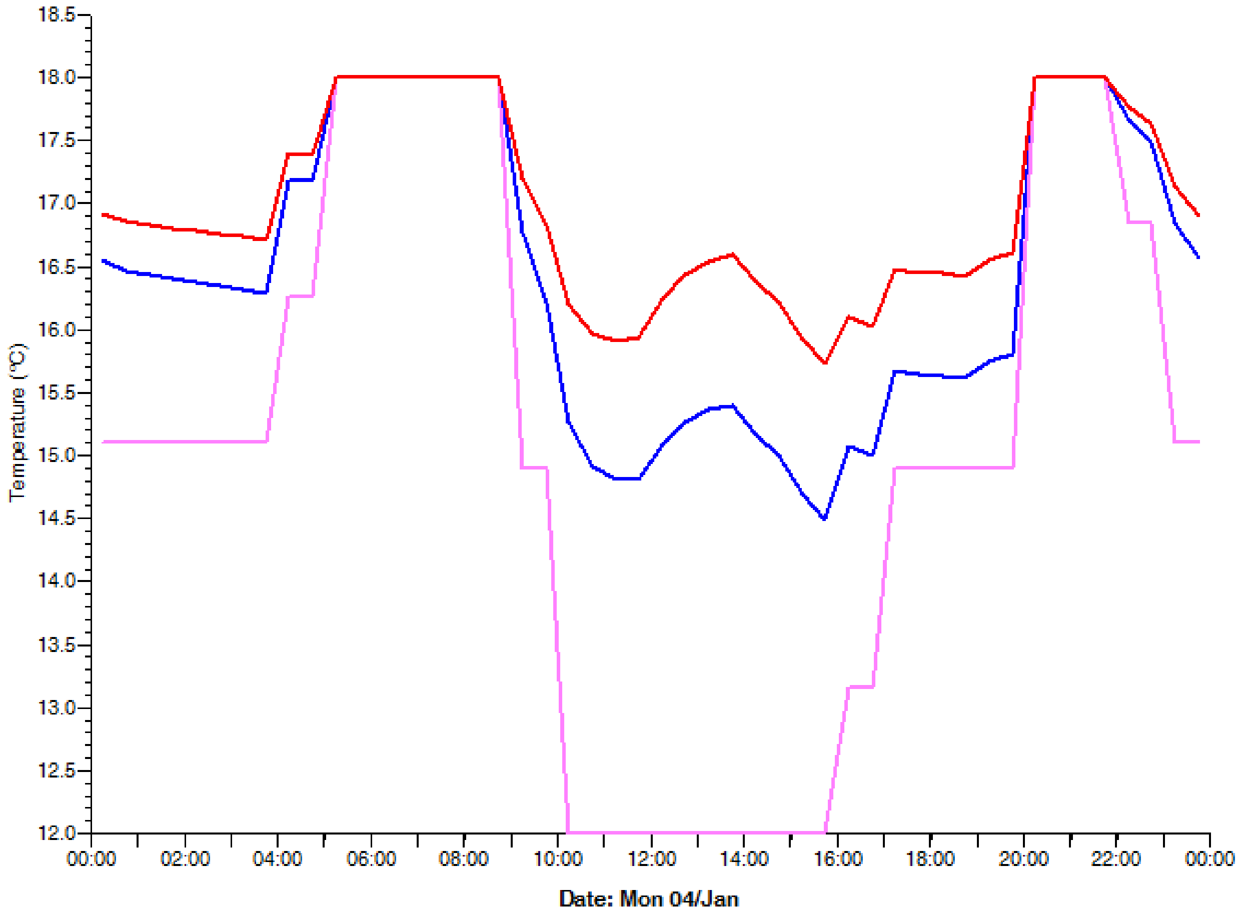


Figure 20: combined air temperature in Apartment 1 (Baseline, Retrofit, Heating Setpoint) on January 4th

The improvement in the building envelope thermal performance can be clearly seen. The minimum air temperature occurring has improved from 14.5°C to 15.7°C, while the maximum unconditioned air temperature has also increased from 15.4°C to 16.6°C.

Mean Radiant Temperature

For the entire building, as can be seen in Figure 21 (Baseline, Retrofit) the mean radiant temperature has increased showing the improvement in the thermal performance of the building envelope from the retrofit solution. The minimum mean radiant temperature value has been improved from 12.2°C to 13.4°C. The maximum mean radiant temperature has decreased from 27.9°C to 27.7°C.

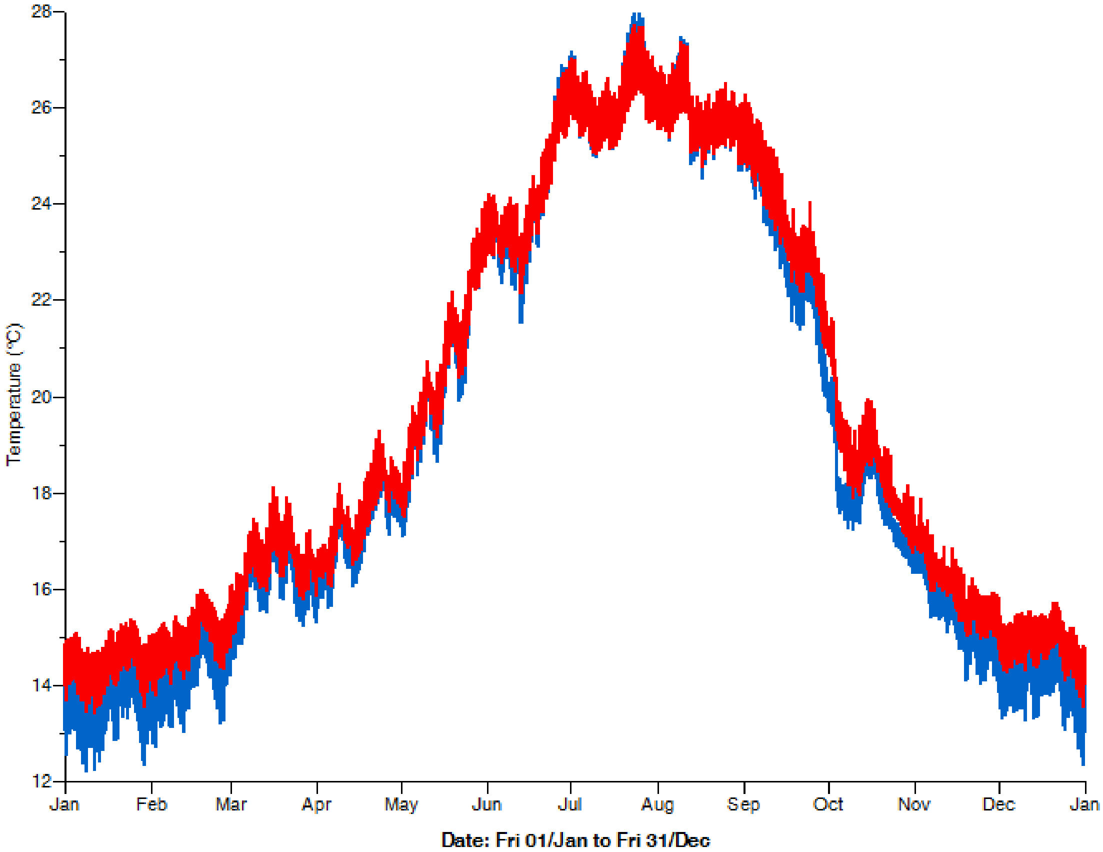


Figure 21: Mean radiant temperature for the whole building (Baseline, Retrofit)

An example of the improvement in mean radiant temperature can be seen from the chart below which displays the mean radiant temperature in Apartment 1 (Baseline, Retrofit, Heating Setpoint) on January 4th, when the worst case external temperature occurs.

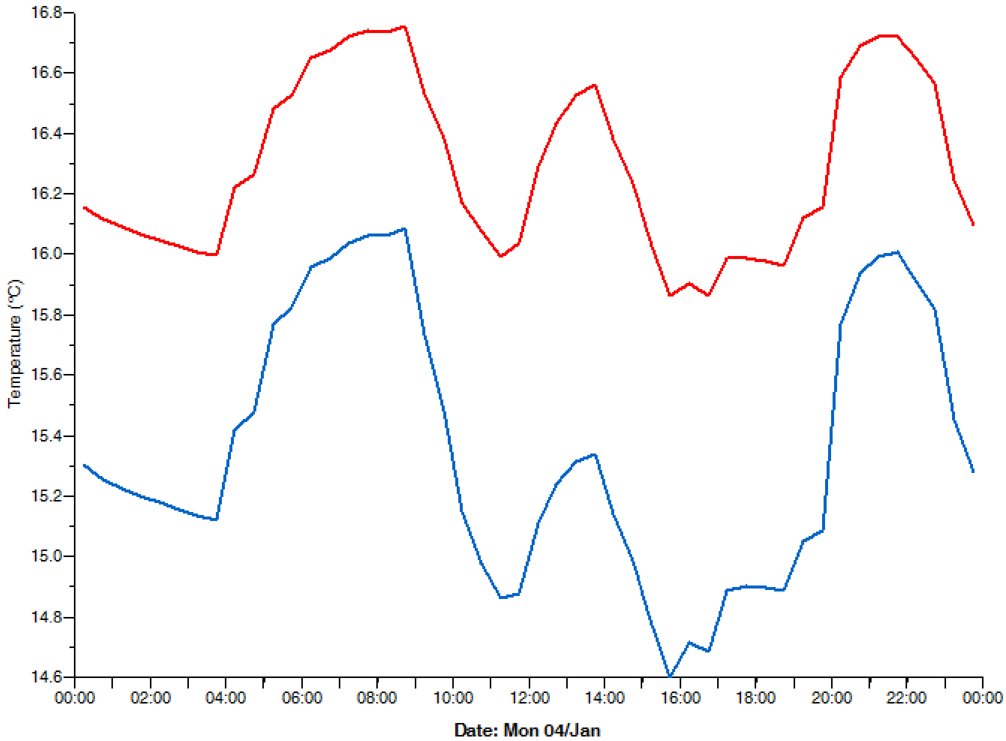


Figure 22: Mean radiant temperature for apartment 1 on January 4th

The improvement in the building envelope thermal performance can be clearly seen. The minimum mean radiant temperature occurring has improved from 14.6^0 C to 15.8^0 C, while the maximum mean radiant temperature has also increased from 16.1^0 C to 16.7^0 C.

Dry resultant temperature

For the entire building, as can be seen from the figure below (Baseline, Retrofit) the dry resultant temperature has increased showing the improvement in the thermal performance of the building envelope from the retrofit solution. The minimum dry resultant temperature value has been improved from 12.3°C to 13.4°C. The maximum dry resultant temperature has slightly decreased from 28.1°C to 27.8°C.

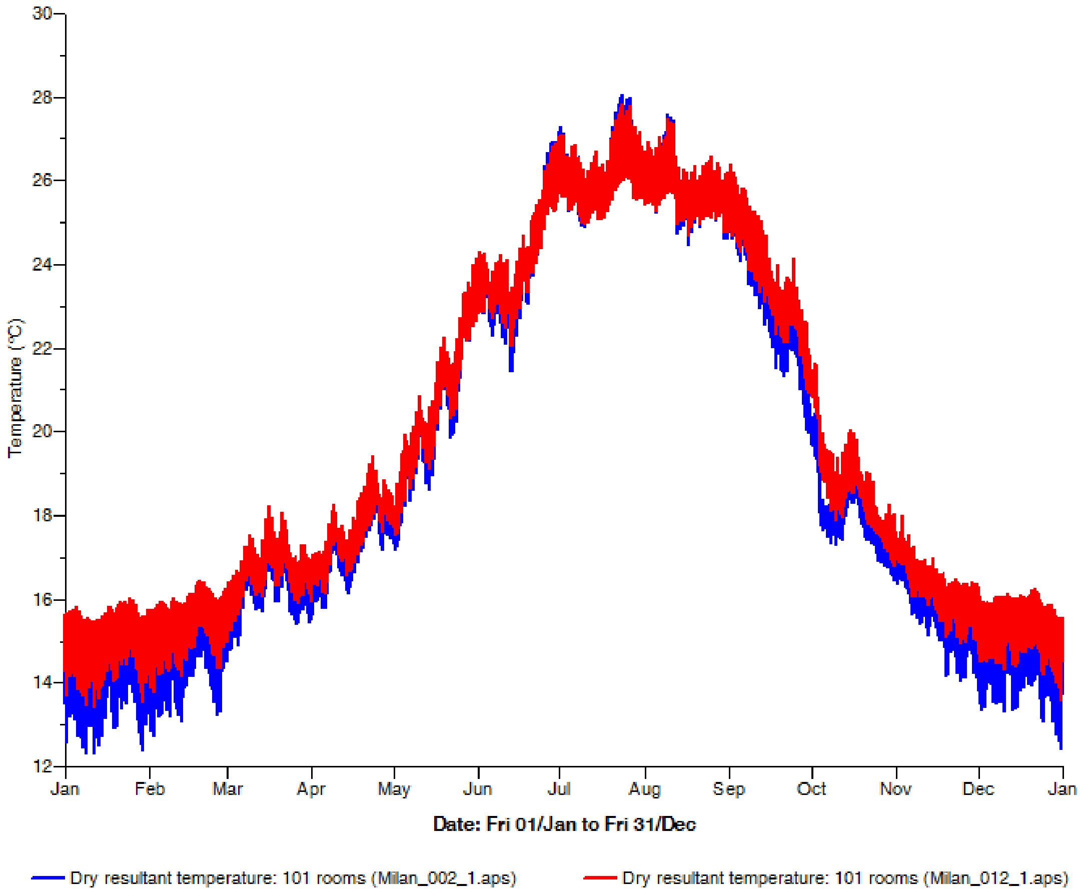


Figure 23: Dry resultant temperature for the whole building (Baseline, Retrofit)

The change in dry resultant temperature for the entire building can be seen in the range test below which shows the amount of hours the dry resultant temperature was in a particular temperature range for the entire building.

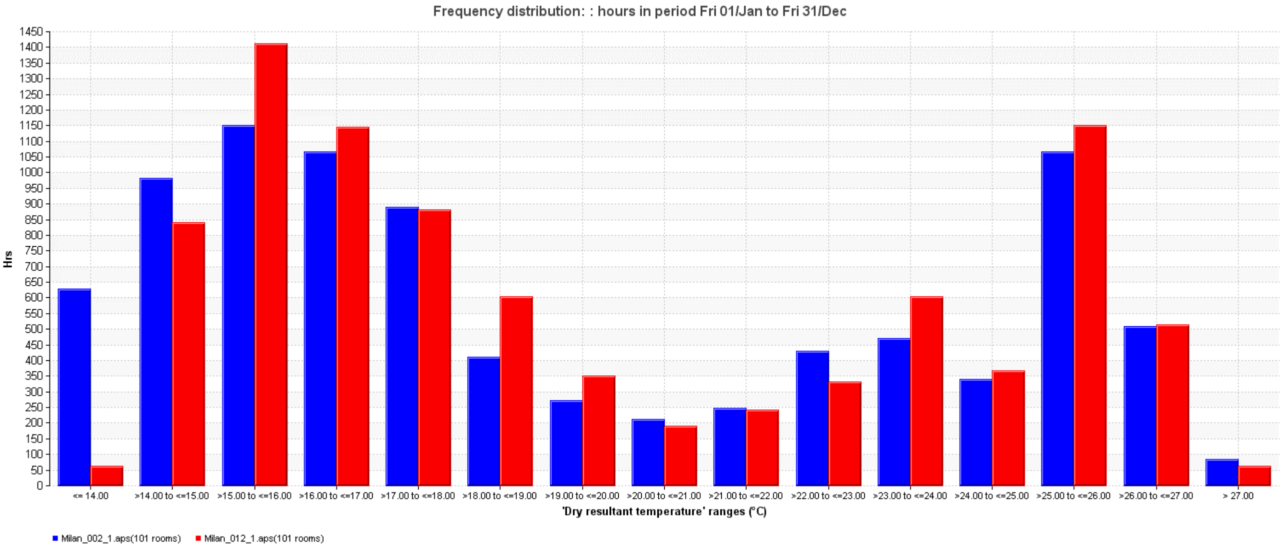


Figure 24: Amount of hours the dry resultant temperature was in a particular temperature range for the entire building

An example of the improvement dry resultant temperature from retrofitting can be seen in the chart below which displays the dry resultant temperature in Apartment 1 (Baseline, Retrofit, Heating Setpoint) on January 4th, the day when the worst case external temperature occurs.

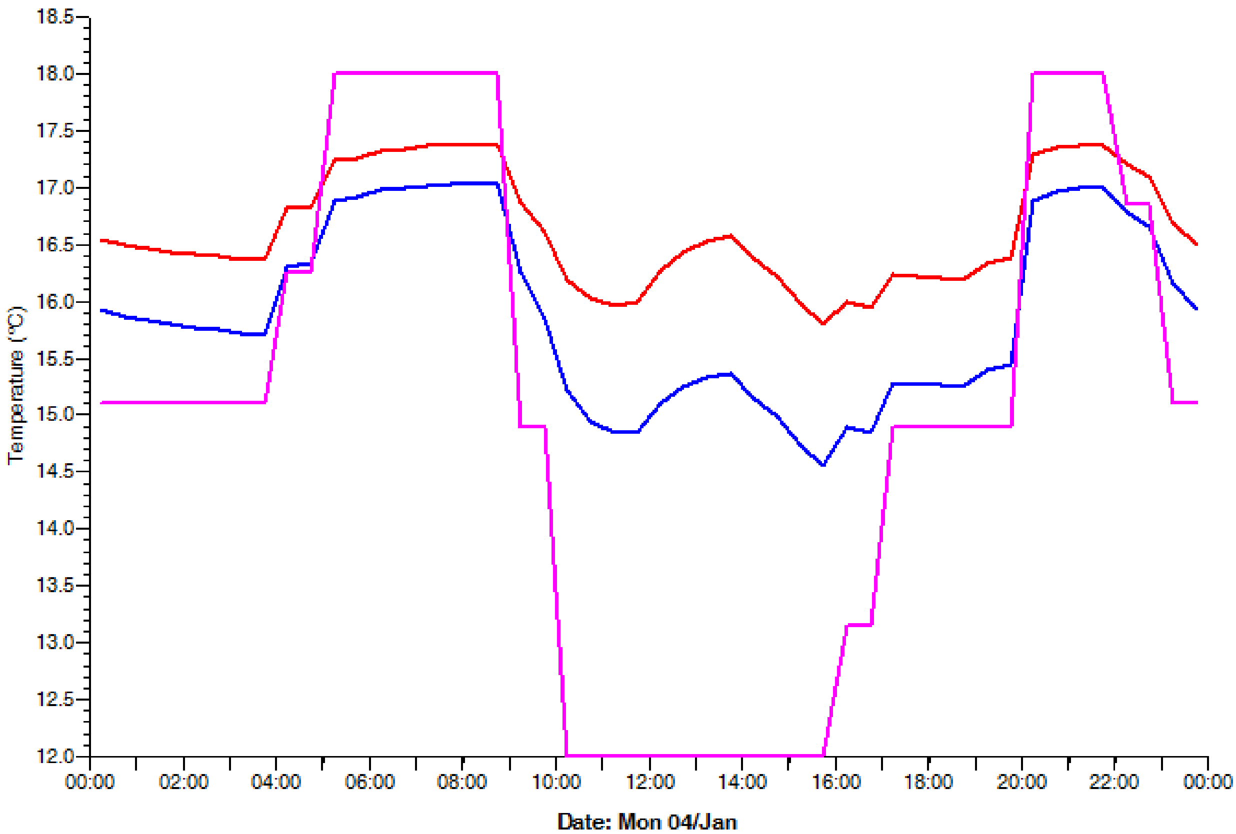


Figure 25: Dry resultant temperature in Apartment 1 (Baseline, Retrofit, Heating Setpoint) on January 4th

The improvement in the building envelope thermal performance can be clearly seen. The minimum dry resultant temperature occurring has improved from 14.5°C to 15.8°C, while the maximum unconditioned air temperature has also increased from 15.3°C to 16.6°C.

ISO comfort indices: Predicted Mean Vote (PMV) & Percentage of People Dissatisfied (PPD)

For the entire building, as can be seen in Figure 26 (Baseline, Retrofit) the PMV has been improved. The minimum PMV value has been improved from -1.70 to -1.49, while the maximum PMV has also improved from 1.50 to 1.45.

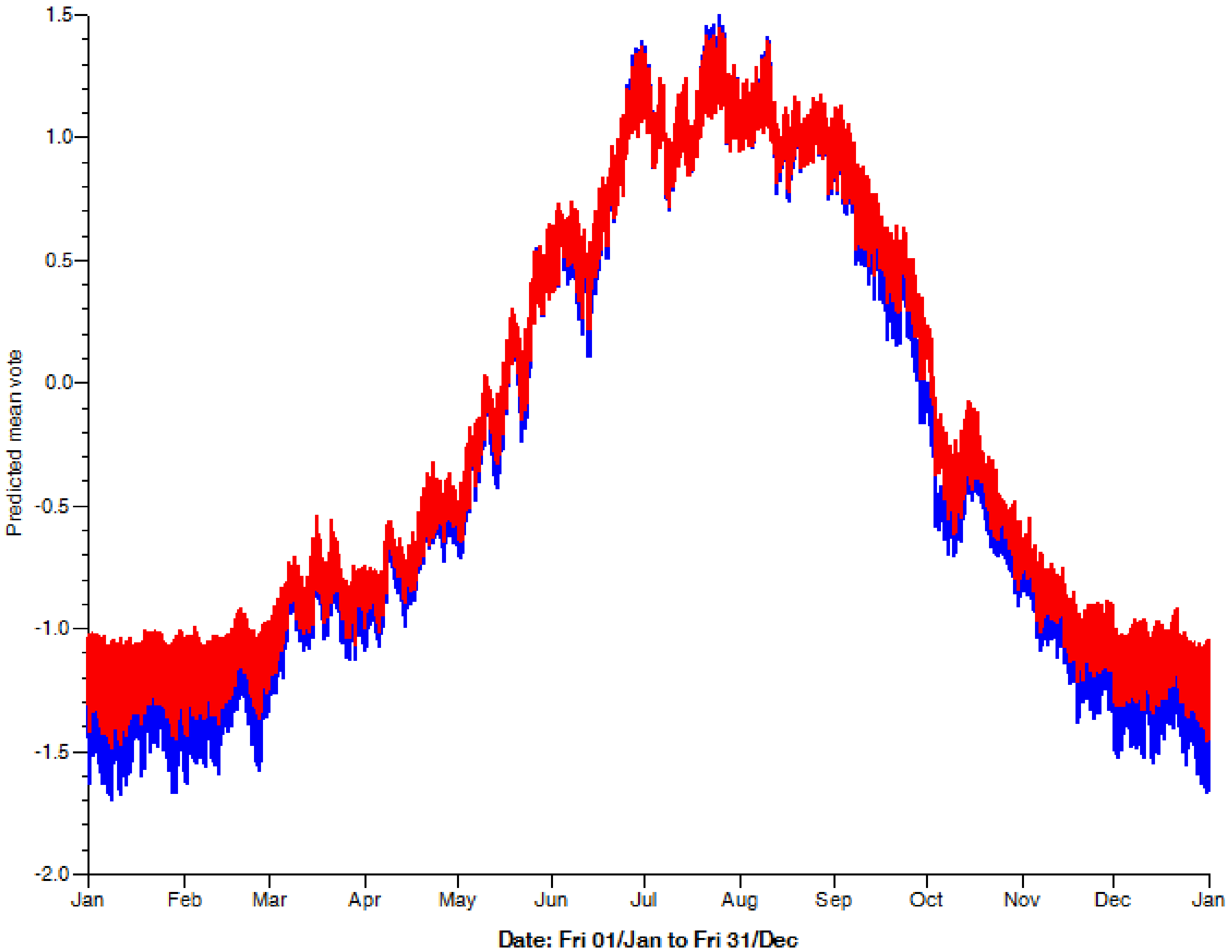


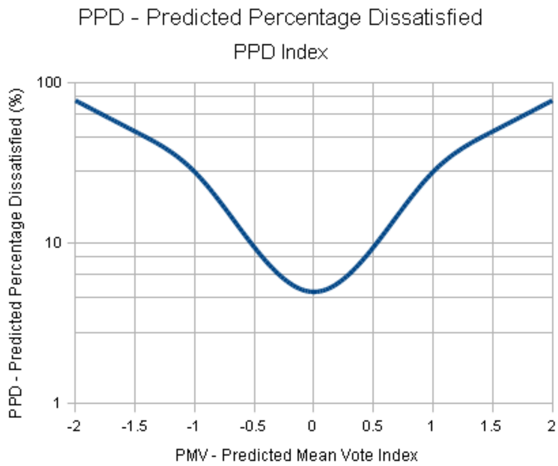
Figure 26: PMV for the whole Italian Demo Building (Baseline, Retrofit)

Simulations have been carried out for each of the 6 apartments of the building and for all of them the minimum and maximum PMV has improved after retrofitting.

Predicted Percentage Dissatisfied (PPD) index is a quantitative measure of the thermal comfort of a group of people at a particular thermal environment.

PPD is calculated from PMV using the equation:

$$PPD = 100-95*\exp(-0.03353*PMV^4 - 0.2179*PMV^2)$$



At least approximately 5% of people in a group will be dissatisfied with the thermal climate, even with PMV = 0.
The combined PPD for the entire building can be seen in Figure 27 (Baseline, Retrofit). This shows a clear reduction in the PPD across the entire building. A synopsis of the above chart shows an increase of the minimum PPD 5.42% to 5.60%. A reduction in the maximum PPD value from 58.54% to 48.39% and an overall reduction in the mean PPD value from 24.79% to 22.87% can be seen.

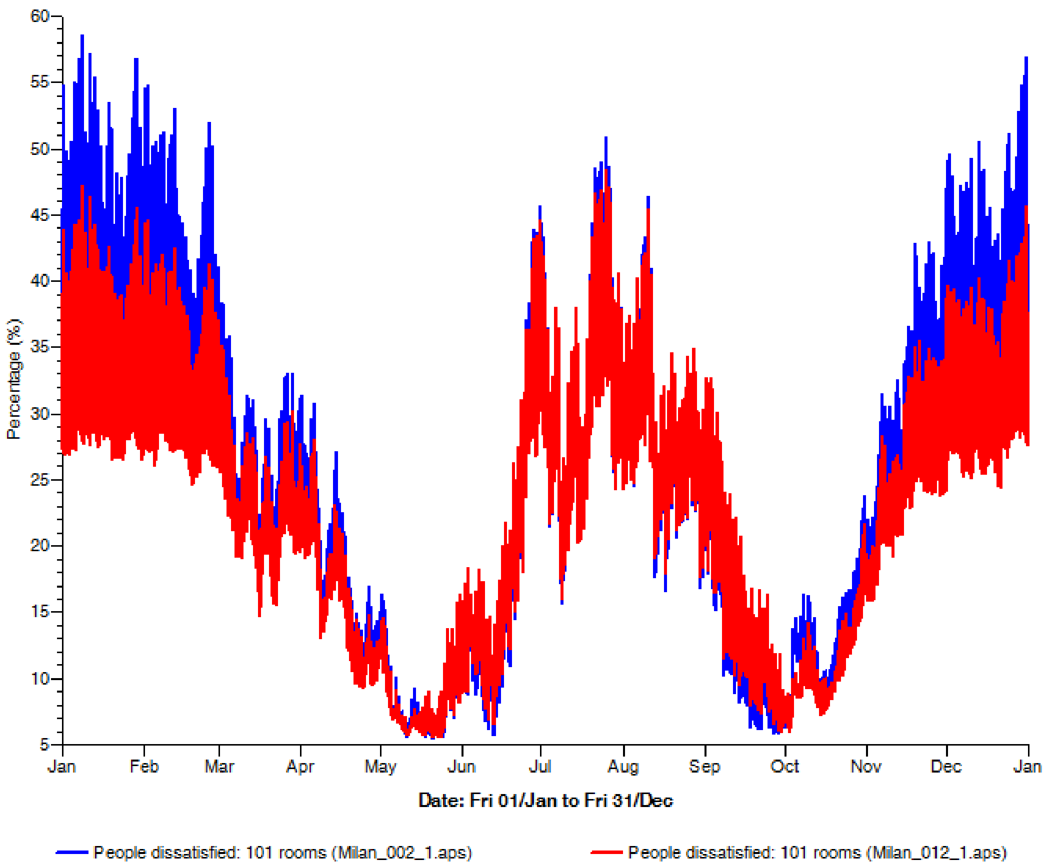
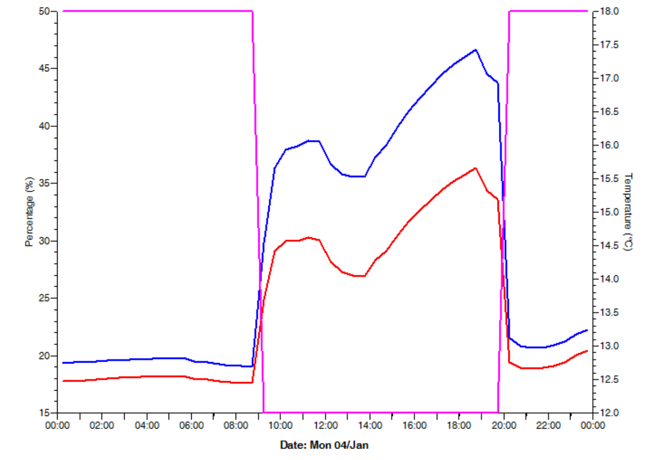
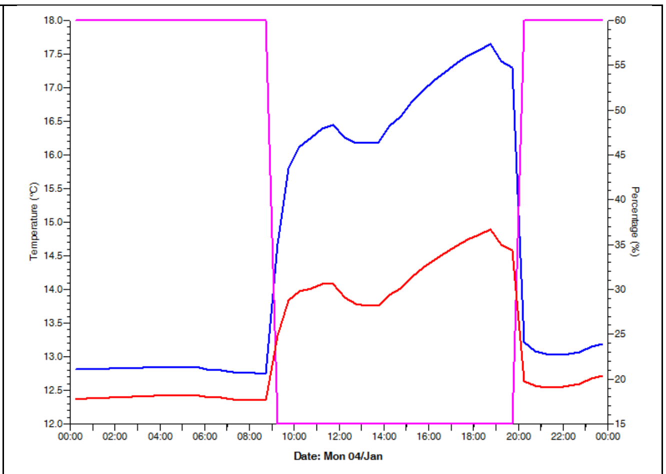


Figure 27: PPD for the Italian Demo Building (Baseline, Retrofit)

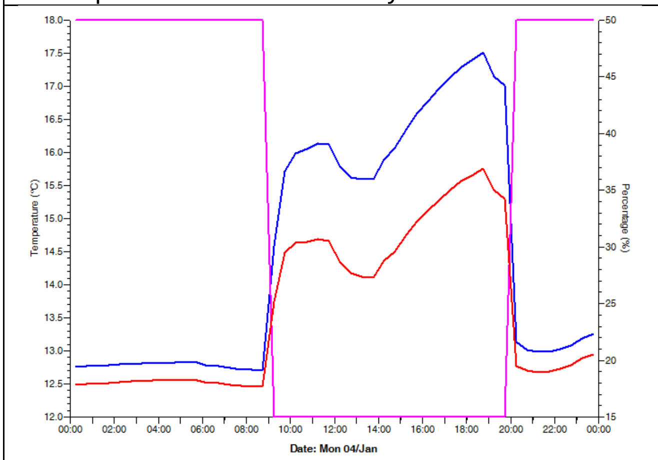
However for PPD looking at the entire building as a whole does not provide a fair reflection on the improvement seen through applying the retrofit solution. This is due to the PPD including times when the building is unconditioned (times where theheating system is off). Better examples of the improvements in comfort obtained by the retrofit solution being applied can be seen in the charts below representing the main bedroom in each apartment on the worst case day for external temperature.



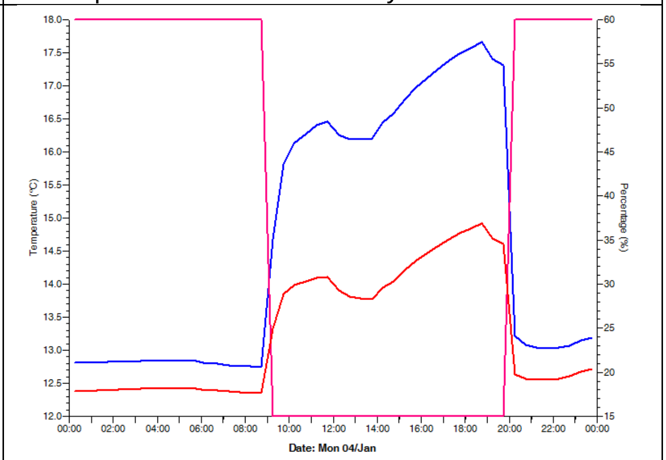
PPD apartment 1- 4th of January



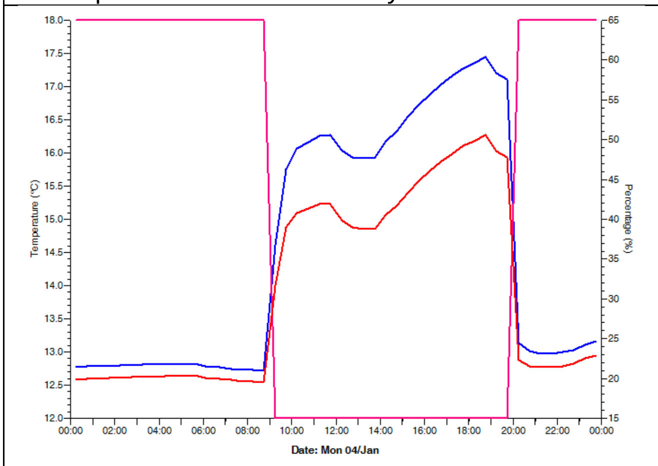
PPD apartment 2- 4th of January



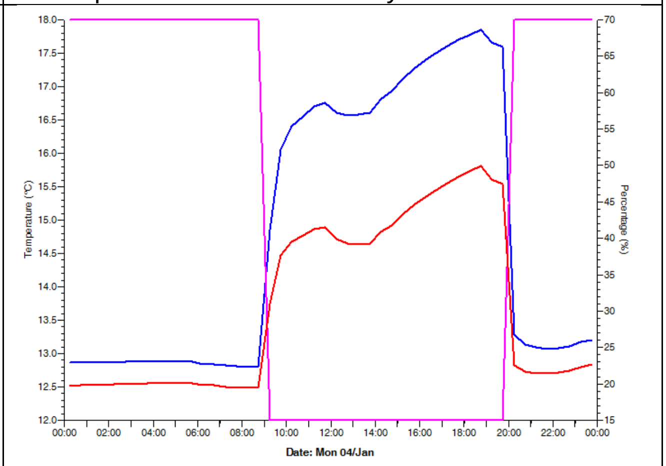
PPD apartment 3- 4th of January



PPD apartment 4- 4th of January



PPD apartment 5- 4th of January



PPD apartment 6- 4th of January

Figure 28 PPD Italian Demo at apartment level-04th January (Baseline, Retrofit, Heating Setpoint)

The PPD for the main bedroom in each apartment can be seen above in Figure 28. This shows a clear reduction in the PPD at all times but if one looks at the times when the room is conditioned a reduction in the minimum and in the maximum PPD value between 2% and 4% can be seen.

As a further confirmation of the improvement in comfort, the heat flux and the surface temperature level has been also measured, and they are shown in the following Figure 29 and Figure 30.

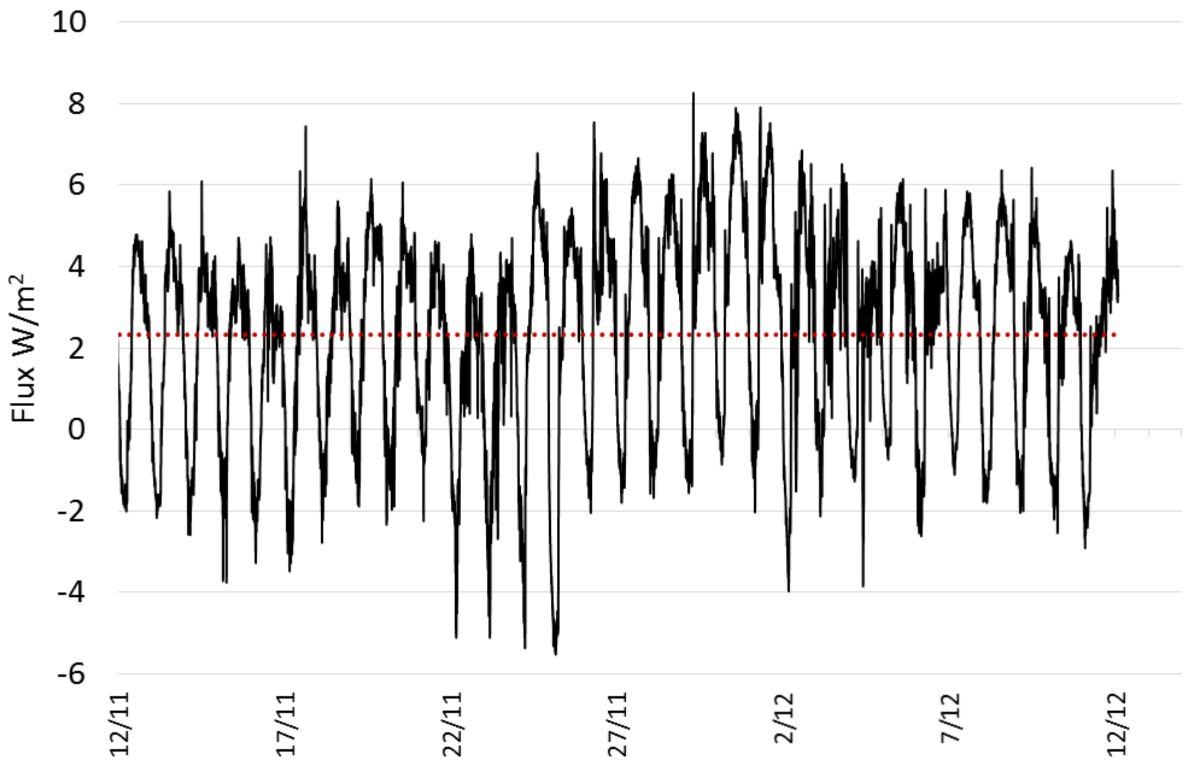


Figure 29: Heat flux [W/m^2] over the monitoring period after retrofitting

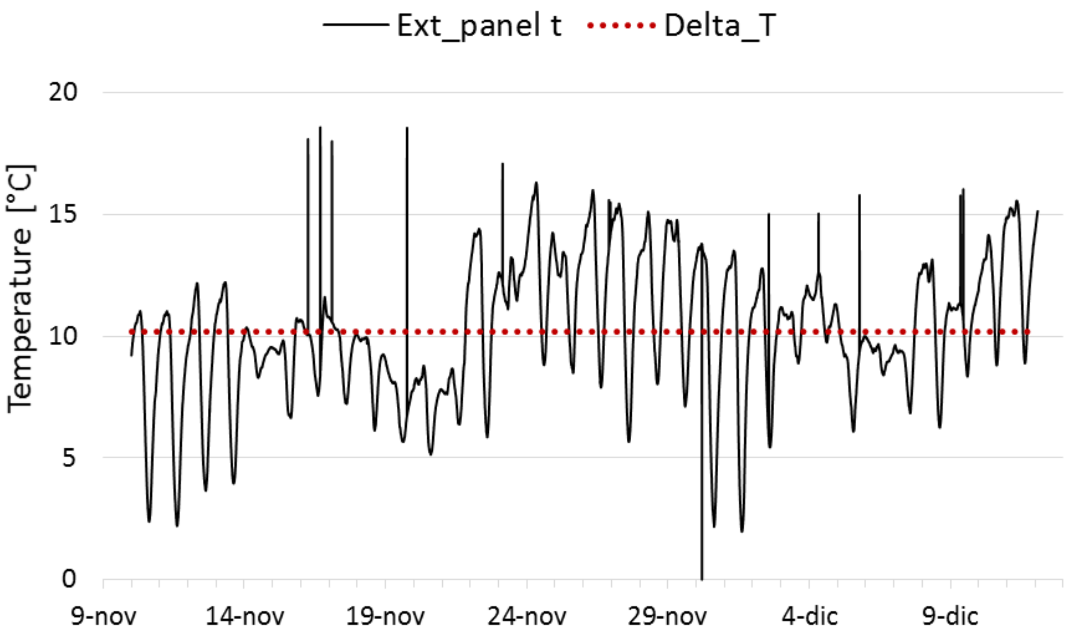


Figure 30: Surfaces temperature level: in black the external surface temperature of the panel and in red the temperature difference between inside and outside surface during the monitoring campaign.

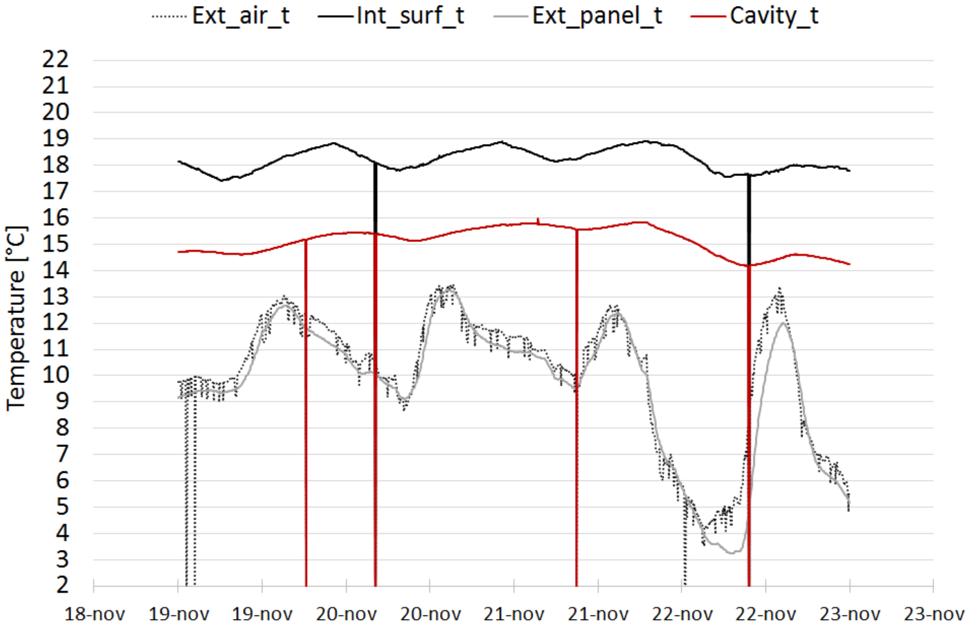


Figure 31: The internal surface temperature of the wall shows a reduced temperature variation (night and day) due to the increase thermal insulation

The monitoring campaign shows an improved thermal internal behaviour due to the increased efficiency of the building envelope. As shown in detail by the figure below the combination between thermal mass and thermal insulation allowed the reduction of the inner temperature variation during the complete cycle of thermal charge and discharge of the envelope.
The data has been supported by the information collected by informal interview of the owner. People were satisfied by the renovation from both thermal comfort and aesthetics point of view. Moreover in some case a malfunctioning of the heating systems and especially of the heaters reduced the perceived thermal comfort.

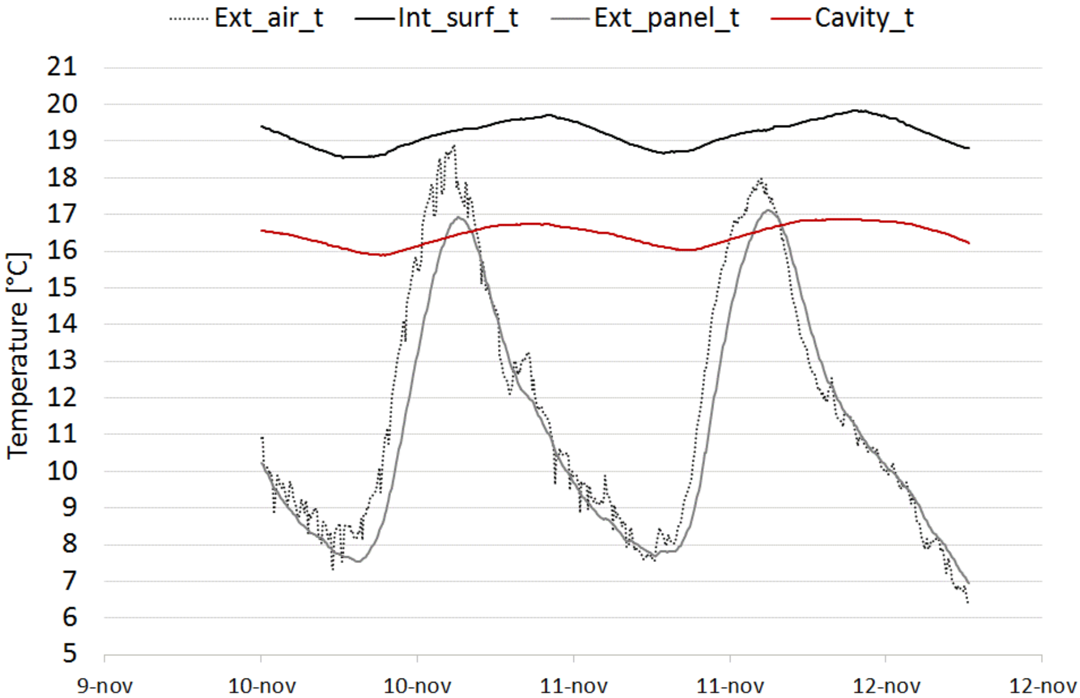
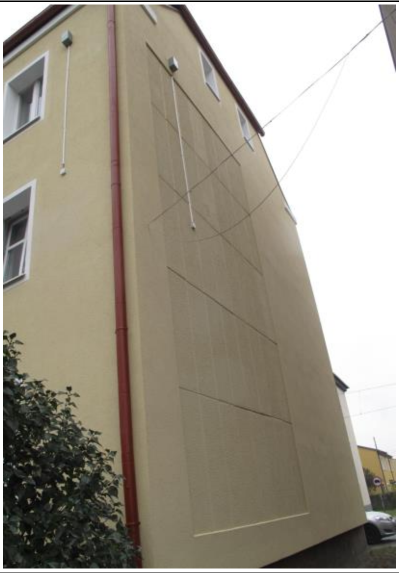


Figure 32: The temperature level over two day monitoring on November 2015

2.2.2 Polish demo building

 <	
• Multi-storey building (3 floors, 6 apartments) in Gdansk • Age of construction: 1950 • Owner: Municipality • (Building under protection of Cultural Heritage Conservator (CHC))	Installation of 40 EASEE panels (50cm x150cm x12,4cm) on the South East Façade while the rest of the building has been retrofitted through traditional system (ETICS)

2.2.2.1 Energy performance evaluation

<u>Comparison of façade temperatures, outer surface reflectance and heat flow through the data from monitoring systems</u>

As first step before calculating the retrofitting impact of the intervention, the aggregated thermal profiles for façade before/after thermal improvement have been observed after verifying if the selected period was representative for thermal retrofitting efficiency.

Indeed, the climate impact was observed through a weather station since October 2013. As the novel thermal panels were assembled late 2015 (autumn), only the impact of insulation during autumn–winter time was evaluated, i.e., when the heat flow is directed from house to air and insulation impacts onto heating costs. To identify the impact of thermal retrofitting on the building, the period October 1st – January 31st was chosen. Observed solar irradiation was modified due to the building positioning against sun and neighbourhoods reflection in line with simplified formula:

$$I_t^* = I_t * [C(\theta, \varphi)^{SE120} + r * C(\theta, \varphi)^{NW300}]$$

where

I_t – direct sun illumination measured by weather station
$C(\theta, \varphi)^{SE120}$ – coefficient for sun position against south-east wall
r – refraction coefficient from neighbourhood building
$C(\theta, \varphi)^{NW300}$ – coefficient for sun position against north-west wall

The direct building shading as well as diffused reflection was not considered. Solar irradiation for 2014 and 2015 has been compared (see Figure 33), the ambient temperature of air is reported in Figure 34, humidity in Figure 35 and wind velocity in Figure 36.

Demo Gdańsk: 01.10.2014-31.01.2015	Demo Gdańsk: 01.10.2015-31.01.2016

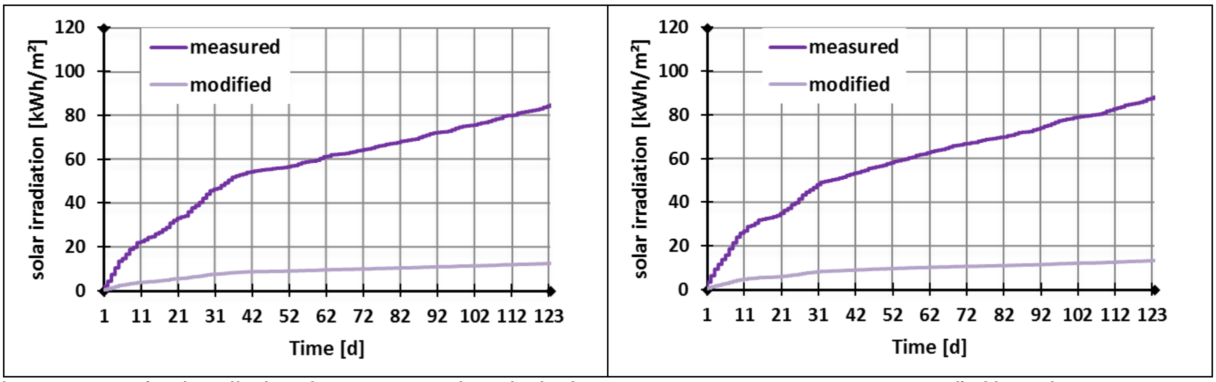


Figure 33: Solar irradiation for compared period of year: 01.10.2014—31.01.2015 (left) and 01.10.2015 ---31.01.2016 (right)

Demo Gdańsk: 01.10.2014-31.01.2015	Demo Gdańsk: 01.10.2015-31.01.2016

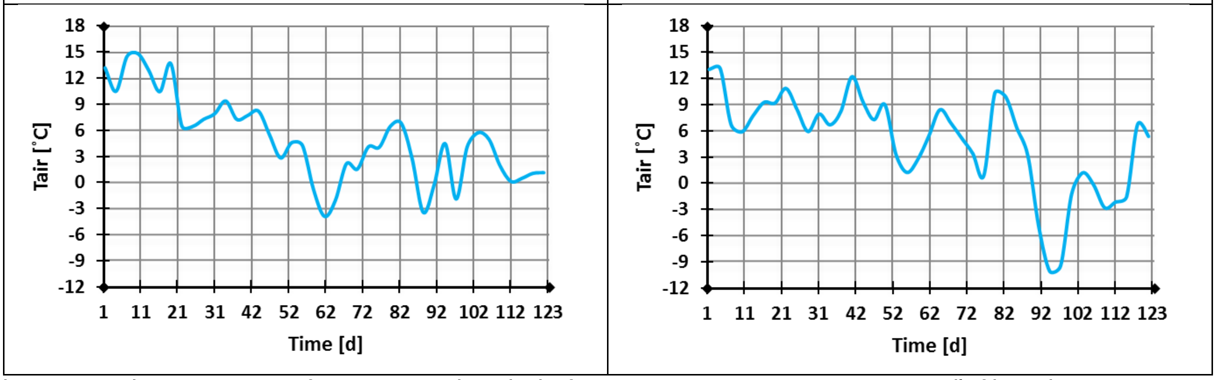


Figure 34: Air temperature for compared period of year: 01.10.2014—31.01.2015 (left) and 01.10.2015 ---31.01.2016 (right).

Demo Gdańsk: 01.10.2014-31.01.2015	Demo Gdańsk: 01.10.2015-31.01.2016

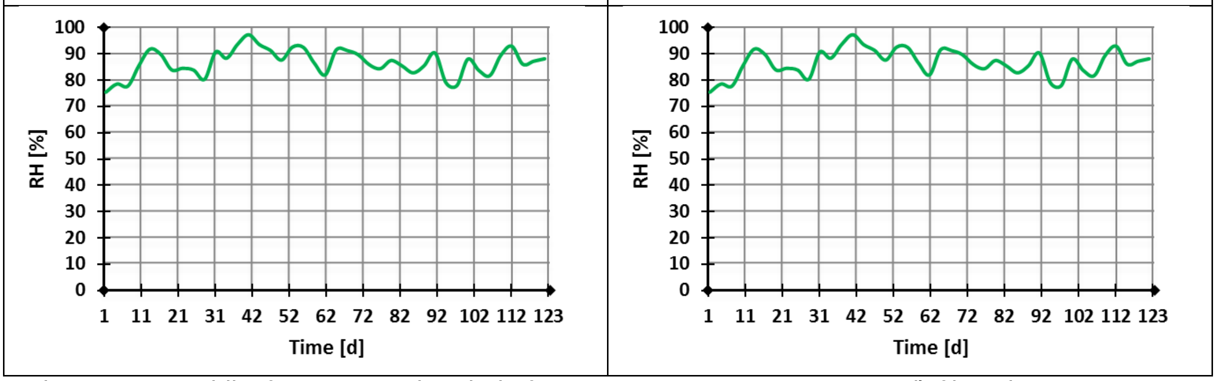


Figure 35: Humidity for compared period of year: 01.10.2014—31.01.2015 (left) and 01.10.2015 ---31.01.2016 (right)

Demo Gdańsk: 01.10.2014-31.01.2015	Demo Gdańsk: 01.10.2015-31.01.2016

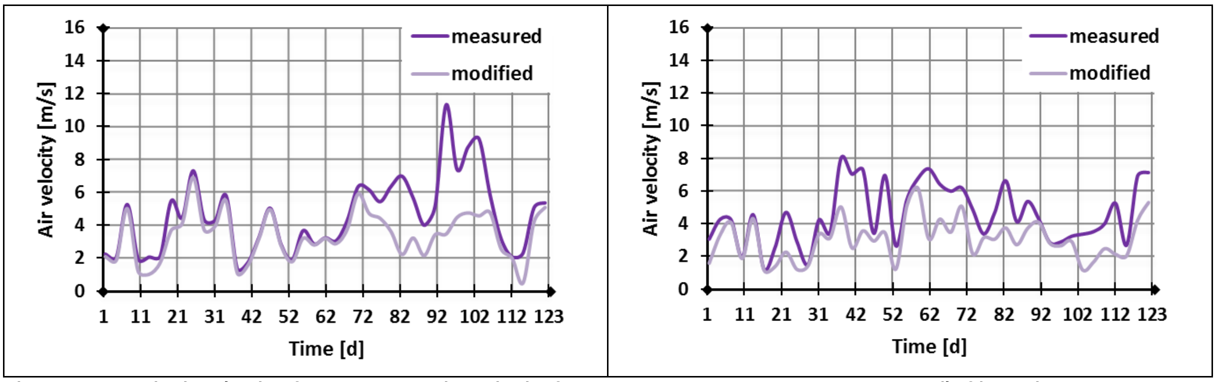


Figure 36: Wind velocity for compared period of year: 01.10.2014—31.01.2015 (left) and 01.10.2015 --- 31.01.2016 (right)

The weather station was mounted on the roof and therefore in order to extrapolate the wind velocity acting on the SE wall the air flow velocity was modified according to the following formula:

$$V^{*} = V * cos\big(0.5 * (\theta - 120°)\big)$$

where:
V – wind velocity measured on the weather station
θ – wind direction measured bythe weather station

As a conclusion, the selected period seemed to be representative for thermal retrofitting efficiency. Indeed, the weather conditions by average were for the considered period almost the same: average air temperature for 01.10.2014-31.01.2015 was 5,05 °C and for 01.10.2015-31.01.2016 was 4,85 °C. Also the average wind velocity, important for heat transport conditions, was the same i.e. 4,56m/s. However it should be noticed, that on the break of months December 2015-January 2016 the temperature dropped significantly.
In order to identify the retrofitting impact, temperatures on the inner and outer wall surfaces were collected (see Figure 37 where numbers 1, 2, 3, 4 correspond to the numbers of sensors location, in particular sensor 3 and 1 are referred to the traditional retrofitting (respectively 1st and 2nd floor) while sensors 4 and 2 to EASEE retrofitting (respectively 1st and 2nd floor).

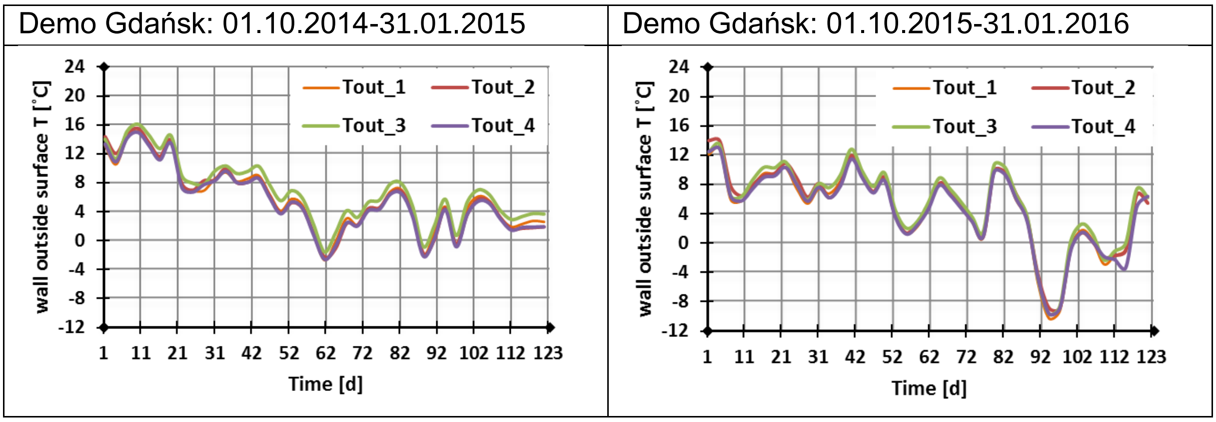


Figure 37: Temperature on the outer surface of wall for compared period of year: 01.10.2014—31.01.2015 (left) and 01.10.2015 --- 31.01.2016 (right)

The façade temperatures are following the air temperature with local differences up to 12K and mean value for period up to 0,5 K. That is originated from solar irradiation of wall surface and by heat accumulation effect in the façade.
When comparing NE façade (retrofitted with traditional systems, ETICS) with SE (retrofitted through the EASEE prefabricated panels), the SE facade keeps ca 1-2 K higher temperature than NE both before and after retrofitting, as shown in Figure 38:.

As the influence of cold loft was meaningful (cold ceiling), the temperature on the inner walls of façade had to be observed separately for second and first floor.

Demo Gdańsk: 01.10.2014-31.01.2015	Demo Gdańsk: 01.10.2015-31.01.2016

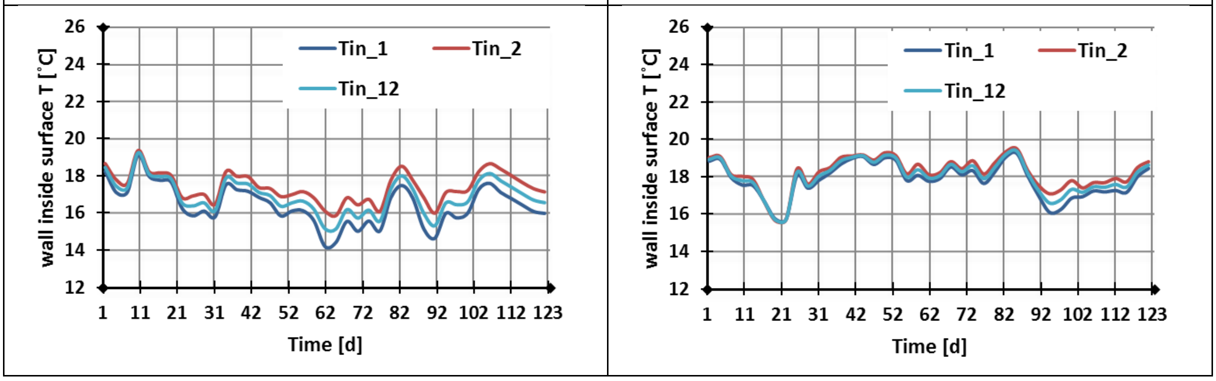


Figure 38: Temperature on the inner surface of wall of second floor for compared period of year: 01.10.2014—31.01.2015 (left) and 01.10.2015 --- 31.01.2016 (right). Sensor 12 represents the average value.

When the second floor is considered (cold ceiling), the thermal improvement was estimated by average 1 K observed easily on the inner surface of the wall for period October – November, when heating program was not changed. The effect of different irradiation from sun may be observed as difference between temperatures T_{in1} on NE (colder wall) and T_{in2} on SE (warmer wall). That effect is partly eliminated with thermal retrofitting (see Figure 38 – right panel), with the exception of days when a difference larger than 20K between outer and inner temperature is observed.

Demo Gdańsk: 01.10.2014-31.01.2015	Demo Gdańsk: 01.10.2015-31.01.2016

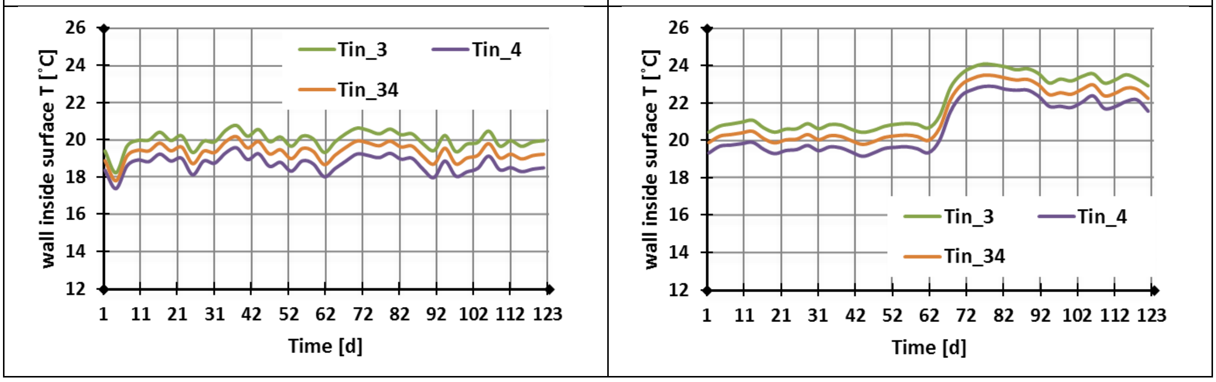


Figure 39: Temperature on the inner surface of wall of first floor for compared period of year: 01.10.2014—31.01.2015 (left) and 01.10.2015 --- 31.01.2016 (right).

The first floor has more stable thermic conditions. The thermal improvement is estimated by 1K. The effect of different panels used for retrofitting may be observed as a difference between T_{in3} and T_{in4} kept within average 2K. The temperature increase in December is caused by higher settings on heating system.
To keep in mind the impact of real level of solar energy absorbed on the facade, the outer surface wall reflectance was measured before and after retrofitting for visible and NIR spectra of sun irradiation with spectrophotometer, as shown in Table 5. For that purpose, samples of façade plaster before retrofitting and surface of EASEE panel sample were measured. As observed below, the EASEE panels improved reflectance more than twice.

Table 5: Reflectance of facade outer face

	Demo Gdańsk: before retrofitting	Demo Gdańsk: after retrofitting
Total solar reflectance TSR	21,90%	47,05%
Visible spectra component 250nm →750nm	10,01%	19,50%
NIR spectra component 750nm← 2300nm	11,90%	27,55%

As a conclusion, the following results may be observed:

1. The second floor measurements display lower temperature inside than the one observed on the first floor; that may be an impact of the loft not being thermally retrofitted
2. The inner temperatures of the wall retrofitted with EASEE technology are slightly lower than the one with ETICS technology. The reason could be different thickness of insulation material on different panels:
    a. For the EASEE panels the thickness of EPS layer was 10 cm.
    b. For the ETICS, the thickness of EPS layer was 15 cm.
3. The reflectance impact onto building thermal retrofitting could not be evaluated as that is mainly observable during summer period.

Finally, in order to compare overall impact of thermal retrofitting concerning demo building heat balance, the heat flow into façade walls (from inner space) was compared day by day for the monitored period. The obtained retrofitting impact is referred to 1 m^2 of façade.

Demo Gdańsk: 01.10.2014-31.01.2015	Demo Gdańsk: 01.10.2015-31.01.2016

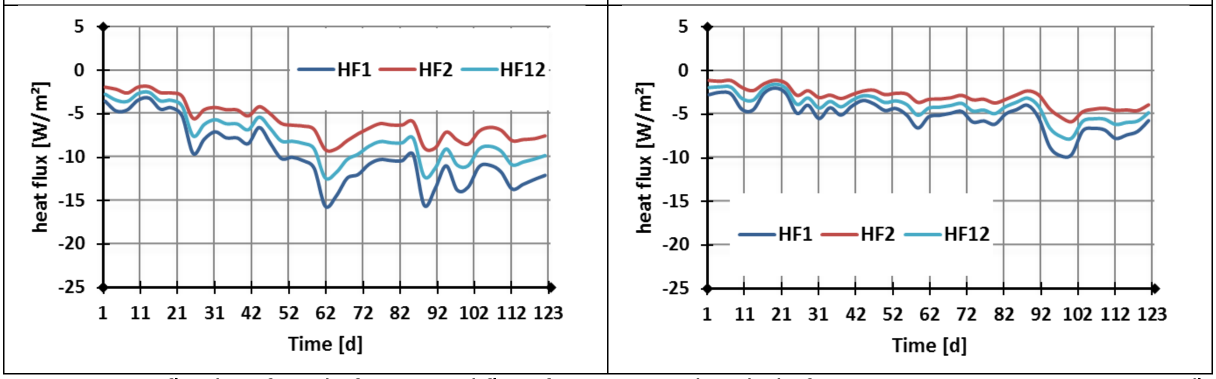


Figure 40: Heat flux into façade for second floor for compared period of year: 01.10.2014—31.01.2015 (left) and 01.10.2015 --- 31.01.2016 (right)

The impact of thermal retrofitting should be observed separately for each floor. For the second floor, the average heat flux HF12 across the façade decreased by ca 47%.

Demo Gdańsk: 01.10.2014-31.01.2015	Demo Gdańsk: 01.10.2015-31.01.2016

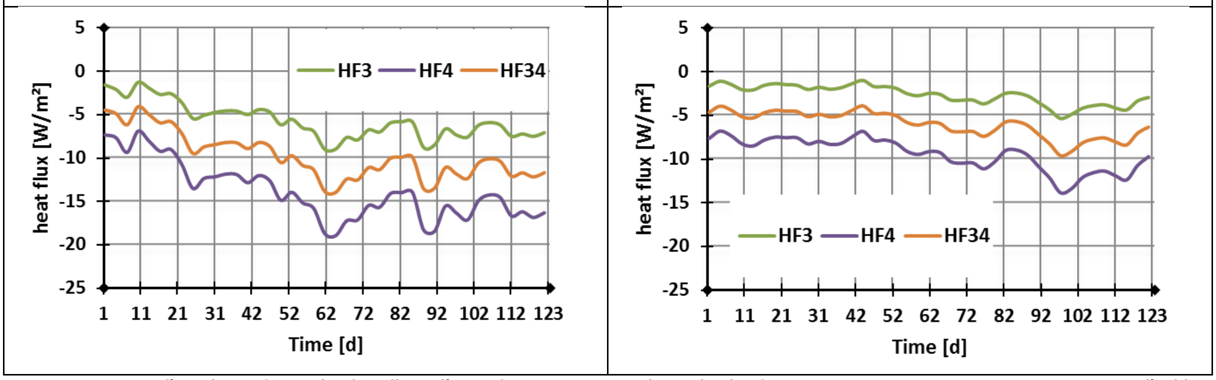


Figure 41: Heat flux into façade for first floor for compared period of year: 01.10.2014—31.01.2015 (left) and 01.10.2015 --- 31.01.2016 (right)

For the first floor, the heat flux decreased by ca 43%. The difference was probably originated from different heating conditions of the rooms.
Finally the impact of thermal retrofitting concerning heating savings was calculated. The total of heat transported across 1m^2 of facade for the monitored period was calculated and compared for not retrofitted and after retrofitting (see Figure below).

Demo Gdańsk: 01.10.2014-31.01.2015	Demo Gdańsk: 01.10.2015-31.01.2016

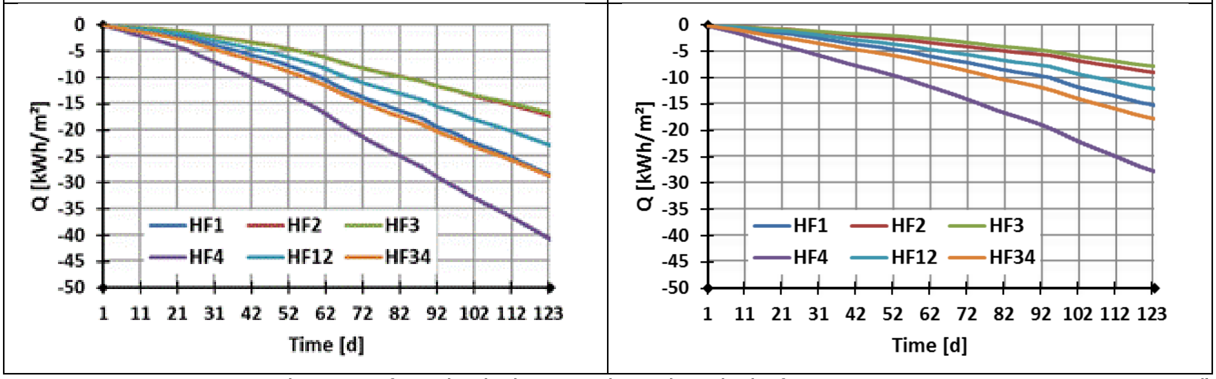


Figure 42: Heat transported across façade during monitored period of season: 01.10.2014—31.01.2015 (left) and 01.10.2015 --- 31.01.2016 (right)

Heating performance before and after retrofitting was estimated for 1 m^2 of façade before and after retrofitting – see below. The savings are obvious and economically they reach almost 45 %, when heating period (winter) is regarded. Similar savings are expected in the summer season (to be monitored after EASEE project termination by those involved in).

Table 6: Retrofitting efficiency

		Period		Savings
Sensor	Unit	01.10.2014-31.01.2015	01.10.2015-31.01.2016	p/p %
HF1 – N_E_30	[kWh/m^2]	**28.58**	**15.29**	**-46.5**
HF2 – S_E_120	[kWh/m^2]	**17.29**	**9.03**	**-47.8**
HF3 – N_E_30	[kWh/m^2]	**16.82**	**7.83**	**-53.5**
HF4 – S_E_120	[kWh/m^2]	**40.88**	**27.85**	**-31.9**
Heating costs [1]		10.2014 – 01.2015	10.2015 – 01.2016	r/r %
Gas heating [2]	[PLN/m^2]	**6.7**	**3.88**	**-42.1**
Electric heating [3]	[PLN/m^2]	**15.95**	**9.24**	**-42.1**

*) prices for Poland: 0,22 PLN/kWh; annual boiler efficiency 85%

**) prices for Poland: 0,616 PLN/kWh; annual electric radiator efficiency 100%

Thermographic survey campaign

Thermographic images have also been taken of the building before and after retrofitting and they are shown in the following figure. They clearly show an improvement in the homogeneity of the outer façade temperature after retrofitting with the EASEE panels.

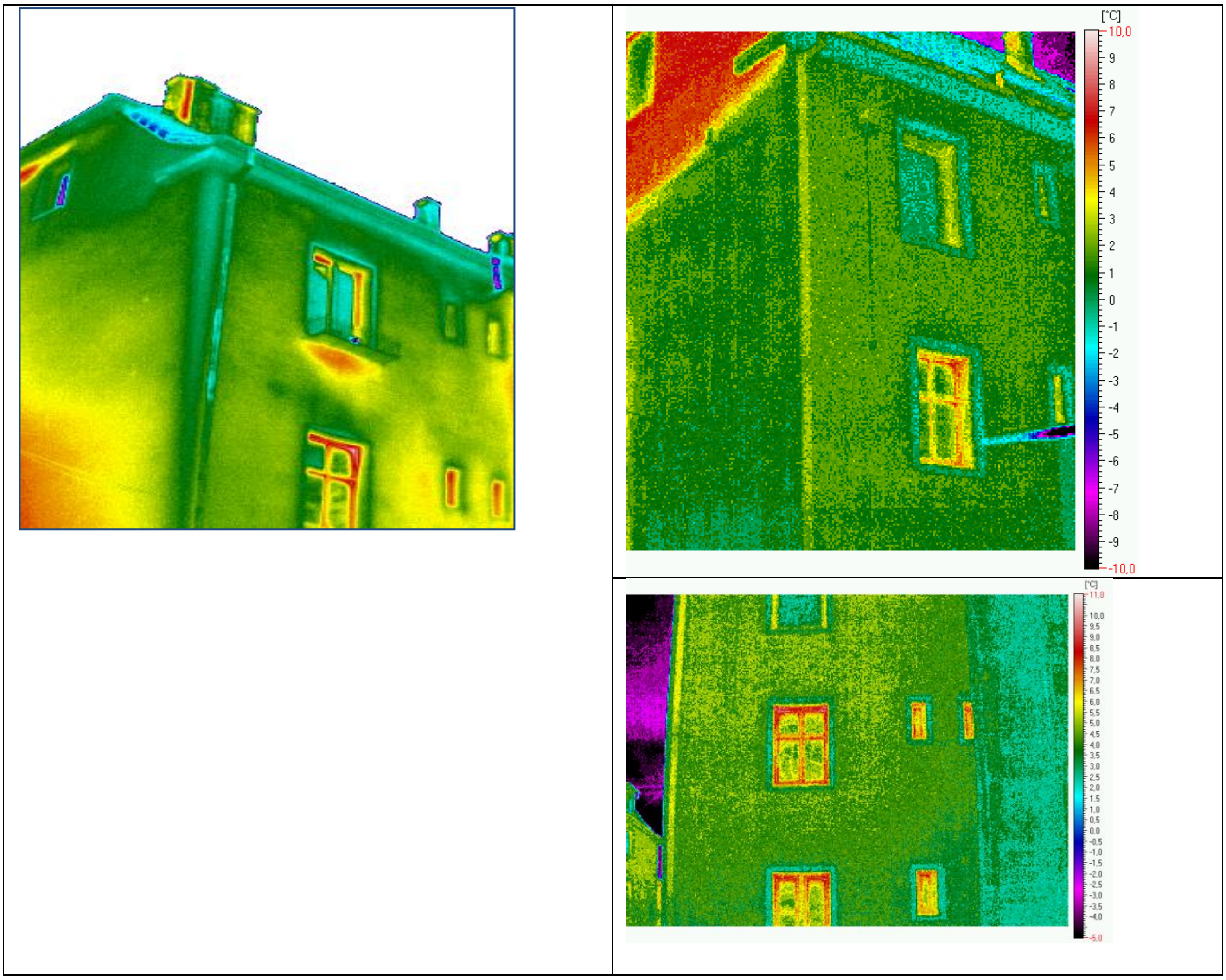


Figure 43: Thermography of the Polish demo building before (left) and after retrofitting (right)

2.2.2.2 **Energy consumptions evaluation through Retrofitting Planner simulation**

Three sets of simulations have been carried out on the Polish demo building consisting of a baseline run and a run with the EASEE prefabricated panels applied on one of the facades as described in D8.1. The baseline model was calibrated using survey data to align with the energy utility figures received for the site and the EASEE solution that was applied. The EASEE construction database was used to assign constructions to the other elements of the building envelope.

- For set 1 the external wall construction was also assigned from the EASEE Construction Database created using data on historical U-values standards. The database currently contains 396 options for 6 different locations (UK, Germany, Italy, France, Spain and Poland). This database of constructions allows the user to quickly make realistic construction base on location and period when survey data is not available.
- For set 2 the baseline was ran with the external wall construction calculated in the VE
- For set 3 the U-Value specified on the test site summary was applied

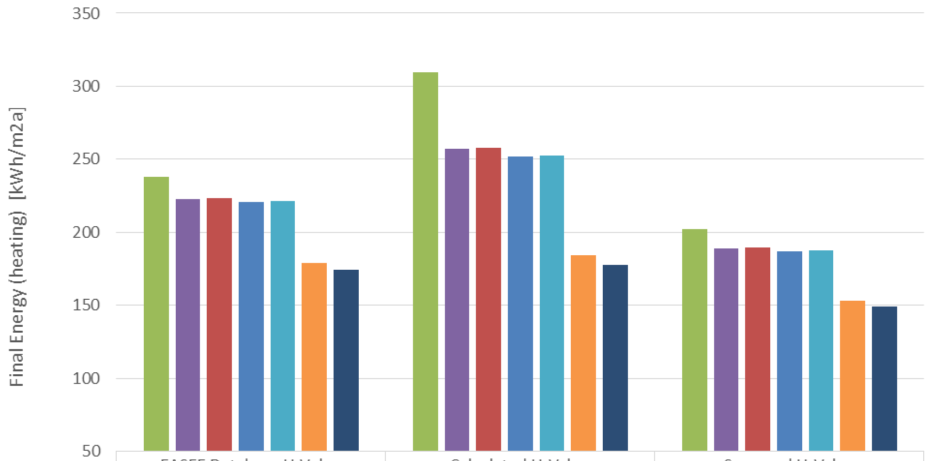
For each set, different simulations were carried out taking into account the EASEE retrofitting solutions used:

1. Baseline
2. Actual case with EASEE panels on one façade and ETICS panels on the rest of the façade
3. Actual case, adding to case 2 the EASEE wallpaper solution for the inner wall of the room where it was installed.
4. Ideal case with the EASEE panels installed in the whole façade

5. Ideal case with the EASEE panels and wallpaper installed in the whole building.

For cases 2 and 3, both actual and corrected thickness for the EPS layer in the ETICS panels were considered.

Figure 44 below shows the total heating energy for the building obtained from simulations with the Retrofitting Planner integrated within the IES VE software.



	EASEE Database U-Value	Calculated U-Value	Surveyed U-Value
Total Energy (Heating) Base Simulated	238.267914	309.8334576	202.4441281
Total Energy (Heating) Panel Solution Simulated	222.8443269	257.2108106	188.7756762
Total Energy (Heating) Panel Solution Simulated ETCI thickness corrected to match panel	223.4074526	257.7746142	189.3562018
Total Energy (Heating) Added Wallpaper Solution Simulated	220.7879692	251.8640544	187.1780444
Total Energy (Heating)Added Wallpaper Solution Simulated, ETCI thickness corrected to match panel	221.3508689	252.427858	187.7583441
Total Energy (Heating) Panel Solution Simulated Ideal Whole Building	178.8344293	184.2428762	153.0705263
Total Energy (Heating) Added Wallpaper Simulated Ideal Whole Building	174.3233227	177.5023162	149.0802883

Figure 44: Simulated total heating energy for the Polish demo building

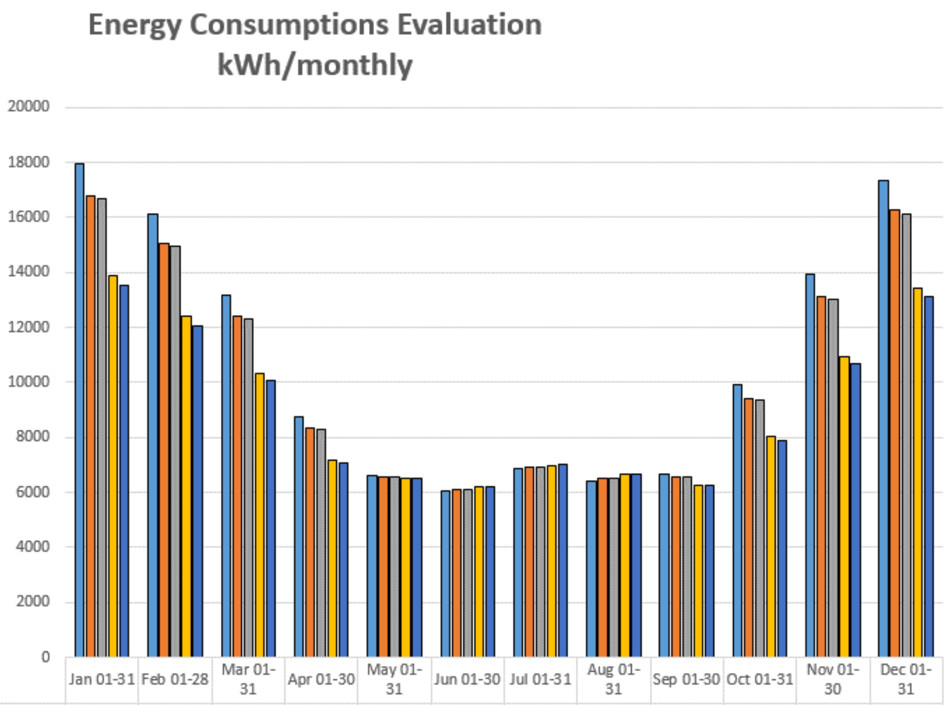
The following results could be observed.

1. The EASEE Database construction assigned was the medium weight Polish 1964 wall construction with a U-Value of 1.16 W/m^{2}K. Baseline results are 15% greater than the surveyed results. Applying the EASEE panel solution to the test site with this configuration provides a 6.5% reduction in energy use across the year or 15.4 kWh/m^2 per annum. Applying the EASEE panel solution in an ideal case to the whole test site building with this configuration (orange bar in the figure above) provides a 24.9% reduction in energy use across the year or 59.4 kWh/m^2 per annum. Also applying the EASEE wallpaper solution to the test site with this configuration provides a 7.3% reduction in energy use across the year or 17.5 kWh/m^2 per annum. Applying the EASEE wallpaper solution together with the EASEE panels in an ideal case to the whole test site building with this configuration (dark blue bar in the figure above) provides a 26.8% reduction in energy use across the year or 63.4 kWh/m^2 per annum.
2. The construction U-value for this configuration was calculated in the VE. Material properties were assumed from the VE material database. The U-value of the construction was 2.18 W/m^{2}K. Baseline results are 34.7% greater than the surveyed results. Applying the EASEE panel solution to the test site with this configuration provides a 17% reduction in energy use across the year or 52.6 kWh/m^2 per annum. Applying the EASEE panel solution in an ideal case to the whole test site building with this configuration (orange bar in the figure above) provides a 40.5% reduction in energy use across the year or 125.6 kWh/m^2 per annum. Also applying the EASEE wallpaper solution to the test site with this configuration provides a 18.7% reduction in energy use across the year or 57.9 kWh/m^2 per annum. Applying the

EASEE wallpaper solution together with the EASEE panels in an ideal case to the whole test site building with this configuration (dark blue bar in the figure above) provides a 42.7% reduction in energy use across the year or 132.3 kWh/m^2 per annum.

3. The construction U-value for this configuration was surveyed and applied in the VE. The U-value of the construction was 1.0 W/m^{2}K. Applying the EASEE panel solution to the test site with this configuration provides a 6.7% reduction in energy use across the year or 13.67 kWh/m^2 per annum. Applying the EASEE panel solution in an ideal case to the whole test site building with this configuration (orange bar in the figure above) provides a 24.4% reduction in energy use across the year or 49.4 kWh/m^2 per annum. Also applying the EASEE wallpaper solution to the test site with this configuration provides a 7.5% reduction in energy use across the year or 15.3 kWh/m^2 per annum. Applying the EASEE wallpaper solution together with the EASEE panels in an ideal case to the whole test site building with this configuration (dark blue bar in the figure above) provides a 26.4% reduction in energy use across the year or 53.4 kWh/m^2 per annum.

The simulation of heating energy for the baseline situation in Simulation set 2 are very far from the actual values so the related savings are too optimistic. Therefore, sets 1 and 3 can be considered as the most realistic ones. In view of this, the savings in heating energy predicted by the simulations due to the installation of the EASEE panels are about 24%. If this is kept over one year, the expected energy savings estimated through Retrofitting Planner are up to 4000 kWh/month in the winter season (see Figure 45 below).



	Jan 01-31	Feb 01-28	Mar 01-31	Apr 01-30	May 01-31	Jun 01-30	Jul 01-31	Aug 01-31	Sep 01-30	Oct 01-31	Nov 01-30	Dec 01-31
Total energy (kWh) Baseline	17939.1	16110.3	13194.7	8764.9	6609	6066.5	6857.4	6418.3	6683.2	9930.9	13956.7	17353.3
Total energy (kWh) EASEE External	16803.5	15073.2	12411.6	8343.5	6581.4	6102.5	6895	6494.5	6564.7	9414.9	13123	16265.6
Total energy (kWh) EASEE Internal	16672.5	14953.7	12318.1	8291.8	6576.1	6103.4	6896.7	6498.4	6547.6	9352	13026.3	16140.6
Total energy (kWh) EASEE External Whole Building	13882.2	12391.4	10300.7	7192.1	6523.1	6191.6	6987	6649.5	6242.6	8012.4	10947.9	13452.4
Total energy (kWh) EASEE Internal Whole Building	13538.1	12076.9	10059.3	7085.5	6533.9	6218	7002.6	6675.2	6235.7	7869.9	10695.5	13120.1

Total energy (% Reduction)					
Date	Baseline	EASEE External	EASEE Internal	EASEE External Whole Building	EASEE Internal Whole Building
Jan 01-31	0.00%	6.33%	7.06%	22.61%	24.53%
Feb 01-28	0.00%	6.44%	7.18%	23.08%	25.04%
Mar 01-31	0.00%	5.93%	6.64%	21.93%	23.76%
Apr 01-30	0.00%	4.81%	5.40%	17.94%	19.16%
May 01-31	0.00%	0.42%	0.50%	1.30%	1.14%
Jun 01-30	0.00%	-0.59%	-0.61%	-2.06%	-2.50%
Jul 01-31	0.00%	-0.55%	-0.57%	-1.89%	-2.12%
Aug 01-31	0.00%	-1.19%	-1.25%	-3.60%	-4.00%
Sep 01-30	0.00%	1.77%	2.03%	6.59%	6.70%
Oct 01-31	0.00%	5.20%	5.83%	19.32%	20.75%
Nov 01-30	0.00%	5.97%	6.67%	21.56%	23.37%
Dec 01-31	0.00%	6.27%	6.99%	22.48%	24.39%

Figure 45: Heating energy savings across one year for the Polish demo building

2.2.2.3 Thermal comfort evaluation

The impact of the EASEE panels retrofitting on thermal comfort has been evaluate again through the IES VE software by simulating the air temperature, mean radiant temperature and dry resultant temperature before and after the retrofit. The results are shown below.

Air Temperature

For the entire building, as can be seen in Figure 46 below (Baseline, Retrofit) the air temperature has increased showing the improvement in the thermal performance of the building envelope from the retrofit solution. The minimum air temperature value has been improved from 13.1°C to 14.6°C. The maximum air temperature has slightly decreased from 27°C to 27.06°C. While the mean air temperature for the entire building has increase from 19.5°C to 20.4°C.

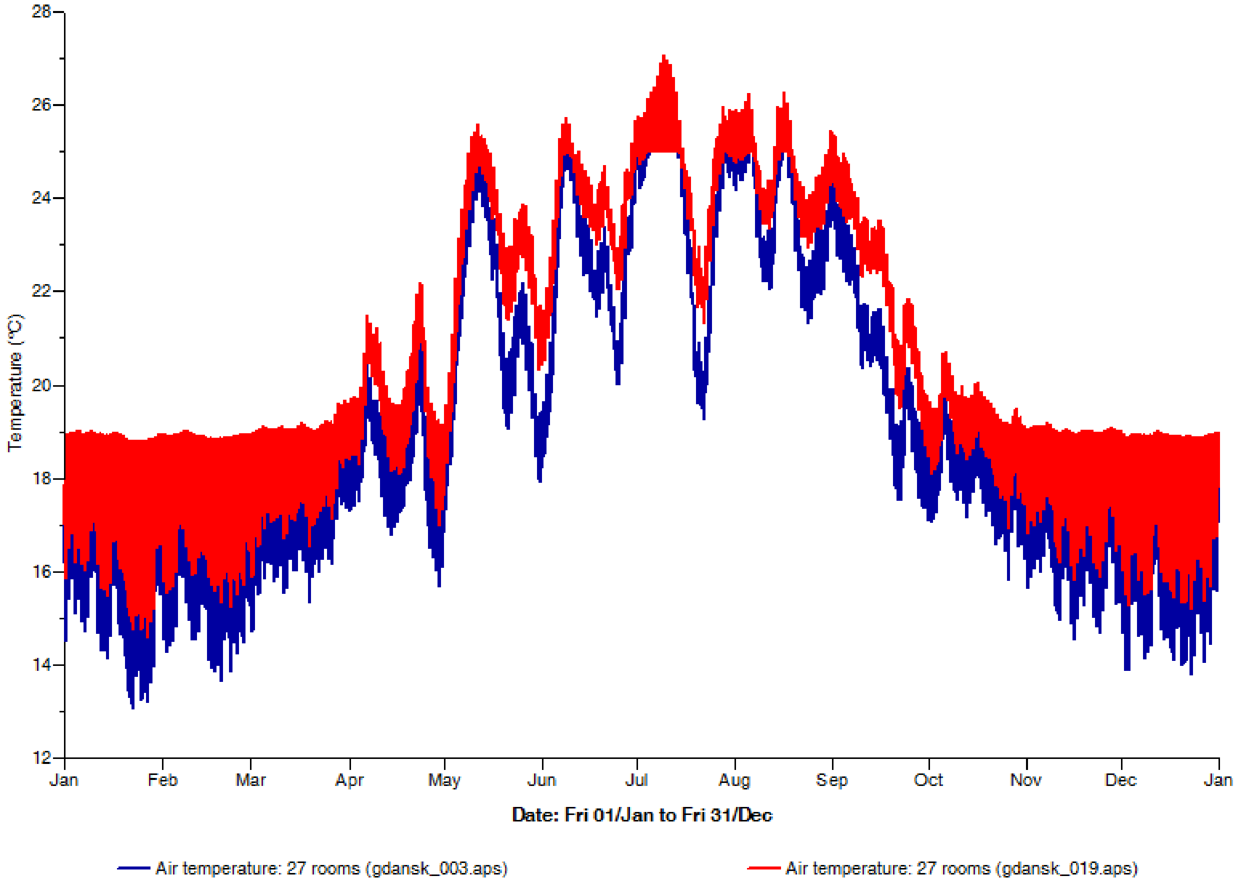


Figure 46: Air Temperature for the whole Polish Demo Building (Baseline, Retrofit)

The change in air temperature for the entire building can be seen in the range test below which shows the amount of hours the air temperature was in a particular temperature range for the entire building.

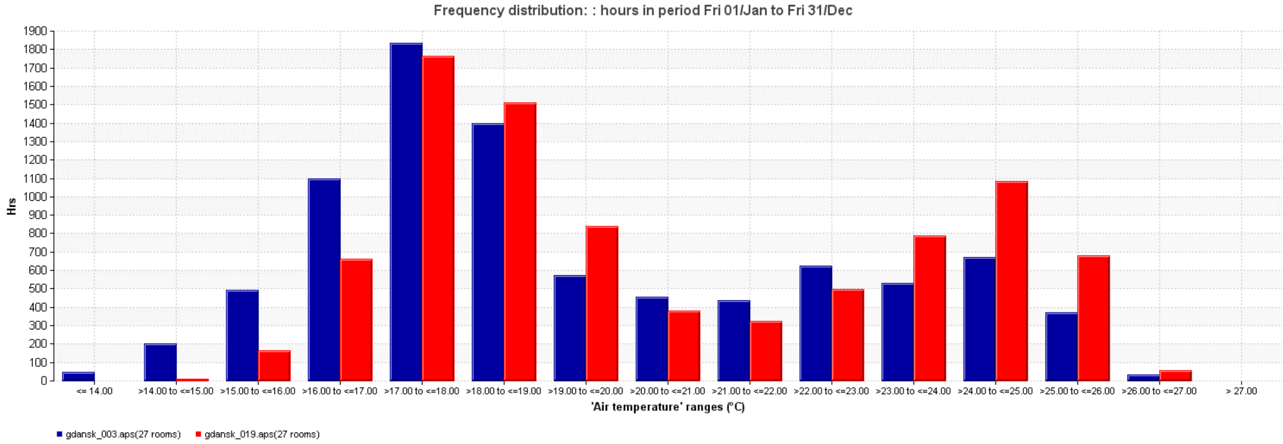


Figure 47 Amount of hours the air temperature was in a particular temperature range for the entire building.

An example of the improvement air temperature from retrofitting can be seen in the chart below (Baseline, Retrofit) which displays the combined air temperature in Apartment 2 on the day the worst case external temperature occurs, on January 23rd.

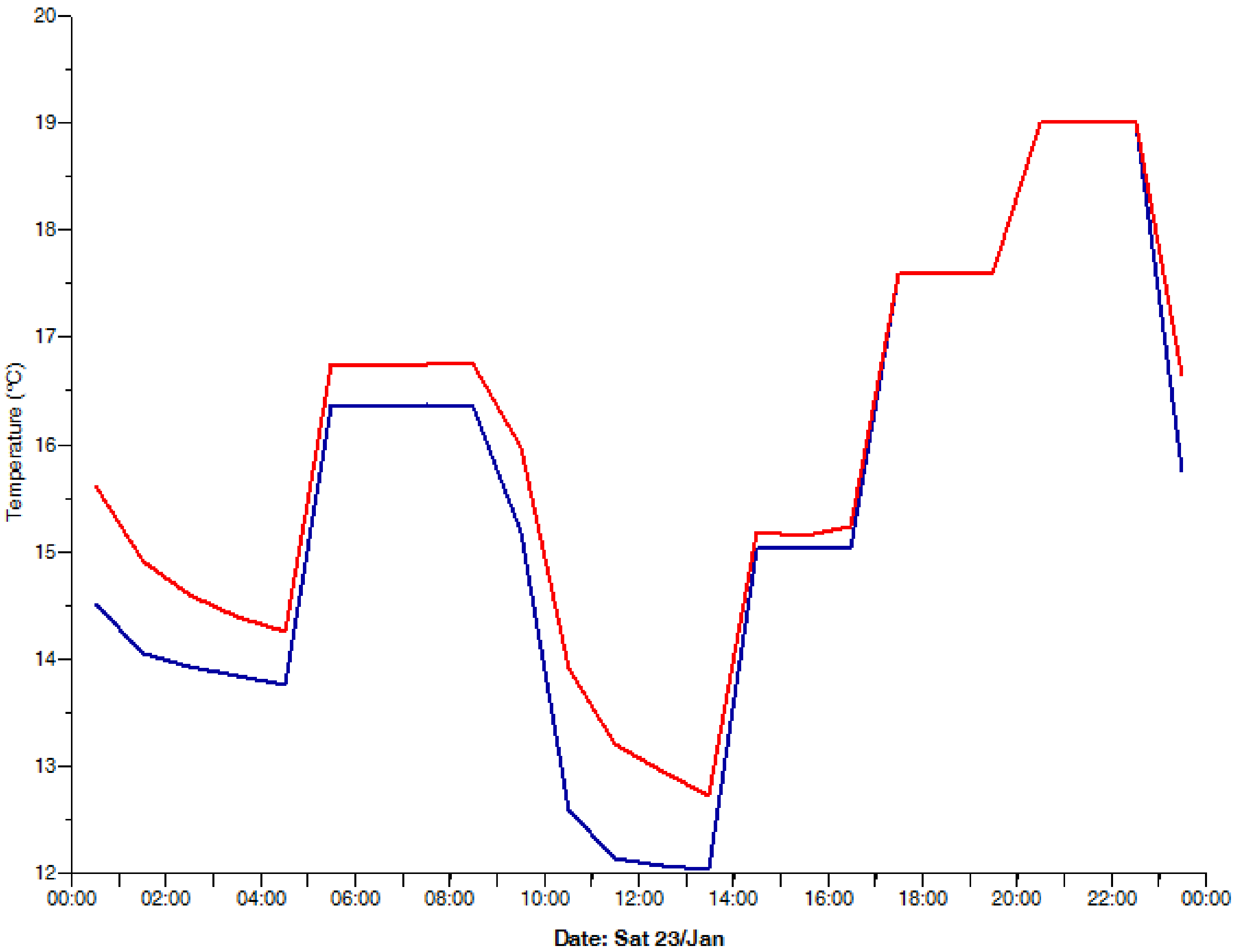


Figure 48: Combined air temperature in Apartment 2 (Baseline, Retrofit) on January 23rd

The improvement in the building envelope thermal performance can be clearly seen. The minimum air temperature occurring has improved from 12.03°C to 12.7°C, while the mean air temperature has also increased from 15.4°C to 15.9°C.

Mean Radiant Temperature

For the entire building, as can be seen in Figure 49 (Baseline, Retrofit) the mean radiant temperature has increased showing the improvement in the thermal performance of the building envelope from the retrofit solution. The minimum mean radiant temperature value has been improved from 13.1°C to 14.7°C. The maximum mean radiant temperature has remained unchanged at about 27°C.

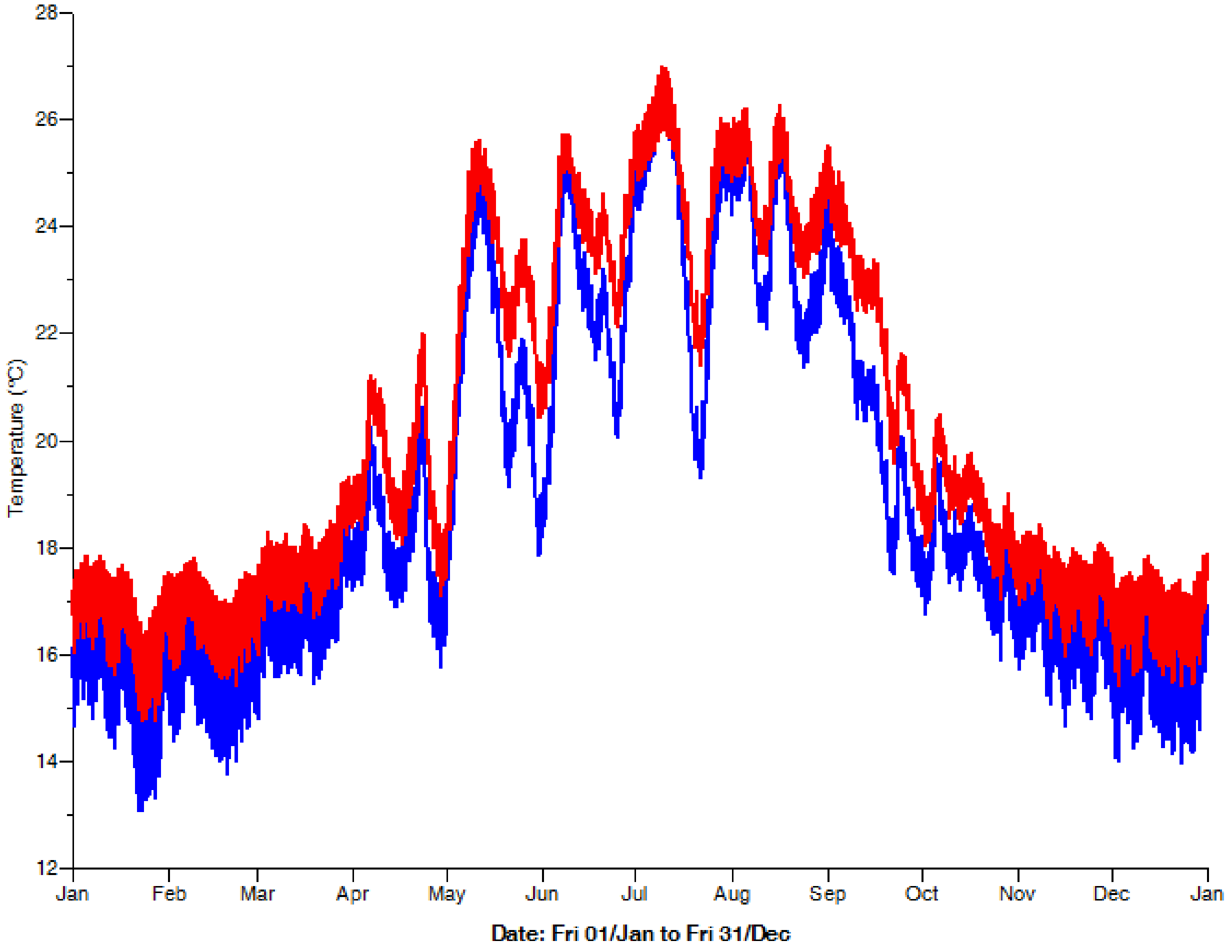


Figure 49: Mean radiant temperature for the whole building (Baseline, Retrofit)

An example of the improvement mean radiant temperature from retrofitting can be seen in the chart below (Baseline, Retrofit) which displays the combined mean radiant temperature in Apartment 2 on the day the worst case external temperature occurs (January 23rd).

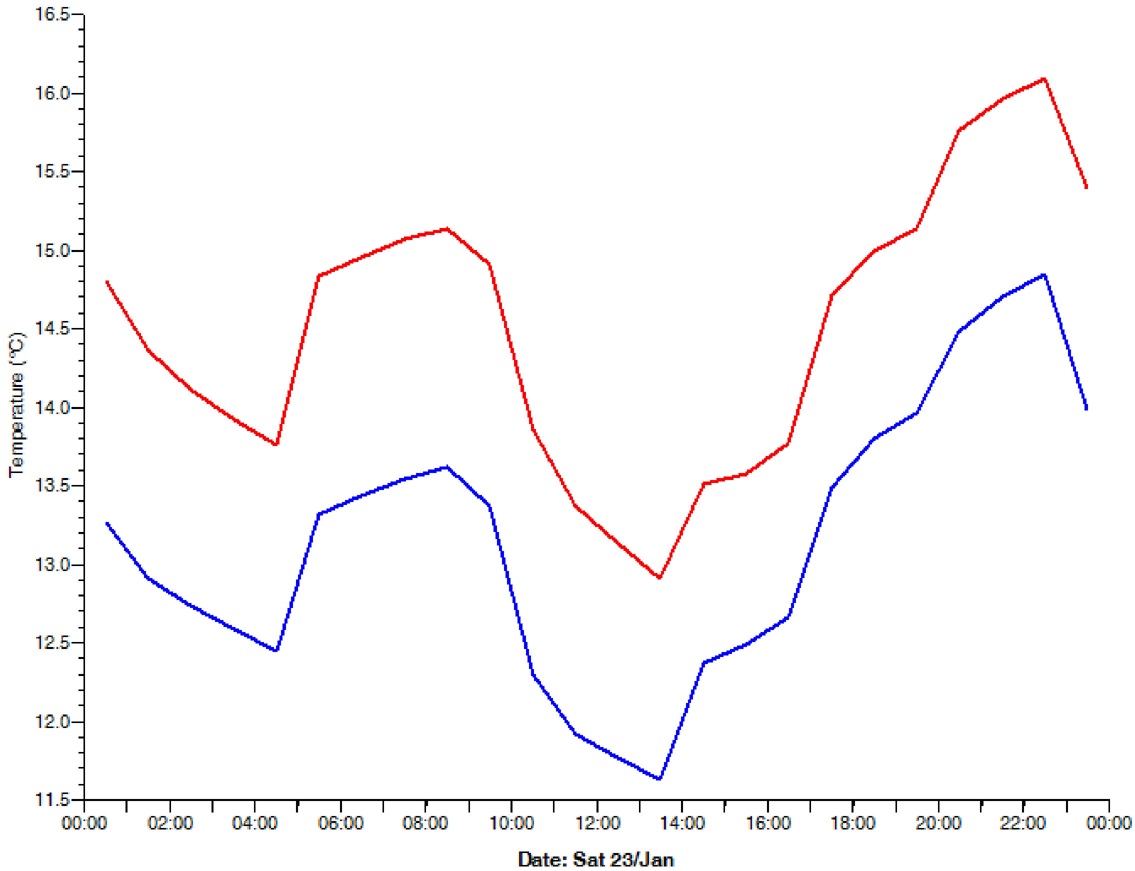


Figure 50: Mean radiant temperature for apartment 1 on January 23rd

The improvement in the building envelope thermal performance can be clearly seen. The minimum mean radiant temperature occurring has improved from 11.6°C to 12.9°C, while the maximum mean radiant temperature has also increased from 14.8°C to 16.1°C.

Dry, resultant temperature

For the entire building, as can be seen in Figure 51 (Baseline, Retrofit) the dry resultant temperature has increased showing the improvement in the thermal performance of the building envelope from the retrofit solution. The minimum dry resultant temperature value has been improved from 13.06°C to 14.7°C. The maximum dry resultant temperature remained unchanged.

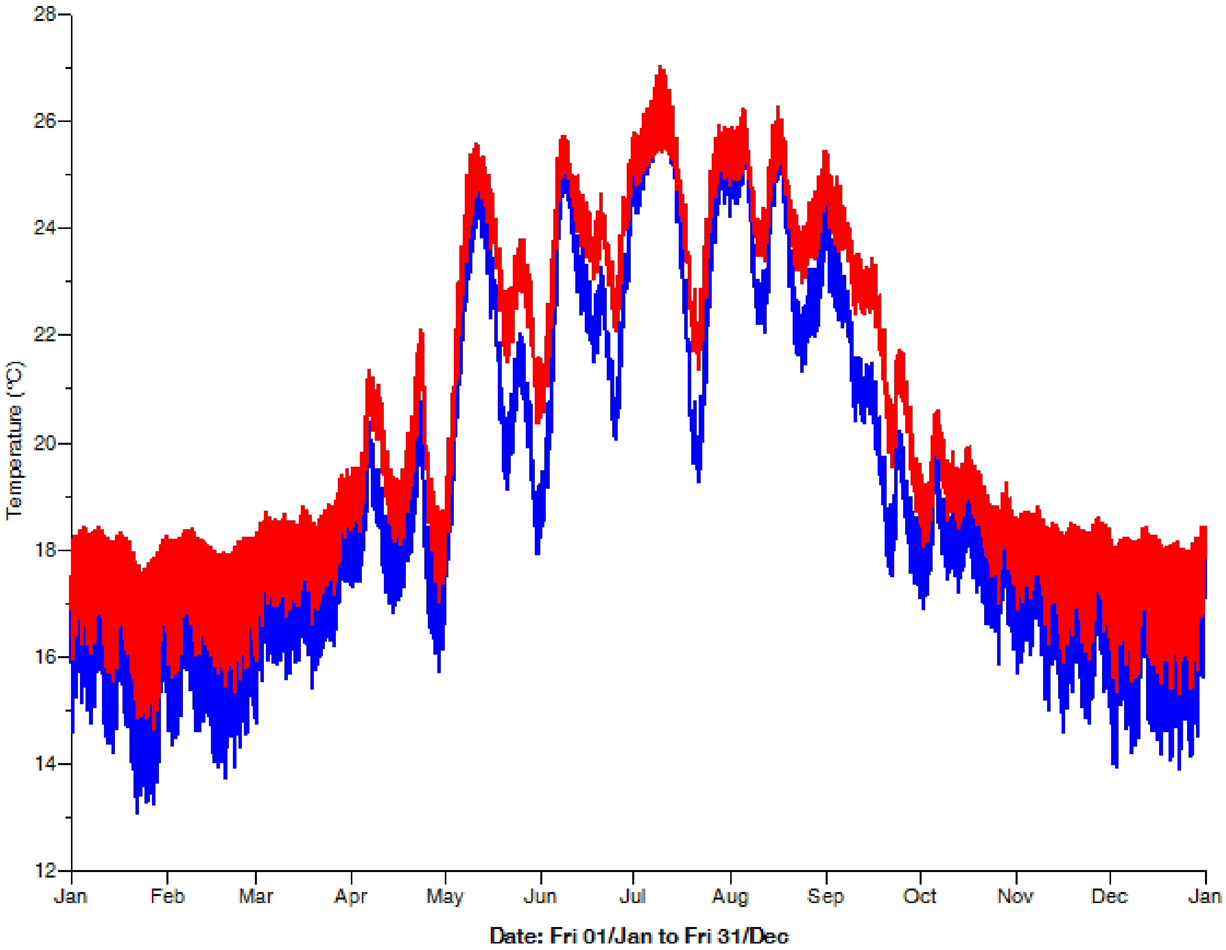


Figure 51: Dry resultant temperature for the whole building (Baseline, Retrofit)

The change in dry resultant temperature for the entire building can be seen in the range test below which shows the amount of hours the dry resultant temperature was in a particular temperature range for the entire building.

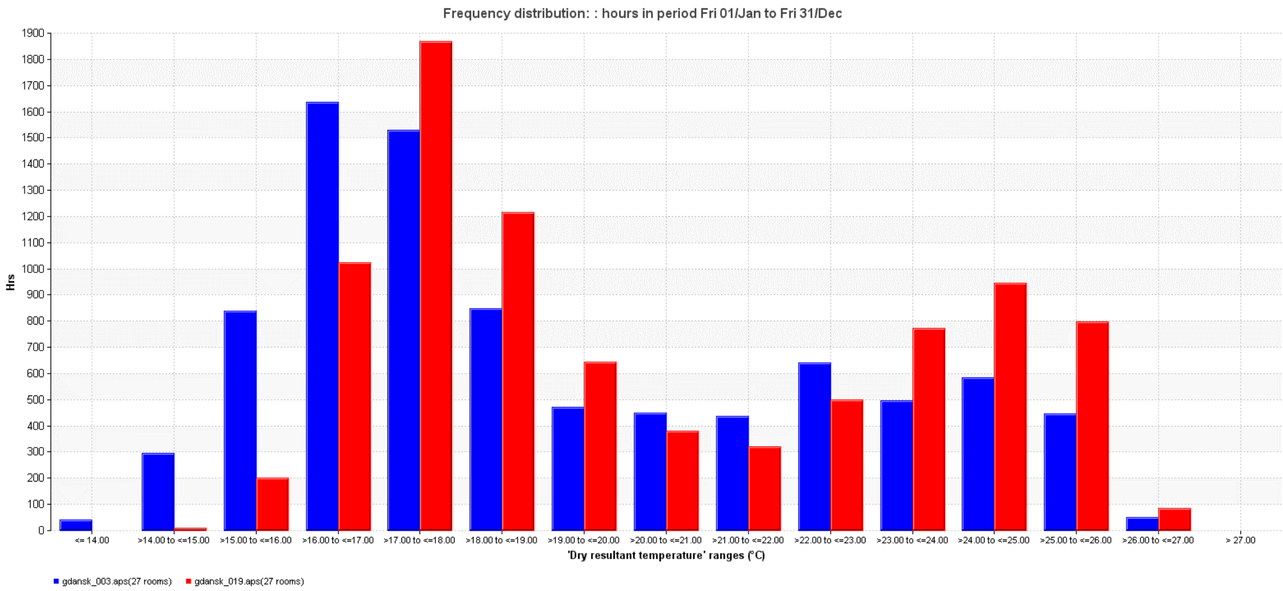


Figure 52: Amount of hours the dry resultant temperature was in a particular temperature range for the entire building

An example of the improvement dry resultant temperature from retrofitting can be seen in the chart below (Baseline, Retrofit) which displays the combined dry resultant temperature in Apartment 2 on the day the worst case external temperature occurs January 23rd.

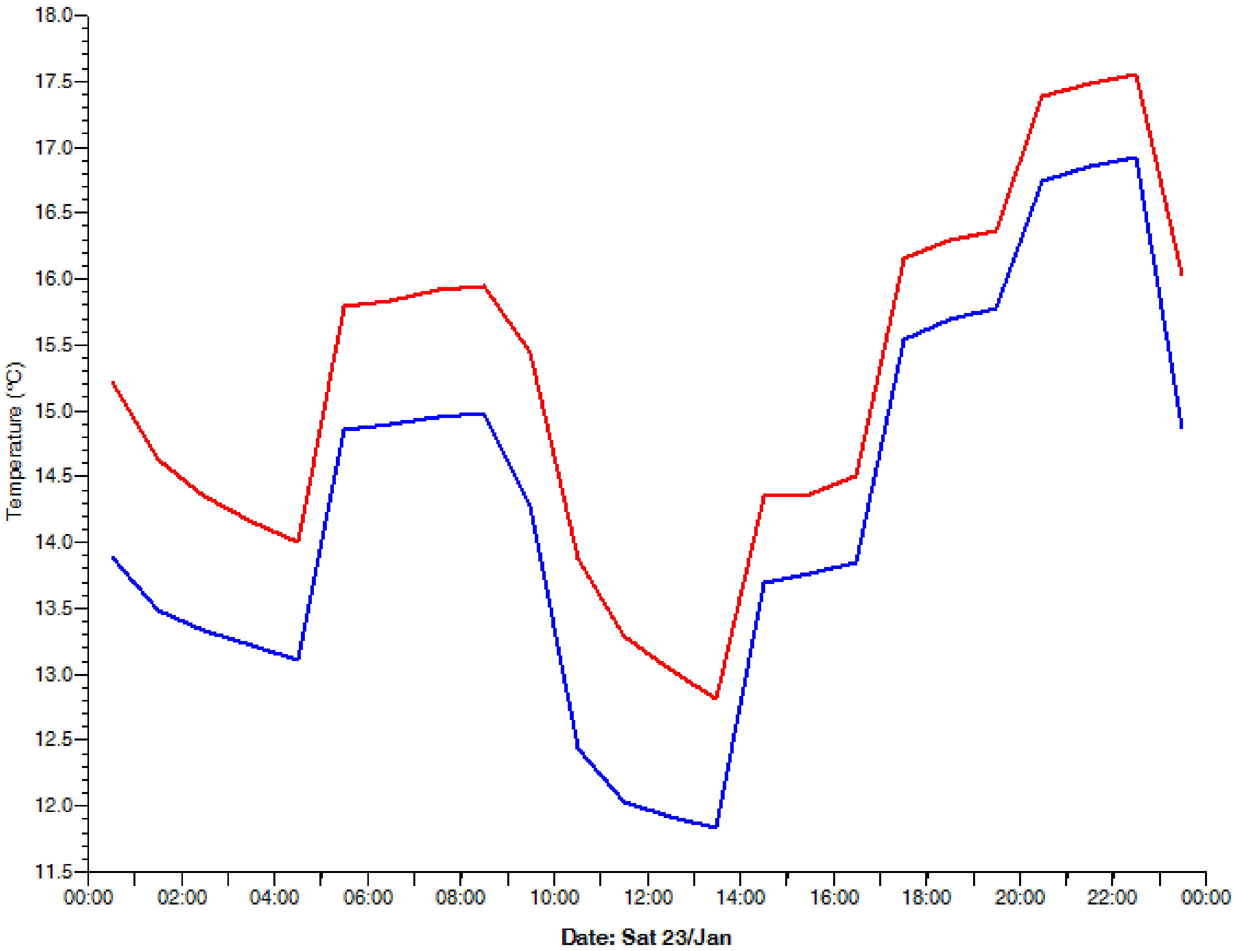


Figure 53: Dry resultant temperature in Apartment 2 (Baseline, Retrofit) on January 23rd

The improvement in the building envelope thermal performance can be clearly seen. The minimum dry resultant temperature occurring has improved from 11.8°C to 12.8°C, while the maximum dry resultant temperature has also increased from 16.9°C to 17.5°C.

ISO comfort indices: Predicted Mean Vote (PMV) & Percentage of People Dissatisfied (PPD)

For the entire building, as can be seen in Figure 54 (Baseline, Retrofit) the PMV has been improved. The minimum PMV value has been improved from -1.67 to -1.33. The maximum PMV has slightly increase from 1.31 to 1.33, while the average combined PMV for the entire building has improved from -0.34 to -0.13.

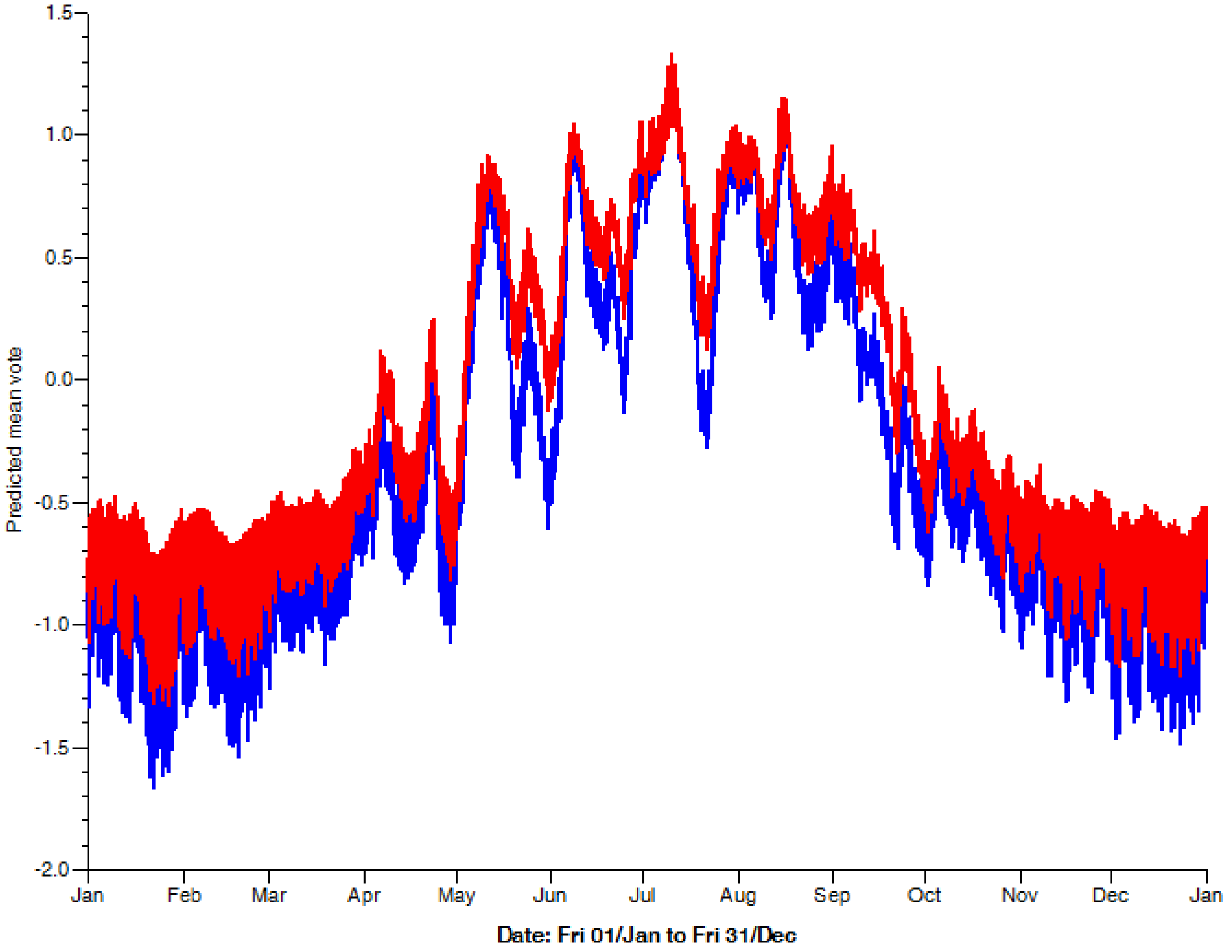


Figure 54: PMV for the whole Polish Demo Building (Baseline, Retrofit)

Simulations have been carried out for each apartment of the building and for all of them the minimum and maximum PMV has improved after retrofitting.

As far as Predicted Percentage Dissatisfied is concerned, the combined PPD for the entire building can be seen below in Figure 55 (Baseline, Retrofit). This shows a clear reduction in the PPD across the entire building. A synopsis of the above chart shows an increase of the minimum PPD from 5.39% to 5.76%. A reduction in the maximum PPD value from 60.03% to 42.89% and an overall reduction in the mean PPD value from 17.98% to 16% can be seen.

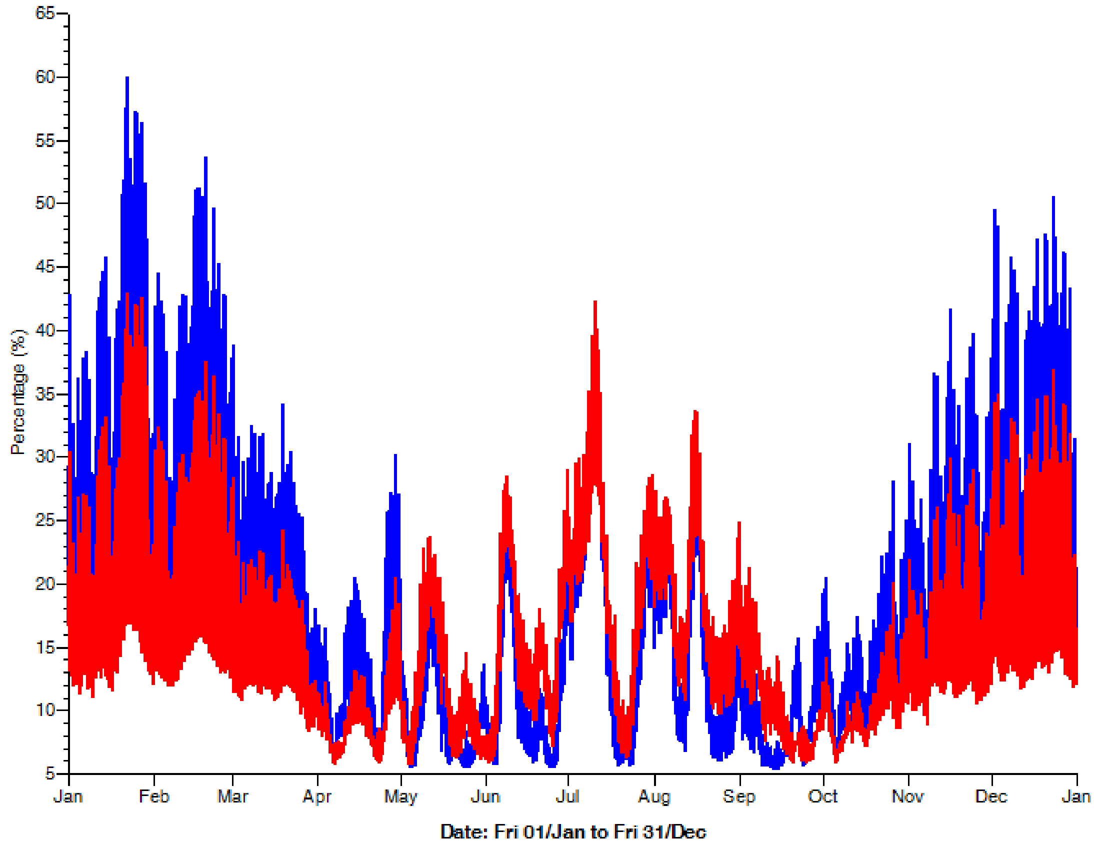


Figure 55 PPD Polish Demo Building

As already mentioned for the Milan demo building, for PPD looking at the entire building as a whole does not provide a fair reflection on the improvement seen through applying the retrofitting solution. Therefore, results are shown also for the main bedroom in each apartment on the worst case day for external temperature.

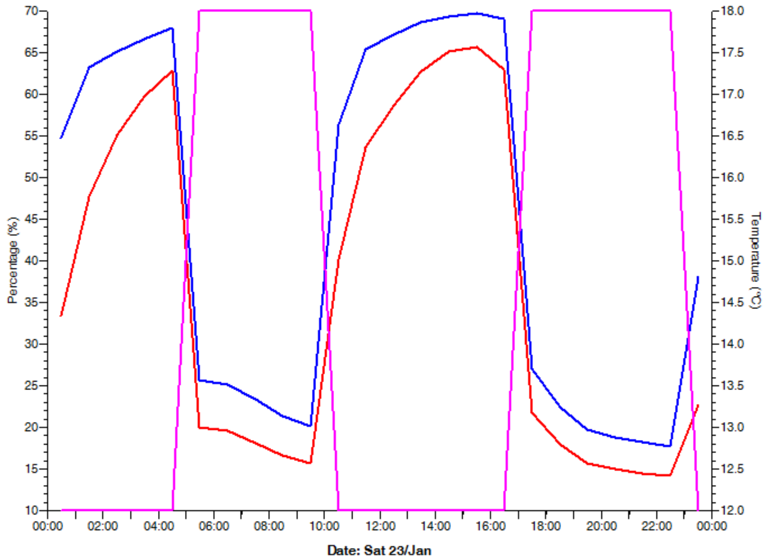
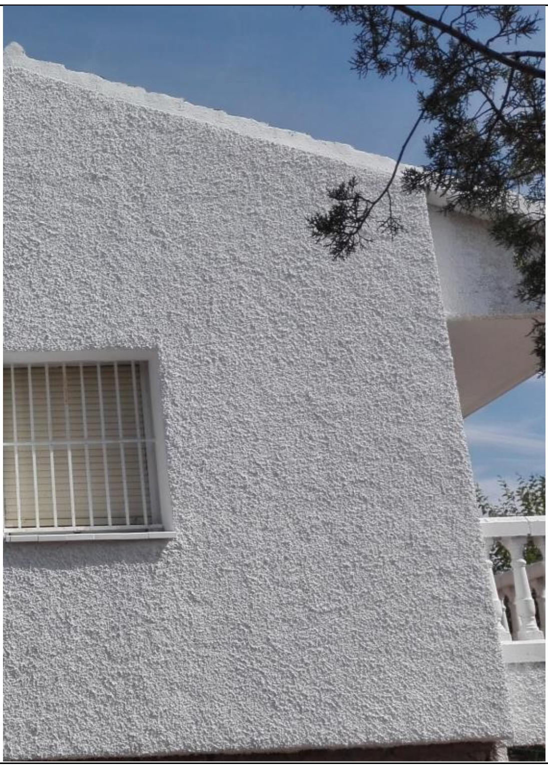


Figure 56: PPD for the Kitchen in Apartment 2 (Baseline, Retrofit, Heating Setpoint)

As an example, the PPD for the Kitchen in Apartment 2 can be seen above in Figure 56. This shows a clear reduction in the PPD at all times but if one looks at the times when the room is conditioned a reduction in minimum PPD from 17.64% to 14.12% can be seen and reduction in the maximum PPD value from 26.81% to 21.67%. Similar results were obtained for Apartment 4 and 6.

2.2.3 Spanish demo building

	
• Single family house in Batres (Madrid) • Age of construction: 60s • Owner: Private - mid-age Spanish family	Cavity wall retrofitting through innovative perlite combined with the installation of 12 EASEE panels on the same facade

2.2.3.1 Energy performance evaluation

Comparison of U-value empirically evaluated through the data from static calculation validated by mean of monitoring systems

The Spanish demo building selected was a single family house built during the 1960's and located in Batres (Madrid), a small town in the autonomous community of Madrid in central Spain.

Figure 57: Spanish demo building

The original walls of the building were made of 24 cm solid bricks. The inside and outside finish of the walls were respectively a 1 cm gypsum plaster coating and a 2 cm layer of mortar and Tyrolean plaster (Figure 58).

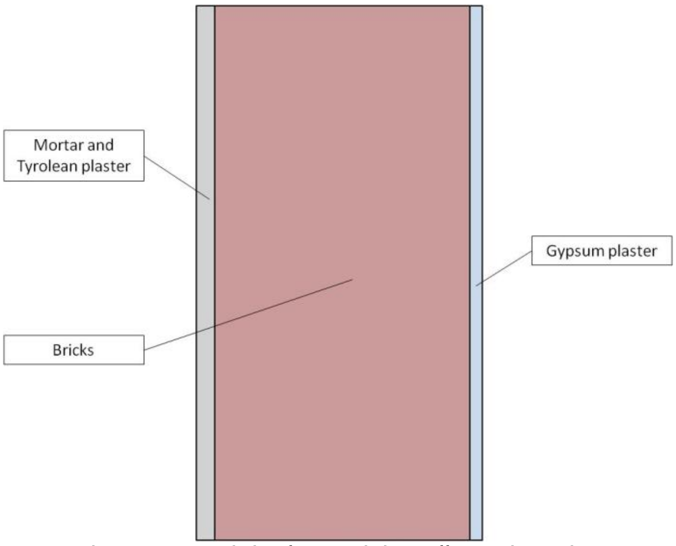


Figure 58: Original Spanish wall stratigraphy

Using the conductance values of the different materials that composed the original wall of the building, a static calculation of the thermal transmittance of the wall was carried out.

Table 7: Original Spanish wall characteristics

Material	Thickness (m)	Conductivity (W/m·K)
Tyrolean plaster	0,02	0,2
Solid bricks	0,24	1,6
Gypsum plaster	0,01	0,1

With this values and using a computational modelling software (Therm) the overall U-value obtained for the original wall configuration was 1,879 W/m^2·K, with 0,27 m of thickness.
The first retrofitting solution implemented was the construction of the cavity wall filled with perlite. Therefore the new wall stratigraphy is as represented in figure below.

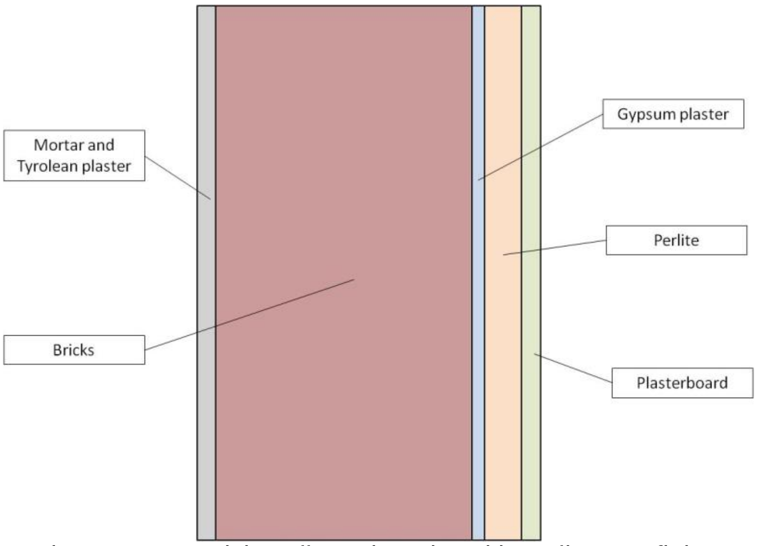


Figure 59: Spanish wall stratigraphy with perlite retrofitting

Following the same process of static calculation as for the original building wall, the overall U-value obtained for the wall with the perlite retrofitting was 0,714 W/m^2·K, with 0,316 m of thickness.

Table 8: Spanish wall with perlite retrofitting characteristics

Material	Thickness (m)	Conductivity (W/m·K)
Tyrolean plaster	0,02	0,2
Solid bricks	0,24	1,6
Gypsum plaster	0,01	0,1
Perlite	0,03	0,04
Plasterboard	0,016	0,17

The last retrofitting procedure that was performed in the Spanish demo building was the placement of the panels manufactured for the project as it is shown in figure below.

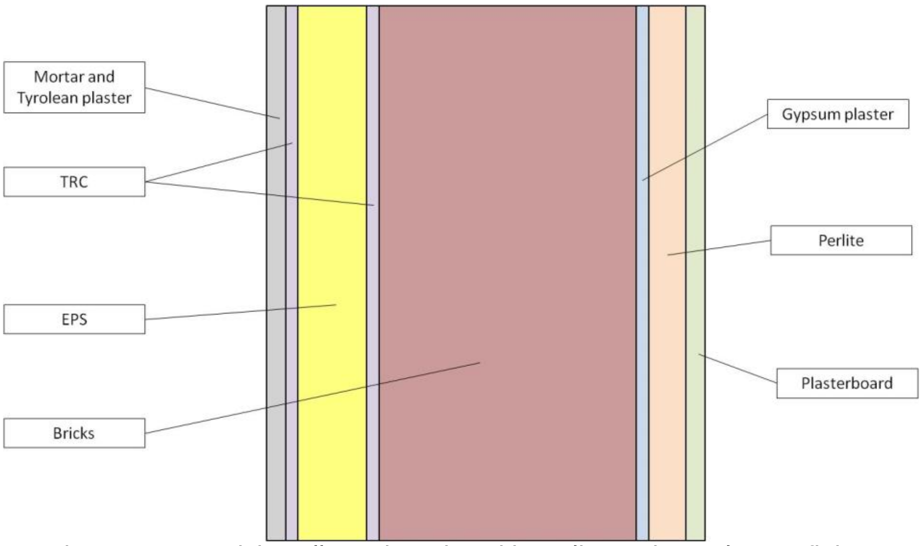


Figure 60: Spanish wall stratigraphy with perlite and panels retrofitting

The characteristics of this new layer, together with the remaining layers that composed the final wall of the Spanish demo building are displayed in the following table.

Table 9: Spanish wall with perlite and panels retrofitting characteristics

Material	Thickness (m)	Conductivity (W/m·K)
Tyrolean plaster	0,02	0,2
TRC	0,024	1
EPS	0,08	0,045
Solid bricks	0,24	1,6
Gypsum plaster	0,01	0,1
Perlite	0,03	0,04
Plasterboard	0,016	0,17

By using again the Therm software, the final U-value of the retrofitted wall (both in the cavity and from the exterior) in the Spanish demo building was 0,312 $W/m^2 \cdot K$, with a thickness of 0,42 m.
As it can be seen from the previous modelling results, a noticeable improvement in the U-value was achieved with the solutions developed in this project and applied to the Spanish demo building. In comparison with the initial wall configuration of the building, a reduction of 62% in the U-value of the perlite retrofitted wall was calculated. The external retrofitting reduced the U-value from the perlite retrofitted wall of 56,3%. Therefore, the combination of the two retrofitting solution resulted in a reduction of 83,4% in the U-value from the original brick wall.

<u>Thermographic survey campaign</u>

The following thermal images also demonstrate the benefits of the retrofitting intervention. As it can be seen in **Error! Reference source not found.**, the façade before retrofitting was not thermally omogeneous, which means that the heat loss in the façade was not correctly distributed (the wall had bad insulation areas).

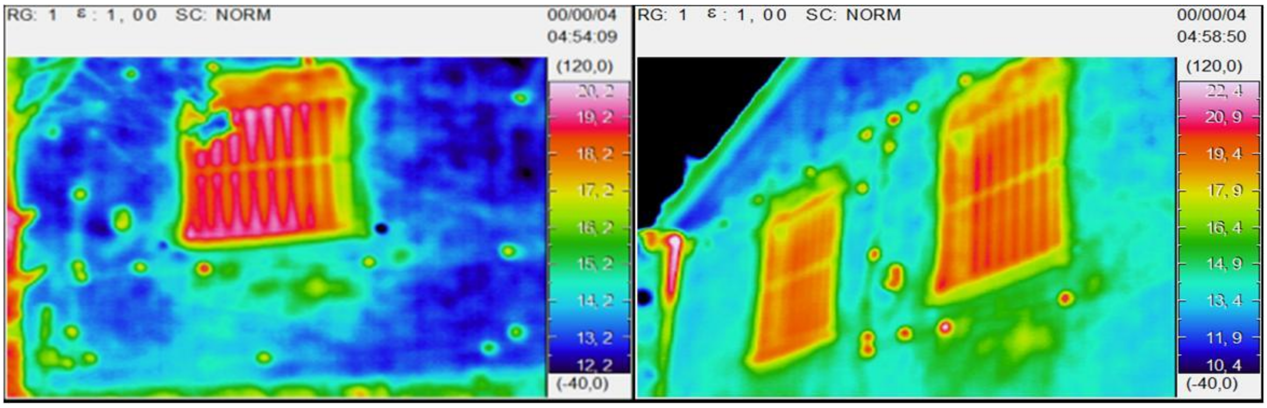


Figure 61: Thermal view before retrofitting

In the following figure taken after retrofitting (Figure 62), the homogeneity improvement can be easily seen, as well as the improvement in the insulation performance. The only areas where some homogeneity is missed are in the panel joints, which can be distinguished in the picture.

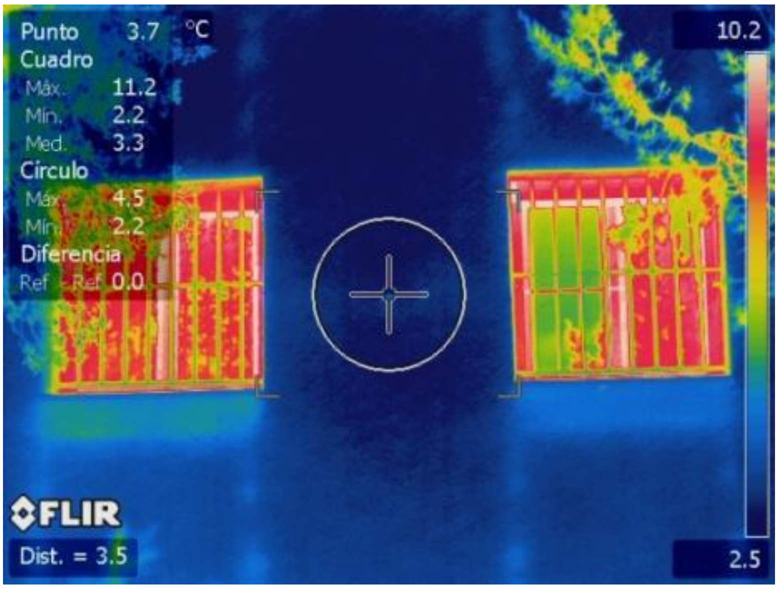


Figure 62: Thermal view after retrofitting

Last but not least, a thermal comparison between the retrofitted wall and an original wall (not retrofitted) was performed. Figure 63 shows one of the edges of the building where the retrofitted façade meets an original one without retrofitting.

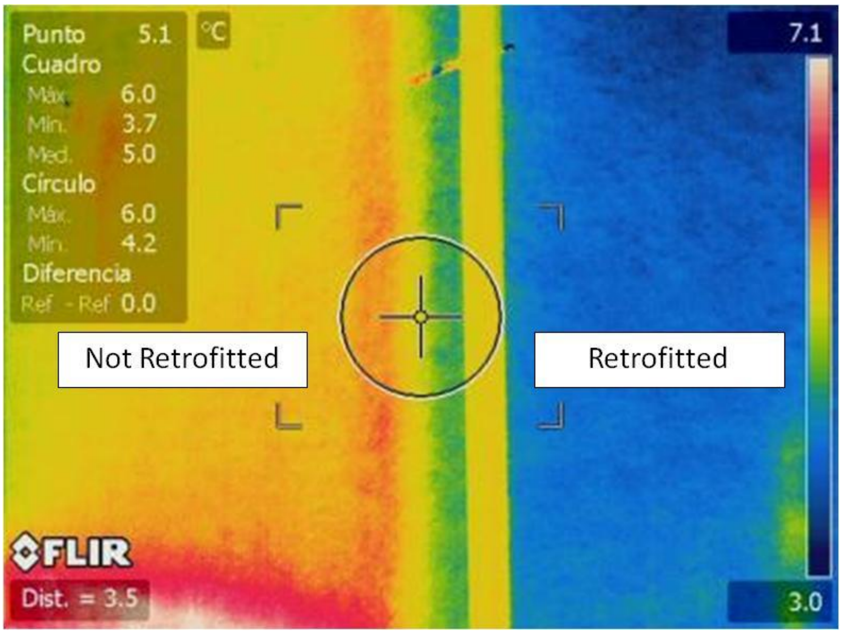


Figure 63: Thermal view comparison

The difference between the retrofitted and the not retrofitted wall is noticeable, as the not retrofitted wall transmits (loses) more heat than the retrofitted one, providing worst insulation properties.

2.2.3.2 Energy consumptions evaluation through Retrofitting Planner simulation

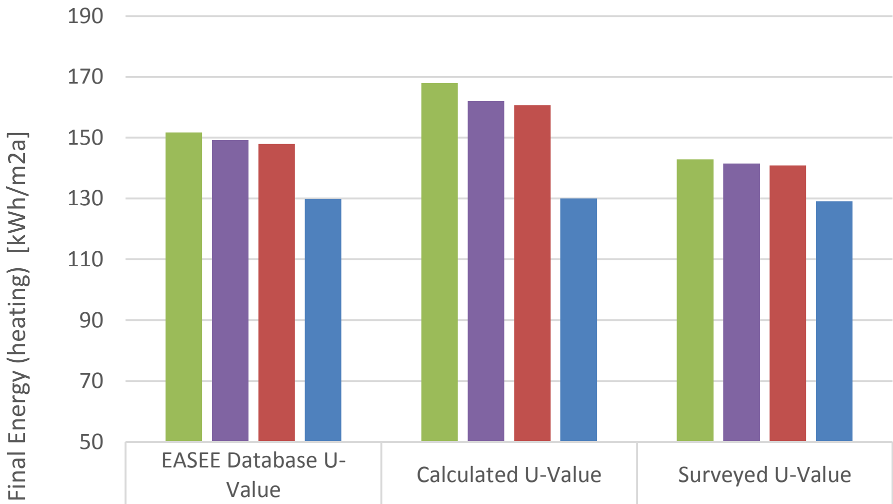
Three sets of simulations have been carried out on the Spanish demo building consisting of a baseline run and a run with the EASEE Retrofit Panel Solution applied on one of the facades as described in D8.1. The baseline model was calibrated using survey data to align with the energy utility figures received for the site and the EASEE solution that was applied. The EASEE construction database was used to assign constructions to the other elements of the building envelope.

- For set 1 the external wall construction was also assigned from the EASEE Construction Database. The EASEE construction database was created using data on historical u-values standards. The database currently contains 396 options for 6 different locations (Great Britain, Germany, Italy, France, Spain and Poland). This database of constructions allows the user to quickly make realistic construction base on location and period when survey data is not available.
- For set 2 the baseline was ran with the external wall construction calculated in the VE
- For set 3 the U-Value specified on the test site summary was applied

For each set, different simulations were carried out with the EASEE retrofit solutions:

1. Baseline
2. Actual case with EASEE panels on one façade
3. Actual case adding to case 2 the EASEE cavity wall insulation on the same wall
4. Ideal case with the EASEE panels and cavity wall insulation applied to the whole building.

Figure 64 below shows the total heating energy for the building obtained from simulations with the Retrofitting Planner integrated within the IES VE software.



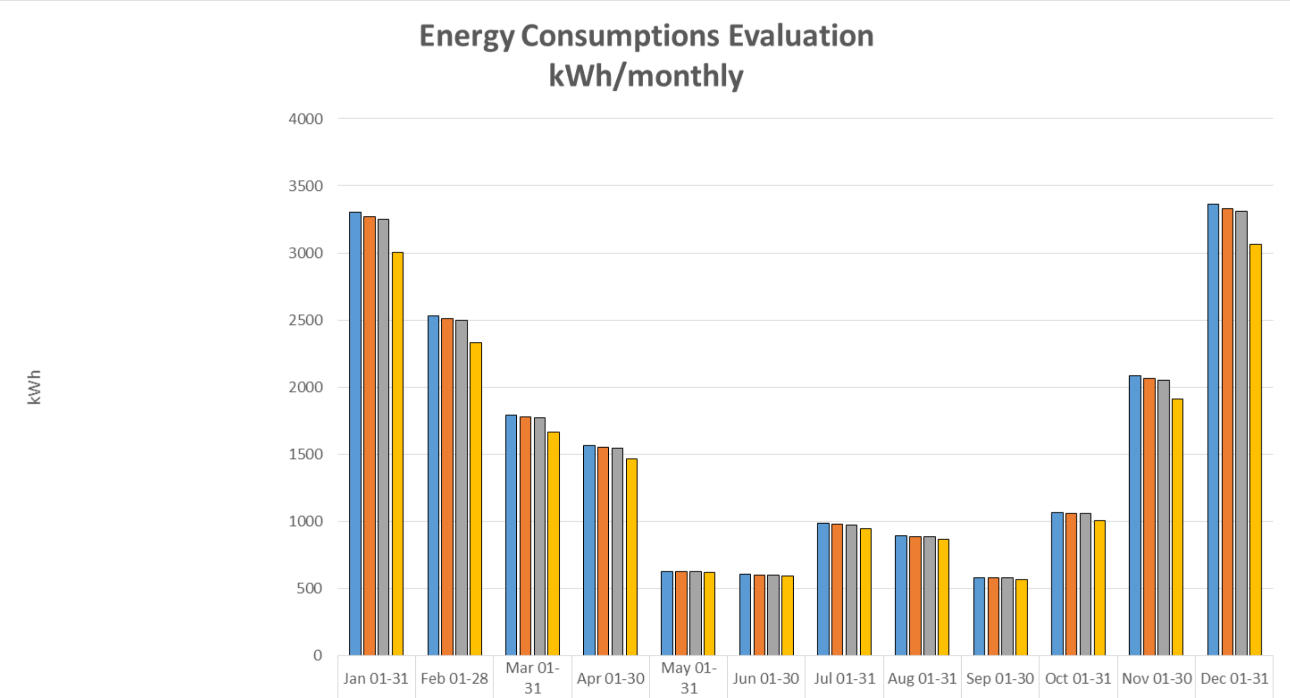
	EASEE Database U-Value	Calculated U-Value	Surveyed U-Value
Total Energy (Heating) Base Simulated	151.7566235	167.9451975	142.8592872
Total Energy (Heating) Solution Simulated Phase 1 Cavity	149.2395892	162.1099558	141.5421362
Total Energy (Heating) Solution Simulated Phase 2 Panel	147.9186856	160.6539598	140.8704267
Total Energy (Heating) Solution Simulated Ideal Whole Building	129.8800961	130.0667863	129.1323971

Figure 64: Simulated total heating energy for the Spanish demo building

The results presented above represent the total heating energy for the building.

1. The EASEE Database construction assigned was the medium weight Spanish 1960-78 wall construction with a U-Value of 1.45 W/m^2K. Baseline results are 6% greater than the surveyed results. Applying the EASEE cavity solution to the test site building with this configuration provides a 1.7% reduction in energy use across the year or 2.5 kWh/m^2 per annum. Applying the EASEE panel solution to the test site building with this configuration provides a 2.5% reduction in energy use across the year or 3.8 kWh/m^2 per annum. Applying both the EASEE solutions in an ideal case to the whole test site building with this configuration provides a 14.4% reduction in energy use across the year or 21.9 kWh/m^2 per annum.
2. The construction U-value for this configuration was calculated in the VE. Material properties had to be assumed from the VE material database. The U-value of the construction was 2.3 $W/m^2.K$. Baseline results are 15% greater than the surveyed results. Applying the EASEE cavity solution to the test site building with this configuration provides a 3.5% reduction in energy use across the year or 5.8 kWh/m^2 per annum. Applying the EASEE panel solution to the test site building with this configuration provides a 4.3% reduction in energy use across the year or 7.3 kWh/m^2 per annum. Applying both the EASEE solutions in an ideal case to the whole test site building with this configuration provides a 22.5% reduction in energy use across the year or 37.9 kWh/m^2 per annum.
3. The construction U-value for this configuration was surveyed and applied in the VE. The U-value of the construction 0.96 $W/m^2.K$. Applying the EASEE cavity solution to the test site building with this configuration provides a 0.9% reduction in energy use across the year or 1.3 kWh/m^2 per annum. Applying the EASEE panel solution to the test site building with this configuration provides a 1.4% reduction in energy use across the year or 1.98 kWh/m^2 per annum. Applying the EASEE solutions in an ideal case to the whole test site building with this configuration provides a 9.6% reduction in energy use across the year or 13.7 kWh/m^2 per annum.

The simulation of heating energy for the baseline situation in Simulation set 2 are very far from the actual values so the related savings are too optimistic. Therefore, sets 1 and 3 can be considered as the most realistic ones. In view of this, the savings in heating energy predicted by the simulations due to the installation of the EASEE panels are about 9%. If this is kept over one year, the expected energy savings estimated through Retrofitting Planner are up to 400 kWh/month in the winter season (see Figure 65 below).



	Jan 01-31	Feb 01-28	Mar 01-31	Apr 01-30	May 01-31	Jun 01-30	Jul 01-31	Aug 01-31	Sep 01-30	Oct 01-31	Nov 01-30	Dec 01-31
Total energy (kWh) Baseline	3303.2	2529.6	1789.4	1561.5	622.9	602.2	981.8	890.8	576.3	1064.6	2082.4	3362.2
Total energy (kWh) EASEE Cavity	3269.8	2507.6	1776.5	1550	622.5	599.8	976.4	887	575.3	1058.7	2062	3328.5
Total energy (kWh) EASEE Internal	3252.2	2496.3	1771.1	1545.3	622.3	598.1	972.6	884.3	574.7	1055.5	2050.9	3310.7
Total energy (kWh) EASEE Whole Building	3001.7	2329.9	1663.8	1463.9	617.3	588.8	946.7	865.7	566.6	1005	1908.2	3060.4

Total energy (% Reduction)				
Date	Baseline	EASEE External	EASEE Internal	EASEE Whole Building
Jan 01-31	0.00%	1.01%	1.54%	9.13%
Feb 01-28	0.00%	0.87%	1.32%	7.89%
Mar 01-31	0.00%	0.72%	1.02%	7.02%
Apr 01-30	0.00%	0.74%	1.04%	6.25%
May 01-31	0.00%	0.06%	0.10%	0.90%
Jun 01-30	0.00%	0.40%	0.68%	2.23%
Jul 01-31	0.00%	0.55%	0.94%	3.58%
Aug 01-31	0.00%	0.43%	0.73%	2.82%
Sep 01-30	0.00%	0.17%	0.28%	1.68%
Oct 01-31	0.00%	0.55%	0.85%	5.60%
Nov 01-30	0.00%	0.98%	1.51%	8.37%
Dec 01-31	0.00%	1.00%	1.53%	8.98%

Figure 65: Heating energy savings across one year for the Spanish demo building

As the Spanish demo building was not used by the family apart from vacation periods, the use of energy bills to study the energy savings was not an option. Therefore an additional evaluation of the energy savings was done by Ancodarq through simulations with another software by the Institute for the Energy Saving and Diversification (IDEA). The IDEA published this new procedure for the energy certification of existing buildings, establishing also the official calculation methodology for EPCs (Engineering, Procurement and Construction). The procedures for existing buildings account for the assessment of energy efficiency measures. The software procedures are already recognized as official documents, according to the procedure established by the Ministry of Industry, Energy and Tourism, and the Ministry of Public Works.

These procedures enable the energy certification of existing residential buildings, as well as of small and large tertiary buildings, establishing a degree of energy efficiency based on CO_2 emissions and primary energy consumption, arising from consumption related to heating, cooling, water heating, ventilation and lighting needs The calculated values are compared with a series of reference values that vary according to the local climate, and with a reference building of the same shape, which abides by the building energy regulations, depending on whether it is a new or existing building, or a residential or non-residential one.

The simulations were performed for a model based on the real retrofitting process that was carried out in the house where one of the walls was retrofitted. The characteristics of the house disposition were as shown in the following figure:

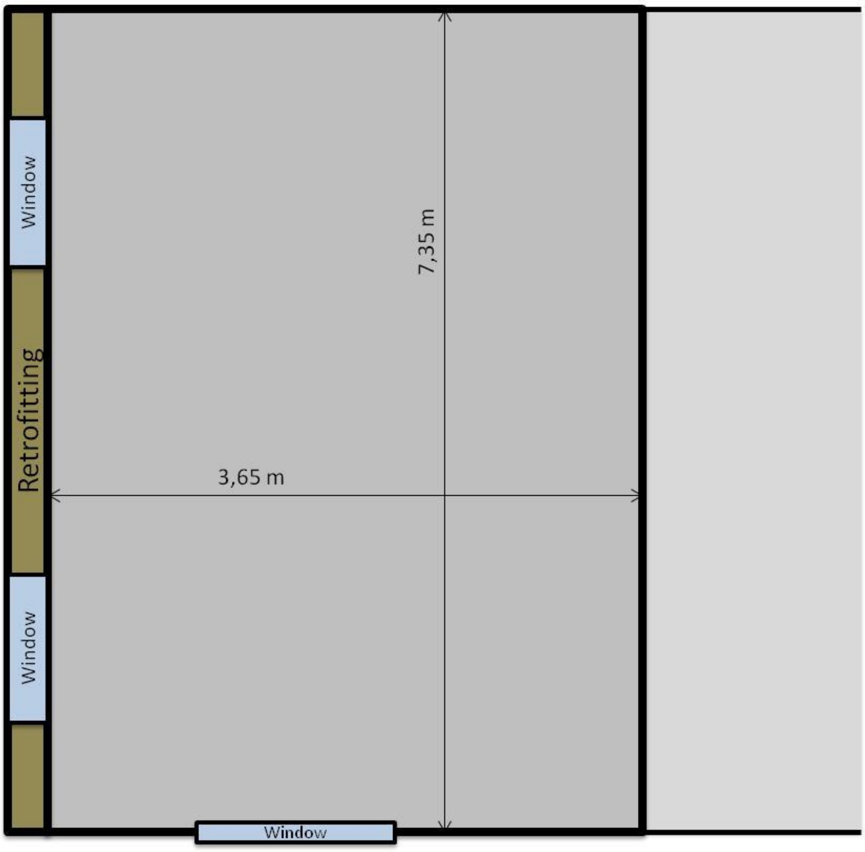


Figure 66: Spanish demo building calculation model

The height of the walls is 2.85 m and one of them was an inside wall. The simulations were performed taking into account the three windows of the building as well as the retrofitting solutions installed in one of the three walls in contact with the external environment. The orientation of the house was also a key parameter taken into account in this simulation.

The simulation carried out for the original building returned a heating demand value of 83.7 kWh/m^2·year, and 42.1 CO_2 kg/m^2·year of heating emissions. This result was also given in primary energy for heating, with a value of 159.61 kWh/m^2·year.

The simulation performed for the building with the retrofitted solutions implemented in one of the walls produced satisfactory outcomes in terms of energy efficiency improvement. The heating demand was 55.8 kWh/m^2·year, with 26.3 CO_2 kg/m^2·year of heating emissions. The primary energy for heating after the EASEE retrofitting was reduced to 99.76 kWh/m^2·year.

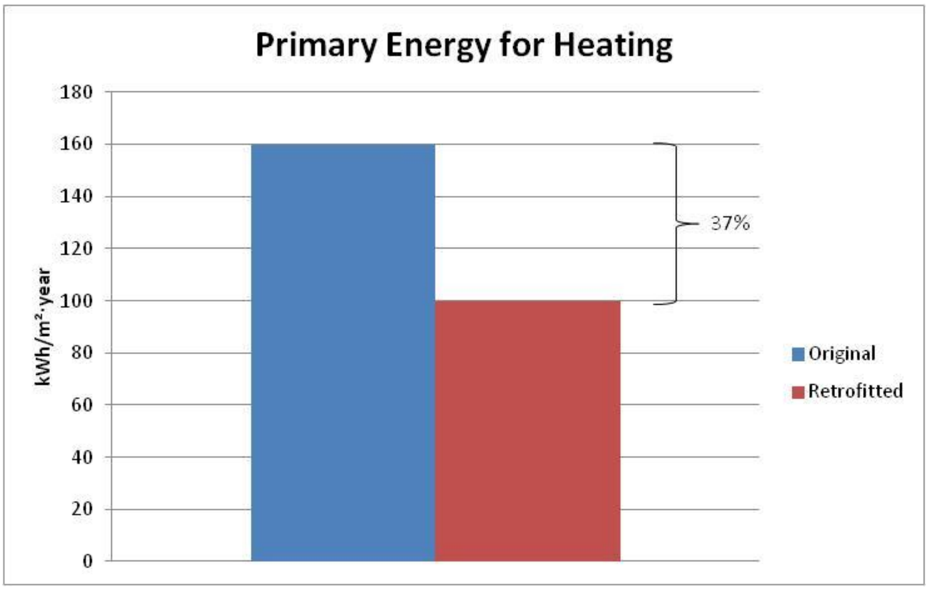


Figure 67: Primary Energy for Heating Comparison

As it can be seen in Figure 67 and Figure 68, the retrofitting solution developed in the EASEE project reduced a 37% of the primary energy demand for heating, and a 38% in heating emissions.

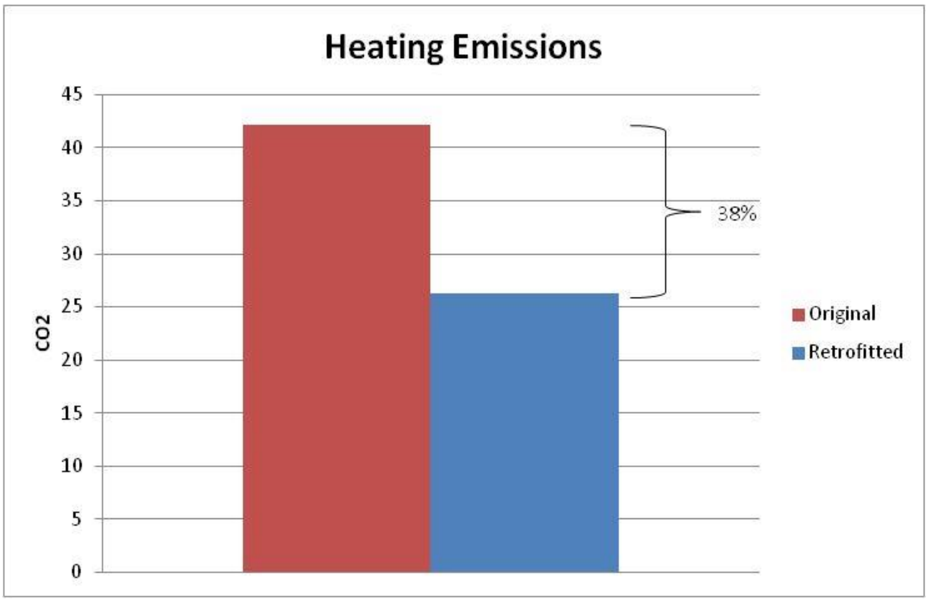


Figure 68: Heating Emissions Comparison

The savings calculated with this software are larger than those estimated by the retrofitting planner (based on the commercial IES VE software suite). This difference in the results was because the building model used in the IDEA software was performed considering only the room where the retrofitting was performed, and not taking into account the rest of the building (as in Figure 65). Which means that the simulation model used was a building the size of the demo house room, with one retrofitted wall, two non-retrofitted walls, and the last wall was modelled as a wall with no heat loss.

Therefore, the model used for this simulation was smaller than the real Spanish demo building (as small as the Spanish demo building room) and did not considered any other heat losses that could take in the rest of the building.

2.2.3.3 Thermal comfort evaluation

The impact of the EASEE panels retrofitting on thermal comfort has been evaluate again through the IES VE software by simulating the air temperature, mean radiant temperature and dry resultant temperature before and after the retrofit. The results are shown below.

Air Temperature

For the entire building, as can be seen in Figure 69 (Baseline, Retrofit) the air temperature has increased showing the improvement in the thermal performance of the building envelope from the retrofit solution. The minimum air temperature value has been improved from 12.3°C to 12.6°C. The maximum air temperature has remained almost constant at about 30°C.

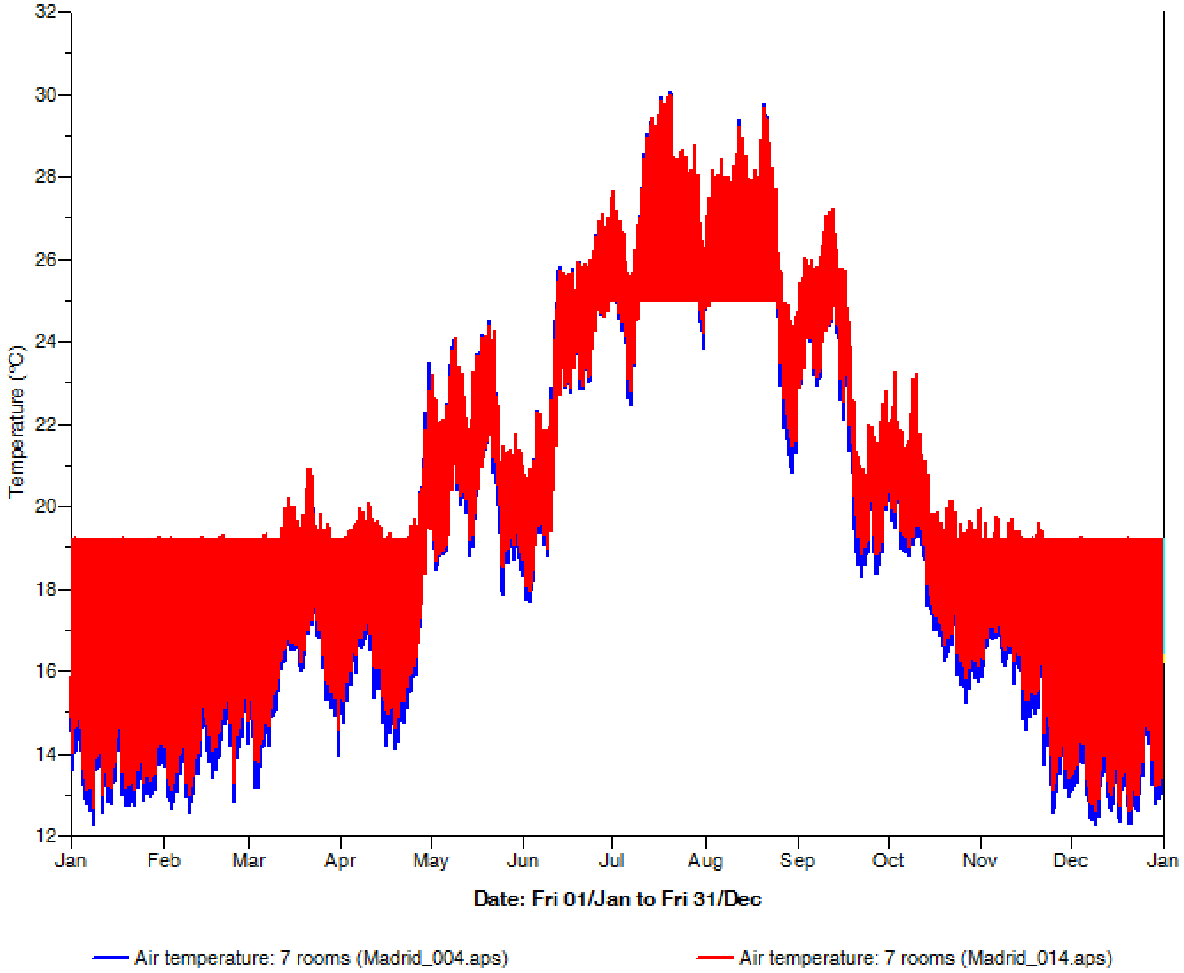


Figure 69: Air Temperature for the whole Spanish Demo Building (Baseline, Retrofit)

We can see the change in air temperature for the entire building in the range test below which shows the amount of hours the air temperature was in a particular temperature range for the entire building.

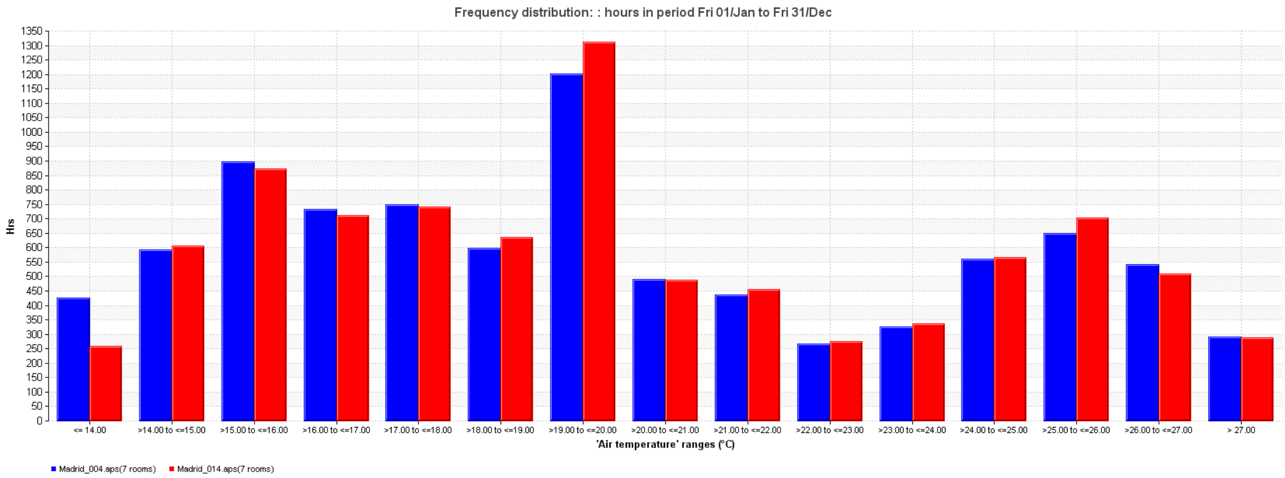


Figure 70 Amount of hours the air temperature was in a particular temperature range for the entire building

An example of the improvement air temperature from retrofitting can be seen in the chart below (Baseline, Retrofit, Heating Setpoint) which displays the combined air temperature in on the day the worst case external temperature occurs January 23rd.

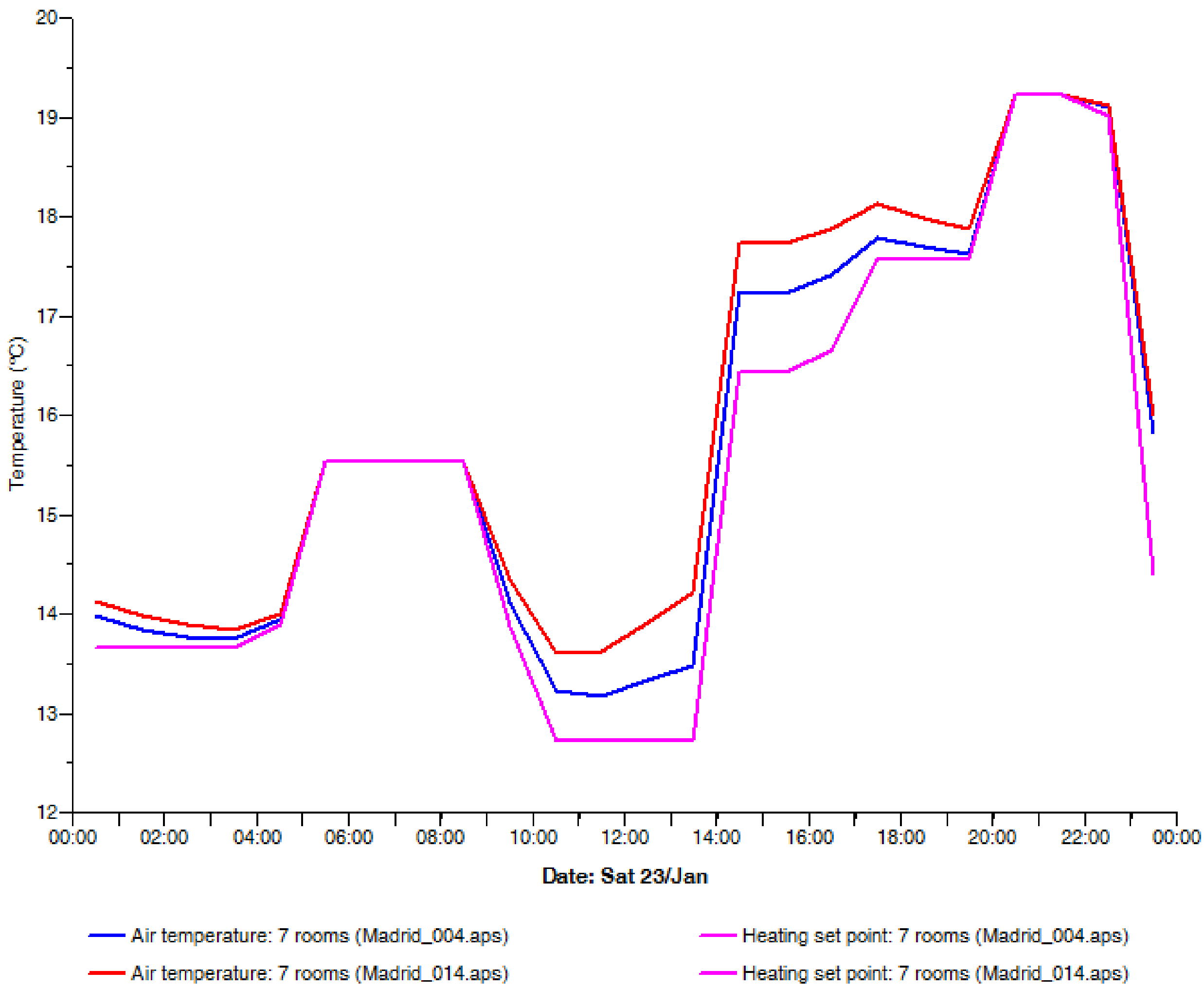


Figure 71: Combined air temperature (Baseline, Retrofit) on January 23rd

The improvement in the building envelope thermal performance can be clearly seen. The minimum air temperature occurring has improved from 13.2°C to 13.6°C while the mean air temperature has also increased from 15.7°C to 15.9°C.

Mean Radiant Temperature

For the entire building, as can be seen in Figure 72 (Baseline, Retrofit) the mean radiant temperature has increased showing the improvement in the thermal performance of the building envelope from the retrofit solution. The minimum mean radiant temperature value has been improved from 11.7°C to 12.3°C. The maximum mean radiant temperature has decreased from 30.06°C to 29.9°C.

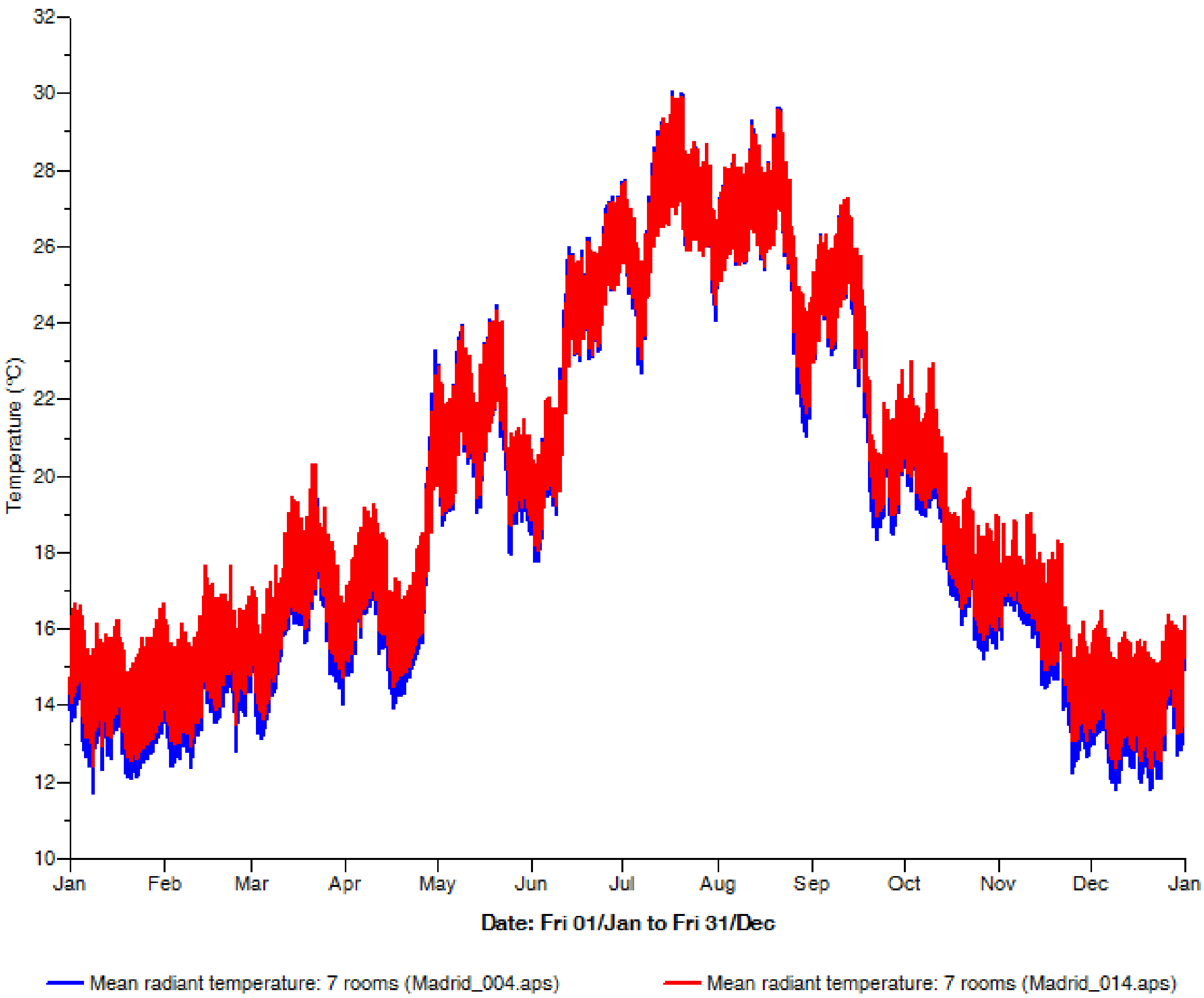


Figure 72: Mean radiant temperature for the whole building (Baseline, Retrofit)

An example of the improvement mean radiant temperature from retrofitting can be seen in the chart below (Baseline, Retrofit) which displays the combined mean radiant temperature on the day the worst case external temperature occurs (January 23rd).

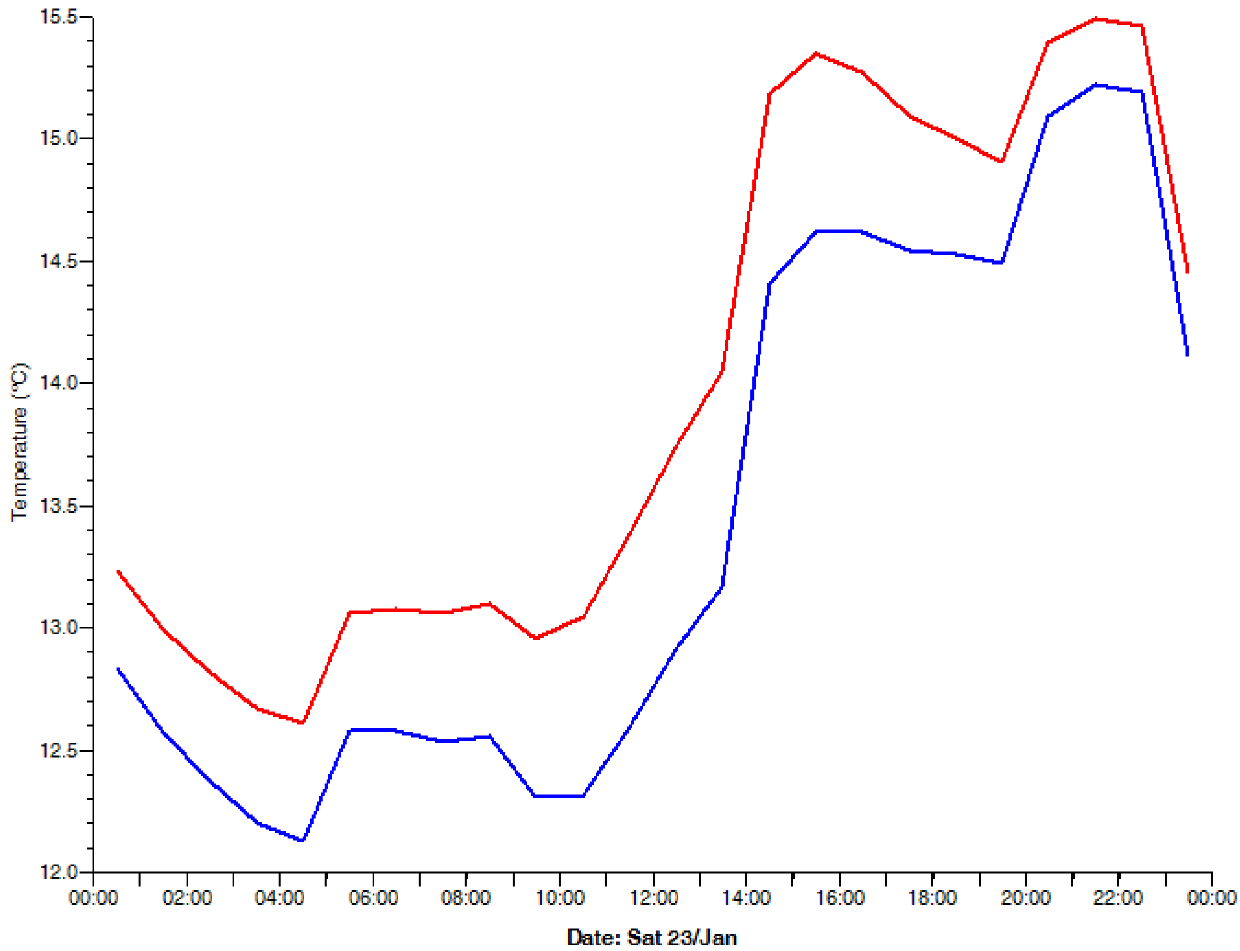


Figure 73: Mean radiant temperature for apartment 1 on January 23rd

The improvement in the building envelope thermal performance can be clearly seen. The minimum mean radiant temperature occurring has improved from 12.1°C to 12.6°C while the maximum mean radiant temperature has also increased from 15.2°C to 15.5°C.

Dry, resultant temperature

For the entire building, as can be seen in Figure 74 (Baseline, Retrofit) the dry resultant temperature has increased showing the improvement in the thermal performance of the building envelope from the retrofit solution. The minimum dry resultant temperature value has been improved from 11.9°C to 12.5°C. The maximum dry resultant temperature has only slightly decreased from 30.04°C to 29.97°C.

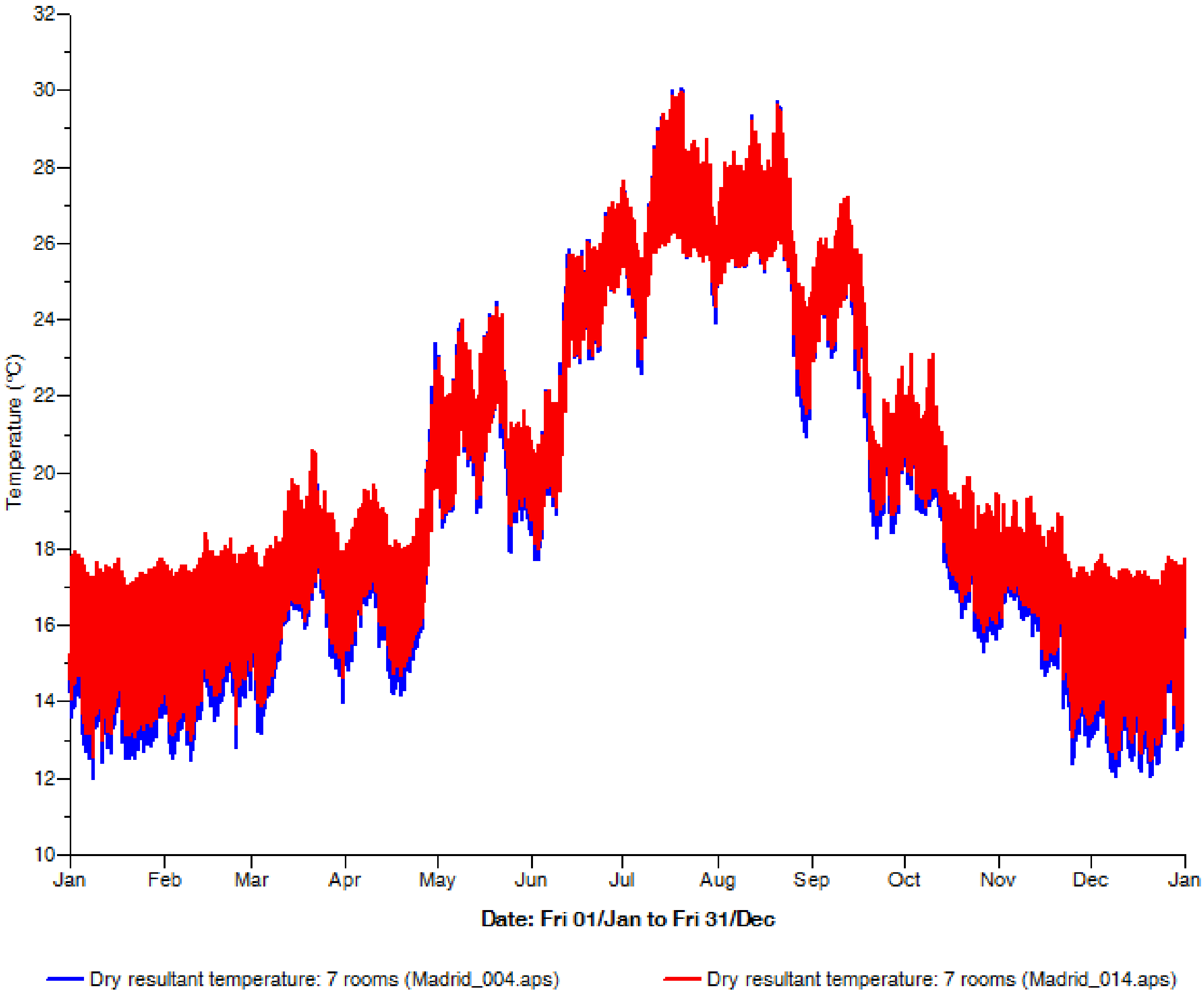


Figure 74: Dry resultant temperature for the whole building (Baseline, Retrofit)

The change in dry resultant temperature for the entire building can be seen in the range test below which shows the amount of hours the dry resultant temperature was in a particular temperature range for the entire building.

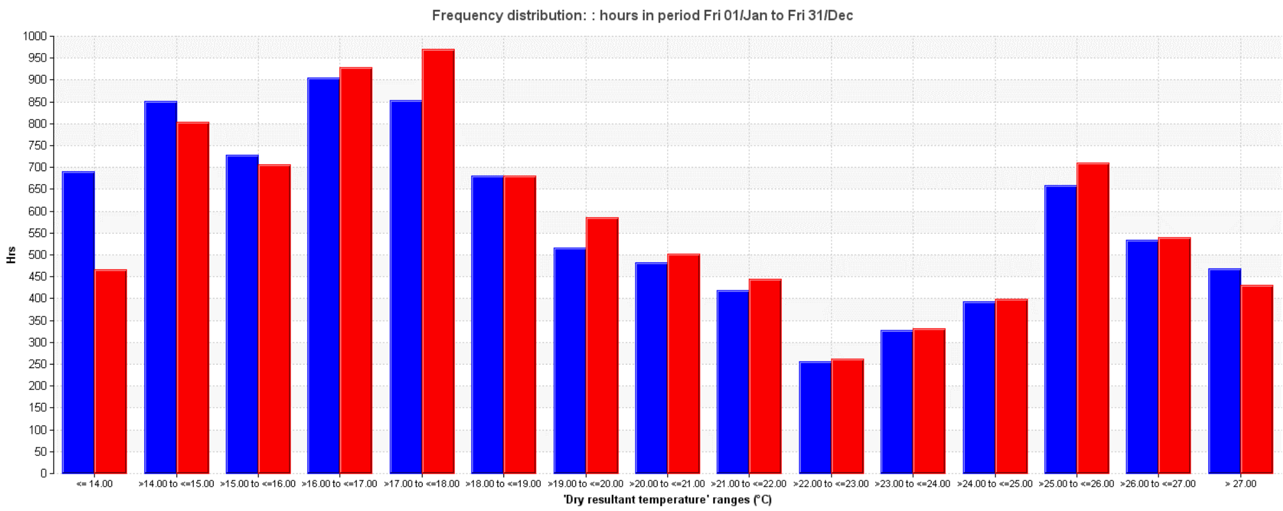


Figure 75: Amount of hours the dry resultant temperature was in a particular temperature range for the entire building

An example of the improvement dry resultant temperature from retrofitting can be seen in the chart below (Baseline, Retrofit) which displays the combined dry resultant temperature on the day the worst case external temperature occurs January 23rd.

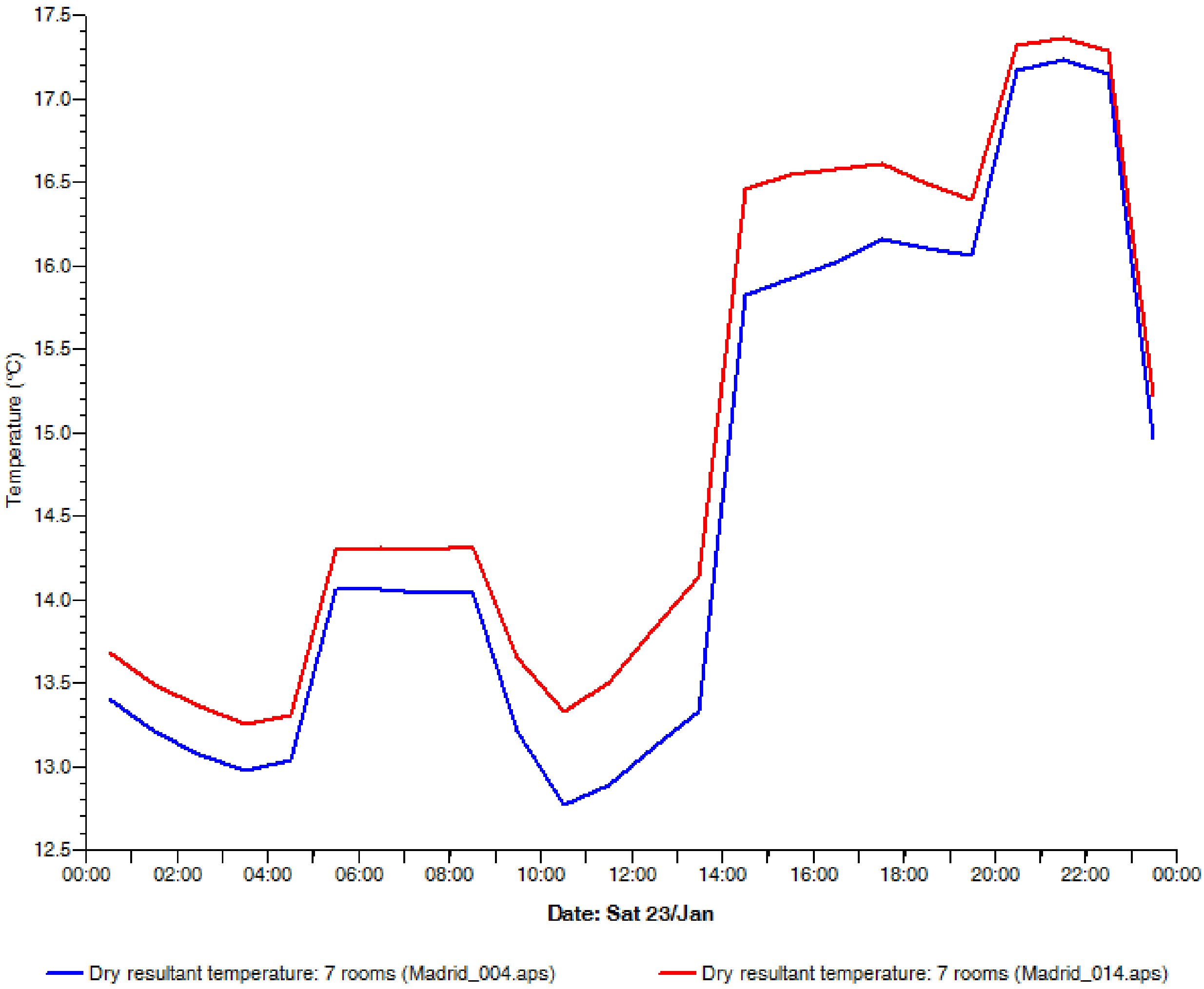


Figure 76: Dry resultant temperature (Baseline, Retrofit) on January 23rd

The improvement in the building envelope thermal performance can be clearly seen. The minimum dry resultant temperature occurring has improved from 12.8°C to 13.3°C. While the maximum dry resultant temperature has also increased from 17.2°C to 17.4°C.

ISO comfort indices: Predicted Mean Vote (PMV) & Percentage of People Dissatisfied (PPD)

For the entire building, as can be seen in Figure 77 (Baseline, Retrofit) the PMV has been improved. The minimum PMV value has been improved from -1.82 to -1.71. The maximum PMV has slightly decrease from 1.76 to 1.74, while the average combined PMV for the entire building has improved from -0.30 to -0.26

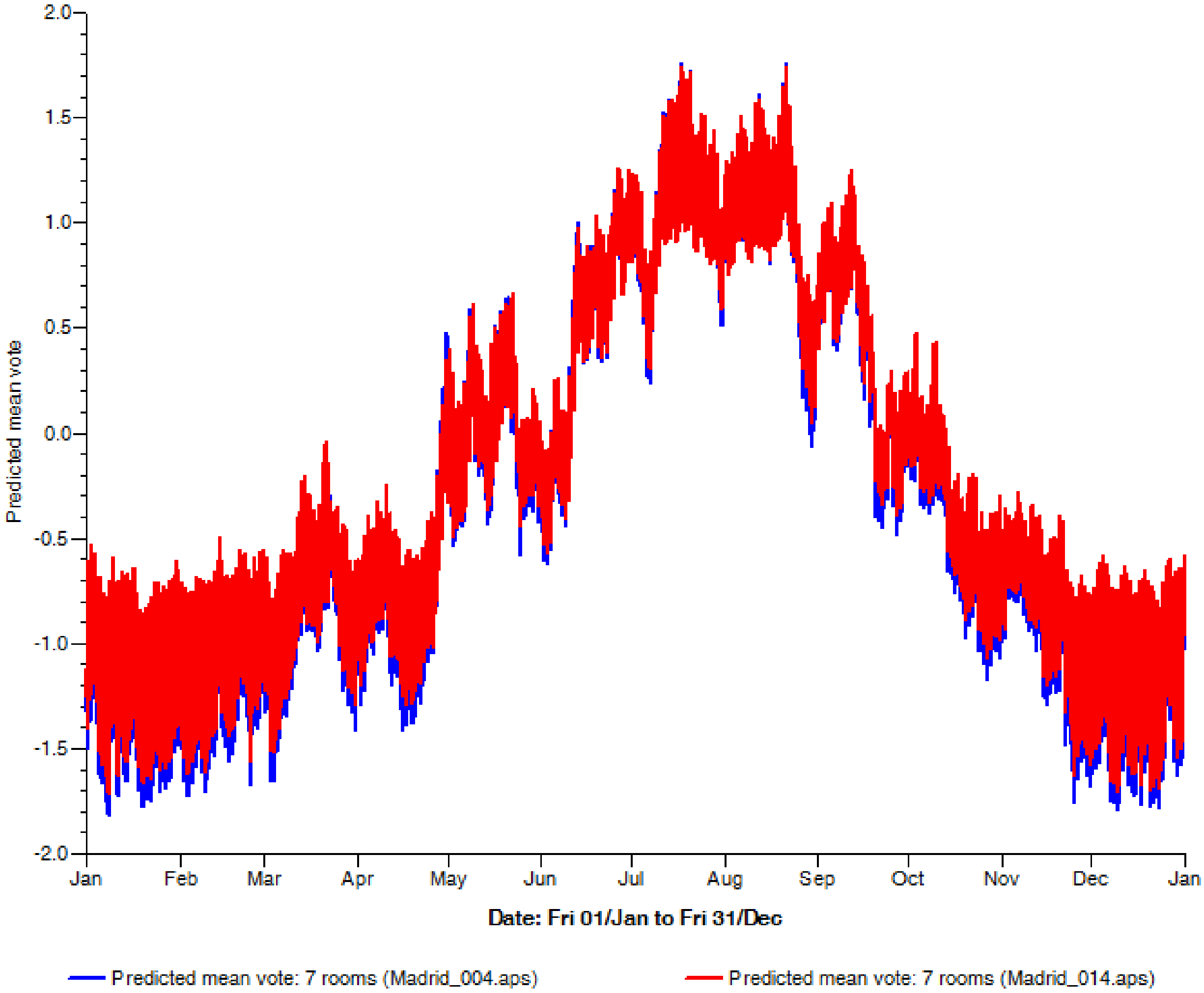


Figure 77 PMV for the whole Spanish Demo Building (Baseline, Retrofit)

The combined PPD for the entire building can be seen in Figure 78 (Baseline, Retrofit). This shows a clear reduction in the PPD across the entire building. A synopsis of the above chart shows an decrease of the minimum PPD from 5.03% to 5.01%. A reduction in the maximum PPD value from 67.72% to 63.34% and an overall reduction in the mean PPD value from 23.80% to 22.39% can be seen.

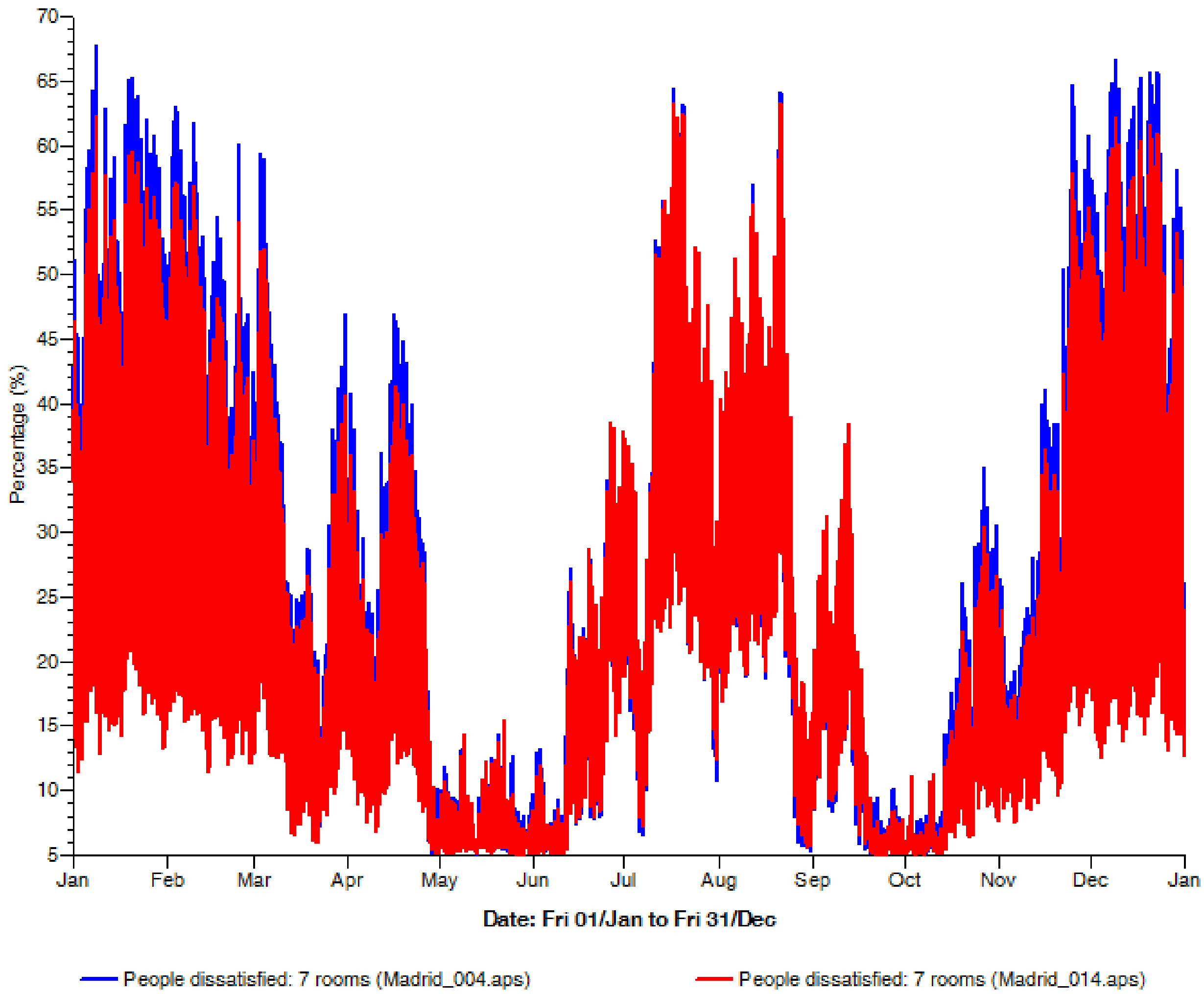


Figure 78 PPD Spanish Demo Building

As said, for PPD looking at the entire building as a whole does not provide a fair reflection on the improvement seen through applying the retrofit solution. Therefore, results for the kitchen on the worst case day for external temperature are shown below.

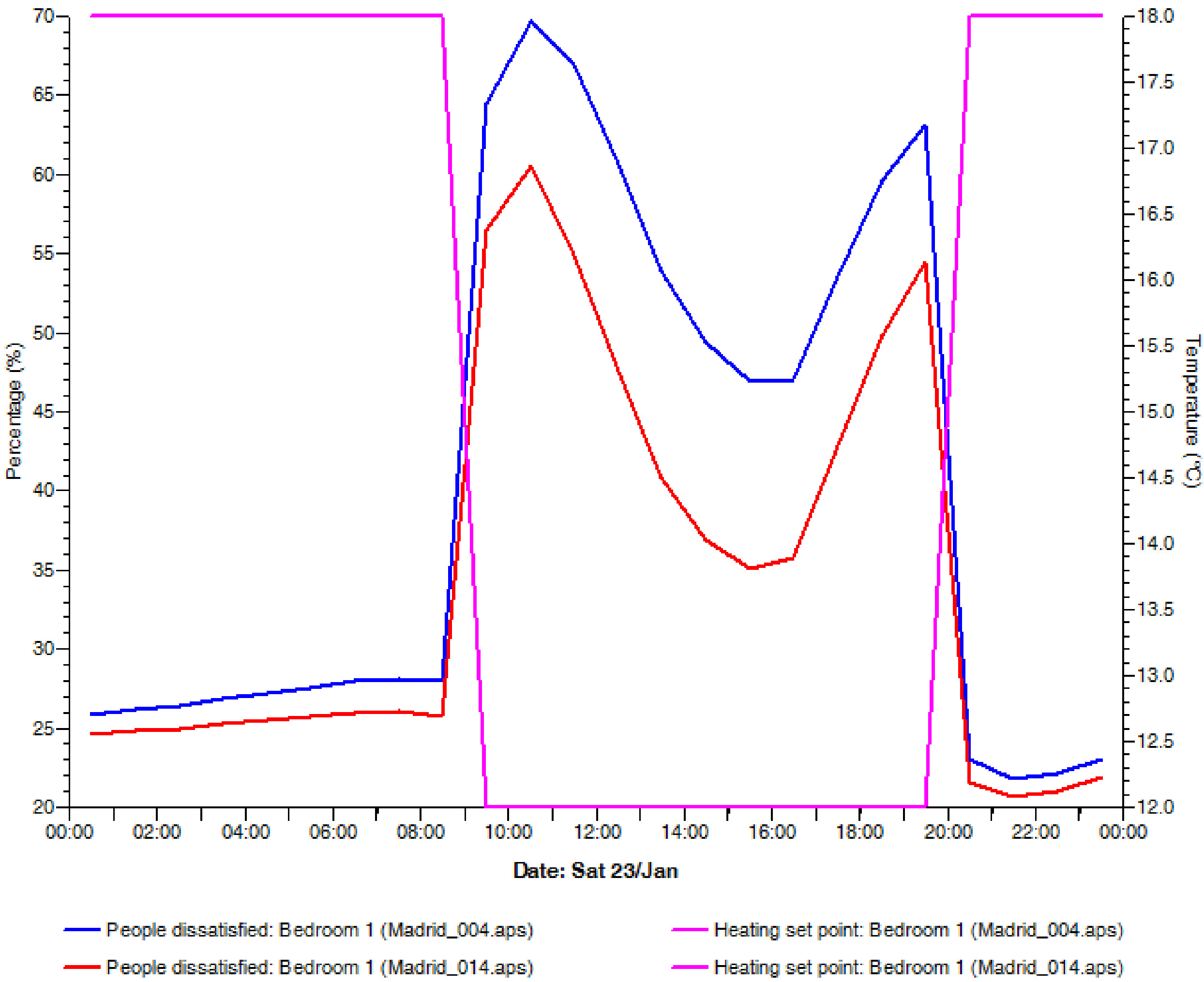


Figure 79: PPD for the Kitchen (Baseline, Retrofit, Heating Setpoint)

The PPD for the Kitchen can be seen above in Figure 79 (Baseline, Retrofit, Heating Setpoint). This shows a clear reduction in the PPD at all times but if we look at the times when the room is conditioned we see a reduction in minimum PPD 21.82% to 20.68%. A reduction in the maximum PPD value from 27.96% to 25.80%.

The Spanish demo building is a property that the owners only use in holidays. So it is not a building which is occupied the entire year, therefore buildings occupants were unable to give an opinion about the performance of the retrofitting. However, inner temperatures in the different stages of the retrofitting interventions have been evaluated as a measure of the improved comfort due to the EASEE solutions.

In the following graph monitoring data during a day related to the initial configuration of the building (wall without insulation) is provided. As it can be seen, the variation in the interior temperature is of 3.1°C. This variation is quite significant and was due to the bad isolation that the façade provides to the building.

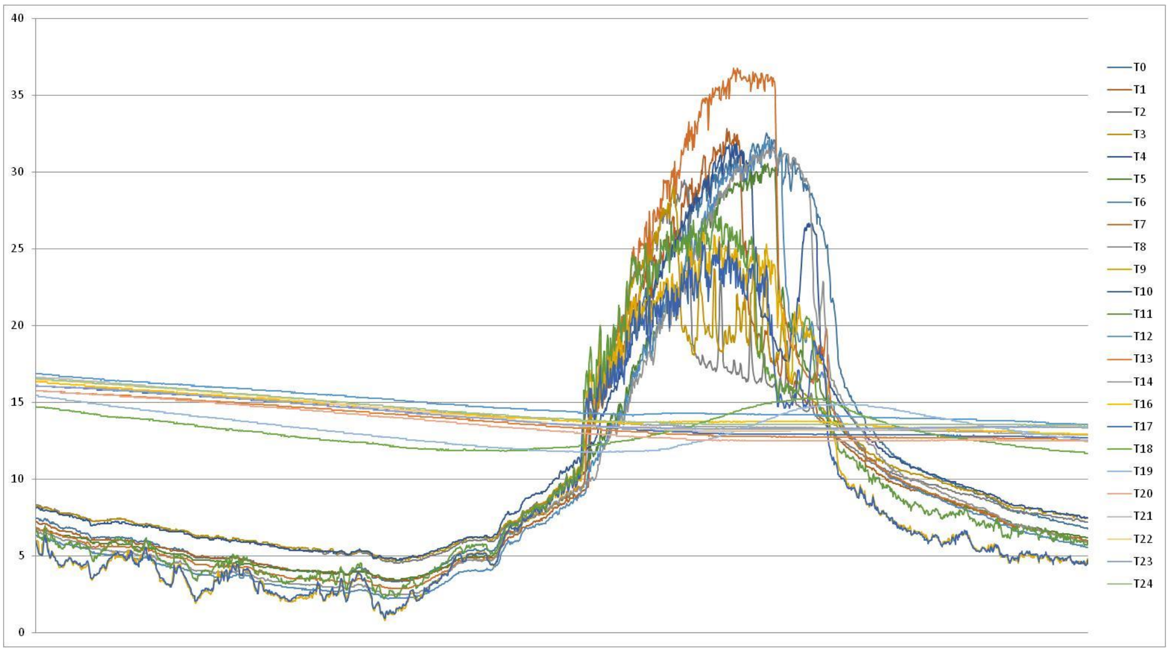


Figure 80: Before retrofitting data logging (27/01/2015)

In the Figure below, a representation of the data logged after the internal retrofitting of the building is displayed. As it can be seen, the variation of the internal temperature ranges from 11,6°C to 10,3°C. This variation is smaller than in the previous case without any retrofitting, which means that the isolation has improved.

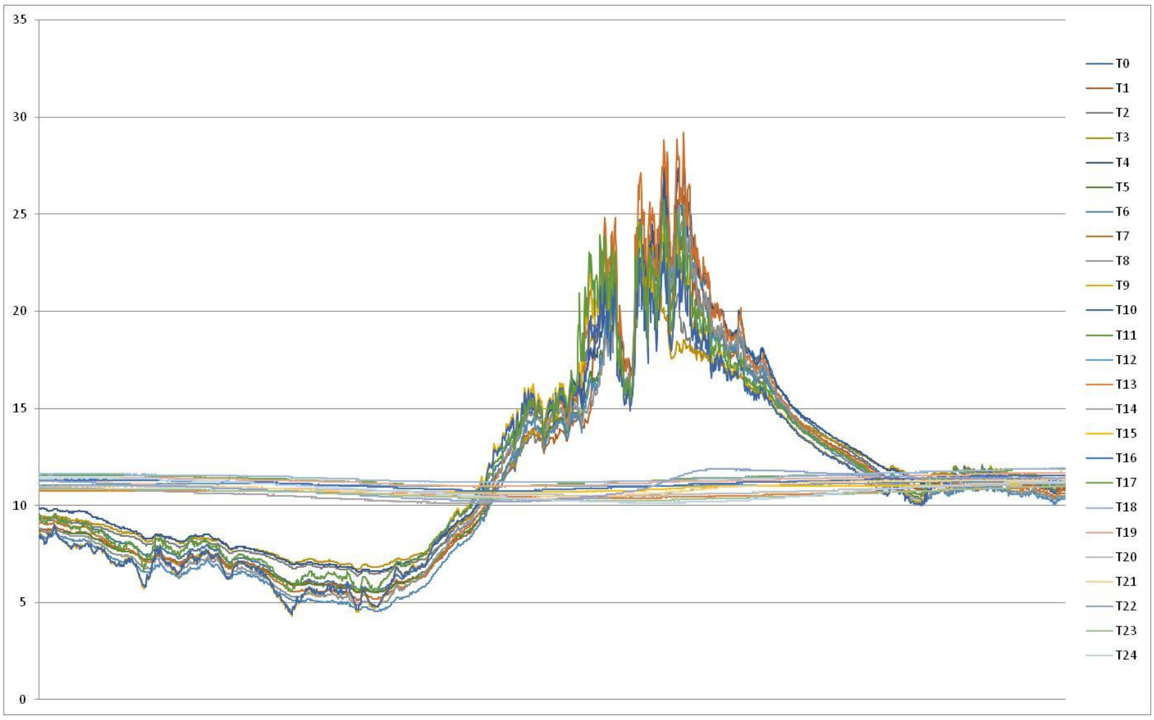


Figure 81: After internal retrofitting data logging (28/02/2015)

Figure 82 represents the final stage of the retrofitting solution (cavity and external retrofitting). The difference between the maximum and minimum temperature in the inside of the building was 0,8°C. And as it can be understood by comparing this value with the previous obtained, the improvement of the thermal comfort in the building has increased significantly.

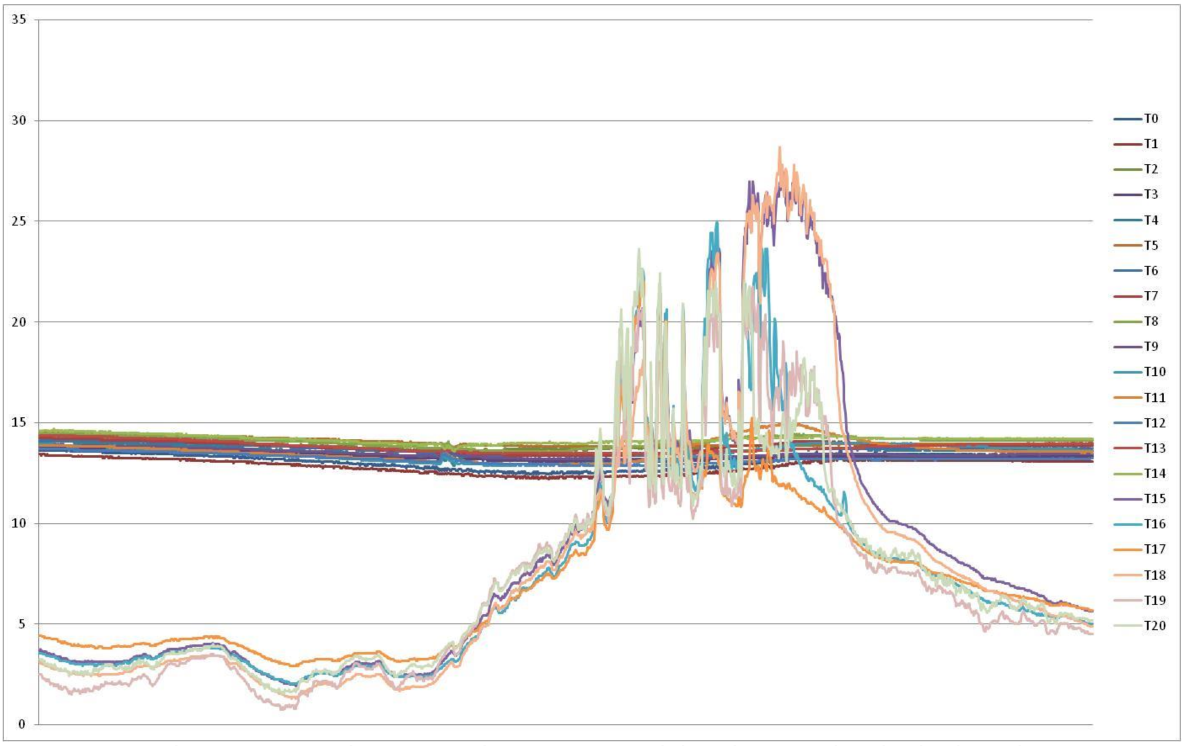


Figure 82: After internal and external retrofitting data logging (18/01/2016)

3 Economic impacts

3.1 Goal and scope

The industrial target of EASEE was to achieve the energy performance required by national regulation with a combination of innovative solutions whose initial price will be higher than standard ones, but that will reduce or even eliminate the additional costs related to standard retrofitting procedure thanks to the easy installation of modular components on the existing façade without scaffolding. Furthermore, part of the cost could be recovered through the energy savings during the years.

In the following sections, an estimation of the economic impact of the EASEE retrofitting solutions is provided starting from the experience of the demo buildings. The analysis has been performed using the Retrofitting Planner, which uses the LCC module of the IES VE software and the DEFT tool. LCC module allows to estimate the running cost associated with the building operation, analyses the capital cost and the cost of ownership over the life of a building, compares the trade-offs in terms of cost among a selection of various constructions, materials or systems. DEFT is a data comparison tool that takes the measurements of a set of key performance indices such as capital cost and thermal performance directly from the model files and quickly allows the user to compare the effectiveness of each retrofitting option against a base option.

3.1.1 Main assumptions and Key Indicators (KI)

The main assumptions for the analysis were the following:

- Data from D9.4 have been taken concerning the Ex Work costs of the project solutions;
- Different scenarios have been considered per each demo according to the solutions installed;
- For the LCC input values, the sum of Installation costs, scaffolding costs, manpower costs and finishing costs was taken as the construction cost for the panel. Data were obtained from D9.4 as well as from interviews with the partners involved in the demo buildings retrofit.

As key indicators of the economic impact, the following quantities have been considered:

- Economic savings: €/year
- Payback time

3.2 Main results per demo building

3.2.1 Italian demo building

The following table shows the output of the analysis with the DEFT tool for the Italian demo building in Cinisello Balsamo, where option 1 is the building before retrofitting while option 2 is the retrofitting solution applied to the construction and the matching EASEE costing data.

The variables which are shown in DEFT are user defined and here a selection which allows us to quickly compare the two options can be seen.

How much energy and money would be saved over the course of a 60 year lifecycle analysis by using the EASEE retrofitting panel solution is provided. The annual energy savings would be around 71,500 kWh per annum and if a kWh unit rate of € 0.14 is taken, that would be up to € 10000 saved per annum for the whole building.

The calculated payback time is 7,8 years to save back the additional cost , which is in line with the expectations in the proposal. In the remaining years of the 60 included in the analysis, about €350000 will be saved along with 4,291 MWh of energy.[1]

[1] Please note that the unit £ in the table corresponds to Euros

Index	Unit	Option 1	Option 2
Performance			
Total CE	kgCO2	91,837.40	83,964.10
Total energy	MWh	636.73	565.19
Cost			
Lifecycle total costs	£	113,819	173,075
Lifecycle costs excl. construction cost	£	58,791.40	118,048
Construction cost	£	55,027.50	55,027.50
Maintenance / repair/ decorate / replace cost	£	58,791.40	79,767.90
Cleaning cost	£	0	38,280
Building form			
Core / perimeter area ratio	%	14.04	14.04
External surface area to volume ratio	%	44.90	44.90
External wall area	m²	957.03	957.03
% external windows area / external walls area (all)	%	10.44	10.44
Opaque constructions			
External wall constructions surface area weighted U value	W/m²·K	1.21	0.40

Figure 83: Economic impacts of the EASEE panels for the Italian demo building

3.2.2 Polish demo building

The following table shows the output of the analysis with the DEFT tool for the Polish demo building in Gdansk, where option 1 is the building before retrofitting while option 2 is the building renovated with the EASEE panels and internal insulation (assuming that the whole building would have been retrofitted).

How much energy and money would be saved over the course of our 60 year lifecycle analysis by using the EASEE retrofit panels and internal insulation is provided.

Energy savings up to 24,650 kWh per annum could be achieved and if a kWh unit rate of € 0.14 is taken, that would be € 3450 saved per annum for the whole building.

The calculated payback time would be around 7.3 years, in line with the objectives of the proposal and in the remaining years of the 60 included in the analysis the saved money would reach €123,500 along with 1,480 MWh of energy.

Index	Unit	Option 1	Option 2
Performance			
Total CE	kgCO2	38,605	33,998.30
Total energy	MWh	129.93	105.28
Cost			
Lifecycle total costs	£	65,983	83,011.10
Lifecycle costs excl. construction cost	£	34,082.50	56,618.60
Construction cost	£	31,900.50	26,392.50
Maintenance / repair/ decorate / replace cost	£	34,082.50	38,258.60
Cleaning cost	£	0	18,360
Building form			
Core / perimeter area ratio	%	0	0
External surface area to volume ratio	%	56.09	56.09
External wall area	m²	459.07	459.07
% external windows area / external walls area (all)	%	8.18	8.18
Opaque constructions			
External wall constructions surface area weighted U value	W/m²·K	1	0.27

Figure 84: Economic impacts of the EASEE panels for the Polish demo building

3.2.3 Spanish demo building

The following table shows the output of the analysis with the DEFT tool for the Spanish demo building in Madrid, where option 1 is the building before retrofitting while option 2 is the building renovated with the EASEE panels and cavity wall insulation (assuming that the whole building would have been retrofitted).

How much energy and money would be saved over the course of a 60 year lifecycle analysis by using the EASEE retrofitting solution is provided. Savings would be around 320 kWh per annum that, if a kWh unit rate of € 0.14 is assumed, would correspond to € 315 saved per annum.

The estimated payback time with those saving would be about 10 years, slightly higher than those foreseen in the proposal but still reasonable for an innovative solution. In the remaining years of the 60 included in the analysis the total savings would be above €15600 along with 200 MWh of energy.

Index	Unit	Option 1	Option 2
Performance			
Total CE	$kgCO_2$	6,971.09	6,560.40
Total energy	MWh	19.24	18.02
Cost			
Lifecycle total costs	£	24,437.90	27,704.20
Lifecycle costs excl. construction cost	£	13,972.90	14,509.20
Construction cost	£	10,465	13,195
Maintenance / repair/ decorate / replace cost	£	13,972.90	14,509.20
Cleaning cost	£	0	0
Building form			
Core / perimeter area ratio	%	0	0
External surface area to volume ratio	%	101.66	101.66
External wall area	m^2	181.75	181.75
% external windows area / external walls area (all)	%	9.41	9.41
Opaque constructions			
External wall constructions surface area weighted U value	$W/m^2 \cdot K$	0.96	0.37

Figure 85: Economic impacts of the EASEE panels for the Spanish demo building

4 Indirect industrial impacts

4.1 Retrofitting process duration and workforce

In this section the process and duration of the installations in the three demo buildings is summarised in order to verify what was expected in the Description of Work in terms of developing an easy to install retrofitting solution.

It is widely recognized that traditional retrofitting approach to energy efficient envelope retrofitting, especially for residential multi-storey buildings, is an extremely labour intensive procedure based on the manual removal of the whole or large part of the plaster which covers the façade and on the subsequent installation of a series of layers (adhesive mortar, insulation foam, mechanical fasteners, reinforcing mesh and an exterior layer including a base coat and a finish) through a wet process. Further to this, the duration of the intervention is increased also due dead times associated to the wet process in unfavorable weather conditions and removal of waste associated to existing plaster removal. Finally, many workforces are needed to carry out manual operations.

In the three demo sites, the retrofitting process was carried out considerably quickly than the usual time. In particular, in the Polish demo building, the EASEE panels were applied on one façade while the rest of the building was renovated with a standard ETICS system. This allowed for a comparison of the installation time between the two solutions, that in that case were applied with scaffoldings. Taking into account the two different retrofitting processes, the installation process of EASEE panels was relatively fast and efficient. The average time of installation of 1 m^2 of EASEE solution was 25 minutes (1h = 2,5m^2), while the installation of 1m^2 of system based on ETICS required 120 minutes (1h = 0,5 m^2).

Another important advantage with the prefabricated EASEE panels was the possibility to cover building imperfection by adjusting the anchorage system, as for example the non-perfect wall inclination. Last but not least, the prefabricated nature of the EASEE panels and the fact that they do not need any finishing allowed to work also in bad weather conditions due to the dry process used, considerably reducing the dead times especially in cold climates.

Concerning the Spanish demo building, the retrofitting procedure was mainly constituted by two processes: the cavity wall retrofitting through hydrophobized perlite and the external retrofitting through prefabricated panels.

The first step of the cavity wall retrofitting was the installation of the plasterboard and then the cavity wall was filled with perlite. This retrofitting process took two days.

The external retrofitting was performed through the installation of the insulating panels and anchoring system developed in the project. The assembly of the insulating panels in the anchoring system was done using a truck crane. Here the façade was also painted for aesthetical reasons, thus increasing the time for intervention. However, the entire process took two weeks of which only two days were needed for the assembly of the panels.

For the Italian demo building, the retrofitting process consisted in the installation of more than 186 panels for a total of 26 different typologies in terms of size, colors and textures.

More than 580 square meters have been retrofitted through the EASEE panels without scaffoldings in less than 3 months. The process was entirely carried out without scaffoldings and this was really appreciated by the building occupants.

As an overall conclusion, the EASEE panels showed a shorter installation time in three different conditions of applications (with scaffoldings, with external finishing and at full building scale), thus confirming the overall increased efficiency of the proposed retrofitting approach.

4.2 Minimum burden on occupants

One of the main advantages of the EASEE solution for external retrofitting is the fact that the panels are ready to install and they do not need any on-site finishing or wet processes, which

considerably speed up the installation process, minimising the burden to occupants. In two of the three demo buildings, the panels were installed without fixed scaffoldings, as described in detail in Deliverable D8.1 “Solutions applied to demo buildings”.
Informal interviews have been carried out with occupants of the Polish and Italian demo buildings in order to understand their impressions on the retrofitting intervention carried out during the project. For the Spanish demo site, this was not done as the building was not occupied at the time of the intervention.
Concerning the Polish demo building, the occupants really appreciated the mixed retrofitting approach used, combining two different façade system in one building, a more traditional and a more innovative ones. The quick installation time was also appreciated.
For the Italian demo building, as said before occupants were positively impressed by the quick installation time and by the fact that everything was done without scaffoldings. They also mentioned that the internal comfort was improved in the few weeks after the completion of the intervention.

4.3 Environmental impacts

The environmental impact of the EASEE retrofitting solutions can be evaluated in terms of reduction of CO_2 emissions associated to the improved energy performances.
The CO_2 saved thanks to the retrofitting intervention through EASEE approach was obtained from simulations with the Retrofitting Planner (based on the IES VE software) per each demo building (see the tables in sections 3.2.1, 3.2.2 and 3.2.3).
Overall, reduction of about 10% in CO_2 emissions has been obtained in each of the demo buildings. In particular, in the winter period, 1600, 920 and 100 kgCO_2 were saved per month in the Italian, Polish and Spanish buildings respectively.

4.4 On site waste production

In all the demo buildings, no plaster removal or wall surface preparation or correction was needed before performing the retrofitting. And as no surface preparation in the wall was needed, not much waste was generated with regards to the plaster removal. The other main benefit of the solutions developed in the project, was that unlike the traditional retrofitting processes, the EASEE solution is manufactured “ready to install” with simple anchoring and does not need many manual work on site. This working methodology provided a reduced production of waste on site.

4.5 Indirect economic benefits

4.5.1 Increase of turnover for the EU construction sector

In order to derive the indirect economic benefits, it is necessary firstly to quantify the potential market for EASEE products, once they have been fully commercialised. For the purposes of this estimation, the target year is 2020, i.e. some 2 years after all the insulation products have been launched commercially.
In 2014, the total market for thermal insulation products in EU-27 was 235 million m^3, weighing 7.4 million tonnes, with an approximate market value of €11.5 billion. 87% of the market, i.e. €10 billion, is in commercial and domestic buildings, with the remainder in industrial applications[2]. The market is poised to grow at a rate of 2.8% year-on-year, giving a total demand for thermal insulation products in the European buildings sector worth approx. €11.8 bn in 2020 in today’s money.

[2] www.ialconsultants.com, 2015

This growth in market is likely to come from a number of factors, primarily legislative, with drivers such as the Energy Performance of Buildings Directive and the Energy Efficiency Directive, as well as initiatives at national, regional and local level to address the historic legacy of the majority of buildings having been constructed without minimum thermal performance requirements. Equally, growth will come from new products, such as those developed within EASEE, which offer the potential to open previously inaccessible markets with the new solutions, or by offering easier and/or cheaper solutions compared to existing products on the market.
Assuming one third of the growth is due to new products, the market value of new products in 2019 could be around €0.6bn. EASEE products are poised to capture a share of that market, as well as by displacing part of the original market. Assuming EASEE captures 5% of the new market, and displaces 1% of the existing market, the market size would be:

0.05 x €0.6 bn = €30M/a (new market)
0.01 x €10 bn = €100M/a (existing market)
TOTAL = €130M/a

This is the value of the raw insulation material. The total installed cost, inclusive of labour, transport, marketing, financing and other material costs (e.g. fixings) etc. is typically up to twice the raw material, so one can envisage a retail market worth €260M/a.
Assuming the insulation will generate energy cost savings with a 4-year payback (after product optimisation), this investment leads to cost savings of €65M/a.

Job Creation

According to estimates collated by BPIE[3], energy efficiency investment generates 17 jobs for every €1M investment. Hence, the job creation potential of EASEE insulation products is 4420.

Multiple Benefits

Investing in energy efficiency not only results in cost savings to households and business. There is a raft of other benefits, ranging from improved comfort and health to job creation and improved productivity. Collectively, the full range of impacts is known as the multiple benefits of energy efficiency. The International Energy Agency has promoted this concept in recent years with numerous events and publications, the most recent being “Capturing the Multiple Benefits of Energy Efficiency”, published in 2014[4]. The full range of benefits is summarised in the illustration below, taken from the report.

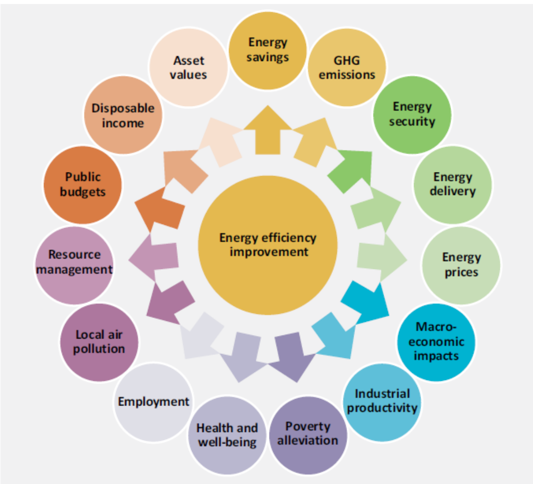


Figure 86: Benefits of energy efficiency[4]

[3] Europe’s Buildings Under the Microscope http://bpie.eu/publication/europes-buildings-under-the-microscope/
[4] http://www.iea.org/publications/freepublications/publication/Captur_the_MultiplBenef_ofEnergyEficiency.pdf

These benefits are rarely monetised when appraising energy efficiency investments, yet they can represent a major additional value, to investors and to society, over and above the energy cost savings. A recent (December 2015) report by ACEEE, "Recognizing the Value of Energy Efficiency's Multiple Benefits"[5] has sought to quantify those benefits, in aggregate. It states: "*The overall value of participant benefits for single-family whole-home programs is between approximately 50% and 300% of utility bill savings*". Clearly these benefits will vary from building to building, and estimating some of the benefits is an inaccurate science, hence the wide range.
Using the ACEEE figures, the aggregate value of the additional benefits arising from EASEE investments would be in the range €32.5-195 M/a.

The Romanian Government, in its national renovation strategy[6] adopted an alternative way of quantifying some of the multiple benefits, from a societal perspective. It identified the following benefits:

- **Economic** – The increased economic activity resulting from the jobs created and investment stimulated has been estimated by the US Environmental Protection Agency to generate 1.5 times the value of energy cost savings in additional output. Additional unquantified benefits arise through increased property values.
- **Societal** – Copenhagen Economics estimate that the health benefits from energy retrofits could be worth around the same value as the saving in energy costs.
- **Environmental** – buildings are the biggest source of CO_2 emissions, and hence the biggest contribution to climate change. The value of the environmental benefit from renovation could be worth of the order of 10% of energy cost savings.
- **Energy System** – In addition to the energy security benefits of being less dependent on energy imports, saving in peak loads through sustainable energy improvements in buildings, including self-generation, are worth approximately the same as the energy cost savings, according to a study by Ecofys[7]. These accrue to all users.

These benefits, expressed as a multiple of the energy cost saving, are summarised in the table below.

ITEM	**MULTIPLIER**
Energy Cost Saving	1.0
Economic Stimulus	1.5
Societal (health) Benefits	1.0
Environmental Benefits	0.1
Energy System Benefits	1.0
TOTAL	**4.6**

Applying these factors to EASEE, the total societal benefit could therefore be as much as 4.6 x €65M/a = €300M/a.

[5] http://aceee.org/research-report/ie1502
[6] http://ec.europa.eu/energy/sites/ener/files/documents/2014_article4_ro_romania.pdf
[7] "Saving energy: bringing down Europe's energy prices for 2020 and beyond", Ecofys, 2013

5 Greek demo buildings

5.1 Design of mock ups and U-values

The small scale demo buildings in Lavrion, are new constructions dedicated to the evaluation of the cavity wall insulation solutions developed within the EASEE project, namely the hydrophobised Natural Expanded Perlite (ENP) and the Synthetic Expanded Perlite (ESP).
The mock ups were built with certain specifications regarding the orientation, the sizes and the materials used and were identical. The walls have a 5cm thick cavity with a total width with the bricks and plaster of 25cm. In Figures below, the design and final constructed buildings can be seen. (Figure 87 and Figure 88)

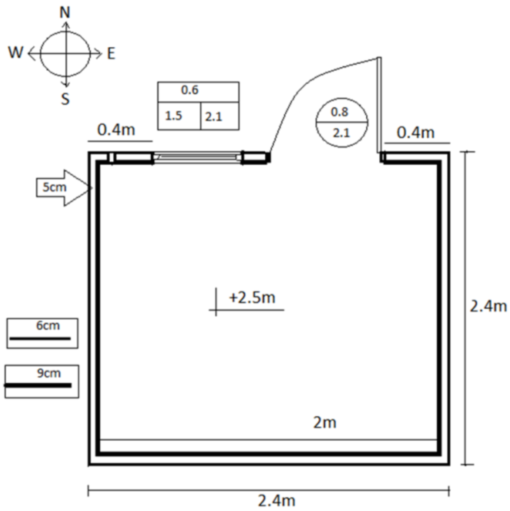


Figure 87: Design of mock ups

Figure 88: Final constructed buildings for monitoring

The theoretically calculated U-values based on the thermal conductivities of the plasters used, of a typical brick wall and of the values measured for the insulating materials are shown in Table below.

Table 10: Theoretical calculated U-values (kW/m^2K)

U-value without insulation	1.53
U-value with ESP	0.53
U-value with hydrophobised ENP	0.64

The walls filled with the two materials were the East and the South for both buildings, while the west wall was left empty as reference and the north wall having the door and a window was filled with a state of the art expanded polystyrene insulating board, so as not to interfere with the other measurements.

5.2 The monitoring system and measured data

A continuous monitoring campaign has been carried out since the beginning of November 2015 which will continue after the project's end to cover a whole year's measurements. However the first 2 months (November 2015 - December 2015) did not present reliable results as the materials in the new constructions were still drying, and thus the period selected for evaluation was from 7^{th} January 2016 to 9^{th} March 2016. No monitoring took place before the insertion of the insulating materials, as they were new construction and the materials were inserted while building them.

In order to better meet the requirements for the evaluation, the focus was on the following kind of data:

- **Weather data**: They are necessary in order to have a correct interpretation of the relative properties of EASEE products and to understand under which conditions the new materials better perform.
- **Indoor thermal conditions**: Indoor temperature and humidity are two of the main parameters for the evaluation of indoor thermal comfort.
- **Heat fluxes and wall temperatures**: the general approach adopted for the measurement system was to measure the wall temperatures on the outside, inside and into the cavity.

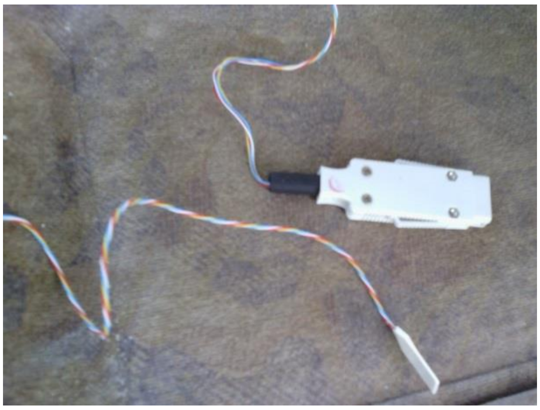
A complete set of sensors, necessary for the thermal conductance evaluation, has been installed in each wall. Each wall has been equipped with 4 sensors, all from Ahlborn Company, in the centre of the surface. On the external side of the wall as it might be exposed to a harsh environment, especially during hot summer or cold winter days, a Pt-100 temperature sensor was used, while for the cavity and the internal side of the wall, T-type thermocouples Cu-CuNi were installed. On the internal wall also a heat flow plate was placed and in the centre of the room a humidity and room temperature sensor was hanged. More specifically the types of sensors were:

- Thermo- wire T 190-2 T Cu- CuNi Type T, with application temperature -10o to +105oC
- Temperature sensor 683 Pt 100 4L, system ALMEMO silicone flat sensor for temperatures -70o to +200o C (Figure 89, c)
- Heat flow plate Type 150-1 System ALMEMO (Figure 89, b)
- Precision humidity/ temperature sensor FHAD36RIC102, with ALMEMO-D6-connector and 4 measuring channels: temperature, relative jumidity, dew point, atmospheric pressure (Figure 89, e)

The data acquisition system where all sensors were connected was ALMEMO 5690-iM (Figure 89, d). All sensors were remotely monitored from the NTUA’s building in the Park. Outside this building a weather station was also installed gathering data for the weather conditions throughout the monitoring period, only 40m far for the mock ups.

a)

b)



c)

d)

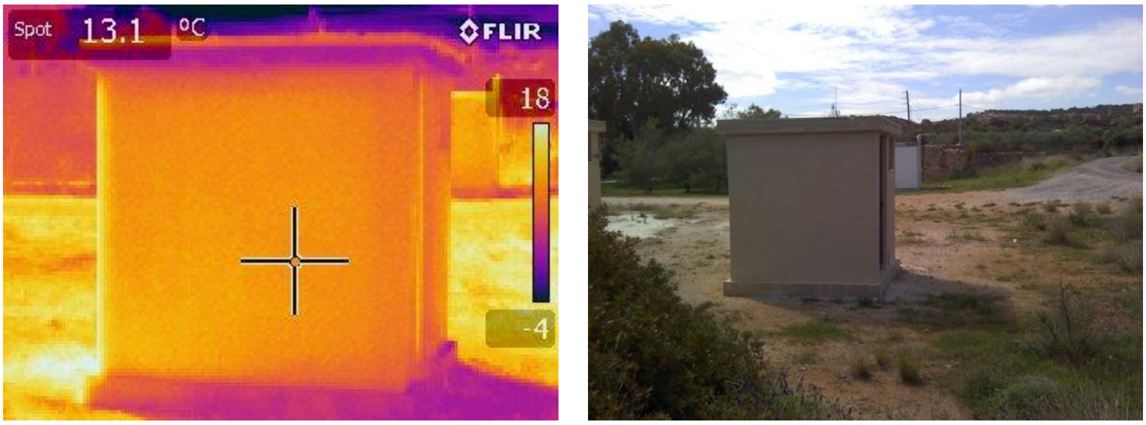
e)

f)

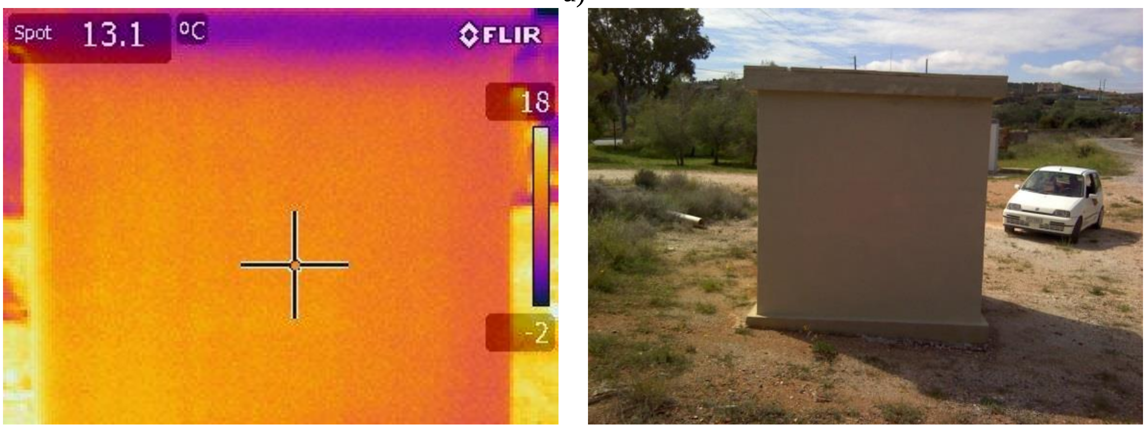
Figure 89: Precision humidity/ temperature sensor FHAD36RIC102 (a); Heat flow plate Type 150-1 (b); Temperature sensor 683 Pt 100 (c); Data acquisition system (d); Inside sensors for wall temperatures, heat flux and indoor temperature and humidity (e); Outdoor temperature sensor (f)

5.3 Thermal Assessment

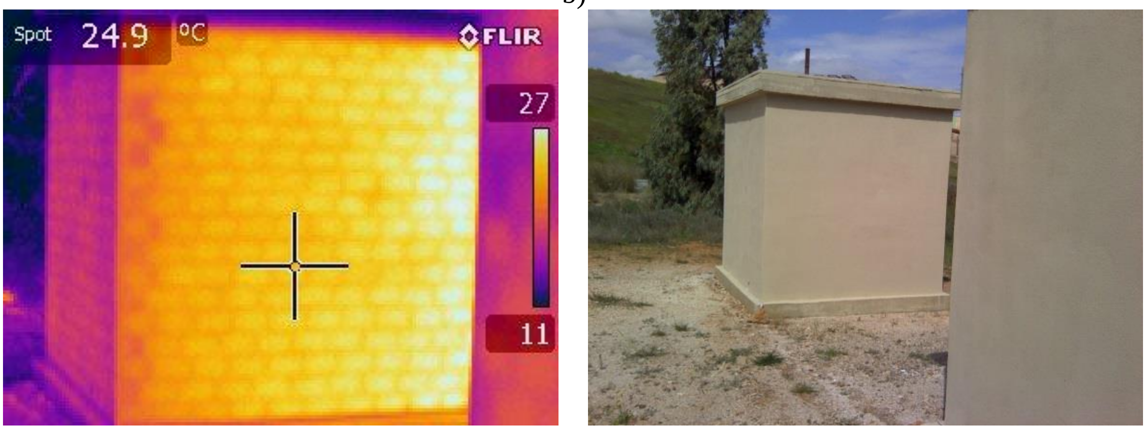
The two buildings were inspected with an infrared camera FLIR. The images presented in Figure 90 (from a) to d)) were taken at middle temperature ambient conditions (13^{o}C). The images of the walls show a homogeneous thermal distribution with no thermal bridges, while the wall temperatures follow the weather temperature (at 13:00: East wall has 13^{o}C and South wall that receives more solar radiation at the time has ~25^{o}C). Also the walls with the same orientation for the building filled with ESP and the one filled with ENP, presented the same temperature for both buildings.
The thermo-photos clearly show that the goal to build two identical buildings has been fully achieved and the measured differences in temperature and heat flux, if any, were only dependent on the insulating material used in the cavities.



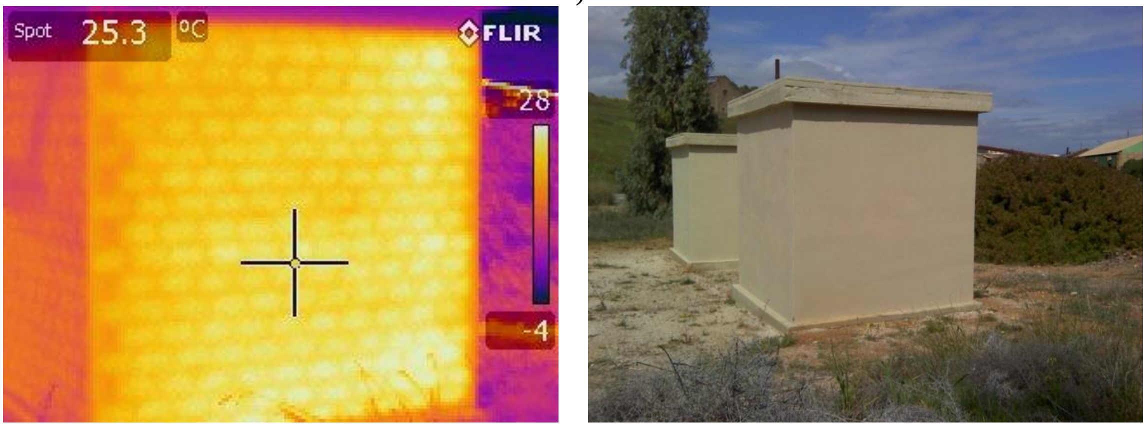
a)



b)



c)



d)

Figure 90: East Wall ESP (a), East Wall ENP (b), South Wall ESP (c), South Wall ENP (d)

5.4 Temperature and heat flux measurements

Figure 91 collects the Heat Flux data from the 3 monitored walls for both buildings along with the outer temperature for reference giving a general overview of the heat flow fluctuations occurring during a typical winter in Greece. Figure 92 concentrates the results obtained on a certain week of February 2016 showing again all the heat flux graphs, but with more details. From these two Figures the following conclusions can be drawn:

- The West walls with no insulation, presented major variations in heat transfer which results in intense heat loses (see also Table 11).
- The South walls showed very low fluctuation of Heat Fluxes, with no evaluable differences.

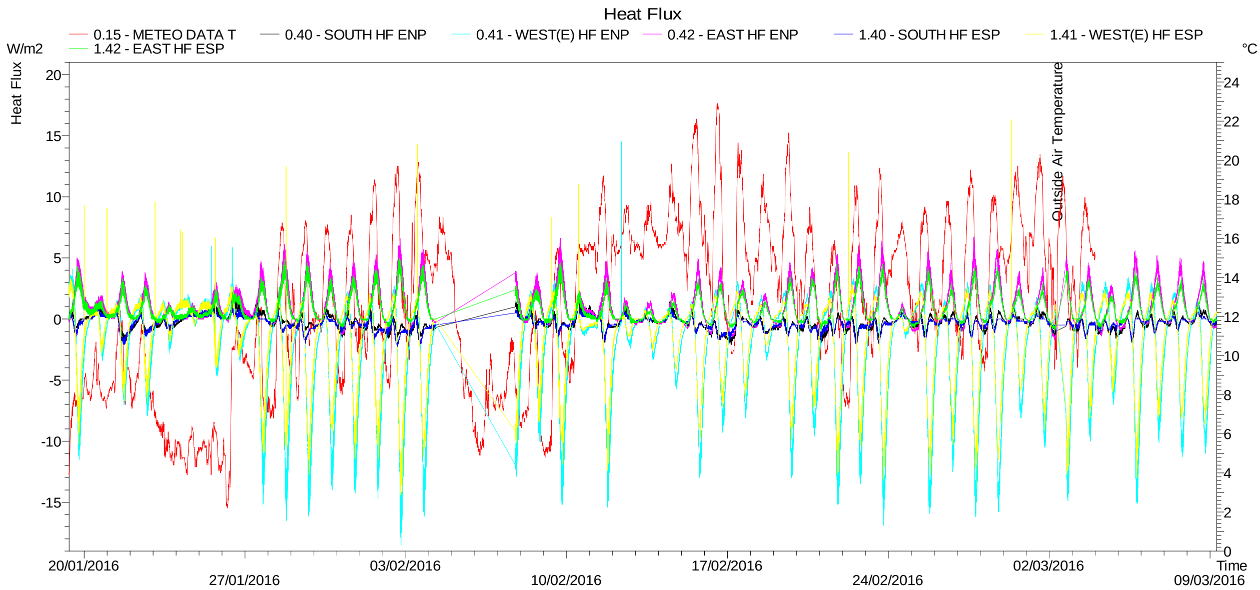


Figure 91: Heat Flux in 3 walls for each building

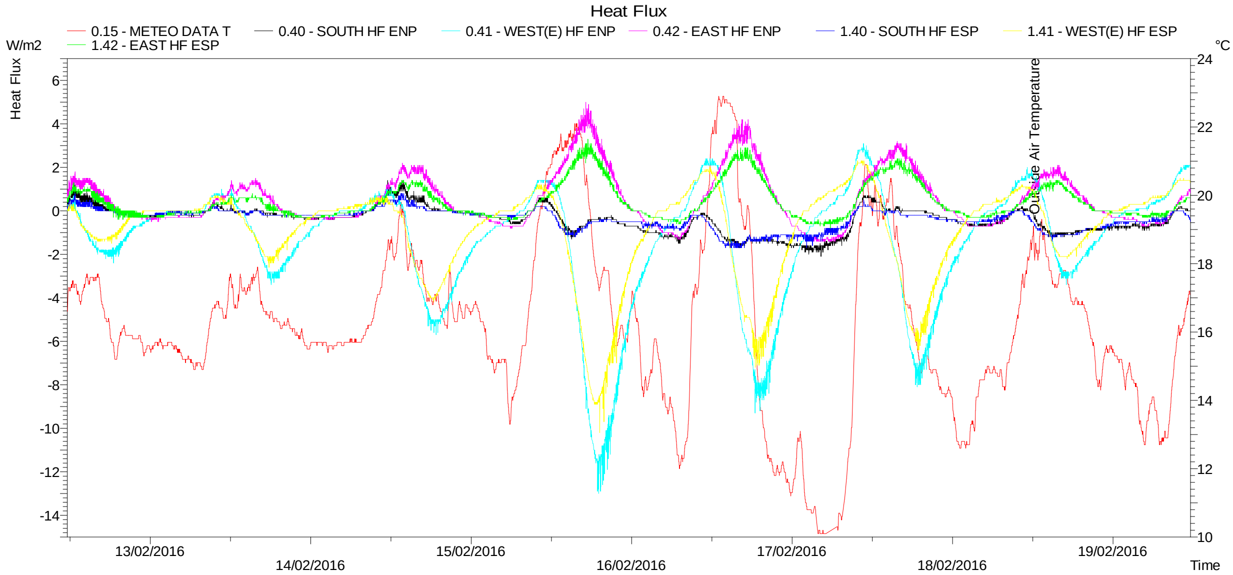


Figure 92: Heat Flux in South and East walls during a certain week

Table 11: West wall's temperatures and heat flux values for period 9/2/2016 – 9/3/2016

	Min		Max		Average	
	ENP	**ESP**	**ENP**	**ESP**	**ENP**	**ESP**
External Wall T	-	3.1		43.1		16.44
Cavity T	5.1	3.7	33.1	38.6	16.75	17.02
Internal Wall T	0	-1.4	21.9	21.1	15.18	14.55
Heat Flux	-16.9	-13.9	14.53	16.31	-2.1608	-1.5311

As mentioned before, even in a closer look, the fluctuation of the South walls' heat flux values was very low (Figure 93),resulting in temperatures for the two buildings very close to one another (Table 12), and thus no further evaluation could take place.

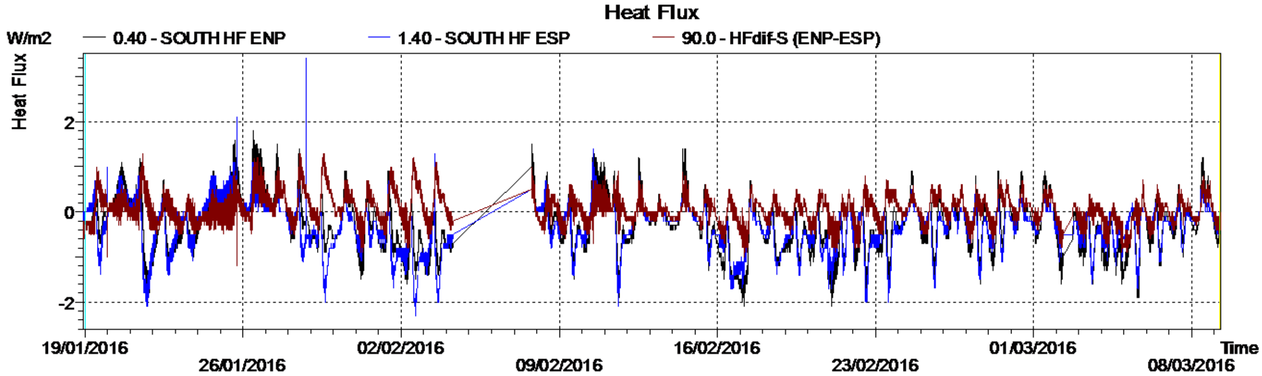


Figure 93: Heat Flux in the South walls

Table 12: South wall's temperatures and heat flux values for period 9/2/2016 – 9/3/2016

	Min		Max		Average	
	ENP	**ESP**	**ENP**	**ESP**	**ENP**	**ESP**
External Wall T	4.1	2.9	45.5	42.5	18.34	17.43
Cavity T	4.2	3.6	40	38.4	17.24	17.49
Internal Wall T	8.8	8.5	19.7	20.1	14.61	14.92
HF	-2.1	-2.1	1.4	1.4	-0.278	-0.2929

For the East walls the graphs (Figure 94 and Figure 95) show interesting results. First of all the measured values for ESP and ENP have obvious differences. The absolute values of heat flux were higher for the ENP, meaning that it allowed heat go through the walls easier, which makes the synthetic material more insulating. For the maximum (positive) values at around 17:00 every day when the heat flow is from outside to the inside, the ENP has higher Heat Flux values, while for the minimum (negative) values at around 6:00 every day when the heat flow is from the inside to the outside, the ENP has the higher values as well resulting in lower temperatures in the room. The heat flux difference varies from -1 to 3.5 W/m^2, when the values for the building with the ENP range between -1.7 to 6.7 and for the ESP range between -0.9 to 5 W/m^2, another indication that ESP results in smaller variations in heat transfer, meaning that it has a better insulating behavior. The max heat flow difference (3.5 W/m^2) corresponds to more than 50% of the absolute measured values, which makes the results evaluable.

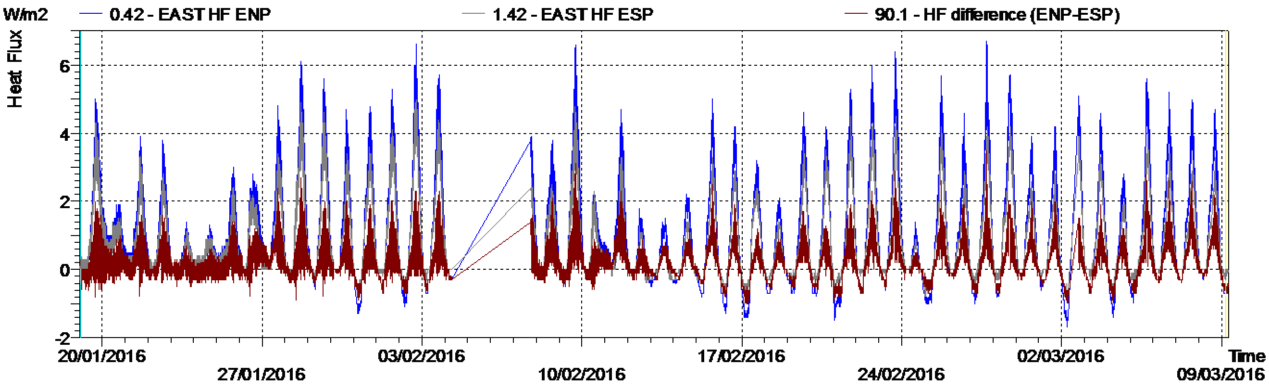


Figure 94: Heat Flux in the East walls

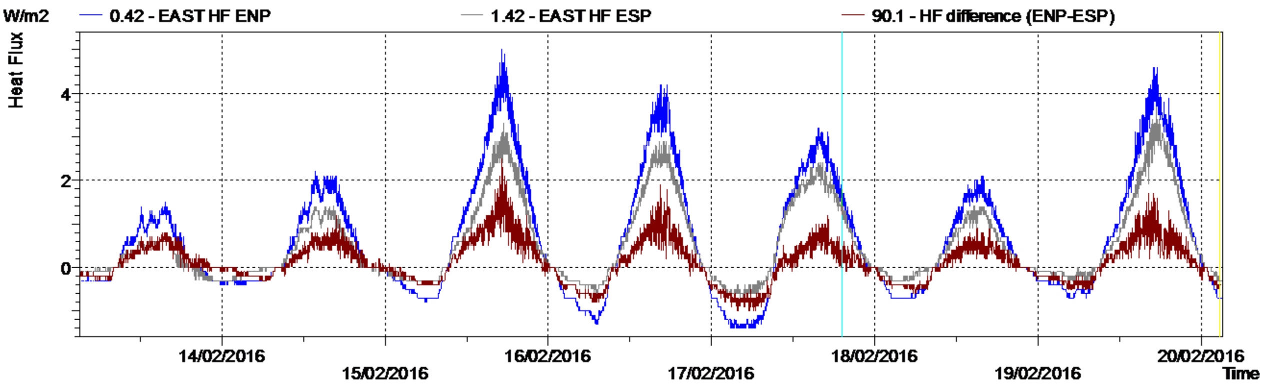


Figure 95: Heat Flux in the East walls during a certain week

Regarding the temperatures on the inside of the East walls, the building with the ESP as insulation, shows lower temperatures in the morning and higher temperatures in the evening. For the ENP the minimum temperature was 6.8^{o}C and the maximum 18.2^{o}C, while for the ESP the minimum temperature was 5.1 ^{o}C and the maximum 19.6^{o}C (Table 13). When the temperatures were at their peak points at around 17:00 every day, the wall in the building with the ESP has always higher temperatures with the minimum difference at 1.6^{o}C.

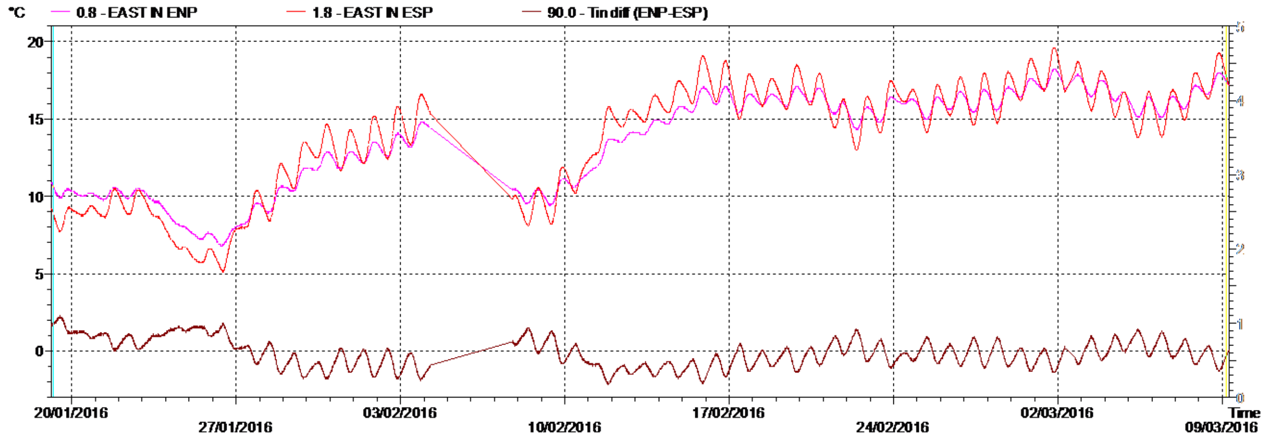


Figure 96: Temperature of the inner East wall

Table 13: East wall's temperatures and heat flux values for period 9/2/2016 – 9/3/2016

	Min		Max		Average	
	ENP	**ESP**	**ENP**	**ESP**	**ENP**	**ESP**
External Wall T	2.6	2.7	24.5	23.9	13.78	13.8
Cavity T	3.6	3.2	23.6	23.7	14	14.02
Internal Wall T	9.4	8.2	18.2	19.6	14.01	14.48
HF	-1.7	-0.9	6.7	4.8	0.9431	0.7133

Figure below shows the relative humidity in both buildings. The percentage of the difference of the two buildings is very low compared to the values of the humidity measured, but the trend is that the building insulated with ESP has always lower Relative Humidity values.

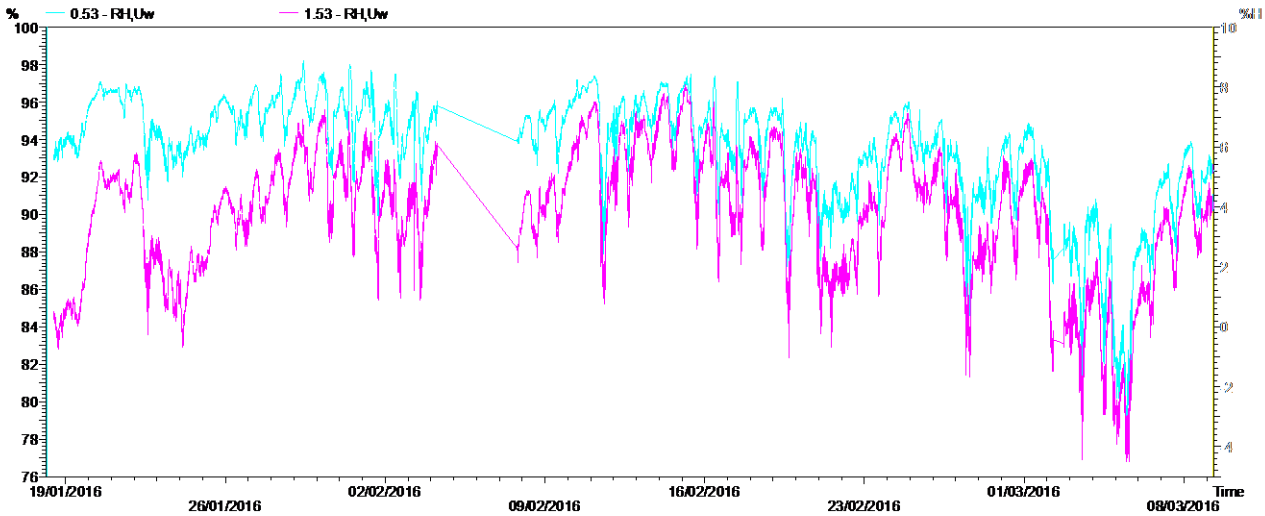


Figure 97: Relevant Humidity in the room

6 Conclusions

According to the analysis performed, the EASEE retrofitting approach will have several quantitative impacts (calculated thanks to the demo sites experience and, when necessary, estimated and simulated). These constitute important buying drivers able to address technical and non technical barriers, clearly showing to the apartment owners advantages and benefits of the new solutions from many different point of view.

Concerning the small scale demo buildings in Lavrion, they were built to be identical so as to compare and evaluate the 2 solutions for the cavity wall insulation. Heat Flux monitoring provides the Expanded synthetic perlite to be slightly better insulating than the hydrophobised expanded natural perlite, preventing not only the cold winter weather but also the humidity to affect the indoor environment of the building. However when comparing the behavior of the walls insulated with the one without insulation, both products change dramatically the values measured, minimizing the heat transfer up to 60%.

Concerning the large scale demo buildings across Europe, in quantitative terms, the energetic and economic impacts on each demo building is summarised in the following table. Of course the results varies according to the size, location and use of the building, but if one refers to the Italian demo building that was entirely retrofitted with the EASEE panels, one can conclude that the objectives of the Description of Work were mostly achieved.

Table 14: Summary of the impacts for the three demo buildings

	Italian demo	Polish demo	Spanish demo
Reduction in heating energy use	25%	26%	9%
Annual economic savings (€)	10,000	3,450	350
Payback time (years)	7.8	7.3	10
Duration of the intervention	3 months	2 weeks	2 weeks

Starting from the above numbers for the Italian demo building and considering as a target market 2% of the 10 million of residential buildings built before 1975, a potential annual energy saving of almost 8 million kWh corresponding to 2 billion euros per year can be obtained.
Of course these numbers refer to an optimised product, which according to the project partners could be achieved in 2 years from now.