D 3.5 Assessment of performance of "combined" solutions

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0 Abstract

Historical buildings could be retrofitted with compatible and conservatively passive and active solutions in order to reach high efficiency energy standards.

The aim of this study is to define a combination of measures aimed to decrease the energy demand and improve the energy performance of the building. Both active and passive strategies need to be considered for this kind of study.

In the first part of the report the methodology is presented. It can be summarised in the following main steps:

Step 0: Definition of representative climate zones:

- The cities of the analysis have been selected following a climate analysis and represent three different typical climate zones in Europe: Copenhagen, Bolzano, Palermo.

Step 1 :Definition of the baseline building:

- An existing historical building has been modelled with E+. The most common and representative uses are considered and modelled for each climate zone. This part of the study allowed to understand the energy consumption of a reference historical building, with a common HVAC System.

Step 2: Improvement of the HVAC System:

- The most suitable HVAC system has been defined for the considered building types in each climate zone. The analyses have been run using the software E+, in order to assess the improvement in terms of energy consumption.

Step 3: Combination of active and passive strategies:

- Passive and active strategies have been combined and optimized. Using E+ the energy consumption has been assessed, and results compared each other and with the baseline building. The following passive energy efficiency solutions have been integrated:
    - Step 3-A:

      infiltration reduction and windows replacement. They have been integrated with the active systems analysed in the Step 2.
    - Step 3-B:

      This second passive strategy is the insulation of roof and external slabs and will be combined with the precedent ones in Step 3-A.
    - Step 3-C:

      In this final step, a last passive strategy is combined with the precedent scenario (3-B): natural ventilation is introduced in all thermal zones.

Finally all the comparisons between each step have been analysed in order to understand the importance of each strategies on the total energy saving and the maximum energy reduction for each climate zone and building type.

Besides the analysis made on CS1 using a dynamic simulation model (EnergyPlus), in the last chapter a variant analysis was performed on CS5 using a monthly energy balance calculation tool (PHPP) investigating different combinations of energy efficient solutions as well as the performance for different locations and climates.

1 Climate Zones

In order to easily define the different European climate conditions, it was decided to use 3 different climate zones with 3 different climate combinations:

- Copenhagen: cold winter, mild summer;
- Palermo: mild winter, hot summer;
- Bolzano: cold winter, hot summer.

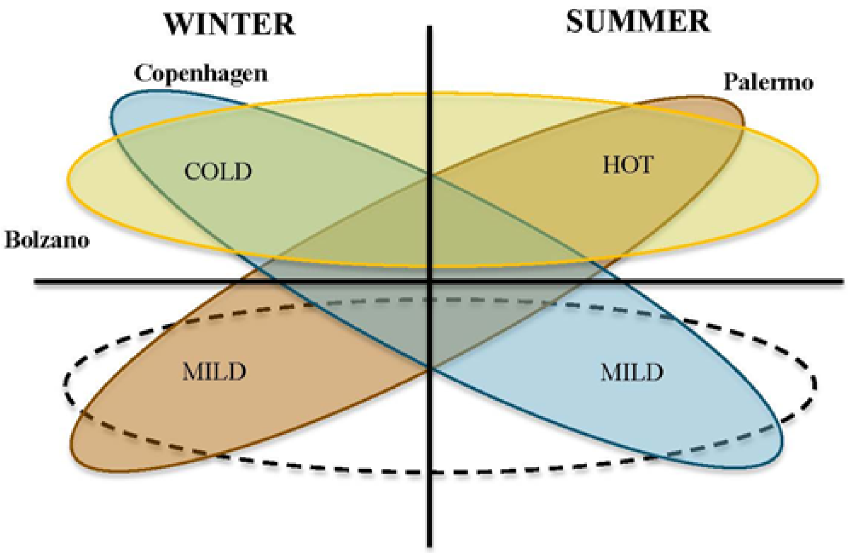


Figure 1 Climate zones

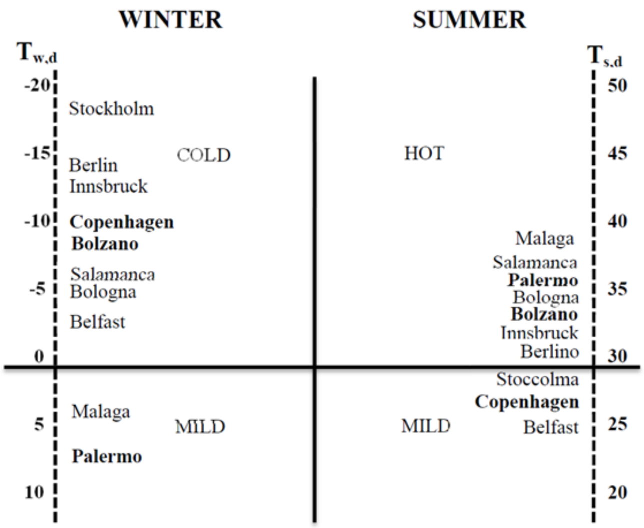


Figure 2 Climate zones: temperature conditions

The figures above show the climate conditions of the cities chosen for this analysis. In detail, the second scheme represents the outside temperature for the winter conditions on the left axis (Tw,d) and for the summer conditions on the right axis ($T_{s,d}$).

1.1 Cooling and heating seasons

The conditioning seasons have been chosen according to the different climate conditions. For heating season, the conditioning periods are reported below:

- Copenhagen: 15 October – 15 April
- Bolzano: 15 October – 15 April
- Palermo: 1 December – 31 March

The internal temperature set-point is 20°C and 50% of RH.

For cooling season, the conditioning periods are reported below:

- Copenhagen: 1 Jun – 31 Ago
- Bolzano: 1 Jun – 31 Ago
- Palermo: 1 Jun – 31 Ago

The internal temperature set-point is 26°C and 60% of RH.

2 Internal Loads

In order to evaluate the different energy consumption for each destination use, the internal loads (Lighting, People, Electrical Equipment) have been choose accordingly to the ASHRAE 90.1/2007. The values adopted below represent the minimum average daily value of each category.

People

Building Type	People		
	Sensible	Latent	Occupancy
	W/person	W/person	pp/m²
Office	73.27	58.61	0.055
Retail	73.27	58.61	0.036
Museum & Showrooms	73.27	58.61	0.036
Residential	73.27	58.61	0.043

Equipment

Building Type	Equipment	
	Sensible	Radiant Fraction
	W/m²	%
Office	16.15	22%
Retail	2.69	22%
Museum & Showrooms	2.69	22%
Residential	2.69	22%

Lighting

Building Type	Lighting	
	Sensible	Radiant Fraction
	W/m²	%
Office	11.84	45%
Retail	16.15	45%
Museum & Showrooms	11.84	45%
Residential	15.07	45%

2.1 People

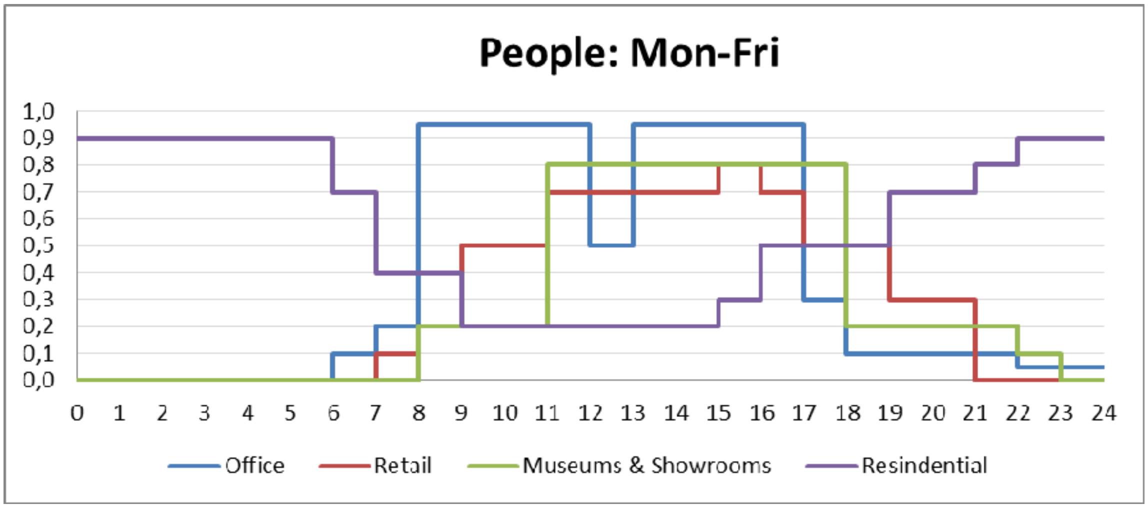


Figure 3 Internal gains: People Monday - Friday

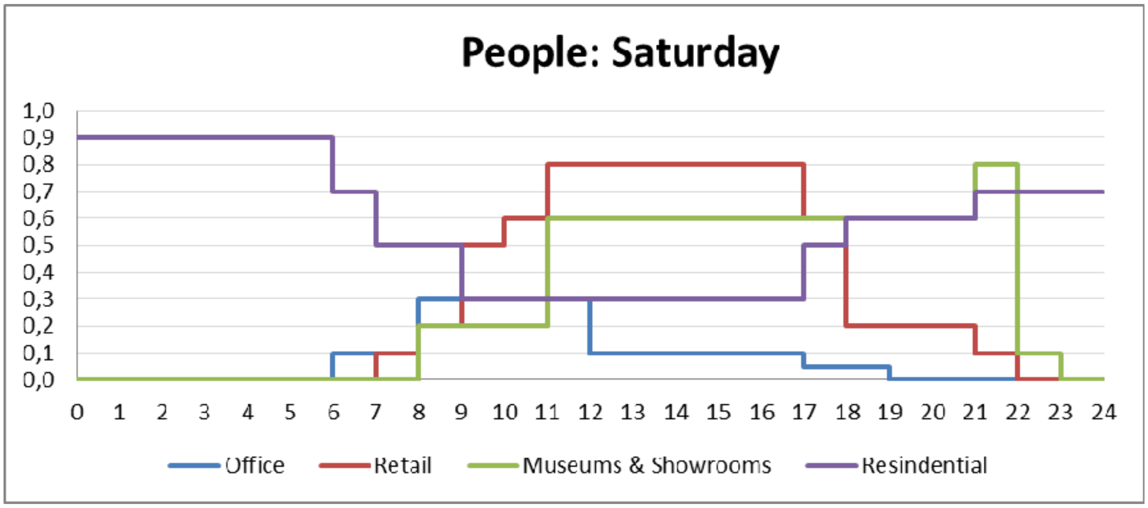


Figure 4 Internal gains: People Saturday

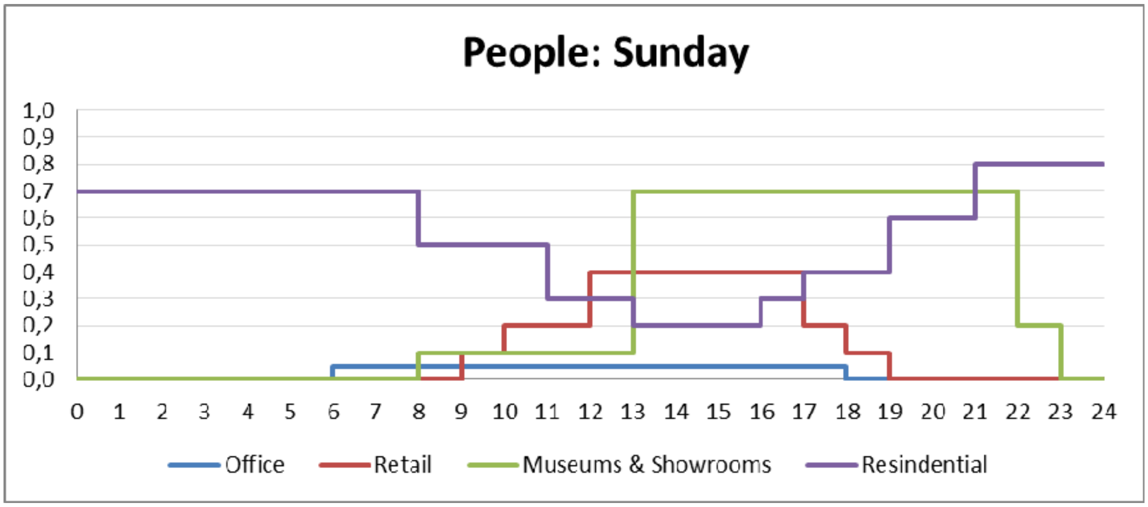


Figure 5 Internal gains: People Sunday

2.2 Equipment

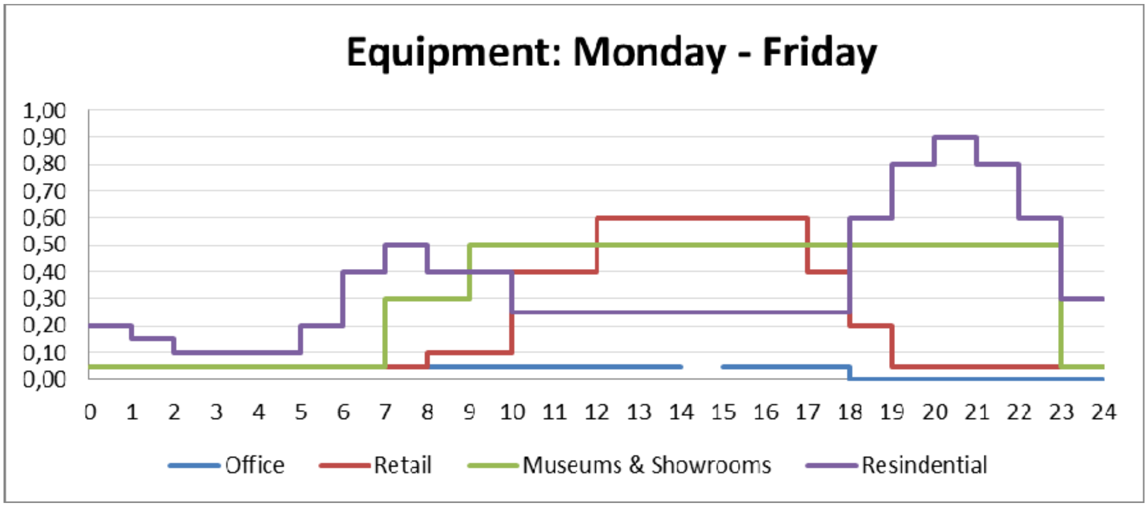


Figure 6 Internal gains: Equipment Monday – Friday

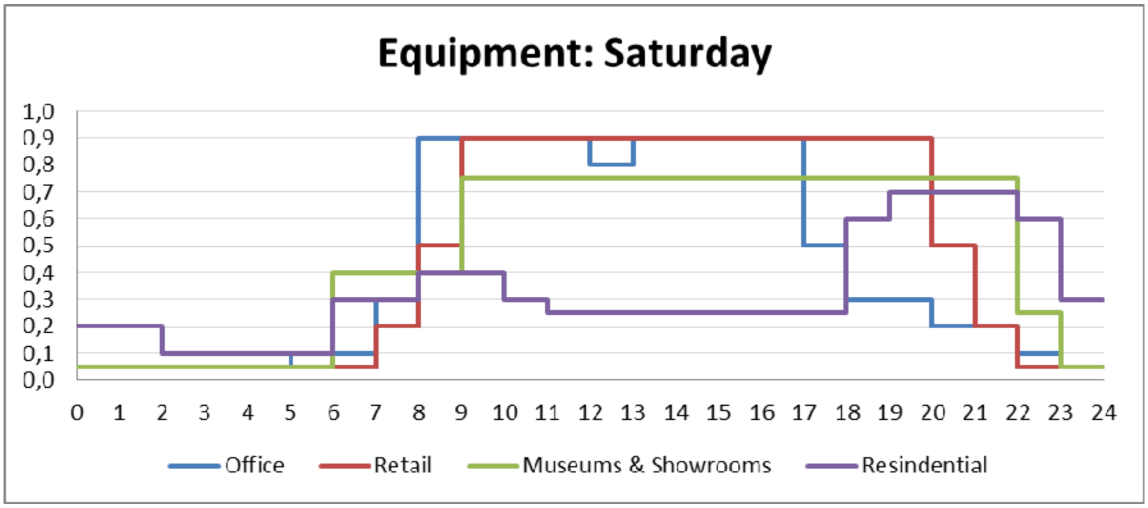


Figure 7 Internal gains: Equipment Saturday

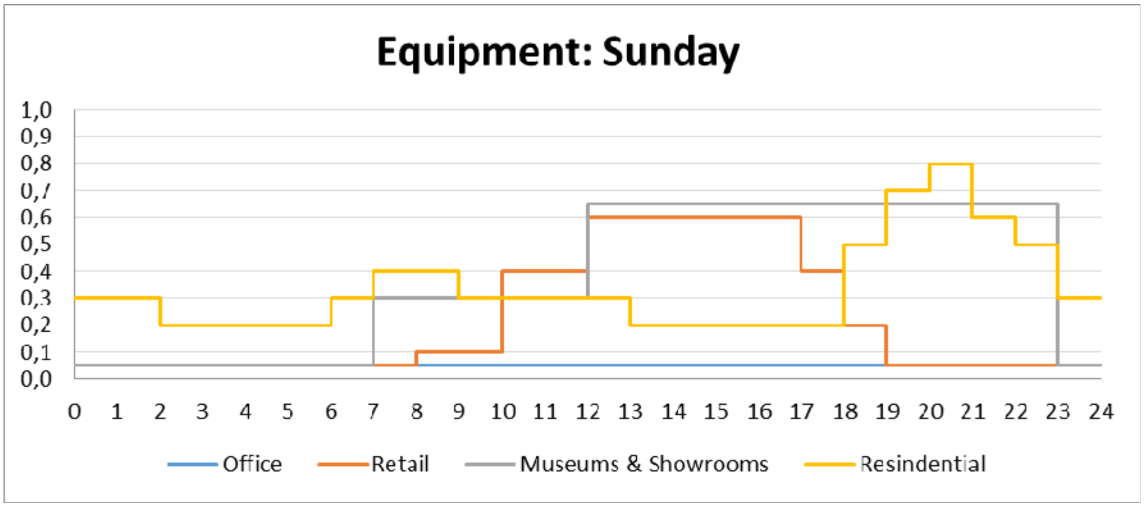


Figure 8 Internal gains: Equipment Sunday

2.3 Lighting

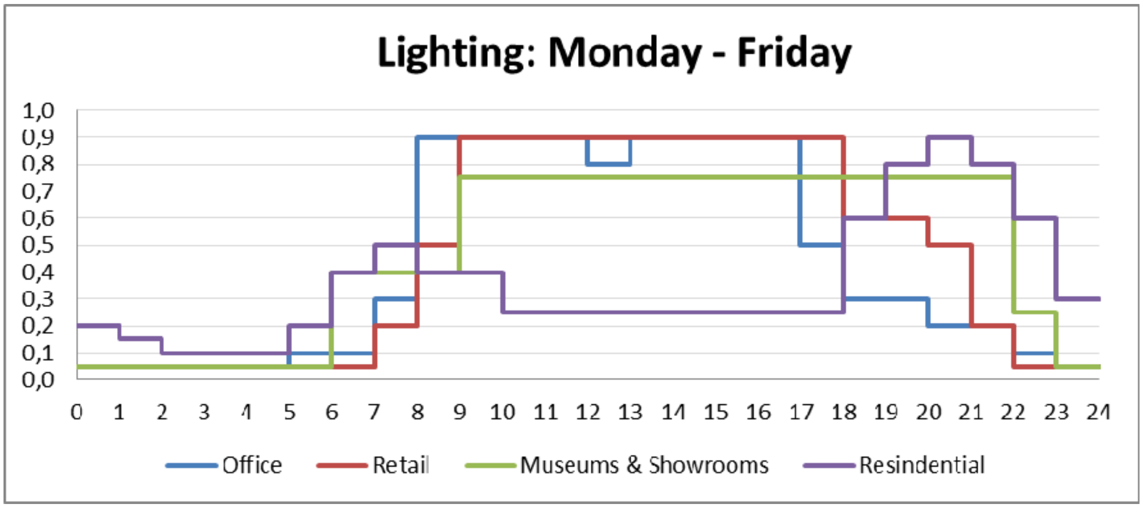


Figure 9 Internal gains: Lighting Monday – Friday

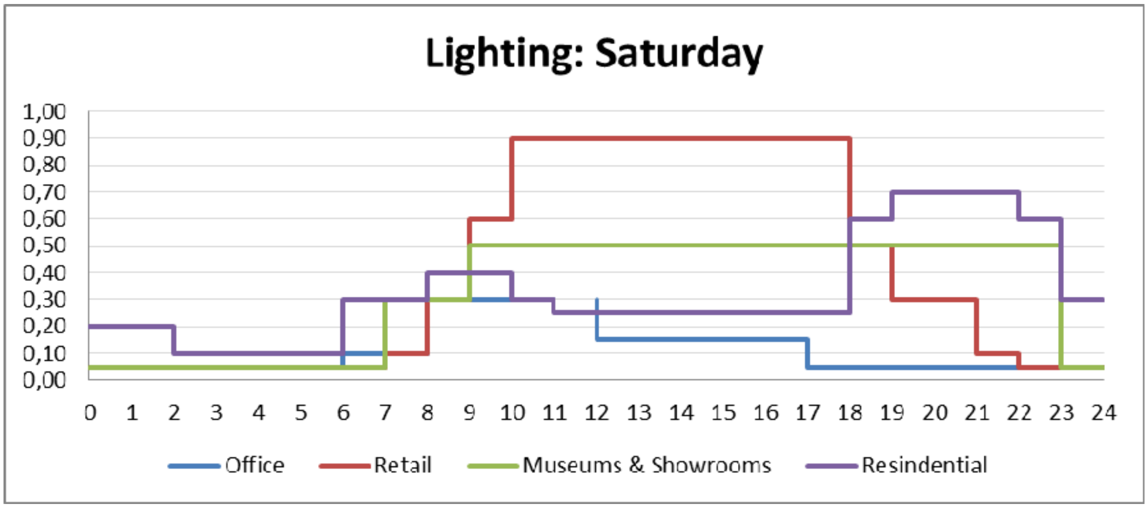


Figure 10 Internal gains: Lighting Saturday

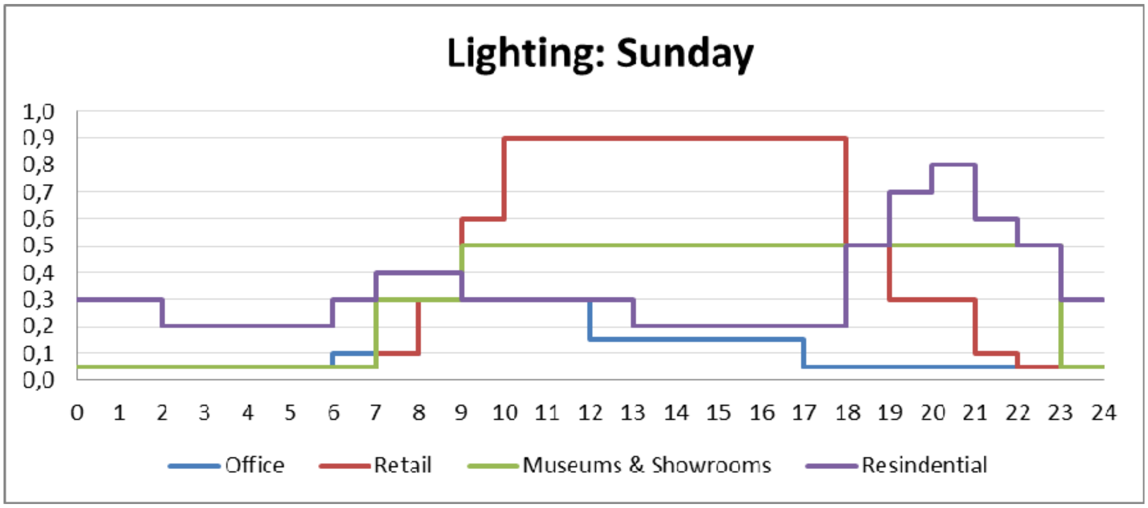


Figure 11 Internal gains: Lighting Sunday

3 Methodology and process of the analyses

Four building types have been analysed for the three climate zones:

- Office;
- Retail/Department store;
- Showrooms and museums/library;
- Residential.

	LIST OF BUILDING TYPES
3 CLIMATE ZONES	Office
	Retail/Department store
	Showrooms and museums/library
	Residential

For each building type, two HVAC systems are developed for the reference building used for the analyses. The reference building used as a reference is the Waaghaus Case Study in Bolzano.

The case study on which the reference building is based on is the “Waaghaus” (weigh house), a XIII-century building originally used as medieval weigh house. It is a four stores building, with thick stone-walls and a wooden roof, in the historic-center of the city Bolzano/Bozen (Northern Italy).

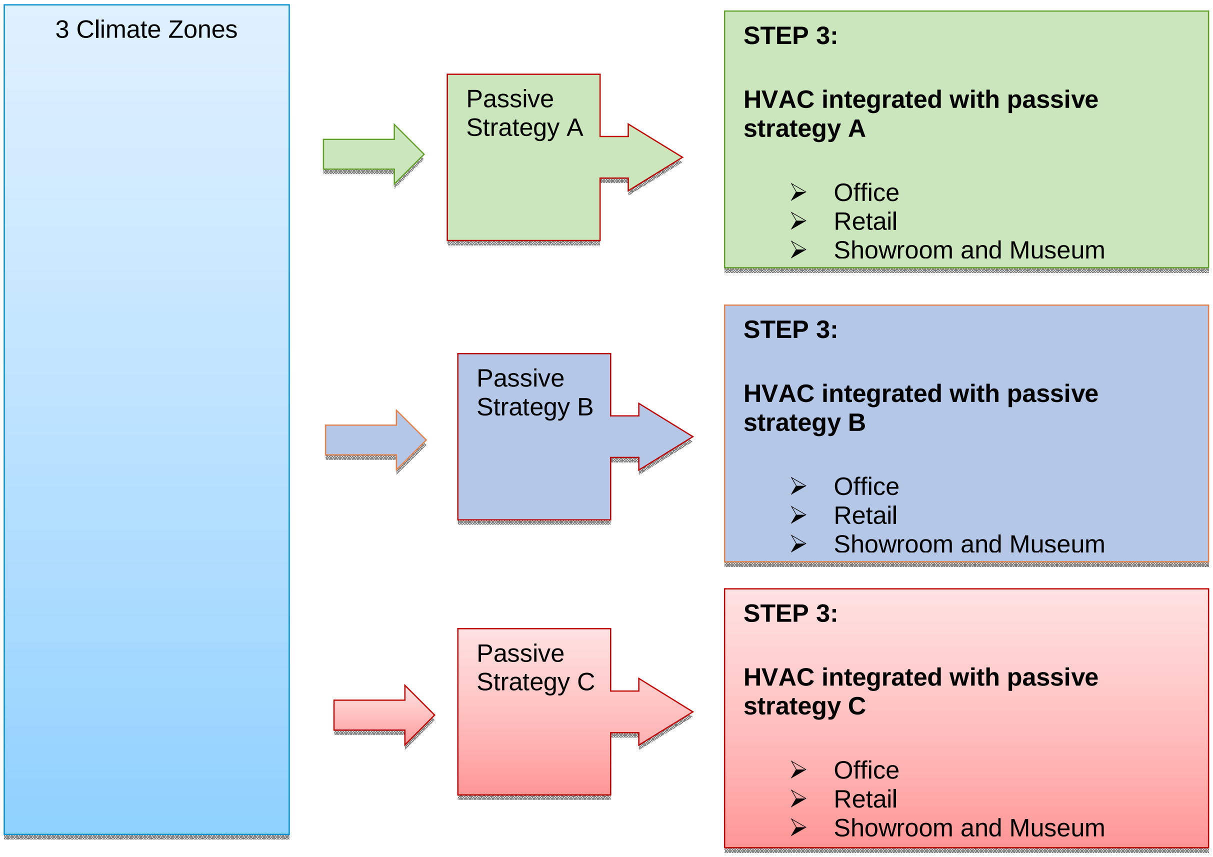
In “STEP 1 – Baseline”, the following heating and cooling systems have been considered:

- HEATING: Gasoil Boiler with radiators;
- COOLING: Air condensed split system.

Nowadays, these HVAC systems represent those most commonly used in historic and existing buildings, as they are a well consolidated technology and the most widespread in the last 30 years for typical applications. All the other proposed systems are more advanced technologies and would represent an improvement in terms of energy efficiency.

In “STEP 2 - Energy efficient solution”, the most suitable HVAC System for the reference historical building has been identified analysing 6 different HVAC strategies.

Finally, In STEP 3, the HVAC “energy efficient solution” is integrated with the proposed passive strategies.



Calculations and analyses have been carried out according to the matrix here below and the results are reported, step by step, in the following sections.

3 Climates zones	Reference historical building		Historical building with integrated passive strategy	
	STEP 1: Baseline (12 Energy Models)	**STEP 2:** Energy Efficient Solution (12 Energy Models)	**STEP 3:** Energy Efficient Solution integrated with passive solutions (36 Energy Models)	
	Office	Office	Passive Strategy A	Office - A
				Retail - A
				Showroom And Museum - A
	Retail	Retail		Residential - A
			Passive Strategy B	Office - B
				Retail - B
	Showrooms And Museum	Showrooms And Museum		Showroom And Museum - B
				Residential - B
			Passive Strategy C	Office - C
	Residential	Residential		Retail - C
				Showroom And Museum - C
				Residential - C

4 Step 1

In Step 1 simulations have been conducted with detailed models of the buildings, considering a common HVAC system formed by:

- HEATING: Gasoil Boiler with radiators
- COOLING: Air condensed split system

Simulations have been conducted in all 12 cases (4 types of building within 3 different climate zones).

In the table below the progress of the analyses is summarised:

3 Climates zones	Reference historical building		Historical building with integrated passive strategy	
	STEP 1: Baseline (12 Energy Models)	**STEP 2:** Energy Efficient Solution (12 Energy Models)	**STEP 3:** Energy Efficient Solution integrated with passive solutions (36 Energy Models)	
	Office	Office	Passive Strategy A	Office - A
				Retail - A
				Showroom And Museum - A
	Retail	Retail		Residential - A
			Passive Strategy B	Office - B
				Retail - B
	Showrooms And Museum	Showrooms And Museum		Showroom And Museum - B
				Residential - B
			Passive Strategy C	Office - C
	Residential	Residential		Retail - C
				Showroom And Museum - C
				Residential - C

Overall Energy consumption

The results obtained by the energy modeling are presented and analyzed in this chapter.

Simulations results are here presented in terms of overall primary energy consumption for Step 1.

Primary energy factors used for the conversion are respectively 1 for gas and 2.5 for electricity.

The cooling and heating energy demand graphs are reported in the Appendix.

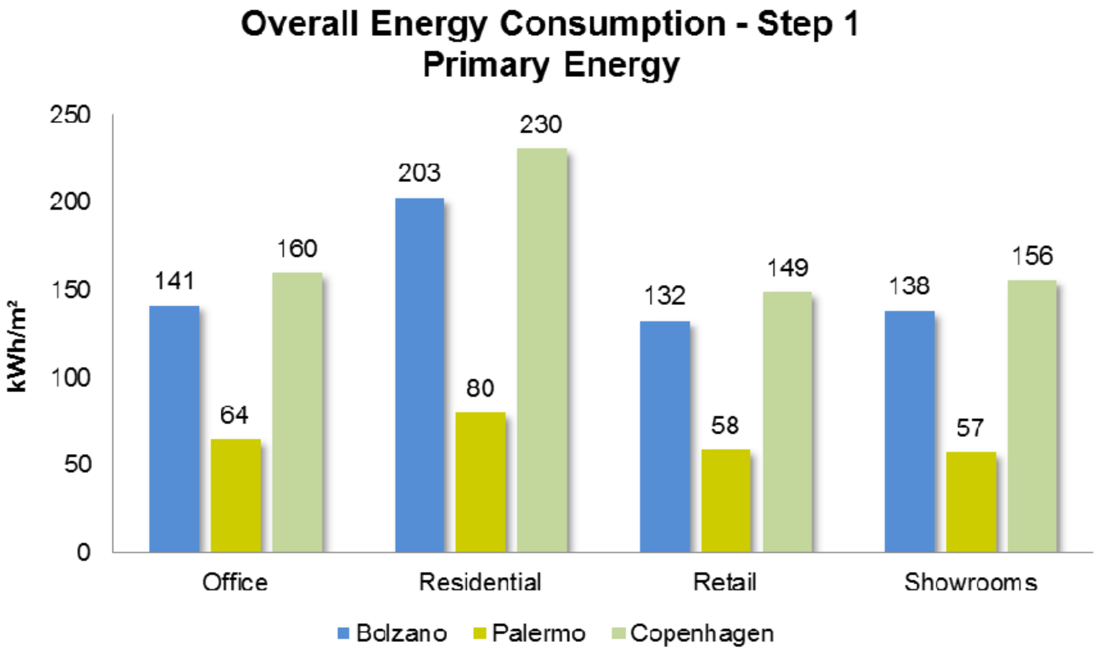


Figure 12 Step 1: Overall Primary Energy Consumption

According to the climate conditions, in this baseline set Copenhagen has the highest overall primary energy consumption, then Bolzano and Palermo.

5 Step 2

In Step 2 simulations have been carried out with accurate models of the buildings, considering the case of an air condensed heat pump with a high efficiency HVAC system, in all 12 cases (4 types of building within 3 different climate zones).

In order to select the most efficient HVAC system, a pre-assessment has been run on 6 selected different systems on the reference building. As it is the most diffused destination and it has a complex and complete combination of internal loads, pre-assessment analyses have been run for the residential.

In the table below the progress of the analyses is summarised:

	Reference historical building		Historical building with integrated passive strategy	
3 Climates zones	**STEP 1:** Baseline (12 Energy Models)	**STEP 2:** Energy Efficient Solution (12 Energy Models)	**STEP 3:** Energy Efficient Solution integrated with passive solutions (36 Energy Models)	
	Office	Office	Passive Strategy A	Office - A
				Retail - A
				Showroom And Museum - A
	Retail	Retail		Residential - A
			Passive Strategy B	Office - B
				Retail - B
	Showrooms And Museum	Showrooms And Museum		Showroom And Museum - B
				Residential - B
			Passive Strategy C	Office - C
	Residential	Residential		Retail - C
				Showroom And Museum - C
				Residential - C

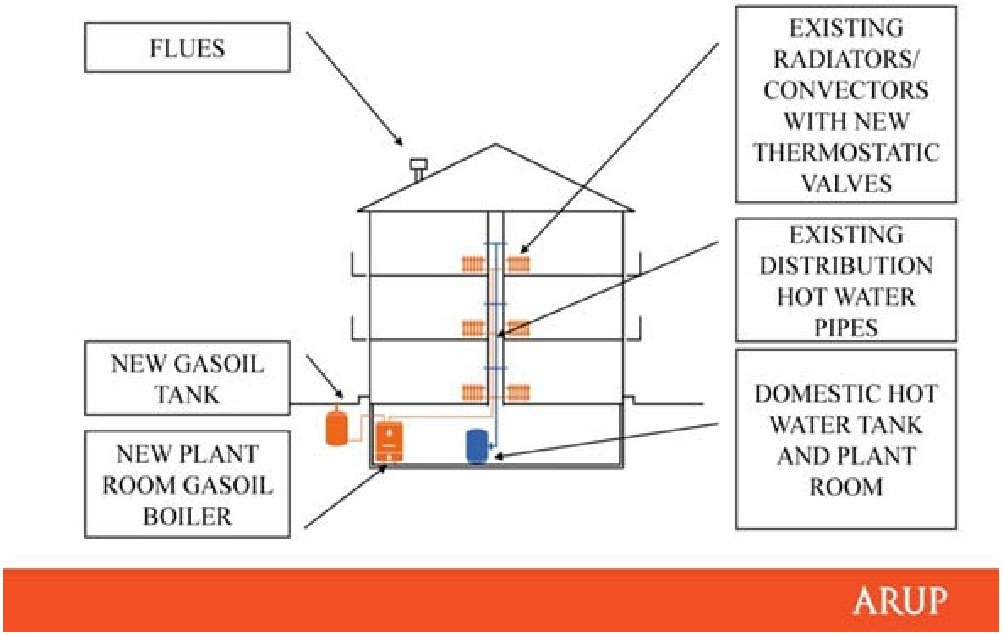
5.1 Step 2 – Pre-assessment of the HVAC system

The Energy simulations are run with Energy+; the case study is the reference historical building used for the analyses, that has been created from the case study in Bolzano (case study 1). In Step 2, in order to define the most efficient HVAC System, 6 different HVAC strategies were analysed and dynamic simulations run. Then ,the most efficient solution for the building has been identified. The HVAC systems analyzed are the following and described in the following pages:

S1	**Gasoil Boiler**
S2	Natural Gas Condensing Boiler
S3	Wood pellet Boiler
S4	Electric Heater
S5	Air-Air condensed heat pump (DX)
S6	Water condensed heat pump

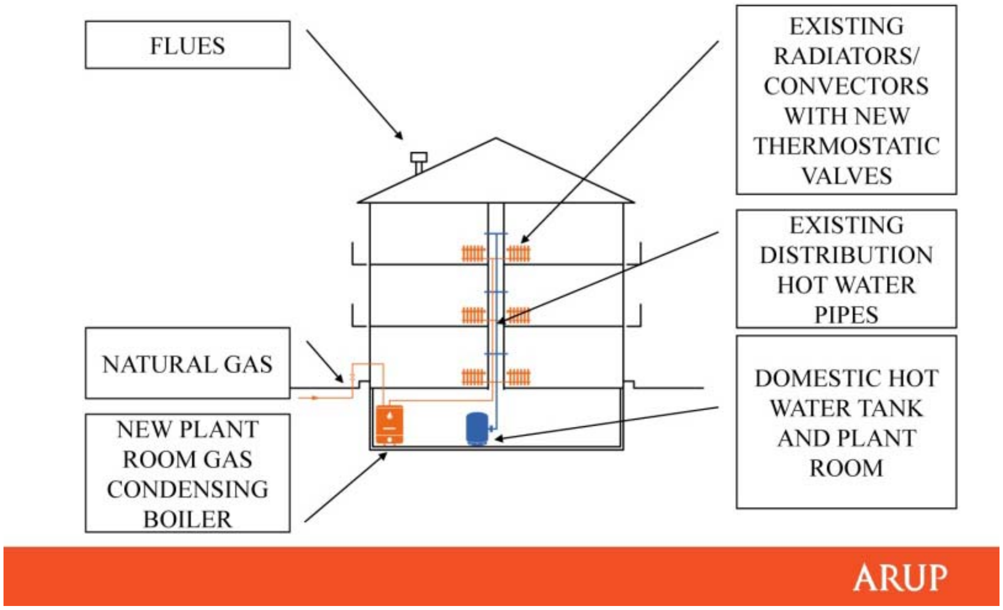
5.1.1 S1. Gasoil Boiler

S1	GASOIL BOILER	Centralised gasoil boiler system for heating and domestic hot water production. COOLING SYSTEM: VRV multisplit.	Gasoil boiler and related equipment sized for design days according the .epw weather files. Main components: Multisplit, gasoil boiler, expansion vessel, pipework and valves, chimney and flues, control system, domestic hot water tank, pumps and heat meters. Solar thermal system: NO Terminals: Radiators with thermostatic valves.



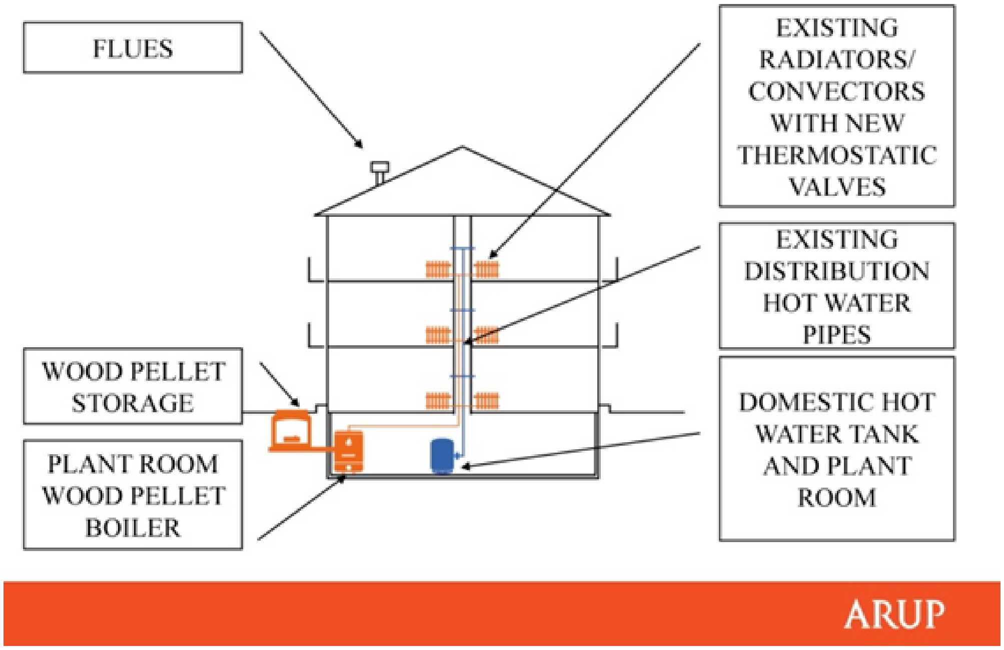
5.1.2 S2 - Natural Gas Condensing Boiler

S2	NAT GAS COND BOILER	Centralised natural gas condensing boiler system for heating and hot domestic water production. COOLING SYSTEM: VRV multisplit.	Natural gas boiler and related equipment sized for design days according the .epw weather files. Main components: gas boiler, expansion vessel, pipework and valves, chimney and flues, control system, domestic hot water tank, pumps and heat meters. Solar thermal system: NO Terminals: Radiators with new thermostatic valves.



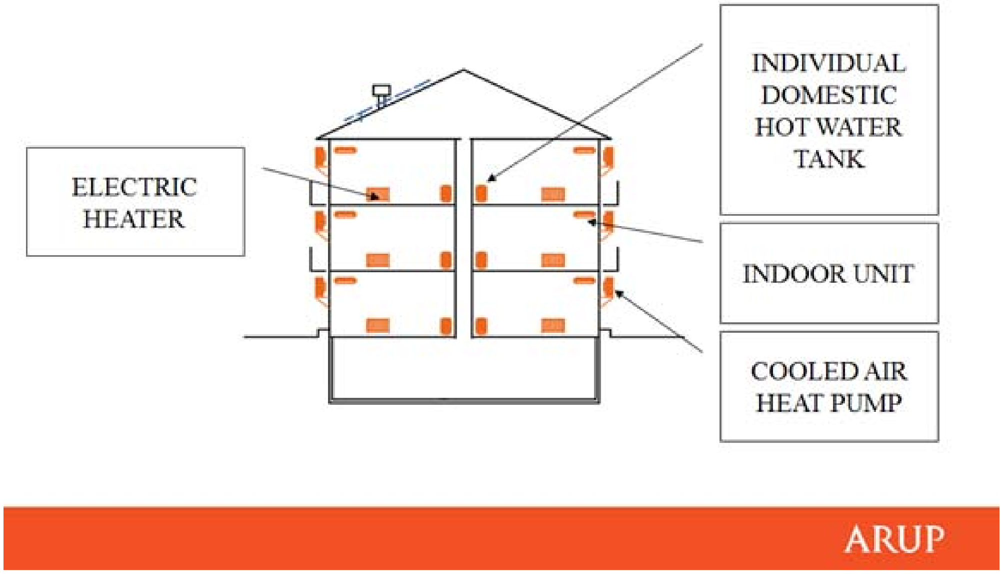
5.1.3 S3 - Wood pellet Boiler

S3	WOOD PELLET BOILER	Centralised wood pellet boiler system for heating and hot domestic water production. COOLING SYSTEM: VRV multisplit (three indoor units)	Wood pellet boiler and related equipment sized for design days according the .epw weather files. Main components: Multisplit, wood pellet boiler, expansion vessel, pipework and valves, chimney and flues, control system, domestic hot water tank, pumps and heat meters. Solar thermal system: NO Terminals: Existing radiators with new thermostatic valve and wireless heat meter



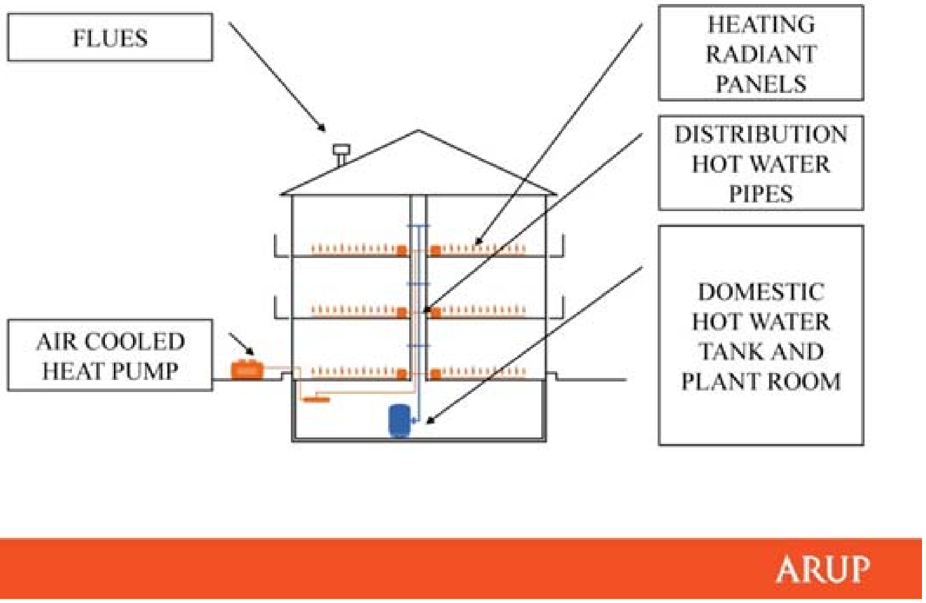
5.1.4 S4 - Electric Heater

S4	ELETRIC HEATER	Electric heater for heating and domestic hot water production. COOLING SYSTEM: VRV multisplit	Electric heater and related equipment sized for design days according the .epw weather files. Main components: Multisplit, electric heaters, domestic hot water tank. Solar thermal system: NO Terminals: Radiators with new thermostatic valves



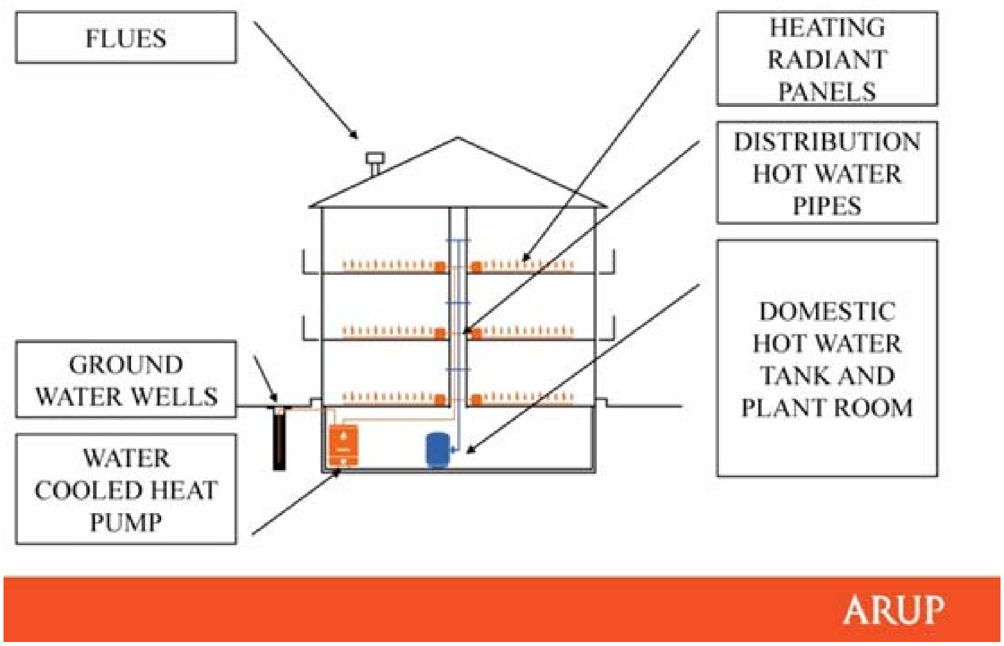
5.1.5 S5 - Air-Air condensed heat pump (DX)

S5	AIR CONDENSED HEAT PUMP	Centralised air HP system for heating and domestic hot water production. COOLING SYSTEM: VRV multisplit	Air HP and related equipment sized for design days according to the .epw weather files. Main components: Multisplit, centralized air HP, expansion vessel, pipework and valves, control system, domestic hot water tank, pumps and heat meters. Solar thermal system: NO Terminals: radiant panels.



5.1.6 S6 – Water condensed heat pump

S6	WATER CONDENSED HEAT PUMP	Centralised water HP system for heating, cooling and domestic hot water production.	Water HP and related equipment sized for design days according to Italian legislation. Main components: water HP, expansion vessel, pipework and valves, chimney and flues, control system, domestic hot water tank, pumps, heat meters and wells for ground-water. Solar thermal system: NO Terminals: radiant panels Centralized air treatment for fresh air.



5.2 Step 2 – Pre-assessment results

The aim of this pre-assessment is to define the best HVAC system in terms of energy efficiency and impact reduction on the existent building. In fact, the comparison takes in to account both the global energy efficiency, measured in terms of primary energy consumption, and the possible conservation problems caused to the new HVAC systems installation requirements.

The residential type has been chosen as the most common destination use for historical buildings.

In order to define the best solution for each climate zone, the results obtained by the energy modelling are presented and analysed in this chapter.

5.2.1 Heating Consumption – Residential

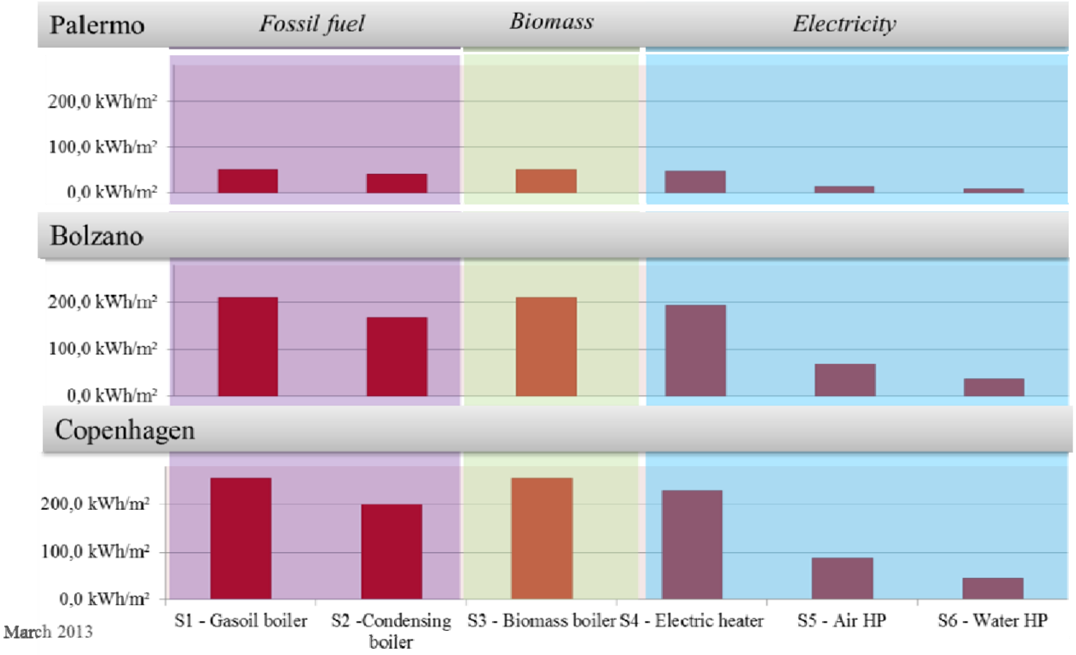


Figure 13 Step 2 Pre-assessment: Heating Consumption

Considering heating consumption only, the results show that the S6 system (water condensed heat pump) is the most efficient solution in all climate zones.

Palermo has the lowest heating energy demand, in fact external temperature is quite high during the winter season. For this reason, the possible energy saving is not significant.

Gasoil boiler and condensing boiler are the less efficient solutions, and the most efficient are Air condensed and Water condensed Heat Pump. Biomass boiler do not have high efficiency, but it can be an interesting application, as biomass is usually considered renewable in most of the national regulations.

Copenhagen and Bolzano have similar results, but, as expected, Copenhagen heating demand is the highest. In a cold climate the energy saving obtained with efficient HVAC solutions is significant.

5.2.2 Cooling electrical consumption

Figure 14 Step 2 Pre-assessment: Cooling Electrical Consumption

Considering electrical cooling consumption only, the results show that the S6 system (water condensed heat pump) is the most efficient solution in every climate zone, though the differences between all solutions are limited.

Copenhagen has the lowest cooling energy demand; in fact external temperature is quite low during the summer season. For this reason, the possible energy saving is not significant.

S1, S2 and S3 , as described in the previous pages, were simulated considering a split system. The Energy Plus simulations confirm that this is the less efficient solution in every climate zone.

The Air condensed HP (S5) is less efficient than the water condensed HP (S6), however, in Copenhagen, the difference is almost zero. In fact, air condensed HPs have a very high efficiency when external air is relatively low (20 -28 °C).

5.2.3 Electrical Aux Consumption

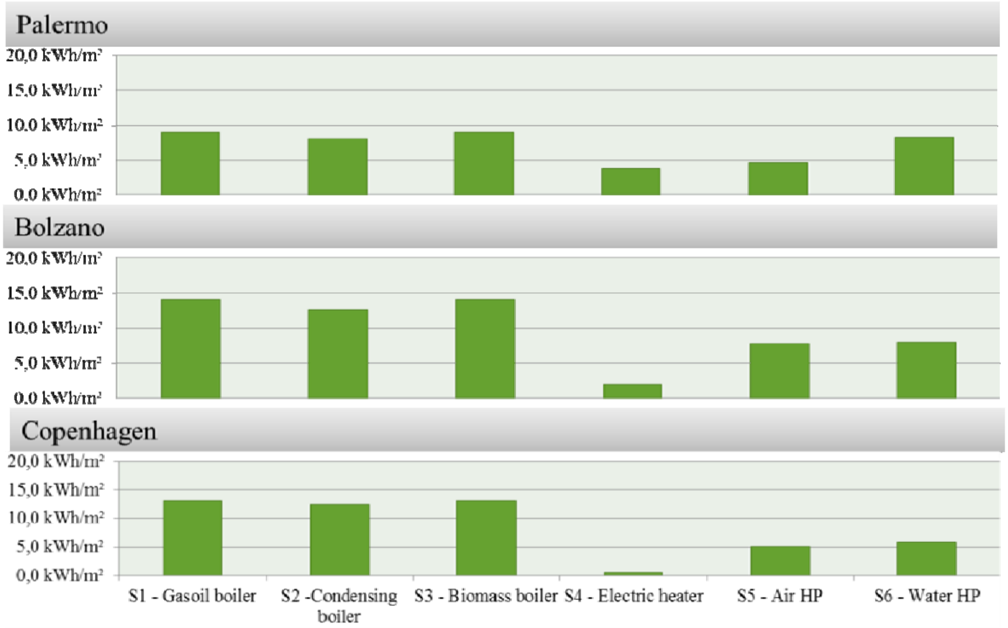


Figure 15 Step 2 Pre-assessment: Auxiliary Electrical Consumption

The electrical auxiliary consumption represents the energy demand for pumps and fans. This value is proportional to the sum of the heating and cooling demand.

Considering these consumption only, as expected Bolzano has the highest values because the climate is quite hot during the summer season and very cold during the winter season. Palermo and Copenhagen have only one season that has high energy consumption, for this reason annual auxiliary demand is a bit lower.

5.2.4 Total Primary Energy

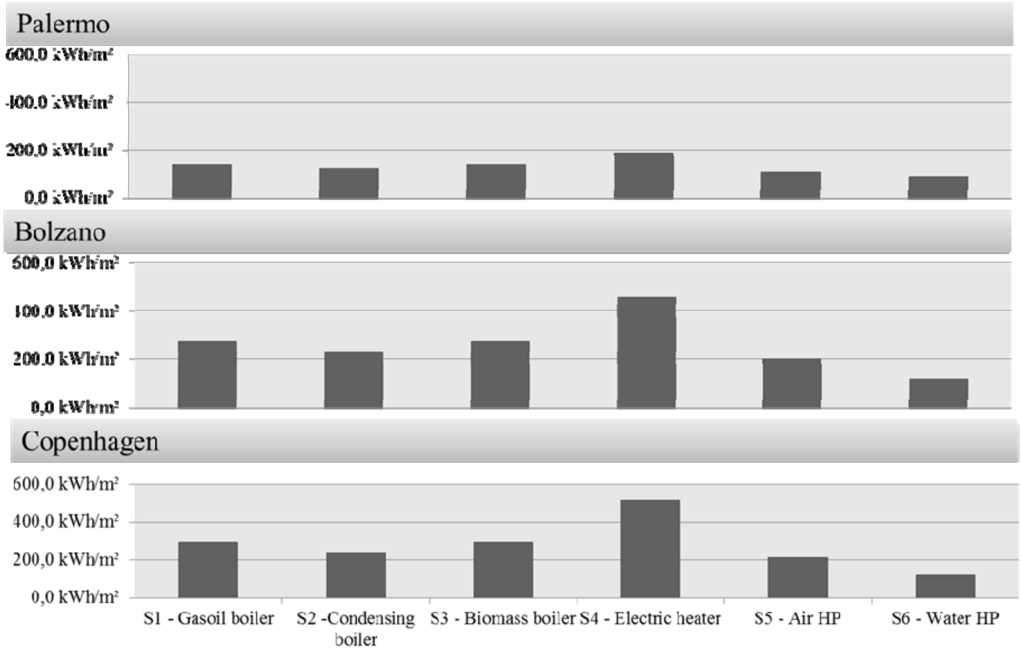


Figure 16 Step 2 Pre-assessment: Total Primary Energy Consumption

Calculation of the total primary energy allows to define the most efficient solution for each climate zone, in relation with the compatibility to the conservation of historical building. This would allow us to proceed with the STEP 2 of the methodology.

For this calculation the primary energy is calculated considering the Italian grid efficiency of 46%.

The figure above shows the sum of the previous three tables in term of primary energy. From this table we have the confirmation that the water condensed HP (S6) and air condensed HP are the most efficient solution in every climate zone.

Nevertheless, flexibility, reversibility and materials impact of each solutions have been evaluated in relation to building conservation issues, in order to define the most viable option. Comparing the most efficient ones, the S5 system Air condensed heat pump has been chosen because it is characterized by the minimum impact in terms of installation works on the existing buildings. Instead, as it requires access to ground water by the creation of boreholes into the ground, the S6 System could be less applicable in some urban areas and would have some additional costs for excavations. A detailed description of the system and its operation is reported in the following page.

5.3 Step 2 – Final results

Following the pre-assessment, the selected solution has been analysed for the 12 combinations (4 Building types in 3 Climate zones).

Therefore, the model in Step 2 is characterized by the same envelope of the baseline building with the HVAC efficient solution, suitable for the building use, that has been selected among those analysed: an air condensed heat-pumps with splits. Heat pumps are hydraulic mechanical systems that are used to produce hot water through an inversion of the chilled circuit. Air condensed heat pumps always operate on mechanical energy driven by electricity. Air condensed heat pump uses external air to condensate the refrigerant. The efficiency of the heat pumps, ranges from 2 up to 4,5. For the integration of this generation system it is necessary to provide space (external) for the condenser. Higher efficiency is achievable with low temperature emission systems.

Figure 17 Air condensed Heat Pump

The integration of heat pumps in existing buildings usually has a low impact on the construction. The main issue could be related with aesthetic, as air HPs are usually placed outside and require fans that could be noisy. Moreover, depending on the power needed, their dimension can be relevant. However they can be placed on roofs and the installation is reversible: HPs can be dismantled.

The results obtained by the detailed energy modeling are presented and analyzed in this chapter.

Simulations results are here presented in terms of overall primary energy demand for Step 1 and Step 2.

Primary energy factors used for the conversion are respectively 1 for gas and 2.5 for electricity.

The cooling and heating energy demand graphs are reported in the Appendix.

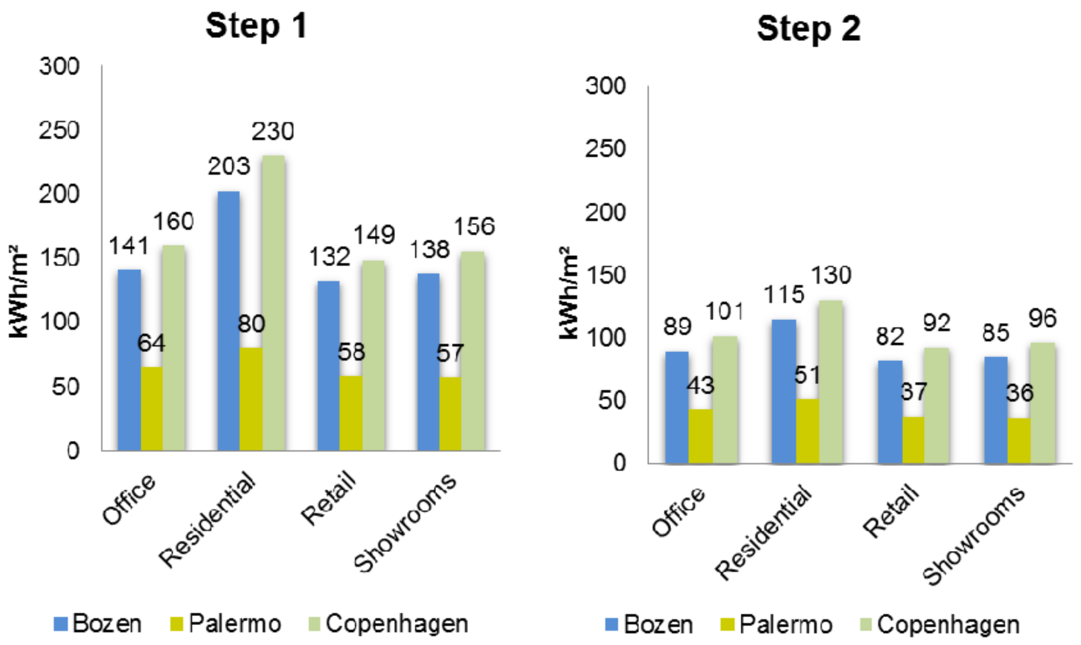


Figure 18 and Figure 19: Step 1 and Step 2 Overall primary energy consumption

In Step 2, Copenhagen results to have the highest overall primary energy consumption, then Bolzano and Palermo for all destination uses.

A comparison in terms of overall primary energy consumption has been carried out between Step 1 and Step 2 simulations in the following page.

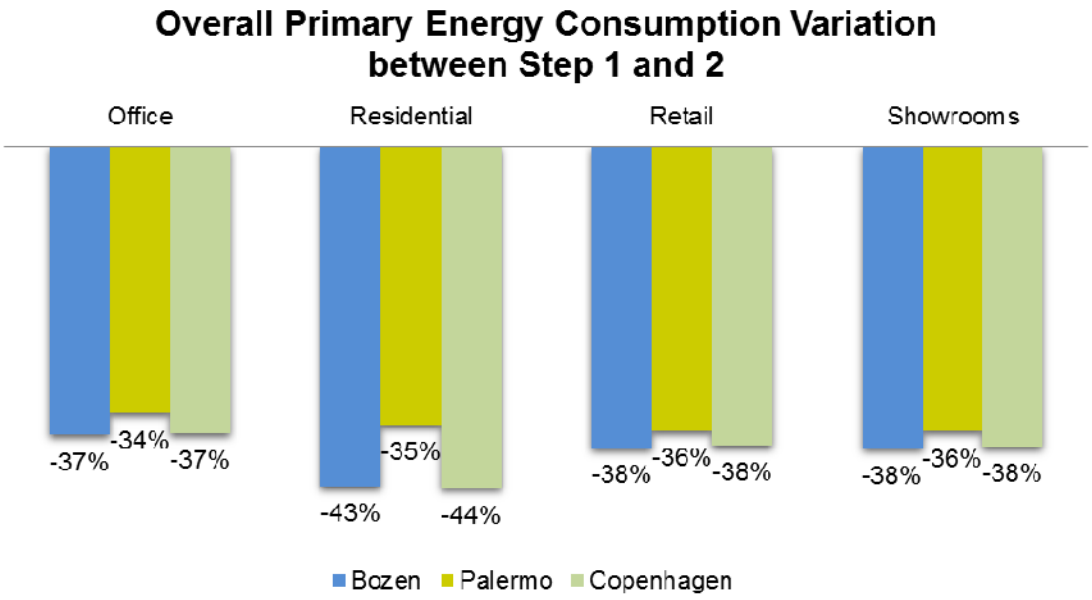


Figure 20 Overall Primary Energy Consumption Variation between Step 1 and 2

The comparison shows an Overall Primary Energy Consumption reduction for all the analyses.

In general, the new HVAC system (air-air condensed heat pump) could reduce the consumptions compared with Step 1.

The most important reduction is observed in the residential destination and in colder climate zones. The lowest energy consumption reduction is Office Palermo (-34%) and the highest one is Residential Copenhagen (-44%).

This second step shows as just a HVAC system replacement could significantly improve the energy saving for all the destination uses and climate zones, ensuring at least more of 30% of energy saving.

6 Step 3

In Step 3 simulations have been carried out with accurate models of the buildings, including Step 2 improvements (air condensed heat pump HVAC system), two energy efficient envelope refurbishments (3-A and 3-B) and a passive cooling strategy (3-C) for all 12 cases (4 types of building within 3 different climate zones).

The 3-A Passive Strategy is the replacement of windows and reduction of infiltration (Uw = 1.2 W/m2K, g-value of 0.6 and a low-infiltration rate of 0.3 ach).

The 3-B-Strategy, based on 3-A-Strategy model (new windows and infiltrations reduction), consists in additional insulation for roof and external slabs.

The 3-C-Strategy, based on 3-B Strategy, integrates the passive cooling strategy (natural ventilation during the shoulder seasons and summer).

In the table below the progress of the analyses is summarised:

	Reference historical building		Historical building with integrated passive strategy	
	STEP 1: Baseline (12 Energy Models)	**STEP 2:** Energy Efficient Solution (12 Energy Models)	**STEP 3:** Energy Efficient Solution integrated with passive solutions (36 Energy Models)	
3 Climates zones	Office	Office	Passive Strategy A	Office - A
				Retail - A
				Showroom And Museum - A
	Retail	Retail		Residential - A
			Passive Strategy B	Office - B
				Retail - B
	Showrooms And Museum	Showrooms And Museum		Showroom And Museum - B
				Residential - B
			Passive Strategy C	Office - C
	Residential	Residential		Retail - C
				Showroom And Museum - C
				Residential - C

6.1 Step 3-A, Windows replacement – Results

The results obtained by the energy modeling are presented and analyzed in this chapter.

Simulations results are here presented in terms of overall primary energy consumption for Step 2 and Step 3-A.

Primary energy factor used for the conversion is 2.5 for electricity.

The cooling and heating energy demand graphs are reported in the Appendix.

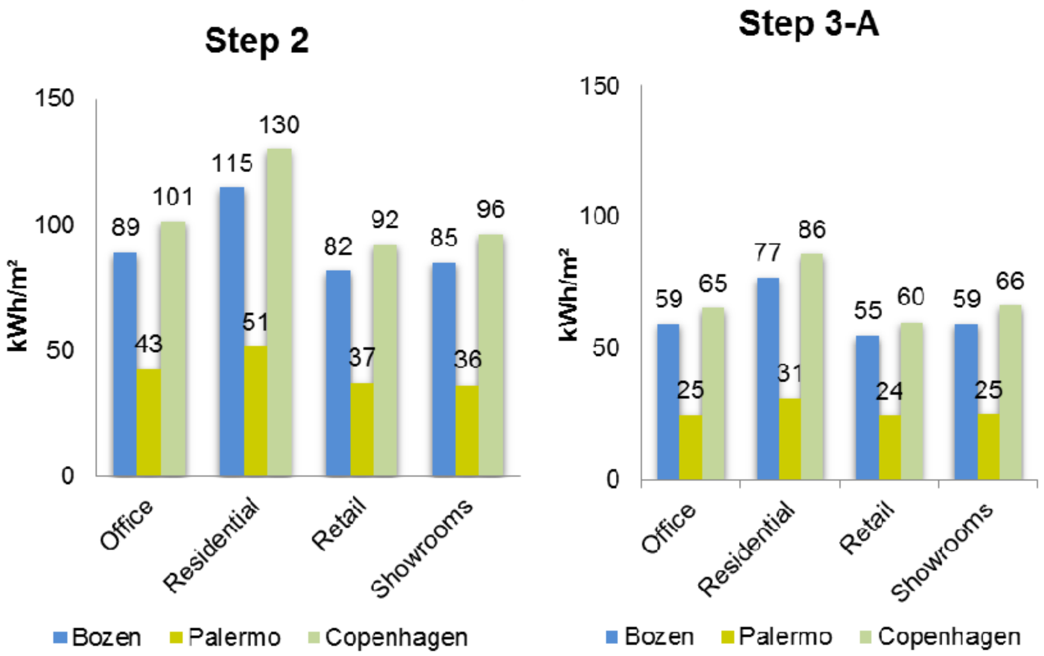


Figure 21 and Figure 22: Overall primary energy consumption of Step 2 and Step 3-A

In both cases, Copenhagen results have the highest overall primary energy consumption.

A comparison in terms of overall primary energy consumption has been carried out between Step 2 and Step 3-A simulations.

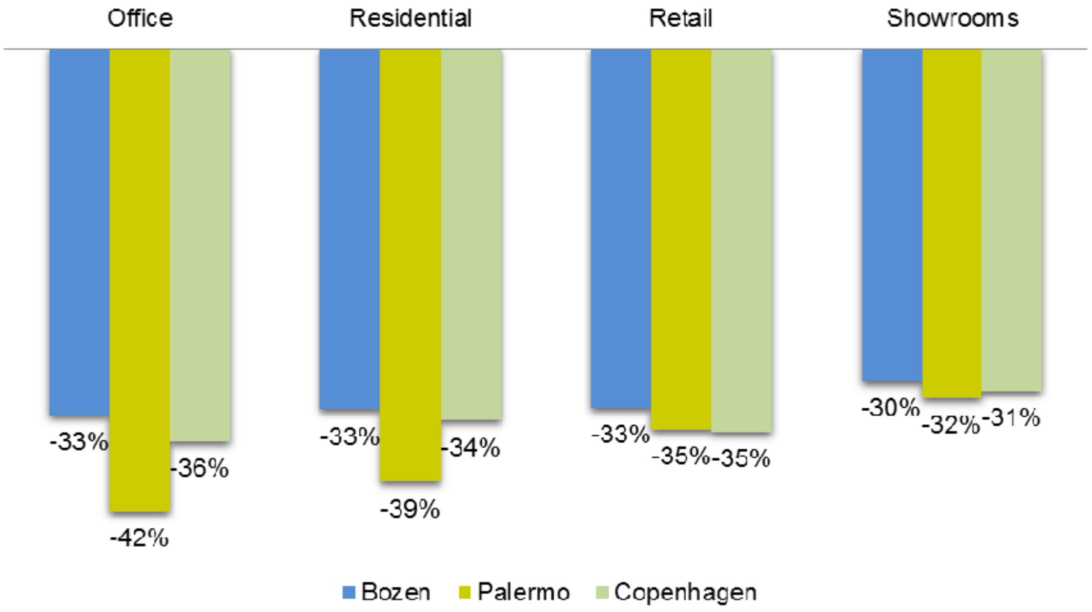


Figure 23 Overall primary energy consumption variation between Step 2 and Step 3-A

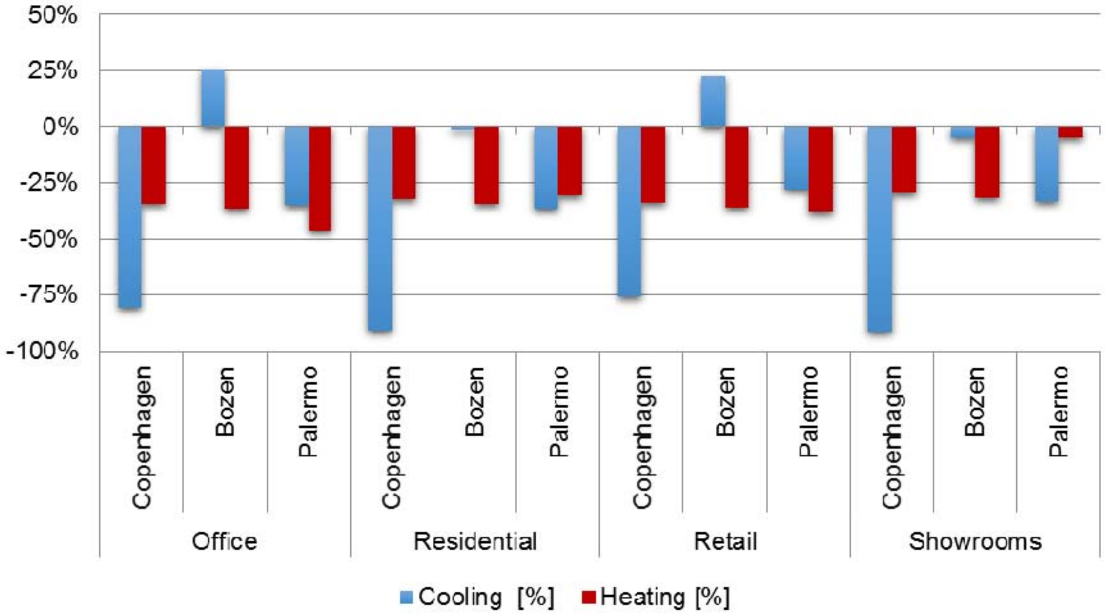


Figure 24 Heating and cooling primary energy consumption variation between Step 2 and Step 3-A

This strategy could reduce the overall energy consumption compared with Step 2.

The replacement of windows and reduction of air infiltration could reduce approx. 30% of the total energy consumption for each different climate zones. The reduction is more sensible for the warm climate as Palermo (32%-42%).

The only exception is the cooling increase for office and retail type in Bolzano. However this increase is not that significant, as the absolute primary energy consumption for cooling in Bolzano is low, then the percentage increase means an even lower absolute value.

The new envelope performance, with improved thermal performance and reduced air infiltration, and high internal loads might cause higher internal cooling loads during the warm periods.

6.2 Step 3-B, Roof and external slab insulation - Results

The results obtained by the energy modeling are presented and analyzed in this chapter.

Simulations results are here presented in terms of overall primary energy demand for Step 2 and Step 3-B.

Primary energy factor used for the conversion is 2.5 for electricity.

The cooling and heating energy demand graphs are reported in the Appendix.

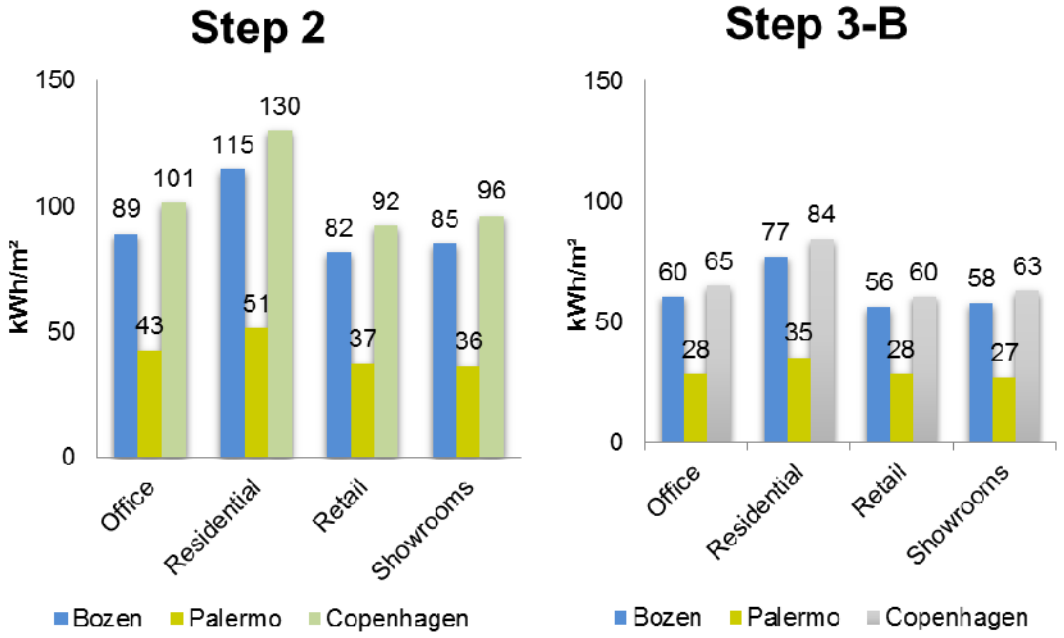


Figure 25 and Figure 26: Overall primary energy consumption of Step 2 and Step 3-B

In both cases, Copenhagen has the highest overall primary energy consumption.

A comparison in terms of overall primary energy consumption has been carried out between Step 2 and Step 3-B simulations.

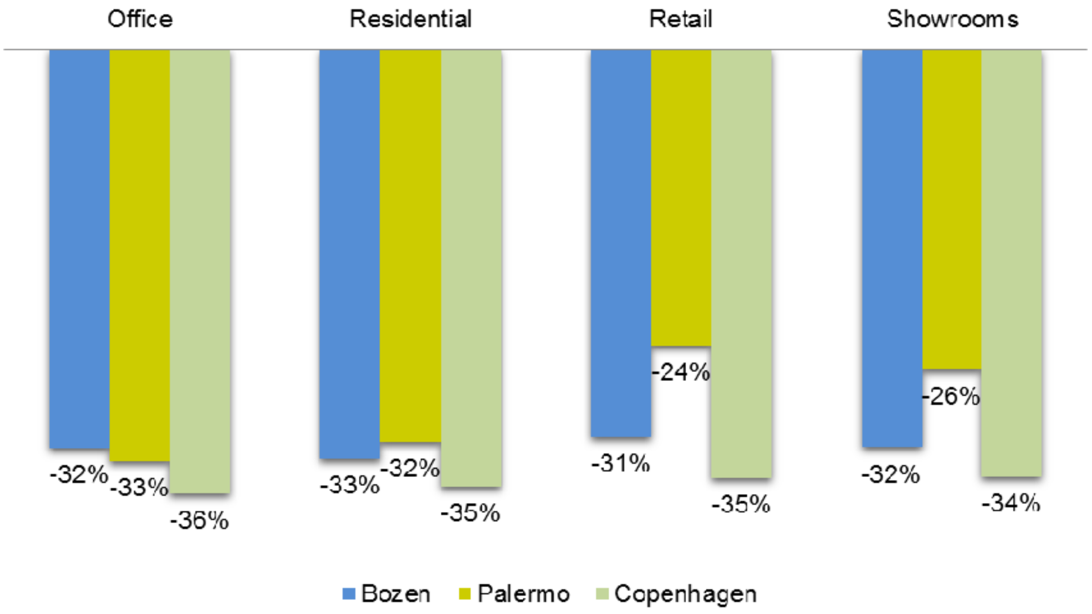


Figure 27 Overall primary energy consumption variation between Step 2 and Step 3-B

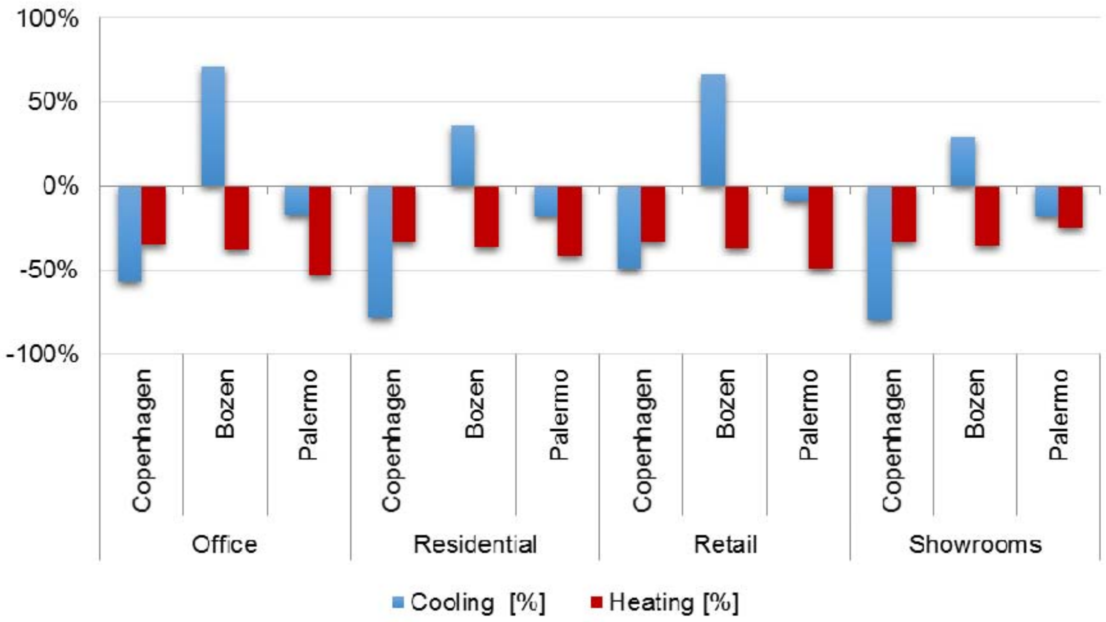


Figure 28 Heating and cooling primary energy consumption variation between Step 2 and Step 3-B

In general, this strategy could reduce the overall energy consumption respect to the Step 2, but it increases the cooling consumption for Bolzano. The new building envelope performances (new windows, low infiltrations, roof and external slab insulation) reduce the thermal losses and, in combination with the internal loads, cause the increase of cooling demand and the decrease of the heating demand respect to the Step 2.

As discussed in the paragraph above, the only exception is the cooling increase for office and retail type in Bolzano. However this increase is not that significant, as the absolute primary energy consumption for cooling in Bolzano is low.

Nevertheless, the total cooling consumptions were just very low before this Step (see graphs in the Appendix) and so the these increases don’t affect significantly the total primary energy reduction.

6.3 Step 3-C, Natural ventilation - Results

The results obtained by the energy modeling are presented and analyzed in this chapter.

Simulations results are here presented in terms of overall primary energy demand for Step 2 and Step 3-C.

Primary energy factor used for the conversion is 2.5 for electricity.

The cooling and heating energy demand graphs are reported in the Appendix.

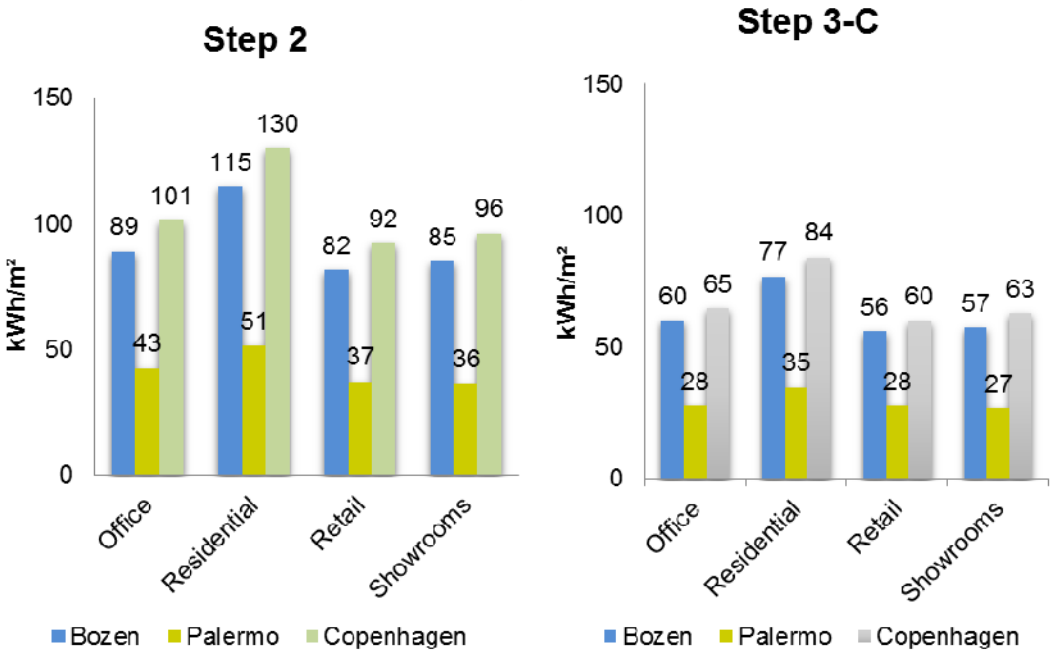


Figure 29 and Figure 30: Overall primary energy consumption of Step 2 and Step 3-C

In both cases, Copenhagen results to have the highest overall primary energy consumption.

A comparison in terms of overall primary energy consumption has been carried out between Step 2 and Step 3-C simulations.

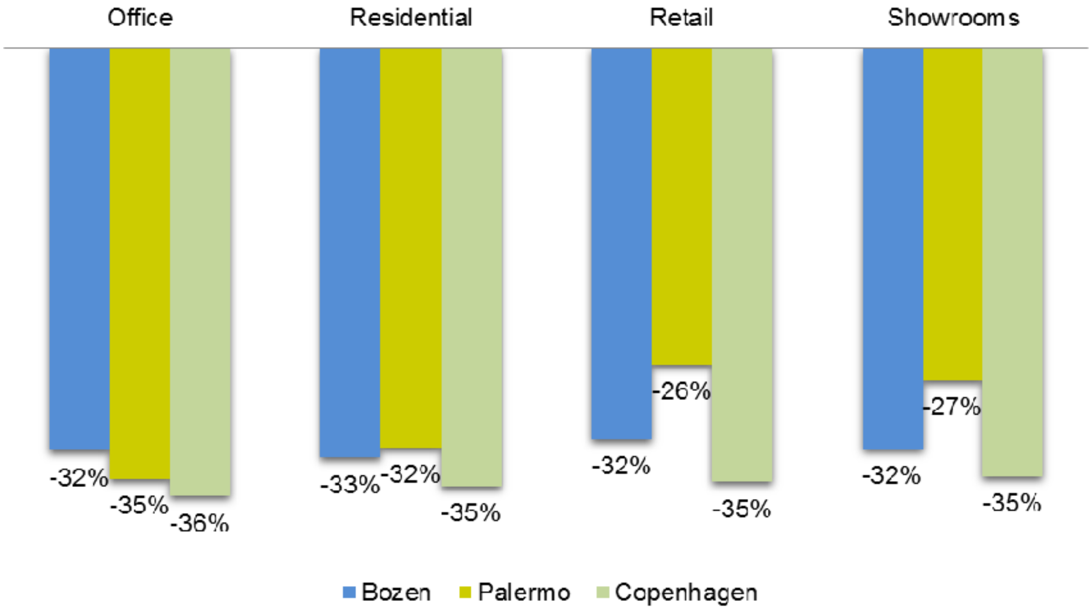


Figure 31 Overall primary energy consumption variation between Step 2 and Step 3-C

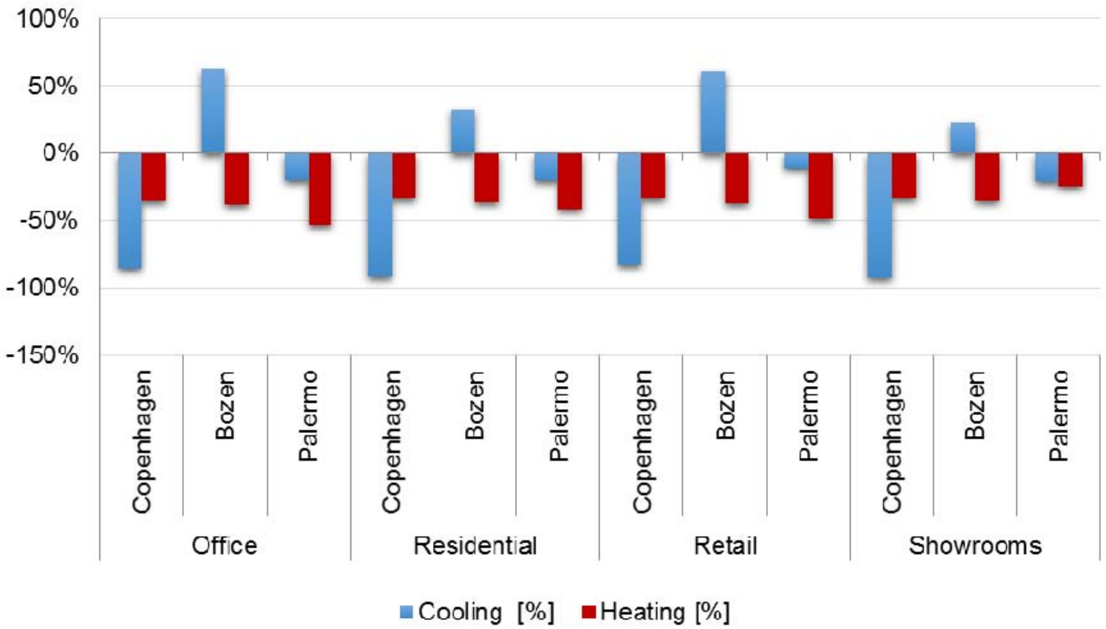


Figure 32 Heating and cooling primary energy consumption variation between Step 2 and Step 3-C

The results show as this approach could reduce the energy consumption compared with Step 2 for every climate zone and building type.

The natural ventilation ensures high cooling energy reduction for all the climate zones and building types compared with Step 2, except in Bolzano where the cooling increase due to the precedent step (3 B) and is not reduced by the integration of natural ventilation.

7 Application of monthly based energy balance calculation (PHPP) for variant calculations for Case Study 5 NMS Hötting, Innsbruck (Austria)

The assessment of performance for CS5 was evaluated with the parameter study tool developed by PHI within 3ENCULT project. Within this section the comparison of several refurbishment variants as well as the performance at different sites and climates is described.

At the refurbishment works at the school in Hötting, within the 3ENCULT-Project, two classrooms so called prototype classrooms were redeveloped to demonstrate the possible energy efficient solutions and to get important experiences for the renovation of the whole school. Because only parts of the building were refurbished so far, there is no clear boundary between the renovated part and the old part. The refurbished prototype classrooms are located in the middle of an arrangement of rooms and the central corridor. The analysis of the influence and improvement caused by partial refurbishment are not feasible and thus the comparison between the calculated annual heating demand and monitoring data after intervention is not possible.

In the following sections of this report are presented different variants considered for refurbishing of the school building. The Passive House Planning Package (PHPP) was used for mutual comparison of the energy balances of various refurbishment solutions and various climate zone locations.

Since the computational model for the status quo was very well corresponding to the reality, the presented consequences of various solutions were very trustworthy as a prediction for the real construction work.

7.1 Comparison of PHPP energy efficient refurbishment variants

To generate the refurbishment variants some inputs located in various sheets have been linked to the new "parameter" sheet where they can be diverse for individual variations. The Figure bellow was represented with the results of the additional sheet "parameter" of PHPP 2007.

For example the difference between the calculation of variant 1 "before intervention" and variant 2 "Windows" is only the input of the g- und the Ug-value of the glazing of the box-type window in the sheet "WinType". The changes were carried out in the new sheet "parameter". This function was developed by Passive House Institute for purposes of the 3ENCULT project.

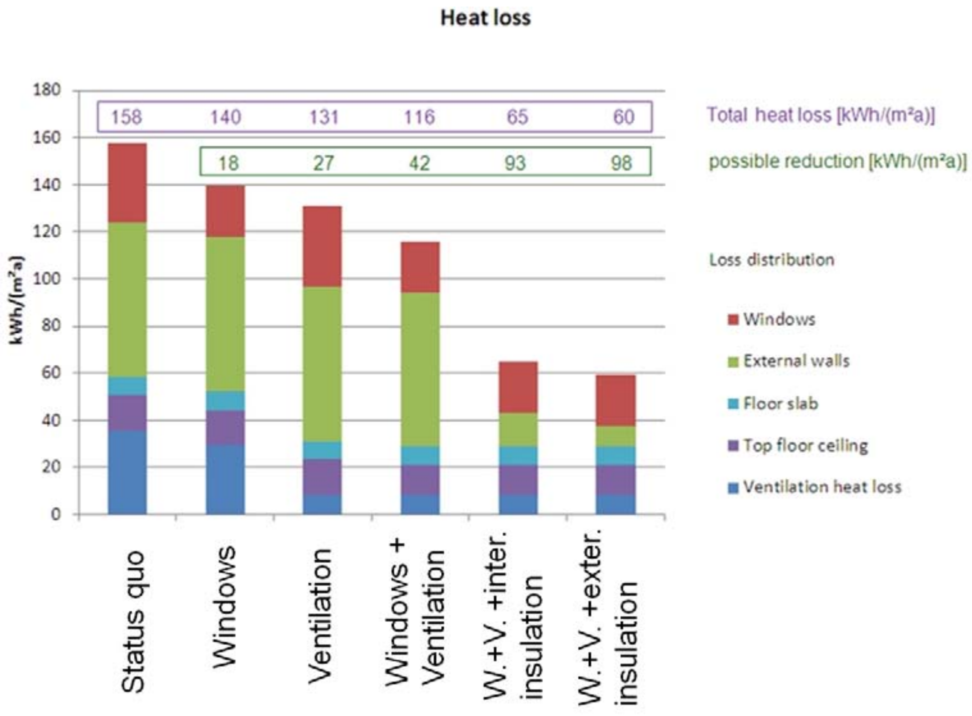


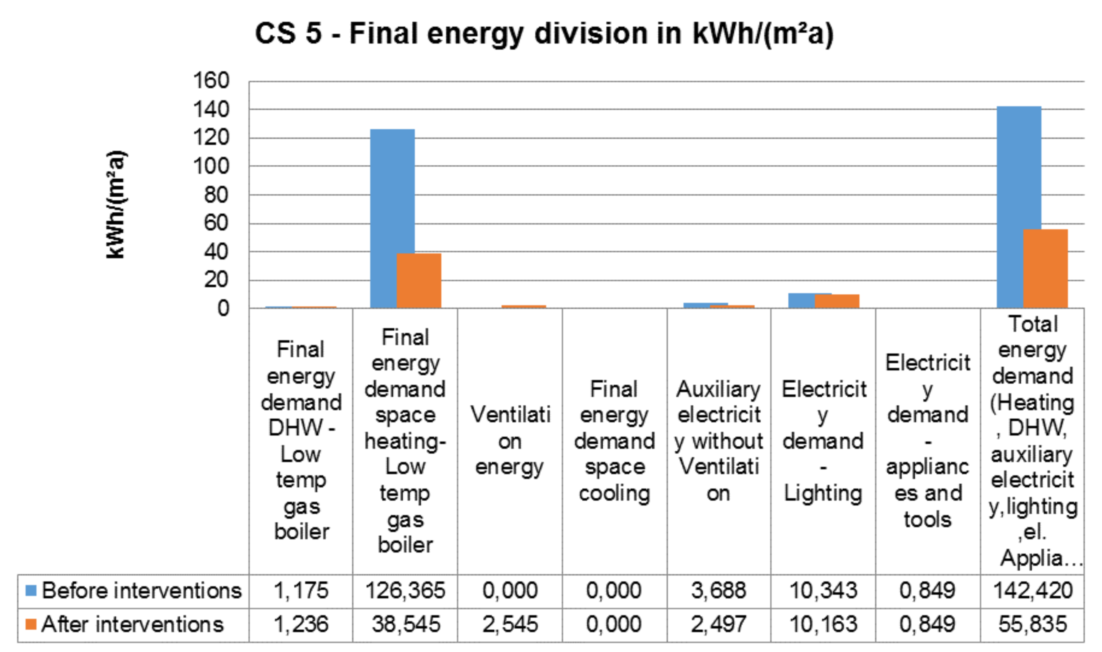
Figure 33 Diagram to compare the heat losses of different refurbishment solutions

The diagram in Figure 33 presents the selected best examples of reduction variants of the annual heat losses considering transmission heat losses over windows, external walls, floor slab, ceiling on the top floor and the ventilation heat losses. The first column of the diagram shows the heat losses of the status quo - before renovation with a total value of 158 kWh/ (m²a).

As clearly visible in the diagram the main reductions of the heat losses are possible due to the improvement of the external wall (green part of the column) and the ventilation situation (lowest blue part of the column). After installing 120 mm thick **external insulation** on the external walls the high losses over the thermal bridges would be strongly reduced; e.g. the connection between the load bearing steel beams of the ceiling, the brickwork of the external wall. The external insulation itself has a potential of reduction of 58 kWh/ (m²a) what is the highest impacted at the heat losses in the building. Despite the benefits of external insulation the application is not possible in order to protect the genuine look of the facade. In a case of applying 80 mm of **internal insulation** the second highest reduction would be reached by value of 53 kWh/ (m²a). Nevertheless the losses caused by the thermal bridges would not be solved in this case.

The reduction of 27 kWh/ (m²a), compare to the status quo, is possible due to the improvement of **airtightness** (such as the new seals on windows, or the fixing of leakages in the thermal envelope) and installation of a **new ventilation system** with an energy efficient heat recovery. The study of variants with single ventilation situation and single improved air tightness of the thermal envelope showed that only their combination makes sense otherwise the potentials of these measures is not fully utilized. The installation of energy efficient ventilation in combination with the improvement of the air tightness is the second most effective refurbishment task.

The biggest share of airtightness heat losses are caused by old **windows**, thus its replacement by more airtight once with a better U_g-value would result in reduction of annual heat losses by 18 kWh/(m²a).



	Final energy demand DHW - Low temp gas boiler	Final energy demand space heating- Low temp gas boiler	Ventilation energy	Final energy demand space cooling	Auxiliary electricity without Ventilation	Electricity demand - Lighting	Electricity demand - appliances and tools	Total energy demand (Heating, DHW, auxiliary electricity, lighting, el. Applia…
🟦 Before interventions	1,175	126,365	0,000	0,000	3,688	10,343	0,849	142,420
🟧 After interventions	1,236	38,545	2,545	0,000	2,497	10,163	0,849	55,835

Figure 34 CS 5 - Final energy division

On the Figure 34 above and below can be seen closed division of energy consumptions outlined by PHPP simulation tool. The variation after intervention contains all proposed energy efficient solutions.

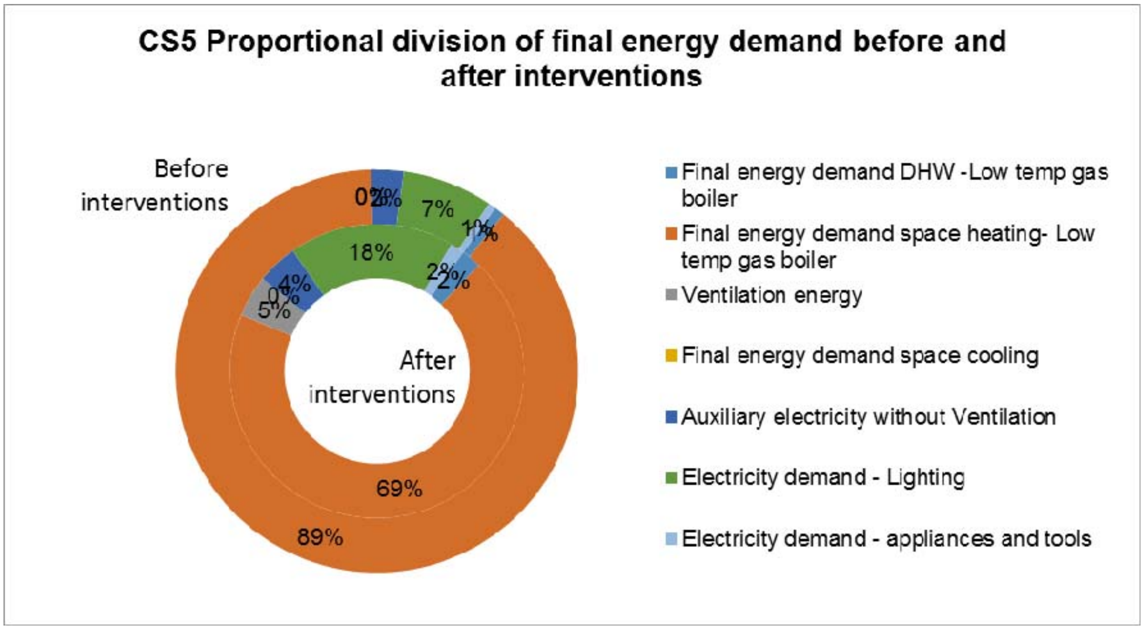


Figure 35: CS5 Proportional division of final energy demand before and after interventions

The energy demand after interventions is higher because the "Marginal Utilisability of Additional Heat Gains" from heating system are smaller. The detailed energy balance together with main building characteristics like the building envelope properties is reported in the appendix.

7.2 Comparison of the heat losses of the status before intervention of the Höttinger School located in different climate zones

The **Error! Reference source not found.** below presents the annual heating demand for a scenario when the Höttinger School in Innsbruck is placed in 4 different locations. This comparison was carried out when the “Climate Data” sheet was changed in the PHPP calculation file.

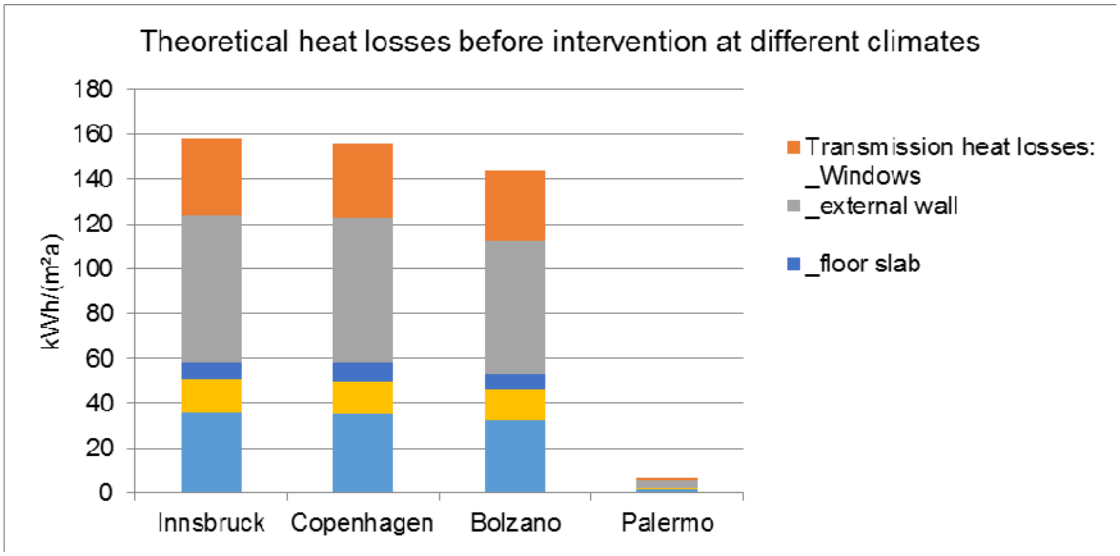


Figure 36 Theoretical heat losses before intervention in Innsbruck, Copenhagen, Bolzano and Palermo

From the results shown above is clear that heating needs for the mentioned schools are highly dependent on influences by the local climate. In Innsbruck, Copenhagen and Bolzano, the transmission losses of the external walls are the most significant fraction. In Palermo, the heating would be neglectable.

8 Conclusions

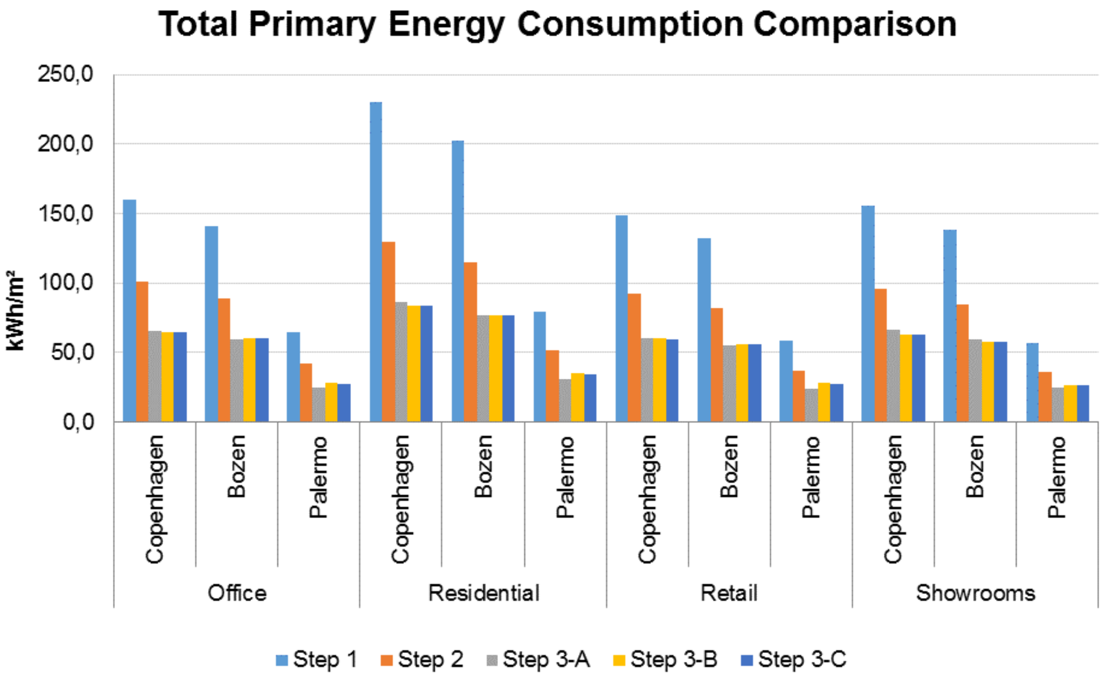


Figure 37 Total primary energy consumption comparison

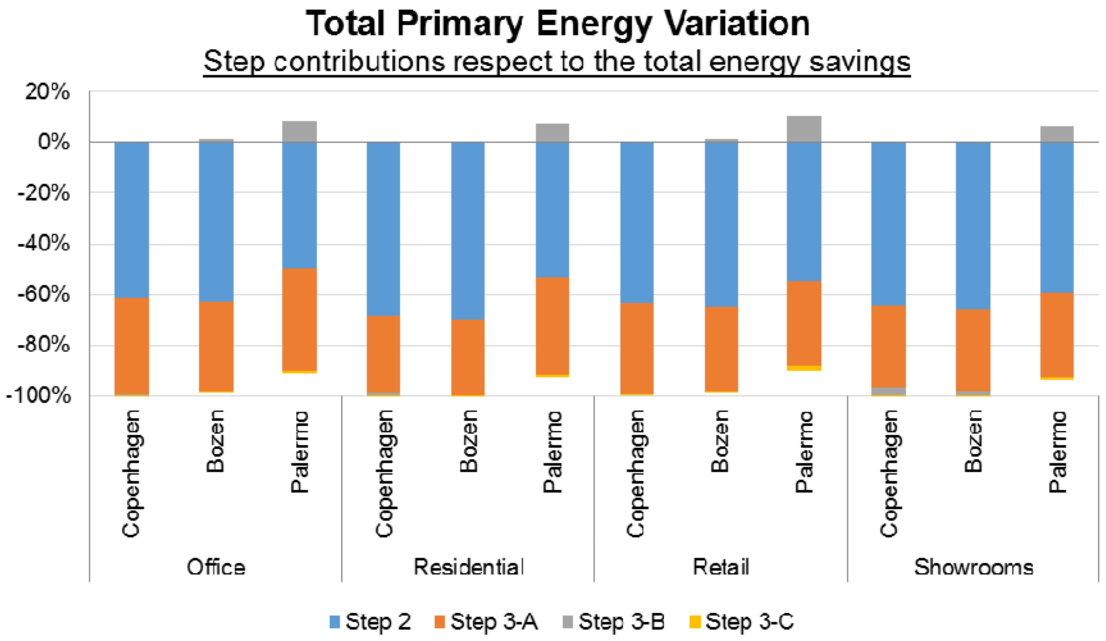


Figure 38 Total primary energy variation - step contributions respect to the total energy savings

The studies proposed in this report show as the combination of active and passive solutions for the historic buildings energy renovation could bring to significant energy savings. Two different models and methods were applied for the analysis. The assessment of performance for CS1 was done with an dynamic simulation tool (EnergyPlus) whereas the model of CS5 was a monthly based energy balance model (PHPP). In both cases variants of combined solutions were investigated, the outcome was as follows.

Analysis on CS1

As explained in this report, the results show as the main energy saving could be obtained by a properly studied and integrated HVAC system replacement, depending on the climate conditions and to the building types. In fact, the new generation system that has been adopted (air condensed heat pump) allows to reduce the total energy consumptions for 55-60% minimum for all the climate zones and building types. Overall, the improvement of the HVAC systems allows for the most consistent energy reduction in terms of primary energy.

Furthermore, the analysis shows that the passive strategies focused on the glazed envelope performance improvement (step 3-A), may provide further savings. The windows replacement and infiltration reduction (U_w = 1.2 W/m^{2}K, g-value of 0.6 and a low-infiltration rate of 0.3 ach) may provide an additional 37% average energy saving from the previous step (respect to the maximum calculated considering all the strategies).

The additional insulation for roof and exposed slabs (Step 3-B) could cause an increase of cooling loads, due to the internal loads that are not dissipated to the outside, and consequently of the energy consumption. This strategy could reduce the overall energy consumption in comparison with Step 2 (HVAC replacement) but it doesn’t show the reduction of consumptions when compared with the Step 3-A, except for the showrooms and residential building types. The new building envelope performances (new windows, low infiltrations, roof and external slab insulation) reduce the thermal losses and, in combination with the internal loads may cause an increase of cooling loads and a decrease of the heating demand.

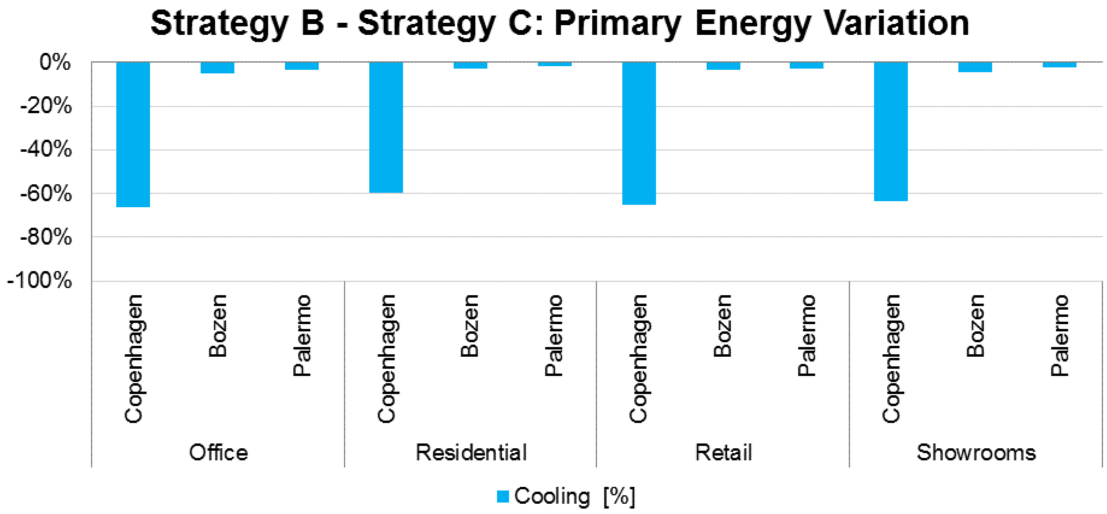


Figure 39 Strategy B - Strategy C: Primary Energy Variation

Natural ventilation (Step 3-C) allows for the reduction of the energy consumption for all climate zones and building types. In the overall comparison with Step 2, a cooling increase is shown, due to the Step 3-B that is not balanced by the contribution of natural ventilation.

Respect to the total energy saving, this contribution is small because of the very low cooling demand already obtained in the Step 3-A and Step 3-B. Nevertheless , the cooling consumption is reduced respect to the Step 3-B, underlining the importance of the passive strategies integration for all climate zones and building types.

Finally, the energy saving strategies here developed can reduce the overall energy consumption between 55% - 60% for all climates and building types assessed, with peak values of 70%. The results show as both the importance of an efficient HVAC system choice (HP air condensed + split system) and the active and passive strategies integration are fundamental for the energy renovation of an historical building.

Analysis on CS5

As decided by the building owner (IIG) of CS5, the whole school building will be refurbished within the next two years. The school building is part of the upcoming EU-demonstration project SINFONIA with a total area of 66.000 m² of dwellings and school buildings to be refurbished in Innsbruck (A) and Bolzano (I).

The research and investigations on possible interventions (especially in terms of energy efficient solutions) performed within 3ENCULT are an important basis for future decisions. The evaluation of the losses of the thermal envelope showed, that the effect of a wall insulation (together with a significant enhancement of the airtightness of the building) is one of the key issues for comfort and energy efficiency. The installation of a heat-recovery ventilation is necessary for air quality reasons and to avoid damages by moisture at the same time. The active overflow concept in combination with a central heat recovery at the attic turned out to be a well performing solution. The combination of shading and daylight redirection integrated within the box-type-window avoids a glare and overheating problems and enhances the daylight autonomy.

All of these results, as well as the cost estimation from the prototype installations in the class rooms and at the roof allows for a detailed forecast of investment, comfort and payback to be expected for the full scale refurbishment.

The PHPP-calculations before and after interventions shows the range of potential savings. Moreover the comparison of different refurbishment solutions shows the effects of single interventions as well as combinations of solutions. This will help to find a technical solution with high impact on energy savings while will met the requirements for the architectural, conservational and technical demands.

Once the PHPP with variants of different refurbishment solutions is ready, it is an easy task to calculate the performance at different sites with other climates. Each historic building is unique and individual, however the results might be useful for similar buildings in terms of geometry, thermal envelope and thermal mass. In comparison with the dynamic simulations done for CS1, the effort on input data (both, geometry and material data) is much lower and more fail-save for non-scientific users. With the new “Design PH” tool is the 3D-geometry input similar to “EnergyPlus” where both works with an “Sketchup/Trimble” plugin.

Appendix A

A.1 Step 1

Heating Demand

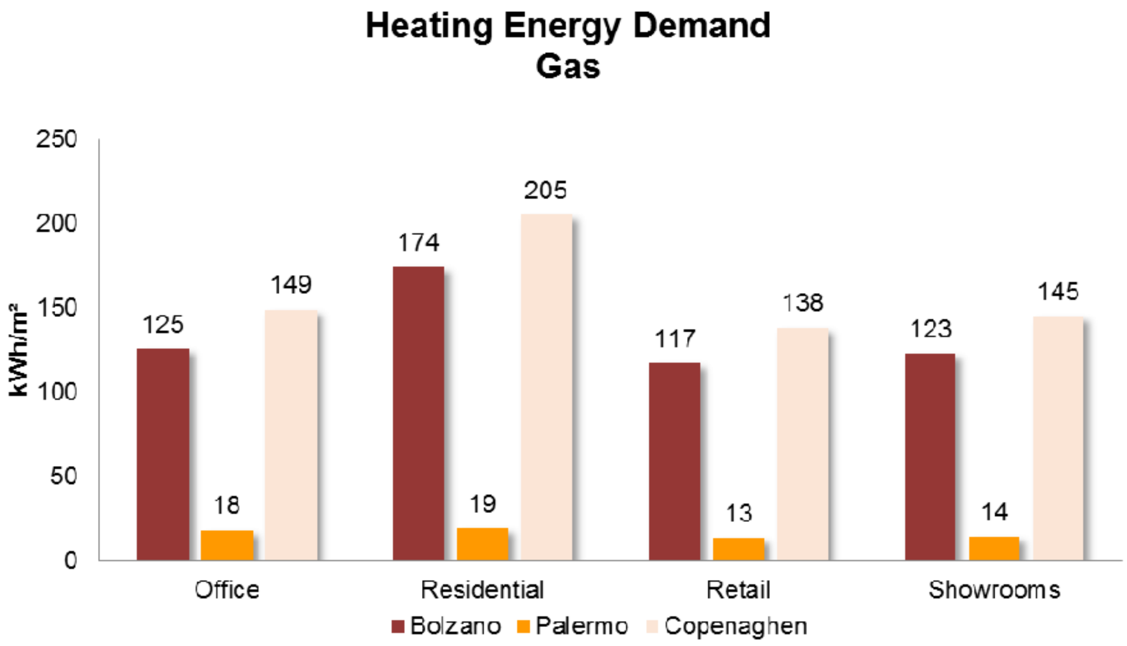


Figure 40 Heating energy demand - Gas

These results show that Palermo has an extremely low heating energy demand due to the warm climate zone.

Copenhagen, on the contrary, has the highest heating energy demand due to the cold weather.

Cooling Demand

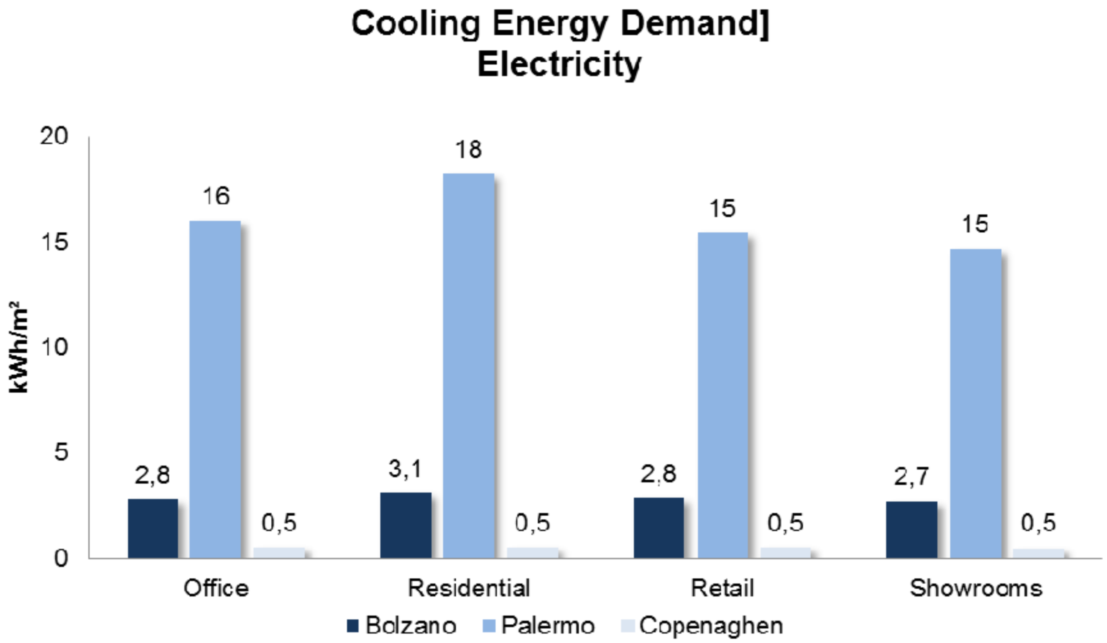


Figure 41 Cooling energy demand - Electricity

Results show that Copenhagen has a low cooling energy demand due to mild summer temperature. Palermo, on the contrary, has the highest cooling energy demand due to the hot weather.

A.2 Step 2

Heating Demand

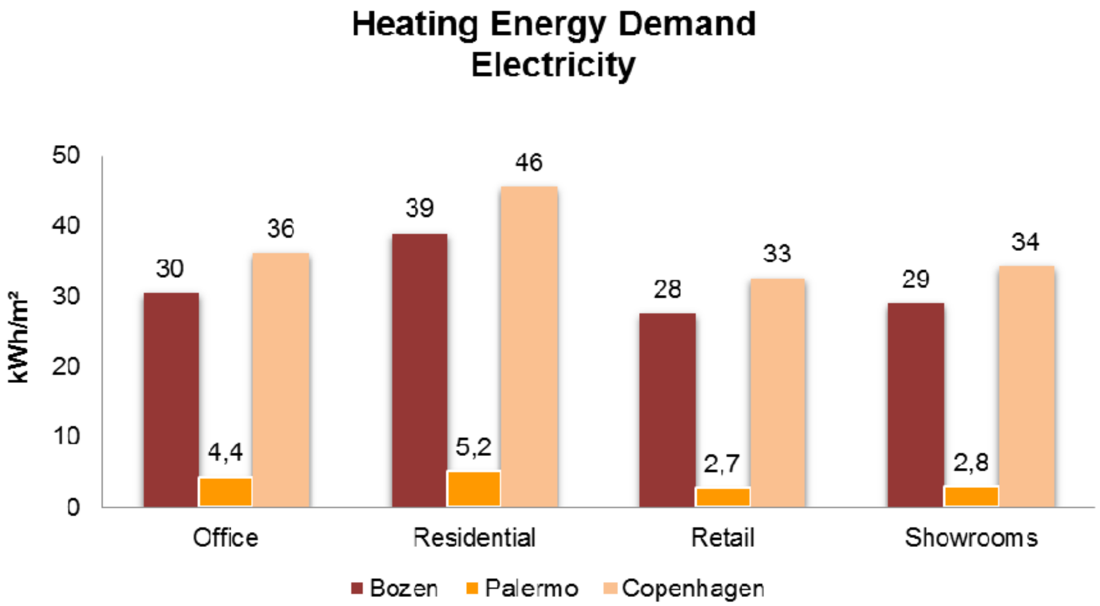


Figure 42 Heating energy demand - Gas

These results show that Palermo has an extremely low heating energy demand due to the warm climate zone.

Copenhagen, on the contrary, has the highest heating energy demand due to the cold weather.

Cooling Demand

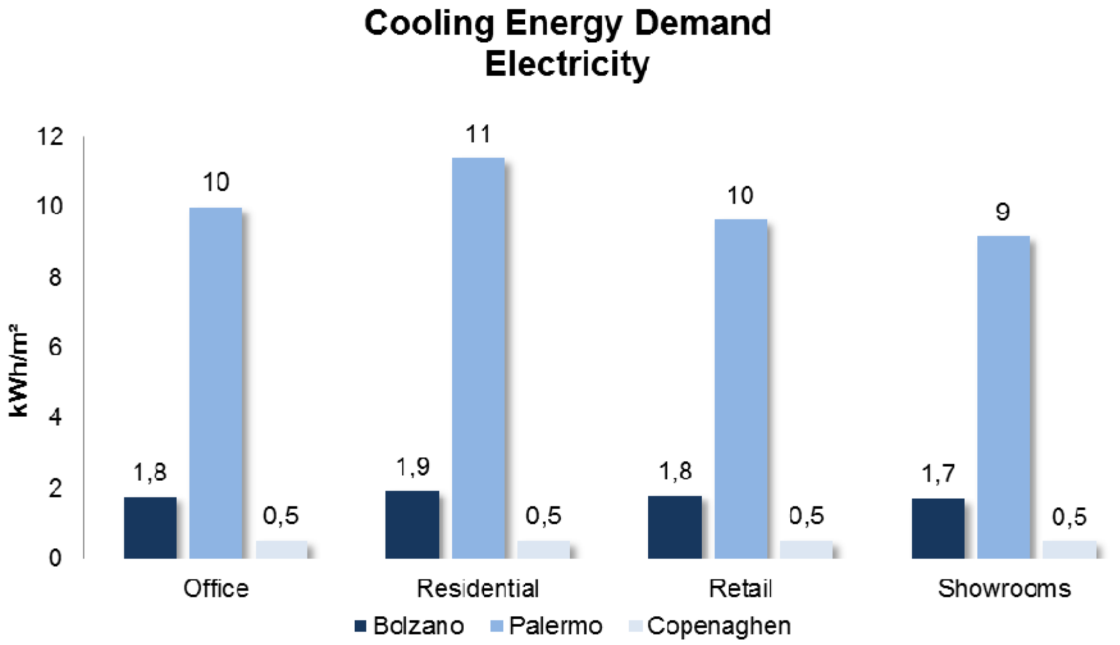


Figure 43 Cooling energy demand - Electricity

Results show that Copenhagen has very low cooling energy demand, for each building type, due to mild summer temperature.

Palermo, on the contrary, has the highest cooling energy demand due to the hot weather.

A.3 Step 3-A

Heating Demand

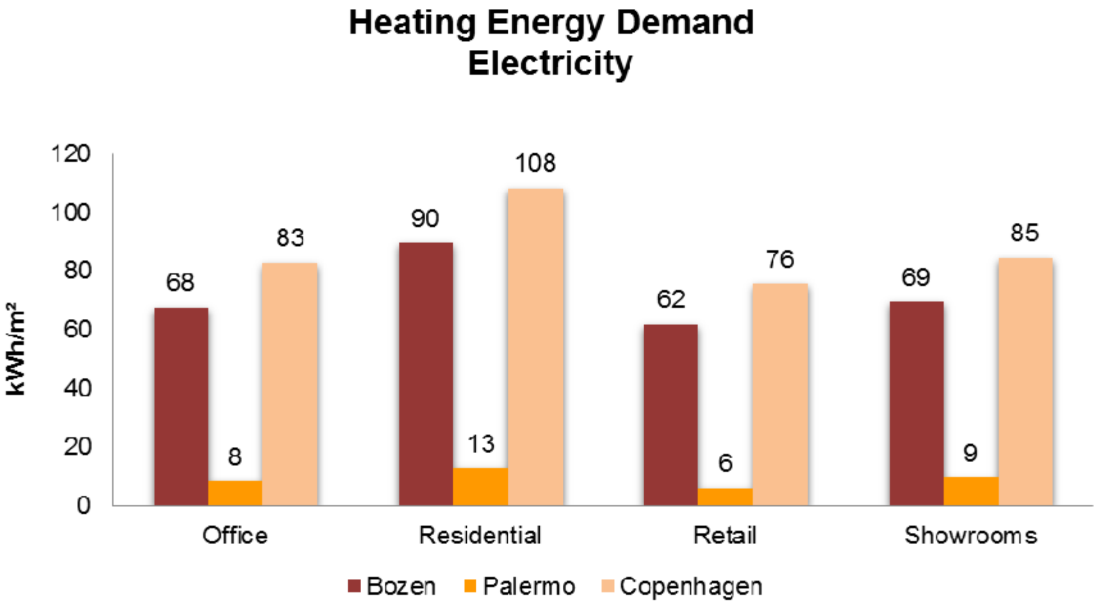


Figure 44 Heating energy demand - Gas

These results show that Palermo has an extremely low heating energy demand due to the warm climate zone.

Copenhagen, on the contrary, has the highest heating energy demand due to the cold weather.

Cooling Demand

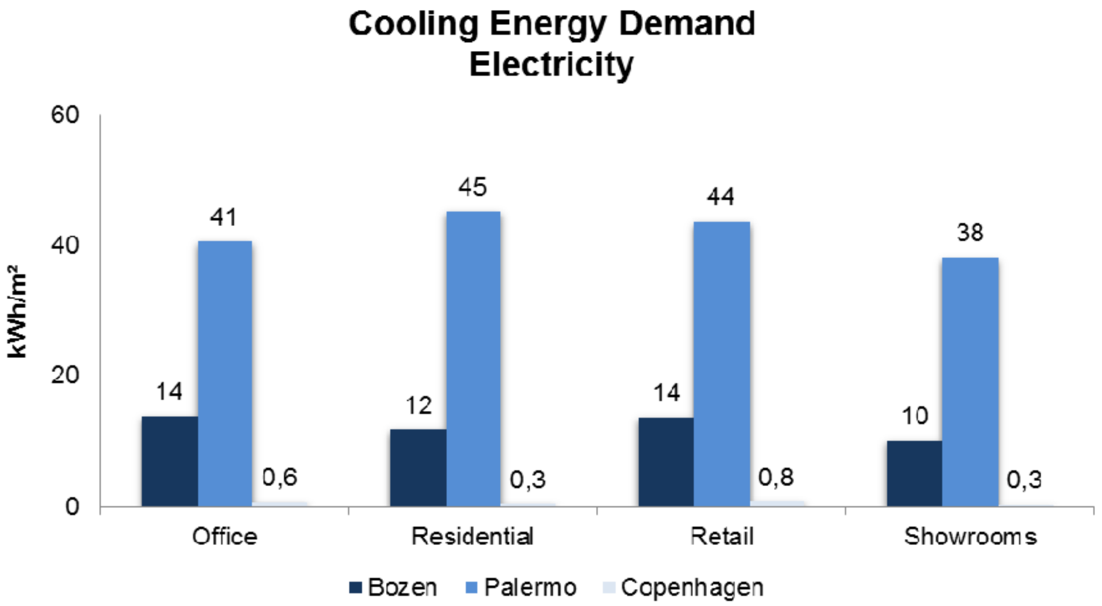


Figure 45 Cooling energy demand - Electricity

Results show that Copenhagen has very low cooling energy demand due to mild summer temperature.

Palermo, on the contrary, has the highest cooling energy demand due to the hot weather.

A.4 Step 3-B

Heating Demand

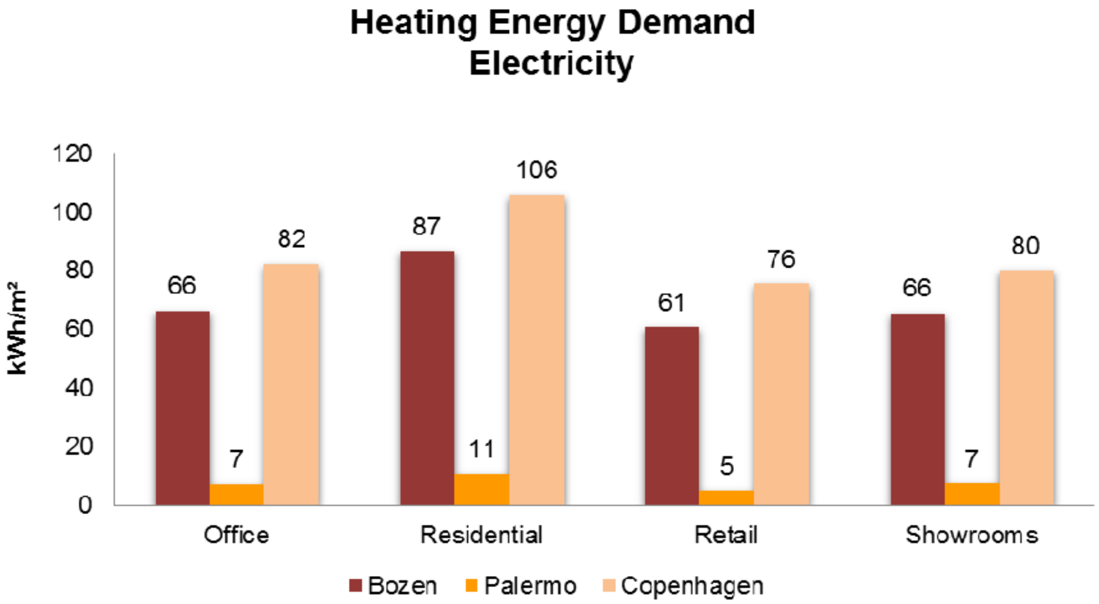


Figure 46 Heating energy demand - Gas

These results show that Palermo has an extremely low heating energy demand due to the warm climate zone.

Copenhagen, on the contrary, has the highest heating energy demand due to the cold weather.

Cooling Demand

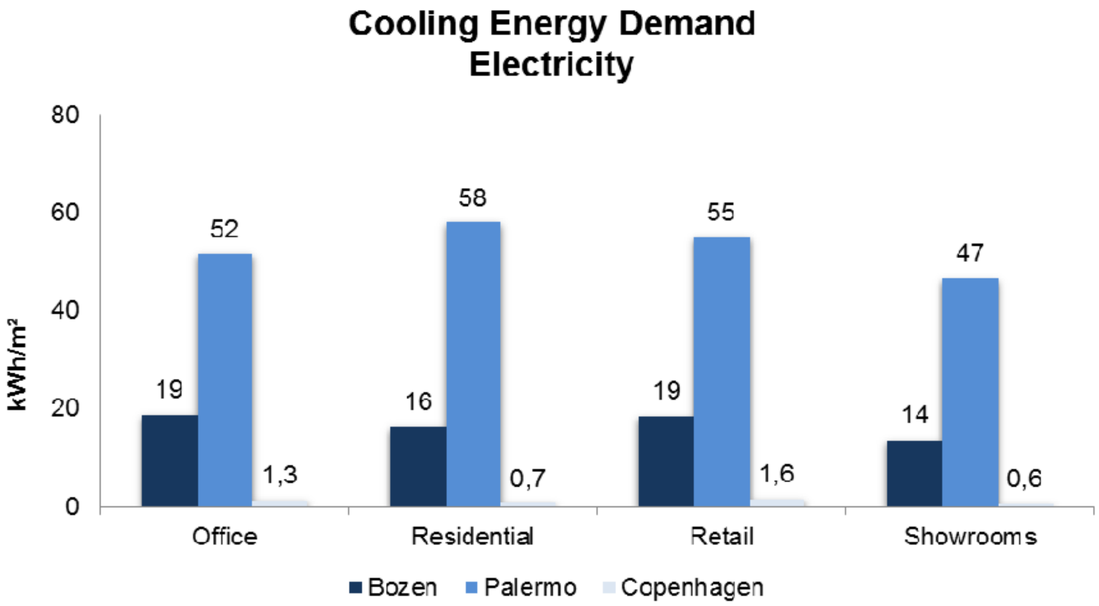


Figure 47 Cooling energy demand - Electricity

Results show that Copenhagen has a low cooling energy demand due to mild summer temperature. Palermo, on the contrary, has the highest cooling energy demand due to the hot weather.

A.5 Step 3-C

Heating Demand

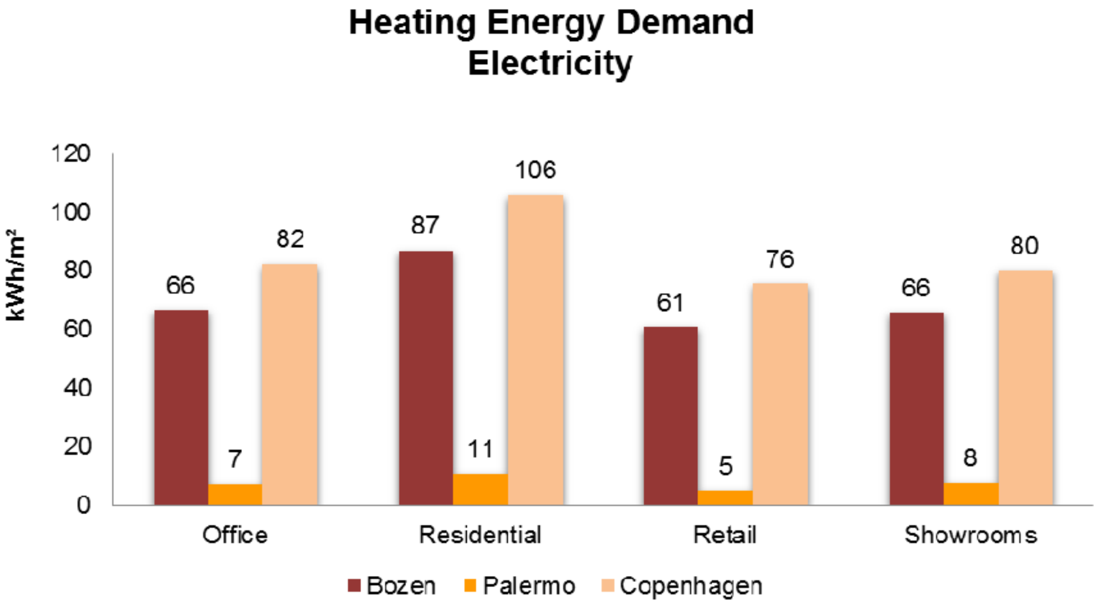


Figure 48 Heating energy demand - Gas

These results show that Palermo has an extremely low heating energy demand due to the warm climate zone.

Copenhagen, on the contrary, has the highest heating energy demand due to the cold weather.

Cooling Demand

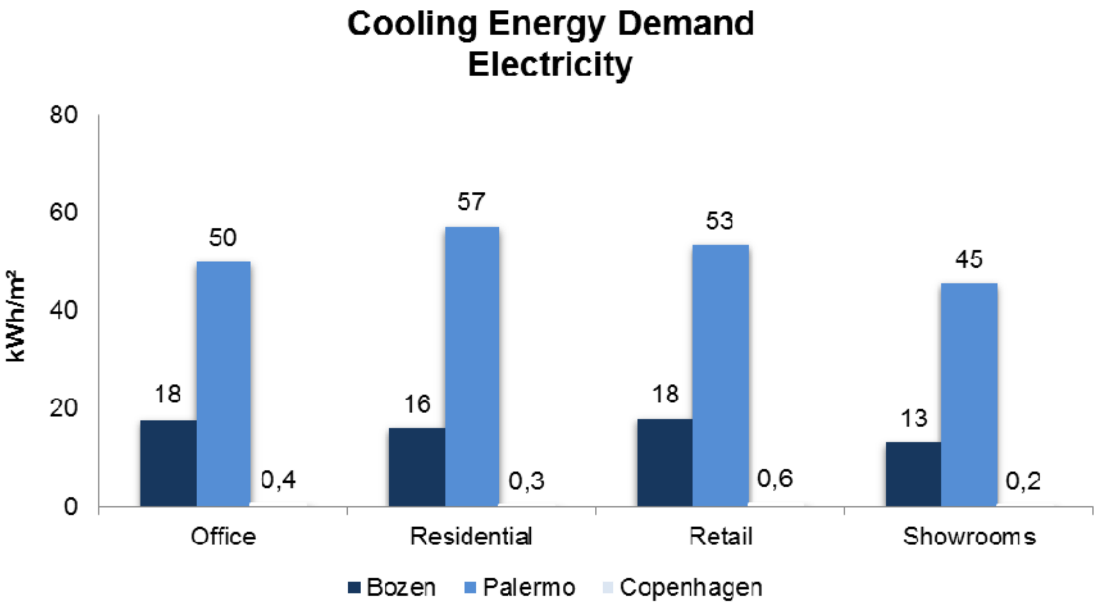


Figure 49 Cooling energy demand - Electricity

Results show that Copenhagen has a low cooling energy demand due to mild summer temperature. Palermo, on the contrary, has the highest cooling energy demand due to the hot weather.

A.6 PHPP of CS 5

				PHPP		
Aspect	***Before***	***After***	***Unit***	***Before interventions***	***After interventions***	***Unit***
Treated floor area AREA:	4089,860	4089,860	m²			
Energy demand						
Space heating demand	528983,686	157411,166	kWh/a	129,340	38,488	kWh/(m²a)
Heating load non-residential	62,225	21,826	W/m²			
Frequency of overheating (> 25 °C)	0,000	0,000	%			
Space cooling demand	78,373	12,200	kWh/a	0,019	0,003	kWh/(m²a)
Domestic hot water demand	4458,517	4686,201	kWh/a	1,090	1,146	kWh/(m²a)
Interior temperature winter:		17,44558208	°C			
Interior temperature summer:		25	°C			
Average building envelope quality						
Average U-value of walls	1,804	0,350	kWh/a			
Average U-value of external insulation to ground	1,804	0,350	W/(m²K)			
Average U-value windows and doors	2,162	1,373	W/(m²K)			
Average U-Roof/Ceiling - Ambient	0,540	0,455	W/(m²K)			
Average U-Floor slab/ basement ceiling	2,350	2,350	W/(m²K)			
Pressurization test result n50	4,4	0,6	1/h			
Measurable - Final energy need						
Final energy demand DHW -Low temp gas boiler	4805	**5057**	kWh/a	1,175	1,236	kWh/(m²a)
Final energy demand space heating- Low temp gas boiler	516815	157643	kWh/a	126,365	38,545	kWh/(m²a)
Ventilation energy	-	10411	kWh/a	-	2,545	kWh/(m²a)
Final energy demand space cooling	-	-	kWh/a	-	-	kWh/(m²a)
Auxiliary electricity without Ventilation	15083	10211	kWh/a	3,688	2,497	kWh/(m²a)
Electricity demand - Lighting	42301	41563	kWh/a	10,343	10,163	kWh/(m²a)
Electricity demand - appliances and tools	3472	3472	kWh/a	0,849	0,849	kWh/(m²a)
Total energy demand (Heating, DHW, auxiliary electricity, lighting, el. Appliances)	582476,630	228355,935	kWh/a	142,420	55,835	kWh/(m²a)
Primary energy need						
Primary energy demand DHW	5285,492	5562,244	kWh/a	1,292	1,360	kWh/(m²a)
Primary energy demand space heating	568496,873	173406,877	kWh/a	139,002	42,399	kWh/(m²a)
Ventilation energy demand	-	-	kWh/a	-	-	kWh/(m²a)
Primary energy demand space cooling	-	-	kWh/a	-	-	kWh/(m²a)
Auxiliary electricity - without Ventilation	39215,993	26547,683	kWh/a	9,589	6,491	kWh/(m²a)
Electricity demand - Lighting	109982,819	108064,430	kWh/a	26,892	26,423	kWh/(m²a)
Electricity demand - appliances and tools	9027,564	9027,564	kWh/a	2,207	2,207	kWh/(m²a)
Total energy demand (Heating, DHW, auxiliary electricity, lighting, el. Appliances)	732008,740	322608,798	kWh/a	178,981	78,880	kWh/(m²a)