Contents

1 INTRODUCTION

These guidelines aim to present an example about how the *Passivhaus* Standard could be applied in a country such as Italy, characterized by climate and socio economic conditions that are very different from the original context of application, that is Germany.

The models presented in this text might serve as examples during the development of a project, but obviously this will need to be adapted to the context, the climate and to the specifications and preferences of the buyer.
Planners will always need to considerate the hypothesis on which some tendency lines described here are based on, and then compare with those of the practical situation in which the model has to be applied to.

We have focused on residential sector, and we have chosen as reference typology the solution of terraced house. The analysis has been developed through the dynamic simulation of the energy behaviour of building models properly defined.

The aim is to identify at least a package of technological solutions and control strategies able to satisfy the energy performance requisites (useful net sensible energy for heating and cooling) and the comfort requisites of the revised Passivhaus Standard.

In this context we considered as an advantage for the methodology to begin from the experience already consolidated in Centre Europe and, with a number of sensitivity analysis, we aimed at optimizing the project results with proper modifications and integrations.
The analysis that we present in the next chapters follows the following methodological steps:

- characterization of the climate context
- individuation of a basic model, built from the consolidated experience of *Passivhaus* in northern Europe, integrated in advance with some cooling strategies
- an analysis aimed at adapting the main characteristics of the initial envelope to different climate conditions considered and to recognize the optimized models
- evaluation of summer thermal comfort of optimized buildings.

2 CLIMATE CONTEXT

Italy is generally considered as a country that enjoys Mediterranean climate. However Italy has a varying typology of mountains and planes stretching 1 500 km from North to South and is subject to considerable climate variations.

Italian legislation (law 10/91) identifies six official winter climate zones based on degree days (DD) from the warmest Zone A (DD < 600) to the coldest Zone F (DD > 3 000).

Even though the climate variety is very remarkable also during the summer period, reference norms don't give a subdivision of the territory in summer climate zones. In order to fill this gap one can refer to a CNR proposal which, in 1990, identified seven summer climate zones (from the coldest one, n. 7, to the hottest, n. 1). CNR analyzed the main climate local parameters (relative humidity, wind speed, air temperature and solar radiation).

Taking into account these differences, we have decided to develop a *Passivhaus* proposal for the climate conditions of Milan, Rome and Palermo: they are respectively located in North, Centre and South Italy, and they belong to winter climate zones E, D and B.

The data shown in table 1 and 2 indicate that Rome, considering the whole year, offers probably the most convenient climate conditions: winter is mild and summer not too critical. Wind speed and summer day-night temperature swing make a favourable condition for the exploitation of the potential of night natural ventilation.

Even if in Palermo the winter season is quite mild, summer is hot, with a high solar radiation and a limited temperature swing from day and night; the last condition could reduce the effectiveness of night ventilation of the thermal mass of buildings.

In Milan winter conditions with very cold temperature and little solar radiation are predominant. During summer low wind speed could restrict the effectiveness of night ventilation.

Table 1: Winter climatic data (from November 1st to February 28th) .

	Climate Zone	Winter Degree Day	Temp. mean	Temp. min	Wind speed (average)	Relative humidity (average)	Global solar radiation (average)
			[°C]	[°C]	[m/s]		[Wh/m² day]
Milan	E	2 404	2,8	-11,0	0,7	83%	1 263
Rome	D	1 415	9,9	-4,0	4,1	79%	2 048
Palermo	B	751	13,9	4,8	4,3	73%	2 143

Table 2: Summer climatic data (from June 1st to August 31st).

	Climate Zone (CNR)	Summer Degree Day	Temp. mean	Temp. max	Daily temperature variation (average)	Wind speed (average)	Relative humidity (average)	Global solar radiation (average)
			[°C]	[°C]	[°C]	[m/s]		[Wh/m² day]
Milan	7	482	21,7	32,6	8,9	1,0	71%	4 855
Rome	3	568	23,3	31,8	7,5	3,3	75%	4 918
Palermo	1	842	25,1	34,0	4,0	3,3	74%	6 471

We note here that the climatic data that have been used during the simulations (and are summarised in tables 1 and 2), are referred to "typical years" built using the surveys made by the meteorological stations at nearby airports (Linate, Fiumicino and "Falcone and Borsellino").
It is important to note that climate conditions inside urban centres present some difference compared to those at airports: due to "heat island" effect, summer temperatures are generally higher and, due to the city structure, wind speed is generally lower.
In order to reduce this discrepancy and in this way adapt available meteorological data to real conditions, we have corrected the air speed depending on the typical urban context but, even with this correction, we invite reader to use caution and consider the examples presented as more appropriate and pertinent to houses located in suburban areas, where they are not subject to the "heat island" effect.

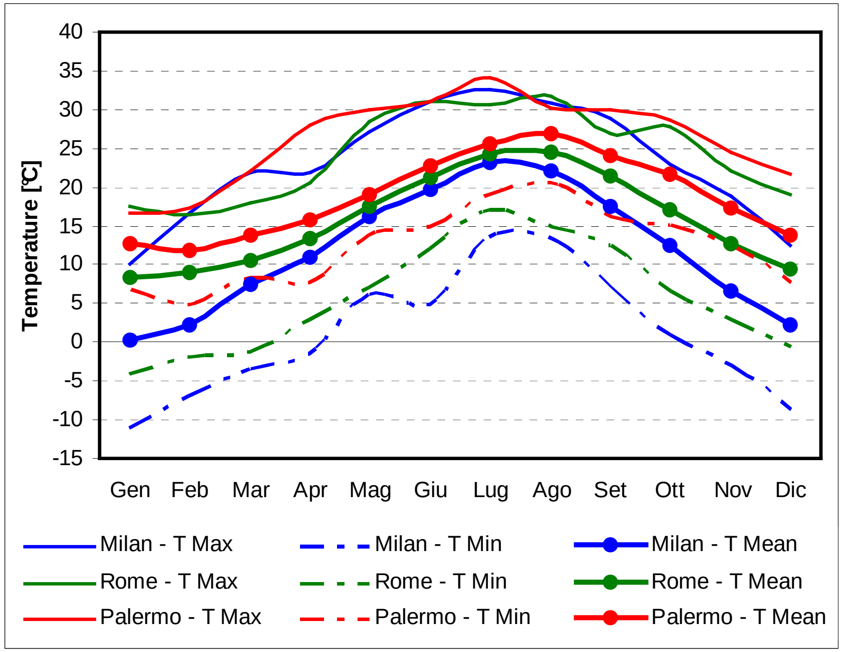

Figure 1: Monthly average, minimum and maximum temperatures for Milan, Rome and Palermo.

3 BASE MODEL

As mentioned before, our first step is to evaluate how the building envelope of a traditional *Passivhaus*, properly integrated with passive cooling strategies, responds to the climate conditions that we have considered.
With this preliminary result we want to gather general indications about its potential transfer in the considered climates, finding possible critical issues and obtain indications for the following optimization steps.

In order to make more explicit the context on which the results are based, we present a table of the main characteristics of the building from which we start the analysis and, in the following paragraphs, a description of these characteristics: geometry, building components, cooling and heating strategies and air exchange rate.

Table 3: Principal characteristics of base model.

Surface =	103		m^2
Room height =	2,70		m
S/V Ratio =	0,88		m^2/m^3
Air infiltration: n_{50} =	0,60		h^{-1}
Envelope U-value	wall	0,135	$W/m^2/K$
	roof	0,135	$W/m^2/K$
	floor	0,135	$W/m^2/K$
	glazing	0,700	$W/m^2/K$
Thermal mass =	450		kg/m^2
Occupation	n° people	4	
Internal gains	appliances	2,0	W/m^2
	lighting	1,2	W/m^2
Heating strategies	Air-Distribution System		
	Heat recovery with efficiency of 85%		
	Reversible heat pump		
Cooling strategies	Solar protections		
	Night natural ventilation		
	Reversible heat pump		
Air change rate =	0,74		h^{-1}

1.1. BUILDING GEOMETRY

This study aims at quantifying the energy and comfort performances of a terraced two floors house with a habitable net area of about 100 m², comprising a basement, ground and first floor. A stairwell links the basement, the living area on the ground floor and the sleeping area on the first floor. Basement and garage are exterior to the insulated envelope.
We decided to consider a building such as a terraced house, located at the end of the row and with a S/V ratio of 0,88 m^{-1}. To optimize solar gains (favouring them in summer and restricting them in winter), the largest glass area faces south.
For the aesthetic aspects and in the rooms arrangement, the *Passivhaus* developed for Italy is in line with the style adopted in a large fraction of new housing construction in countryside and suburban areas in the last years, at least in the Centre-South. The choice of a terraced house as our reference aims to show how it is possible to meet the *Passivhaus* Standards while at the same time satisfying the characteristics commonly required on the housing market. It's anyway important to remember that other solutions should be considered also. In particular one should include in the analysis the fact that low density building models could imply a higher energy consumption (for heating and cooling but also for services, transports and infrastructures) compared to medium density building models, such as block of flats.
The results presented are hence valid for this particular living unit, but they can be considered as a first indication also for block of flats solutions, but bearing in mind that the latter have S/V ratio and thermal dispersion lower than the terraced house and hence they can more easily reach the Standard.

Concerning the transparent surfaces of the reference building model, the design has been done in order to respect the requirements set by the health regulations in force in Italy, that is the glazing[1] area of each room must not be lower of one eighth of the total useful floor surface of the same room.
The conformity to this principle implied that the total glazing of the south façade represents around the 20% of the façade.

Figure 2: The south (left) and north (right) facades of the he Italian Passivhaus.

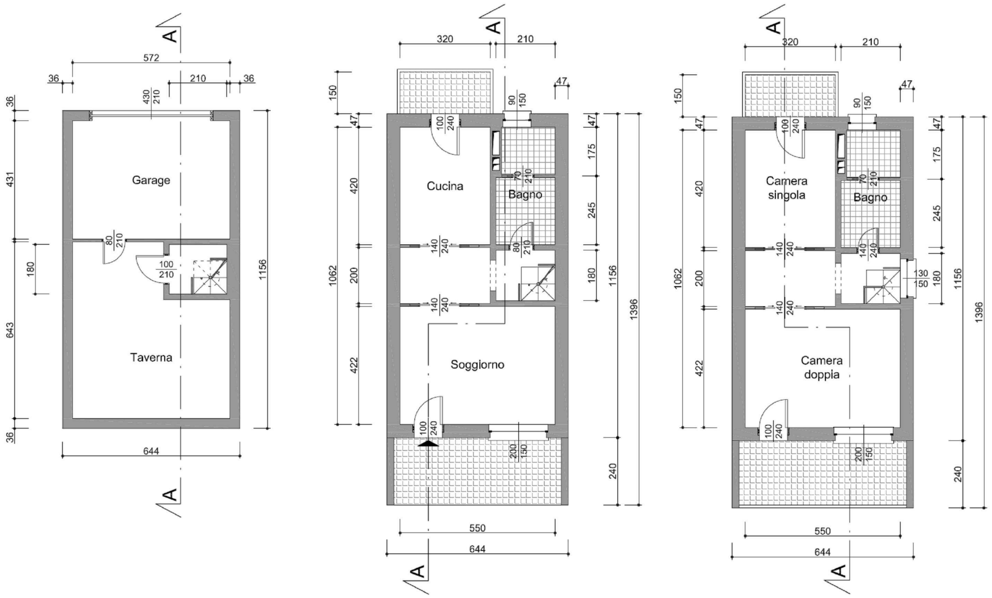

Figure 3: House plans for basement (left), ground (middle) and first floors (right).

[1] For the definition and calculation procedure, refer to the Health Regulation of Milan, Art. 3.4.15.

1.2. BUILDING COMPONENTS

For the definition of the building model object of the study, we adopted the usually employed building techniques in the majority of the newly built residential buildings in Italy, properly combined.
In particular, considering the size of the building rooms considered, for the vertical components of the envelope we used a structural system with a frame made of reinforced concrete and in order to obtain a high and efficient thermal inertia, we used infilling with solid brick (15 cm thickness). On the external side of this layer, after the application of a layer of regularization, we decided for a insulated layer (25 cm thickness), protected and supported in the outside part by self supporting cavity blocks (12 cm), completed with lime plaster. On the inner surface of the perimeter walls there is a layer of a lime and gypsum plaster.
The slab closing the superior part of the envelope (toward the unheated garret), is made of a cement-brick load bearing structure (20 + 4 cm) on which, in order, are posed: a high density (25 cm) insulation panel, a loads distribution layer of 5 cm, a cement and sand layer of 6 cm and finally the ceramic tiles coat. The lower slab (toward the unheated basement) presents the same layers with a reverse order, while the slab between two floors (ground and first floor) is made by the same building layers, but it’s not insulated.
If we consider an insulating material with a conductivity of 0,037 W/mK, all the thermal transmittances of the building elements surrounding the heated rooms (walls, roof and basement) have a value of 0,134 W/m^2/K, a value typical of the Central Europe *Passivhaus*.

In the first instance, for the glazed components we referred to the same technologies used in German *Passivhaus*, aimed first of all at winter performances (three pane glasses made of two low emissive glass pane and a clear glass pane, cavities filled with argon), able to limit the centre of glass thermal transmittance at 0,700 W/m^2/K, reduce the local winter discomfort due to the lower temperature of transparent surfaces while not reducing too much winter solar gains (solar factor = 0,53). Combining this kind of glazing with high thermal performance frames, enables to limit the total transmittance of the windows at 1,0 ÷ 1,2 W/m^2/K, depending on the size of the windows.

The Standards and the good practice of Central Europe demand that building envelopes limit the air exchange by air infiltration at a maximum of 0,60 h^{-1} for a pressure difference of 50 Pa (n_{50} <0,60 h^{-1}). In order to reach this technical specification the windows frames of the house have an air permeability of 0,31 kg/h for each meter of joint.

Concerning the building thermal mass, experiences and analysis show its influence on the energy requirements: Swiss regulation SIA 382 for example, sets a minimum value of thermal effective mass at 350 kg per m^2 of net floor area, in order to limit the cooling requirement.
The considered building components imply for the analyzed *Passivhaus* an average thermal effective mass[2] of 450 kg/m^2. Generally, it’s possible to attribute a medium-high thermal inertia to the building, in line with the building solutions normally used in Italy.
We underline that in order to be really effective for passive cooling, the thermal mass must be put in contact with the night airflow. That means, on the one side, that the mass should be left exposed and, on the other hand, that it’s necessary to position and size the ventilation opening so that the inside walls and the slabs are washed by the night air flows.

Concerning the thermal bridges, we have to consider that in Italy often new constructions are made of a load bearing reinforced concrete frame and brick wall infill. Usually, this practice implies thermal bridges in correspondence of the beams and the pillars and along the bonds between the bricks and the load bearing structure.
Other thermal bridges exist where the gutters lie on the perimeter walls, at the window openings and in the foundations.
In standard buildings it’s typical to find thermal bridges with linear transmission coefficients of 0,1 ÷ 0,8 W/m/K. If we assume transmittance values of the perimeter walls and the roof at 0,4 W/m^{2}K, typical values in newly built in Italy, thermal bridges are in important part of the total loss for conduction through the building envelope.
In a well insulated building, if thermal bridges are not corrected, dispersions due to them might amount to roughly the double of the total loss through the walls and the roof. This implies a higher heating and cooling requirement, but also it could cause water condensation problems in winter.
In order to limit the *Passivhaus* thermal bridges at 5% of the total loss via the building envelope, it’s necessary to reduce the linear transmittance to 0,01 W/m/K.

[2] Calculated starting from the ISO 13786 norm procedure.

1.3. INTERNAL GAINS

Concerning the internal gains due to the presence of occupants, to the use of household appliances and to the lighting systems, we chose to consider a family of four people, and also the use of low energy consumption devices: efficient electrical appliances and compact fluorescent lamps.

For the characterization of the power installed in the analyzed *Passivhaus* we used the data collected trough a measuring campaign conducted in 110 Italian houses during the period 2 000 ÷ 2 002[3] which derived an average electric energy consumption of around 3 000 kWh per year per household[4].
We used for our Passivhaus model the hourly schedules of use of appliances and lighting obtained by the metering campaign, while the installed power levels have been modified based on the following considerations:

- measurements carried out during the period 2 000 ÷ 2 002 reflect the type of electrical appliances and lighting systems consumptions generally present in the Italian houses in that period; in the following years the more obsolete appliances have been changed with newer ones, with lower consumptions, bringing an increase of the average efficiency of the installed stock; sales have moved towards models with higher position in the labelling scale. also for lighting, several programmes have been carried out, and they have brought a larger fraction of CFL compared to the initial situation. When simulating a recent or new house it's hence reasonable to assume the presence of new and more efficient appliances.
- another important aspect to determine the consumptions are the occupants habits, concerning the choice of the quality and quantity of electrical appliances in the house, but also concerning the usage: it's reasonable to assume that occupants of a passive house pay attention choosing low consumption appliances and that they use them correctly.
- The third consideration, it's the need to maintain the use of primary energy below 120 kWh/m^2/year in order to respect the *Passivhaus* Standard. The hypothesis to consider an electric energy consumption of a total 3 000 kWh per year for appliances and lighting would imply overcoming this limit. In this way the definition of *Passivhaus* demand to occupants particular attention to the consumption and also to the daily management of the building.

On the basis of the above, we have assumed the energy consumption values as shown in table 4 and the electrical power installed of the appliances and the lighting has been fixed to 3,2 W/m^2.

In particular, the fan energy consumption has been estimated on the basis of the guidelines of Passivhaus Institute, that quantifies the energy consumption at 0,4 Wh per m^3 of outside air inlet. Using this specific consumption data and taking into account the air change rate fixed for the house (see chapter 3), we have obtained the yearly electric energy consumption.

Table 4: Energy consumption of appliances and lighting in the proposed base model.

End Use	Energy [kWh/m^2/year]	Energy [kWh/year]	Primary energy[5] [kWh/m^2/year]
Appliances	10,9	1 129	28,6
Lighting	4,1	421	10,7
Hot water	21,3	2 209	18,7
Cooking (with natural gas)	5,8	600	5,8
Heating	15,0	1 556	13,2
Cooling	15,0	1 556	13,2
Mechanical Ventilation	7,0	730	18,5
Other	1,0	100	2,5
TOTAL			**111,2**

[3] Monitoring conducted by eERG for the EURECO and MICENE projects, financed by the SAVE programme of the European Community and by the Italian Ministry of Environment.

[4] Excluding hot water and air conditioning, and with an average family composition of 3,62 persons/household.

[5] We assume the use of a electric heat pump for heating, cooling and hot water and a conversion factor of electrical energy in primary energy of 1 / 0,38.

1.4. HEATING AND COOLING STRATEGIES

In the houses built according to the *Passivhaus* Standard and its Center European interpretation the heating system is strictly connected with the building envelope, in order to form an integrated and rationalized system.
The heat demand is limited by reducing the cold air infiltrations through the envelope and, in order to guarantee the needed air changes, it's then necessary to install a forced ventilation system able to keep the indoor air quality at the desired level.
An active ventilation system can also be complemented with the recovery of heat from texhaust air, with a consequent important reduction of the heating load associated with air changes.
The *Passivhaus* model analysed here has been developed on the premise that the project solutions chosen in the Central Europe interpretation of a *Passivhaus* are pertinent to many zones of Italy which have relatively harsh winters and could, if integrated with additional solutions, give efficient strategies also for summer passive cooling: a well insulated structure with a medium-high thermal inertia gives an effective base to use the low temperature of the outside air at night and in early morning, in order to increase comfort during the following day.
The night air can flow through the building by a natural ventilation strategy (window opening or other openings) or using fans of the active ventilation system.

The *Passivhaus* considered in this study presents the typical integrated system of the centre European experience, characterized by:

- an air distribution system consisting of ducts with a 10 ÷ 20 cm diameter and two fans (around 40 W each) for the fresh air inlet and the exhaust air extraction;
- an air to air heat exchanger with a 85%[6] efficiency for the pre-heating of air in winter
- a heat pump of low power to be used when additional heating of the thermo vector fluid is needed in order to reach the internal 20 ℃ setpoint in winter.

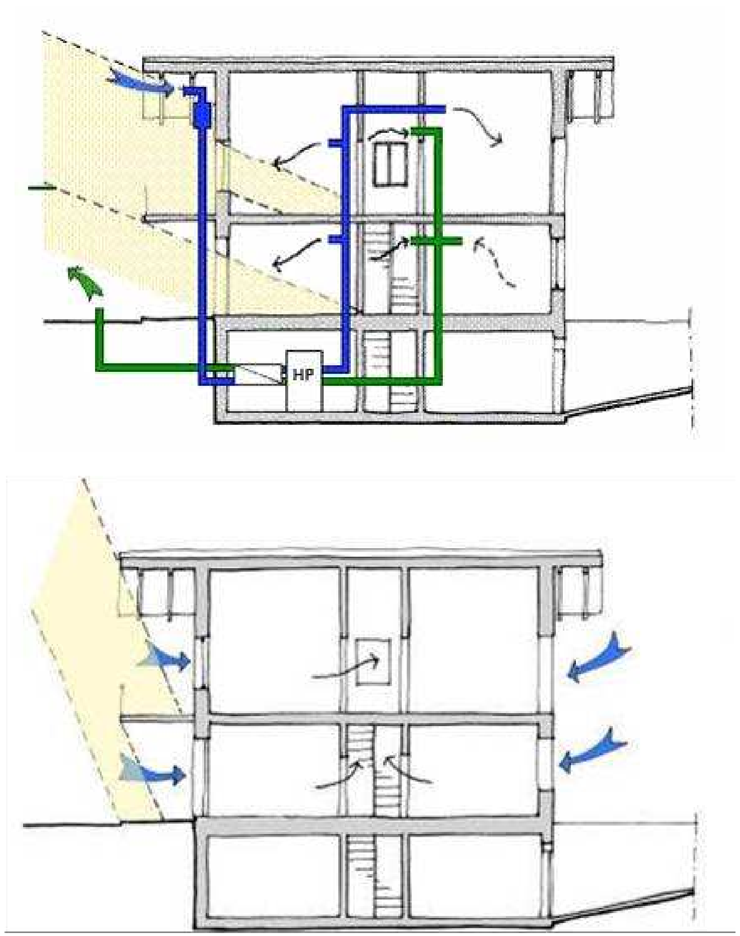

Figure 4: Summary of main design strategies employed to censure winter (top) and summer (bottom) comfort.

[6] Value guaranteed by some exchanger models, already on the German market.

It uses the following additional solutions:

- shading of south and east windows by means of the roof eaves and the use of reflecting external blinds, sized and controlled to block the direct solar radiation, but not the diffuse one that can be used for daylighting;
- a night ventilation strategy by controlled frames opening, properly conceived to remove efficiently the heat stored during the day and to avoid local discomfort conditions in the sleeping rooms of the building.
- the use of a cooling active system able to limit indoor temperatures to 26℃[7] activated when the nocturnal ventilation is not sufficient for this aim; this additional contribution could be given by a low power reversible heat pump (the same device used during winter heating).

The advantage of creating the basic model of *Passivhaus* for Italy on the concepts used in Central Europe lays on the fact that those concepts could be integrated in houses with presently commonly accepted aesthetic appearence. For example there's no need of large glazing area facing south or solar greenhouses, in order to assure sufficient winter thermal gains. The active ventilation system can be used in summer to supply night ventilation without having to add ventilation towers.
On the other hand we don't want to suggest that the considered project solutions are the best possible architectural solutions, neither to impose a particular type of passive systems for heating and cooling. Other choices are possible in order to achieve the required comfort condition in winter and summer, as described in the extensive *Passivhaus* Standard (2007).

[7] For details on this specification, see first chapter of the third part of the Guidelines.

1.5. AIR CHANGE RATE

One project parameter that has a high influence on the building energy balance is the air change rate that, depending on the room volume, determines how much indoor air is replaced by outside air.

An adequate ventilation level is needed in order to maintain indoor air quality. Obviously an increase of the ventilation rate implies an increase of the energy consumption for heating and cooling the building.

National and European institutions have set calculation procedures, codified in more specific or general laws, that allow the determination of minimal values of air change rate, in order to ensure a good indoor air quality.

There are a few different procedures in literature and norms to set air changes as a function of type of use of rooms and number of occupants (table 5 gives a brief synthesis), but they don't converge to exactly the same suggestions.

The Italian law considers the number of the air exchange from two points of view: energy performance on one side and air quality on the other.

The European law, recently approved, aims to connect the two aspects. The procedure called PHPP has been created in order to verify if the original voluntary *Passivhaus* Standard is met by the building and proposes its own ways to set air changes.

This outline is quite heterogeneous concerning assumptions and therefore also the results. We have chosen an attitude that seems the most consonant to the principles on which the *Passivhaus* Standard is based on: excellent levels of indoor comfort and air quality and reduction of energy consumptions, setting a value of 0,74 h^{-1}, for our calculation, obtained from the UNI 10339 norm taking into account occupants presence.

We underline that it would be difficult to suggest these considerations in case of buildings without a ventilation system and a strategy of heat recovery in winter: the plant considered here is particularly apt to guarantee air quality without burdening the energy balance.

Table 5: Synthesis of the main norms that codify the air exchange rate calculation. Reported values are calculated taking into account the geometry and to the disposition of the room in the considered building.

Norm	Air change rate [h^{-1}]	Applicability	Topic
UNI EN 832:2001	0,50	Italy	Energy performance of buildings
UNI EN ISO 13790:2005	0,30	Italy	Energy performance of buildings
UNI 10339:1995	1,08	Italy	IAQ
EN 15251:2007	0,36 ÷ 1,18	Europe	Energy and Comfort in buildings
PHPP	0,35 ÷ 0,6	Passivhaus voluntary certification	Energy and Comfort in buildings

1.6. ENERGY PERFORMANCE

Considering the extended *Passivhaus* Standard (part 1), for this model of house it's necessary to respect an energy limit of 15 kWh/m^2/year, for the heating season as for the cooling season, and to guarantee the summer comfort level described in the Fanger model.

Dynamic simulations made on the described building have allowed to quantify the energy demand to satisfy the inside thermal comfort requirements in the three chosen climate contexts.
As showed in figure 5, the analysis confirms the initial hypothesis on the possible transfer and integration of the strategies used in Central Europe and points out in a quantitative way the margin of intervention in order to relax the requirements on the basic model. The estimated demand seem to allow for a simplification of the envelope technologies in the three climates, particularly for Rome and Palermo, considering both the heating and the cooling season.

It's therefore possible to intervene further in order to reduce costs and simplify the building techniques. In this direction we have developed two optimization analysis with the aim of defining the possible ranges of modifications and to test by step reductions in requirements regarding the permeability and the thermal resistance of the building envelope.

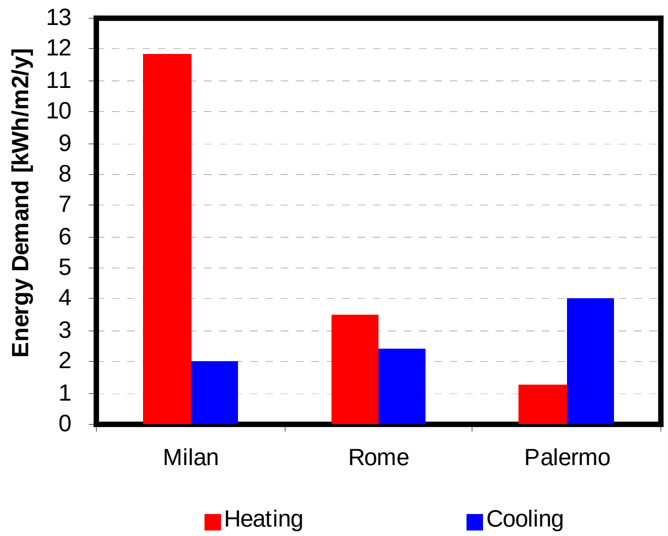

Figure 5: Net useful energy demand for heating and cooling of the Italian *Passivhaus* in the three test climates.

4 OPTIMIZATION ANALYSIS

Hereby we'll describe the process for the refinement in the requirements and we'll give quantitative results that may help to guide the preliminary project of a *Passivhaus* in an Italian context.

4.1 Optimization analysis on air permeability of the building envelope

Uncontrolled external air infiltrations in the indoor space imply potential risk of drafts and the growth of the winter heating needs. In a similar way, in summer, the infiltrations of hot outside air implies an increase of cooling demand. As already discussed, the *Passivhaus* Standard for cold climate tries to limit the undesired airflows and imposes to the permeability of the building envelope the limit of 0,60 h^{-1} at 50 Pa. Even if achievable, this value implies an increase of the building costs, and its attainment could cause some problems above all due to uncareful installation: it is generally necessary to carry out some test before meeting the Blower Door Test in the verification procedure. Relaxing the limit of the n_{50} parameter would allow a simplification in the construction process.
As shown in figure 6 analysis show that in the considered locations energy limits can be reached by applying less strict specifications than those generally used in the *Passivhaus* Standard. We found that it is still possible to meet the Passivhaus energy requirements with values of n_{50}:

- in the range 1,0 ÷ 1,5 h^{-1} for Milan;
- values even higher for Rome and Palermo.

Air infiltration has a higher effect on the heating demand than on the cooling demand, since:

- during summer the house, as a consequence of night ventilation, is exposed to the external airflow, so that the percentage weight of infiltrations on the energy balance is reduced; on the other hand, in winter, when the opening of the frames is at its minimum, the relative importance of infiltration becomes relevant;
- the difference of air temperature between indoor and outdoor is in average larger during winter than in summer and consequently winter infiltrations imply an increase of energy need proportionally higher.

Considering that a value of n_{50} of 1,0 h^{-1} already implies a good simplification of the installation procedures and of windows tests, we have chosen to use this value in all the three climates and proceed with further analysis.

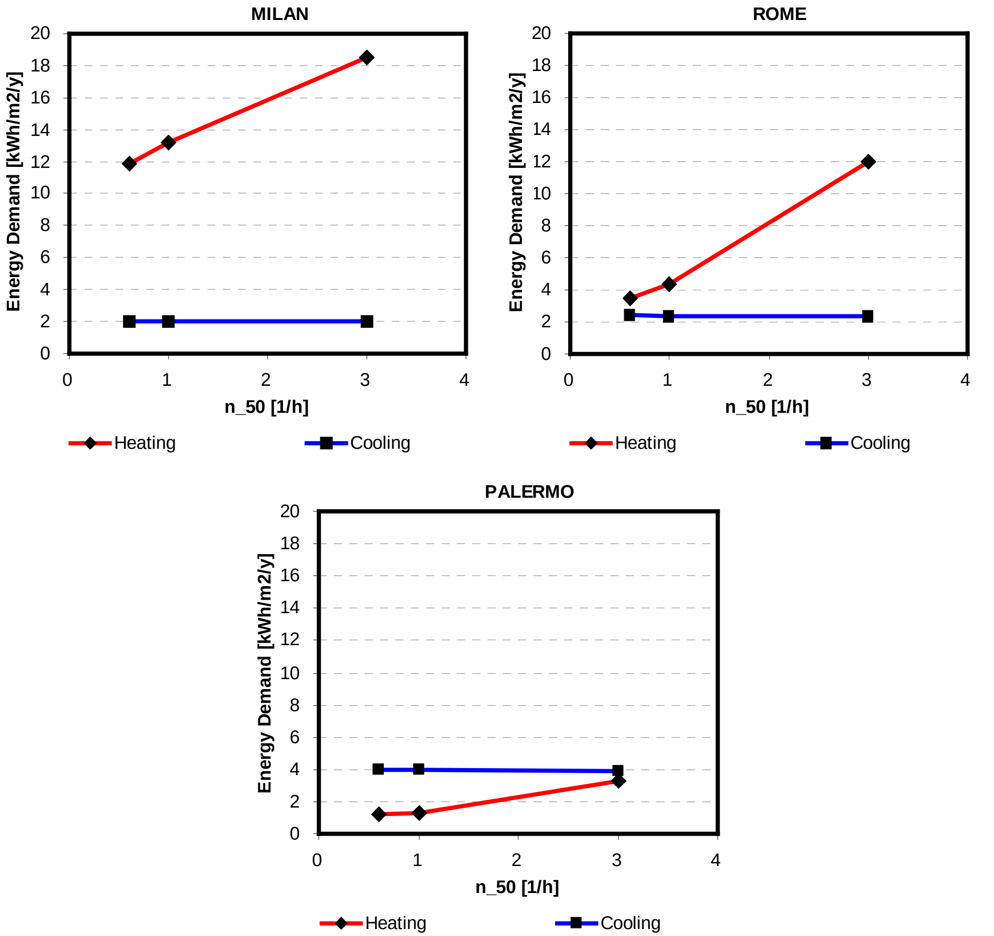

Figure 6: Winter and summer net useful energy demand as a function on the building envelope air tightness (expressed by the n_{50} value).

4.2 Optimization analysis on envelope insulation: glazing surfaces

A typical German *Passivhaus* uses special 3 pane low-e windows.
But 3 pane high performance windows are not widely available on the market in Italy apart in the area of Bolzano, and obviously they are more expensive and to a degree bulky which may not respond to the aesthetic tastes of everyone. Given the general milder climate of Italy it is reasonable to investigate whether less stringent characteristics can be applied to windows.
Chart of figure 7 compares the net useful energy demand for our prototypal house in the three climates using triple low-E glazing (with U-value = 0,700 $W/m^2/K$ and solar factor of 0,50), double low-E glazing (with U-value = 1,400 $W/m^2/K$ and solar factor of 0,60) and standard double glazing (with U-value = 2,700 $W/m^2/K$ and solar factor of 0,80). It can be observed that:

- the replacement of 3 pane low-E with 2 pane low-E always implies a slight increase of the total energy need (about 0,5 ÷ 1,5 $kWh/m^2/year$);
- changing the 3 pane low-E with clear glass 2 pane implies a relevant increase of the total energy need in case of harsh winters (e.g. an increase of 52% in Milan);
- in climate contexts characterized by good levels of solar irradiation and winter temperatures relatively high (Rome and Palermo), the use of double low-E glazing could imply a positive balance between higher solar gains and fewer dispersions, and consequently, a reduction of heating demand;
- as for the cooling demand the use of transparent components with high performance compared to standard solutions reduces the energy performances to a rather limited extent and proportionally to the importance of the summer climate conditions. It should be kept in mind that this conclusion is valid with reference to our prototypal building with relatively limited glazed area and in which the external (vertical and horizontal) solar protections block direct solar radiation that would fall on window areas during summer.

Considering these points, for the examined climates it does not seem to be necessary to adopt triple glazing while it might prove inadequate (from the energy point of view and for local comfort) the use of standard clear glazing. We have therefore decided to adopt 2 pane low-E glazing in all the three climates and continue the analysis of the building model with this assumption.

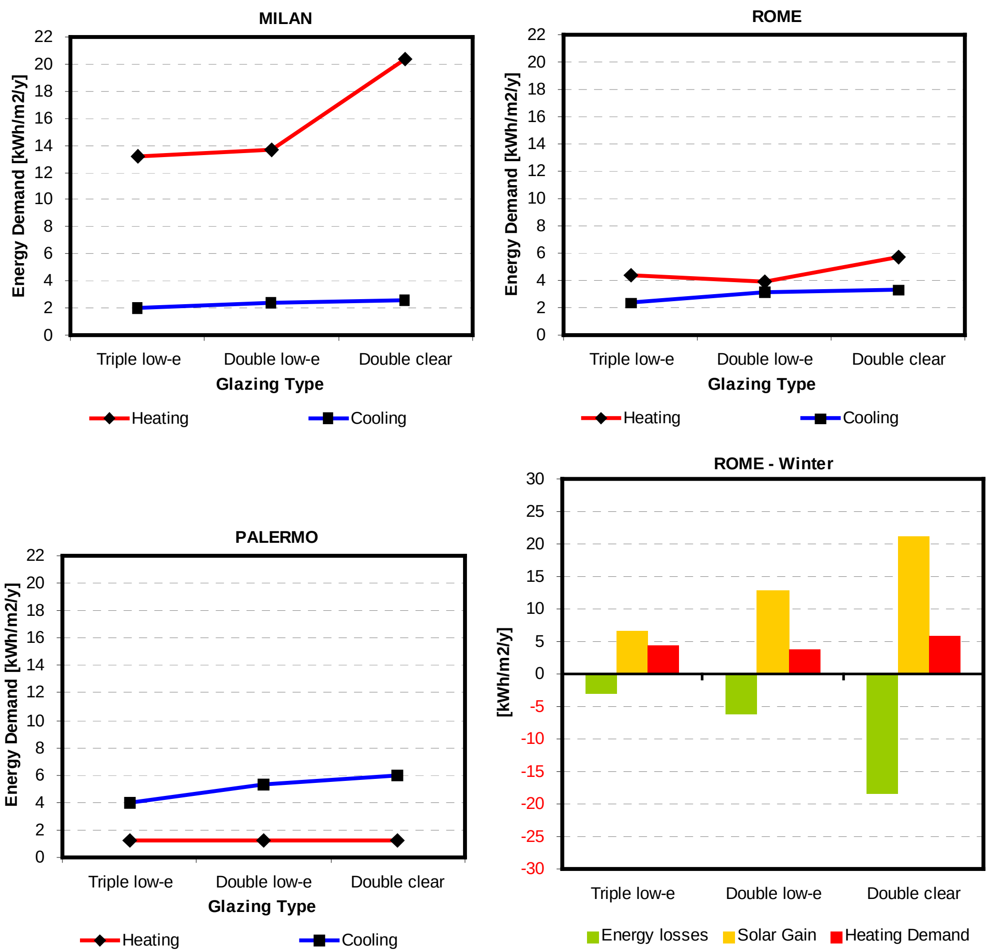

Figure 7: Net useful energy demand as a function of glazing type and building energy balance for the Rome climate.

4.3 Optimization analysis on envelope insulation: opaque surfaces

The *Passivhaus* model developed for the Northern and Central European climate includes as one fundamental characteristic a high level of insulation of opaque elements. Transferring the *Passivhaus* concept to lower latitudes, the levels of insulation can probably be reduced, in some cases, even though it will result anyway much higher than in the current building practice.

In order to properly describe the effect on the net useful energy demand of various insulation levels applied to the building components (walls, roof and basement), we have performed an optimization analysis on 16 combinations (table 6) of 7 basic variants. Highest numbers are those with lowest insulation levels.

The general conclusions of the model analysis are (please remind that summer night ventilation is part of our models in order to dissipate the thermal energy stored in the structures):

- marginal benefits (that is the connected to the addition of one cm of insulation to the thickness already considered) on the heating demand are progressively reduced when the considered thickness increases, up to becoming little relevant beyond certain thermal transmittance values, which depend on the climate;
- a good level of insulation of vertical walls and of the roof is beneficial both in winter and in summer: the heating and cooling demand decrease when increasing transmittance of the two building elements;
- a high insulation of the basement reduces the energy demand for heating; on the other hand during summer, is necessary to consider how a very insulated basement, in low rise buildings as the one in exam, leads to an increase of the cooling demand. The importance of this effect and the choice of the optimal insulation level is strictly connected to the climate; in particular in hot climates, where the critical period is summer, it might result beneficial to choose a not very insulated basement, while in cold climates with harsh winters, the choice would be an important insulation of the basement.

In the following chapters we present in more detail the results obtained in the three different climates as a function of the insulation variants described in table 7,

Table 6: Variation of insulation levels: 16 model combination of the variants of table 7.

	Wall (P)	Roof (T)	Floor (B)
Mod0	x	x	x
Mod1	+	+	+
Mod2	+	+	o+
Mod3	o+	+	o+
Mod4	o+	o+	o+
Mod5	o+	o+	o
Mod6	o	o+	o
Mod7	o	o	o+
Mod8	o	o	o
Mod9	-	-	-
Mod10	o-	o-	o-
Mod11	n	n	n
Mod12	+	o	+
Mod13	+	+	n
Mod14	o	+	o
Mod15	o+	+	n

Table 7: Thermal insulation variants. We consider insulation material with thermal conductivity of 0,037 W/m/K.

		Wall		Roof		Floor	
Variant		U-value [W/m^2/K]	Insulation thickness [m]	U-value [W/m^2/K]	Insulation thickness [m]	U-value [W/m^2/K]	Insulation thickness [m]
Very high insulation	x	0,100	0,345	0,100	0,344	0,100	0,344
High insulation	+	0,135	0,250	0,134	0,250	0,134	0,250
Medium-high insulation	o+	0,200	0,160	0,200	0,159	0,300	0,097
Medium insulation	o	0,300	0,098	0,300	0,097	1,000	0,011
Medium-low insulation	o-	0,500	0,049	0,300	0,097	0,700	0,027
Low insulation	-	0,540	0,044	0,420	0,062	1,340	0,001
No insulation	n	1,489	0,000	1,404	0,000	1,404	0,000

4.3.1 Milan

For the climate conditions in Milan, the net useful energy demand derives predominantly from the heating demand, due to the harshness of the winter season, and we observe a large influence of the insulation levels on heating demand. Cooling demand of our prototypal building is not particularly high and it is influenced slightly by the thermal resistance of the different building components; therefore we don't find here any discordant effect of insulation in any of the various building elements.

As shown in figure 9 it is necessary a high insulation of all building components, in order to limit the net useful energy demand for heating under 15 kWh/m^2/year as required by the *Passivhaus* Standard. Out of the two highly insulated models (Mod0 and Mod1) it is possible to chose anyway the one with less insulation (25 cm), characterized by walls, roof and basement transmittance of 0,134 W/m^2/K.

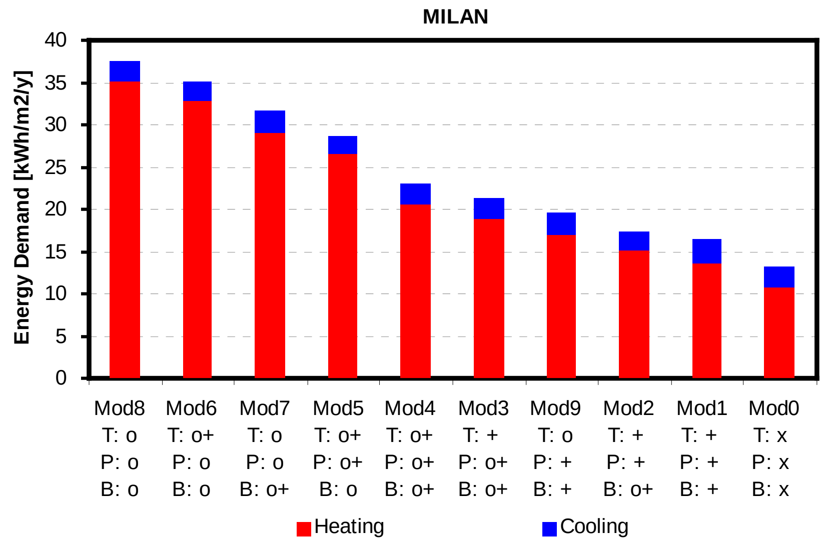

Figure 9: Milan – Useful net energy demand for different thermal insulation models.

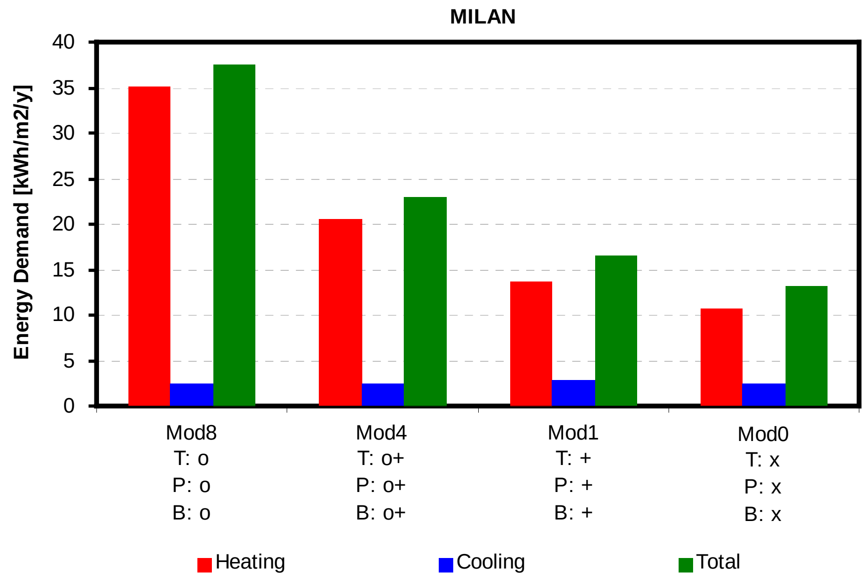

Figure 10: Milan – Useful net energy demand in models whit uniform insulation of building components.

4.3.2 Rome

In Rome the cooling load is higher and hence the effects of insulation on the building behaviour in summer, are some more evident. Reducing the thermal resistance of the building envelope, the need of useful net energy for heating increases, while the demand of cooling depends on both on the quantity and the position of insulation.
As shown in figure 11 the combinations that reduce more the cooling need are those characterized by a high insulation level on the perimeter walls and roof and by relatively limited basement insulation (Mod13 and Mod15).
These models, that allow to transfer to the ground the thermal energy stored into building structures, should be considered with more attention when the cooling demand increases. In the case of Rome, as summarized with the comparisons of figure 12, it's not advisable to reduce too much the thermal resistance of the basement slab: when renouncing to its insulation, the balance between the increase of winter demand and the reduction of summer one, results largely negative.
We remind that we are considering a two floor terraced house and that these considerations are not valid for higher rise buildings.

When having the objective of reaching the Passivhaus Standard, Rome shows the possibility of reducing the insulation levels to medium – high levels: the first building model that meets the requisites for heating demand – and that limits the cooling demand – is the one characterized by roof, walls and basement slab transmittance of, respectively, 0,2 , 0,3 and 1,0 W/m^2 (Mod6).

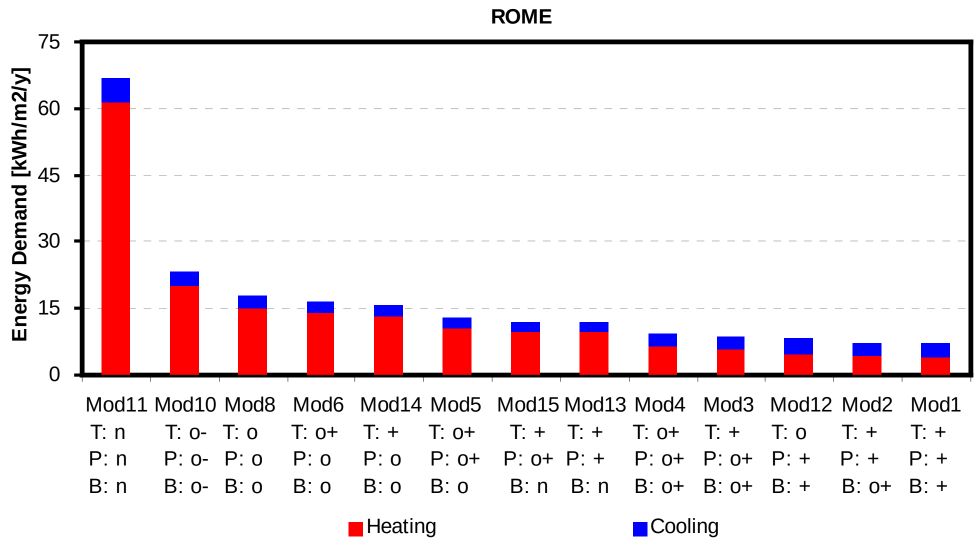

Figure 11: Rome – Energy demand as function of envelope thermal insulation.

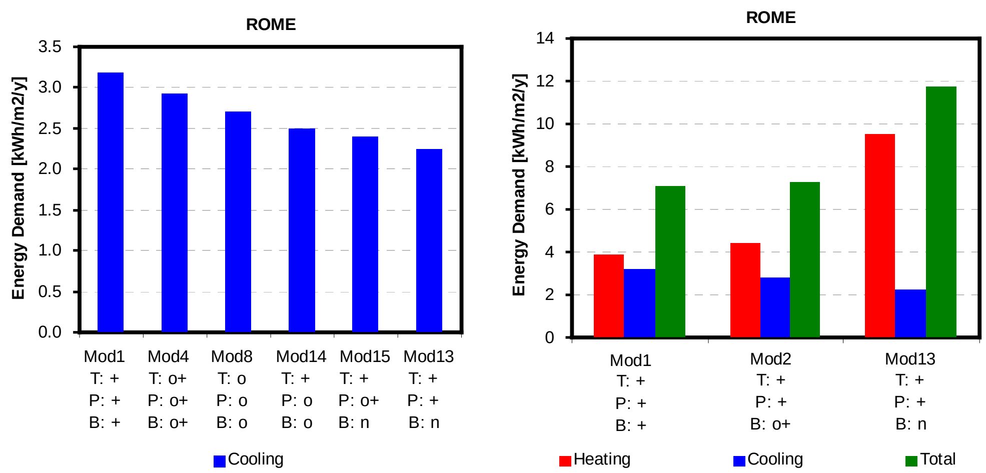

Figure 12: Rome – Net useful energy demand for cooling as a function of levels and position of insulation. Total net useful energy demand as a function of basement slab insulation.

4.3.3 Palermo

In the climate of Palermo milder winters and higher summer temperatures imply a different distribution of the total demand in the models that comply with the Standard: here, in fact, the net useful energy demand for summer cooling is higher than the one for winter heating.
In this context, the analysis shows that a very high level of insulation of the building components does not really improve the winter behaviour of the building and that, more than in other cases, the basement insulation penalizes summer behaviour. Moreover, differently from Rome, a complete removal of the insulation from the basement slab doesn't result unfeasible from the energy point of view (figure 14): savings on summer cooling exceed winter losses. A check on radiant temperature distribution in winter should be done before confirming this choice. Even during the hot season, insulation of perimeter walls and roof allows for relevant energy savings (as much as 75% compared with the non insulated model), so that, Mod13 and Mod15 with high levels of roof insulation show the lowest energy demand for cooling (figure 14).

For our prototypal building the requirements identified by the *Passivhaus* Standard can be met with moderate levels of insulation. The first model that meets these requirements is the one with 5 cm insulation in the walls (U = 0,540 W/m^2/K), with 6 cm in the roof (U = 0,420 W/m^2/K) and with a non insulated basement (U = 1,340 W/m^2/K).
In order to avoid misunderstandings, we remind here that these results have been obtained considering buildings with a heat recovery strategy on exhaust air.
If we renounce to this contribution – generally not present in traditional housing construction in Italy – the requirements on insulation presented above are no longer sufficient in order to meet the Passivhaus Standard. Without heat recovery much higher insulation levels would be needed (close to the levels of Mod13).

This configuration might represent an interesting one to explore in more detail in the specific context, if there were a desire to reduce the need for mechanical ventilation and high efficiency heat recovery in the southern regions, via higher levels of insulation.

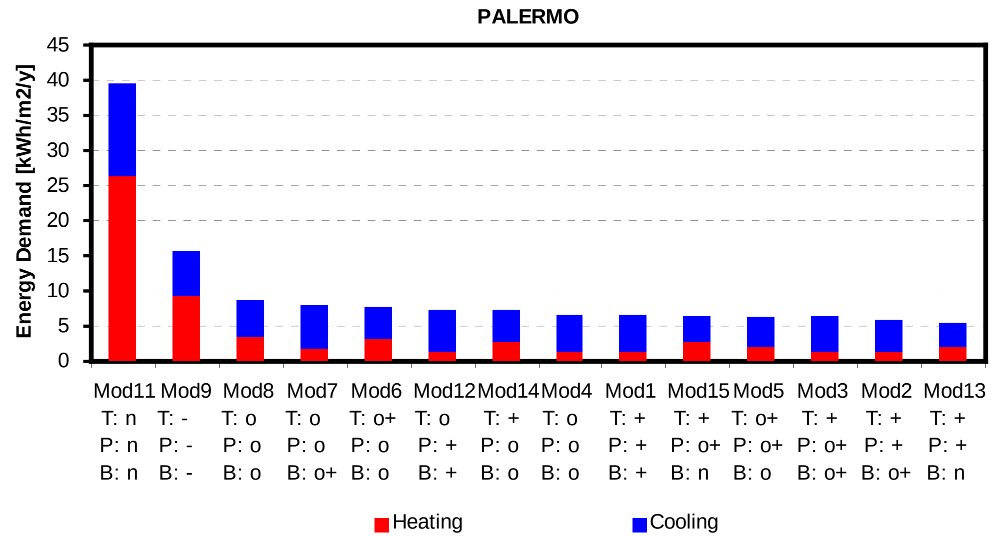

Figure 13: Palermo. Net useful energy demand as a function of envelope thermal insulation.

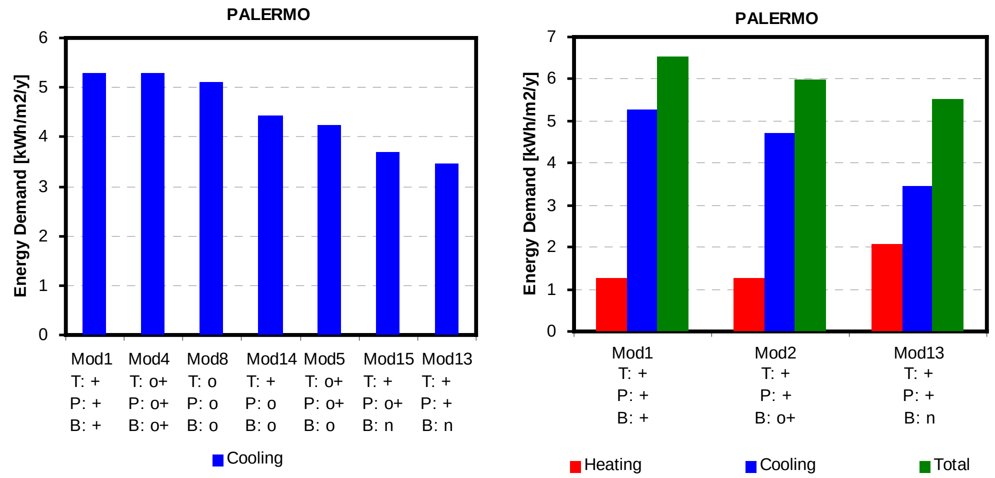

Figure 14: Palermo – Net useful energy demand for cooling as a function of levels and position of insulation. Total net useful energy demand as a function of basement slab insulation.

5 OPTIMIZED MODELS

Even if the considered house adopts several German *Passivhaus* technical solutions, the analysis presented shows how it would be possible and desirable to modify some specifications. Generally the milder Italian climate allows to reach energy and comfort limits of the *Passivhaus* Standard using less strict criteria concerning:

- envelope air tightness: in Milan a value of n_{50} equal to 1,00 h^{-1} is acceptable, and even more so for Rome and Palermo;
- thermal transmittance of transparent surfaces: triple glass generally used in Center Europe may be replaced by double low-e glazing;
- insulation of opaque surfaces: a German *Passivhaus* has typically 25 ÷ 35 cm of insulation on the external walls and 30 ÷ 40 cm on the roof. In Milan the Standard can be met with insulation layers of about 25 cm, and in Palermo 5 ÷ 6 cm may be sufficient (if one maintains the mechanical ventilation and heat recovery) or it's possible to explore a solution without heat recovery / mechanical ventilation and higher insulation levels.

As a summary of the results of the analysis, the minimum specifications to meet the *Passivhaus* Standard in the three towns are listed in table 8.

Analysis show that with a small additional effort in the southern-most places, for example increasing the insulation of opaque surfaces, the chosen energy consumption target for the extended *Passivhaus* Standard could be improved, going below the 15 + 15 kWh value. This aspect should be kept in consideration during the scheduled revisions of the Standard.

The models of building obtained from the optimisation analysis have been subsequently subject to a sensitivity analysis in order to evaluate the effect on the energy demands of other project parameters, and the results of the sensitivity analysis are presented in the following chapters.

Table 8: Envelope insulation levels and air tightness required of the proposed Italian Passivhaus

	Air permeability n_{50}	Building envelope transmittances U-value				Insulation levels		
		Roof	Wall	Floor	Glazing	Roof	Wall	Floor
	[h^{-1}]	[$W/m^2/K$]	[$W/m^2/K$]	[$W/m^2/K$]	[$W/m^2/K$]	[cm]	[cm]	[cm]
Milan	1,00	0,134	0,135	0,134	1,400	25	25	25
Rome	1,00	0,200	0,300	1,000	1,400	16	10	1
Palermo	1,00	0,540	0,420	1,340	1,400	5	6	0

6 SENSITIVITY ANALYSIS

In the following chapters we present how the net useful energy demand can change in the optimized buildings when changing other characteristics of the building envelope (glazing area, Surface versus Volume ratio, orientation) and the applied passive strategies (solar protections, natural ventilation, heat recovery).

6.1 Variation of glazing area

In general the windows facing south can produce useful solar gains in winter that reduce the heating demand, but their over sizing may imply an increase of winter thermal losses and summer overheating.

Figures 15 shows the effect on the energy demands for heating and cooling when the percentage of glazing facing south changes from 20% (minimum required to satisfy daylighting requirements) to 30% and 40%. The graphs show that for every location:

- larger glazing area can reduce the net useful demand for heating proportionally to the incident solar radiation: reductions up to 1,5 kWh/m^2/year in Milan and up to 4,5 kWh/m^2/year in Rome and Palermo;
- an increase in the area of glazing facing south, being the glazing well shielded from direct solar radiation by the solar protections chosen, has a lower influence on cooling demand, that increases in the same way for the three climates, up to about 0,5 kWh/m^2/year.

If on one hand the results of this analysis suggest choices that take profit of solar gains, on the other hand it is necessary to be careful in the sizing of windows that, obviously, represent one of the most “delicate” elements of the building envelope and that might create problems (radiant asymmetries, glare, unwanted solar gains) also as a consequence of the day by day behaviour of the occupants.

To this extent we underline that the results depend on the use proper use of well dimensioned solar protections in order to block direct radiation during summer and to take stock of solar gains during winter.

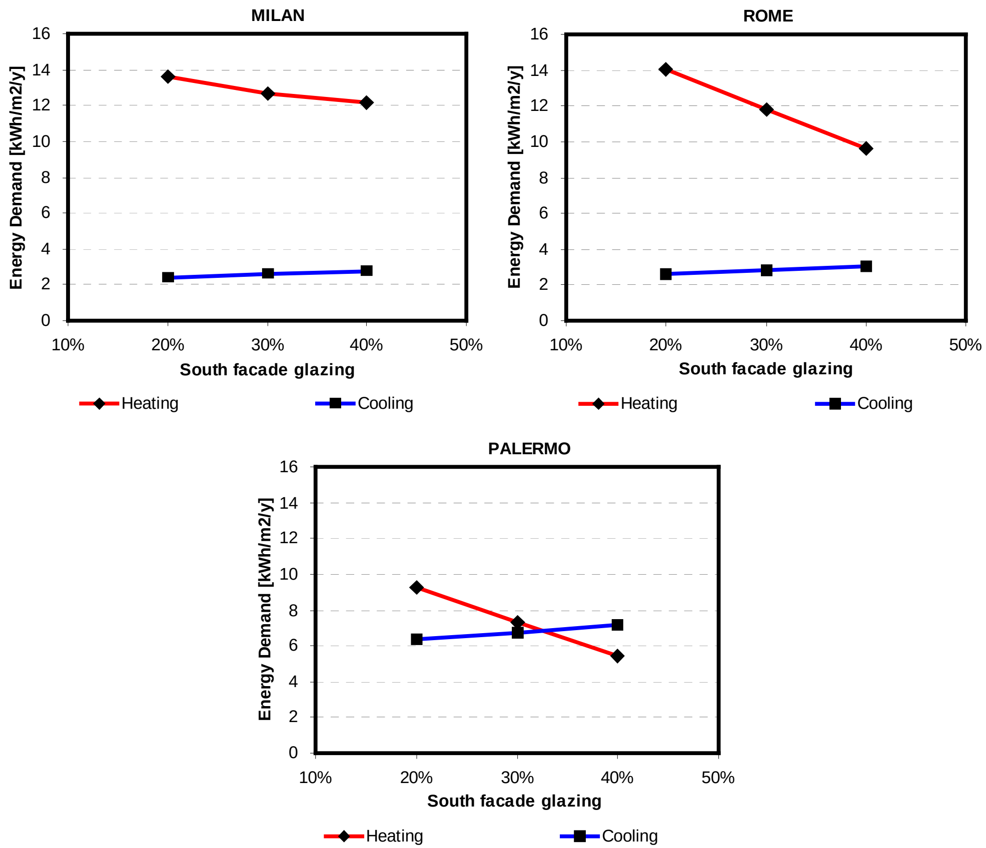

Figure 15: Net useful energy demand for heating and cooling as a function of the glazed proportion of the south façade in the three test climates.

6.2 Variation in the Surface versus Volume ratio

As general rule, lowering the ratio between the area of external surfaces and treated volume has the effect of reducing heat losses in winter and heat gains in summer. These effects are obviously more important in buildings with low levels of insulation.
Even if it's possible to reach the *Passivhaus* Standard in the case of detached house, this results simpler and less expensive using more compact building shapes.
Figure 16 shows that net useful energy demand for heating of our prototypal *Passivhaus* when considered as a terraced house in a middle of a row position (S/V = 0,81) is 20 ÷ 30% lower than the same house when considered as a detached house (S/V = 0,96). Moreover the model optimised for the Rome climate is no longer able to meet the limit of 15 kWh/m^2/year if considered as a detached house instead of a middle-row terraced house.
Cooling demand increases only slightly when the S/V ratio increases. The influence is a little more evident in the Southern locations.

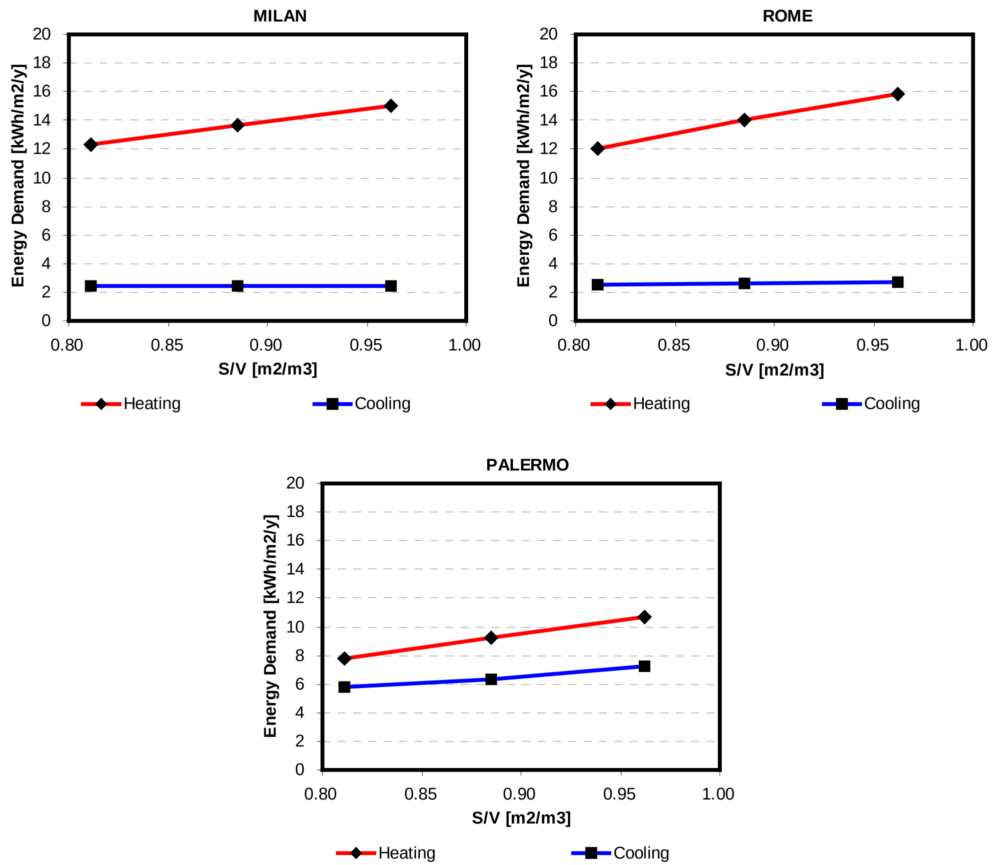

Figure 16: Net useful energy demand for heating and cooling as a function of the S/V ratio in the three test localities.

6.3 Variation of the orientation

Generally, best results are obtained by orienting the building with the façade having a larger glazed area facing South. This choice allows for a correct shading of the glazing by the roof and balcony overhang, in order to maximize the gains in winter and minimize summer loads.
Local constraints can oblige to develop the building with another orientation. Figures 17 shows the effect of the orientation of the prototypal *Passivhaus* (maintaining its geometry, including overhang shape) along axes slightly rotated (maximum 45°) in comparison with the optimal soluti on. We have not analysed a completely different orientations, because it's reasonable to think that in that case the shading strategies of transparent surfaces could be adjusted in a quite different way.
The graphs show that for the three sites and the particular geometry and type of solar protections, the cooling and heating demands are not much influenced by the building rotation. This would not hold true in case of really different geometries or solar protections not optimized.

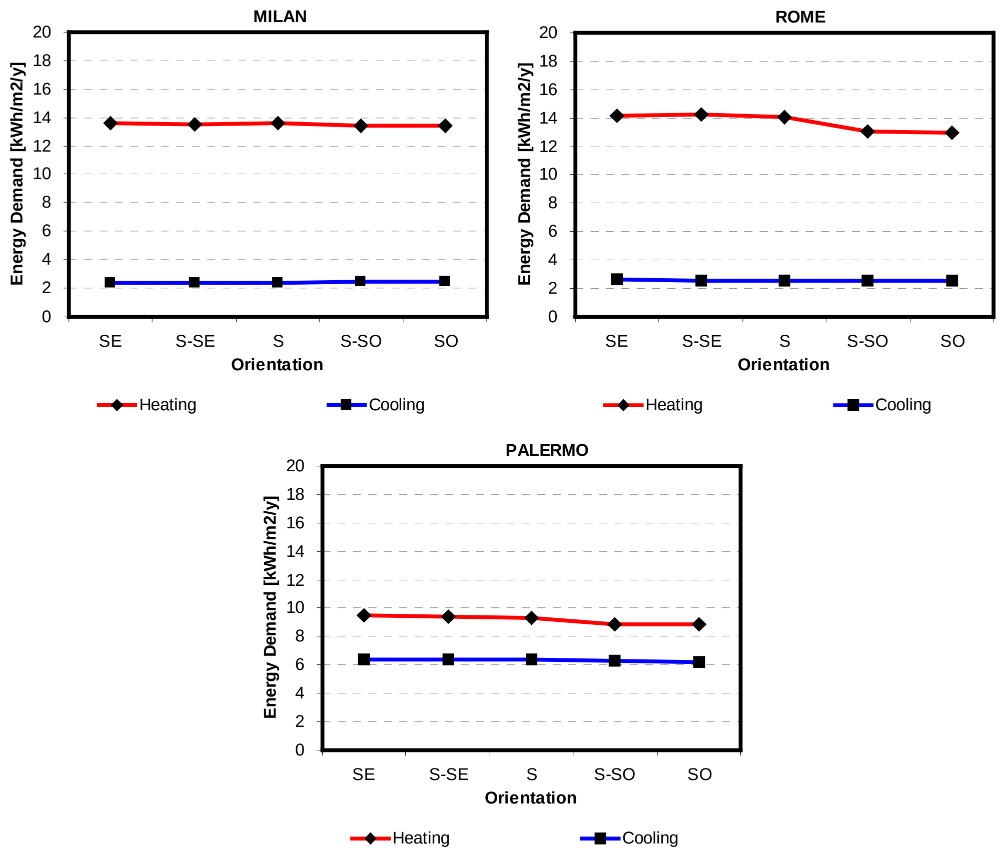

Figure 17: Net useful energy demand for heating and cooling as a function of the building orientation in the three test sites.

6.4 Variation of strategy of solar radiation control

In order to reduce summer solar gains it's possible to adopt different solutions: intervene directly on the solar factor of glazing or put independent systems of shading (inside or outside).
In order to optimize the building behaviour during both winter and summer conditions, from the beginning we have decided to make use of the efficacy and of the usage flexibility of exterior slat blinds. If properly controlled in fact, these components don't thwart the winter solar gains, the use of day lighting and strategies of natural ventilation when external temperature conditions allow for them. The same can't be done easily using only solar control glazing and internal protections (curtains and interior blind).

We chose slat blinds with an horizontal rotation axe, high reflection coefficient (0,70), positioned at 15 cm from the glass. they are controlled in order to let in the diffuse solar radiation and to adapt their orientation to block direct radiation. The blinds also allow for air circulation, that removes the absorbed thermal energy.

In graphs 18 the cooling demand of a models of house with blind optimized control are compared to a model that doesn't use any solar protection strategy and to a model that uses a less strict solar control strategy: the simple use of fixed angle Venetian blinds in correspondence of high solar radiation. This solution is representative of to the typical behaviour in houses where the automation plant for solar control is not present.
The results of the analysis show that in all the three climates:

- the absence of external protections implies an increase of 25 ÷ 30% of the cooling demand;
- the substitution of automatic controlled slat blind with manually controlled venetian blinds produces an increase of 20% of the cooling demand.

In absolute terms In Milan and Rome the increases are anyway small (0,7 kWh/m^2/year) while in Palermo the use of automated blinds implies relatively relevant improvement (2,0 kWh/m^2/year).

We have to remind that in our case, the shade produced by the roof and the balcony, during summer, protects to a good extent the glazing from direct radiation, therefore the influence of the vertical solar protections on the windows is limited.

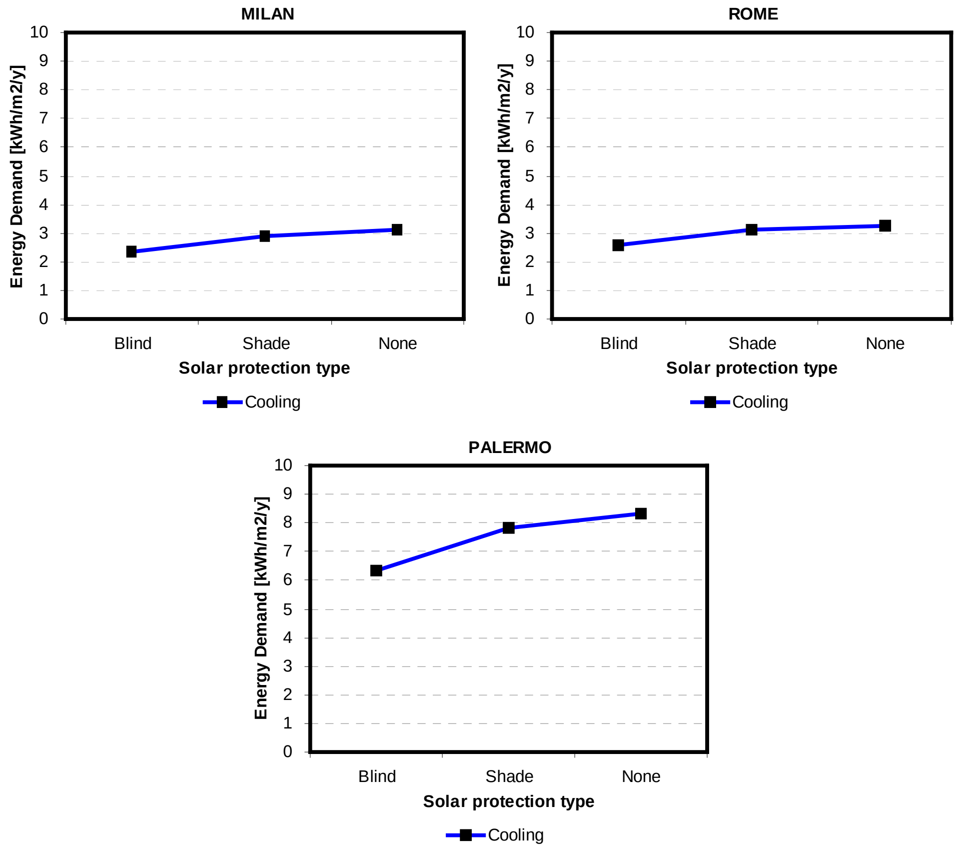

Figure 18: Net useful energy demand for cooling as a function of solar control strategy in the three climates.

6.5 Variation of summer night ventilation strategy

In order to evaluate the effect of the natural ventilation strategy that has been applied to the basic model of this analysis, we have decided to vary it by changing the fraction of window area which is opened during the night in the hottest periods.
In particular, beginning from a solution (called "Vent - ") that provides for the partial opening of the windows in the living area (ground floor and stairs) and the sole use of the forced ventilation system in the sleeping area (first floor), we have considered the cases with a complete closure of the frames also in the living area ("No Vent") and with the opening of all the windows ("Vent +").
For both ventilation solutions we have fixed:

- night maximum opening period: from 10:00 pm to 7:00 am;
- modulation strategy: windows are opened when the outside temperature is lower than the indoor one, but for differences higher than 6,0 ℃ the size of the opening is reduced and they are completely closed for temperature differences higher than 10,0 ℃.

Figures 19 show the results of the analysis. In particular we can observe that:

- renouncing to the night ventilation strategy (no Vent) always implies a large increase of cooling demand;
- in Milan, where the envelope is highly insulated, nigh ventilation is an efficient mass cooling system; this mechanism is helped by the relatively large temperature swing of external temperature between day and night. In Palermo, the envelope is less insulated than in Milan, so that in summer some of the heat transfer from the hot indoor to the ambient takes place through the envelope; the effectiveness of the mechanism of night ventilation is hampered by the small temperature difference between day and night. This small difference makes more difficult for the air to remove thermal energy.;
- the additional increase of the area of glazing which is opened ("Vent+") doesn't produce a relevant additional reduction of cooling demand.

Night ventilation is, even if in a different way in response to the climate and the building insulation, an effective mean for removing the thermal energy stored during the day in a house with a large thermal mass exposed to airflow.

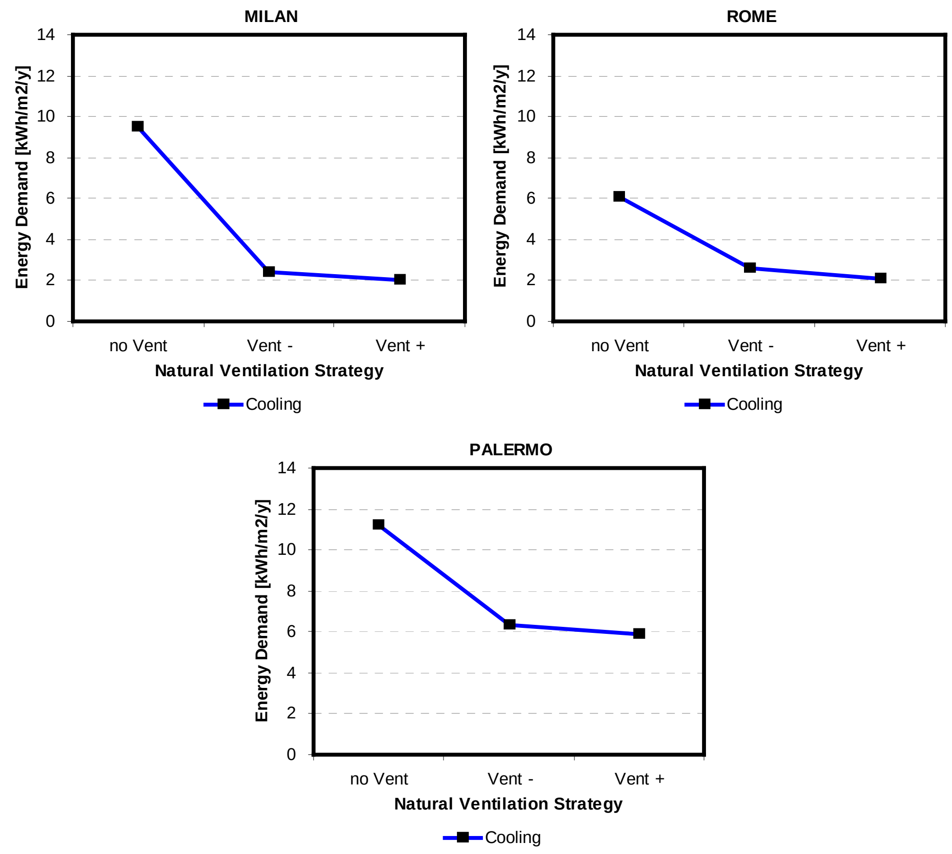

Figure 19: Net useful energy demand for cooling as a function of night natural ventilation strategy in the three test climates.

6.6 Variation of air change rate and heat recovery efficiency

Concerning the air distribution system we have evaluated how much the air exchange rate and the heat recovery efficiency can influence the energy demands. Results are shown in figures 20.

As one expects, the influence of this parameters on the energy demands is high, above all on the heating demand. This effect has a larger percentage weight in buildings, as the one considered, characterized by very low infiltration levels and for which the importance of the energy loss connected to air changes produced by mechanical ventilation is large. In these cases it seems fundamental to integrate a heat recovery strategy; the type of exchanger to be used is linked to the air change rate: if the air change rate increases the recovery efficiency has to be increased in order to meet the energy demand criteria.
In particular, in order to meet the *Passivhaus* Standard:

- in Milan and Rome it is not possible to abandon the strategy of heat recovery but, if air changes are relatively small, it is possible to limit the recovery efficiency: if conditions are such that air quality can be assured with an air change of 0,30 h^{-1}, then it would be enough to have a recovery efficiency of 60%;
- in Palermo one might consider avoiding heat recovery on exhaust air, in case insulation levels are as high as those proposed for Northern Italy and air change rates are in the order of 0,50 ÷ 0,60 h^{-1}.

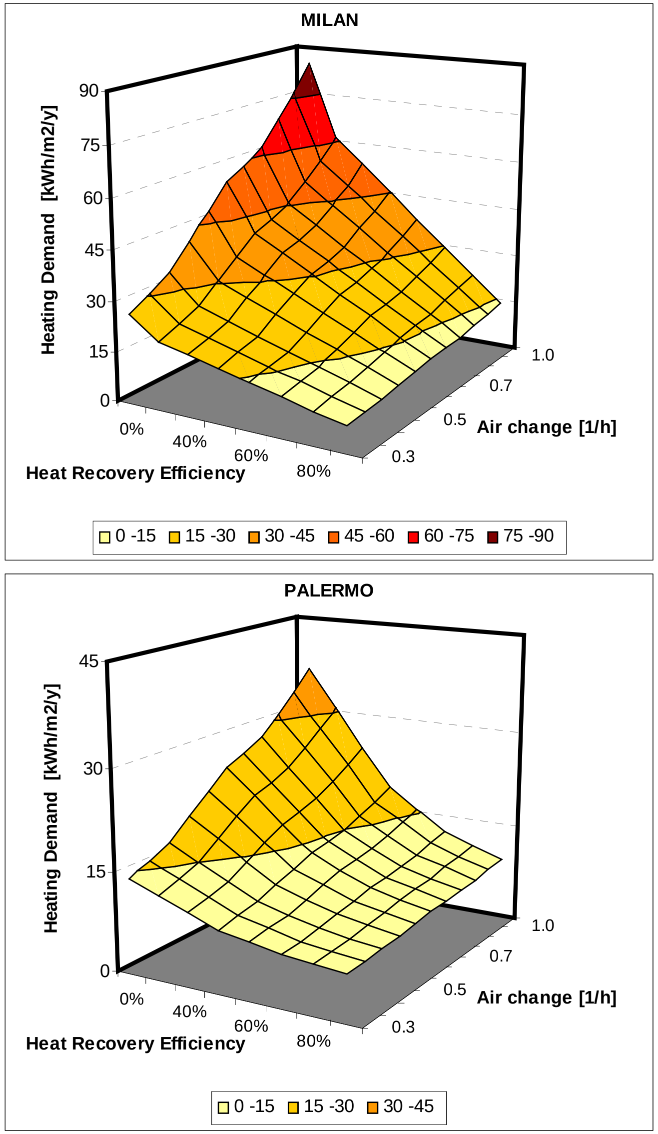

Figure 20: Heating demand as function of air change rate and heat recovery efficiency in Milan and Palermo.

7 COMFORT ANALYSIS

In every phase of the analysis and optimisation process, comfort conditions have been provided by the envelope features, the passive strategies and by the cooling and heating active systems, capable to meet a set point of 20 ℃ in winter and 26 ℃ in summer, and meet in this way the comfort t argets according to Fanger model.

It's now interesting to verify how the optimized models of buildings would behave with a complete passive cooling strategy, that works only with solar control and natural ventilation as described in previous paragraphs. We remind that in these cases the EN 15251 norm allows to describe the indoor comfort using the Adaptive model, characterized by a comfort temperature range that changes with the climate (in particular with a weighted average of the outside temperatures in the previous days), unlike the Fanger one that is relatively fix (for further information see part 3 of the guidelines).

Figures 21 show the indoor comfort conditions when we apply a totally passive indoor ventilation strategy in Milan, Rome and Palermo. The graphs show that the indoor operating temperatures are below the comfort temperature limit as fixed by the EN 15251 norm, so the indoor rooms have comfort conditions in accordance to the adaptive model.
Besides this, in Milan and Rome, if we consider the use of fans that increase the speed of indoor air (of 0,2 m/s), indoor operating temperatures exceed rarely (for the 1 ÷ 3% summer hours) the Fanger comfort range[8].

In Palermo indoor temperatures are closer to the upper value of the adaptive limit and often are higher (for the 15% of the summer period) than the Fanger limit, even using fans that increase the indoor air speed of 0,5 m/s.

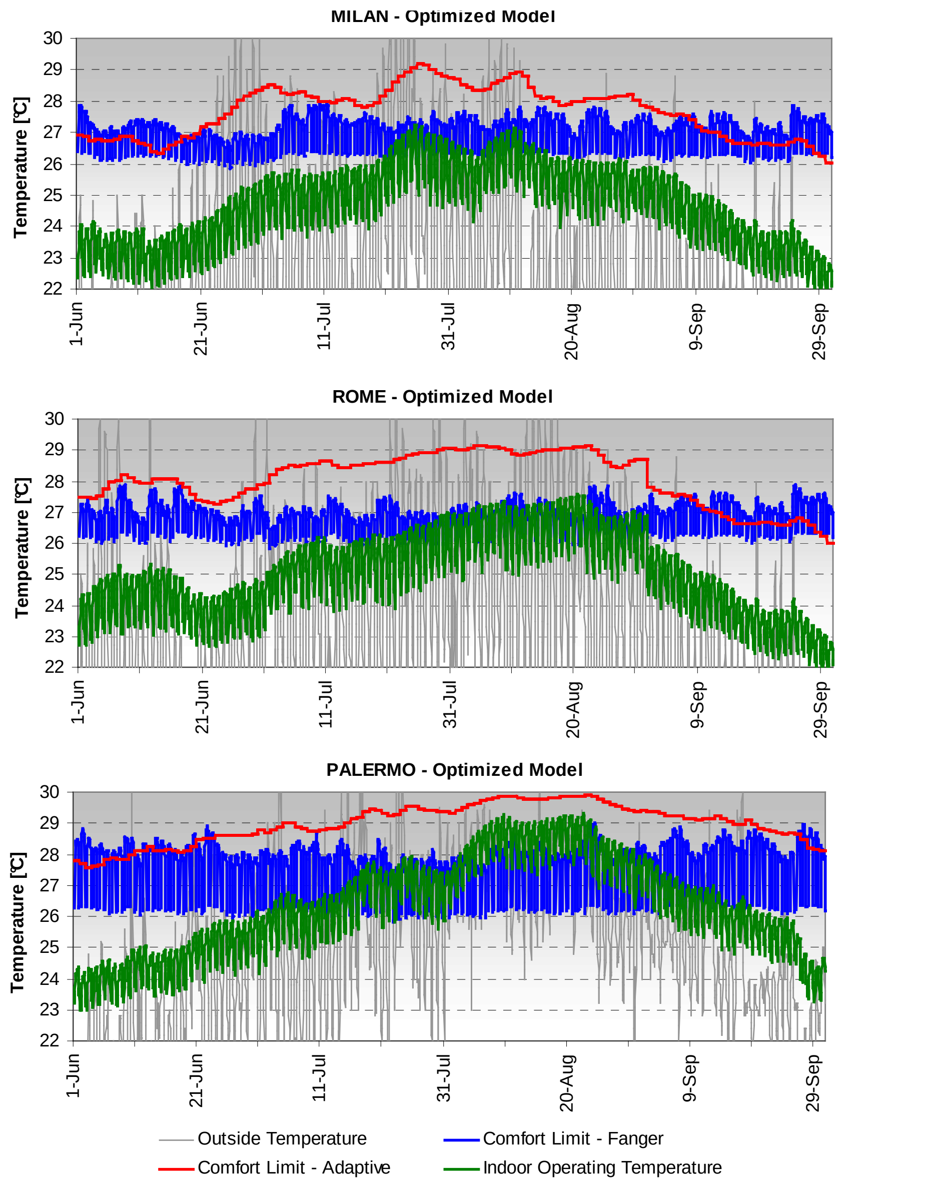

Figure 21: Indoor Operating Temperatures of optimized buildings compared the acceptable Comfort Temperature in Summer as defined by the Fanger's model and the Adaptive model for completely naturally ventilated houses according to the EN 15251 standard.

[8] The Fanger limit temperature has been calculated by setting the metabolic activity of the occupants to 1,2 met and the thermal resistance of their clothes to 0,5 clo, and considering the instantaneous relative humidity and air speed values obtained trough the simulations.

In Palermo, in order to improve indoor conditions, it is possible to further improve the building envelope features: as shown in figure 22, if we increase to 25 cm the insulation levels of the perimeter walls and the building roof (Mod14, presented in chapter 3.3) it is possible to reduce (of about 1 °C) the indoor temperature peaks and obtain results that can be compared to those of Milan and Rome.

In the end, we underline that the results presented here are referred to building models with limited internal loads (in case of residential buildings this can be obtained by choosing accurately electric appliances and lighting systems of high efficiency and not oversized), simulated in not extreme climate contexts. We advise to acknowledge the essence of the analysis more than the detailed quantitative results :

- in the considered climates is possible to aim at to avoiding the use an active system for cooling;
- a relevant insulation of opaque surfaces, if combined with other strategies considered here (high thermal mass, night ventilation, low internal gains) can improve the thermal behaviour of the building and the comfort performance.

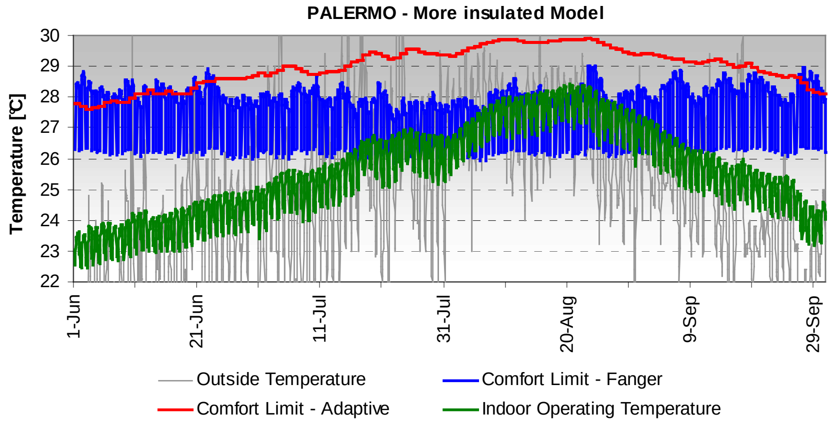

Figure 22: Palermo – Indoor Operating Temperatures of a more insulated model compared the acceptable Comfort Temperature in Summer as defined by the Fanger's model and the Adaptive model for completely naturally ventilated houses according to the EN 15251 standard.