404: Dynamic simulation of a passive house in different locations in Italy

Alessia Giovanardi[1]*, Alexandra Troi[1], Wolfram Sparber[1], Paolo Baggio[2]

*EURAC Research, Drususallee 1, 39100 Bozen, Italy[1]**
alessia.giovanardi@eurac.edu
Università degli studi di Trento, Italy[2]

Abstract

Based on a validated building model, the performance of one of the first multifamily houses, satisfying the Passivhaus standard South of the Alps and constructed in Bronzolo/Italy, has been determined by means of dynamic simulation. The analysis aimed at whether and how the – in Central and Northern European countries well established and experimented – Passivhaus concept can be transferred to warmer European climates, where ensuring summer comfort might even be the predominant issue.
The building is being monitored since two years and a TRNSYS model had been developed and validated during previous research. Within the here presented study, the building was virtually transferred to four Italian locations, i.e. Milano, Villafranca di Verona, Roma and Palermo, which were selected on the basis of a climate study. Energy consumption and temperature trends were calculated for a number of different (adaptation) strategies, regarding the building orientation, automatic shading devices, different insulation thickness and different ventilation rates in free-cooling. Results showed that the studied building concept, comprising good insulation standard, high thermal inertia and relatively low glazed surface, can be transferred, with appropriate adaptations, also to warmer European climates.

Keywords: Mediterranean climate, passive design, dynamic simulation, summer comfort

1. Introduction

The Passivhaus Standard, as developed by the Passivhausinstitut Darmstadt, has considerably supported the spreading of energy-efficient buildings in Northern and Central Europe. The concept is, however, focused on winter comfort and consumption. Furthermore, the experiences how it behaves in the warmer European climates, where ensuring summer comfort might even be the predominant issue, are rare.
The European project “Passive-On” pointed out the advantages of a well defined product such as the Passivhaus in disseminating high quality low energy and passive design [1] and proposed a revised standard for Passivhaus in the Mediterranean [2]. This Standard includes as additional criteria (i) a maximum sensible cooling demand of 15 kWh/m²a, (ii) the application of the adaptive comfort temperature (according EN15251) for only passively cooled buildings and (iii) a relaxed air-tightness limit for mild winter zones and buildings without mechanical ventilation. Furthermore, specific design criteria were developed for different climatic regions and exemplified in pilot projects. The national proposal for Italy [3] is based on the commonly implemented central European Passivhaus, with special attention, however, to building inertia, solar shading and night time ventilation.
One of the first multi-family-buildings satisfying the Passivhaus standard south of the Alps was constructed by the regional institute for social dwelling in Bronzolo/Italy and is being monitored since the dwellings were handed over in summer 2006 [4]. The monitoring activity aims at verifying the indoor comfort and at individuating the real energy demand [5]. At the same time, a model of the building and its active system has been implemented and validated in TRNSYS, i.e. a program of dynamic simulation, in order to develop optimization strategies for the building performance [6].
This validated building model was taken and virtually transferred to other Italian climates. The building’s good insulation standard, high thermal inertia and relatively low glazed surface promised good results – with a certain need of adaptation to the different climatic conditions in the sense of shading and ventilation strategy, of course.

2. Methodology

Within this study the validated model of a passive house in Bronzolo/Italy was transferred to other Italian climates, varying both building parameters (orientation, insulation) and control strategies (shading, ventilation) in order to determine their influence on thermal comfort and energy demand. Furthermore, an active cooling was considered, for selected cases, as an option, and the provision of the necessary energy by renewable sources was evaluated.

2.1 The building and its model in TRNSYS

The passive house is a multifamily building of eight apartments with a total net surface of 577 m². It has a considerable thermal inertia, given by brick walls of 25 cm. Thermal insulation of the envelope is provided by 28 cm of mineral wool and windows with three glazed layers. The percentage of glazed surface amounts to 20%. An air exchange of 0,8 volumes pro hour is guaranteed by a mechanical ventilation system with heat recovery in a counter flow exchanger. Every single apartment is equipped with a re-heater [4]. The measured energy demand for heating amounts to 23,5 kWh/m^{2}a, which exceeds the design value of 14 kWh/m^2, but it is still within the typical range of measured performances in comparable studies [5].

Fig 1. Multifamily passive house in Bronzolo / Italy

In the TRNSYS model developed for the passive house in Bronzolo, the space was divided in 35 thermal zones. Each one was characterized by volumes, surfaces, windows and doors and by orientation, solar gains, ventilation rate, infiltration and switch-on/off conditions of the heating. Input data to the model were outdoor temperature, relative humidity and global solar radiation; TRNSYS gave thermal loads, solar gains, indoor temperature and relative humidity trends as output [6].

After modelling the building, some strategies were proposed in order to optimize the energy performance, which were implemented in the basic model considered within this study: the observed recycle of waste air was eliminated and the switch-off of the heat recovery system was shifted from 24°C to 23°C. Furthermore different ventilation rates were taken into account: 0,5 V/h with heat recovery and 1,2 V/h in free-cooling to decrease the indoor temperatures in summer. The free-cooling strategy worked when the nightly summer inside mean temperature was higher than 24°C and at the same time higher than outside [6].

This basic model was further modified as follows:

- no buildings around the passive house;
- different values for nightly and daily use infiltration, i.e. 0,13 and 0,15 V/h, for Northern and central Italy, 0,15 and 0,20 V/h for Southern Italy;
- set-point temperature of 20°C for heating.
- set-point temperature was 26°C - in the case of active cooling. This one worked only when the outside temperature was high and the free-cooling was not sufficient to guarantee a good comfort level.

2.2 Climates

The hourly values of climate data, required by dynamic simulation, are taken from the "G. De Giorgio" climatic data archive [7]. In this collection, the standard years are defined on the basis of measured data from 1951 to 1970, providing air temperature and relative humidity, wind speed as well as direct and diffuse solar radiation. From the comparison of climate data among 49 Italian locations, four of these were selected.

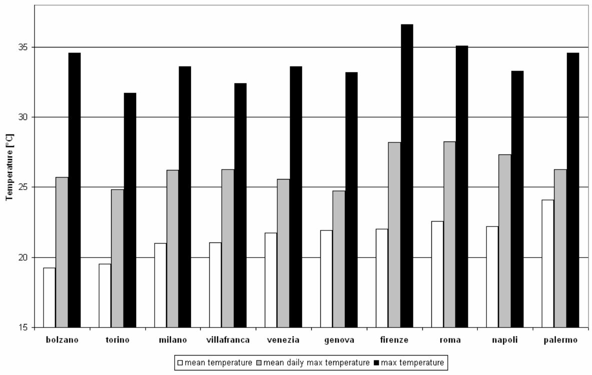

Fig 2. Comparison among seasonal, daily maximum and maximum mean temperatures, for the hotter months, for the main Italian towns.

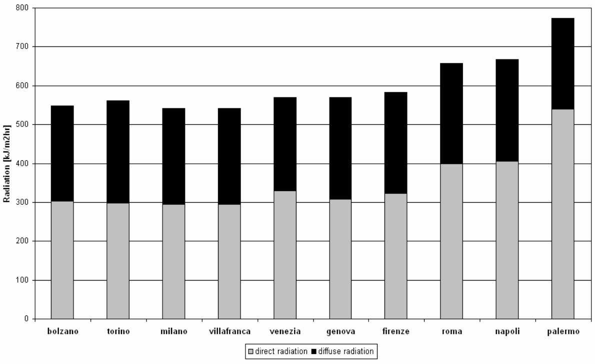

Fig 3. Comparison of yearly mean total radiation for the main Italian towns.

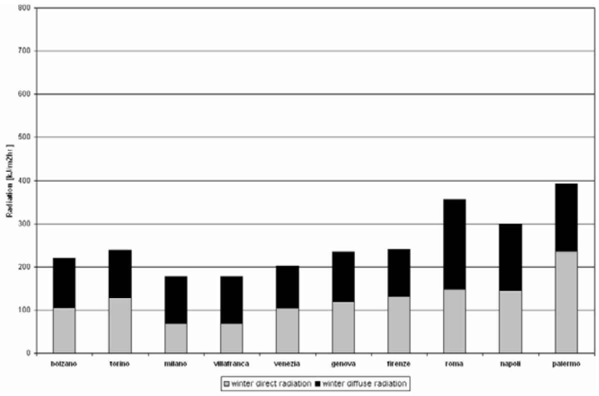

Fig 4. Comparison of winter mean total radiation for the main Italian towns.

Fig 2 illustrates that, while the seasonal mean temperature increases moving southwards, the mean maximum temperature depends highly on other factors as e.g. the geographical position.

Even though Milano and Villafranca, both collocated in Northern Italy, show similar seasonal and daily maximum mean temperatures, they have different maximum temperatures: in fact Milano is considered a sort of warm isle. From the comparison of direct and diffuse yearly solar radiation averages (see fig 3), it can be observed that they increase moving southward and that in winter season the values regarding Milano and Villafranca are lower than the other locations in the North (see fig 4). Since also the relative humidity is high there, this can be explained with a typical phenomenon of Padana Valley: the fog, which acts as a filter for direct radiation. It could be concluded that Milano and Villafranca in the North, Roma in Centre and Palermo in the South were most interesting for a study of the thermal behaviour of the passive house in winter and in summer season respectively.

2.3 Comfort evaluation

Since all studied cases are equipped with mechanical ventilation system, the internal temperature was assessed applying the comfort limits of the Fanger model or PMV model. This model is based on the correlation between climatic variables (temperature and relative humidity) and subjective conditions (metabolic activity and thermal resistance of the clothes). If the “predicted mean vote” or PMV index is within the range between -0,5 and 0,5, there are less than 10% of unsatisfied persons. All the strategies considered in this work had to guarantee a satisfactory level of comfort, i.e. the corresponding PMV had to be within the range previously described.

2.4 Variation of building parameters and control strategies

The results of the varying the following four parameters is described in this paper:

1. Building orientation: three orientations of the most glazed surface were simulated - South-West, South and South-East - in order to see how both winter and summer energy demand change.
2. Automatic shading devices: in order to avoid overheating, external shading devices were automatically activated if (i) the indoor temperature exceeds 26°C and (ii) at the same time the solar radiation on the glass surfaces exceeds 800 W/m^{2}hr.
3. Insulation thickness of outer walls: For every location, the dynamic sensible heating and cooling loads were calculated taking into account three values of thickness (see table 1).

Table 1: Thickness of insulation layer [mm] and total U-value of the wall corresponding to the thickness [W/(m^{2}K)].

Thickness of insulation layer [mm]	Total U-value of the wall [W/(m^{2}K)]
280	0,130
200	0,160
150	0,210

4. Ventilation system: If the proposed ventilation rate for free-cooling of 1.2 V/h did not lead to satisfactory comfort levels, two different approaches were tested: either (i) the ventilation rate for free-cooling was increased (stepwise) up to a value of 2.5 V/h, or (ii) active cooling with a set-point temperature of 26°C was assumed.

Furthermore for the case of Palermo a complete switch-off of the heating system was considered.

2.4 Photovoltaic system

In the study of the passive house in Palermo, the possibility to install a photovoltaic system on the plain roof was taken into account.

The electrical energy demand of the passive house in Palermo was estimated as follows: The electrical demands for the eight apartments, for common lighting, for the elevator and for the technical room were obtained from the monitoring system and considered valid also for Palermo. The electricity demand for the ventilation system (with the supposed ventilation rates) was estimated, whereas that for a chiller was obtained from the sensible cooling load simulated with TRNSYS, considering a compressor chiller with COP 3.

Two PV scenarios were evaluated with a dynamic model in TRNSYS: in the first analysis, the capacity of the PV system was calculated to satisfy just the chillers energy demand, in the second case to satisfy the total electricity demand.

3. Results and discussion

The combination of passive and active strategies, evaluated in this study and adapted to the local climatic conditions, aimed to have thermal control of the passive house both in winter and in summer. In the following chapters the results are presented and discussed.

3.1 Building orientation

Changing the orientation of the building from South-West to South-East had practically no effect – neither on the winter nor on the summer behaviour of the building: both heating and sensible cooling loads varied less than 0.5 kWh/m²a were not much influenced. These results could be due to the particular geometry, the massive structure and the optimised structural shading of the passive house.

The same observation is reported from the Passiv-On national study for Italy [3], which however underlines, that the result might be quite different for buildings with other geometry and without optimised shading.

3.2 Automatic shading devices

The results of simulation with and without automated shading devices showed, that solar gains can be reduced by 30% to 40% - which corresponds to a reduction of up to 2.5 kWh/m²a in Palermo.

This result is in the same order of magnitude than what was observed by Pagliano at al. in [3]:

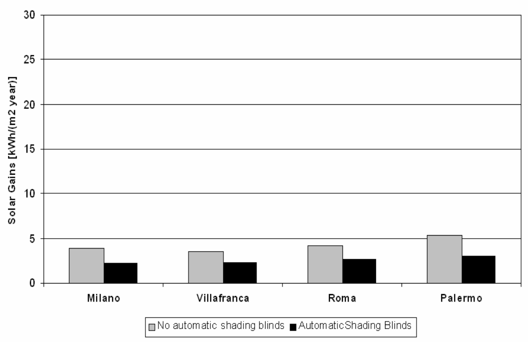

Fig 5. Yearly mean solar gains trend with the use of automatic shading devices.

3.3 Envelope insulation

From the energy point of view, the TRNSYS simulations pointed out a different reaction of the passive house to insulation variations in summer and in winter: whereas there is a marked dependence of the heating loads on insulation thickness, the cooling loads are much less influenced (see Table 2).

Table 2: Heating loads and sensible cooling loads (kWh/m²a) for different insulation diameters .

	Milano	Villafranca	Roma	Palermo
Heating load				
28 cm	19.9	20.0	7.2	0.48
20 cm	23.0	22.9	9.1	0.95
15 cm	26.3	26.2	11.1	1.57
Cooling load				
28 cm	0.86	0.69	2.38	6.6
20 cm	0.85	0.68	2.42	6.7
15 cm	0.85	0.67	2.46	6.7

In the cases of Milano and Villafranca, the simulations verified that the reduction of the insulation layer of outer walls did not give good results, since the heating load increased and therefore 28 cm in thickness was maintained. Whereas in Roma and Palermo, where the simulated heating loads were very low, this design strategy was possible. For Roma a thickness of 20 cm was suggested and for Palermo 18 cm respectively – allowing thus to comply with the Passivhaus limit for the thermal transmittance of 0,20 W/(m^{2}K). In this way, both low thermal loads and less investment in insulation materials could be satisfied.

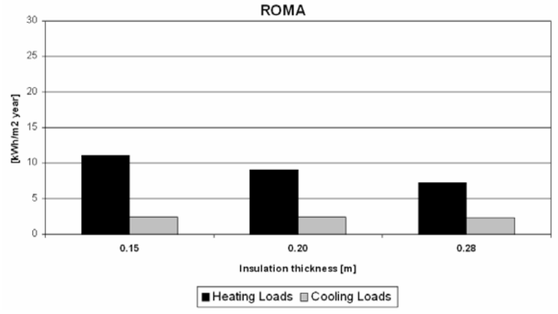

Fig 6. Heating and cooling sensible loads in function of insulation thickness in Roma.

The results show hence, that while the highest standard insulation is a major aspect for a Passivhaus in Northern and Central Europe, less restrictive insulation requirements can be formulated for warmer countries. In line with the results of this study, Pagliano at al. [3] recommend in the Passive-On study Italy, for Milano high insulation (U-value 0.13 W/m²K), for Roma medium high insulation standard (U-value 0.2 W/m²K) and for Palermo moderate insulation (U-value 0.3 W/m²K). They thus exceed the Darmstadt limit for minimum U-value. However, they emphasize, that these insulation levels are no longer enough in buildings without ventilation and heat recovery. Furthermore, their results point out, that no insulation would in all cases give much worse results.

3.4 Ventilation system

In the locations of Milano and Villafranca, the simulations carried out with the ventilation of 1,2 V/h in free-cooling gave good results regarding the internal temperature trend. In Roma and in Palermo, however, it was necessary to increase the ventilation rate to 1,8 V/h and 2,5 V/h respectively, to reduce the degree hours exceeding the 26°C to acceptable levels. Fig 7 illustrates in an exemplary way the internal temperature trend for the location of Palermo.

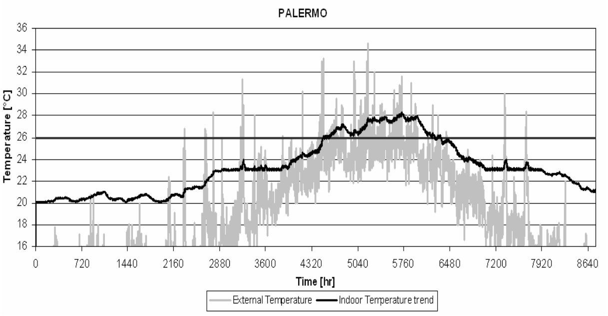

Fig 7. Outdoor and Indoor temperature trends in Palermo. This graphic was obtained with a ventilation in free-cooling of 2,5 V/h.

3.5 No heating in Palermo

The study of the passive house moved to Palermo was the most interesting, since it pointed out significant differences regarding the thermal behaviour in winter and in summer. Therefore, another simulation was carried out with assuming the switch-off of heating in winter season. The results showed an internal temperature trend always above 18°C.

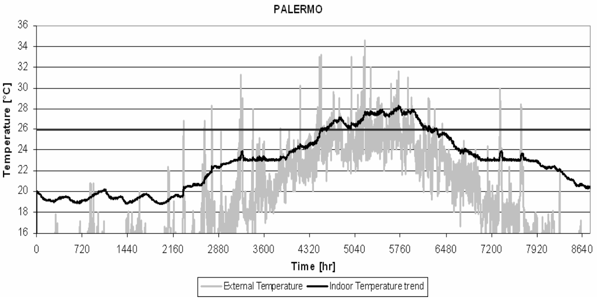

Fig 8. Outdoor and Indoor temperature trend in Palermo. It was obtained with a ventilation in free-cooling of 2,5 V/h and heating switching-off in winter.

3.6 Active cooling in Palermo

In summer time, since the number of degree hours above 26°C, obtained with free-cooling, still amounted to 1921 °Ch, a compressor chiller was taken into consideration in order to reach a constant internal temperature of 26°C and a satisfactory comfort level. In this case, the ventilation rate of free-cooling, corresponding to the working of the chiller, was decreased from 2,5 V/h to 1,2V/h.

That fact that Palermo behaves particularly “bad” in summer and responds much worse to free-cooling and night ventilation concepts is also due to the lower difference between day and night temperatures, as it is also illustrated in [3].

The simulations show however, that the cooling demand of 1283 kWh/a can easily be satisfied by a PV plant with 1.4 kWp. If the whole roof area would be used for PV panels (31°inclination, no reciprocal shading), this would amount to a total capacity of 11.76 kWp, which would provide two thirds of the demanded electrical energy.

4. Conclusion

The strategies proposed for the four selected locations – Milano, Villafranca di Verona, Roma and Palermo – succeeded in providing a good internal comfort in the passive house.

A different orientation of the building resulted in a minimal reduction of the loads, whereas the use of automatic shading devices decreased the mean solar gains up to 40%. Moreover it was shown, that for locations as Roma and Palermo the insulation diameter can be reduced without loss in energy performance but with reduced investment in building materials. The variation of ventilation rate in free-cooling on the basis of the local climate permitted to reach very good internal conditions both in the two Northern locations and in Roma – and, however, acceptable ones in Palermo. There, the necessary electrical energy demand for an active cooling could easily be provided by PV panels.

To sum up, fig 9 illustrates the heating and cooling loads when applying the optimum strategies for the four sites.

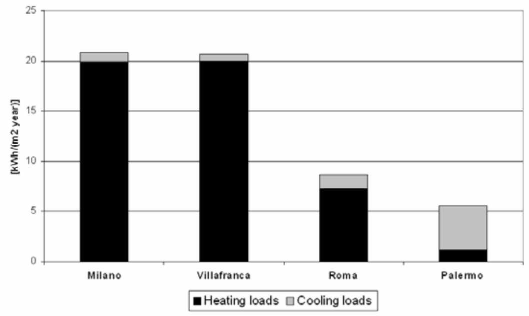

Fig 9. Heating and cooling loads for the studied sites (1.2 V/h free-cooling for Milano and Villafranca, 1.8 for Roma and 2.5 for Palermo, 28 cm insulation for Milano and Villafranca, 20cm for Roma and 18 cm for Palermo)

These loads represent the energy per m^2 to put inside and to take out from the rooms in order to have satisfying internal comfort. The cooling regards only the sensible load, since the dehumidification, i.e. the latent load, was not evaluated.

It can be concluded that a building concept, following the Darmstadt Passivhaus Standard, as the passive house in Bronzolo, can be transferred - with appropriate adaptations - also to warmer European climates. The simulation study with parameter variation based on a model validated with monitored data provides encouraging results.

7. References

1. Passive-on (2007), Passive-On Long Description. Available at http://www.passive-on.org/en/ [Accessed: 25 Februar 2008].

2. Ford, B., Schiano-Phan, R. and Zhongcheng, D. (2007) *The Passivhaus Standard in European warm climates: Design guidelines for comfortable low energy homes. Part 1. A review of comfortable low energy homes.* Available at http://www.passive-on.org/en/cd.php [Accessed: 10.6.2008]

3. Pagliano, L., Carlucci, S., Toppi, T. and Zangheri, P. (2007) *The Passivhaus Standard in European warm climates: Design guidelines for comfortable low energy homes. Part 2. National proposals in detail: Italy.* Available at http://www.passive-on.org/en/cd.php [Accessed: 10.6.2008]

4. IPES - Istituto per l'Edilizia Sociale della Provincia Autonoma di Bolzano/Institut für den Sozialen Wohnbau des Landes Südtirol, (2006). *La casa passiva Bronzolo / Das Passivhaus Branzoll,* Bolzano-Bozen. [http://www.eurac.edu/Org/alpineEnvironment/RenewableEnergy/publications/index.htm]

5. Schmitt, Y., Dal Savio, S., Sparber, W. (2007) PaMo: Monitoring of a multi familly Passive House in South Tyrol, Italy. In *11th International Passive House Conference*, Bregenz - Austria, April

6. M. Castagna, Y. Schmitt, A. Troi (2008), Analysis and optimization of a monitored passive house in Italy with dynamic simulation. In *12. Internationale Passivhaustagung*, Nürnberg, DE, April 11-12. [http://www.eurac.edu/Org/alpineEnvironment/RenewableEnergy/publications/index.htm]

7. Bufera, F. (1981). Le classificazioni climatiche. *Risparmio di energia nel riscaldamento degli edifici*. CNR, PFE. Milano.