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Effectiveness of passive measures against climate change: Case studies in Central Italy

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Research Article

Abstract

This paper focuses on the effectiveness of passive adaptation measures against climate change, in the medium (2036–2065) and long term (2066–2095), for three case studies located in Florence (central Italy). In order to identify and highlight the passive measures which can provide comfort conditions with the lowest net heating and cooling energy demand, the input assumptions consider a constant thermal comfort level and don't take into account either the effect of HVAC system's performance and the degradation of the materials by ageing. The study results show that, in case of poorly insulated buildings, on the medium term, the reduction of energy needed for heating could be bigger than the increase for cooling, resulting in a total annual net energy need decrease, while in the long term the opposite happens. Conversely, considering a high level of thermal insulation, due to the large increase in cooling demand, the total annual energy need rises in both periods. Furthermore, attention should be paid to internal loads and solar gains that, due to the projected climate change, could become main contributors to the energy balance. In general, since the magnitude of energy need increase for cooling and decrease for heating is very significant on the long term, and varies in function of the type of building, the passive measure adopted and the level of thermal insulation, the research results lead to pay close attention to different types of energy refurbishment interventions, that should be selected in function of their effectiveness over time.

Keywords

climate change,
passive adaptation measures for buildings,
energy refurbishment of existing buildings,
Mediterranean climate,
building energy simulation,
reference Italian buildings

Article History

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1 Introduction

In reason of the observance of the Kyoto Protocol and due to energy supply problems, Europe, through the Directive 2010/31/EU on energy performance of buildings, known as EPBD recast (European Parliament 2010), prompts the construction sector to develop actions to make, by 2020, new and existing buildings that are subject to major renovation, nearly zero-energy buildings (nZEB) which are characterized by an extremely low net and primary energy demand, largely covered by renewable sources.

To this scope, a primary action is aimed to promote energy upgrading of existing buildings through the application of the "cost optimal analysis" methodology, which seeks energy measures with the lowest global cost during the economic life-cycle of the building itself, without, however, assessing the effectiveness of climate change adaptation measures. This approach can be inadequate, because global and local warming caused by climate change can vary significantly between different areas and temperatures can locally rise in the range of 6 °C (IPCC 2014).

In particular, the Mediterranean region features a particular climate that may be defined as fragile, since even slight changes in the general circulation of either mid-latitude or sub-tropical areas may produce significant modifications (Giorgi and Lionello 2008). For these reason, this region has been acknowledged as one of the main hot-spots in climate change studies, specifically because of its remarked warming, the large decreases in rainfall, the increases in inter-annual variability of the warm season (Giorgi and

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Lionello 2008; Giorgi 2006), more frequent and pronounced (in terms of duration and severity) heat waves (Kuglitsch et al. 2010) and increased heat stress risk (Diffenbaugh et al. 2007). Furthermore, the consistency of temperature trends during the 20th century with global warming has been acknowledged (Christensen et al. 2007) and is particularly evident for the summer season (Lionello et al. 2012). For instance, the number of observed very hot days (days with maximum temperature exceeding the local 95th percentile of daily maximum temperature distribution over a reference period) has increased significantly across the whole region, while an opposite trend was found for very cold nights (nights with minimum temperature below the local 5th percentile of daily minimum temperature distribution over a reference period); in particular, in Italy the very hot days are observed to be increasing by 3 per decade (Lionello et al. 2012). Several studies are confirming the trend for the region as regards the temperatures: a general increase is likely to occur, with more clear patterns during the summer, with increased risk of drying, increased extreme events both in frequency and intensity, accompanied by a general reduction in accumulated precipitations (especially during the warm season), even if the intensity of events is increasing (Lionello et al. 2012; Christensen et al. 2007; Kovats et al. 2014). Within the Mediterranean area, the Tuscan region features a climate that can be considered typical of a large part of central and southern Italy because it is characterized by a great variability of geographical contexts which range from the Tyrrhenian Sea coast to the Apennine Mountains. Tuscany's capital city Florence, located 80 km away from the coastline, presents one of the hottest summer season of Italy and a not particularly mild winter, resulting in a significant location for highlighting possible criticality in building energy performance response to climate change. Moreover in urban areas such as Florence, temperatures are even higher due to several factors, such as less radiant heat loss and lower wind speed; furthermore, the climate of cities is featuring specific phenomena, among which the most known is the urban heat island. This effect can be generally described as a positive relationship between the temperature and the number of inhabitants and the building density of a city (WHO 2003). It should also be considered that in a near future, about 60% of the global population will live in cities and urban areas (Douglas 1992; UNFPA 1999), with an unprecedented urbanization rate. The European web site on Climate Change Adaptation (European Climate Adaptation Platform 2015), shows that the mean number of hot days combined with tropical nights increases moving southward and in particular the city of Florence is classified in the maximum range of annual number of nights of thermal discomfort, with a value equal to 61.4 nights in the period 2002–2012 (Timmerman 2015).

Regarding final energy consumption, in Italy the largest share (36.7%) is attributable to the civil sector (ISTAT 2012). In particular, the yearly energy demand of the residential sector for air conditioning is around 20 kWh/m^2 and is estimated to double in 2050 (ENEA 2013); these data confirm the importance of verifying the effectiveness of climate change adaptation measures, especially in the Mediterranean area, where, due to very warm summers and mild winters, energy consumption is going to be increasingly dominated by cooling demand (Li et al. 2012). Since there is a medium confidence that climate change will increase problems related to building overheating and a very high confidence that cooling demand will also increase due to climate change, a great attention should be paid to the energy efficiency of buildings in order to reduce energy demand for cooling (Kovats et al. 2014). Several studies highlight that buildings that were originally designed for certain thermal conditions will likely operate in a warmer climate (Kovats et al. 2014; Matthies et al. 2008).

Below is a brief review of the latest research on the field of climate change impact on the energy performance of buildings. To our knowledge, none of the recent studies address this issue considering the specific climatic context of central Italy.

In (Asimakopoulos et al. 2012), for the Greek area, three different climate scenarios are examined and it is shown how the uncertainty of initial assumptions can influence the final results. However, the results converge on a drastic decline of energy needs for heating and an equally drastic increase of energy consumption for cooling necessary to keep the conditions of indoor comfort. The research (Gupta and Gregg 2012), which deals with typical residential buildings, arrives at the same conclusions even if a colder climate (Oxford, UK) is analysed: the major risk of overheating is related to solar radiation and thermal insulation; as a consequence the most effective climate change adaptive measure is solar shading, although, in the long term, this measure is not sufficient to avoid overheating risk, and, thus, mechanical cooling is necessary.

Considering climate conditions in the UK (London and South East England) (Porritt et al. 2012) examines several possible solutions for the renovation of residential buildings, that are able to face the effects of increasingly frequent summer heat waves. It concludes that inhabitants can play a decisive role activating night ventilation and solar shading. Another important consideration is made regarding the higher effectiveness of placing wall insulation layers on the external rather than on the inner side, especially for walls facing East and West.

Also (Coley et al. 2012), comparing the results of non-structural type measures, such as window openings, with the results of structural adaptive measures such as thermal mass increase and solar shading, highlights the importance of inhabitant behaviour in order to deal effectively with the temperature increase in the UK.

For cold climates, like Stockholm, even considering the uncertainty of climate change, (Nik and Sasic Kalagasidis 2013) shows that it is possible to deal with the increased cooling requirements by means of the sole natural ventilation, even in the most critical scenarios.

For the Dutch climate, in (van Hooff et al. 2015, 2016) typical residential buildings are examined, assuming the application of six different adaptation measures to current and 1970s constructions. Evaluating the number of overheating hours (van Hooff et al. 2015) and heating and cooling demand (van Hooff et al. 2016), these researches highlight the risk induced by climate change, in particular for new buildings which, due to high thermal insulation, retain solar heat gains with a consequent rising of internal temperature (van Hooff et al. 2015) and cooling demand (van Hooff et al. 2016). For well insulated buildings the best solutions are solar shading and natural ventilation.

In the case of the Austrian climate (Vienna) and of office buildings built in different periods, in (Berger et al. 2014) the effects of heat islands on the energy balance are assessed and the need to examine multiple factors such as building location, construction period and climate change scenario are highlighted. It is also shown that solar and internal gains are the major drivers of the increased need for cooling.

As for climate conditions in the USA, in (Kalvelage et al. 2014) the results of the research indicate that, in addition to the expected increase of energy consumption for cooling due to the rise of temperature, the impact of the increase of relative humidity must be considered as well. This study shows that in humid climate areas the control of relative humidity would probably, be more energy consuming than the control of air temperature. This is an interesting aspect to pay attention to, which, however, has not been addressed in this research since only operating temperature was assumed as control parameter.

Other studies (Wang and Chen 2014) establish a relationship between energy consumption and climate change in 15 cities of the USA. Different types of buildings are examined and simulation results show a significant increase of net energy need for cooling in hot climate zones with a very important help from natural ventilation in reducing cooling demand, while for colder climates a total energy demand reduction is found. This study highlights also how the type of building strongly influences the results.

As for northern Italy, in (Waddicor et al. 2016) the impact of climate change coupled with the effects of the ageing of building components has been assessed for a public library in Turin with a horizon time up to 2060. Results showed an increase of building cooling demand which is amplified by the effect of HVAC systems performance degradation, while the decrease of heating demand due to warming climate is weakened by building ageing. Among the analysed retrofit measures, wall insulation has found to have an overall limited effect while the most effective one is the installation of a more efficient chiller.

In synthesis, the results of these investigations agree on the importance of evaluating the effects of global warming on the design strategies of different type of buildings and, in particular, on the necessity of a very careful assessment of the effectiveness of thermal insulation increase in those situations where solar shading is not provided. In fact this kind of renovation, if applied in mild climates, can result in the risk of overheating and an annual energy demand increase in order to maintain comfort conditions.

2 Methodology

From these premises, in this study the possible impacts of climate warming on the energy consumption of buildings are examined with a horizon time between 2036 and 2095 depending on the estimated service life of the buildings. We analysed three building types: a detached house, an apartment block and a small office building, which are considered sufficiently representative of the Italian building stock (ISTAT 2016). The energy performance of these reference buildings was analysed by means of dynamic simulation under current and projected climatic conditions for the city of Florence. The first part of this study deals with the development of future weather data in Florence for building performance simulation. In the second part, the impact of increased outdoor temperature on the energy demand of the three reference buildings is assessed by means of dynamic simulation, while in the third part, considering a fixed level of indoor thermal comfort, the effectiveness against the effects of climate change of six passive adaptation measures is evaluated. Finally, the results of the study are discussed and the future prospects of building design for climate change adaptation are analysed.

The methodology of this research was arranged in order to make the comparison of the results with other researches possible. In particular the following common elements can be listed:

- The definition of a set of reference buildings located in different temporal contexts, typically in the 1960s or 1970s (less thermal insulation) and today (major thermal insulation);
- Climate change represented by one or more scenarios with evaluation periods typically extended to the medium and long term, up to 2080–2100; in this paper, one climate change scenario with an increase in average temperature between 1.8 °C and 3.1 °C respectively in the medium

(2036–2065) and long term (2066–2095), is considered;
- The use of dynamic simulation on a sub-hourly basis that allows a contribution to the knowledge of the possible effects of climate change.

The performance indicator used in this study is the *net energy need* for space cooling and heating, normalized to floor surface, which is necessary to provide constant indoor thermal comfort conditions during the year. Other researchers, in order to assess the effectiveness of climate change adaptation measures, use the number of hours of discomfort or overheating; both methods show, from different points of view, similar results. The net energy demand is the parameter that expresses the energy performance of the sole building envelope and thus it is suitable to understand the energy performance of passive refurbishment; thereby it allows to avoid considering the performance degradation over time of the HVAC systems (de Wilde and Tian 2012) and the uncertainty due to the rapid HVAC technological development. The degradation of the materials by ageing is not considered in this study (Waddicor et al. 2016); therefore we consider that the materials used for energy improvement are replaced before they get to a level of deterioration that may affect their performance. Finally, some of the energy efficiency measures analysed in this study, are not affected from the action of the inhabitants, such as wall and window thermal insulation, while for other measures such as ventilation and solar shading a standard users behaviour has been assumed, in order to reduce further uncertainty in the results (de Wilde and Tian 2012).

2.1 Current and future weather data for energy simulations

The energy performance simulations of the three reference buildings were carried out with three different weather data sets. The first one is representative of the current climate (baseline). The other two represent the future climate under a climate change regime, as projected for the periods 2036–2065 and 2066–2095 within the Representative Concentration Pathways 8.5 (RCP 8.5) scenario. The RCP 8.5 scenario is used for the Intergovernmental Panel on Climate Change (IPCC) 5th Assessment Report, and considers a growing concentration of greenhouse gases beyond 2100 (Cubasch et al. 2013). The choice of this worst case scenario is determined by the need to force the results of the analysis in order to detect any problematic issues lying in future building design actions or any critical response to energy refurbishment of existing buildings.

The current weather data set is a Test Reference Year (TRY) prepared by the Italian Heat Technology Committee complying with EN ISO 15927–4 (CTI 2009) on the basis of climatic data collected between 2000 and 2009 by the meteorological station “Firenze Città” of the Agrometeorological Service of the Tuscany Region (43°46'17.4"N, 11°15'52.6"E).

The heating degree days (HDD) and the cooling degree days (CDD) of Florence, calculated on the basis of the current weather file used for simulations, taking a base temperature (θ_b) of 20 °C for winter and 23 °C for summer, are respectively 2037 and 277 (UNI 1994; UNI 2008a; Riva et al. 2012).

Future weather data sets were processed, on the basis of the current weather TRY, by means of the “morphing” method developed by Belcher et al. (2005). The generation of future climatic reference years was based on the differences between present and future average values of monthly maximum and minimum temperature derived from the projections of regional climate simulations models. In this study we used the results of Regional Climate Model (RCM) COSMO CLM developed by the Euro-Mediterranean Centre on Climate Change (CMCC); in particular the data from the nearest RCM cell (43°46'12.0"N, 11°11'24.0"E), with respect to the meteorological station, were extracted and processed. This high resolution RCM is considered adequate to study the impacts of climate change on a land with very complex topography such as the Italian peninsula (Bucchignani et al. 2016). In the study future values of solar radiation, relative humidity and wind speed are kept equal to current values since projections from COSMO CLM model are not available (Guan 2009).

Figure 1 shows the monthly average values of dry bulb temperature for the three weather data sets used in this study. The patterns of some winter mean temperatures in the future periods, where February shows colder values than in January, while in the baseline February is observed to be on average warmer, are mainly due to the future projections, in which the minimum temperatures of February are simulated to be particularly low.

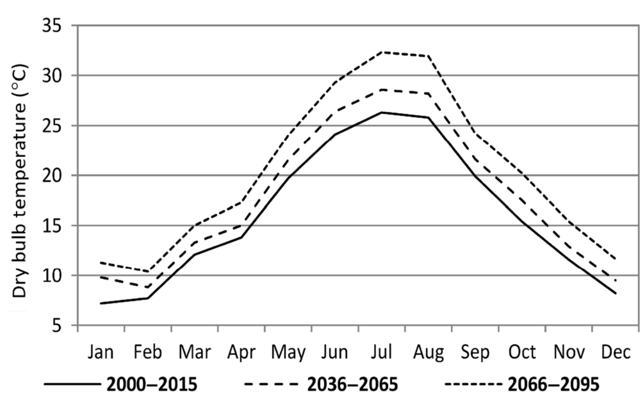

Fig. 1 Monthly mean dry bulb temperature values of the present climate and the future climate reference years

With regard to the processing and selection of climate dataset for building simulations, it must be considered that the data recorded by weather stations located in central and densely populated urban areas can embed possible urban heat island effects; an example of this is that the data recorded by "Firenze Città" weather station from 2000 to 2010 (Agrometeorological Service Tuscany Region 2015) present a minimum average winter temperature and a maximum average summer temperature respectively 1.5 °C and 0.6 °C higher than those recorded, in the same period, by the Florence airport weather station WMO 161700 (ISPRA 2015) located in the North-East suburb of the city.

2.2 Dynamic simulations: Assumptions and case studies

Simulations were performed by means of the software Design Builder (DB) version 3.4.0.041 (Design Builder Software 2015b), a graphical user interface of the dynamic simulation program EnergyPlus version 8.1 (EnergyPlus 2015), which is commonly used by designers and researchers. The algorithms used by EnergyPlus have been positively validated with respect to both North American ASHRAE Standard 140-2011 (Henninger and Witte 2010; Design Builder Software 2014) and European EN 15265 (UNI 2008b; Design Builder Software 2015a) standard, as well as compared with well-known and reliable simulation software (Zhu et al. 2013). Also the airflow network model of EnergyPlus has been successfully validated for natural ventilation flow simulation and the results present good agreement with analytical solutions and other airflow network models (Zhai et al. 2011)

Since the aim of the study is the assessment of passive thermal performance of different energy refurbishment actions against climate change, the energy balance of the building has been calculated considering the following assumptions:

- A constant thermal comfort level is obtained by ideal cooling and heating systems, with theoretical efficiency (η) equal to 1, so, it's not considered the effect of the HVAC system's performance on the passive measures;
- The materials used for energy improvement are replaced before get to a level of deterioration that may affect their performance;
- A constant ventilation rate which includes air infiltration and is considered sufficient to provide acceptable indoor air conditions for average users with reference to standards UNI TS11300-1: 2014 (UNI 2014) and UNI 10339 (UNI 1995); with regard to the office a dual duct mechanical ventilation system equipped with an air-to-air heat exchanger unit has been simulated by means of the EnergyPlus algorithms;
- In order to provide comfortable conditions, the internal operative temperature (θ_o) is kept constant at 26 °C during cooling period and at 20 °C during heating period;
- Constant internal gains which are assumed to be totally sensible and convective;
- Constant soil reflectance (albedo) of 0.2;
- Monthly soil temperatures calculated by means of the EnergyPlus module Slab (LBNL 2013); according to the 2000–2009 climate file and it is left unchanged for the future periods.

With these assumptions, the results of dynamic simulations are given in terms of energy need for heating (Q_H) and cooling (Q_C) in compliance with UNI EN ISO 13790 (UNI 2008c). These values, considering that thermal comfort is fixed at a constant level, vary as a function of climate change and of effectiveness of the applied adaptation measures.

The three case studies analysed in this study, consist of two residential buildings (a detached house and a flat in an apartment building) and a small office building. They were designed by the Italian Heat Technology Committee (CTI) for the validation of energy certification software in compliance with EPBD EU (CTI 2012a,b,c). Their floor plans, facades and main dimensions are reported in Figs. 2, 3 and 4.

The detached house has three floors: the lowest floor is an unheated basement and the top floor is an unheated attic. The apartment building has five floors and six flats of the same size with an unheated attic and ground floor. Finally, the office building has two floors.

All buildings are not shaded by other buildings and are oriented, as shown in Figs. 2, 3 and 4, to make optimal use of sunlight. The effect of different orientations has been analysed turning the main facade of the apartment building and the office from south to west and east while the detached house main facade has been rotated from south-west to south-east, north-west and north-east.

Tables 1 and 2 show a synthesis of the relevant geometric and thermo-physical properties of the reference buildings collected from CTI publications (CTI 2012a,b,c). Thermal bridges have been considered as corrected or absent and thus not relevant for the purpose of this assessment.

The thermal transmittance of windows has been calculated according to UNI EN ISO 10077-1 (UNI 2007) from known values of windows, frame and spacer thermal transmittance. Detached house and apartment building are provided with external wooden roller shutters, except for the 0.80 m × 0.80 m window of the detached house and for the stairwell and attic windows of the apartment building. During the night the roller shutters are assumed to be completely closed. The reduction of thermal transmittance of the windows (U_w) due to the closing of roller shutters during the night is accounted through an added thermal resistance (ΔR) equal to 0.22 ($m^2 \cdot K$)/W which leads to a value of the window thermal transmittance with closed stutter (U_{w+shut}) and to a correct transmittance value ($U_{w,corr}$) which take into account the management of the roller shutters, as it specified in (UNI 2014) at the paragraph 11.1.2.1. The roller shutters are

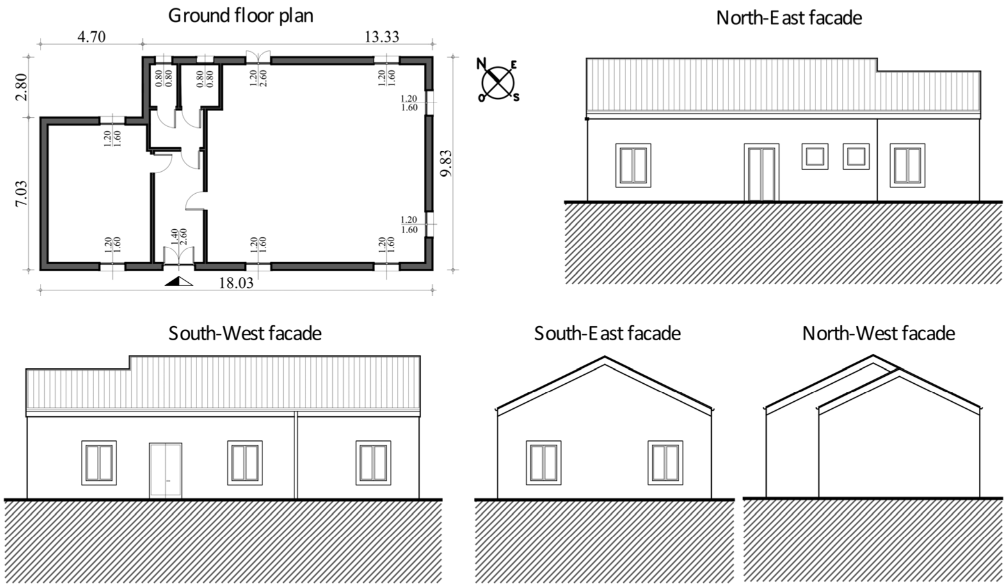

Fig. 2 Ground floor plan and facades of the detached house

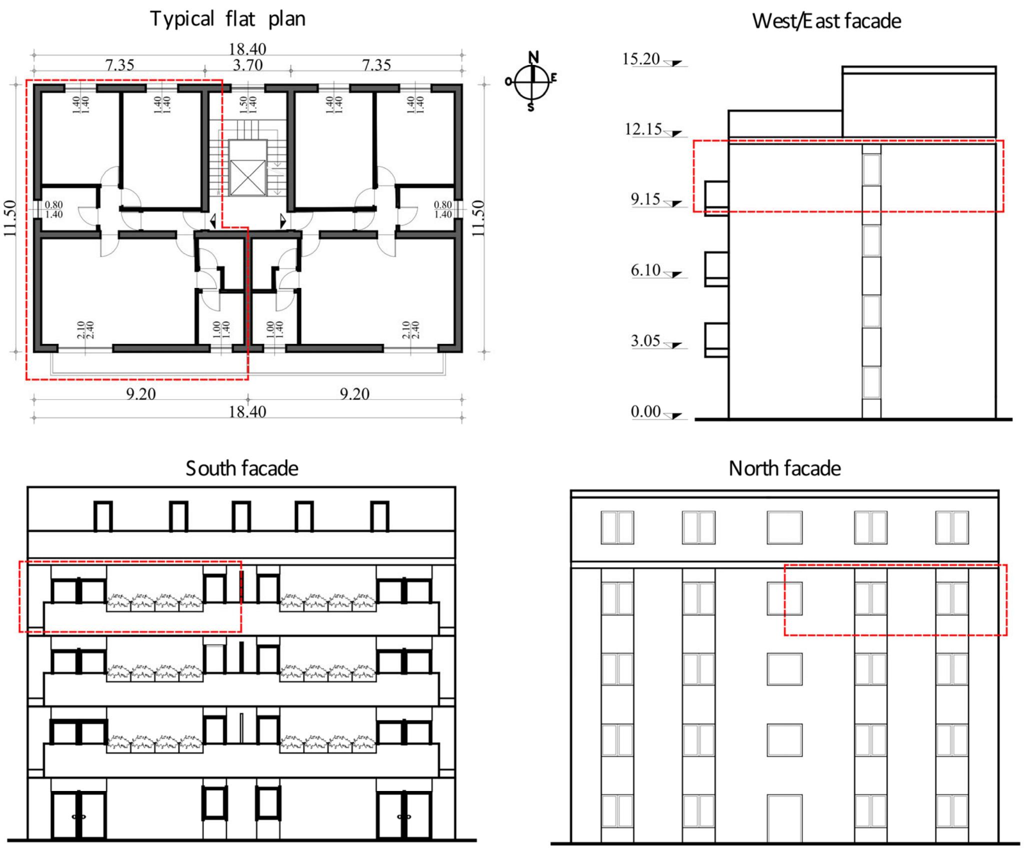

Fig. 3 Typical flat plan and facades of the apartment building. The apartment under investigation is highlighted by dashed box

assumed to be completely open during the day, and therefore do not affect the solar gains.

Only the detached house and office building are provided with internal operable solar shading devices. For the detached house white internal curtains with light transmittance (τ_v) and solar direct transmittance (τ_e) of 0.5, and absorption coefficient (a) of 0.1. For the office building, internal white Venetian blinds with τ_v and τ_e being equal to 0.05 and a being equal to 0.1. The shading devices are considered lowered, in accordance with UNI-TS 11300-1: 2014 Section 14.3.4

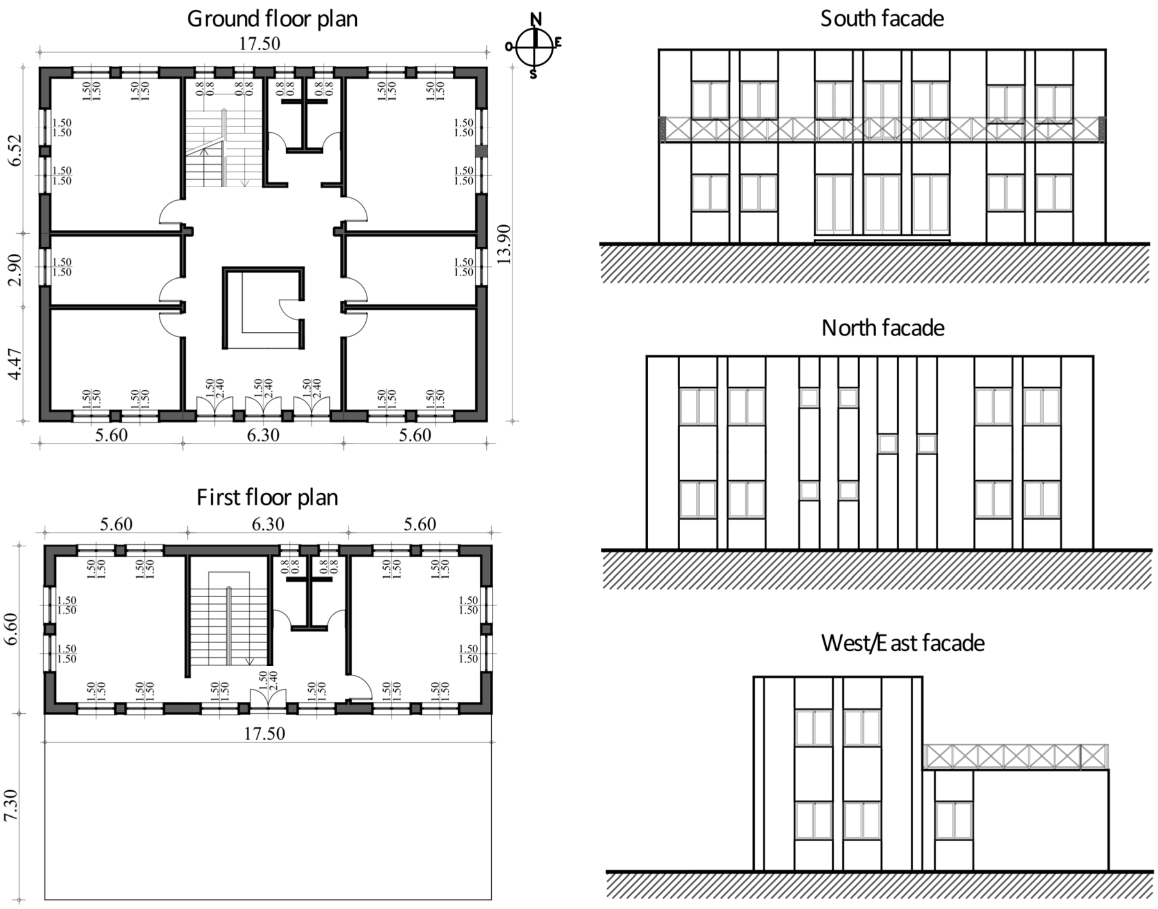

Fig. 4 Plans and facades of the office building

Table 1 Main properties of the reference buildings

	Detached house	Flat in apartment building	Office building
Net floor area of conditioned space (m^2)	143.11	79.32	289.21
Gross floor area of conditioned space (m^2)	164.07	93.87	358.75
Net conditioned volume (m^3)	493.72	214.16	998.01
Gross conditioned volume V (m^3)	689.11	297.25	1309.44
Net envelope surface of conditioned volume (m^2)	466.65	170.32	736.49
Gross envelope surface of conditioned volume S (m^2)	562.17	201.56	1122.65
S/V (m^{-1})	0.82	0.68	0.86
Window surface/net floor area	0.100	0.145	0.193
Internal heat gain (W/m^2)	3.07 00–24 Mon–Sun	4.06 00–24 Mon–Sun	17.5 08–18 Mon–Sun
Air change of natural or mechanical ventilation (h^{-1})	0.3 h^{-1} 00–24 Mon–Sun		0.69 h^{-1} 08–18 Mon–Sun
Occupancy (person/m^2)	—	—	0.06
Design airflow (m^3/(h·person))	—	—	39.6
Heat recovery efficiency of ventilation system	—	—	80%
Heating set-point (°C)	20	20	20
Cooling set-point (°C)	26	26	26
HVAC system type	Totally convective ideal system		
HVAC activation time	00–24 Mon–Sun		08–18 Mon–Sun

Table 2 Thermal transmittance and thermal capacity of the building components

Building component	Thickness (m)	Thermal transmittance U (W/(m²·K))	Internal areal heat capacity κ_i (kJ/(m²·K))	External areal heat capacity κ_e (kJ/(m²·K))
Detached house				
External wall	0.33	0.29	45.32	57.22
Internal wall	0.13	1.48	38.82	38.82
Ground floor	0.35	0.30	—	—
Below grade wall	0.33	0.30	—	—
Semi-exposed floor	0.35	0.31	62.00	51.45
Semi-exposed ceiling	0.40	0.27	88.06	67.95
Roof	0.30	0.24	—	—
Flat in apartment building				
External wall	0.30	0.30	46.74	63.06
Internal wall/stairwell	0.30	0.79	46.83	46.83
Internal wall	0.10	1.80	35.08	35.08
Ground floor	0.35	0.30	—	—
Semi-exposed floor	0.35	0.31	62.00	51.45
Internal floor	0.35	0.32	73.32	59.96
Internal ceiling	0.35	0.32	84.07	68.27
External roof	0.35	0.33	84.33	92.37
Attic roof	0.30	0.24	—	—
Office building				
External wall	0.40	0.205	14.68	122.74
Internal wall	0.15	2.490	69.15	69.15
Internal wall/toilets	0.10	1.801	35.08	35.08
Ground floor	0.35	0.304	59.57	175.04
Internal floor	0.35	0.318	73.32	59.96
Roof	0.30	0.325	15.57	106.19

(UNI 2014), when the value of incident solar radiation (I_{sol}) exceeds the set point value of 300 W/m².

Table 3 shows the values of U_w, U_{w+shut} and $U_{w,corr}$ of the window of the current version of the three buildings. The parapets of the windows are made of the same component of the external wall. U-value of the doors and of the shutter boxes were assumed, respectively, equal to 2.23 W/(m²·K) and 1.00 W/(m²·K).

2.3 Passive measures against climate change

The passive measures that have been analysed were selected considering the data on the energy refurbishment measures that have been mostly applied within the tax benefit programs promoted by the Italian Government since 2006 (Nocera 2015) as well as considering the range of measures that had been evaluated in the studies listed in the introduction. The parametric study was done by simulation considering three different levels of building envelope energy performance:

– Current situation (2010): original CTI buildings that meet the actual Italian energy standards;
– Past situation (1960s), which is representative of existing buildings before renovation: alternative version of the same buildings, characterized by a low energy performance;

Table 3 Window thermal transmittance of the reference buildings

Window size	U_w (W/(m²·K))	U_{w+shut} (W/(m²·K))	$U_{w,corr}$ (W/(m²·K))
Detached house. Windows with wooden frame and double pane glazing (4-8-4 mm) with air filled gap. Emissivity (ε) value of glass pane is assumed equal to 0.837. Total solar factor for normal incidence ($g_{gl,n}$) is equal to 0.75.			
120×160	3.13	1.85	2.36
80×80	3.18	3.18	3.18
120×260	3.13	1.85	2.37
Apartment building. Windows with wooden frame and triple low emissivity pane glazing (4-6-4-6-4 mm) with Argon filled gap. Emissivity (ε) value of glass panes is assumed less than 0.05. Total solar factor for normal incidence ($g_{gl,n}$) is equal to 0.5.			
240×210	1.50	1.13	1.27
100×140	1.58	1.17	1.33
140×140	1.67	1.22	1.40
80×140	1.63	1.20	1.37
150×140	1.51	1.51	1.51
Office building. Windows with thermal brake metal frame and double pane glazing (4-8-4 mm) with air filled gap. Emissivity (ε) value of glass panes is assumed equal to 0.837. Total solar factor for normal incidence ($g_{gl,n}$) is equal to 0.75.			
150×150	3.16	3.16	3.16
150×240	3.13	3.13	3.13
80×80	3.09	3.09	3.09

– Future situation (after 2020): current situation (2010) and past situation (1960s) buildings with increased energy performance of building envelope in compliance with DM 26/06/2015 thermal transmittance limits (Governament of Italy 2015).

Table 4 shows the thermal performance to the 1960s level. Tables 5 and 6 provide a detailed overview of the passive adaptation measures.

3 Results and discussion on the effects of climate change

In this section the results of the energy simulations of the three case studies considering their past and current configuration are reported and discussed. The findings of this study should be interpreted carefully bearing in mind the assumptions regarding the input parameters and the boundary conditions of the simulation, the adopted metrics and the uncertainty related to the complexity of climate change (de Wilde and Tian 2010).

3.1 Influence of the thermal insulation representative of the current construction.

Current situation (2010) baseline building configuration is characterized by a good level of thermal insulation as shown in Tables 2 and 3.

3.1.1 *Detached house*

In Fig. 5 the results of future energy needs are compared to

Table 4 Measures adopted to generate buildings with reduced thermal performance (1960s version)

Building component	Measure
External walls (detached house and apartment building)	Insulating layer replaced by an unventilated air gap of the same thickness with a thermal resistance (R) value equal to 0.18 ($m^2 \cdot K$)/W
External walls (office building)	Insulating layer removed
Roof (all the buildings)	Insulating layer removed
Window (all the buildings)	Current window glazing replaced with a 4 mm single pane glazing with U_g = 5.7 W/($m^2 \cdot K$) and $g_{gl,n}$ = 0.85. Considering the presence of the roller shutter $U_{w,corr}$ is 3.4 W/($m^2 \cdot K$) . Window frame is unchanged.
Mechanical ventilation (office building)	Reduction of the sensible heat recovery system efficiency from 80% to 50%

Table 5 Overview of passive adaptive measures for upgrading the current and the past version of the reference buildings

Climate change adaptation measure	Description	Name
Increased thermal resistance of windows (2010 and 1960s buildings)	Replacement of original glazing with a triple pane low-e glazing with U_g = 0.5 W/($m^2 \cdot K$) and $g_{gl,n}$ = 0.5 (UNI 2007) and replacement of original frame with a high performance one with U_f = 1.0 W/($m^2 \cdot K$), reaching a U_w value of 0.8 W/($m^2 \cdot K$) and considering roller shutters $U_{w,corr}$ = 0.7 W/($m^2 \cdot K$)	R1a
Increased thermal resistance of external walls and roof (only 1960s buildings)	Original thermal insulation level is restored; semi-exposed walls and floors has been kept unchanged, as well as ground floor or below grade walls.	R1b
Increased thermal resistance of external walls and windows (only 1960s buildings)	Measures R1A + R1B	R1c
Increased short-wave reflectivity (albedo) of external walls and roof (2010 and 1960s buildings)	Detached house and apartment building external walls and roof: solar absorptivity reduced from 0.6 to 0.3; Office building roof : solar absorptivity reduced from 0.6 to 0.3; Office building external walls: solar absorptivity reduced from 0.3 to 0.2.	R2
Increased external walls and roof thermal capacity (only 2010 buildings)	– Detached house and apartment building external walls and roof: thermal insulating layer moved outwards (ETICS); – Office building external walls: thermal insulating layer moved outwards (ETICS).	R3
Solar shading (2010 and 1960s buildings)	– Original glazing replaced by solar control glazing with $g_{gl,n}$ = 0.5; – Introduction of a white external venetian blind with solar transmittance τ_s = 0.1 and solar absorptivity a = 0.1 with activation level set at 300 W/m^2 of global solar irradiation incident on the window.	R4
Additional natural ventilation (2010 and 1960s buildings)	Detached house and apartment building: increasing of ventilation rate to 1 h^{-1} when outdoor temperature is 2 °C below internal one. Additional ventilation is shut off when internal temperature drops below 22 °C.	R5
Internal gain reduction (details in Table 6) (2010 and 1960s buildings)	50% reduction of lighting gains; 20% reduction of appliances and electric devices gains.	R6a
	Further 50% reduction of lighting gains; Further 20% reduction of appliances and electric devices gains.	R6b

Table 6 Detailed data regarding internal gains reduction levels (W/m^2)

	Current level	Share	Reduction level 1	Reduction level 2
Detached house (internal gains on 24h/24h from Monday to Sunday)				
People	0.77	25 %	0.77	0.77
Lighting	0.61	20 %	0.31	0.15
Appliances	1.69	55 %	1.35	1.08
Total	**3.07**		**2.43**	**2.00**
Flat in apartment building (internal gains on 24h/24h from Monday to Sunday)				
	Current level	Share	Reduction level 1	Reduction level 2
People	1.02	25 %	1.02	1.02
Lighting	0.81	20 %	0.41	0.20
Appliances	2.23	55 %	1.79	1.43
Total	**4.06**		**3.21**	**2.65**
Office building (internal gains on from 8:00 to 18:00 from Monday to Friday)				
	Current level	Share	Reduction level 1	Reduction level 2
People	2.5	14%	2.5	2.5
Lighting	10	57%	5	2.5
Appliances	5	29%	4	3.2
Total	**17.5**		**11.5**	**8.2**

the current period energy demand (2000–2015); a significant reduction of the energy need for heating (−56%) can be seen, while, on the contrary, there is an important increase in cooling need (+85%); the rise in total annual energy need can be observed starting from the second period (+4%) and becoming evident in the third period (+19%). It can be concluded that the reduction of energy need for heating does not balance the energy need increase for cooling.

It must be highlighted that the current energy need for cooling is slightly higher than that for heating. These results are unexpected in such dimensions. As regards the contribution of the building components to the energy balance it can be observed that:

– Walls and windows have about the same share over the three periods for both dispersions and gains.
– In the last period, heat gains from opaque and transparent envelope components amount to 15 kWh/m^2 and become relevant.
– In the medium term, natural ventilation represent one of the largest contributor to energy need and in the long term, if not properly managed, can represent a heat gain with the same magnitude of the others.
– Internal gains with 27 kWh/m^2 are in the order of magnitude of the solar gains, which amounts to 34 kWh/m^2 and, therefore, great attention should be paid to this parameter. With regard to internal gains it should be highlighted that the use of input data derived from Italian technical standards UNI TS11300-1: 2014 could lead to a possible overestimation.

Moreover, in order to study the effect of different orientations, the detached house has been simulated rotating the main facade, by 90° steps, from the optimal orientation of south west. For this particular building layout the effects of exposure rotation vary in a range from 3% (north-east and north-west) to 5% (south-east) and therefore is not very significant.

3.1.2 *Flat in apartment building*

As shown in Fig. 6, the annual total energy balance of the apartment located on the top floor, is similar to the detached house: energy need for heating drops more evidently (−74%),

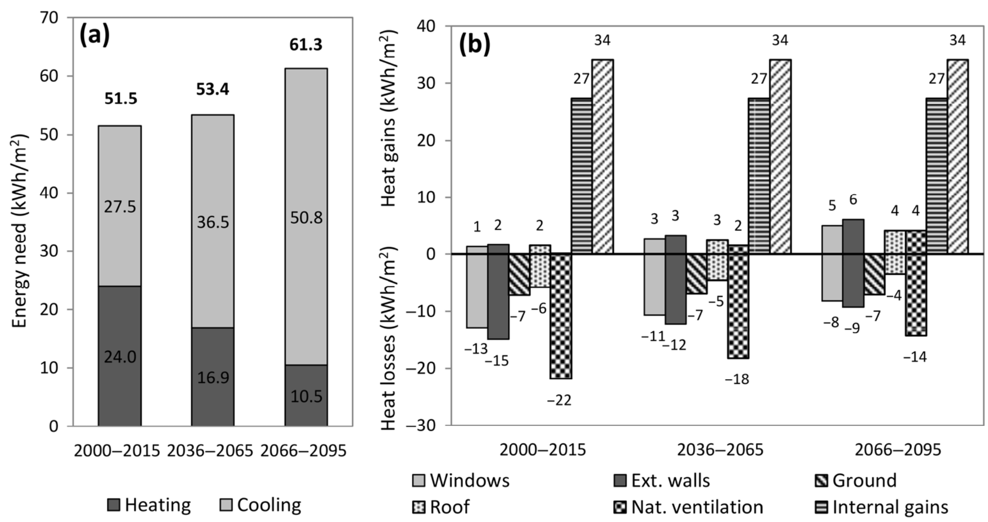

Fig. 5 Detached house: (a) annual energy need for space heating and cooling and (b) annual heat gains and losses through building components, in different time periods

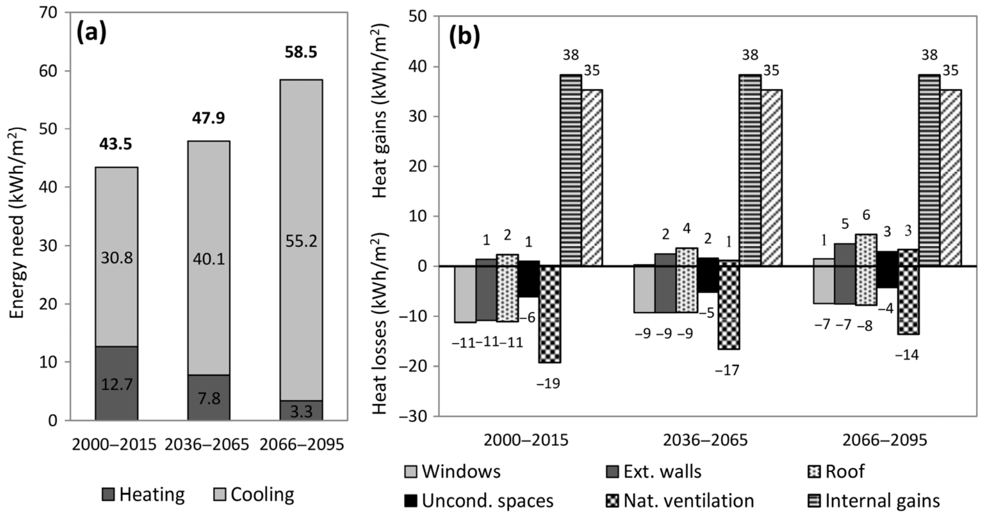

Fig. 6 Flat in apartment building: (a) annual energy need for space heating and cooling and (b) annual heat gains and losses through building components, in different time periods

while a similar rise of energy need for cooling (+79%) can be observed. The total annual energy need trend over the future periods is worse than that for the detached house: the total energy need which rises of 10% in the second period, becomes evidently bigger in the third period (+35%). Even for the current climate the apartment energy need for cooling is much greater than that for heating, while in the last period the total annual energy demand of the apartment is almost totally covered by cooling. Also in this case these results are unexpected in such dimensions. With regard to the contribution to the heat balance of the different components it can be observed that:

– As regards as the walls and the windows, the considerations made for the detached house are still valid for the apartment.
– Heat losses through the roof has higher incidence compared to the detached house.
– Considering the climate scenario 2066–2095, the heat gain through opaque and transparent components becomes important and amounts at 15 kWh/m^2.
– The considerations regarding internal and solar gains and ventilation of the detached house are valid for the apartment as well; however, for the apartment, the internal gains are the biggest source of heat load (38 kWh/m^2), even above solar gains (35 kWh/m^2).

When the effects of different orientations are considered, when rotating main facade of the building from south to west and to east, the total annual energy demand rises significantly, in consequence of the shift of the monthly distribution of solar gains, of, respectively, 32% and 30% on the current period, 28% and 25% on the medium term and 21% and 20% on the long term. From these data west and east orientations appear to be slightly less sensitive to climate change effects than the southern one.

3.1.3 *Office building*

While confirming the general trend observed for the detached house and the apartment, the results for the office building present some peculiarities. It is clear from Fig. 7 that, even considering current climate, energy need for cooling (79% of total demand) greatly exceeds that for heating and that climate change further enhances this issue. There is a 65% decrease in annual energy consumption for the 2066–2095 period for heating with respect to current climate conditions, while the increase in cooling demand is slightly less evident than in the case of the other reference buildings (+62%); this fact can be explained considering that cooling demand is high even in current climate conditions. The total annual energy need rises 11% in the second period and 35% in the third period, which is totally attributable to the increase in cooling demand. As regards as the contribution to the energy balance of the different building components, the same considerations made for the other reference buildings are valid, with a bigger share of gains and losses from the windows due to large glazed surfaces.

Thanks to the heat recovery unit, the contribution of ventilation is much lower, both in absolute and relative terms, compared to the other two reference buildings.

Rotating the main facade of the building from south to west, the total annual energy need of the office building increases by 11% under the current climate and by 9% and 8% respectively in the medium and long term. East orientation results in similar percentage shifts. The total annual energy demand increase is mainly caused by the rise of summer solar gains which leads to higher cooling demand.

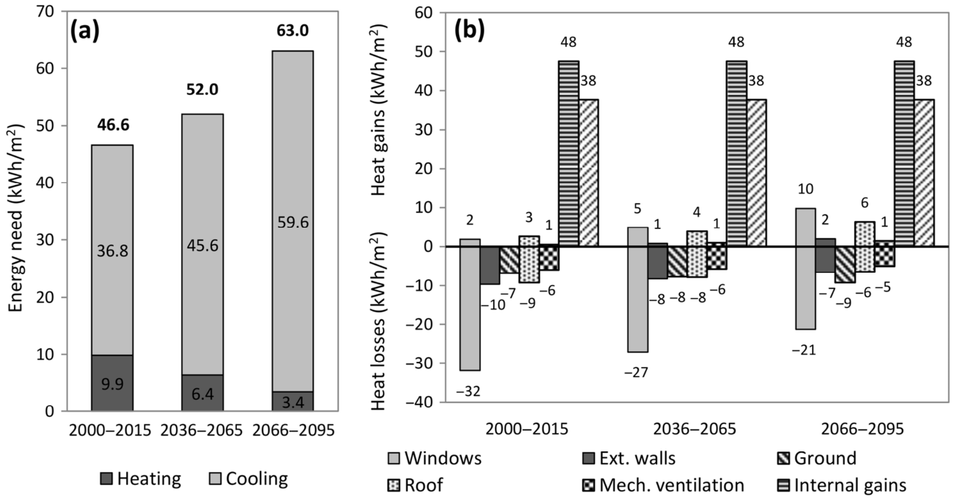

Fig. 7 Office building: (a) annual energy need for space heating and cooling and (b) annual heat gains and losses through building components, in different time periods

3.2 Influence of the thermal insulation representative of the construction from the 1960s

Assuming a constant level of thermal comfort, the energy performance of the three reference buildings has been evaluated considering a construction technology typical of the 1960s, which is characterized by the lack of thermal insulation.

3.2.1 Detached house

As it can be seen in Fig. 8, the simulation results are qualitatively inverted if compared to the 2010 detached house: the energy need for heating (73% of total demand) exceeds that for cooling (27% of the total demand); moreover the total annual energy need tends to decrease in the 2036–2065 period (−2%), while it rises in 2066–2095 (+4%). Obviously total energy need in absolute terms is much higher than that of the 2010 thermally insulated version of the building, but it is significant that, in the absence of measures, energy consumption is reduced in the medium term. Considering the different orientation of the 1960s detached house, simulation results show a marginal rise of total annual energy need (at most 2% for the South East orientation).

In general, it can be observed that, for the detached house, the lack of energy refurbishment measures determines an almost constant trend of annual total energy need through the three periods, balancing heating and cooling demands. It is remarkable that, considering the 2066–2095 scenario, the contribution to the total heat gains of the opaque and transparent components of the envelope, amounts to 60 kWh/m².

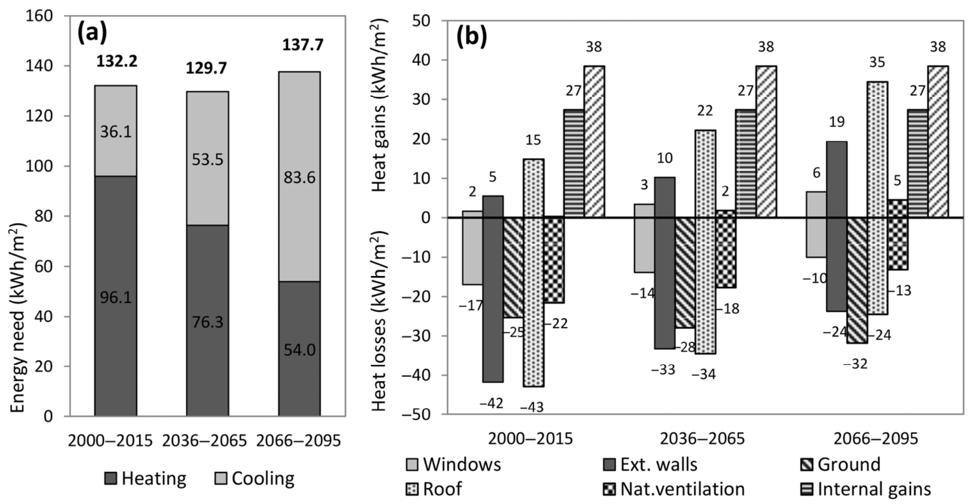

Fig. 8 Detached house built in the 1960s: (a) annual energy need for space heating and cooling and (b) annual heat gains and losses through building components, in different time periods

Considering the annual total energy need, the average difference between an insulated and an uninsulated building is over 100% in the three periods, rising from 55 kWh/m² to 133 kWh/m².

3.2.2 *Flat in apartment building*

As it can be observed from Fig. 9, the total annual energy need of the apartment shows a constant trend until the second period (+1%), because the cooling demand increase is offset by the heating demand reduction; the total annual energy need rises significantly only in the third period (+12%).

In this building the contribution to the total energy need of ventilation is small, while the main share is represented by heat losses/gains from roof, walls and windows. In the three scenarios, the average difference of the total energy need between the insulated and the uninsulated apartments is more than 300% higher, rising from 50 kWh/m² to 181 kWh/m², which is the highest value among the three reference buildings. These results suggest that the apartment located on the top floor of the building is the most sensitive to thermal insulation improvement.

Compared to the 2010 well insulated version, the 1960s poorly insulated apartment in a multi-family house is less sensitive to change of exposure with a total annual energy need rise, on the three periods, ranging from 10% to 8% for west orientation and equal to 6% for east orientation. Thus, the three different orientations do not present relevant differences in the response to future warmer climate.

3.2.3 *Office building*

As can be seen in Fig. 10, ventilation, despite the reduction of efficiency of the heat recovery unit from 80% to 50%, appears to offer a negligible contribution, compared to the other heat gain/losses. The issue of major novelty considering the 2066–2095 period, is that the heat dispersion towards the ground is most relevant (47 kWh/m²), followed by heat dispersion of walls, roof and windows. Even for the office, there is a slight reduction in total annual energy need for

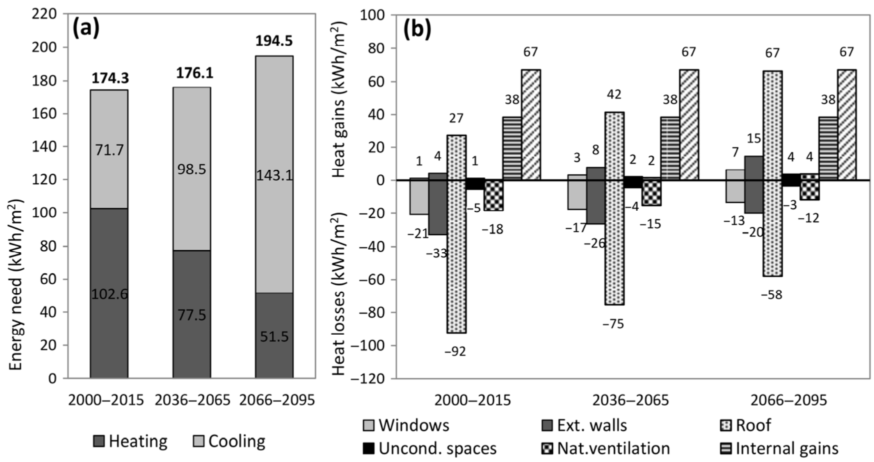

Fig. 9 Flat in apartment building built in the 1960s: (a) annual energy need for space heating and cooling and (b) annual heat gains and losses through building components, in different time periods

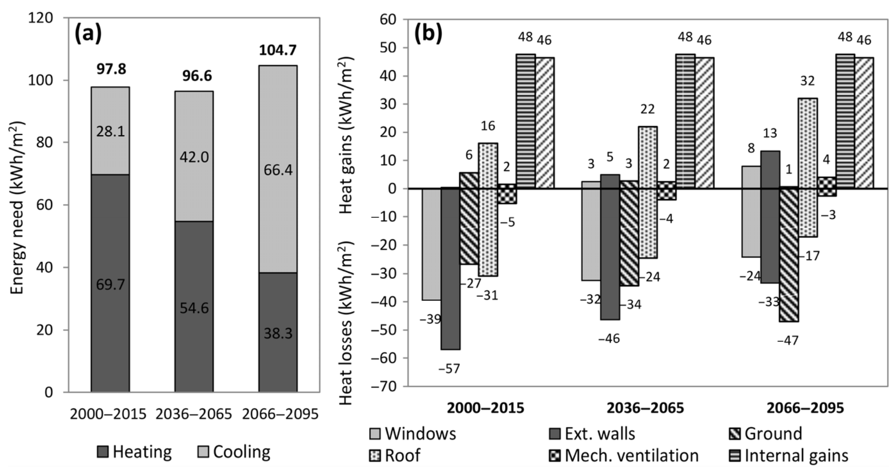

Fig. 10 Office building built in the 1960s: (a) annual energy need for space heating and cooling and (b) annual heat gains and losses through building components, in different time periods

the second period (−1%) and an increase in the third period (+7%). The average difference in total annual energy need between the insulated and the uninsulated offices is more than 45%, rising from 54 kWh/m^2 to 100 kWh/m^2.

Similarly to the other two case studies, when compared to the 2010 version, the 1960s poorly insulated office building is less sensitive to change of exposure: it presents a very low rise (about 3%) in total annual energy need, which is equal both for West and East and keeps constant over the three periods.

3.2.4 Analysis of the results of the 1960s buildings compared to the 2010 buildings

For the examined case studies, it is clear that buildings which lack thermal insulation are able to better address the challenge of climate change. This fact appears to be evident examining Fig. 11, where the change of heating, cooling and total energy need from current climate to the future scenario are reported. It can be seen that for the non-refurbished existing buildings, in the long term, the total annual energy need increases in a range from 4% to 12% and decreases or is unchanged in the medium term; while, for the current well insulated buildings, total energy need increases, in the long term, in a range from 19% to 32%. Obviously, in absolute terms, the average energy need of these buildings is lower by over 60% than that of the uninsulated ones. These results agree with those obtained by the other researchers reported in the Introduction, but they are very significant for their magnitude.

3.3 Passive refurbishment measures for the 1960s buildings

Figures 12, 13 and 14 show the results of the simulations

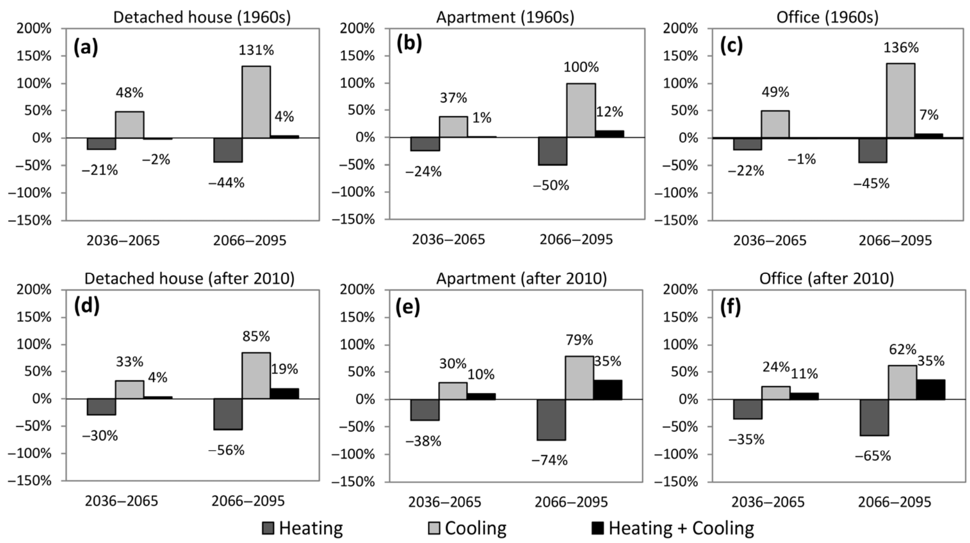

Fig. 11 Percentage change of the net energy need for space heating and cooling of the three reference buildings (1960s and 2010) for medium and long term

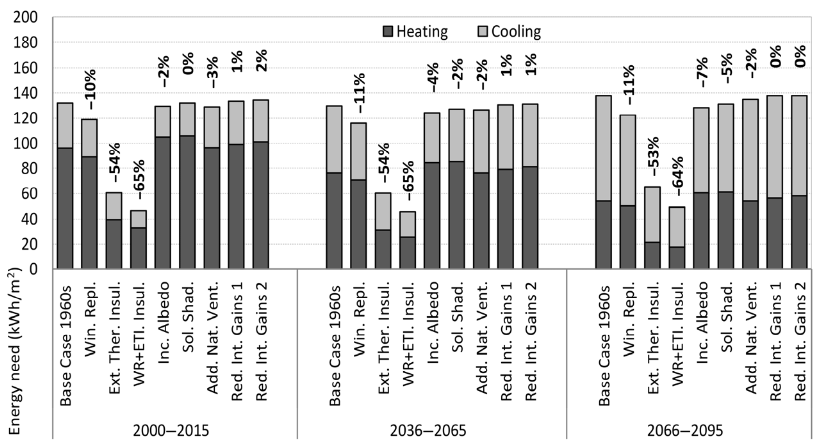

Fig. 12 Detached house (1960s): energy need for space heating and cooling of the base case and the different passive measures in current and in projected future climate

carried out to evaluate effectiveness of passive measures of refurbishment applied to the uninsulated (1960s) version of the three reference buildings.

Considering the 1960s version of the detached house, Fig. 12 shows that the best performances among passive measures is achieved by the insulation of walls and roof, with an additional performance improvement in case of an increase in the thermal resistance of windows and doors. The introduction of solar shading devices and the increase of night ventilation rate are poorly effective measures, even less effective than the reduction in the solar absorption coefficients of the walls and roofs. Attention should be paid to the level of reduction of internal heat gains which results negatively in small total energy need increase in current climate and first future period. In the same figure, for greater clarity, results are also expressed in terms of percentage changes compared to the uninsulated base case from the 1960s. A final remark should be made regarding the thermal resistance increase of windows, the reduction of solar absorption coefficient and the introduction of solar shading devices: these measures are the only ones that show a progressive effectiveness improvement in future periods, while night ventilation, because of external air temperature increase, does not generate particular benefits.

As regards the uninsulated version (1960s) of the flat in the apartment building, Fig. 13 show results that are very similar to those of the detached house, and confirms the effectivity of roof and walls insulation and the increasing performance through future time periods of window replacement and of the reduction of the solar absorption coefficient of external surfaces.

Figure 14 shows the results for the office building, compared to the non-refurbished building (base case from the 1960s). Also for this type of building the opaque envelope

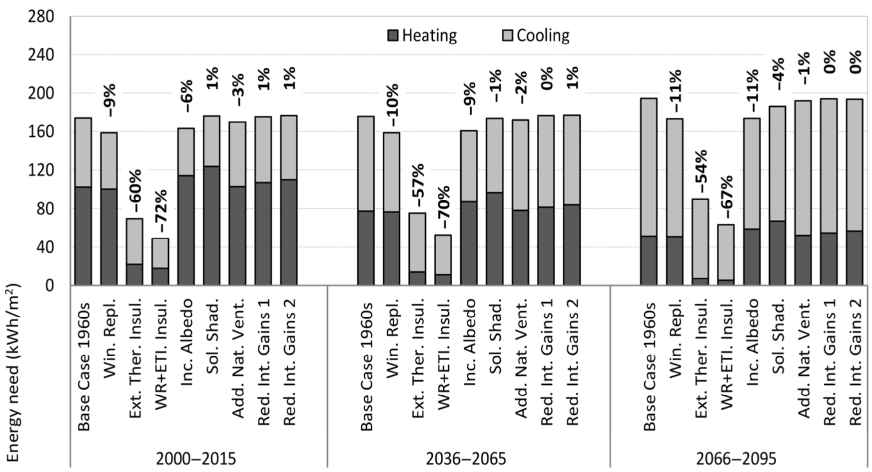

Fig. 13 Flat in apartment building (1960s): energy need for space heating and cooling of the base case and the different passive measures in current and in projected future climate

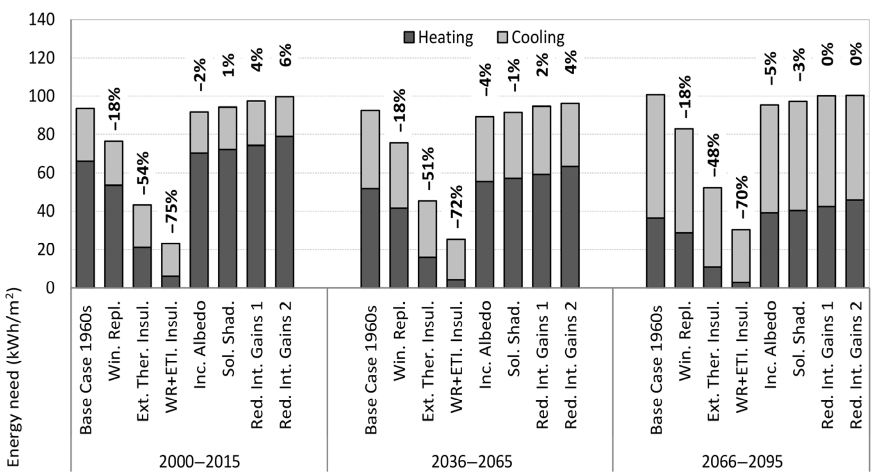

Fig. 14 Office building (1960s): energy need for space heating and cooling of the base case and the different passive measures in current and in projected future climate

insulation is the most effective measure resulting in a total energy need reduction of about 50%, followed by the actions on windows and doors (18% reduction). The introduction of solar shading devices and the reduction of the solar absorption coefficient on the long term generate similar effects with a total energy need reduction, respectively, of 3% and 5%. The reduction of internal gains, conversely, appears to be negative in current climate and to have no effect on the long term. Night ventilation is not applied to the office building.

3.4 Measures to improve current well-insulated buildings

As the last part of the analysis, the hypotheses for improving thermal performance in current buildings has been examined, even if these buildings already have excellent performance due to their high thermal insulation level. The results that concern the detached house are reported in Fig. 15 that show, differently from the uninsulated building (1960s), that the best performance is obtained by substitution of the windows with a reduction of about 20% of total energy need, and by the introduction of solar shading devices which results in an average reduction of 11%. Night ventilation, which is effective considering current climate (−13%), is going to gradually lose its effectiveness in the medium and long term with a reduction of 10% and 7% respectively.

As it can be seen from Fig. 16, for the flat the measures are less effective in all the scenarios with respect to a detached house. The best measure is additional night ventilation, which, however, similarly to the detached house, will reduce its effectiveness as climate change advances. The other measures are relatively less effective, especially those concerning windows thermal insulation and solar shading devices, because current windows already show a high performance, with U_w of about 1.6 W/(m^2·K) and g-value of 0.5.

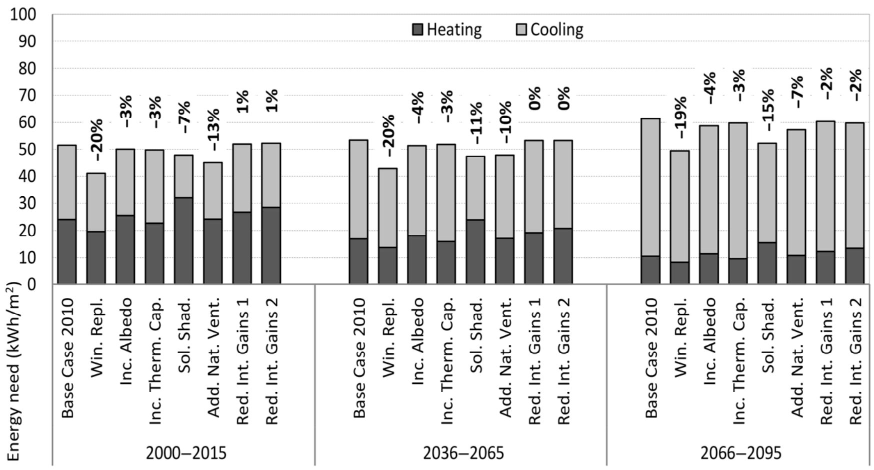

Fig. 15 Detached house (2010): energy need for space heating and cooling of the base case and the different passive measures in current and in projected future climate

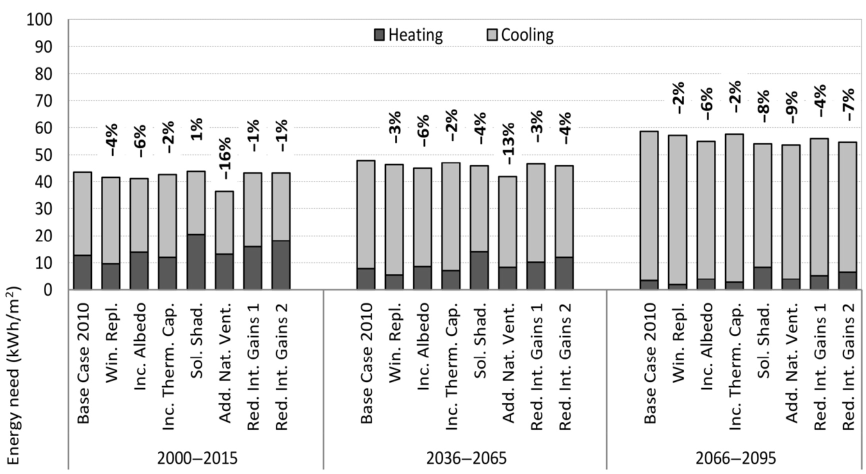

Fig. 16 Flat in apartment building (2010): energy need for space heating and cooling of the base case and the different passive measures in current and in projected future climate

Moreover, since both the detached house and the apartment building are provided with a significant thermal inertia, a further improvement of the same characteristic, obtained by moving the thermal insulation layer on the outer side of the wall, is not appreciable. Finally, the reduction of internal heat gains, considering the scenario 2066–2095, has a little effect on the detached house (−2%) and a more significant effect on the apartment (−7%).

For the office building (Fig. 17), the most efficiency improving measure is the substitution of windows with a total energy need reduction over both medium and long term periods of about 21%, followed by the installation of shading devices, with a reduction of 17%, and the control of internal heat gains which results in a reduction of 9% with the first level and 13% with the second one. Conversely, the increase of thermal inertia appears to be counter-productive as it generates an increase in total energy need of 4% for every period.

4 Conclusions

This study analyses, by means of dynamic simulations, the effects of climate change on heating and cooling net energy demand for three reference buildings (a detached house, a flat in an apartment building and a small office) located in Florence, which are considered sufficiently representative of the Italian building stock. On this basis, the effectiveness of different passive adaptation measures is assessed in the medium (2036–2065) and long term (2066–2095). Figure 18 summarizes the main results of the research, showing the energy performance of the most effective adaptive measures with respect to the base cases, representative of both past (1960s) and current (2010) types of envelope constructions. The results cannot be used to provide general solutions; however, they are useful for highlighting the trend of the effectiveness of passive measures against climate change in central Italy, where Florence, which has an appropriate climate for the purposes of the research, is located.

In summary, considering the assumption made, the results of the research, which are partially unexpected, allow to make the following considerations.

- For the three case studies with poor thermal insulation (1960s envelope construction type), on the medium term the reduction of the energy demand for heating exceeds the increase of energy demand for cooling resulting in a total annual net energy demand decrease, while in the long term the opposite happens; for the three well-insulated buildings (2010 version), the total annual energy demand rises both on the medium and the long term, which is totally attributable to the growth of cooling demand that largely overcomes the reduction of heating demand. These findings are well matched with the conclusion of other studies (Berger et al. 2014; van Hooff et al. 2015, 2016). They show that the effect of climate change on the energy demand of buildings depends on the period of construction and insulation levels: total energy demand of old uninsulated buildings tends to increase less than that of new well-insulated buildings. Moreover our results agree with those researches which considered different climatic areas and found that, in hot climate zones, global warming causes a total energy demand increase, while in colder climates it causes a total energy demand reduction (Kalvelage et al. 2014; Wang and Chen 2014).
- The results of this research, in agreement with similar studies (Robert and Kummert 2012; McLeod et al. 2013), highlight the need to carefully evaluate the passive energy upgrading interventions taking into account the expected effect of global warming on different types of buildings. In warm climates, a special attention should be deserved to building envelope thermal insulation, which can result

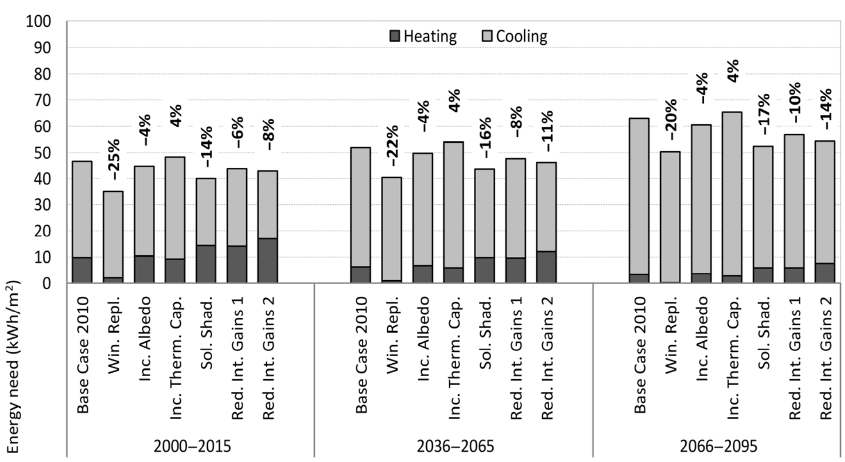

Fig. 17 Office building (2010): energy need for space heating and cooling of the base case and the different passive measures in current and in projected future climate

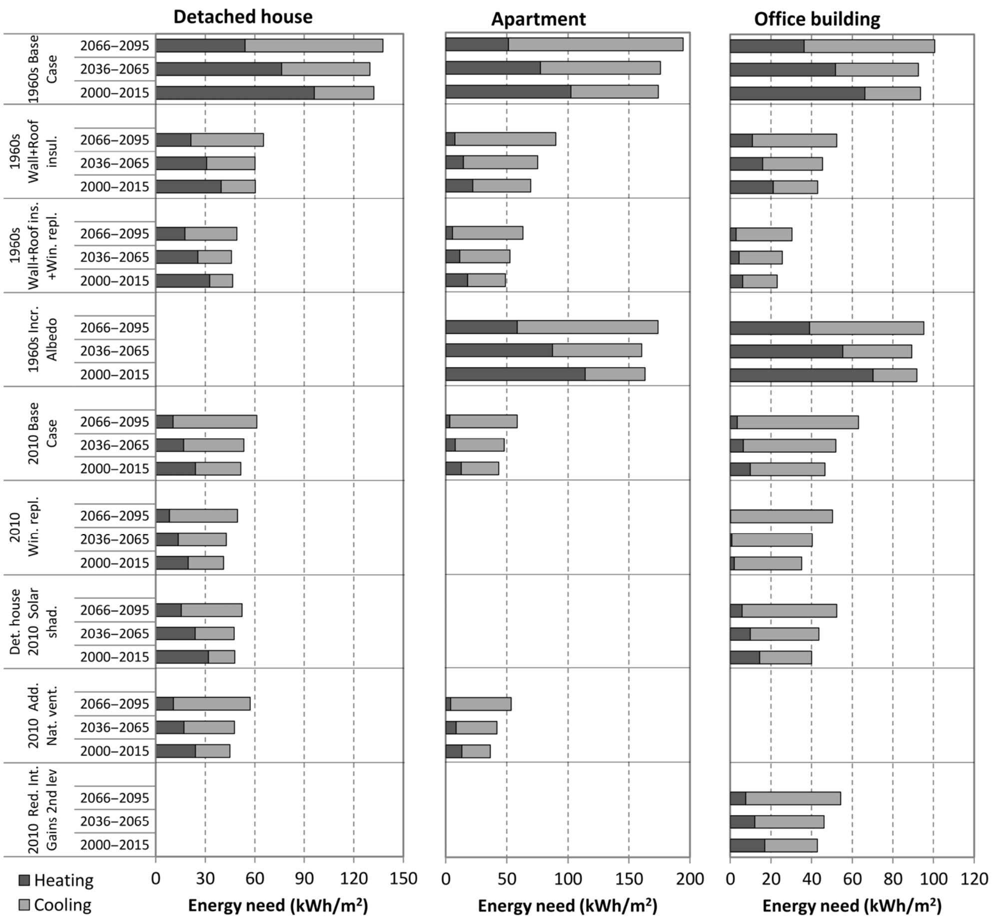

Fig. 18 Energy need for space heating and cooling of the base case and of the most effective climate change adaptation measures for the three case studies

in a total energy demand increase. This necessarily requires a careful energy balance simulation in order to verify that the reduction of energy consumption in winter is not thwarted by the increase of summer energy need for cooling. In particular it can be concluded that the levels of thermal insulation already required by current laws in Italy may represent a limit which it is not convenient to surpass in view of the expected climate change.

– In future periods, considering a worst-case climate scenario, due to the predicted outdoor temperature increase, the net energy demand of well-insulated buildings will be mainly, or sometimes exclusively, attributable to space cooling, and this, in turn, pushes to adopt adequate HVAC systems, such as reversible heat pumps. These results, which substantially agree with the major findings of researches similarly focused on Mediterranean climate (Asimakopoulos et al. 2012) are, however, unexpected with respect to the magnitude of the variations in the energy needs values for cooling and heating, with the latter in some cases dropping near to zero on the long term.
– In well insulated buildings facing climate change, internal gains and solar gains will have the major share among the envelope energy balance contributors. In particular, attention should be paid to internal loads that in some circumstances can be very significant and sometimes similar in magnitude to the contribution of solar radiation.
– With regard to passive adaptation measures, for totally uninsulated buildings (1960s version), despite the climate change, the best performances are achieved by walls and roof insulation, with an additional performance improvement in case of window replacement; while solar shading devices and night ventilation are barely effective, even less so than the reduction of the envelope solar absorption. Considering current well-insulated buildings, the best performances are obtained by means of window replacement and the introduction of solar shading devices, as well as of night ventilation. Reduction of internal gains appears to be an effective measure just for the office building. Similar researches (Berger et al. 2014; van Hooff et al. 2015, 2016) on the effectiveness of passive measures against climate change confirm these results showing that, despite climate change, in old uninsulated buildings the priority action is the winter thermal loss reduction, while new well insulated buildings primarily require solar gains control

(Gupta and Gregg 2012) and heat removal by ventilation. Unlike the mentioned works, which deal with colder climates, our results show that, in the warm Mediterranean climate, natural ventilation will gradually lose its effectiveness in the medium and long term due to air temperature increase.

– Considering the specific layout of the three analysed buildings, the effect of different orientations on the total energy demand is much more evident considering the well-insulated version and strongly differs from one building to the other: while it is negligible for the detached house, it is significant (from 20% to 32%) for the flat in the apartment building and it is of intermediate importance for the office building.
– Since this study shows that the size of energy need increase for cooling and decrease for heating in the long term, in function of the type of passive measure adopted and the different level of thermal insulation, is very significant, it should be highlighted that sustainable design, in order to meet low energy consumption and high thermal comfort requirements, should carefully consider multiple aspects depending on different climatic conditions and different type of buildings.

Finally the main novelty of this study can be summarized in the following points:

– No other recent study, that we are aware of, addresses this issue taking into account the specific climate context of central Italy and considering three case studies that are widely representative of the Italian building stock.
– New future climate file processing for the Florence area, based on updated and high resolution climate model specifically developed for Italy within IPCC AR5 research programs.
– The impact of climate change is studied considering its effect on the heat balance of the components of the building envelope and its effect on the net energy performance of the whole building as a function of the building typology and orientation, as well as the refurbishment level.

References

Agrometeorological Service Tuscany Region (2015). Historical archives consultation (1990–2010). Available at http://agrometeo.arsia.toscana.it. Accessed 30 Oct 2015. (in Italian)

Asimakopoulos DA, Santamouris M, Farrou I, Laskari M, Saliari M, Zanis G, Giannakidis G, Tigas K, Kapsomenakis J, Douvis C, Zerefos SC, Antonakaki T, Giannakopoulos C (2012). Modelling the energy demand projection of the building sector in Greece in the 21st century. *Energy and Buildings*, 49: 488–498.

Belcher SE, Hacker JN, Powell DS (2005). Constructing design weather data for future climates. *Building Services Engineering Research and Technology*, 26: 49–61.

Berger T, Amann C, Formayer H, Korjenic A, Pospichal B, Neururer C, Smutny R (2014). Impacts of urban location and climate change upon energy demand of office buildings in Vienna, Austria. *Building and Environment*, 81: 258–269.

Bucchignani E, Montesarchio M, Zollo AL, Mercogliano P (2016). High-resolution climate simulations with COSMO-CLM over Italy: Performance evaluation and climate projections for the 21st century. *International Journal of Climatology*, 36: 735–756.

Christensen JH, Hewitson B, Busuioc A, Gao X, Held I, Jones R, Kolli RK, Kwon W-T, Laprise R, Magaña Rueda V, Mearns L, Menéndez GC, Räisänen J, Rinke A, Sarr A, Whetton P (2007). Regional climate projections. In: Solomon S, Qin D, Manning M, Chen Z, Marquis M, Averyt KB, Tignor M, Miller HL (eds), Climate Change 2007: The Physical Science Basis: Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge, UK: Cambridge University Press.

Coley D, Kershaw T, Eames M (2012). A comparison of structural and behavioural adaptations to future proofing buildings against higher temperatures. *Building and Environment*, 55: 159–166.

CTI (2009). Methodology for Climate Data Processing to Prepare "Test Reference Years". Milan, Italy: Italian Thermotechnic Committee. (in Italian)

CTI (2010a). Calculation of Energy Performance of Buildings According to Technical Standards UNI TS 11300:2008 Part 1 and Part 2—Case study—Building 4A—Input Data and Calculation Results—Version: January 2010-2. Milan, Italy: Italian Thermotechnic Committee. (in Italian)

CTI (2010b). Calculation of Energy Performance of Buildings According to Technical Standards UNI TS 11300:2008 Part 1 and Part 2—Case study—Building 5A—Input Data and Calculation Results—Version: January 2010-1. Milan, Italy: Italian Thermotechnic Committee. (in Italian)

CTI (2012c). Calculation of Energy Performance of Buildings According to Technical Standards UNI TS 11300:2008 Part 1 and Part 2—Case study—Building 1D—Input Data and Calculation Results—Version 04 of the 10th of May 2012. Milan, Italy: Italian Thermotechnic Committee. (in Italian)

Cubasch U, Wuebbles D, Chen D, Facchini MC, Frame D, Mahowald N, Winther J-G (2013). Introduction. In: Stocker TF, Qin D, Plattner GK, Tignor M, Allen SK, Boschung J, Nauels A, Xia Y, Bex V, Midgley PM (eds), Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge, UK: Cambridge University Press.

de Wilde P, Tian W (2010). Predicting the performance of an office under climate change: A study of metrics, sensitivity and zonal resolution. *Energy and Buildings*, 42:1674–1684.

de Wilde P, Tian W (2012). Management of thermal performance risks in buildings subject to climate change. *Building and Environment*, 55: 167–177.

Design Builder Software (2014). ANSI/ASHRAE Standard 140-2011—Building Thermal Envelope and Fabric Load Tests—DesignBuilder Version 3.4 (incorporating EnergyPlus version 8.1.0). Clarendon Court, UK: Design Builder Software Ltd.

Design Builder Software (2015a). EN 15265/ISO 13790 Standard (2008)—Tests for the Calculation of Energy Use for Space Heating and Cooling. Clarendon Court, UK: Design Builder Software Ltd.

Design Builder Software (2015b). Design Builder Website. Available at http://www.designbuilder.co.uk. Accessed 30 Oct 2015.

Diffenbaugh NS, Pal JS, Giorgi F, Gao X (2007). Heat stress intensification in the Mediterranean climate change hotspot. *Geophysical Research Letters*, 34(11): L11706.

Douglas (1992). The case for urban ecology. *Urban Nature Magazine*, 1: 15–17.

ENEA (2013). Energy and Sustainable Economic Development (2013). Environment and Energy Report. Scenarios and Strategies 2013. Rome: Italian National Agency for New Technologies. (in Italian)

EnergyPlus (2015). EnergyPlus simulation software website. Available at http://apps1.eere.energy.gov/buildings/energyplus. Accessed 30 Oct 2015.

European Climate Adaptation Platform (2015). Thermal comfort. In: Urban Vulnerability Map book—Climatic Threats—Heat Waves—Exposure—Thermal Comfort. Available at http://climate-adapt.eea.europa.eu/tools/urban-adaptation/climatic-threats/heat-waves/exposure. Accessed 30 Oct 2015.

European Parliament (2010). Directive 2010/31/EU of the European Parliament and of the Council of 19 May 2010 on the Energy Performance of Buildings (recast).

Giorgi F (2006). Climate change hot-spots. *Geophysical Research Letters*, 33(8): L08707.

Giorgi F, Lionello P (2008). Climate change projections for the Mediterranean region. *Global and Planetary Change*, 63: 90–104.

Governament of Italy (2015). Ministerial Decree 26/06/2015. Application of methodologies for calculating the energy performance and defining minimum requirements of the buildings. (in Italian)

Guan L (2009). Preparation of future weather data to study the impact of climate change on buildings. *Building and Environment*, 44: 793–800.

Gupta R, Gregg M (2012). Using UK climate change projections to adapt existing English homes for a warming climate. *Building and Environment*, 55: 20–42.

Henninger RH, Witte MJ (2010). EnergyPlus testing with building thermal envelope and fabric load tests from ANSI/ASHRAE Standard 140-2011. Arlington Heights, IL, USA: Gard Analytics.

IPCC (2014). Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Geneva, Switzerland: Intergovernmental Panel on Climate Change.

ISPRA (2015). SCIA—National system for the collection, processing and distribution of climatic data of environmental relevance. Italian National Institute for Environmental Protection and Research. Available at http://www.scia.isprambiente.it/home_new.asp. Accessed 30 Oct 2015. (in Italian)

ISTAT (2012). Energy Balance—Final uses. Italian National Institute of Statistics Available at http://dati.istat.it/Index.aspx?DataSetCode=DCCV_BILENERG. Accessed 28 Oct 2015. (in Italian)

ISTAT (2016). Population and housing census 2011. Italian National Institute of Statistics. Available at http://dati-censimentopopolazione.istat.it/Index.aspx. Accessed 24 Mar 2016. (in Italian)

Kalvelage K, Passe U, Rabideau S, Takle ES (2014). Changing climate: The effects on energy demand and human comfort. *Energy and Buildings*, 76: 373–380.

Kovats RS, Valentini R, Bouwer LM, Georgopoulou E, Jacob D, Martin E, Rounsevell M, Soussana J-F (2014). Europe. In: Barros VR, Field CB, Dokken DJ, Mastrandrea MD, Mach KJ, Bilir TE, Chatterjee M, Ebi KL, Estrada YO, Genova RC, Girma B, Kissel ES, Levy AN, MacCracken S, Mastrandrea PR, White LL (eds), Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part B: Regional Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel of Climate Change. Cambridge, UK: Cambridge University Press. pp. 1267–1326.

Kuglitsch FG, Toreti A, Xoplaki E, Della-Marta PM, Zerefos CS, Trke M, Luterbacher J (2010). Heat wave changes in the eastern Mediterranean since 1960. *Geophysical Research Letters*, 37(4): L04802.

LBNL (2013). EnergyPlus Documentation—Auxiliary EnergyPlus Programs. Berkeley, CA, USA: Lawrence Berkeley National Laboratory.

Li DHW, Yang L, Lam JC (2012). Impact of climate change on energy use in the built environment in different climate zones—A review. *Energy*, 42: 103–112.

Lionello P, Abrantes F, Congedi L, Dulac F, Gacic M, Gomis D, Goodess C, Hoff H, Kutiel H, Luterbacher J, Planton S, Reale M, Schröder K, Vittoria Struglia M, Toreti A, Tsimplis M, Ulbrich U, Xoplaki E (2012). Introduction: Mediterranean Climate—Background Information. In: The Climate of the Mediterranean Region. Oxford, UK: Elsevier. pp. xxxv–xc.

Matthies F, Bickler G, Marin NC, Hales S (2008). Heat-Health Action Plans: Guidance. Copenhagen, Denmark: World Health Organisation (WHO) Regional Office for Europe.

McLeod RS, Hopfe CJ, Kwan A (2013). An investigation into future performance and overheating risks in Passivhaus dwellings. *Building and Environment*, 70: 189–209.

Nik VM, Sasic Kalagasidis A (2013). Impact study of the climate change on the energy performance of the building stock in Stockholm considering four climate uncertainties. *Building and Environment*, 60: 291–304.

Nocera M (2015). 55%–65% Tax Benefits for Energy Renovation of Existing Building Stock in 2013. Rome: Italian National Agency for New Technologies. (in Italian)

Porritt SM, Cropper PC, Shao L, Goodier CI (2012). Ranking of interventions to reduce dwelling overheating during heat waves. *Energy and Buildings*, 55: 16–27.

Riva G, Murano G, Corrado V, Baggio P, Antonacci G (2012). Climatic national parameters update and national climate zoning for cooling energy certification—Report RdS/2012/106. Rome: Italian National Agency for New Technologies. (in Italian)

Robert A, Kummert M (2012). Designing net-zero energy buildings for the future climate, not for the past. *Building and Environment*, 55: 150–158.

Timmerman J (2015). Map book urban vulnerability to climate change—Factsheets. Copenhagen, Denmark: European Environment Agency.

UNFPA (1999). The State of World Population. New York: United Nations Population Fund.

UNI (1994). UNI 10349. Heating and Cooling of Buildings—Climate Data. Milan, Italy: Italian National Association for Standardization. (in Italian)

UNI (1995). UNI 10339. Comfort Ventilation Systems. Milan, Italy: Italian National Association for Standardization. (in Italian)

UNI (2007). UNI EN ISO 10077-1. Thermal Performance of Windows, Doors and Shutters—Calculation of Thermal Transmittance—Part 1: General. Milan, Italy: Italian National Association for Standardization. (in Italian)

UNI (2008a). UNI EN ISO 15927. Hygrothermal Performance of Buildings—Calculation and Presentation of Climatic Data—Part 6: Accumulated Temperature Differences (degree-days). Milan, Italy: Italian National Association for Standardization. (in Italian)

UNI (2008b). UNI EN 15265. Thermal Performance of Buildings—Calculation of Energy Use for Space Heating and Cooling Using Dynamic Methods—General Criteria and Validation Procedures. Milan, Italy: Italian National Association for Standardization. (in Italian)

UNI (2008c). UNI EN ISO 13790. Energy Performance of Buildings—Calculation of Energy Use for Space Heating and Cooling. Milan, Italy: Italian national Association for Standardization. (in Italian)

UNI (2014). UNI/TS 11300. Energy Performance of Buildings—Part 1: Evaluation of Energy Need for Space Heating and Cooling. Milan, Italy: Italian national Association for Standardization. (in Italian)

van Hooff T, Blocken B, Hensen JLM, Timmermans HJP (2015). On the predicted effectiveness of climate adaptation measures for residential buildings. *Building and Environment*, 83: 142–158.

van Hooff T, Blocken B, Timmermans HJP, Hensen JLM (2016). Analysis of the predicted effect of passive climate adaptation measures on energy demand for cooling and heating in a residential building. *Energy*, 94: 811–820.

Waddicor DA, Fuentes E, Sisó L, Salom J, Favre B, Jiménez C, Azar M (2016). Climate change and building ageing impact on building energy performance and mitigation measures application: A case study in Turin, northern Italy. *Building and Environment*, 102: 13–25.

Wang H, Chen Q (2014). Impact of climate change heating and cooling energy use in buildings in the United States. *Energy and Buildings*, 82: 428–436.

WHO (2003). The health impacts of 2003 summer heat-waves. Briefing note for the delegations of the fifty-third session of the WHO Regional Committee for Europe. Paper presented at the 53th session of the WHO Regional Committee for Europe.

Zhai Z, Johnson M-H, Krarti M (2011). Assessment of natural and hybrid ventilation models in whole-building energy simulations. *Energy and Buildings*, 43: 2251–2261.

Zhu D, Hong T, Yan D, Wang C (2013). A detailed loads comparison of three building energy modeling programs: EnergyPlus, DeST and DOE-2.1E. *Building Simulation*, 6: 323–335.