Available online at www.sciencedirect.com

ScienceDirect

Energy Procedia 133 (2017) 243–256

Energy Procedia

www.elsevier.com/locate/procedia

Climamed 2017 – Mediterranean Conference of HVAC; Historical buildings retrofit in the Mediterranean area, 12-13 May 2017, Matera, Italy

Keeping it modern, making it sustainable. Monitoring and energy retrofitting the Urbino University Colleges

Cesare M. Joppolo[a], Davide Del Curto[a]*, Andrea Luciani[a], Luca P. Valisi[a], Mara Bellebono[a]

[a]CLIMATE AND ENERGY FOR CULTURAL HERITAGE (C.E.C.H.) LABORATORY, POLITECNICO DI MILANO, PIAZZA L. DA VINCI, 26, 20133, MILANO

Abstract

This paper presents a research to balance building conservation, users' comfort and energy efficiency of a masterpiece of XX century architecture. The Urbino University Colleges were designed by architect Giancarlo de Carlo and built since 1962 to 1983 beside the Renaissance city. They host more than 1,000 students within 5 dormitories and 62,000 m^2 surface. Authors discuss some outcomes from the "Keeping it modern" research program financed by the Getty Foundation in 2016, which aims at providing the Colleges with a sustainable conservation plan. The goal is to lower heating and operational costs to allow funds in conservation activities. Specific issues regard: the striking dimensions of the complex, the constructive features (brickwork walls, exposed concrete structures, single-glazed windows) and the lack of data about the hygrothermal performances.

The research thus includes a hygrothermal analysis, a proposal for the energy retrofitting, a building-HVAC model, a test on a pilot site. Authors have monitored surface temperatures, indoor air temperature and humidity for one year, even mapping their distribution through a digital psychrometer. Thermal imaging has been used to detect heat losses, thermal bridges and heat gains due to the solar radiation. Data have fed a building-HVAC model, which was a reference to design an appropriate strategy for retrofitting and improving the energy efficiency of the complex. Some solutions are being implemented on a pilot site. The building performances before and after retrofitting are compared.

Results provide indications to merge conservation and sustainability of a XX century heritage building.

In conclusion, the solid knowledge of each case confirms being required to support a retrofit proposal of a heritage building, moreover in case of a XX century building, as the cultural value of such a huge heritage is often disregarded to improve its energy performance.

Peer-review under responsibility of the scientific committee of the Climamed 2017 – Mediterranean Conference of HVAC; Historical buildings retrofit in the Mediterranean area

---

* Corresponding author. Tel.: +39-0223999447; fax: +39-0223995454.
E-mail address: davide.delcurto@polimi.it

1876-6102 © 2017 The Authors. Published by Elsevier Ltd.
Peer-review under responsibility of the scientific committee of the Climamed 2017 – Mediterranean Conference of HVAC; Historical buildings retrofit in the Mediterranean area
10.1016/j.egypro.2017.09.363

Keywords: monitoring, energy retrofitting, building-plant design, XX century architecture.

1. Introduction

The authors present the energy retrofit of the Urbino University Colleges, designed by architect Giancarlo De Carlo, which is part of the project "Conserving Modern Heritage, Urbino's University Colleges". The project was selected and financed by the Getty Foundation in Los Angeles within the international program "Keeping it modern" supporting the preservation of XX century buildings of great architectural interest.

The present research aims to be representative for most of the XX century architecture, which is an increasing relevant part of built heritage, considering the new regulations on energy saving. In fact, the constructive features and facilities of post-war buildings often result in high consumptions and very poor performances, even when compared to pre-industrial buildings. Authors deal with the challenge of balancing conservation issues, users' comfort and energy efficiency in a sustainable conservation plan. Lowering heating and operating cost would allow to save funds for the conservation and maintenance of such a wide complex.

2. The Urbino University Colleges

The Urbino University Colleges is one of the most famous and significant works by architect Giancarlo De Carlo (1919-2005). They are part of an overall strategy of urban development, supported by Carlo Bo, at that time Rector of the University, who aimed at transforming Urbino in a "cultural capital" [1]. The Colleges were built between 1962 and 1983 on Capuccini Hill, 1.5 km from the Renaissance city centre.

In chronological order of construction, the 5 buildings are: "Colle", "Tridente", “Serpentine", “Aquilone" and "Vela". They can accommodate 1,136 people in 975 rooms, for a net usable area of 32,396 m^2 and a gross heated volume of 127,059 m^3. The residential units consist in different types: single or double rooms, with personal or shared toilets and kitchens. Public spaces concentrate in the central body of each college: reception, canteens, dining rooms, conference and meeting rooms, classrooms, offices, technical rooms and a theatre [2]. The general layout of the complex follows land contours, branching and distributing the buildings from the Capuccini Hill to the valley and creating a series of staggered spaces and forms at different levels.

The load bearing facing brickwalls and the exposed concrete beams and slabs are almost completely not insulated, such as many other buildings of that period inspired by the ideas of the Team X [3] or the “New Brutalism” [4]. The original transparent building envelope consists mainly of single-glazed windows with timber frames or iron-framed skylights with a simple glazed panel. As time went by, many original windows have been replaced with several different types of new windows. Many issues affect the state of conservation of these buildings: decay of the reinforced concrete, poor waterproofing and water leakage through the roofs, decay and fails in air and water tightness of windows and doors, compliance with laws and regulations for safety and fire prevention, limited and unplanned maintenance, lack of a conservation plan.

As regards the HVAC systems, before 2012 the power station was constituted by 2 steam generators and 3 hot water generators, for a total capacity of about 7 MW. The kettles with steam heat exchangers for domestic hot water, the autoclaves for the production of DHW and cold, the shell and tube heat exchangers water/water and the condensate steam tanks were located in individual colleges' substations. In 2012 ERSU (Regional agency for the study entitlement University of Urbino) and the Urbino University joined the agreement Consip SIE 2 (Service Integrated Energy 2) promoted by CPL CONCORDIA, which took charge of the energy upgrading works and the regulatory upgrade of the power station. For this reason, 3 pressurized boilers with a rated output of 1,650 kW each, reverse flame, 3 burners with 2 stage progressive/modulating, a CHP (electrical power 637 kWel, thermal power 770 kW, thermal power introduced in 1620 kWth), different systems of storage of technical water, rapid heat exchangers of modules for the production of sanitary hot water, solenoid valves, plate-fin heat exchangers. The district heating circuit consists of a basement distribution ring connected via substations to each colleges. The heat emitting subsystem consists in cast iron radiators at high temperature for all zones, except for the conference room of the main building of the "Colle" building where radiant floor dated back to 1965. A grid connected photovoltaic system (270 panels, 81 kW peak power) was then installed on the roof of "Tridente" building.

3. Methodology

The research includes an in-depth hygrothermal analysis of a representative selection of rooms, an assessment of the energy retrofit proposals through a building-HVAC model, a test on a pilot site. Considering the architectural relevance of the buildings, procedures developed for the analysis and preventive conservations of cultural heritage buildings and objects have been used.

Authors monitored surface temperatures, indoor and outdoor air temperature and humidity for one year (12/2015-12/2016). Local data-loggers and seasonal thermographic and psychrometric mapping were used together in order to assess the current conditions of hygrothermal comfort and the performances of the building envelope. Continuous monitoring was carried out in four bedrooms and in one common area of the “Aquilone” building (blue color in Fig. 1). This building was selected as the most representative among the five colleges. The surveys were seasonally repeated within all the other four colleges also (red color in Fig. 1).

Ten sensors [5] for monitoring temperature (T [°C], accuracy: ±0,1°C at -25°C/+80°C) and relative humidity (RH [%], ±2% at 0%/100%) were installed, four of which also measure the surface temperature (Tsup [°C]). A total of twenty-two measuring points are thus radio-connected by wireless transmitters. Sensors specifications follow the UNI EN 15758:2010 [6] and UNI EN 16242:2012 [7] standards. Their number, position and specific characteristics were determined via a preliminary analysis on-site.

Sensors were installed in a couple of overlapping rooms on different floors (Room B6B and B6D) with original windows. This is the most typical room disposition within the colleges. Sensors were also installed in other parts of the complex, with a different room configuration. Room B8B is similar in position while the original window was already substituted by a new one with aluminum frame without thermal break. Room B6A represents the case of a room not in touch with an external brickwall.

Thermal imaging has been used to detect heat losses, thermal bridges and heat gains due to the solar radiation. A FLIR P620 infrared camera (accuracy: ±2°C at -40°C/+500°C, resolution 640x480 pixels, thermal sensibility 40mK at 30°C) was coupled with an EXTECH MO297 (accuracy: ±0,1°C at -29°C/+77°C for air temperature, ±1% at 0%/100% for humidity) for a real-time correlation via Bluetooth between thermal image and air T and RH.

A digital psychrometer (accuracy 0.1 °C, resolution 0,01°C) patented by Politecnico di Milano [8,9] was used to map temperature and relative humidity on field, along a virtual grid of approx. 1.5m. The results were then interpolated to assess the gradients and spatial distribution (in plan and/or section) of air temperature and humidity [10,5].

Data fed a building-HVAC model, which was used to design some solutions for retrofitting and improving the energy efficiency of the complex. One of them was chosen and it is currently being implemented on a pilot site. The building performances before and after will be compared.

4. Indoor climate monitoring

The indoor climate analyses aims to assess the hygrothermal conditions and if the heating system complies with its set-points or not. This analysis also helps in detecting where the comfort conditions are affected by specific problems or local imbalances. Furthermore, it helps to understand if these imbalances are due to the type of heating system, to a faulty installation or to the control system.

4.1. Hygrothermal analysis

Data have been processed and results presented according to UNI 10829:1999 "Assets of historical and artistic interest - Environmental Storage - Measurement and analysis", in particular Appendix D "Modalities for the calculation of the environmental parameters” [10]. For each measured parameter we determined: maximum, minimum, average, and standard deviation, daily and annual temperature range, time profiles, frequency distribution and cumulative frequency.

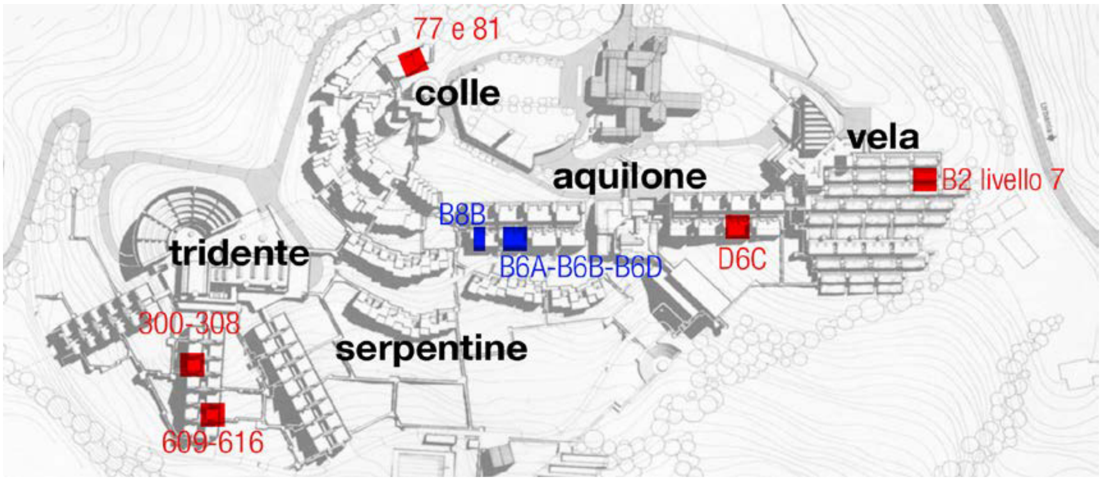


Fig. 1. General plan of the Collegi with the position of the rooms continuously (blue) and seasonally (red) analysed

Fig. 2. Position of the monitored rooms on the South-West façade of the "Aquilone" building

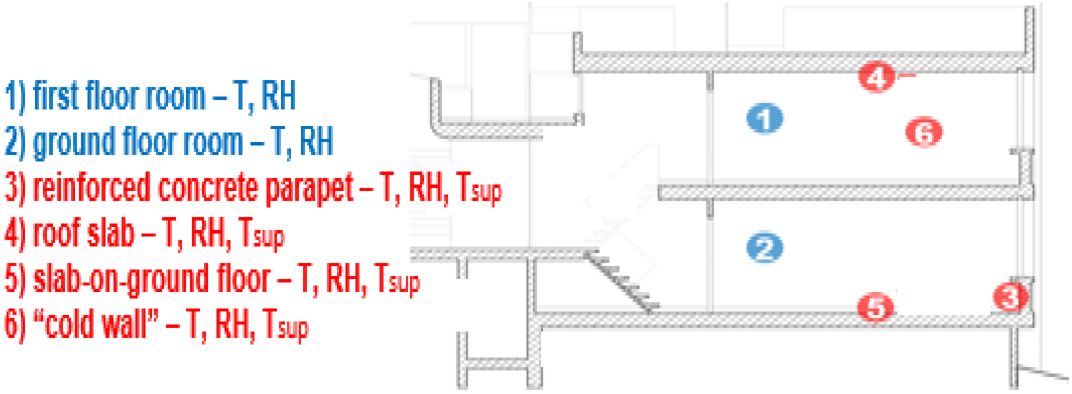


Fig. 3. Position of the sensors along the cross-section of the "Aquilone" building

The results obtained by monitoring few rooms needed to be extended to the whole complex. Is thus requires to move from a detailed to a more synthetic observation, related to the frequency of acceptable ranges. A *Performance Index* was then calculated, i.e. the percentage of time the microclimatic parameters fall within an acceptable range during the winter period (01/12/2015 – 07/05/2016). Two *Failure Indexes*, were also calculated to analyse the causes of the data deviations:

- *Cool Failure Index*: % of time in which the indoor temperature falls below the lower limit of acceptability;
- *Warm Failure Index*: % of time in which the indoor temperature falls above the upper limit of acceptability.

Temperature ranges were defined following the set-points of the heating system. Relative humidity ranges were defined following the standards UNI EN ISO 7730:2006 and ASHARAE 55:

- for average daily temperature: $19°C \leq T_{average,day} \leq 21°C$ $18°C \leq T_{average,day} \leq 22°C$
- for average daily relative humidity: $40\% \leq RH_{average,day} \leq 60\%$ $30\% \leq RH_{average,day} \leq 70\%$

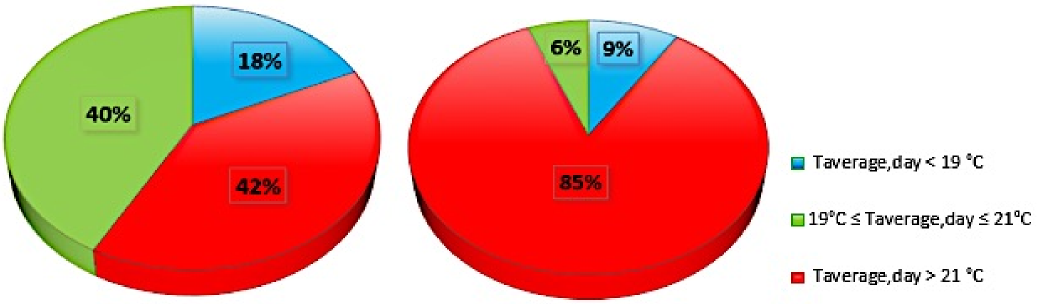


Fig. 4. Average daily temperature - Verification of thermal comfort range for all the selected rooms (left) and for room B6a (right)

A high percentage of Warm Failure Index can be seen in Fig. 4. Room B6a has not external and dispersing walls (right-side graph). High values in temperature are both to the possible over-heating both to the solar gains. The acceptability thresholds defined in the regulations are given by the need to protect the health of the occupants, considering their physiological reactions, such as dry skin, irritation of the eyes and upper respiratory tract, and the need to prevent the proliferation of biological contaminants [11]. In this case, all the sensors respected the relative humidity acceptability intervals for the:

72% of the days, considering a 40% - 60% range
96% of the days, considering a 30% - 70% range

The analysis of the average daily temperature has been compared also to the average temperature calculated during the heating hours. This is to verify if they comply with the temperature set-point or not. An average of 20 °C in all the rooms can be observed in Fig. 5. Different values have been measured by the sensors placed into the block of the common spaces and by the sensor placed close to the external wall. The temperature remains below 20° C in 50% of the common areas. Common areas are large spaces separating the rooms from the outdoor environment. They are equipped with some radiators placed around their perimeter. Considering the huge volume to be heated, the lack of insulation and of a temperature control, these radiators are not enough. Moreover, common areas do not benefit nor from free solar gains as the rooms, since they have not any large window facing South-West, nor from thermal gains due to the presence of people, as they are underused.

Near the dispersant wall in room B6B, air temperature was < 20° C for the 54% of the days monitored. It highlights a possible local discomfort. The air operating temperature was thus considered beside the ambient air. Data show how the indoor climate and the internal comfort is influenced both by the low thermal inertia of the not-insulated building, both by the high thermal transmittance of the windows (see par. 4.2).

The analysis then focused on comparing data from two weeks with the heating system respectively switched on or off. Two weeks characterized by bad weather days (due to rain, snow and/or fog) or clear sky were chosen. This was to detect how the solar gains contribute to the general warming, in particular when the heating system is off.

Since the building has no cooling system, the analysis of the summer monitoring period (08/05/2016 – 15/10/2016) requires, in accordance with the UNI EN 15251:2008, a "thermal adaptive comfort model", which incorporates the definition of psychological well-being and considers the users' perception of the environment. The adaptive model consists in identifying a correlation between the thermal sensation and the main climatic variables. The acceptability interval Class II represents a normal level of expectation and should be used for new buildings and renovations. The acceptability interval Class III represents an acceptable, moderate level of expectation and may be used for existing buildings. They both have been verified. Fig. 6 shows the trends of daily average temperatures for all the sensors and the acceptance bands calculated according to the adaptive method. The thick black line represents the comfort temperature under varying external conditions, calculated according to the adaptive method [12]. The dashed black lines represent the Class II comfort range. The black dotted lines represent the Class III comfort range. Fig. 6 thus shows as rooms are all over heated, especially room B6a (in magenta).

The summer period was analysed also by assessing the thermal excursions and the influence of solar radiation. Solar radiation increases the temperatures in the rooms in contact with the roof (12/07/2016). These rooms disperse heat only towards neighbouring rooms and towards the roof slab. During summer the roof reaches the highest temperatures. The indoor air temperatures are consequently very high, with a maximum of 41.3° C in B8b room (in blue), 39.6° C in B6a (in magenta) and 39.0° C in B6b (in red). These high temperatures are also due to the incoming solar gains through the windows, since they lack any external screen and indoor curtains made of cotton are the only protection. These rooms are thus warm and dry negatively affecting the thermal comfort. For example, relative humidity is < 30% for the 66% of the days in room B6a.

The hygrothermal comfort was then analysed through the air operating temperature, which includes the linear average radiation temperature. In fact, a complete analysis should not consider only the air temperature, but the local thermal discomfort also. The mean radiant temperature is obtained by five different points in four rooms, through the calculation of the view factors [13]. We analysed the most critical situation in winter conditions. We considered the air temperatures registered by all the sensors during the coldest weeks (01/12/2015 - 24/01/2016). We distinguished the averages registered when the heating system was in operation (from 8 am to 10 pm) from the averages registered when the heating system was turned off (from 11 pm to 7 am).

The air temperature in room B6B is 20.6°C while the linear radiating temperature next to the dispersant wall (point C) is 17.5°C, thus resulting in a 3.0°C difference (Fig. 7). During the nights, when the heating system is not operating, the temperature falls to 16,3°C. Considering the average of the two, an operating temperature of 19.1° C is obtained, thus resulting in a discomfort of 1.5° C. The thermal discomfort was higher close to the walls and to the windows with high thermal transmittances (5,522 W/(m K)).

The local thermal comfort indices PMV (Predicted Mean Vote) and PPD (Predicted Percentage Dissatisfied) were calculated in a couple of critical points [14]. A software provided by AICARR based on UNI EN ISO 7730:2006 [15] was used. The clothing thermal resistance were set equal to 1 clo (1 clo = 0.155 m2 · K / W), as estimated by the table for standard winter home clothing's man. The metabolic rate is equal to 1.1 met (1 met = 58.2 W / m2), corresponding to the metabolic activity of a person sitting in an office (for the point C) and 0.8 met for a person sleeping (point B). Point C is the most uncomfortable when the heating system is on. Supposing a student sitting at a desk by the window during the day, the PMV is -0.99, outside the limits of acceptability of ± 0.5 according to UNI EN ISO 7730. It thus corresponds to class C. The PPD expressing the feeling "very cold" results in 25.6%. Supposing a student lying down on the bed during the night (point B) the PMV is -2.85. It corresponds to a condition of absolute thermal discomfort. The PPD expressing the feeling "very cold" results in 98.2%.

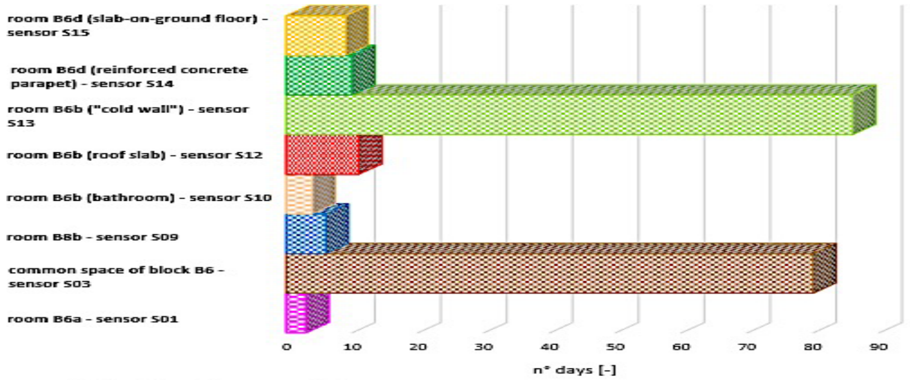


Fig. 5. Number of days with indoor temperature < 20° C from 8 am to 10 pm (159 total days of measurement, corresponding to the periods when the heating system was in operation: from 1/12/2015 to 21/12/2015, from 04/01/2016 to 14/04/2016, from 28/04/2016 to 07/05/2016)

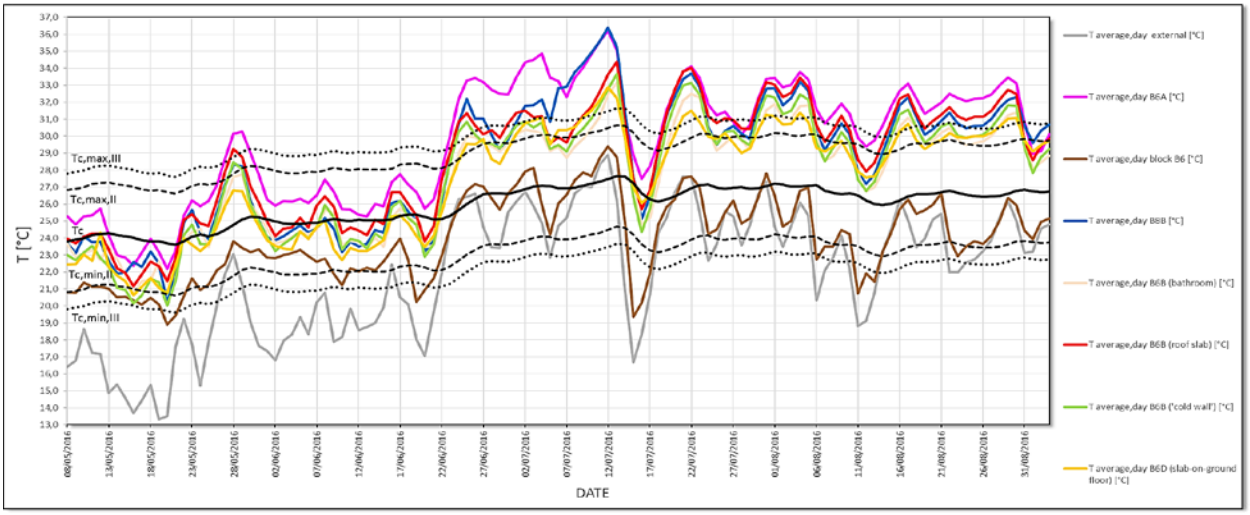


Fig. 6. Daily average air temperatures with the acceptance bands according to the adaptive method

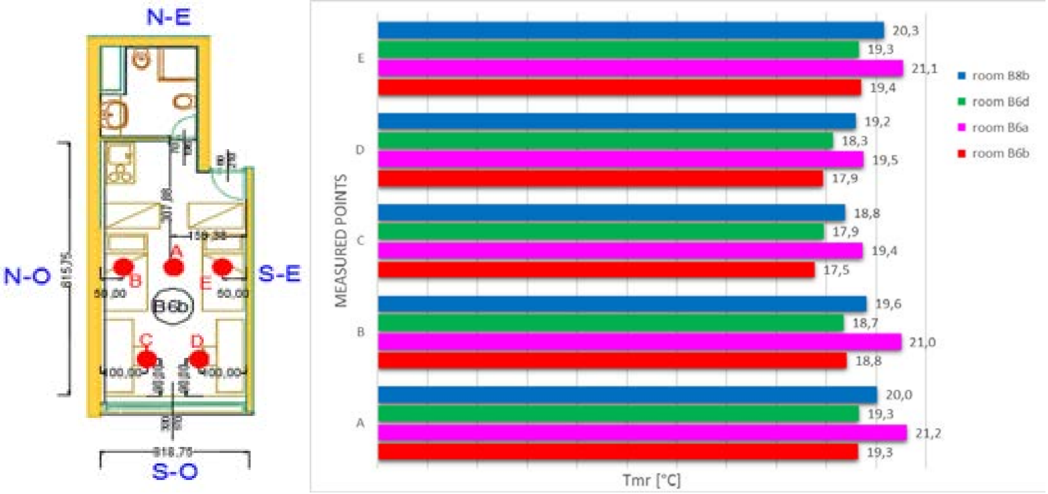


Fig. 7. Room B6b with the position of five measurement points. Mean radiant temperature when the heating system is operating (right)

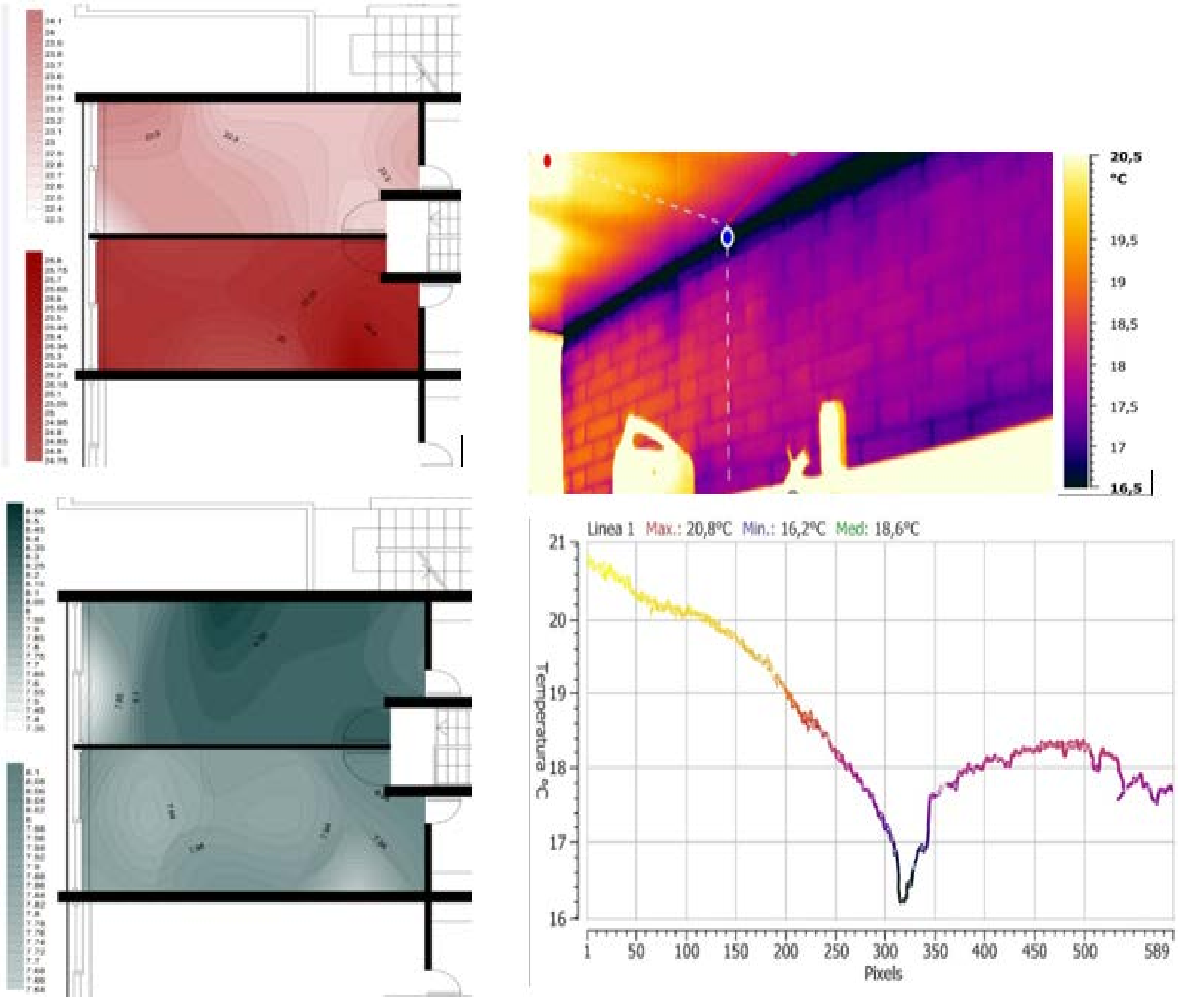
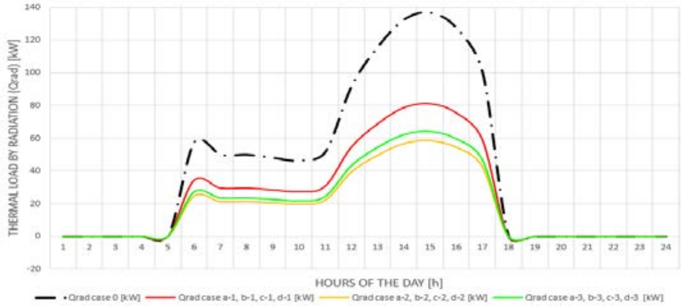


Fig. 8. Distribution of temperature (top left) and specific humidity (bottom left) in B6b room (top) and B6a (bottom) of the “Aquilone” building – 31/11/2015. Thermal image of B6b room with the thermal bridge between the wall and the roof - 12/01/2015 (right).

Fig. 9. Distribution of temperature (left) in B6b room (top) and B6a (bottom) compared with the common space (in the middle) of the “Aquilone” building– 14/07/2016. Thermal image of B6b room - 14/07/2016 (right).



TYPOLOGY OF GLASS TO SOLAR CONTROL: DOUBLE-GLAZED WINDOW WITH	g [-]	ε_{ext} [-]	ε_{ext} [-]	selectivity
CASE 1: STRATIFIED LOW- EMISSIVITY GLASS	0,43	0,04	0,29	1,56
CASE 2: STRATIFIED SELECTIVE GLASS	0,31	0,02	0,46	1,90
CASE 3: TEMPERED SELECTIVE GLASS	0,34	0,04	0,41	1,68

Fig. 10. Thermal load by radiation in the existing windows and after the substitution of the window glass

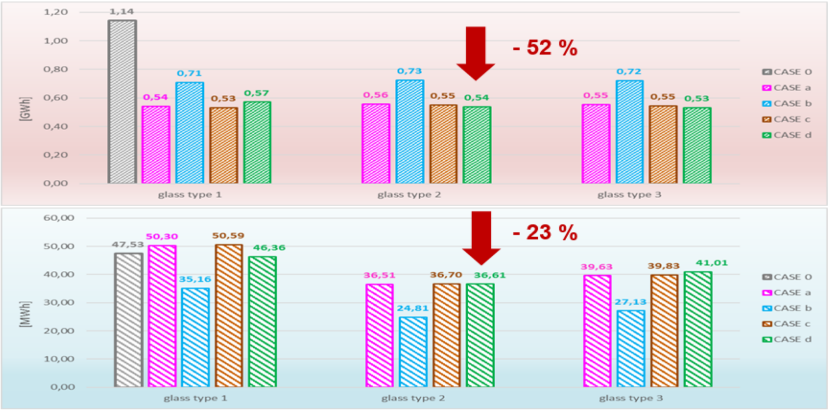


Fig. 11. Thermal energy demand for heating (top) and for cooling (bottom) in the twelve intervention scenarios and in the existing situation

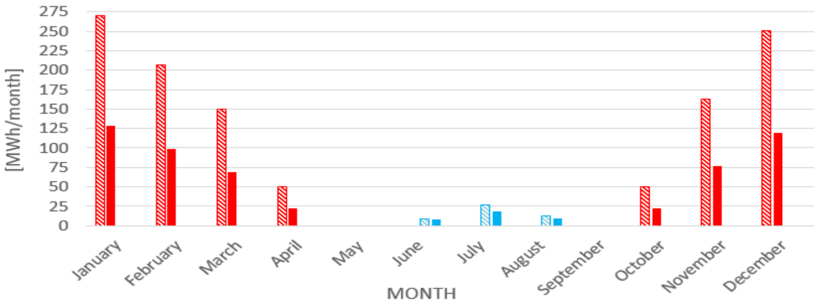


Fig. 12. Comparison between the existing energy performances and the simulated after the chosen solution

4.2. Thermographic survey and psychrometric mappings

The building envelope performances and the indoor hygrothermal comfort, were analysed more in depth by means thermographic survey and psychrometric mappings. Thermographic surveys were made to map the surface temperatures of the inner and outer walls, to detect thermal losses of building's components, thermal bridges, presence of moisture. Along with thermography, a portable digital psychrometer was employed to map the temperature and humidity distribution in different rooms and common areas of the five colleges. Surveys were repeated every three months to monitor the behaviour of the building in different seasons.

Thermography has confirmed the thermal discomfort of the outer dispersant wall, which has been discussed in the previous paragraphs. A thermal gradient results between the roof slab and the dispersant wall (Fig. 8, right), as the wall is cooler than the slab (17.5°C < 20.8°C). A thermal bridge results at the connection between the two, where surface temperature has a minimum of 16.2°C. Similar thermal discomforts were also detected in other colleges, as in the "Colle" building, where a surface temperature of 12°C was measured (room 83, 25 March at 10 a.m.). The psychrometric mapping (Fig. 8, left), confirms as the air temperature in a room with an outer wall (B6b, 23.5°C) is lower than in an inner room (B6a, 25.5°C). Near the "cold" wall, a low air temperature results in a rise of specific humidity, probably due to the evaporating effect of leaked water. Thermograps and psychrometric charts also reveals as the poor performance of the windows is a major issue for obtaining stable conditions.

The same rooms were analysed during summer (Fig. 9). On the left, the temperature in rooms B6b and B6a (around 30°C) is compared to the common space (24°C). In the corresponding thermal image, the ceiling's concrete joists are perfectly visible, just like all the non-insulated structures. The surface temperature of the inner side of the roof is 35°C, thus confirming the data mentioned in the previous paragraphs.

5. The energy retrofit of the building

After the analysis, the building-HVAC system was studied through an energy simulation software. Information on facilities and equipment has been collected by means of archival research and on-site inspections. The building-HVAC simulation was carried out with the "MasterClima MC 11300 PRO" by AERMEC. Two blocks of rooms of the "Aquilone" building were modeled, including bathrooms, connection spaces and common lounges (gross volumes of 14,143.70 m^3, usable area of 3944.00 m^2). The "Aquilone" building was chosen as the seat to implement a pilot site to test the energy retrofitting. This allows to compare data before and after the retrofitting. The model was then validated through a comparison between the real consumption of methane and the temperatures measured by the installed sensors.

The simulation model applied to the original configuration allowed a calculation of the thermal load in the winter (585.85 kW) and summer conditions (377.66 kW). This initial analysis suggested the need to correct thermal bridges by means of insulating the opaque components, and to improve the performances of the windows, even considering their possible substitution. The roof slab, for example, resulted to be responsible of 12.3% in the total dispersion. It thus needs some improvement, also considering the recurring problems of water leaking from the roof.

Any proposal of retrofitting the envelope had to cope with the historical and architectural value of the *Collegi*. Insulating by external coating was thus considered unacceptable in a conservation perspective, even if it would contribute to solve many energy issues. Also filling the wall with insulating materials was not an option, since there is no cavity to fill. The only option for the outer walls was thus internal insulation.

5.1. Wall and roof

Four different scenarios for the insulation of opaque components were thus combined with three different scenarios for the improvements of the windows. It resulted in twelve different "combinations". They were compared to define an appropriate intervention strategy. The chosen combination was later implemented in the pilot site.

Three different proposals were simulated for the roof: an external insulation layer of 8 or 12cm was compared with a warm-roof configuration with the waterproofing layer below the insulating layer. The latter provides a better protection of the waterproofing layer from thermal shocks and avoids the risk of condensing vapour within the insulating layer. All the options were discussed among the different members of the project team, especially with those responsible of the retrofitting design and those in charge of the building maintenance and management. The goal was to find a balance between conservation issues, energy efficiency feasibility of the intervention.

5.2. Windows

The preservation of room windows was a difficult task. Some results already acquired concerning the conservation of historic windows [16] proved to be useful when dealing with the windows of a wide XX century complex, e.g. the *Collegi*. A consistent decrease of the total summer thermal load may be obtained by replacing the transparent components with a solar control glass, since the thermal load by solar radiation is drastically reduced (Fig. 10). This is shown by the gap between the continuous colored lines (solar control glasses) and black dot-dashed line (existing glass). The reduction of the radiation heat output was evaluated considering the solar factor, the emissivity and the selectivity of three different types of solar controlled glass. Solution 1 (red curve) results in terms of thermal power by radiation, a lower reduction compared to the case 0 (black curve) because the low emissivity glass has a solar factor (g) greater than the other two cases. In addition, the low-emissivity glass of type 1 has a lower emissivity on the inner surface. This generally results in a significant reduction of magnitude if the room is air-conditioned in summer. The selective glass of type 2 (yellow curve) is the most powerful in terms of solar factor, of emissivity of the outer surface and especially in terms of selectivity. This window allows the greatest reduction of the heat load in summer conditions given that the high selectivity (1.9) allows an increased light transmittance. The solar factor is the ratio between the solar incident energy on the total glazed incoming surface. The energy expenditure of an air conditioned room can be controlled by keeping this factor as low as possible in the summer. In fact the second type has the lower solar factor (0.31).

5.3. Pilot site

Following the DM 26/06/2016 [17], for each of the twelve cases of intervention, the energy performance indices, the thermal and primary energy requirements and natural gas consumption were calculated, besides the variations of thermal loads in winter and summer conditions. The best intervention scenario was selected considering the combination of the winter and summer case (Fig. 11) and taking into account the data of the energy simulations, the indoor climate monitoring and the psychrometric and thermographic analysis. The selected scenario was implemented in a pilot site on room B6a and B6b, from December 2016 to January 2017.

The sensors were thus reinstalled to measure the new conditions and compare them with those collected before the energy retrofit, and to assess the results obtained. Fig. 12 shows a simulated comparison between the existing and upgraded performances in the thermal energy required. for heating (in red) and for cooling (in blue) the rooms. A decrease of 52.9% is expected for heating, of 23.7% for cooling.

5.4. The integration with controlled mechanical ventilation

Considering the importance of the hygrothermal comfort and of the indoor air quality in a public residential building, a solution for a controlled mechanical ventilation was recommended for the pilot construction site, with a double flow sensible heat recovery unit by Vortice company. The old windows, though causing great thermal dispersions and local discomfort, provided a free indoor air exchange due to air leaking. With new windows, air infiltration would be strongly reduced. It will be necessary to act manually or mechanically to ensure the minimum air exchange for the indoor air quality and to avoid condensation problems.

A pilot project regarding a couple of rooms was thus proposed, since in this phase it was not possible to implement a centralized mechanical ventilation system. It must be also underlined that the *Collegi* have many architectural constraints that limit considerably the possibility of integrating the ductwork without affecting the historical and architectural value of the building. Furthermore, the rooms of the *Collegi* have a very low ceiling (2.45 m), and consequently it is not possible to install air channels within a false ceiling.

In accordance with the prescriptive method for the indoor air quality [11] the flow rate of outside air was calculated, then the air distribution ducts were dimensioned and all the aeraulic system components selected. The project plans to install the heat recovery unit hanging on the ceiling in the hallway at the entrance of the room while the outside air outlets pass through a nearby skylight. The control and regulation logic was outlined to manage two rooms at the same time expecting to use motorized dampers in the supply ducts. The ducts will be set up for both rooms but initially only those that go into one room will be connected to the heat recovery. After a month, the ducts will be connected for both rooms in order to monitor and test the control system. In addition, we will be able to demonstrate the benefits obtained with the heat recovery unit. Such comparison should be implemented in two identical rooms used by the occupants in a similar way, but this is obviously not possible in the *Collegi*.

5.5. The experimental smart community with heat accounting and CO2 sensors

A further suggestion for the future is to provide the residential units with an indirect heat accounting system together with the installation of thermostatic valves for each radiator. Through a WiFi communication system, the data could be concentrated on a server and made available for the energy manager. At the same time, the thermostatic valves would stop the emission of heat when the temperature reaches the desired set-point, preventing the overheating of the built environments. The indoor air quality could also be monitored by means CO2 sensors.

The proposal includes an experimental activity to involve students into the building climate management. If the energy consumptions is measured, virtuous behaviors could be incentivized by giving “green credits” to those students consuming less energy. These benefits could be either written off the rent or spent in the form of vouchers for accessing additional services, such as car and bike sharing and would further boost a correct and efficient use of the building-HVAC system.

6. Conclusions

When retrofitting existing buildings, any decision had to rely on a solid knowledge about the current situation, especially in the case of buildings of architectural and cultural interest. A sound retrofit looks for a sustainable balance between conservation and energy improvement, thanks to the solid knowledge of this specific case – study. The Urbino University Collegese represents a unique case in Italy to be analyzed from different points of view: the building’s energy performance and indoor air quality, on one side, and issues of the preservation on the other side.

The integration between building physics and conservation proves to be effective to design a tailored retrofitting. Monitoring and energy audit allow to analyse the current state. A model implemented through the energy simulations is a guide to design the energy retrofitting. The proposed solution takes advantage from a pilot site.

The results here presented support a comprehensive conservation plan for the Urbino University Collegese. This will address material deterioration and adaptation to ensure the contemporary use of the building while respecting the architect’s original vision. The guidelines for the energy management of the *Collegi* have been outlined following the analysis of the data and they will be included in the conservation plan.

The strategies proposed and studied on the *Collegi* may be implemented in other examples of energy retrofit of XX century buildings. This study confirms the importance of energy retrofitting when preserving a heritage building. A number of studies were already carried out on historic buildings, yet not many on XX century heritage buildings. The results from the *Collegi* aim thus to be a contribution for developing a method for such heritage.

Acknowledgements

"Conserving Modern Heritage, Urbino's University Colleges" is one of the fourteen projects selected in 2015 by the Getty Foundation and, until now, is also the only Italian project that has received this prestigious award. The goal is the preservation of XX century buildings and the implementation of a conservation plan. The authors want to thank the funding institution as well as all the partners of the project: Università di Urbino "Carlo Bo" (Project leader): DISPEA Dep. and DESP Dep. Politecnico di Milano: DASTU Dep. - C.E.C.H. Laboratory (Climate Energy Cultural Heritage) and ABC Dep. MTA Associati – Giancarlo De Carlo Associati”, ICVBC - National Research Council. Technical collaborations were carried out with the companies Vortice and Knauf Insulation.

References

[1] De Carlo G, Rossi L. Giancarlo De Carlo: architectures. Milano: Mondadori; 1988.

[2] Zucchi B. Giancarlo De Carlo. Oxford: Butterworth – Heinemann; 1992.

[3] Lasdun D. Architecture in an age of scepticism. London: Heinemann; 1984.

[4] Banham R. The New Brutalism: Ethic or Aesthetic? London: Reinhold Publishing Corp; 1966.

[5] UNI 2002. UNI EN ISO 7726:2002 "Ergonomics of the thermal environment - Instruments for measuring physical quantities". Standard. Milan: Italian Unification Body.

[6] UNI 2010. UNI EN 15758:2010 "Conservation of cultural heritage - Procedures and instruments for measuring air temperature and the temperature of the surface of objects". Standard. Milan: Italian Unification Body.

[7] UNI 2012. UNI EN 16242:2012 "Cultural heritage - Procedures and instruments for measuring humidity and vapor exchange between the air and the cultural heritage". Standard. Milan: Italian Unification Body.

[8] Del Curto D, Valisi LP, Luciani A. System and method for detecting an environmental size and map a distribution in an environment. Patent n. 102016000051840 filed on 19/05/2016.

[9] Del Curto D, Valisi LP, Luciani A, Camuffo D, Bertolin C, Pallavicini A. Patent for utility models: an electronic detection device of environmental quantities. Patent n. 202016000051842 filed on 19/05/2016.

[10] UNI 1999. UNI 10829:1999 "Assets of historical and artistic interest - Environmental Storage - Measurement and analysis". Standard. Milan: Italian Unification Body.

[11] UNI 2015. UNI 10339 "Aerodynamic systems for air conditioning - Classification, requirements and requirements for the design and supply". Standard. Milan: Italian Unification Body.

[12] UNI 2008. UNI EN 15251:2008 "Indoor environmental parameters for assessment of energy performance of buildings-addressing indoor air quality, thermal environment,lighting and acoustics". Standard. Milan: Italian Unification Body.

[13] ASHRAE 2013. ASHRAE Standard 55. Thermal Environmental Conditions for Human Occupancy. New York: American Society of Heating, Refrigerating and Air-Conditioning Engineers.

[14] Fanger P. Thermal Comfort. New York: McGraw-Hill Book Company; 1972.

[15] UNI 2006. UNI EN ISO 7730:2006 "Moderate Thermal Environments - Determination of the PMV and PPD indices and specifications of the conditions for thermal comfort". Standard. Milan: Italian Unification Body.

[16] Ortelli L, Zurbrügg P, Wall Gago PC, Roch G. Assainissement de fenêtres dans les immeubles d'habitation 1850 – 1920. Lausanne: Laboratoire de construction et conservation, Ecole Polytechnique Fédérale de Lausanne; 2012.

[17] DM 2016. Italian Ministry of Economic Development. 2016. Ministerial Decree DM 26/06/2016 National guidelines for energy certification of buildings. Official Gazette of the Italian Republic.