HIGH EFFICIENCY RETROFIT IN HISTORIC BUILDINGS BY DEMAND-CONTROLLED VENTILATION

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ABSTRACT

Effective conservation of historic buildings subject to monumental restrictions is realized through a re-use for modern functions. In fact an attended and therefore ventilated and climatized building can be maintained in thermo-hygrometric conditions suitable controlled in order to avoid the occurrence of mold. Often only the use can justify a timely and adequate maintenance. Although the sustainability of the requalification requires acceptable management costs and therefore a limitation of the energy consumptions which must be comparable with those today prescribed for new buildings. But the monumental restrictions normally prevent interventions on building envelope. Even more than in modern buildings, it is therefore necessary to focus the efforts on plant efficiency by introducing innovative solutions.

For this goal, significant ventilation rates and high variability in the attendance suggest the realization of central plants necessary for a demand-controlled ventilation and efficient heat recovery even if their design in a monumental building can be very difficult and challenging.

In this paper are described two plants, now under construction, realized in the mainframe of the retrofit of two historic buildings in Venice. For both cases a preliminary analysis by building-plant system simulation is illustrated which was carried on to optimize the design and to assess the energy performances. The results highlight the possibility to achieve strong energy savings without compromise the monumental conservation.

KEYWORDS

Demand-controlled ventilation, historic buildings, refurbishment, energy saving

1 INTRODUCTION

The current European energy context is characterized by the adoption of the 20-20-20 Renewable Energy Directive with the goal to stop the climate change causing by greenhouse effect. The intent of the directive is a 20 percent reduction in CO_2 emissions by 2020 compared with 1990 levels, a 20 percent cut in energy consumption through improved energy efficiency by 2020 and a 20 percent increase in the use of renewable energy by 2020. The subsequent recast of the Energy Performance Building Directive, EPBD (EU Community, 2009), has focused the building energy consumption as the most important sector where to act in order to achieve these goals. The new directive lays down mandatory national targets to be achieved by the member states. For this aim an effective action requires a widespread and incisive intervention on the existing buildings and in particular on the historic ones which constitute the greater part of the architectural heritage. But especially in the old towns full of history, we have often the presence of many buildings subject to monumental restrictions. In this case important retrofit actions regarding the building are forbidden. Therefore, even more than in the new buildings, the effort of the designer must be addressed to increase the efficiency both for energy production and its use. For monumental buildings re-used for public functions and characterized by high level of occupancy, but with significant variability, demand-controlled ventilation (DCV) can be a fundamental solution to reach important energy savings in the heating, ventilating, air conditioning (HVAC) plants.

In this paper two case studies of refurbishment of monumental buildings in Venice are described. In both cases the realization of high efficiency systems for the production of energy with the exploitation of renewable energy sources was joined with a smart management which foresees also the presence of DCV. The authors of this memory has drawn up the preliminary, defined and executive project of the plants and they are now following the work execution. The results of a preliminary study by simulation are presented here as regards the use of DCV. This analysis was carried on to optimize the plant design and to assess the real contribution in terms of energy saving and exploitation of renewable energy sources.

2 CRUCIFERS COMPLEX

The first case study is the ancient Crucifers complex which will be transformed into an university campus. For its history and architectural value the Crucifers complex is subject to heavy monumental preservation restrictions. The convent and hospital was founded in the middle of the 12th century by the order of Crucifers along the church of Santa Maria Assunta to aid and to give shelter to pilgrims and crusaders on their way to the Holy Land. It was then rebuilt after fires in 1214 and 1514, acquired by the Jesuits in 1657 following the suppression of the Crucifers order. When the Jesuits were suppressed in 1773 the monastery became a school and then, in 1808, a barrack. The Jesuits returned in 1844 and still occupy the convent parts to the North of the church. Those to the South remained used as a barrack until 1990. An aerial photo of the Southern part of the convent is showed in fig. 1a.

a) An aerial photo of the Southern part b) The restaurant room

Figure 1: Views of the Crucifers complex

2.1 Description of building-plant system

As showed in the picture 1a the South sector of the former convent presents two cloisters on the left side and two further smaller service courtyards on the right side of the complex. In the middle of each cloister there is a well. Each well is connected to an underground cistern that collects rainwater from the above courtyard through a filtration system based on purposely placed sand. The frontal side towards Campo dei Gesuiti presents the main accesses, the back side is lapped by the channel Rio dei Gesuiti. On the left we have the church of Santa Maria and on the right side the limit is a minor channel. The complex has three long buildings (the sleeves) along the perimeter area and they present a total height of 26 m. Two other lower buildings are located in the central part and they surround the cloisters and courtyards.

This area is the object of the actual intervention of renovation and new destination for university housing for students and visiting professors and ancillary services. In detail the project foresees the creation of 177 apartments for students, each with two bed places, independent bathroom and kitchen and study area (figure 2b). Normally the ground floors are used for various services, while the upper floors are residential units. An height greater than 5 m in each floor of the sleeves has permitted the realization of mezzanines where to locate the cabinets of the rooms while the adjacent long corridors are used as recreational and meeting areas. The design was respectful of the existing architecture especially in the common areas (figure 2a). Further greater 32 residential units will be reserved for visiting professors.


a) An internal corridor b) a room with two beds

Figure 2: Internal views of the Crucifers

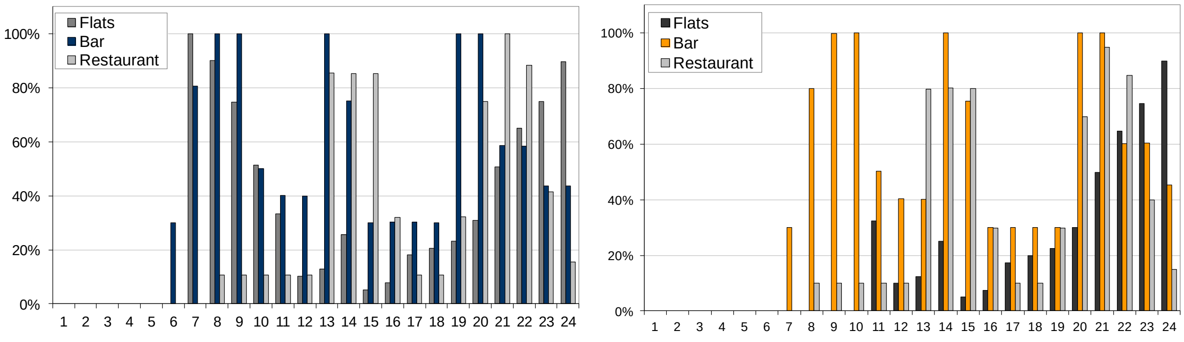
In the residential unit the HVAC plant consists of fan coils embedded in the furnishings and a controlled ventilation system with delivery in the room and aspiration in the bathrooms. The centralized ventilation system allows an efficient heat recovery from exhaust air to pretreat the fresh air. Each residential unit is automatically excluded from ventilation grid in the absence of persons inside the room by two motorized valves installed on the local connections to the air supply and return ducts of the ventilation grid. The total air flow rate is controlled by inverters which act on the fan motors of the centralized recovery units. These recovery units are distributed in the various area of the Crucifers complex and each of them is installed in the garret of the corresponding supplied building.

Facilities like laundry, meeting rooms, classrooms and workshop rooms will be at disposal of the internal guests. While community services: cafe, restaurant with 150 places and relative kitchen, gym, computer room and a library, will be opened also to the local community.

In the greater rooms at the floor level HVAC plants are based on fan coils and primary air distribution ducts. Special effort required the HVAC installation in presence of painted walls like in the restaurant room (figure 1b). In some areas there is also the contribution of radiant panels when there were no preservation restrictions on the floor. The bar and restaurant each present an independent air handling unit (AHU) for the ventilation. Both of the AHUs have a CO_2 sensors on the return duct in order to module the ventilation rate on the basis of the real occupancy of the served room by acting on the inverters which control the fans. The whole ventilation plant will be monitored by the central supervisory system where its working mode will be directly controlled on screen with the possibility of an easy introduction of the set point values The HVAC plants have been chosen to be supplied by low temperature water (40-45°C in heating mode) favorable to the working of the installed heat pump. In fact the lagoon environment has suggested the use of the surface waters coupled to a heat pump as renewable energy source. The technical centrals are located in the tower between the two courtyards on the left side and in underground room expressly dug under the widest of these two courtyards. In the tower we have the installation of the reversible water to water heat pump used to produce hot water for heating and chilled water for air conditioning in summer. The lagoon water is withdrawn from the back channel Rio dei Gesuiti sited near the back side. Auxiliary condensing boilers are also installed to integrate the heat pump.

2.2 Analysis of the performances

The analysis of the performances of the DCV plant has been carry out by simulation as the refurbishment of the building is not finished yet. The scheduling of the crowding in the various types of facilities: flats, bar and restaurant has been elaborated on the basis of an investigation expressly done in similar university buildings and commercial facilities existing in Venice. Different hourly distributions have been built up for week days and week ends. Considering the reduction of the teaching during summer, the scheduling are also diversified between summer and winter. In figure 3 the presence hourly distributions used for the simulation are shown in the case of week days during winter and summer period. These distributions in percentage are referred to the design values of occupancy (100%) which are two persons for each flat, 75 persons for the bar and 150 persons for the restaurant.



a) Winter

b) Summer

Figure 3: Distributions (in percentage) of the presences during week days in the studied rooms for winter and summer period. These trends are referred to the design values of occupancy (100%)

The ventilation rate is assumed to be equal to the design value of 25 m^3/h per persons. In this way it is possible to simulate the variation of the ventilation flow rate in presence of DCV. The energy requirement for ventilation air treatment in heating and air conditioning periods can be then calculated by a simple thermo-hygrometric calculation model on the basis of typical outdoor climatic data of Venice. The same calculation can be repeated considering a constant ventilation flow rate during the working hours of the plants and equal to the maximum design value as happens in absence of DCV.

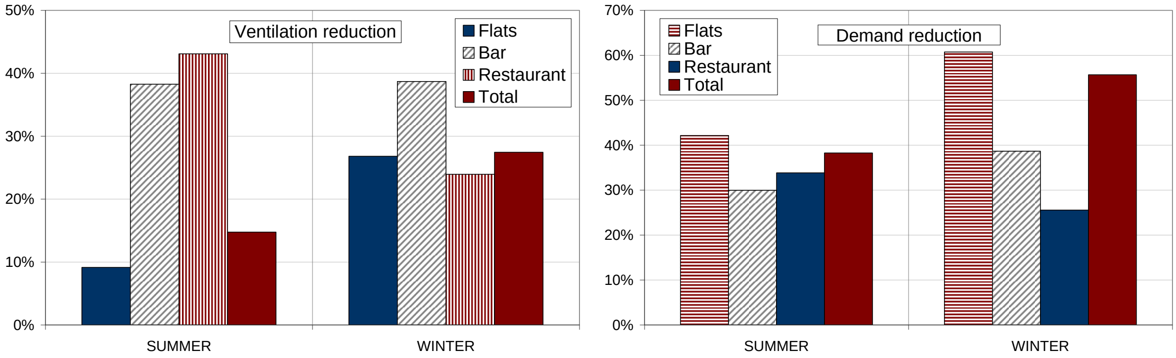


Figure 4: Ventilation rate and energy demand reductions (in percentage) during heating and air conditioning periods. These reductions are referred to the corresponding values without demand-controlled ventilation.

In figure 4 the seasonal reductions of the ventilation rate amount and of the energy demand for ventilation air treatment are reported in heating and air conditioning period for each type of facilities and the total one. These percentage reductions are referred to the corresponding ventilation amount and energy demand of the building in the case without DCV. The ventilation reduction is significant, but the benefit is remarkable especially in terms of reduction of the total energy demand for ventilation both in winter and summer.

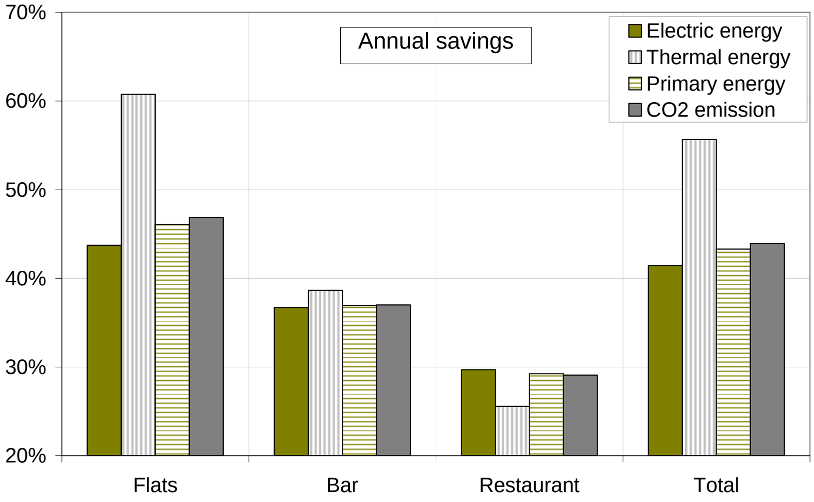


Figure 5: Annual energy savings and CO_2 emission reduction (in percent). These savings are referred to the corresponding energy requirements for ventilation and CO_2 emission without demand-controlled ventilation

The energy requirement of the HVAC plants is due to the electric energy consumption of fans and pumps supplying the coils of the AHUs, but first of all to the electric consumption of the heat pump used both for heating and air conditioning. As the heat pump is assisted by auxiliary condensing boilers, we have also a thermal energy consumption. For this reason the total energy consumption is calculated as primary energy assuming the energy efficiencies of the condensing boilers and of the heat pump calculated by the dynamic simulation of the building-plant system (Schibuola and Tambani, 2012). To calculate the primary energy consumption for electricity production, the Italian official transformation factor of 0.45 has been used. In figure 5 the annual energy saving and CO_2 reduction in percentage obtained thanks to the introduction of DCV are reported for each facilities and the total ones. The primary energy saving about the requirement for ventilation treatment and corresponding CO_2 emission reduction are over 40% on annual basis.

3 TOLENTINI

The second case study refers to the former Convent of Tolentini commissioned by the Fathers Teatini at the end of 1500, but with the arrival of Napoleon it went to the state and became first a barrack and then a deposit. Since the 50s of last century, the property is entrusted to the IUAV University of Venice to become its main house. The movement of the teaching activities to other buildings has allowed today to schedule a transformation of part of the second and third floors already used as classrooms. In figure 6a an aerial photo of Tolentini convent is reported. The building on the left is the object of this refurbishment.

a) On the left the refurbished building

b) The main cloister

Figure 6: Views of the former Convent of Tolentini

Figure 6b shows the main cloister of the convent located on the right of figure 6a.

3.1 Description of building-plant system

In detail for a wing of the building a design was drawn up for the transformation of the old classrooms into two further new reading rooms of the library of the university, each occupying the entire second and third floor respectively which become the first and second floor of the library. In addition in the first floor of the building the complete restoration of

a) Longitudinal section

b) Cross sections

Figure 7: Sections of the building

the HVAC plant of the Aula Magna has been planned. Sections of the building in figure 7 show the characteristics of the areas subject to the interventions. In this context the design of new HVAC systems took up relevant resources. In fact the new HVAC system will substitute the existing system aimed at mere heating by radiators and it will consist, for the reading rooms, in primary air ventilation system and fan-coil terminal units whereas the Aula Magna will be totally air-conditioned by two AHUs. The first AHU is installed in a little room sited near the upper part of the bottom of the Aula Magna as shown in figure 7a and serves the area in the bottom. The second AHU is installed outside and serves the speakers area. Its final distribution ducts are under the platform of the speakers as shown in figure 8a. Demand-controlled ventilation is always adopted. In the first and second floor of the library the main ducts of the ventilation plant are installed under elevated platforms that cover part of the floor for the entire length of the room (fig.8b) without damage this ancient floor. The rebuilding foresees also the installation of a ground source heat pump with vertical double U-tube boreholes heat exchanger in the garden of the palace to produce the heat and the cold required by the new HVAC plants.

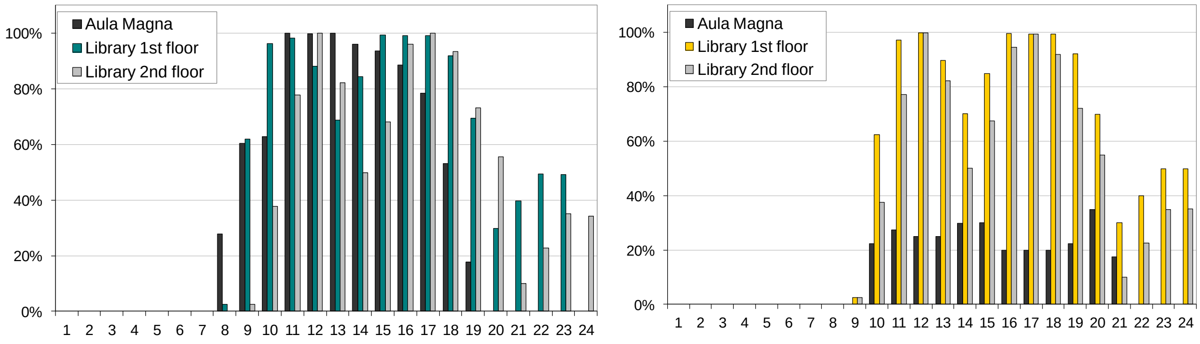
a) Aula Magna

b) First floor of the library

Figure 8: Views of the work in progress at Tolentini

3.2 Analysis of the performances

Also for this test case the analysis is based on the simulation of the performance in presence and in absence of DCV. The scheduling of the crowding has been obtained by the monitoring of the already existing lecture rooms of this university library. For the two new



a) Winter

b) Summer

Figure 9: Distribution (in percentage) of the presences during week days in the studied rooms of Tolentini for winter and summer period. These trends are related to the design values of occupancy (100%).

reading rooms the ventilation AHU, with fans equipped with inverter, is only one. But as four modulating dampers are present, controlled by two different CO_2 sensors installed in the return ducts from each rooms, the DCV is independent for the first and second floor of the library. For Aula Magna DCV acts on the modulating dumpers for air intake and expulsion present in the two installed AHUs.

In figure 9 the presence hourly distributions used for the simulation are shown in the case of week days during winter and summer period. In fact different hourly distributions have been considered again for summer and winter considering the teaching reduction in summer. On Sunday the library is closed. The distributions in percentage are referred to the design values of occupancy (100%) which are 100 persons for each floor of the library and 250 persons for Aula Magna. The design value of 25 m^3/h per person is maintained also for this building. The comparison between the performances in presence or in absence of DCV permits to calculate again the reductions of the ventilation amount and of the energy demand for the studied rooms.

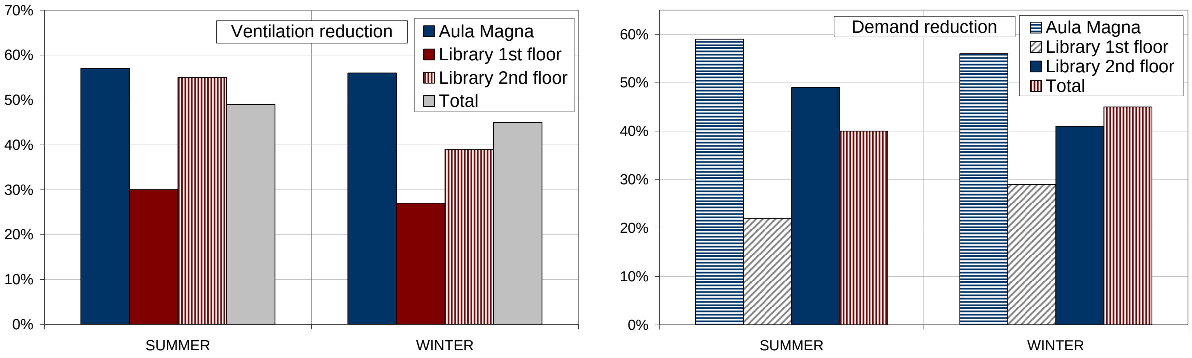


Figure 10: Ventilation rate and energy demand reductions (in percentage) during heating and air conditioning periods. These reductions are referred to the corresponding values without demand-controlled ventilation.

In figure 10 these reductions in percentage are reported for heating and air conditioning periods. They are referred to the corresponding ventilation amount and energy demand of the building in the case without DCV. The best values are in Aula Magna and in the second floor of the library where the occupancy is more flexible during the working hours. In fact

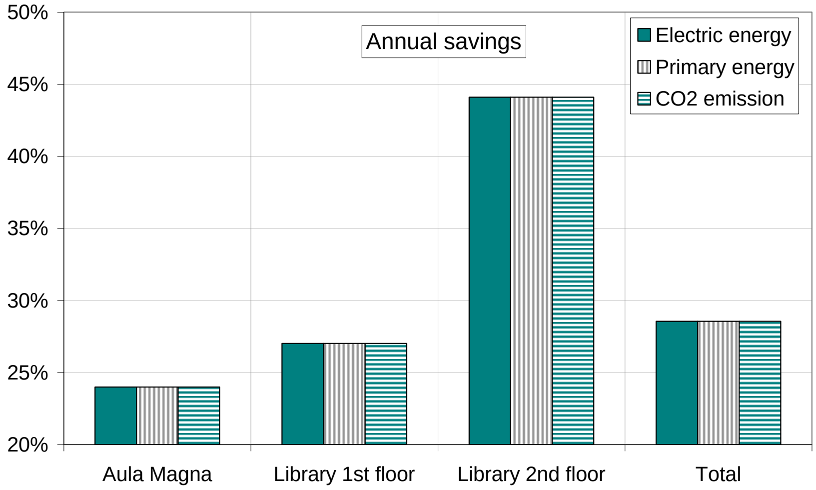


Figure 11: Annual energy savings and CO_2 emission reduction (in percent). These savings are referred to the corresponding energy requirements for ventilation and CO_2 emission without demand-controlled ventilation

Aula Magna is used not only for general meeting, but also for exhibitions and conferences characterized by variable participation. For the library the greatest occupancy is always in the first floor as it is the nearest to the distribution desk therefore we have observed that the presences in the second floor are normally less. In figure 11 the annual energy saving and CO_2 emission reduction in percentage obtained with DCV are reported for each rooms and the total ones. In this case the energy requirement for ventilation plant is only electric energy and it consists in a quota of the total electric energy absorbed by the heat pump, in heating or cooling working, to supply the AHU coils and for the relative auxiliaries, fans and pumps. To convert the energy provided by the heat pump for the ventilation treatments into the electric consumption of the machine, the coefficients of performance (COP in heating and cooling) of the heat pump have been calculated by using the results of the dynamic simulation of building-plant system (Schibuola et alia, 2011). Because of the only electric consumption, the energy savings and CO_2 emission reduction are expressed in percentage by the same value. The benefit is the greatest in the second floor as here we have the highest variability for the occupancy. The total result depends mainly on the library which is the facility more used.

4 CONCLUSIONS

These case studies have highlighted that the introduction of demand-controlled ventilation can give a fundamental contribution to the reduction of the energy requirement for ventilation also in historic buildings re-used for public functions. The consequent reduction of the emission of greenhouse gases is also remarkable. But, above all, its realization does not involve problems regarding restrictions about preservation exigencies. Therefore, among all the possible high efficiency solutions, demand-controlled ventilation should be always considered in the retrofit of HVAC plants in historic buildings. In this way also the refurbishment of monumental buildings can contribute to achieve the target of 20-20-20 within 2020 as indicated by EU parliament.

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