ENERGY SAVING OPPORTUNITIES BY SUITABLE HVAC MANAGEMENT: THE PROCURATIE CASE IN VENICE

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ABSTRACT

The thermo-hygrometric treatment related to the air change in buildings requires a relevant quota of the total energy demand for heating and air conditioning, especially when the ventilation exigency is significant. For this reason a correct energy saving strategy should always focus on the use of suitable techniques in order to reduce this consumption. For example, as the modern comfort science teaches, more flexible values can be accepted for the internal humidity set point without compromising indoor comfort conditions. But demand-controlled ventilation is the fundamental opportunity to reduce energy requirements in presence of high ventilation flow rates. An evaluation of the possible amount of the energy savings following this more flexible control strategy is here presented in a real application case. This refers to two historic buildings in Venice, the Procuratie 5 and 6 near S. Basilio harbour just transformed in modern university facilities and characterized by considerable design occupancy. As frequent in university buildings, the effective crowding has high peaks, but also an appreciable variability during the activity period. In addition to a smart humidity control, in these buildings it is therefore foreseen the presence of a variable ventilation rate on the basis of the real exigency measured by CO_2 sensors installed in the return air ducts in the classrooms and a central system based on fans equipped with inverter. In this way the strong ventilation flow rate can be controlled in each air treatment unit (from one to four units in each classroom). The central supervision system is able to perform an independent control of the air change and of the thermo-hygrometric conditions for each internal unit. An user friendly interface permits an easy intervention of the building manager on the set point values of each unit. Starting from the data of monitoring enabled by the existing supervisory system an investigation about the contribution of demand-controlled ventilation to the energy requalification of one of these two buildings is here presented. The analysis of the performance of ventilation system has pointed out the possibility of remarkable energy savings.

KEYWORDS

Demand-controlled ventilation, historic building, monitoring, ventilation valve modulation

1 INTRODUCTION

The energy demand for the ventilation air treatment can become the predominant quota of the total energy requirement for the climatization. This is particularly true for buildings characterized by high level of occupancy like for example school buildings. Already in the design phase it is therefore necessary to operate in order to reduce the energy amount adopting recovery system on the exhaust air more efficient as possible. But it is also important to investigate if the high level of the peak occupancy, foreseen in the design conditions in order to size the HVAC plant, is constant during the working hours. Otherwise the best way to reduce the energy demand for ventilation it is a modulation of the external air flow rate following the variability of the real presence during the activity period. This precise ventilation control can be simply achieved by the use of CO_2 sensors installed inside the building or in the ducts of the return air. This is the case of the university building object of this analysis. Here the strong ventilation flow rate can be controlled for each classroom on the basis of the real presences by the use of modulating valves for the ventilation rate and a central system based on fans with inverter control. A long term monitoring has permitted to investigate the correct utilization of the ventilation control system and quantify the real amount of these savings.

2 DESCRIPTION OF THE BUILDING-PLANT SYSTEM

The analysed building is one among a group of old customs warehouses named Procuratie in the harbour area in Venice recently subjected to refurbishment . Two of them, Procuratie 5 and 6, were recently transformed in university facilities for the faculty of architecture. In the overall design and work supervision entrusted to ISP, IUAV Studies and Planning, company, the authors of this paper dealt with the plants and their subsequent monitoring (Schibuola and Tambani, 2009).

Figure 1: View of part of the warehouses

The two buildings are identical. Each presents three floors for a total of about 3210 m^2 and a climatized volume of 13450 m^3. In this paper are reported the results about Procuratie 6 which

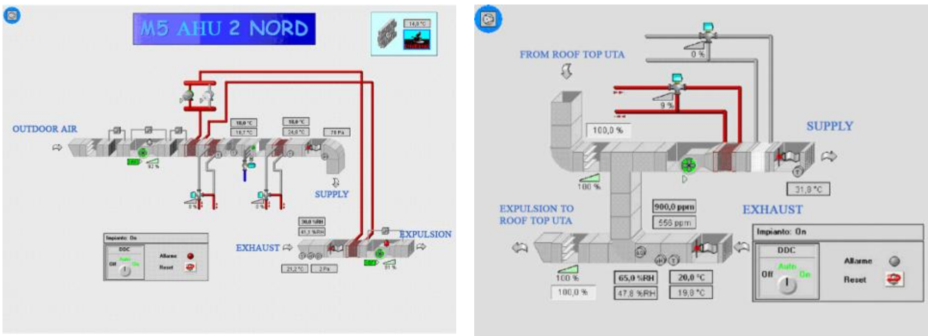
Figure 2: Longitudinal section and one floor map view of the building

is the second building from the right in the photo showed in figure 1. A longitudinal section and one floor map view of the building are reported in Figure 2. Except for one room occupied by electric equipments, the building is completely utilized for classrooms and relative toilette facilities. The entrance to the classrooms is directly from outside by balconies. All the classrooms are formed by modules of 6.4x8.9=57 m^2. Actually we have classrooms with one, two or four modules. Each module has its own internal air handling unit (internal AHU). The air conditioning plant is also equipped by two identical central air handling units installed on the top of the building (roof top AHU). Each of this two roof top AHUs serves half building (side South and North). They treat the ventilation flow rates later submitted to the inside by a network of primary air ducts which supply the internal AHUs. In Figure 3 two photos of one internal machine (a) and of the modulating valves detail (b) are reported. In winter the external air is subject to a complete treatment: preheating, humidification and post-heating. The adiabatic humidification is controlled by a humidity sensor installed in the exhaust air duct before the heat recovery system. Instead in summer we have only the cooling of the air until a fixed temperature controlled by a saturation temperature probe.

a) b)

Figure 3: Photos of one internal AHU (a) and of its air modulating valves

After this pre-treatment the cold air is submitted to the internal AHUs and here mixed with the recirculation air in the plenum installed in the lower part of each machine. In this way the strong cooling necessary to the dehumidification of the outdoor air is not lost as in the case of post-heating of the primary air. Each internal AHU is provided of two coils. The first coil is cold in summer and hot in winter. In summer this coil is driven by the two sensors of temperature and relative humidity located on the return air. The priority is the control of indoor humidity and secondly the coil avoids an increment of the indoor temperature above the set-point temperature. In winter the coil is driven only by the temperature sensor. The second coil operates only in summer in order to post-heat the air, before the introduction in the classroom, up to a minimum input temperature and also to respect a minimum indoor temperature when the exigency of dehumidification is predominant. The ventilation flow rate submitted to each internal AHU is controlled by a carbon dioxide (CO_2) concentration sensor located in the return air duct. This sensor operates on the aperture and closure of two valves installed one in the supply duct and the other in the return duct respectively, which connect each internal AHU to the primary air network. In this way it is possible to modulate the ventilation rate on the basis of the effective exigency due to the real occupancy in any moment during the working period of the building. The building is provided with a supervisory system which permits an ongoing control and verification not only of fire and antitheft safety, but also of the production of heat and cold by a reversible air to water heat pump integrated by condensing boilers and of the working of the HVAC plant. All the measured data are shown on the computer of the management central position. They are visualized on the screen by maps which permit the operator to control the working conditions and also to modify the set-point values (Schibuola and Tambani, 2009). In Figure 4 the maps relative to a roof top AHU (a) and to one internal AHU (b) are shown. The visualized data are also recorded and in this way the supervisory system has permitted the long term monitoring used for the investigation here presented.



a) b)

Figure 4: Supervisory screenshots for roof top AHU (a) and internal AHU (b)

3 DESIGN OF THE VENTILATION PLANT

The realization of the classrooms is simply based on the modularity of the rooms just present in the warehouses. With a module of 57 m^2 is obtained a classroom for 45 students, with two modules for 90 and 180 seats with four module classrooms. For each classroom the specific presence is 45/57=0,79 persons per m^2. This is a value well above the average. For example the Italian standard UNI 10339 (UNI 10339, 1995) establishes a normal crowding of 0.60 pers/m^2 in the classrooms. This high value is a consequence of a precise requirement of the customer. Consequently for each internal AHU the design ventilation rate is 45x25=1125 m^3/h coming from one of the roof top AHU. In fact the ventilation quota per person is assumed to be the typical value of 25 m^3/h (7 l/s). In the end the total design ventilation rate of the building is 44000 m^3/h equally divided in the two roof top AHUs.

The high design ventilation rate and the variability of the crowding have therefore suggested the introduction of a demand-controlled ventilation (DCV) which is easily managed by the central supervision. In fact between the environmental parameters controlled for each internal AHU there is also the carbon dioxide concentration which leads the ventilation rate by the modulation of the aperture of the two motorized valves. At this moment the set-point value is 850 ppm for the CO_2 concentration measured in the return plenum box of each internal AHU. In detail the modulating valves completely open at 900 ppm and close at 800 ppm. In fact international standard (ASHRAE, 1989) recommends to maintain the internal concentration of carbon dioxide under 1000 ppm. However a minimum aperture share equal to 10% of the total is always foreseen in order to ensure a minimum air flow rate, about 0.5 ach, during the working hours. It is important to remark again that the set point of the CO_2 concentration for each AHU can be easily changed by the manager of the building plant on the basis of the requests of the users. Simple, robust and economic motorized air-tight butterfly valves have been installed and their aperture level is controlled by an electric signal coming from the central BMS.

4 EXPERIMENTAL RESULTS

The long term monitoring of the plants enabled by the building management system has provided the performance data of DCV in all the classrooms. As an example the figure 5 shows the average working conditions measured in a classroom during the school hours of a typical week. The extreme variability of the measured CO_2 concentration confirms a presence very variable and the difficult of prediction in advance. This fact is a practical demonstration of the advantage to adapt constantly the ventilation rate to the actual requirement. In addition it can be observed how it is sometimes necessary to have the total design ventilation rate as the set point value of 900 ppm fixed is exceeded. Later it will be shown as this excess is also connected to the choice of the parameters of the control system. In the bottom of figure 5 are reported the opening quotas of the valves modulating the ventilation. A high modulation can be verified. In detail it is significant that sometimes the minimum foreseen opening level (10%) is anyway able to ensure a carbon dioxide concentration within the limits. Conversely, however the total opening is sometimes not enough as already noted in the upper part of the figure 5.

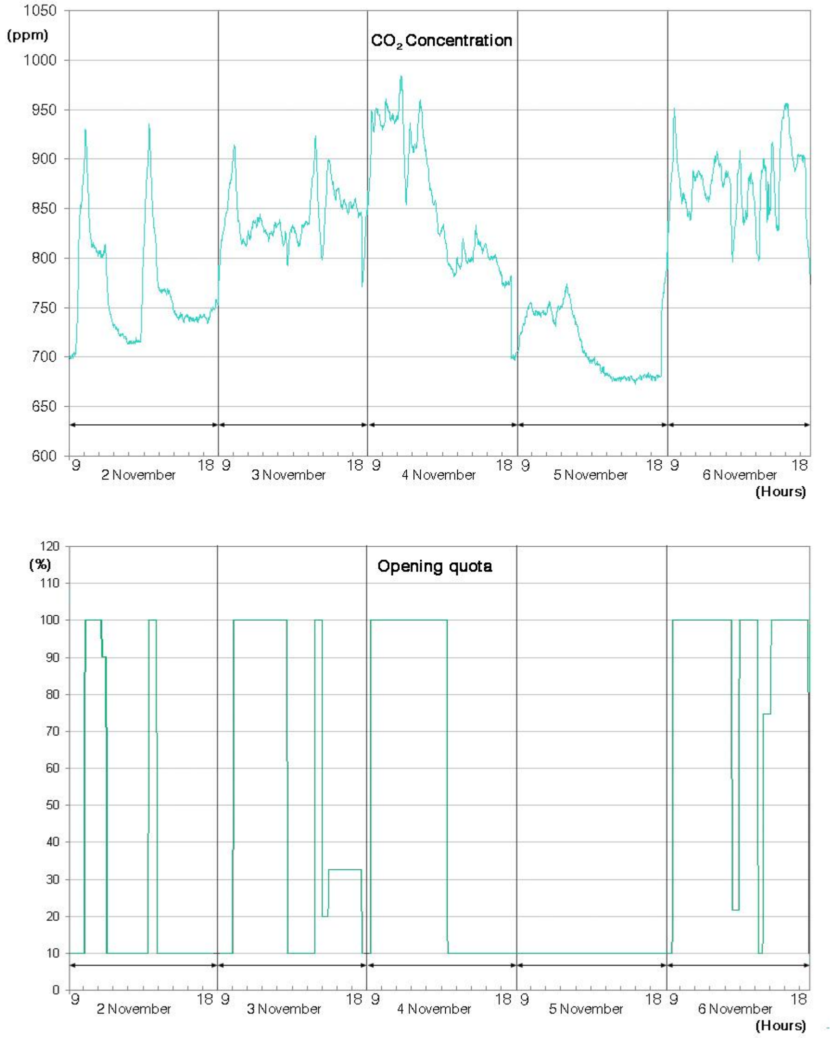


Figure 5: Trends of the CO_2 concentration (ppm) in a classroom during the working hours of a typical week (above) and the corresponding opening quota (%) of the ventilation valves (below)

In figure 6 are shown the occurrence frequencies, in percentage, of the total working hours, when the values of the CO_2 concentration are in the indicated intervals. These values are obtained by measurements recorded every ten minutes at the same time in ten classrooms for various months. It can be observed that the flexibility of the ventilation rate is able to ensure almost always a concentration within the limits fixed and in any case lower then the limit value suggested by the standard (1000 ppm).

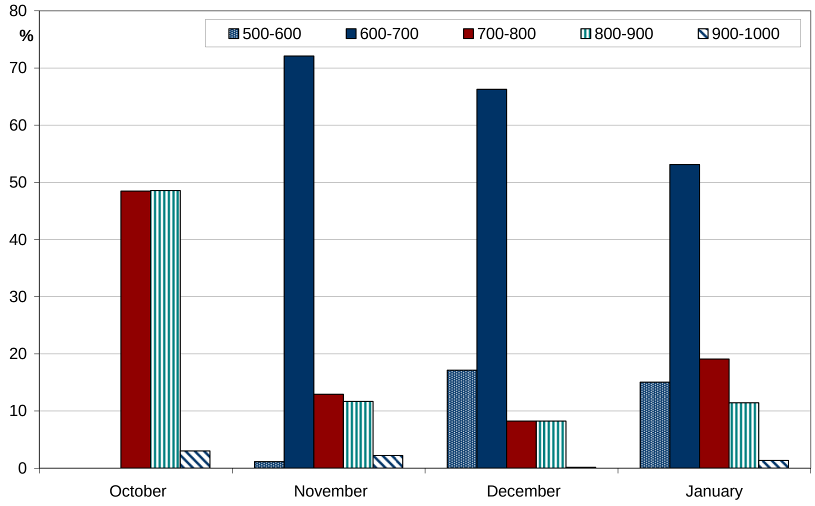


Figure 6: Time occurrence frequencies (%) of the CO_2 concentration (ppm) within different intervals in ten classrooms for three months The percentage is referred to the total of the working hours.

In addition, in December and January, it can be verified a reduction of the frequency of exceeding of the limit of 900 ppm thanks to an optimization of the control parameters obtained in this period and here explained in the next section. For example the frequency of exceeding of the limit goes from 3% in October to 1.4% in January. Figure 7 reports the means of the opening quotas (%) of the ventilation valves during the working hours recorded every minute for three classrooms in the months of November, December and January.

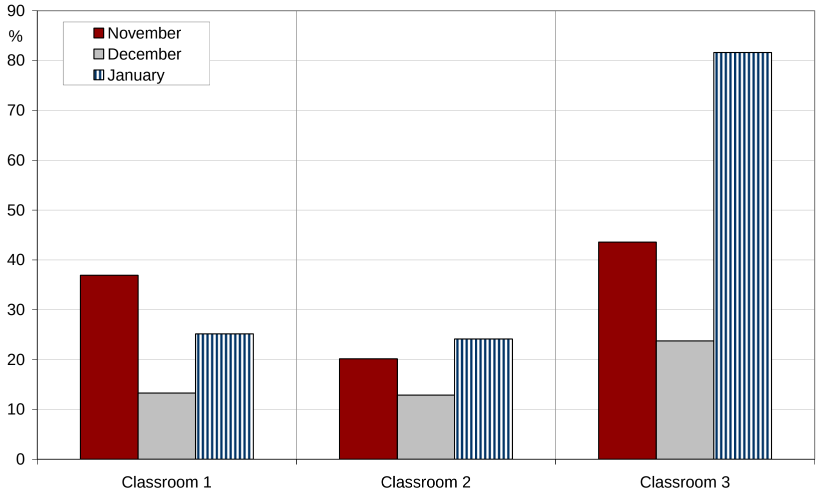


Figure 7: Means of the opening quota (%) of the ventilation valves recorded every minute for three classrooms

It can be noticed again the extreme variability of the opening quotas for each classroom which highlights the different ventilation requirement which characterizes the same classroom in different period. The high average of the opening quotas of classroom 3 (81.6%) in January demonstrates the exigency to have sometimes strong ventilation rate for long periods and at the same time reduced rates in the other classrooms. In total of these three months the averages for the three classrooms of the percentage of opening are respectively 34.3%, 16.5% and 43%. The total average amounts to 31.3%. It is therefore evident the high energy saving which can be achieved if compared to the case of a constant ventilation flow rate.

5 OPTIMIZATION OF THE CONTROL PARAMETERS

The BMS installed in this building adopts a PID control to modulate the ventilation valves. The proportional-integrative-derivative control is a negative feedback system widely used in

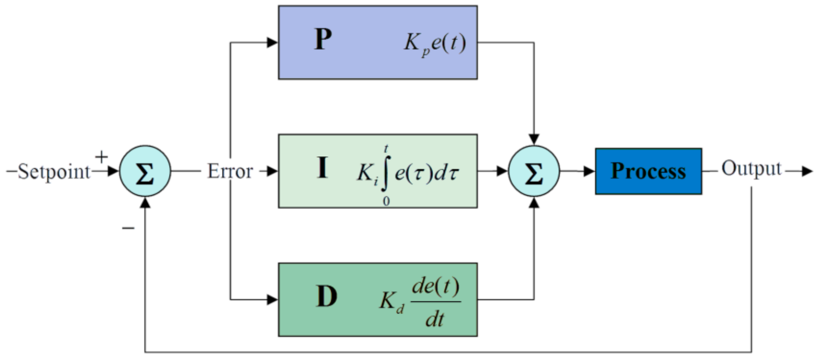


Figure 8: Scheme of a PID controller

control systems. The three actions of a PID controller are calculated separately and simply algebraically added as shown in figure 8.The choice (tuning) of the parameters K_p, K_i, and K_d can be based on experience or on the use of simplified methods (Ziegler and Nichols, Cohen and Coon or others). In the case of the BMS of the Procuratie 5 and 6 the programmers had no experience about DCV so we found butterfly valves which operate only in on-off control as the differential hysteresis was initially very little (5 ppm) causing a continuous and unacceptable oscillation between complete opening and closing. Therefore our first action was to choose a differential value appropriate for a modulating working. Even with the installation of simple butterfly valves, the presence of servomotors with proportional control has permitted to use the opportunity offered by the PID control implemented in the BMS also for the valve control system. But in this case the installed BMS allows the final user to act only on the set value of parameter K_p (gain). However this tuning was absolutely necessary as the initial value of the gain was equal to 1 (maximum possible value) and it showed to be not suitable for this application. Traditionally in cases like this it is usual to employ dedicated tools which require specialized personnel. But, exploiting the opportunities of the simplicity of the user interface typical of these modern BMS, it can be possible for the usual manager of the building to intervene directly adjusting the control values to the needs of the end users. By monitoring the response of the ventilation system, in terms of indoor comfort parameters as consequence of different set values for K_p, it was possible to individuate a more appropriate value.

In the figures 9 and 10, respectively for a classroom with average occupancy and one with a strong occupancy, are reported above the trends of CO_2 concentrations (ppm) and below the corresponding trends of the opening quota (%) of the valves. In each figure two different trends are compared obtained in two similar day (same occupancy) in the same classroom with two different values of K_p. In detail it is reported the working mode obtained with K_p equal 1, as originally set, and with K_p equal to 0.5 which is the best value among those tested.

The best performance is due to a better modulation. In fact with K_p equal to 1 there is a more drastic intervention with an increase of the oscillation.

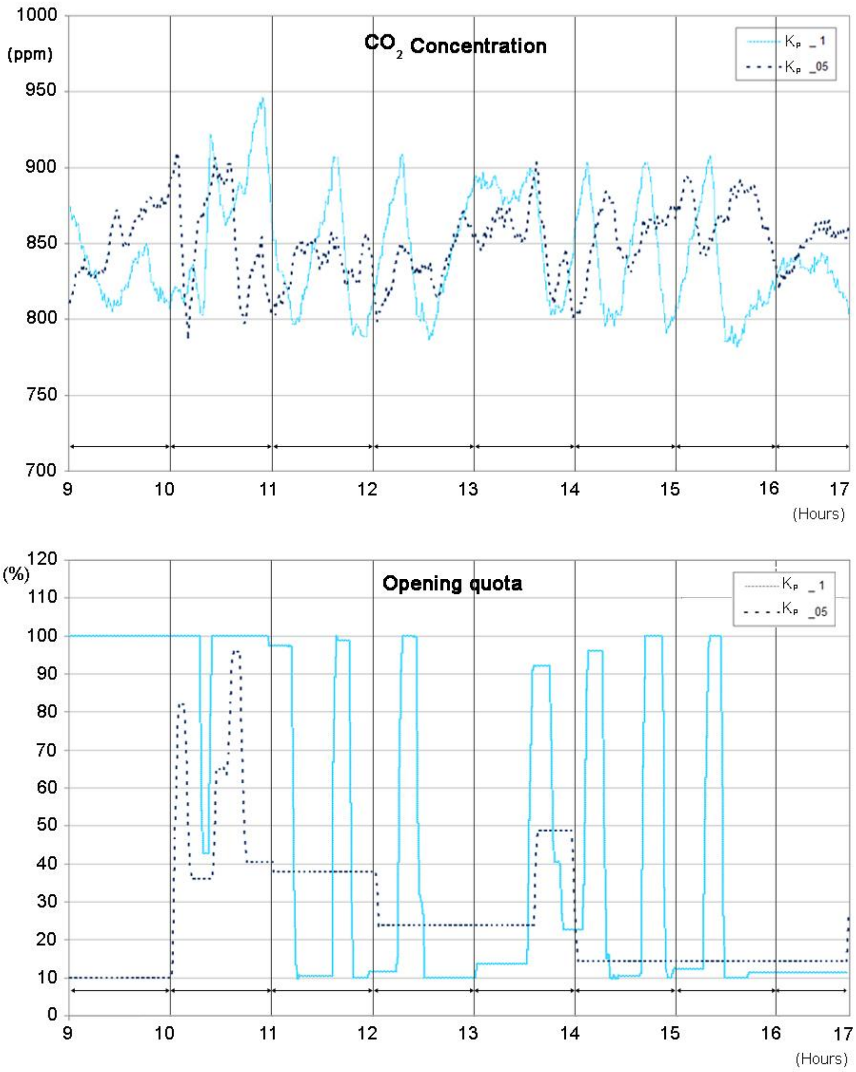
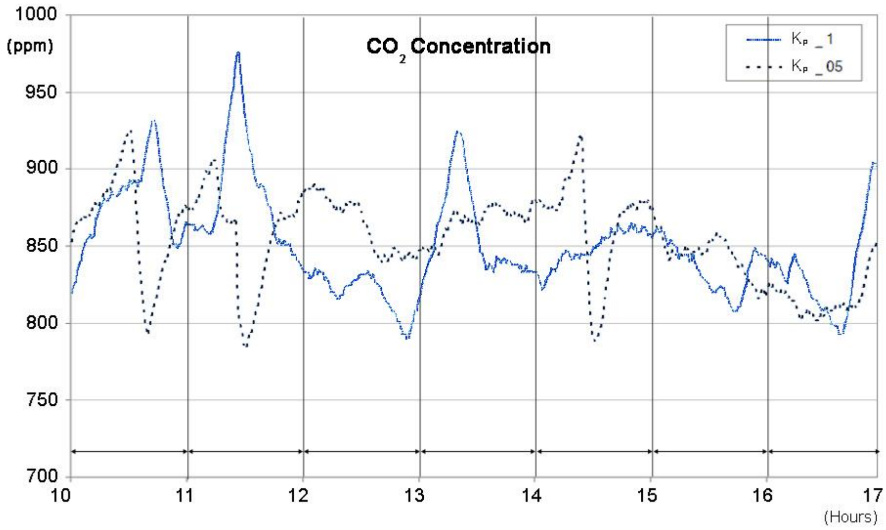


Figure 9: Comparison of the trends of CO_2 concentration (ppm) in a classroom during the working hours of two days with similar crowding but two different K_p value: 0.5 and 1,(above) and corresponding opening quota (%) of the ventilation valves (below). The values refer to a classroom with average occupancy.

Instead with K_p equal to 0.5 there is a control that more closely follows the demand. In this way it is avoided an excessive opening, if compared to the need, that moreover it is sometimes delayed. This involves a poorer control of the peaks about the limit of 900 ppm. This fact is already evident in the comparison reported in these two last figures, but in reality it is much more significant at monthly levels in the values reported in figure 6 where, as already announced, there is a clear reduction of the occurrence frequencies over 900 ppm after the adjustment with K_p equal to 0.5 in two months (December and January) if compared to the previous months.

Overall for the classroom of figure 9, in the two days with about the same occupancy there is an average opening of the valves equal respectively to 49.6% with K_p of 1 and 25.7% with K_p 0.5. In the case of strong occupancy of figure 10, there is an average opening of the valves equal respectively to 81.7% with K_p of 1 and 51.1% with K_p 0.5. Therefore thanks to the setting optimization there is a considerable reduction in the ventilation flow rate amount with a control of the CO_2 concentration even better.



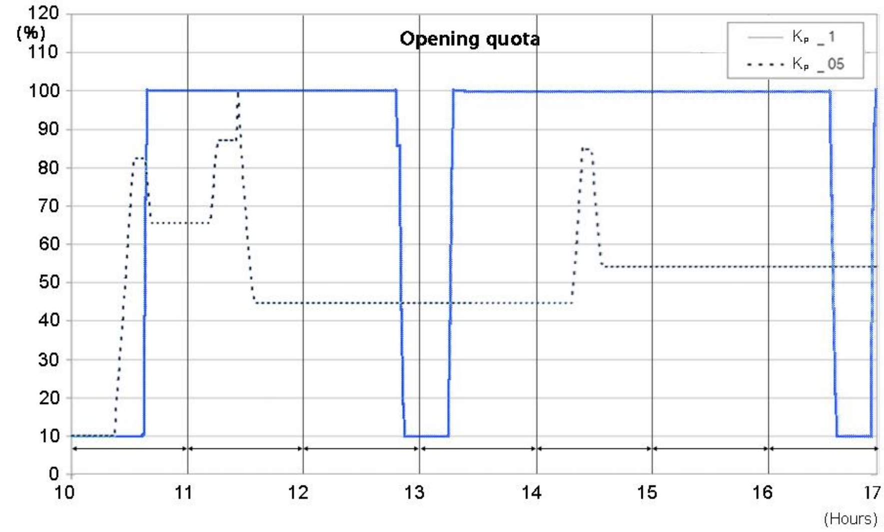


Figure 10: Comparison of the trends of CO_2 concentration (ppm) in a classroom during the working hours of two days with similar crowding but two different K_p value: 0.5 and 1,(above) and corresponding opening quota (%) of the ventilation valves (below). The values refer to a classroom with strong occupancy.

6 CONCLUSIONS

School buildings are particularly suitable to take advantage from a variable ventilation rate by an automatic control based on CO_2 sensors. Therefore especially in this case a careful management of the plants permits to achieve relevant energy and economic savings also in historic buildings subject to monumental restrictions. But a correct tuning of the parameters of the control systems is fundamental to optimize the working of the plant. In presence of a user friendly BMS, monitoring can permit an investigation of the real operating conditions of the ventilation plant in order to achieve this optimization.

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