Ventilation Problems in Heritage Buildings

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Abstract: - The control of indoor conditions in heritage buildings, such as castles or museums, is of paramount importance for the proper preservation of the artworks kept in. As heritage buildings are often not equipped with HVAC systems, it is necessary to provide proper interventions and measures with the aim of monitoring and controlling indoor physical parameters. Moreover, another requirement should be achieved in such buildings, that is the maintenance of the safety conditions in presence of visiting people. This work reports the results of a survey carried on a hall of a historical palace, aimed to assess an useful correlation between CO_2 concentration and occupancy levels.

Key-Words: IAQ; CO_2 Concentration; Ventilation; Heritage Buildings

1 Introduction

Buildings having a great historical and artistic importance are characterized by large surfaces, high ceilings and narrow openings, peculiar characteristics that contribute to create a particular environment and impose specific design and control methodologies. These buildings, often containing exquisite artworks, house conferences and seminars; therefore the preservation of artistic goods and the internal comfort conditions have to be guaranteed at the same time.

Environmental surveys are fundamental since they allow to get information on possible improvements aimed at satisfying comfort and conservation needs, obviously without altering the environment artistic features. However is not always possible to fit out an historical building with a new conditioning and/or ventilation equipment; in such a case the best solution is to advice the managerial body on alternative interventions such as changing or limiting utilization modalities.

As far as microclimatic parameters are concerned, Italy is provided with a set of rules for the correct conservation of artworks having a high historical-artistic value that can be certainly considered innovative when compared to those in other countries all over the world [1] [2] [3].

The new Italian Standards - UNI 10829 [4] and UNI 10969 [5] – besides giving the guidelines to choose and control indoor microclimate in order to correctly keep artworks, candidate themselves as a methodology to analyze and to evaluate thermo-hygrometric and lighting conditions,.

According to this new approach, the rules give some ‘recommended’ values only in appendix, suggesting to use them only in absence of other references.

In detail, the UNI 10829 Standards [4] describe the procedure for collecting information on the climatic history of the artworks, suggest an environmental analysis methodology and give useful instructions in order to decide if the artworks are correctly kept without any risks of deterioration.

As far as historical building ventilation is concerned, given the architectonic characteristics of the considered environments, the above mentioned standards could result insufficient.

A forced ventilation system – not always applicable in environments containing a lot of art pieces - must designed also considering that those halls are not continuously occupied and that they are crowded only in restricted periods.

The main international norms (EN 13779, 2003, and ANSI/ASHRAE Standard 62, 2001,) furnish two different ways to evaluate the acceptability of an environment [6].

Referring to ASHRAE Standard 62.1 [7], that is the most recent normative for commercial, institutional and high-rise residential buildings, the environment air quality can be usefully judged referring both to human health purposes ('Indoor Air Quality' procedure) or to comfort purposes ('Ventilation rate' procedure).

The first procedure ('*Indoor Air Quality*') is based on the concentrations of chemicals toxic to humans, whereas the second ('*Ventilation Rate*') requires the knowledge of the amount of outside ventilation air, essentially referred to people utilization levels and based on considerations of a physiological and personal type and on the expert judgments [8].

In detail, the Indoor Air Quality Procedure requires that minimum ventilation rates be determined on target contaminant concentrations and specified occupant satisfaction levels.

The Ventilation Rate Procedure requires a minimum outdoor fresh airflow in breathing zones based on both a per-person and a per-unit-area rate.

Indoor CO_2 concentrations have often been described and used as an indicator of indoor air quality [9] [10]. In fact, as people exhale CO_2 depending on their activity level, CO_2 concentrations could be used as an indicator of the room's occupancy level [11].

Then CO_2 concentrations can be considered good indicators if referred to gaseous pollutants of various nature and origin.

However it must be highlighted that CO_2 concentrations in closed rooms cannot be always correctly used [12] [13]; in fact they are altogether insufficient when referred to organic or inorganic submicronic particle pollutants coming from the outside (car traffic and so forth) and the inside (cigarette smoke).

2 CO_2 concentration measurements

At the beginning of 2002, the Chancellor of the University of Palermo entrusted our workgroup with the task of verifying indoor climatic conditions and air quality of several halls particularly relevant for their artistic merits, located in the Chiaramonte Palace formerly known as 'Steri', seat of the Chancellorship [14] [15] [16] [17].

Among these rooms the 'Sala dei Baroni' (Hall of Barons) is particularly relevant for the marvelous painted wooden ceiling dating back to the XIV century [18]. The hall is 27,3 meters long, 8,5 meters wide and 8,70 meters in height (Fig. 1) and it is currently used for conferences and meetings.

In order to measure the indoor and outdoor CO_2 concentrations have been used specific sensors whose characteristics are reported in Table 1.

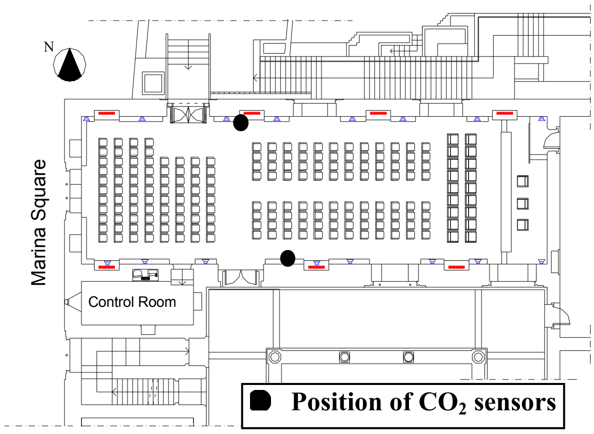

Figure 1: Plan of the Hall of Barons

Carbon Dioxide Measuring Probe LASTEM Mod. BSO103	
Measuring Element	Infrared absorption cell
Measuring Field	0 – 3000 ppm
Repeatability	1 % of range
Response Time (T90)	< 30 sec
Resolution	1 ppm
Zero Shift between +20 and	0,1 % of range/°C

Table 1: CO_2 sensor characteristics

Figure 2 shows, as an example, the daily course of the outdoor CO_2 concentration in July 15th 2004. The curve highlights the increase of the average level of CO_2 concentration during the night in spite of the decrease of the city traffic.

This is probably due to the effects of the magnificent and age-old "*Ficus magnolioides*" in the near Garibaldi Garden.

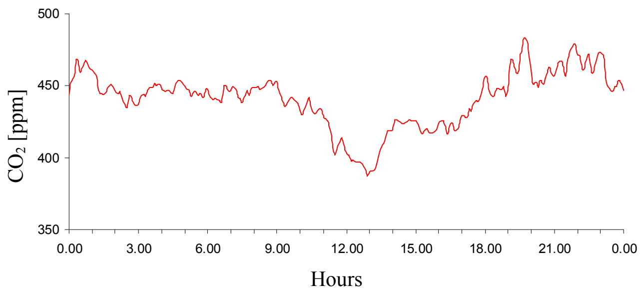

Figure 2: July 15th 2004 – Outdoor CO_2 concentration course

The indoor CO_2 concentrations can be evaluated as a function of time using Meckler equation [19]:

$$C_{in}(t) = C_{out}(t) + (C_o - C_{out})e^{-(Q_v t / V)} + \frac{G}{Q_v}\left[1 - e^{-(Q_v t / V)}\right] \quad (1)$$

where:

$C_{in}(t)$ = indoor CO_2 concentration [ppm] at the instant t

$C_{out}(t)$ = outdoor CO_2 concentration [ppm] at the instant t

C_o = re-circulated CO_2 concentration [ppm] from HVAC system

Q_v = outdoor airflow rate into the zone [l/s]

G = CO_2 generation rate in the zone [l/s]

In equilibrium conditions the equation yields [10] [20]:

$$Q_v = \frac{G}{C_{in} - C_{out}} \quad (2)$$

The above equation holds if the following conditions are met:

1. CO_2 measurements should be taken in 'steady-state' condition, or when the internal concentration not fluctuate over 100 ppm;
2. Outside CO_2 concentrations are constant;
3. Human respiration rate is the same for all occupants, regardless of age, sex, size, diet, health, etc.

These requirements considerably limit the applicability of the concentration balance technique. In spaces where large, abrupt changes in occupancy (and hence in CO_2 levels) can occur, this method may prove unreliable.

The Hall of Barons is often used for university personnel training courses.

The presence is compulsory and people involved are not allowed to leave the hall during course sessions; even lunch is provided in the hall.

It implies that, for many days, the hall will have very long periods (thus reaching steady-state conditions) of constant level of occupancy with a homogeneous group of persons all involved in the same activity.

This fortunate combination of events allowed us to use the Meckler equation in our application.

3 Methodology

Into the Hall of Barons air renewal is provided by natural ventilation only. The hall can hold up to 200 people and therefore, in tightly packed conditions, the indoor air quality, particularly with low ventilation rates, could become unsatisfactory causing drowsiness, fatigue or headaches.

With the aim of assessing the ventilation rates inside the hall, the authors used the data recorded by the acquisition system they had set up within the context of the task given by the Chancellor [14] [21] [22] [23].

Some particularly meaningful days – well suited for calculating the internal ventilation rates - were chosen, in particular those days when the inside conditions turned out to be such as to fulfill the hypotheses required for the balance equation.

The ventilation rate assessments were determined by using equation (2) on the basis of the knowledge of the indoor and outdoor CO_2 levels, by repeatedly counting people in the hall and waiting for the steady state conditions.

The activity level was assumed 1 met for everybody (seating, quiet) and, as a consequence, the CO_2 emission rate was assumed 0,0045 l/s·person. Then the results from the calculated ventilation rates were introduced in Meckler equation (1) to evaluate the inside, instantaneous CO_2 concentrations. Successively they were compared with the measures achieved through the sensors.

The good correspondence between measured and calculated results allowed us to determine the natural ventilation rates in the hall under different conditions. The knowledge of the smallest and the highest ventilation values allowed us to apply the balance equation in other situations similar to those used to evaluate the ventilation rates. The occupation values obtained from equation (2) were compared with the ones got from counting the number of people present in the hall, thus achieving a correlation between the measured CO_2 levels and the occupant number.

The possibility to estimate the expected CO_2 concentrations from the number of people present in the room allowed us–through the percentage of Dissatisfied People PD - to estimate the air quality and to furnish indications on the maximum number of people that can occupy the hall under comfort conditions.

4 Results

Figures 3 and 4 show, as examples, the time behaviour of the CO_2 concentrations inside the Hall of Barons along with the measured values.

The figures show the good correspondence among the calculated and measured values and put in evidence the occurrence of the steady state conditions.

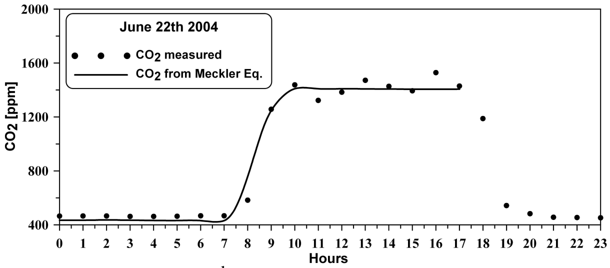

Figure 3: June 22nd 2004 - Measured and calculated CO_2 levels in the Hall of Barons

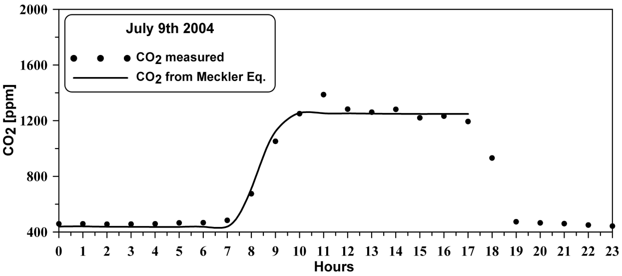

Figure 4: July 9th 2004 - Measured and calculated CO_2 level in the Hall of Barons

Table 2 summarizes the ventilation rate values calculated by means of the Mass Balance Equation at the days chosen for this investigation.

The Table reports the number of people, the total ventilation rate, the ventilation rate per person and the estimated air changes.

From data reported in Table 2, it is possible to note that the natural ventilation rates range from 7,17 l/s·person to 3,38 l/s·person. These values allow us to give a correlation between the number of people present in the Hall and the CO_2 concentration.

Date	People	Vent. [l/s]	Vent. [l/s·person]	AC/h
12/05/04	102	605	5,93	1,08
22/06/04	152	698	4,59	1,25
9/0704	137	749	5,50	1,34
7/10/04	210	710	3,38	1,27
19/12/04	111	796	7,17	1,42

Table 2: Calculated ventilation rates

The validity of the correlation between the number of occupants and the carbon dioxide concentrations was tested by applying the balance equation (2) during 13 days, when the Hall was being used for seminars or training courses for the university personnel.

In figure 5, the actual number of people present in the hall is plotted against the number of people present in the hall calculated through CO_2 concentrations for the two aforementioned extreme ventilation conditions.

The graph shows the good correlation between the counted number of occupants and the provision made through the maximum and the minimum ventilation rates along with the linear best fit for both sets of data.

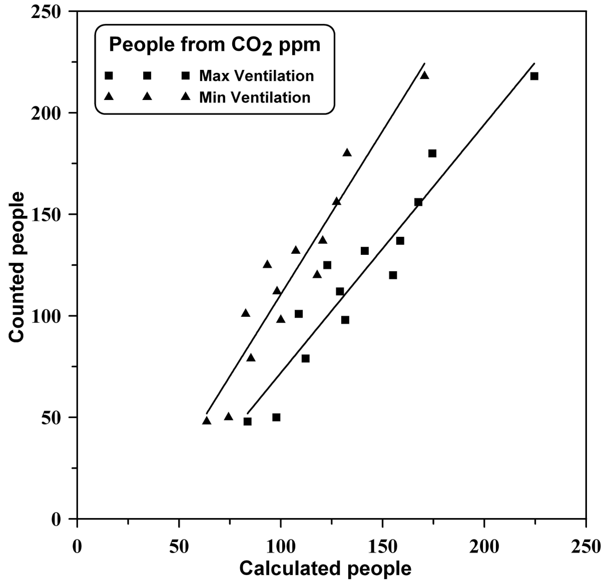

Figure 5: Measured and calculated occupancy levels

Being able to calculate CO_2 concentrations inside the Hall through the number of people present in it, also allowed us to evaluate the Percentage of Dissatisfied PD through the following equation:

$$\Delta CO_2 = 167353\ [\ln(PD) - 5.98]^{-4} \quad (3)$$

Relation (3) holds for standard conditions, i.e. for "adapted" occupants; the dissatisfaction degree is certainly greater for "unadapted" individuals, i.e. for those who are coming in from the outside.

In this case the Dissatisfied Percentage PD can be calculated by the relation:

$$\Delta CO_2 = 55833\ [\ln(PD) - 5.98]^{-4} \quad (4)$$

The correlations in figure 6 allow to calculate the dissatisfied percentage inside the Hall of Barons as a function of the crowding degree, the adaptation states and for the maximum and minimum ventilation conditions.

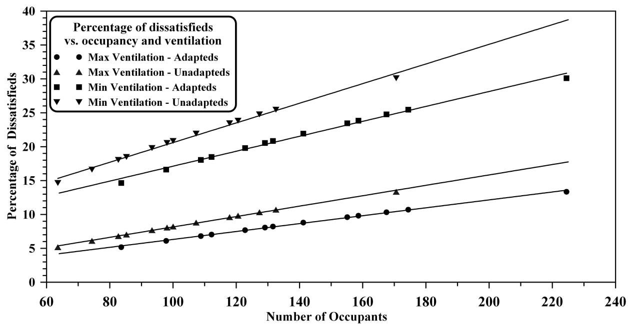

Figure 6: The Hall of Barons: dissatisfied people percentage as a function of the occupation level

5 Conclusions

This paper presents the results of a survey carried out by the Authors in a Hall of the Steri Palace, seat of the Chancellorship of the University of Palermo.

The experimental results presented here are framed in the context of a wider survey carried out by the authors in several halls of 'Palazzo Steri. The survey, still ongoing, has as objective the correct conservation of the artistic goods in the Hall of Barons, one of the richest halls of Palazzo Steri

The graphs and tables highlight that the Hall of Barons doesn't meet the minimum conditions required by the more recent recommendations.

In fact, the results obtained so far singled out the lack of an adequate ventilation level and have allowed us to draw an interesting correlation between CO_2 and occupancy levels, which can provide useful suggestions for corrective designs.

In conclusion, without a forced ventilation plant, it will be necessary to restrict the occupancy level on the basis of the drawbacks outlined in this paper; moreover the results here presented allow us to plan the actions and the appropriate procedures aimed at the preservation of the artworks and the enjoyment of them.

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