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Performance optimization of a demand controlled ventilation system by long term monitoring

Luigi Schibuola*, Massimiliano Scarpa, Chiara Tambani

University IUAV of Venice, Dorsoduro 2206, Venice 30123, Italy

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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 of HVAC systems, especially when the ventilation demand is significant. A correct energy saving strategy therefore should always focus on the use of suitable techniques to reduce this energy consumption. As proved by the modern theories on comfort, less strict values can be accepted for the internal humidity set points without compromising indoor comfort conditions. In addition, Demand Controlled Ventilation (DCV) gives the opportunity to reduce energy requirements. This paper investigates the opportunities offered by the installation of a DCV system and a Building Management System (BMS) able to perform long term monitoring of the HVAC system in a real case study. This refers to a historic building in Venice in the area of the harbour and recently transformed into a modern university facility. Starting from the experimental data recorded by BMS, an optimization of the control strategies and simple tuning actions of the DCV controller were possible. Results validate the use of more flexible set points of indoor relative humidity and long term on-line tuning even in absence of self-learning control systems, as well as they highlight the achievement of remarkable energy savings thanks to these actions. The research demonstrates the fundamental contribution of successive control performance assessments by long term monitoring to individuate possible weaknesses in DCV system management.

1. Introduction

In the recent past the environmental emergencies focused the efforts towards the fundamental goal to achieve NZEB condition especially in the refurbishment of existing building. But nowadays, the necessity to combine energy saving with the increasing interest for better indoor comfort and air quality is become a very relevant topic [1,2]. In Europe, people stay in indoor environments about 90% of the day [3]. Air pollution has such a concentration in indoor environments that causes adverse health effects especially in case of long exposure periods as shown in [4] and [5]. Indoor air quality (IAQ) is an important public health problem causing social and economic consequences as proved in [6,7]. This is especially true in school buildings [8]. As a consequence standards about IAQ have become increasingly strict [9], corresponding to higher ventilation flow rates. [10]. On the other hand in modern buildings the envelope is highly insulated and airtight, thus leading to the reduction of natural ventilation flow rates [11]. Therefore the use of mechanical ventilation, ensuring appropriate air change rates, is spreading. Consequently the energy demand for ventilation air handling grows and often becomes the prevailing share in the total energy required by heating, ventilation and air conditioning (HVAC) systems [12]. Therefore, especially in buildings characterized by highly variable attendance as in the case of educational buildings considered in this study, a precise information about the actual occupancy patterns permits to elaborate ventilation strategies [13] and operational tools [14] to achieve significant energy savings.

The exigency to optimize energy requirement for ventilation becomes even more strategic in the case of historical buildings subject to preservation order. Here the impossibility to modify the envelope obliges the designer to reduce energy consumption by focusing on ventilation and HVAC system management in order to achieve an energy saving retrofit . Otherwise the refurbishment of historical buildings for modern uses would be difficult to accept in terms of energy consumption and operating cost [15–17]. Therefore, a suitable building management system (BMS) becomes fundamental to achieve the lowest energy consumption without compromising indoor comfort conditions, as noted in [18] and [19], especially when operating by means of demand controlled ventilation (DCV) [20]. In particular, CO_2-based DCV [21] may enable easy real time adaption to current occupancy especially when characterized by strong variability, as proved in [22–24]. In this context, this paper focuses on the new potentialities offered by modern BMS today easily able to collect a great data flow for long periods to help energy/facility managers to redesign strategies in each appli-

* Corresponding author.
E-mail address: luigi.schibuola@iuav.it (L. Schibuola).

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Nomenclature

Abbreviations

HVAC	Heating Ventilation Air Conditioning
DCV	Demand Controlled Ventilation
BMS	Building Management System
BIM	Building Information Modeling
IAQ	Indoor Air Quality
DSM	Demand Side Management
NZEB	Nearly Zero Energy Building
AHU	Air Handling Unit
VSD	Variable Speed Drive
PI	Proportional Integrative
PID	Proportional Integrative Derivative
CPA	Control Performance Assessment
PMV	Predicted Mean Vote
PPD	Predicted Percent of Dissatisfied
RH	Relative Humidity

Symbols

n	actual rotor speed [rpm]
n_{full}	full air flow rate rotor speed [rpm]
n_0	asynchronous speed [1500 rpm]
f	line frequency [Hz]
p	number of poles [4]
s	slip [–]
$\dot{V}$	air flow rate [m^3/s]
$\dot{V}_{full}$	full air flow rate [m^3/s]
ρ	air density [kg/m^3]
h_i	inside air enthalpy [J/kg]
h_o	outside air enthalpy [J/kg]
q	ventilation load [W]
k_p	proportional gain [–]
k_i	integrative gain [–]
k_d	derivative gain [–]
T_i	integral time [min]
T_d	derivative time [min]

cation case. Adopting a case study approach, this study investigates the ability of this method to individuate specific shortcomings in a DCV system and to resolve them by simple tuning actions usually undervalued in traditional HVAC control system. In detail, the paper treats the actual issue of the optimization of ventilation systems [25] by using the approach of the demand side management (DSM) [26–28]. In this case by CO_2-based DCV and satisfaction index evaluation with a particular care to the possibility of a performance improvement by using long term monitoring to optimize control parameters The outcomes are based on a monitoring campaign carried on in the context of the energy retrofit of an historical building in Venice. The acquired experimental data allowed the authors to optimize the use of the DCV system by: i) analysis of the operative mode, ii) control performance verification and consequent tuning intervention, iii) test of more flexible humidity control strategies by assessing the effect on energy demand of different set points, both in winter and summer. In spite of its potentiality, this technique is still poorly used in practice, because it lacks of experimental verifications in different application contexts. In this scenario a case study is here presented to provide a contribution to spread awareness of the advantages resulting from its systematic application.

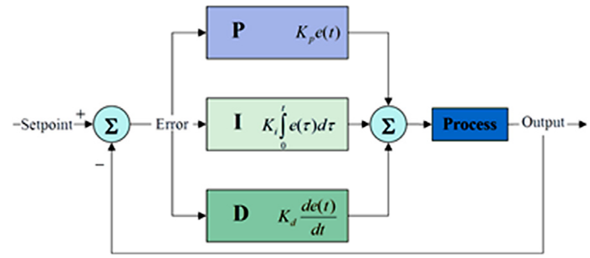

Fig. 1. Scheme of a PID controller.

2. Background

BMS is normally intended only for control and management of the operation of HVAC system. Conversely, this study evaluates the opportunities of a generalized use of a BMS also designed to measure and to record all the data necessary for a complete analysis of the indoor environment and energy performance.

Data collection by using BMS to improve the design and operation of buildings is a hot research focus. The recent developments of data science underline the increasing opportunities of its application in the area of building energy management [29]. By collecting data concerning building operation, it is possible to proceed to the elaboration and consequent validation of management strategies adapted to the particular application case [30]. For this reason, this approach concerns the active control of energy-dependent systems in the operation phase of the building. Naturally also the design stage offers the opportunity to influence deeply future energy performance. In this framework, building information modeling (BIM) can play an important role. In fact modern BIM permits to take advantage of the integrated design data in order to evaluate the expected results in term of building performance and energy consumption [31]. The use of BIM also in the post-construction phase is a research topic in rapid development, but it requires to bridge existing gaps between design and operation phase of the building. To achieve this goal, it is necessary to integrate the technological advances in BIM with a BMS specifically designed for a systematic experimental data collection [32–34]. The potential of a BMS applied to building performance visualization and optimization is therefore investigated here.

Long term monitoring by BMS is proposed as a tool to assess and optimize DCV control performance even in the case of traditional PID control systems which remain the most diffuse in HVAC applications [35], rather than other more sophisticated controllers. The aim is the experimental validation of the contribution in energy retrofit of on-line tuning actions, simple but based on long term analysis, possible in all standard PID systems. To point out their advantages in the existing building, today usually underestimated and therefore neglected in refurbishment projects.

Unlike temperature and humidity control, sudden and wide oscillations are usual around the set point value of CO_2 concentration. This is a peculiarity of CO_2-based DCV, since actual ventilation demand is often more dynamic than the DCV system operation, which is characterized by the inertia of the response of the room control and of the mechanical components involved in the air flow rate modulation. For this reason, new control algorithms were proposed based on adaptive or genetic approaches such as [36–38]. But the simpler PI and PID controls are still the most popular and widespread in usual applications for HVAC systems [39,40]. In the analysed building a PID control modulates the ventilation dampers with a negative feedback strategy. The three actions available in PID controller are calculated separately as shown in Fig. 1 and simply added algebraically [41]. As every controlled process has unique characteristics, the choice (tuning) of the parameters K_p, K_i, and K_d requires a field testing of the values previously determined