Available online at www.sciencedirect.com

ScienceDirect

Procedia Computer Science 130 (2018) 926–931

Procedia Computer Science

www.elsevier.com/locate/procedia

9th International Conference on Ambient Systems, Networks and Technologies, ANT-2018 and the 8th International Conference on Sustainable Energy Information Technology, SEIT 2018, 8-11 May, 2018, Porto, Portugal

Towards an Intelligent Approach for Ventilation Systems Control using IoT and Big Data Technologies

F. Lachhab[a,b,*], M. Bakhouya[a], R. Ouladsine[a], M. Essaaidi[b]

[a]*International University of Rabat, Faculty of Computing and Logistics, ECINE, TICLab Technopolis, Sala El Jadida, Morocco*
[b]*ENSIAS, Mohammed V University Rabat, Morocco*

Abstract

Heating, ventilation and air conditioning systems are generally deployed in buildings for maintaining occupants' comfort. They are the most considered systems in improving the energy saving while sustaining occupants' comfort. Several approaches have been proposed, in the past few years, to develop an optimal control for ventilation systems. However, these approaches could not be efficiently performed under diverse contexts. In fact, we introduce an intelligent approach that selects the most appropriate control among three existing strategies. This paves the way to approaches in which an antifragile platform learns and adapts which strategy to enact. The proposed approach is implemented using IoT devices and recent Big-data technologies for real-time monitoring and data processing. A case study was deployed in our EEBLab test site for real testing. Experiments have been conducted and preliminary results show the effectiveness of using adaptive control approaches for ventilation systems control.

Keywords: EEB; ventilation system; algorithm's selection; real-time processing; IoT and Big Data Technologies.

* Corresponding author. Tel.: +212-064-285-3793.
E-mail address: fadwa.lachhab@uir.ac.ma

1877-0509 © 2018 The Authors. Published by Elsevier B.V.
Peer-review under responsibility of the Conference Program Chairs.
10.1016/j.procs.2018.04.091

1. Introduction

Buildings consume over 40 percent of the total energy consumption. Among Building's services, Heating, ventilation and air conditioning (HVAC) systems are generally used for maintaining occupants' comfort, but they are the most considered systems in improving the energy saving[1]. In this work, we focus on standalone ventilation systems, which are highly energy demanded if not well controlled[2]. Several approaches have been proposed, in the past few years, to develop optimal control for ventilation systems. These approaches could be categorized into two main families: static and dynamic control approaches. Static approaches operate at a fixed rate based on either time-triggered or fixed threshold values. The fresh air is injected into the specific area by varying the ventilation rates, but this injection could result in higher energy usage with humidity increases, which could affect the indoor air quality. However, dynamic approaches use contextual data to adjust the ventilation rates accordingly. These approaches consider that wireless sensors network technologies could be integrated with context-driven services into a holistic platform for controlling ventilation systems. These approaches could lead to the most energy saving than static approaches mainly in building spaces having dynamic and unpredictable occupancy (e.g., meeting areas, auditoriums). The CO_2 sensors could be, for example, used to monitor in real-time indoor CO_2 concentration that will be processed and used by a context-driven control service in order to adjust the amount of needed ventilation air rates to best suit the actual building occupancy (e.g., presence, number, behavior). Mainly, this paves the way to approaches in which an antifragile platform learns and adapts which strategy to enact[13]. In fact, the platform makes the best of the experiences gathered while interacting with building's occupants and the deployed things[10,11].

In our previous work, we have investigated several control approaches and then presented a CO_2-based strategy using a state feedback for controlling ventilation systems in energy-efficient buildings[3,4]. The principal objective of the developed controller is to improve optimal balance between energy efficiency and indoor air quality by maintaining the indoor CO_2 concentration at the comfort set point with an efficient ventilation rate while reducing energy consumption. Basically, we compared the proposed feedback control approach with a PID and an ON/OFF controller and validated their performance using the BCVTB co-simulation framework together with building environment parameters. Obtained simulation results showed that the state feedback control leads to better comfort with improved energy saving as compared to the PID and ON/OFF control strategies. Furthermore, we have implemented and deployed the CO_2-based state feedback control into our EEBLab test site. Experiments have been conducted and obtained results showed the usefulness of dynamic regulation of ventilation rates. Mainly, results showed that the CO_2-based state feedback control is able to maintain the CO_2 concentration in the comfortable zone, while minimizing energy consumption by almost 47% against the ON/OFF based control approach.

In this work, we implemented and deployed an adaptive control approach that selects the most appropriate control among three strategies: the state-feedback, the PID and the ON/OFF control. This selection is based on generic algorithm that determines the best way to operate a ventilation system based on contextual data from the building's context. A platform that combines IoT and Big data processing technologies for real-time control of building's systems was deployed in our EEBLab for real-testing. The control strategy was integrated into the platform[14,15] and evaluated using comfort and energy metrics. Experimental results are reported and show the usefulness of adaptive control based on algorithm's selection principles. The remainder of this paper is organized as follows. Section 2 briefly describes the considered strategies we have deployed for ventilation systems control. In Section 3, the proposed ventilation control is introduced and presents the generic algorithm that was used to determine the appropriate control strategy. Section 4 presents the real-time monitoring and processing platform prototype for gathering and processing data coming from IoT devices in order to carry out the suitable control strategy. The deployed case study together with preliminary experimental result is discussed in Section 5. Finally, conclusions and perspectives are given in Section 6.

2. Overview of control strategies

The ventilation system is one of most studied systems in smart buildings in order to improve energy savings while maintaining occupants' comfort within a suitable thermal comfort (i.e., humidity and temperature) and good air quality[5]. In fact, the ventilation systems depend initially on the control strategy used to adjust the ventilation rates either manually or automatically. Most control approaches are based on predefined occupancy or fixed schedules, which could not improve simultaneously both energy efficiency and occupant's comfort. In our previous investigations[3,4], we have implemented a PID controller and ON/OFF and compared them with our proposed CO_2-based state feedback control in terms of several metrics. The PID controller performs a closed-loop control to regulate the ventilation speed of the fans in order to decrease the CO_2 concentration according to the defined set point. However, the ON/OFF strategy switches the ventilations system ON with the maximum ventilation rate when the space is occupied (i.e., the indoor air quality is poor) or OFF when the space is unoccupied (i.e., the carbon concentration is within the suitable range between 400 and 700 ppm). Unlike ON/OFF and PID, the CO_2-based state feedback control considers the relationship between the ventilation rates and the indoor air quality by tracking the carbon concentration. In fact, we have used the model of perfect mixture[6], which is based on a mass balance of the CO_2 in the building and allows the coupling between the fresh airflow and air quality. The resulting state feedback control uses a linear control method to provide an optimized adjusting of the ventilation system's speed. In order to regulate the ventilation rate, we measured in real-time the indoor CO_2 concentration and the ventilation rate that are continuously processed by the platform for selecting the best suitable rate. According to this study, as summarized in Table I, none of these control approaches could optimally balance between energy saving and occupants' comfort in all different building's contexts. In this work, we have introduced an approach based on algorithm's selection[10] for energy efficient ventilation systems control, which is presented in the next section.

Table 1. Developed control strategies.

Control strategy /Operation	State feedback	PID	ON/OFF
Performance	Good response and robustness	Low robustness for different states	Poor performance in the switch ON/OFF
Complex construction	Multiple inputs outputs	Single input/ output	N/F
Steady state error	Zero	Relatively small	N/F
Stability	Stable	Stable for single input/output	Poor stability
Settling time (ms)	<0.42	<0.50	More time
Disturbance	Reduced noise	Low perturbation	High disturbance
Consumption	Low consumption	Low consumption	High consumption
Feedback	Real-feedback	Near real feedback	Poor feedback

3. Intelligent ventilation control

The ventilation system type used is the cross air-flow in which the fresh air is injected from the supply air fan while the polluted air is removed from inside the building with the return air fan, as illustrated in Figure 1. Since the building is a complex system and depends on the occupants' preferences and their perception of the indoor and outdoor conditions[7], it is therefore difficult to have a standalone control approach that could meet all operating contexts. So, an intelligent approach that selects the best control strategy to suit the actual context is required. Contextual data (i.e., the indoor air temperature, the relative humidity, the occupancy and the outdoor temperature) can help in defining as accurate as possible the current context based on data stream inputs (i.e., events). As illustrated in Figure 2, the control approach can use sensors' inputs in order to process the right decision based on conditions and rules. Basically, each input depends on contextual data and weather events that are transmitted to the control algorithm. When all conditions are met, a rule strategy is generated to deliver a decision control as an output of the system according to the standards established by the American Society of Heating Refrigerating and Air Conditioning Engineers (ASHRAE)[8].

The generic algorithm, as presented in Figure 3, operates on OFF mode whenever the space is unoccupied or the thermal comfort and good indoor air quality are satisfied. The ON mode is operated in both fans when the indoor air quality is poor[9] (i.e., the carbon dioxide is more than or equal 1000). However, in occupied space and normal indoor air quality (i.e., carbon dioxide between 400 and 1000 ppm) the ventilation operates on PID mode by adjusting the ventilation rates in order to maintain the CO_2 concentration between 400 and 600 ppm. In complex situations, the state feedback control is operated, which tracks the thermal comfort through humidity and temperature measurements. In this case, the humidity must be between H_{min} =20% and H_{max}=70% of the relative humidity calculated continuously using DHT22 sensors as well basic data from ASHARE in which the indoor air temperature must be lower than the outside temperature T_{ext} in summer periods and greater than T_{ext} in winter periods.

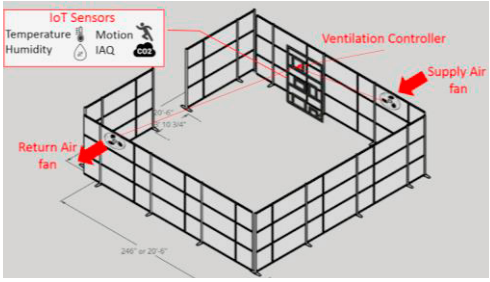

Fig. 1. The SketchUp of the ventilation system type

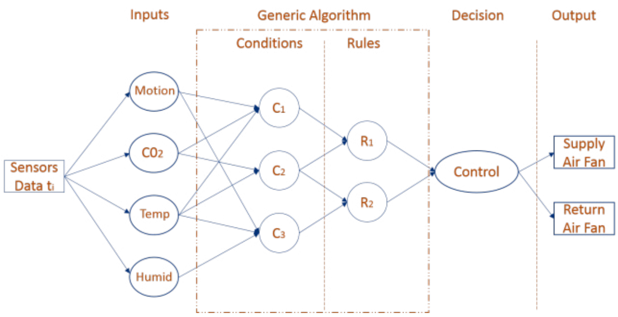

Fig. 2. The data monitoring/processing topology

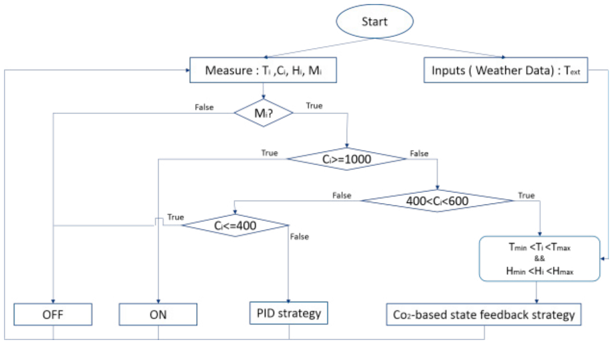

Fig. 3. The algorithms' selection principles

4. The real-time monitoring and processing platform

The proposed holistic platform is composed of hardware components and software components as depicted in Figure 4.

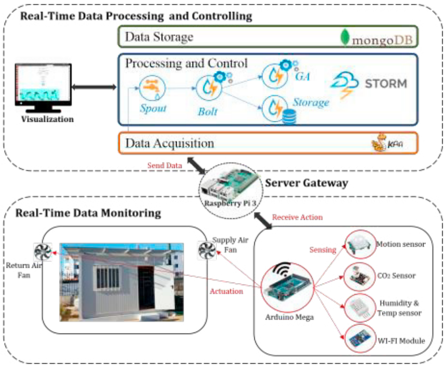

Fig. 4. The architecture of the platform for real-time monitoring processing and controlling

The hardware components installed in the EEBLab are the supply and return air fans for ventilation system, which are connected to an Arduino mega with a controller shield for performing the control strategy. The temperature and humidity sensors, motion sensor (PIR) and carbon concentration (MG811 CO_2 sensor) are also embedded in the micro-controller for gathering data values and sending them via a WIFI module to the server broker for data collection using the MQTT protocol. On the other hand, the software components are based on IoT and Big Data technologies and composed mainly of three layers: *i)* data collection with the Kaa application, which is an open-source middleware tool for building, managing and integrating various IoT devices, *ii)* data processing with the Apache Storm[12] services that allows real-time processing of collected data, and *iii)* data storage and visualization with a MongoDB. The data collection component gathers the contextual data form sensors and actuators and sends them to the data processing and controlling layer, which is based on two main classes: a spout and a bolt. The *spout* gets the stream events from the data collection and sends them to the connected bolt in which we used three main *bolts*, the first one processes arrived events and transfers them to the control bolt (i.e., the control component) that implements the generic algorithm. This algorithm uses contextual data to select the right control strategy that must be performed as a feedback by the ventilation system. The third *bolt* stores the received events with the obtained results from the control *bolt* for eventual visualization and analysis (i.e., data analytics).

5. Case study and experiment results

The main goal of this experiment is to control the ventilation system in order to maintain the indoor air quality and the thermal comfort of the building's occupants while improving energy savings. We considered only one day for easy visualization of the results. We have evaluated two main metrics: *i)* the comfort metrics (e.g. the actual indoor CO_2 concentration, the indoor air temperature and the relative humidity), *ii)* the energy metrics (e.g. ventilation rates, rotation of fans and the power consumption). A real testing scenario was deployed in our EEBLab to measure and control the ventilation system in the winter period as illustrated in Figure 5.

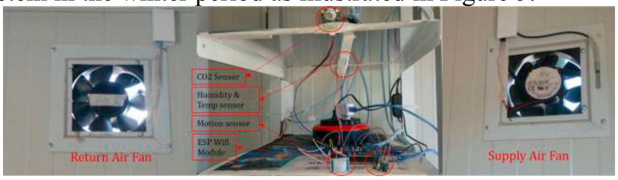

Fig. 5. The prototype of the case study in our EEBLab

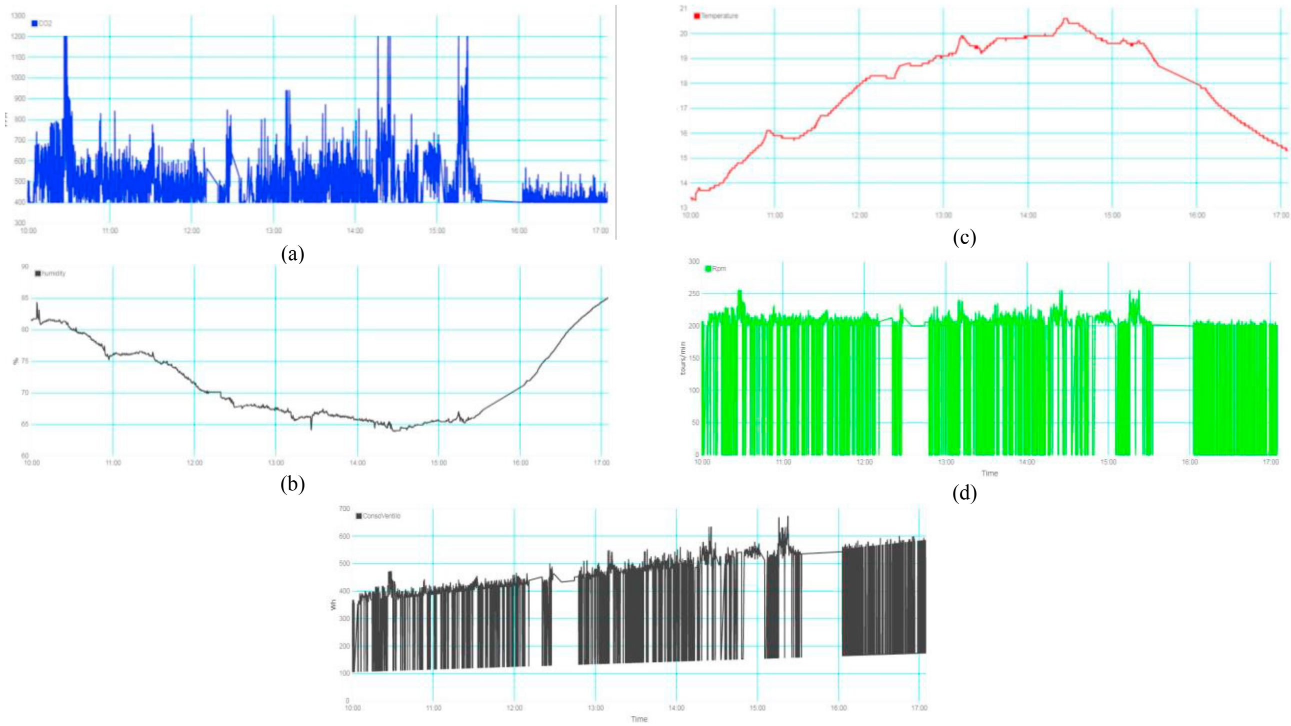

Fig. 6. a) Indoor Carbon Concentration (in ppm), b) Relative Humidity (in %), c) Indoor Air Temperature (in °C), d) the rpm of the ventilation system (in tours/min), f) the power consumption (in Wh)

Preliminary results are depicted in Figure 6 as follows: CO_2 concentration (Figure 6 (a)), the relative humidity (Figure 6 (b)) and the indoor air temperature (Figure 6 (c)). As shown in these figures, unlike using individual control strategy the proposed control approach selects among three different control strategies: state feedback, the PID and the ON/OFF. When the room is unoccupied and the indoor air quality is good there is no need to operate the ventilation system. For instance, the ventilation rate responds rapidly in ON state when the CO_2 is more than 1000ppm, while the PID and the state feedback still switching in order to satisfy the thermal comfort among the average of the outside temperature. However, as illustrated in Figure 6 (d), the speed of the ventilation is varying according to the control strategy used, but it does not exceed its maximum rate (fixed to 0.5 m^3/s). Furthermore, as depicted in Figure 6 (e), the average energy consumption is reduced by 30.25% when using an individual control strategy.

6. Conclusions and perspectives

In this paper, we have introduced an algorithm for selecting the control strategy that best suits current context. The algorithm was developed using a real-time platform, which includes IoT and Big data technologies together with required sensors, prototyping devices, and wireless communication technology. Mainly, the proposed approach determines the appropriate control among three control strategies: state feedback control, the PID and the ON/OFF. Experiments have been conducted and reported results show the operational use of the platform and the efficiency of the algorithms' selection approach. Obtained results showed that the proposed algorithm is able to maintain the comfortable indoor air quality and thermal comfort while reducing energy consumption. We envision that future ambient control systems (ACS) will require more and more intelligence as well as the ability to monitor and learn from the experiences, thus realizing an antifragile ACS[10,11,13]. Future work shall investigate how to practically realize such an ACS in energy efficient buildings.

Acknowledgment

This work is supported by CASANET project (2016-2018, funded by MESRSFC and CNRST), and partially supported by MIGRID project (grant 5-398, 2017-2019), which is funded by USAID under the PEER program.

References

1. Pérez-Lombard, L., Ortiz, J., Pout, C. A review on buildings energy consumption information. Energy and buildings. 40(3), 394-39; 2008.
2. Hussain, S., & Oosthuizen, P. H. Validation of numerical modeling of conditions in an atrium space with a hybrid ventilation system. Building and Environment, 52, 152-161; 2012.
3. F. Lachhab, R. Ouladsine, M. Bakhouya, M. Essaaidi. A state-feedback approach for controlling ventilation systems in energy efficient buildings. In the proc. of IRSEC 2015, the 3rd International on Renewable and Sustainable Energy Conference, DOI: 10.1109/IRSEC.2015.7454986, 10-13 Dec; 2015, Marrakech.
4. Lachhab, F., Bakhouya, M., Ouladsine, R., Essaaidi, M. Monitoring and controlling buildings indoor air quality using WSN-based technologies. The 4th International Conference on Control, Decision and Information Technologies, April 5-7; 2017, Barcelona, Spain.
5. Noh, K. C., Jang, J. S., & Oh, M. D. Thermal comfort and indoor air quality in the lecture room with 4-way cassette air-conditioner and mixing ventilation system. Building and Environment,42(2), 689-698; 2007.
6. Feustel, H. E. Fundamentals of the multizone air flow model. COMIS Berkley, California; 1990.
7. Lachhab, F., Bakhouya, M., Ouladsine, R., Essaaidi, M. Buildings as complex systems: approaches and challenges. In Nonlinear Systems and Complexity Series, Springer, volume 18, pp 247-265; 2016.
8. ASHRAE Standard 55. Thermal environmental conditions for human occupancy. American Society of Heating, Refrigeration and Air-Conditioning Engineers, Inc., Atlanta, GA; 2010.
9. ASHRAE Standard 62.1. Ventilation for acceptable indoor-air quality. American Society of Heating, Refrigeration and Air-Conditioning Engineers, Inc., Atlanta, GA; 2010.
10. Bakhouya, M., Gaber, J. Approaches for engineering adaptive systems in ubiquitous and pervasive environments. Journal of Reliable Intelligent Environments: Volume 1, Issue 2; 2015, pp 75-86.
11. De Florio, V., Bakhouya, M., Coronato, A., Di Marzo, G. Models and concepts for socio-technical complex systems: towards fractal social organizations. Syst. Res. Behav. Sci. 30(6), 750–772; 2013.
12. Ranjan, R. Streaming big data processing in datacenter clouds. IEEE Cloud Computing, 1(1), 78-83; 2014.
13. De Florio, V. On resilient behaviors in computational systems and environments. J Reliable Intell Environ, Vol. 1, Issue 1; 2015, pp 33-46.
14. Nait Malek, Y., Kharbouch, A., El Khoukhi, H., Bakhouya, M., De Florio, M., Elouadghiri, D., Latre, S., Blondia, C. On the use of IoT and Big Data Technologies for Real-time Monitoring and Data Processing. ICTH-2017, Lund, Sweden, Procedia Computer Science, Volume 113; 2017, pp 429-434.
15. Bakhouya, M., NaitMalek, Y., Elmouatamid, A., Lachhab, F., Berouine, A., Boulmrharj, S., Ouladsine, R., Felix, V., Zinedine, K., Khaidar, M., Elkamoune, N. Towards a Data-Driven Platform using IoT and Big Data Technologies for Energy Efficient Buildings. In CloudTech'18; 2017, pp. 1-5, Rabat, Morocco.