HVAC system for experimental research and educational applications

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ABSTRACT

This paper describes an educational and experimental tool developed under LabVIEW environment at LASH/DGCB (France) laboratory of ENTPE. The objective of this tool is to make students sensitive with HVAC equipments, measurements, heat recovery, and regulation techniques in order to expand and test heating, cooling and ventilation control strategies.

A large room of the Buildings Sciences Laboratory (LASH) is equipped with balanced mechanical ventilation and a global control/data acquisition system. To familiarize with ventilation heat recovery, a run-around coils system with Air-Fluid-Air exchange as well as heat exchangers performances of the two air-to-water heat pumps can be studied with duct temperature sensors. Moreover, the experiments conducted by students led them to identify optimal parameters for each developed control strategy, in order to reach a good thermal comfort, indoor air quality and stability of actuators at the least energy cost. A global control strategy for heating and cooling period (PID & fuzzy regulator), based on interior temperature has been implemented in winter, mid season, and summer conditions. A measurements campaign during an occupied period is shown with an overview of actuators behavior.

This tool aims also at highlighting the key role of advanced control techniques to manage heating and cooling systems.

1. INTRODUCTION

HVAC is an acronym that stands for “heating, ventilating, and air conditioning”. The three functions of heating, ventilation and air-conditioning are closely interrelated. All seek to provide thermal comfort, acceptable indoor air quality, and reasonable installation, operation, and maintenance costs. HVAC systems can provide ventilation control during occupation, power regulation for heating or cooling period.

2. GENERAL DESCRIPTION

2.1 Building

The experimental building B003 is a large meeting room of the Buildings Science Laboratory, used for practical and lab work. This large hall, whose temperature can be controlled to create an artificial climate, contains an experimental test cell (TwinCells). The B003 has a slopped wall (70°), and is 20 m long by 16 m wide and it is 4.4 m high.

2.2 Heating and cooling systems

The power of the global heating/cooling system has been voluntarily oversize in order to generate an artificial climate whatever the season in the large room.

The mains components are:
- a reversible air-to-water heat pump: 40 kW
- a second heat pump (only chilled water): 24 kW
- an electric coil (24 kW)
- two regulated fans (supplied & exhausted air): 0-6000 m$^3$/h
- a run-around coils system with air-fluid-air exchange, and commanded by a circulation pump.

Figure 1: Commanded HVAC equipments

Figure 1 illustrates the global overview of the HVAC equipments, and the reversible heat pump with water/glycol solution as heat transfer medium (Fig. 2). The fan speed choice for exhausted and supplied air is done by a frequency regulator with a 0-10V input signal. Run-around coils comprise two fin type heat exchangers, one of which is installed in the supply air and the other in the exhaust. A water/glycol solution is used as
the heat transfer medium and is continuously pumped between the exchangers using a circulation pump. Heat in the exhaust air stream is then transferred to the supply air via the heat exchangers.

2.3 Ventilation network
The large room called B003 is equipped with balanced mechanical ventilation, and five air inlet/outlet locations. Ventilation is used to control indoor air quality and to supply hot or chilled fresh air. Local ventilation control strategies, using commanded damper valves have been developed (Cordier, 2006), to reduce energy consumption of air renewal and air conditioning.

3. REMOTE CONTROL INTERFACE

3.1 Measurements
A computer equipped with a data acquisition and control card (NI SCXI 6220) lets the possibility to group the many measurements from various points of the HVAC. Universal 1000-ohm nickel sensors (Ni 1000) are used for duct temperatures associated with a resistor/voltage transformer. All the water and air duct temperatures are linked to the data acquisition card. (Fig. 4)

The heat exchangers performances of the two air-to-water heat pumps can be analysed with air and water duct temperature sensors.
For example, figure 5 illustrates the heat transfer between exhaust air and supply air via the water/glycol solution directly observed by students.
We can observe the exhaust (respectively supply) air temperature decrease (increase) as soon as the heat recovery pump is turned on. Meanwhile, the water temperature oscillates along the pipe until the mix is done.

Seeing that information, this kind of system can generally transfer sensible heat and has a relatively efficiency of 40 to 60%. (Liddament, 1996)

3.2 Commanded equipments
The remote control interface lets us have a global overview of the HVAC, and its commanded components. The card belongs to the digital output direct voltage
card category, and enables output of several independent channels that can control fans, valves, pump relays, etc. The maximum voltage and current range of the analog signal is 0-10V and 0-20mA, respectively.

Figure 6: Manual remote control

Figure 6 illustrates the global overview of the commanded equipments. The manual remote control let the user manually control each part of the HVAC. Consequently, students could directly observe all the characteristics of the commanded equipments, such as the open loop response of a process and its time delay response.

4. HVAC MANAGEMENT

This tool offers various control strategies for heating and cooling or ventilating. Thus students can run experimentations using PID or fuzzy regulator to control indoor or supply air temperature, or indoor air quality of the room thanks to local CO₂ sensors. The experimental platform gives the possibility to the student to test control accuracy for such techniques.

4.1 Advanced control techniques

In buildings, PI (or PID) controllers are usually used in HVAC systems for heating and cooling valve control in Air Handling units or 3-way valve control in a hot water network for radiators or fan coils supply. Initially, PID control part in our tool allows students to modulate the controller’s parameters and thus to test finer control of heating or cooling.

Since PID controllers are sensitive to system dynamics and could result in important instabilities if not accurately tuned, the interface gives also the possibility to set PID controller parameters using for example Ziegler-Nichols method (Flaus, 1994).

In PID control, the students must specify a process variable, and a setpoint with bias such as the indoor or supply air temperature. A PID controller determines also a controller output value, such as the three ways valve position of the hot/chilled water (Fig. 7). The controller applies the controller output value to the system, which in turn drives the process variable toward the setpoint temperature.

Figure 7: The commanded three way valves

In the same manner, students can use fuzzy logic to control a process temperature or an extractor fan speed to regulate indoor air quality. The student, as an expert in a specific process, must use a set of linguistic control rules, based on experience that he can describe generally and intuitively. Fuzzy logic provides a way to translate these linguistic descriptions to the rule base of a fuzzy logic controller.

4.2 Annual control strategy

We first let the students develop a global control strategy of the HVAC system. On the one hand, the aim was to provide a good thermal comfort during the practical and lab work. On the other hand, we intend to have an acceptable indoor air quality with the least energy consumption. Consequently, three different controllers have been developed for summer, mid-season and winter conditions. Practical work showed that a “steps On-Off” controller on interior temperature was preferred to select the season. This choice was the simpler manner to satisfy quickly an express demande of a setpoint temperature. In that case, users have to choose two setpoint temperatures, such as:

- $T_w$: the winter setpoint temperature (for example 20°C)
- $T_s$: the summer setpoint temperature (for example 25°C)

The setpoint temperature $T_m$ is equal to the half of the winter and the summer temperature. Figure 8 illustrates the HVAC control architecture for the three seasons. Because of the major sources of heat gains from lights, computers and occupants, the free cooling potential using exterior temperature sensor is used in our strategy.
4.3 HVAC control during a summer period

Actually, “active cooling” is used as a mechanism to flush hot air from the building to be replaced by cooler outdoor air. “Flushing” may further be used, especially at night, to cool the structure of the building itself (night cooling). This method of cooling is attractive since the ‘active’ conditioning of air (by the heat pumps) may be avoided. This technique is primarily intended for the summer climate of Lyon (France) in which low temperature during the night is possible.

Figure 9 illustrates a fuzzy control of the two water valves in a summer mode. During the first day, we can observe the second valve opening when the first one is completely open to control the indoor temperature around the setpoint $T_s$ (25°C) with a 0.5°C bias. During the night period, “free cooling” is used to cool the heavy structure of the building with a higher ventilation rate (the supply fan speed is increased from 50 % to 70 %).

The actuators stability of the HVAC active equipments is mainly dependent on their lifespan. A particular attention is devoted to have a good control stability of the two tree-ways valves actuators.

4.4 Indoor air quality controlled during mid-season

Ventilation is essential for health and comfort of building occupants. It is particularly required to dilute and/or remove pollutants emitted by occupant’s metabolism. The concentration of metabolic CO$_2$ is well correlated to metabolic odor intensity. Therefore CO$_2$ concentration can be efficiently chosen as an indoor air quality indicator when occupants are the main pollution source inside the buildings (Richieri, 2006).

Consequently, a CO$_2$ sensor has been installed in the middle of the room, where the concentrations are quite uniform. The control strategy for a mid-season period let the indoor temperature oscillate between $T_w$ and $T_s$. Because there is no need to modify the thermal comfort, students decided to reduce the fan consumption with a fuzzy (or PI) control of the fan extractor speed.

As example, a 3.5 hours lab work with 30 students let them test and tune a two-input fuzzy regulator ($CO_2$ – SetPoint; $dCO_2/dt$). A variable fan extractor speed is controlled to keep a setpoint concentration in the B003 room (700 ppmv) with a 50 ppmv bias. The experimentation required on top of a 10 minutes waiting time between each speed modification.

The results of a fuzzy control on the mechanical ventilation during a practical work occupation in the afternoon are shown on figure 10.

To satisfy the 700 ppmv of CO$_2$, the fuzzy regulator is stabilized on 30 %, i.e. 1800 m$^3$/h for 30 working students. In such a case, its large advantage remains mainly the fan actuator stability compared to ON/OFF controllers, and a regulation adapted as well to the variable number of occupant, as its occupation schedule.

5. CONCLUSIONS

In the frame of the ENTPE pedagogical program, engineering students have tested the educational and experimental tool on HVAC systems these last years. This tool has been largely appreciated and has contributed to a good understanding of Building Energy Management System process.

Other experimental applications intended to teach local control of ventilation techniques and advanced control strategies based on fuzzy control have also been combined with this tool in order to initiate students to a global management of the building.

Moreover, this tool gives the possibility to develop automatic tuning strategies for fuzzy controller’s architecture.
The flexibility of the program under LabView makes it possible for a user to easily insert control modules separately programmed.

REFERENCES