Impact of Pump Control on Indoor Climate and Energy Efficiency of Hydronic Networks

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ABSTRACT

The use of variable speed pump allows to save energy. Therefore, the impact of these technologies on the heating system and thermal comfort in buildings is rarely highlighted. The objective of this study is to show the possible impact of variable speed pump control on thermal comfort, energy consumption and costs in buildings.

The paper describes a method to evaluate the performance of a heating system in terms of thermal comfort and global costs. A simulator has been implemented under Matlab/Simulink using the SIMBAD Toolbox to carry out annual simulations. The simulator is then used to applied the developed methodology and to evaluate an exemplary building.

The results in this particular case show that constant speed pump control leads to good results regarding thermal comfort. Pump control based on differential pressure provides similar results to those with constant speed pump in terms of comfort. However, these methods allows to save about 90% of energy consumptions for pumping and also reduce by 5% the consumptions for heating. Control of pump speed based on demand allows to save even more energy but with restrictions in thermal comfort

INTRODUCTION

Comfort and energy savings have become more and more a concern in modern buildings which are equipped with a rising number of sophisticated products. This potentially allows to operate the building in a performant manner but also requires attention on good design and control of the building and its equipment in order to ensure this good operation in practice.

One of the elements in these buildings is the hydronic network for a heating or cooling system. Therefore, design and sizing are the first steps towards a system with good performance. The second step, treated more in details in this paper, is the method to control the pump. As buildings envelopes become more and more efficient, heating loads are less important than in the past. Electric power for auxiliaries as pumps take thus a more significant part in the total balance and have to be optimized in order to minimize the final energy consumption.

New technologies appear in heating system like variable speed pump and dynamic balancing methods. Their impact on energy consumptions or thermal comfort are, in most cases, derived from simplified calculations and are not well known. Moreover, the coupling and integration of these systems and technologies within the building has even been less analysed.

OBJECTIVES OF THE STUDY

The objectives of the study is to demonstrate the impact of coupling different strategies for pump control with hydronic static [Petitjean, 1994] or dynamic [Bernadou, 2003] balancing on thermal comfort, energy consumption and global costs. Therefore, four pump control methods are compared on the same building with an identical heating system (Figure 1).

The study shown in this paper is limited to the evaluation of the pump control methods coupled to a static hydronic balancing. The study of other hydronic balancing types will be presented in the future.

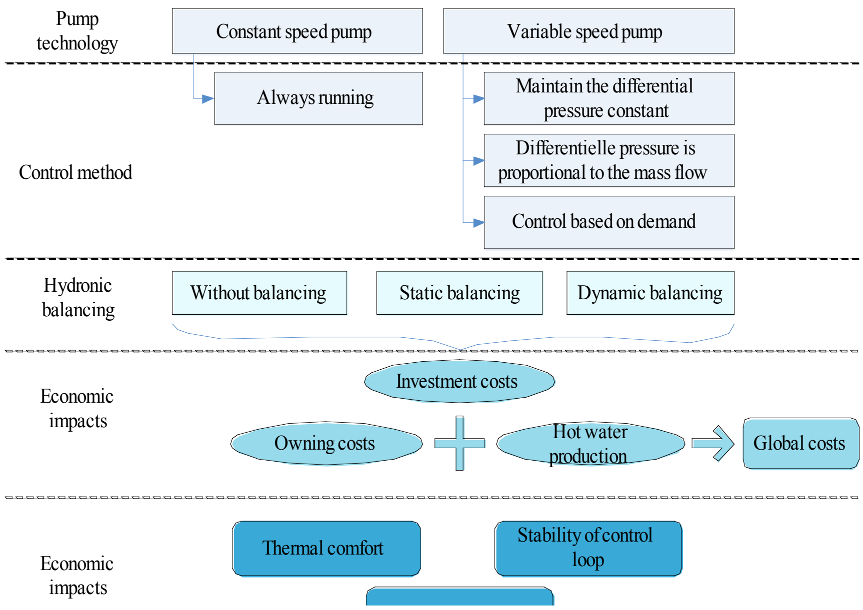


Figure 1 : Objectives of the study

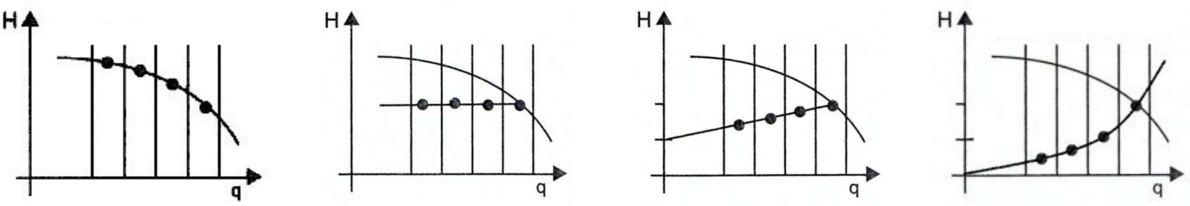
HYDRONIC PUMP TECHNOLOGIES

Several technologies of circulation pumps are available on the market :

- Constant speed pump : this type of pump is always running independently of the others parameters (Figure 2). To prevent the case where terminal controllers are closed, a differential pressure valve is installed in the primary circuit.

Figure 2 : Type of control of pump

Constant speed pump | Variable speed pump - Δp constant | Variable speed pump – Δp proportional | Variable speed pump – based on demand



- Variable speed pump : the speed of the pump is automatically controlled depending on the conditions in the water network in order to reduce electrical power consumption of the pump. Several methods of control can be used :
  - The first method consists in maintaining the differential pressure constant at one point in the hydronic network (Figure 2). The point is generally the underprivileged emitter.
  - The second method consists in controlling the differential pressure at one point of the hydronic network proportionally to the mass flow rate (Figure 2).
  - The third method is based on the demand (Figure 2). The percentage of opening of the terminal controller, balanced with their nominal mass flow rate, define the command of the pump.

THE SIMULATOR OF HYDRONIC NETWORKS

The development of the simulator for the study of hydronic networks as well as the pre-processing for its sizing has been shown in a previous study (Couillaud et al, 2004). It is developed under Matlab/Simulink environment with the SIMBAD Toolbox (SIMBAD, 2005)..

The simulator has been divided into three parts :

- Block “Buildings Zones”: it represents the model of the building simulated with the scenario for occupation, internal gains, and ventilation. The building description is carried out using the “SimBDI Interface” (Chlela, 2004). The building used is a multizone model (El Khoury et al, 2005) in which air mass flows are imposed as constant.
- Block “Hydronic Network”: this block includes the hydronic network of the described building, from the circulation pump to the emitters. The structure of this network is explained in (Couillaud et al, 2004).
- Block “Hot Water Production”: it represents the hot water production (boiler or other system) and the primary distribution of the hydronic installation.

This structure allows, for other studies, to modify easily the details and internal structure of each block, e.g. to modify the hydronic system without a need to change the rest of the model.

An automatic sizing procedure including expert rules has also been implemented in a pre-processor of the simulator. Sizing steps are described in [Couillaud et al, 2005].

SIMULATED BUILDING

The building selected for this study is an exemplary, idealised office building composed of 17 zones on two floors. The heating system is a hot water system with radiators equipped with terminal control. The two corridors in the building are not heated. The set point temperature for heating is 19°C during occupation and 15°C during inoccupation. The building is located in Trappes, France.

Air mass flows for ventilation are imposed as a constant in the building. One air entrance is defined for each zone. Total air mass flow is extracted in corridor by a mechanical ventilation system. Air flow rates correspond to the minimum fresh air supply (18 m^3/h/occupants for offices).

The office building is continually occupied from 9 am to 18 pm, from Monday to Friday. Internal gains are assumed to 14 W/m².

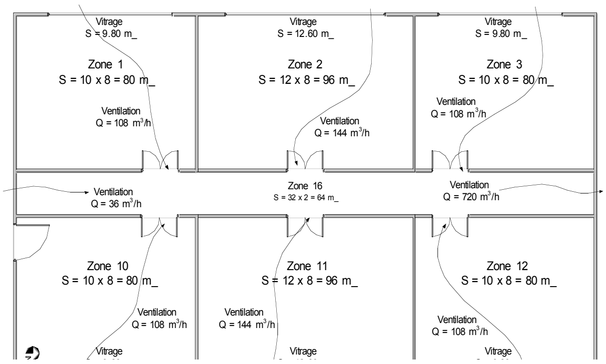


Figure 3: Plan of the first level

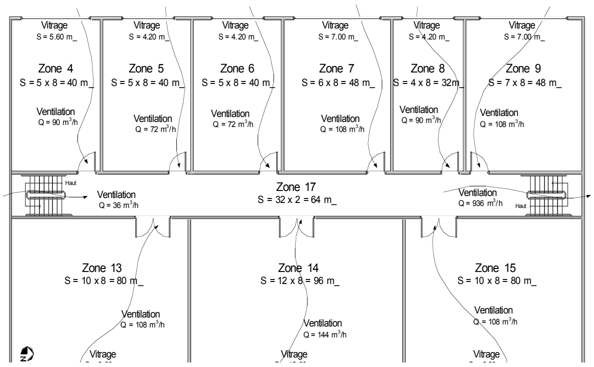


Figure 4 : Plan of the second level

The first floor (Figure 3) of the office building is composed of 3 open space zones of each side of the corridor from 80 m² to 96 m². The second floor (Figure 4) is composed of 6 zones on the east and 3 other open space zones on the west façade.

Hot water production is ensured by a modulated gas boiler. Building heat emission is ensured by hot water radiators equipped with terminal controllers. The supply temperature of hot water to the emitters is controlled by a 3-way mixing valve depending on the outside temperature considering a typical heating curve. The network is composed of two columns supplying facades east and west. Hot water is provided to each floor by a floor distribution. Elementary modules are equipped with a balancing valve and static balancing method is used. Primary distribution is equipped with a compensation valve.

RESULTS

The following table details the nomenclature used in figures:

	RP_CSP_ES	Use of a constant speed pump with static balancing
	RP_VSP_BCD_ES	Use of a variable speed pump controlled depending on demand with static balancing
	RP_VSP_DPC_COL_ES	Use of a variable speed pump maintaining differential pressure of a column constant with static balancing
	RP_VSP_PDP_COL_ES	Use of a variable speed pump maintaining differential pressure of a column proportional to mass flow with static balancing

The resultant temperature of typical zones is shown in terms of cumulated frequencies. This calculation is carried out for the heating season period and for in two periods: occupation and inoccupation periods. Zone number 6 is a middle size zone of 40 m² at the second floor faced to west. Zone number 11 is a largest one in the first floor faced to east.

Figure 5 shows that, for zone number 6, best control of temperature is obtained with a constant speed pump. Set point temperature is achieved earlier in the morning than using the other control methods. With control depending on demand, the difference between set point and resultant temperature is at least of 0.5°C during 30% of the occupation period.

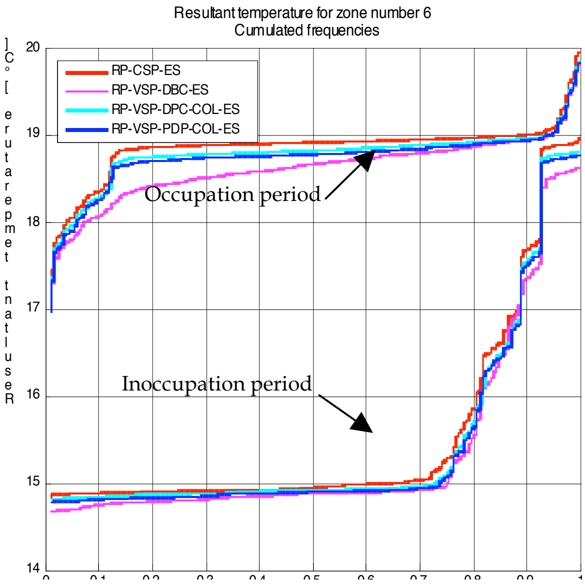


Figure 5 : Cumulated frequencies of resultant temperature for zone 6

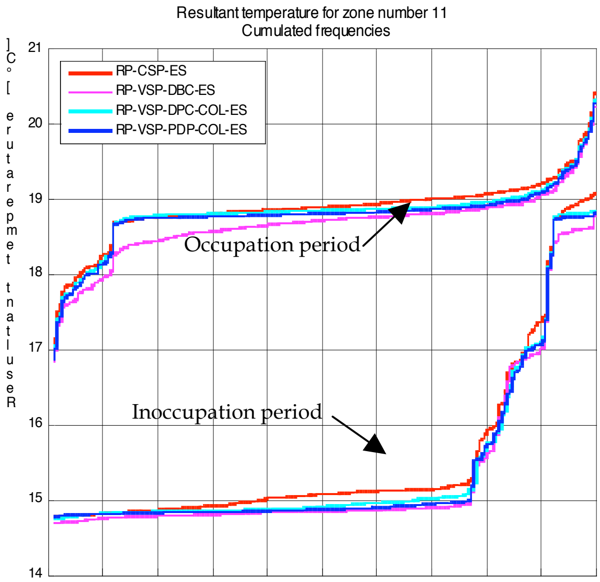


Figure 6 : Cumulated frequencies of resultant temperature for zone 11

For zone number 11, Figure 6 shows that results of constant speed pump and differential pressure control are similar in terms of temperature: set point temperature is achieved during about 88% of the occupation period. The difference is greater than 0.5K during 30% of the occupation period. Results are similar for the inoccupation period, independent on the used control strategy.

Annual consumptions of pumps and boiler are shown by Figure 7 and Figure 8.

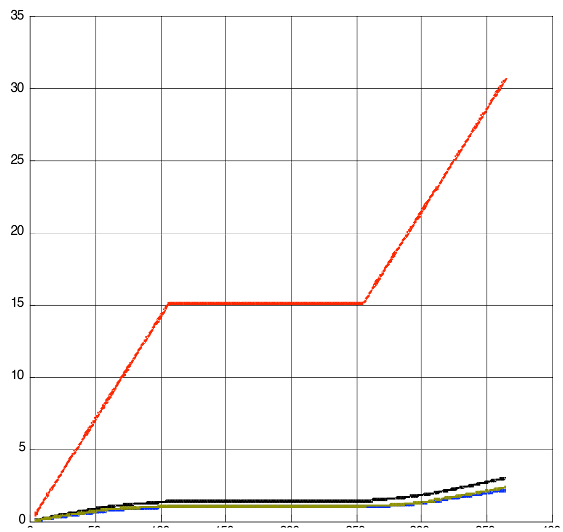


Figure 7 : Annual pump consumptions

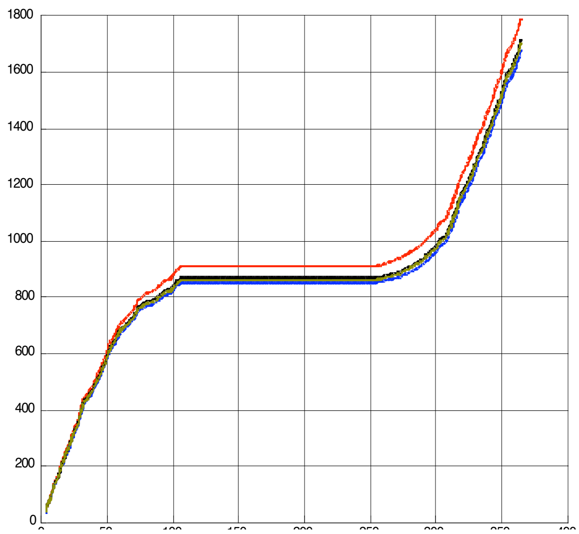


Figure 8 : Annual boiler consumptions

In terms of energy, variable speed pump control strategies allow to save 90% for constant differential pressure and 92% for proportional differential pressure of pump consumptions (Figure 7) compared to the reference, the constant speed pump. At the same time, the reduced flow rates in the network also allow minimizing the distribution losses and result thus in lower gas consumptions of the boiler: cost savings can achieve 4-5% in the studied case (Figure 8). In the case of demand based control, pump consumptions are reduced by 93% and boiler consumption by 6.5%. However, using this strategy, restrictions have to be made for thermal comfort since set point temperature is achieved only during 30% of occupation time.

Figure 9 shows the global costs of the heating system for an amortization period of 15 years. The global costs take into account investment costs, costs for balancing and operation costs for pumps and boiler [ASHRAE, 1984].

Figure 9 : Global costs for the four pump control methods (first column is missing !!!)

Pump speed control method	Investment costs	Primary pump annual consumptions	Recycling pump annual consumtions	Boiler annual consumptions	Appliance balancing method costs	Global costs (15 years)
RP_CSP_ES	12 456 €	25,97 €	4,88 €	1 796 €	361 €	76 659 €
RP_VSP_DBC_ES	12 456 €	1,57 €	0,61 €	1 680 €	361 €	71 624 €
RP_VSP_DPC_COL_ES	12 456 €	1,97 €	1,08 €	1 717 €	361 €	72 927 €
RP_VSP_PDP_COL_ES	12 456 €	1,70 €	0,67 €	1 705 €	361 €	72 494 €

Constant speed pump control is characterized by the highest global costs of about 76 659€. Control strategy depending on demand reduces these costs by about 6.6%. Inbetween these both methods, control depending on differential pressure reduce the costs by 4.9% for method maintaining differential pressure constant and 5.4% for method maintaining differential pressure proportional.

CONCLUSION

This paper deals with the evaluation of pump speed control in terms of thermal comfort and global costs of heating system using a numerical simulator of hydronic networks and buildings. This simulator has been developed under Matlab/Simulink within the SIMBAD Toolbox.

Constant speed pump control provides accurate temperature in building zones. For control strategies depending on differential pressure acceptable results are obtained in terms of zone temperature but with the advantage of about 90% energy savings for pumping and of 4-5% for heating energy. The last studied control strategy, the control based on demand leads to save more energy: about 93% for pumping and 6% for heating, but with some restrictions in thermal comfort since set point temperature is achieved only during 30% of occupation time.

Considering global costs of the heating system with the different pump control strategies, the speed pump control method maintaining differential pressure at a column proportional to mass flow is observed to be a good compromise between costs and thermal comfort for the case studied.

Future works will deal with the study of coupling this pump speed control strategies without hydronic balancing and with a dynamic one to complete this study.

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