INFLUENCE OF COMPONENT SELECTING SIZE METHOD OF HYDRONIC NETWORKS ON GLOBAL COSTS AND COMFORT

Nicolas COUILLAUD[1], Peter RIEDERER[2],
[1] PhD Student, CSTB, 84 avenue Jean Jaurès, 77447 Marne-la-Vallée cedex 2, FRANCE
[2] Research engineer, CSTB, Route des Lucioles - BP 209, 06904 Sophia Antipolis Cedex, FRANCE

ABSTRACT

Comfort and energy savings have become more and more a concern in modern buildings. Therefore, design and sizing is the first step towards a performant building. This paper deals with the study of hydronic networks in terms of design and component sizing. A methodology for an ease simulation of hydronic systems is implemented in the SIMBAD Building and HVAC Toolbox (SIMBAD, 2005) to study its performance and to suggest potential actions for their improvement. Practically, several types of sizing procedures are implemented as a pre-processor of the simulator to analyse its influence on owning costs, operating costs, energy consumption and the occupant comfort in zones during a French heating season.

INTRODUCTION

Modern buildings are equipped with a rising number of sophisticated products. This potentially allows to operate the building in a performant way, but also requires attention on good design and commissioning of the building and its equipment in order to ensure good operation.

This is especially true for buildings equipped with hydronic networks. A hydronic network represents a complex system that requires at the same time to correctly solve design, sizing and control-related questions: a design error in one part of the hydronic network, for example, affects at the same time the rest of the network. To deal with that problem, a large number of components such as balancing valves (Petitjean R., 2003 and Petitjean R., 2002) and methods exist (Petitjean R., 1994). Moreover, to correct bad operation of unbalanced networks, (hydronic networks without balancing) building operators mostly increase head of pumps or/and hot water supply temperature to ensure comfort in all zones of the building. The results of these actions are:

- Increased energy consumption of pumps,
- Probably growth of primary energy to produce hot water,
- Overheating of hydraulically favoured zones,
- In some cases instability of control loops.

As a result, occupants will have to pay more to have the same comfort as they would do with a well designed hydronic network.

The aim of this study is to evaluate, for a small residential housing how to ensure the comfort in the building while minimising the global cost of the installation for its cycle life (Couillaud N. et al, 2004).

This study will detail the influence of sizing procedure on:

- Owning costs,
- Operating costs,
- Thermal comfort,
- Analysis of water velocity.

Simbad Building and HVAC toolbox (Simbad, 2005) is used to simulate the whole building including its technical devices.

THE SIMULATOR

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 N. et al, 2003). It is developed under Matlab/Simulink environment with the SIMBAD Toolbox (SIMBAD, 2005) developed by the CSTB, a French research centre, till ten years.

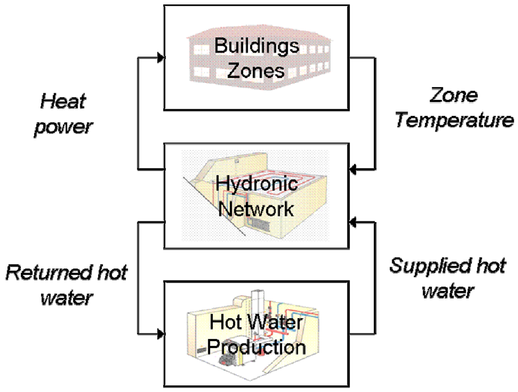

Figure 1 : Structure of virtual laboratory

The simulator developed for this study is divided into three main 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 made with the "SimBDI Interface" (Chlela F., 2004) and the used building model is a newly developed multizone model for Simbad (El Khoury Z. et al, 2005).

- 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 N. 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 study, to modify easily the details and internal structure of each block, e.g. to modify the hydronic system without a need to change of the rest of the model.

A sizing procedure including expert rules has also been implemented in a pre-processor of the simulator. The sizing steps are described hereunder.

The sizing operation of the hydronic network starts with the calculation of heat demand for each zone (no occupation, no internal gains, no solar gains, constant external reference temperature of -7°C, and constant setpoint temperature of 21°C).

The procedure for component selecting size and characteristics in specific data bases follows the steps shown on Figure 2:

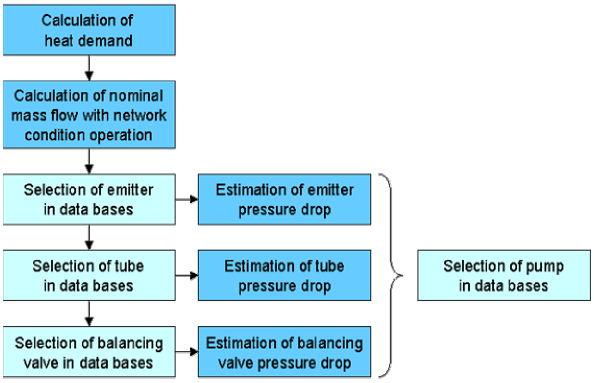

Figure 2 : Sizing procedure of hydronic network

These steps are:

A. Calculation of nominal flow rates for emitter with the network conditions for the planned operation of the building (water supply temperature, temperature drop in the emitters),

B. Selection of emitter in data bases depending on heat power (the nominal emitter power is therefore corrected to the temperature operating conditions in the building),

C. Selection of tube sizes and characteristics in data bases depending on section (the ideal section of the tubes are calculated considering flow rates and maximum/minimum water velocity),

D. Selection of balancing valves depending on kvs values (Equation 1).

$$Kv = 36 \frac{q}{\Delta p} \qquad [1]$$

E. Calculation of pressure drops at nominal operating point for the whole hydronic network composed of emitters, tubes and all balancing valves.

F. Selection of pump in data base depending on nominal mass flow and nominal head using data from pressure calculation.

To date, the data bases include not only physical characteristics of the components but also costs. This allows to estimate the owning costs. In a next step, average values for installation costs will be implemented in the procedure allowing an estimation of the overall owning costs of the complete hydronic network.

OBJECTIVE OF THE STUDY

The main objective of this study is to evaluate the influence of sizing method procedure on:

- Global costs (it considers costs for an extended period of time) of the heating system of the building composed of:
  - Owning costs for the hydronic network,
  - Operating costs for a life cycle of twenty years,
- Thermal comfort for two zones representative of the building,
- Analysis of water velocity in terms of acoustic discomfort and risk of mud deposing.

To study performance of a hydronic network concerning these criteria, parametric studies are carried out for an exemplary building. The Figure 3 resumes the parametric study.

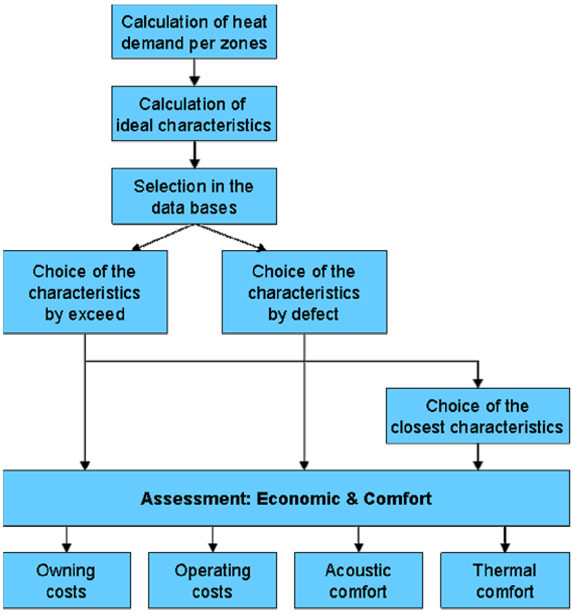

Figure 3 : Parametric studies

The different steps of the previously described sizing procedure are carried out corresponding to Figure 2 and Figure 3.
Step C of the sizing procedure is carried out in different ways in order to analyse the following three possible types of installation that are different in terms of component selection as for duct sizing written in (ASHRAE, 1985) :

- Size method 1: components are selected in the data base by taking the size which is superior to the ideal value, (oversizing).
- Size method 2: components are selected in the data base by taking the size which is directly below the ideal value (undersizing).
- Size method 3: components are selected in the data base by taking the size which is closest to the ideal value (mixing of over- and undersizing).

A simulation of a representative heating season is carried out for each of the above three cases to analyse the impact of each method on:

- Global costs (ASHRAE, 1984). Owning costs are obtained by addition of prices of all components of the installation. Operating costs, mainly primary energy and pump consumptions, are integrated over the heating season.

  Global costs of heating system are calculated for the life cycle of the installation (assumed to 20 years without considering maintenance or related costs to simplify the calculation), from owning and operating costs.

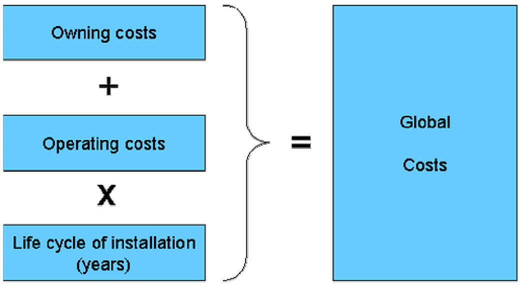

Figure 4 : Method calculation for global costs

- The estimation of thermal comfort for occupants of the building.

  The comfort in building zones is good when the setpoint temperature is reached whatever the operation condition and outside temperature are.

  The quality of terminal regulation is also evaluated by its adaptability to the operation conditions.

- Acoustic comfort and mud deposing risk are estimated. Therefore, water velocity in tubes has been used as an indicator.

  - On the one hand, water velocities under 0.2 m/s carry the risk of mud deposing in the installation (tubes, valves etc.),
  - On the other hand, water velocities above 0.7 m/s, promote acoustic discomfort and also premature degradation.

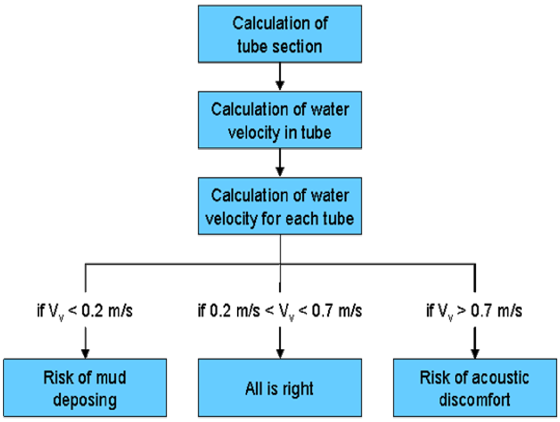

Figure 5 : Procedure of analysis of water velocity

For this study, two risk indicators have been defined for velocities outside this range (Delourme J, 2001):

- Acoustic risk indicator is 1 if v > 0.7m/s.
- Mud deposing risk indicator is 1 if v< 0.2m/s

SIMULATIONS

For this study, a small office building, two storey building has been simulated. The first floor has two zones (Figure 6), and the second one nine zones (Figure 7). The internal halls are included in the zones 9, 10 and 11.

Figure 6 : Plan of the first floor of the simulated building from the SimBDI Interface

Figure 7 : Plan of the second floor of the simulated building from the SimBDI Interface

This building is located in Paris, France. The outside reference temperature is -7°C and the setpoint temperature is 21°C for heating. The building has no cooling system.

Table 1 details the general settings concerning building operation and occupation of the building.

Table 1 : General parameters of building

	Building zones										
	1	2	3	4	5	6	7	8	9	10	11
Surface [m²]	245	35	28	35	42	21	56	28	245	154	91
Number of occupants [-]	30	3	2	3	4	2	5	2	30	19	11
Occupation period [h]	8h - 18h										
Setpoint temperature during occupation period [°C]	20										
Setpoint temperature during inoccupation period [°C]	16										
Heat demand [W]	8760	1185	896	1197	1494	808	1770	1088	10806	6513	3920
Nominal water flow through each emitter [l/h]	275	29	21	30	39	21	53	29	592	181	108
Ventilation air flow [m^3/h]	540	54	36	54	72	36	90	36	540	342	198
Internal gains [W]	1715	245	196	245	294	147	392	196	1715	1078	637

The hydronic network of the building is assumed to be balanced. The compensated balancing method is used to balance this network (Petitjean R., 1994). This is done in a separate simulation before starting the parametric study.

Figure 8 shows the structure of the hydronic network. Supply and return flow paths are not represented in this figure for simplicity. The network is in fact a real bi-tube network. There is one column for each façade of the building. The hot water production is ensured by a gas boiler. The supply temperature is controlled by a heating curve depending on outside temperature.

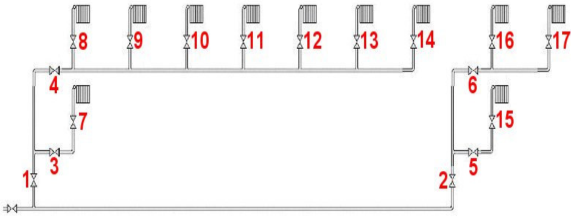

Figure 8 : Structure of the simulated hydronic network of the simulated building including balancing valves

The hot water production is ensured by a gas boiler. The supply temperature is controlled by a heating curve depending on outside temperature (Wallon, 1992).

Simulations are made for 20 days, from 1st January till 20th January.

ANALYSIS OF RESULTS – DISCUSSION

Characteristics of the network

The network is characterized by the unbalance factor (Didier G., 2004). It determines which branches of the network are privileged and those that are underprivileged. The higher this value is, the more balancing of the network is important in order to operate properly. As an example, a perfectly balanced network has an unbalanced factor of 1.

Table 2 shows unbalanced factors for the studied building according to the three cases of sizing to be analysed.

Table 2 : Unbalanced factors

	Oversizing	Undersizing	Closest
Unbalanced factor [-]	3,5	8,5	4,6

Table 2 shows that the first component sizing method, compared to methods 2 and 3, gives a lower factor of unbalance. The oversizing of the network also minimises the pressure drop, due to friction of fluid.

Generally it can be stated that, for high factors of unbalance, pressure drops in networks due to balancing operation will be higher since the balancing valves have to be closed until a balance is obtained. This will lead to higher pump consumptions. The two last sizing methods in table 2 can thus be expected to increase pump consumption.

In a first step, a simulation realising the balancing of the network has been carried out. A simulation model for the compensating method has been implemented in the Simbad environment that carries out the necessary steps during balancing. Table 3 presents the results for this balancing operation for all three studied cases and details the pressure drops for each balancing valve. The values confirm the results presented in Table 2.

Table 3 : Results of balancing for the three cases

BV number	Oversizing		Undersizing		Closest	
	Position [-]	Pressure losses [kPa]	Position [-]	Pressure losses [kPa]	Position [-]	Pressure losses [kPa]
1	2,0	51	2,3	79	1,6	71
2	4,0	2	4,0	12	4,0	2
3	4,0	4	4,0	4	4,0	4
4	2,3	18	2,2	15	2,1	17
5	4,0	1	4,0	6	4,0	6
6	1,9	58	1,8	63	1,7	69
7	4,0	4	4,0	4	4,0	4
8	1,0	3	0,6	6	0,7	4
9	0,8	3	0,4	5	0,5	4
10	1,2	2	0,8	3	0,8	3
11	1,5	2	1,4	2	1,4	2
12	1,0	1	0,5	2	0,5	2
13	4,0	0	4,0	0	4,0	0
14	1,9	1	1,0	2	1,0	2
15	4,0	1	4,0	6	4,0	6
16	4,0	2	4,0	2	4,0	2
17	2,3	5	2,6	3	2,7	3

The classification of the balancing valves is represented by the Figure 8.

Pressure drops of the hydronic installation are maximum for sizing method 2. Methods 1 and 3 lead to a reduction of pressure drops of about 56% and about 46% respectively.

These differences prove that component sizing method has a non negligible influence on the operation conditions for the hydronic network. This influence on thermal comfort and global costs will be analysed in the next sections.

Thermal comfort

Zone temperatures are shown for two zones (zone 7 and 8), selected as "representative" for the building. They have been in either favorised or unfavorised parts of the network.

Resultant temperatures for all three sizing methods are plotted in Figure 9 and Figure 10 for 3 weeks. The building is occupied from 8 to 18h from Monday to Friday. Building is unoccupied on Saturday and Sunday.

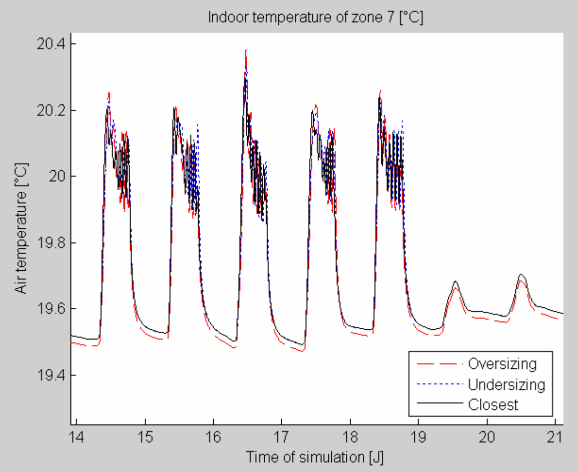

Figure 9 : Zone temperature in zone 7

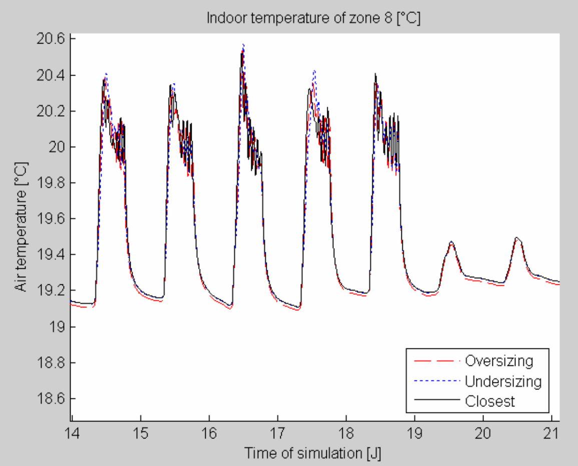

Figure 10 : Zone temperature in zone 8

As indicated in both figures setpoint temperature is reached for all three sizing methods. The difference in terms of zone temperature, indicator for thermal comfort, is negligible. During morning boost, the setpoint temperature is reached depending on inertia of building zones, with very little influence of the balancing method.

During day time, the zone temperature is oscillating with about half degree amplitude. This is due to a default value of the proportional and integral gains of the controller.

Water velocity analysis

The water velocity analysis consists on measurement of water velocity in each section of the hydronic network. The aim is to check if water velocity is lower or higher than the limit values defined by (Delourme J., 2001) for the transient case.

Figure 11-13 show the results of analysis of water velocity for the three studied cases.

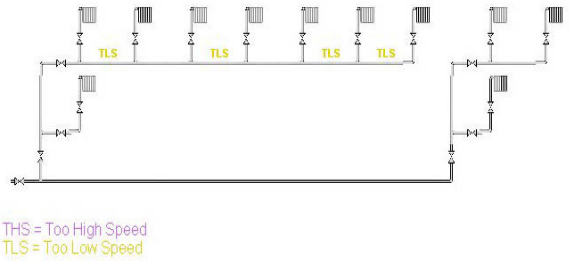

Figure 11 : Analysis of water velocity for sizing method 1

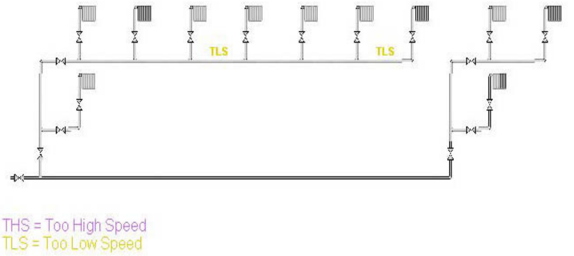

Figure 12 : Analysis of water velocity for sizing method 2

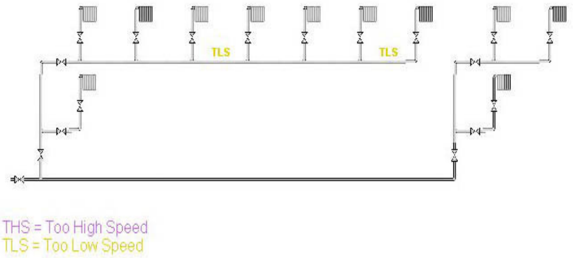

Figure 13 : Analysis of water velocity for sizing method 3

In the first case, the total length of tubes where water velocity is lower than 0.2 m/s is higher than in the two others cases.

As in the first case components are lightly oversized, water velocity is lower for the nominal case. A risk of mud deposing in the concerned branch is thus increased.

No case has been observed where water velocity raised above the maximum authorized value. A risk of acoustic discomfort due to the heating system with is thus negligible for all sizing methods in this building.

Global costs

Global costs of this building for heating system are estimated for a typical french heating season of 20 days representative of the total heating season. The results for these 20 days are extrapolated to the global heating season that is estimated to 5 months considering the location of the building.

Table 4 shows the owning costs for hydronic network installation slipped off for the main components. Owning costs are more expensive for size method 1 as it leads to oversize hydronic network. The second method is cheapest, as it's lightly undersized and the third is inbetween the two previous methods.

Table 4 : Owning costs for the 3 sizing methods

	Oversizing	Undersizing	Closest
BV costs [€]	628 €	592 €	602 €
Tubes costs [€]	648 €	554 €	573 €
Emitters costs [€]	5 126 €	5 029 €	5 049 €
Total investment costs [€]	6 402 €	6 175 €	6 224 €

The Figure 14 shows the operating costs of the network for the three sizing method for a simulated period of 20 days during french heating period.

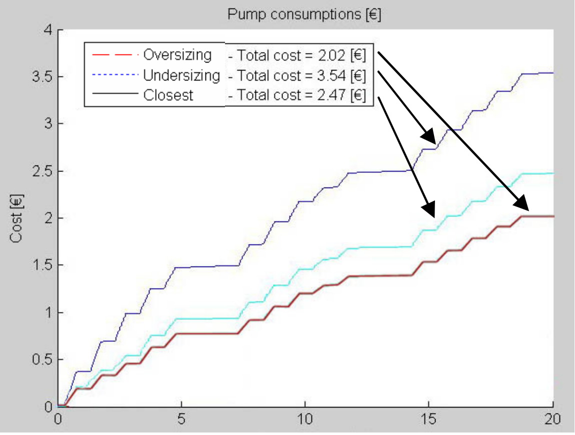

Figure 14 : Operating costs of the network for the 3 sizing methods

Pump consumption is directly related to pressure drops of the hydronic network. The higher the pressure drop in the hydronic network is, the more expensive pump consumptions get. The first method with lower pressure drops is characterised by the lowest pump consumptions: 43% lower than the second method and 33% lower than the third.

In a next step, operating costs for the life cycle are estimated from the simulation results. The life cycle is assumed to be 20 years. The results for one characteristic year are thus multiplied by the number of years. Table 5 details these operating costs for a cycle life of twenty years. More the pump is powerful, more consumptions are expensive. For the second component selecting size method, they are about 50% expensive than the first method.

Table 5 : Operating costs of the installation for a twenty years life cycle

	Oversizing	Undersizing	Closest
For 20 days of heating period [€]	2,02 €	3,54 €	2,47 €
For typical heating season [€]	15,15 €	26,55 €	18,53 €
For life cycle of 20 years [€]	303,00 €	531,00 €	370,50 €

In a last step, global costs, an important parameter for the building manager, are calculated. They include installation costs as well as operating costs. Table 6 shows those results. All three results are very close, because:

- The oversizing of the hydronic network which minimises pump consumptions, leads at the same time to have more expensive owning costs.
- On the other hand, the undersizing of the hydronic network in order to minimise owning costs leads to have higher pump consumptions.

Table 6 : Global costs of the installation for a twenty years life cycle

	Oversizing	Undersizing	Closest
Total investment costs [€]	6 402,00 €	6 175,00 €	6 224,00 €
For typical heating season [€]	303,00 €	531,00 €	370,50 €
Global costs for 20 years life cycle [€]	6 705,00 €	6 706,00 €	6 594,50 €

Theoretically the best solution is a mixture of these two solutions. As the Table 6 shown, the minimum global costs, about 6 594 €, is obtained with the third sizing method that chose the closest value of the component size.

CONCLUSION

This paper deals with the optimisation of the conception of the hydronic network of a hot water heating system. Therefore, a new simulator based on the models of the SIMBAD Building and HVAC Toolbox has been developed.

The simulator implemented in this study allows to study the influence of component sizing methods on thermal comfort and global costs. It also allows to analyse the risk of mud deposing and acoustic discomfort, both function of the water velocity in the different elements of the hydronic network.

The results of the study show that the component sizing method has very little influence on thermal comfort in the building zones.

On the other hand, the influence on global costs and risk of mud deposing is proved. An oversized hydronic network leads to have higher owning cost with lower auxiliary consumptions. An undersized hydronic network leads to have lower owning costs but higher auxiliary consumptions.

This study shows that the best way to size a hydronic network is probably to use the third component sizing method where the components are sized corresponding to the value as closet to ideal values. This method has shown slightly lower global costs than the two other sizing methods.

Moreover, this study shows that a high auxiliary consumptions level doesn't influence the thermal because of the terminal regulation. So, the study in details of the heating system and control strategy is vital to minimise its consumptions.

Since the differences of this studied building have been shown to be small, the next step will be to carry out parametric studies for larger buildings where the networks and thus pump costs are more important.

Future development of the simulator will treat also allow several new analyses:

- the development and evaluation of new control strategies for the control of a variable speed pumps to minimise pump consumptions,
- the implementation of new balancing method (such as methods using differential pressure controllers) into the simulator,
- the study of influence of supply temperature level as well as temperature drop in the emitter.

NOMENCLATURE

m/s: meter per second

BV: Balancing valve

q : water flow [m^3/h]

Kv : coefficient of the valve [m^3/h]

Δp : differential pressure applied to the valve [bar]

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