DESIGN TOOL FOR HYDRONIC BUILDING INSTALLATIONS

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ABSTRACT

This paper discusses a method for designing hydronic circuits for heating, covering both the full-load situation and the part-load situation. The method is supported by a software tool. The method and the tool are based on a modular approach, starting with the heat demands required by the various functions and locations in the building and from there gradually building and evaluating the complete hydronic system. The method provides standard modules for building the hydronic system, consisting of configurable user modules (heat supply), supplier modules (heat generation) and distribution modules (heat distribution). The user gets support for choosing the correct modules, such that both the full-load situation is sufficient and the part-load situation results in optimal control.

INTRODUCTION

In practice, in many buildings people experience comfort problems, problems that are often related to a climate installation that is not operating optimally. This is even the case in modern buildings equipped with the most recent control techniques. Common problems are:

- Some zones or rooms never reach the desired temperature, especially when the internal heat load is variable.
- The room temperature is not constant but fluctuates considerably around the setpoint.
- The design supply power of the heating units in a room is never reached, needed for example during startup after the weekend.

Often, the cause of such problems is found in a malfunctioning of the duct system or the hydronic system, or a wrong balance between the two systems. It appears that the design of these systems is crucial, in combination with the commissioning of the installations before the actual operational use.

With respect to the hydronic system, the distribution of the water flows through the system is often not as originally designed, due to flaws in the design and during commissioning. This leads an unbalance in the heat transfer to the rooms, some rooms having a high temperature and other rooms having a low temperature (for example an undesired difference between the lower and the top floors of a building). When occupants complain about the comfort, the building manager often reacts by increasing the heating curve temperature. This primitive approach might solve the most urgent problems but will definitely lead to an increased energy use (approximately 7% for each degree Celsius temperature increase for an average office building in the Netherlands).

To improve this situation, the whole process from design to operational use needs to be improved. A good handbook on the subject of hydronic balancing is PetitJean, 1994, and references therein. Since this publication is in English, this limits the accessibility for people in the Dutch practice. Fortunately, several Dutch publications exist that support the designer and the commissioner of hydronic systems (see ISSO, 1987; ISSO, 1995; ISSO, 1996; ISSO, 1998a; ISSO, 1998b; ISSO, 2002). However, also these pubications are hardly used in practice since a lot of theoretical background is required.

The project that is described in this paper intends to improve the accessibility of these publications by the development of a software tool for the design and dimensioning of hydronic systems, based mainly on ISSO, 1998b. The tool offers a high-level design method, based on chaining standard hydronic modules and showing directly the implications of the design while hiding the low-level details. The tool differs from existing products like described in Couillaud *et al.*, 2004 and Hegetschweiler and Gaehler, 2004 by not offering a general-purpose tool but by intentionally limiting the number of cases to the ones used in common Dutch practice.

The next section describes a general overview of the complete proces to design, commission and use a hydronic system. Then, the paper focuses on the modular design method for a hydronic system, enabling the user to design the system in such a way that all user modules can be controlled in a rather decoupled way, and guaranteeing the required full-load. Finally, the paper describes the software supporting this design method and shows the benefits of the approach.

PROCES FOR HYDRONIC DESIGN

Adjustment and balancing of a hydronic system is part of the complete process of designing the hydronic system in connection to the design of the building and the rest of the technical installation. For optimal results, the quality of every aspect of the total chain needs to be guaranteed, since the weakest link determines the final outcome. The total process is shown in Figure 1.

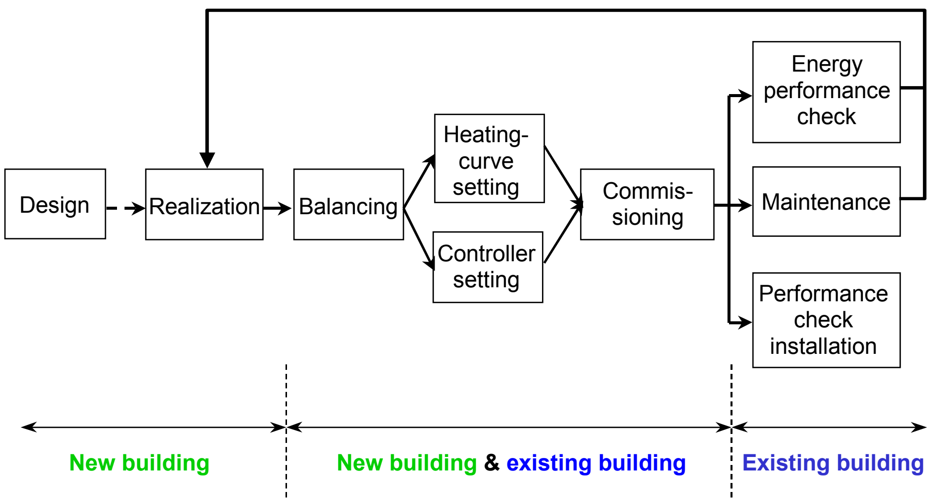

Figure 1 Development cycle for HVAC installations (water and air)

The following stages need to be addressed:

1. Design.

   The criteria with respect to usability, comfort and energy performance need translation to the technical specification of the hydronic system.

   Important conditions for flexible later adjustment are:

   - The presence of adjustment provisions, like adjustment valves.
   - The correct location of these adjustment provisions.
   - The correct size of the adjustment provisions.

   For control purposes during the operational phase:

   - The correct size and type of control valves, in order to have a linear response characteristic in the whole range of operation.

2. Realisation.

   This stage is normally not a problem, unless the system requires a different layout than originally designed. The latter will also lead to changes with respect to adjustment.

3. Adjustment and balancing.

   The main bottlenecks with hydronic adjustment are related to the market pressure (proper adjustment competes with offering a low price), knowledge (guidelines and proper tools) and legislation (see Hiemstra and Schiebaan, 2001).

4. Setting of heating curve and controllers.

   After adjustment of the air and water flows, the next step is to set the heating curves for both subsystems, i.e. the temperature levels of both media. The balance between the two is crucial for supplying the amount of heat that is required by building and organisation, both at full load and (even more) at part load. This requires the application of the correct controllers, in supplement of the control dampers and valves.

5. Commissioning, maintenance and energy assessment or building certificate.

   When the building is renovated or its function and organisation is changed, a new assessment of energy and comfort is likely to lead to other technical requirements to the installation of the building. The whole process needs to be repeated.

Reinforcing the process sketched above requires the recognition the bottlenecks and to remove these. Below a short overview of the most important threats:

1. Knowledge.

   As said before, the knowledge is present in hardly accessible college books, hand books and guidelines, but is hardly picked up in practice.

2. Guidelines and procedures.

   In the Netherlands, the foundation ISSO has published three publications related to the design and adjustment of climate installations (ISSO, 1995; ISSO, 1998b; ISSO, 2000). Combined, the publications cover the whole process as sketched before. However, the value of the publications is not recognized very well in practice. Though the publications contain a wealth of information, both theoretical as practical, the information is difficult to grasp for the average practitioner.

3. Tools.

   These consist of guidelines, calculation tools and tools for adjustment on the spot (measuring instruments).

4. Hardware components.

   The commercially available components, like radiators, valves, are not a limiting factor for broad application of adjustment.

The design method and tool described in this paper addresses the bottlenecks described above and will be extended to cover the complete design and commissioning process of climate installations in the near future.

DESIGN METHOD

The design method covers the following aspects:

- Easy access to the publications of the foundation ISSO.
- Design of the hydronic part of the climate installation.
- Modular approach of the design, in which fixed modules are used to build the complete hydronic system; the modules are based on the ISSO publications.
- Analysis of the design in full-load and part-load conditions.
- Output of the design for use in the adjustment phase.

The expectation is that especially the design tool will lower the threshold for developing well-designed hydronic systems, which perform more according to the original design criteria with respect to comfort and energy use.

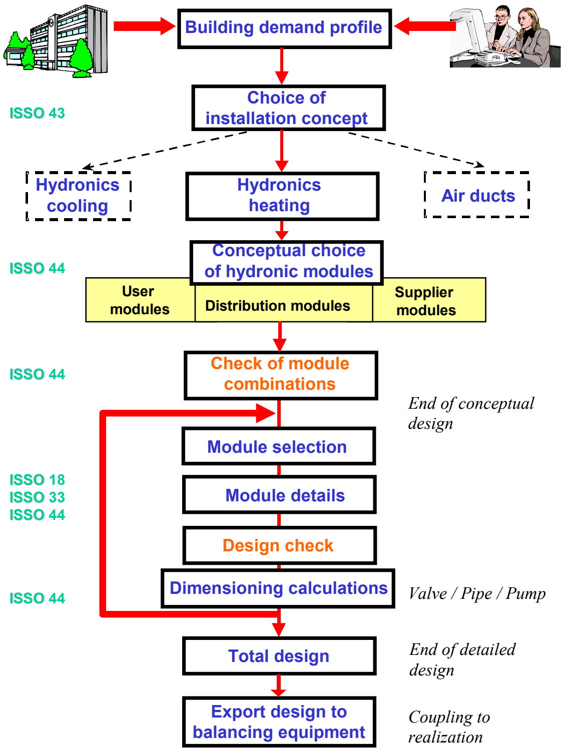

Figure 2 Design of a hydronic system

Figure 2 gives an overview of the design method incorporated in the tool. The method starts with the requirements to the climate installation as determined by the building design and the organisation that will occupy the building. This will lead to the choice of the installation concept, according to ISSO, 1998a. With respect to the hydronic part of the installation, this forms the starting point of the design method as implemented in the tool.

The design of the hydronic side of HVAC installations in buildings is in practice often limited to only the full-load situation. Most of the time however, an installation operates in part-load situations. In all situations, a good operation of the complete system and its subsystems is crucial for the demands on interior climate and comfort, and on the energy consumption.

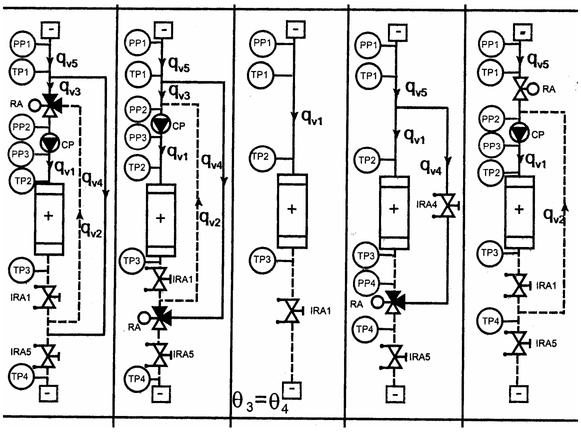

Figure 3 Examples of standard hydronic user modules

Based on the heat and temperature levels that the various building functions and locations require, the method gives a suggestion of predefined user modules that the designer might be incorporated in the design (see Figure 3). The user modules have a structure that, when they are placed in parallel in the containing distribution module, guarantee an independent behaviour, in the sense of control. When the user modules have been chosen, the rest of the system can be layed out, including the distribution module (active or passive) and the supplier module with one or more heat generators in parallel or in series. This results in the setup of the total system (see Figure 4).

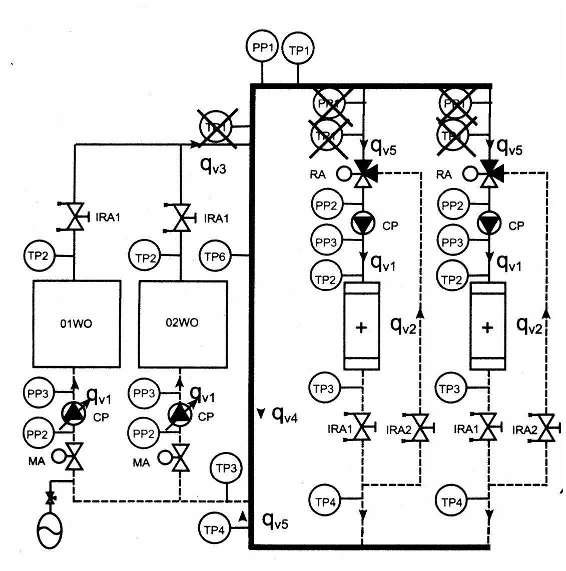

Figure 4 Hydronic system built with predefined modules

The next step is the dimensioning of the components in the modules, such that the full-load demands are reached and the control behaviour during part-load operation is taken care of as well. For that purpose, each module is accompanied by a set of design and adjustment guidelines. Following the guidelines assures the proper behaviour of each individual module.

The dimensioning of the individual modules also has consequences for the dimensioning of the total system, .i.e. the size of the distribution pump in the distribution module and the adjustment of the supplier modules.

The next step is checking the operation of the complete system, especially under part-load conditions. Without some kind of calculation tool, capable of solving the pressure equations of the system, this is not an easy task. For this reason, a software tool has been developed to support the design method.

SOFTWARE TOOL

The software supports the designer in choosing the correct modules and in configuring the modules in such a way that the complete system behaves well under full-load and part-load conditions. The tool allows the designer to define various part-load situations and calculates the hydronic consequences (pressures, temperatures, supplied power).

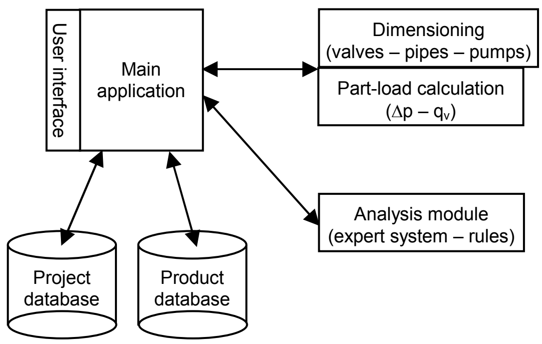

Figure 5 Setup of the software tool

The overall setup of the software is shown in Figure 5. The system consists of several parts. The main application takes care of the interaction with the user through the user interface. It also stores the project information in a central project database and retrieves information about the used components from product databases. Furthermore, the main application contains the data model for the composition of the distribution system, assembling the system from predefined modules.

The main application is connected to a calculation core, which is capable of dimensioning the system (size of adjustment valves, pumps and control valves). It is also responsible for the part-load calculations for arbitrary settings of the control valves of the user modules.

Finally, an analysis modules checks whether the design is behaving properly. It uses as input the results of one or more calculations of the calculation module. It highlights the areas of the design where problems are expected in the user interface, and gives suggestions for improvement to the user.

In a later stage, the tool will be coupled to a building simulation tool, which will allow for calculating the dynamic demands of the building and providing realistic part-load information. Then, the control of the hydronic system can be optimised.

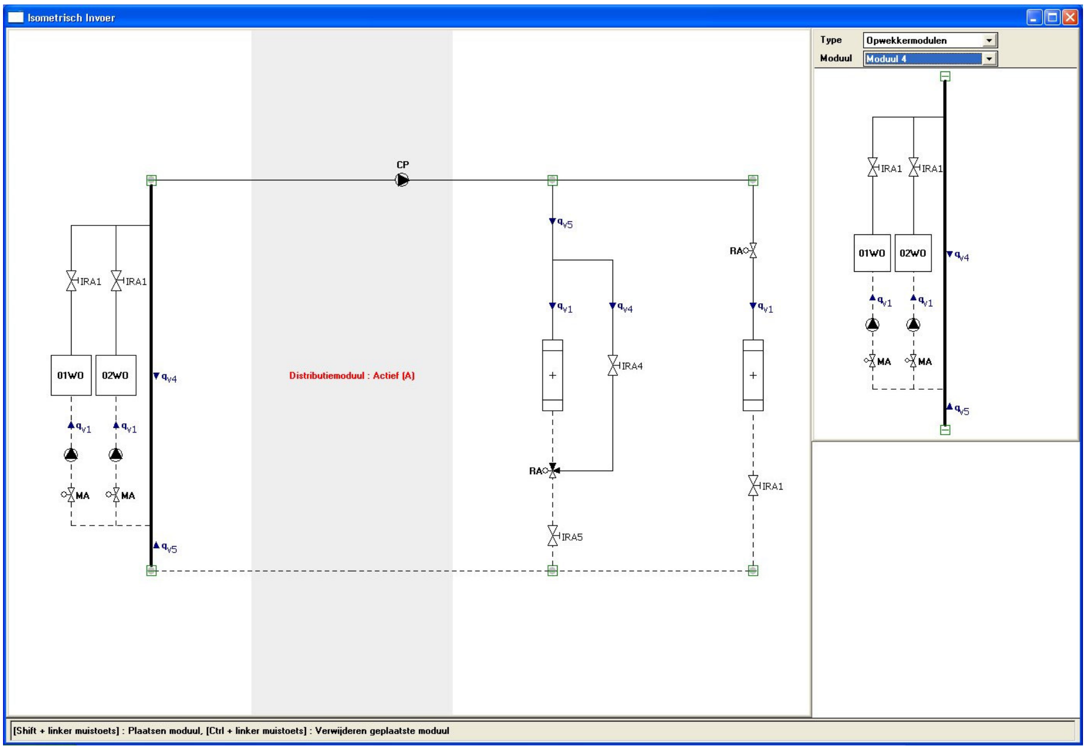

Figure 6 Main form of the user interface of the software tool

The user interface of the main application gives the user the possibility to compose a hydronic system from a library of modules in a graphical way (see Figure 6). The application assures that only logical combinations of modules are chosen by the user. Through the same interface, the user adjusts the properties of the components in the system. After invoking the calculation module and at a later stage the analysis module, the results of calculation and analysis are shown in the same user interface. Based on the outcome, the user can make changes to the design and can restart the evaluation.

The calculation module works indepently of the rest of the programme. It is fed with information about the hydronic system through an XML input file. The structure of the file reflects the composition of the system based on supplier, user and distribution modules. The same building blocks also appear in the internal object-oriented structure, as shown schematically in Figure 7.

The algorithm for solving the (non-linear) equations of pressure versus flow also reflects this structure. The equations are not solved as one system, with a linearized set of equations for the whole system, but on two levels. The top level represents the complete distribution system, with the individual user and supplier modules modeled as black boxes, each with a specific flow and pressure loss; the second level models each individual user and supplier module, based on components like pipes, valves and pumps. The solving process consists of several repeated steps:

- On the level of the distribution module, a reasonable initial estimate of the flow through the distribution branches to the user and supplier modules is made. This estimate is passed as input to the algorithm on the level of each supplier and user module.
- On the level of the supplier and user modules, the pressure loss over each module is calculated,

based on the flow from the previous step. Since the equations are non-linear, this is an iterative process besed on linearisation of the equations around the current working point.

- On the level of the distribution module, the new values of the pressure loss over the supplier and user modules leads to a recalculation of the flow through the distribution branches, also based on a linearisation of the equations on distribution level.
- This process is repeated until convergence has been reached.

Iteration takes place on two levels, on distribution level and on module level. In both cases, the non-linear equations are linearized around the working point. Since determination of the derivative in the working point is involved, another point close to the woking point is also needed. This requires two calculations per iteration step for the supplier and user modules, one for the working point and one for the nearby point.

The advantage of the approach is that the complicated step of linearisation of the complete hydronic system on all levels at the same time is avoided. Instead, the two-level approach gives a modular process, keeping the equations relatively simple. The algorithm can be easily extended when new modules are required.

Tests show that common hydronic systems typically require not more than ten iteration steps at each level. Therefore, solving the equations is a fast process.

The analysis module consists of an expert system containing several rules describing the desired behaviour of hydronic system. These rules are derived from the ISSO publications and represent common knowledge from practice. The analysis module is capable of checking the outcome of the calculations against these rules.

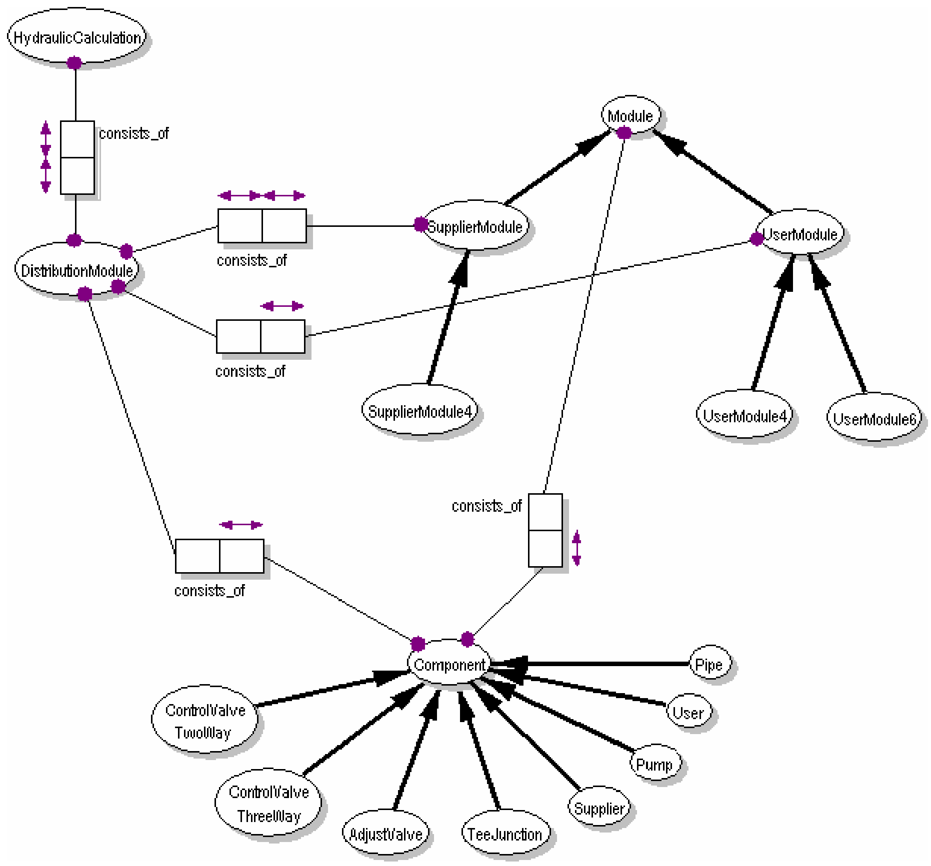

Figure 7 Object structure of the calculation module

CONCLUSIONS

The design method for hydronic systems as described in this paper, and perhaps even more the accompanying design tool give the designer of hydronic systems an instrument to develop a hydronic system that is close to its original design criteria. In this way, it should be possible to develop the technical specifications, as the basis for a well-behaved working system.

The software tool gives the designer the possibility to evaluate the behaviour of the hydronic system under arbitrary par-load situations. The tool signals situations where the design leads to inappropriate behaviour and makes also recommendations on how to improve the design

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