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TESTING AND VALIDATION OF SIMULATION TOOLS OF HVAC MECHANICAL EQUIPMENT INCLUDING THEIR CONTROL STRATEGIES. PART I: DESCRIPTION OF THE VALIDATION TEST CASES

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ABSTRACT

This paper presents the work carried out under Subtask D of the International Energy Agency SHC Task 34/ECBCS Annex 43 (Testing and Validation of Building Energy Simulation Tools). The goal of this Subtask (Mechanical Equipment and Control Strategies) was to develop methods to help evaluating, diagnosing and correcting HVAC mechanical equipment simulation software.

INTRODUCTION

Validation of computational simulation programs is of significant importance for tool developers and users (i.e. design engineers) to avoid bugs and ensure quality of software. Under the scope of the IEA, a lot of effort has been spent in the past years to establish different validation exercises useful for the validation of building energy simulation software. In that sense IEA SHC Task34/Annex 43 is the logical and consequent continuation of other relevant projects as IEA Task12 or Annex 21. Subtask D of this joint IEA project Task34/Annex 43 was on Mechanical Equipment and Controls. This paper gives a short overview only of what was handled within this Subtask. Information that is more detailed can be found in two additional papers.

The Mechanical Equipment consists of a chilled water system and a heated water system. This paper treats both systems - one after the other. The chilled water system is consisting of an air-cooled scroll compressor chiller and a cooling coil located inside an air-handling unit. The heated water system is consisting of a gas fired condensing boiler and three heating coils located in 3 different air-handling units.

For each component, validation test cases are described. Two types of validation tests have been defined: comparative tests and empirical tests. Both tests have been designed for testing the capability of the simulation programs to predict the performance of the mechanical equipment including their control systems. Comparative test cases do not represent a truth standard but give the opportunity to compare results to the outputs calculated with other models and to detect some problems eventually. In empirical tests cases, simulation results are compared to experimental data collected on real installations found in a laboratory building.

The paper gives a description of the overall test logics used for validation of each component model as well as the diagnosing methods. The different validation test cases allowed modelers detecting some bugs and improving their source code. Main difficulties encountered during the exercises as well as some model improvements are described in the paper.

Results of the validation tests for the simulation models of the cooling/heating coil and the air-cooled chiller are presented in two companion papers (Felsmann et al., 2009; Lemort et al., 2009).

CHILLED WATER SYSTEM

The chilled water system consists of:

- An air-cooled scroll compressor chiller (ACCH)
- A cooling coil located inside an air-handling unit (ChW Coil)
- Hydraulic network including a circulating pump and a mixing valve

and is used to serve cooling loads of an air conditioning system (Air Handling Unit – AHU). Figure 1 shows a very simplified scheme of the chilled water system including measuring points.

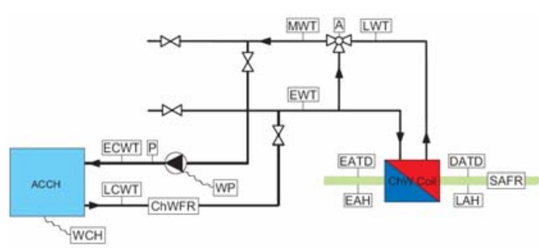

Figure 1: Scheme of the chilled water system with measuring points

This system has been installed at the Energy Resource Station located at Ankeny, Iowa (USA). Further details about the test facility are available at http://www.energy.iastate.edu/ers/.

A lot of physical data and detailed information about the mechanical system required to set up a simulation model is available via the Iowa Energy Center FTP site. This site is a limited access, password protected site. Nevertheless the ERS staff would be able to provide detailed information to interested parties in response to any requests.

The idea behind this chilled water system tests are as follows: for the validation of the simulation programs, it should be possible to focus on the behaviour of the main components as well as have a look at the operation of the whole system.

Chiller

The chiller that has been examined in this project is an air-cooled liquid chiller manufactured by McQuay. Figure 2 provides a scheme of the chiller loop.

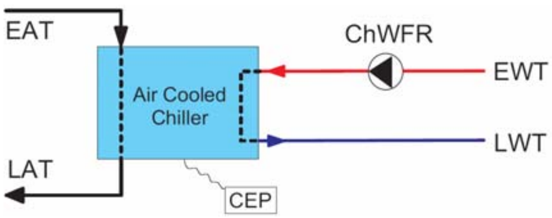

Figure 2: Scheme of the chiller loop

The chiller by itself is a complete, self-contained automatic refrigerating unit that is completely assembled, factory wired, charged, and tested. It consists of air-cooled condensers, two Copeland Compliant Scroll hermetic compressors, one brazed plate-to-plate evaporator, and a complete refrigerant piping. Liquid line components include sightglass/moisture indicator, solenoid valve, and thermal expansion valve. The electrical control centre includes all equipment protection and operating controls necessary for automatic operation. Figure 3 offers a simplified and schematic view of the chiller's refrigeration circuit.

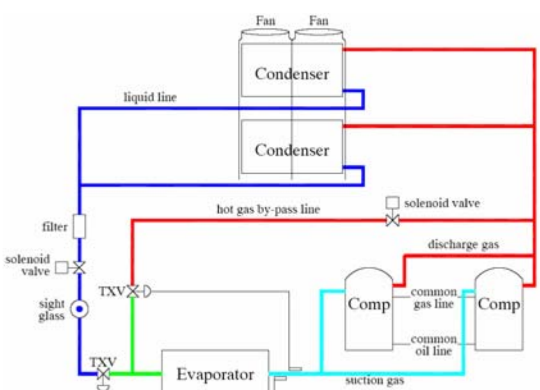

Figure 3: Air-cooled chiller refrigeration circuit

The only simulation results that have been provided during the IEA project was running are from the University of Liège. The modelling approach used to calculate data are described in a special paper (Lemort et al. 2008). It was concluded that compressor performance tables should always be given as part of the chiller performance data. This exercise showed that they allow a pretty good identification of the compressor model parameters. This was confirmed by the analysis of the experimental data (where the compressor was "dissociated" from the heat exchangers by imposing the saturation pressures as input of the compressor model). Moreover, the condensing power could also have been given in these compressor performance tables. Based on this additional information, the heat exchange coefficients introduced in the modelling could have been better identified. Analysis of the experimental results showed that it was necessary to account for the fan control in the model (in order to represent the air flow rate decrease when entering air temperature decreases). The proposed fan control model seems realistic. However, it could certainly be improved if more information on the fan control was made available. Moreover, the identification of the condenser parameters would have been easier if the air flow rate was given in the (full load and part load) performance tables.

Cooling Coil

The high performance fin tube coil is an integral part of a central station air handling unit manufactured by Trane. It can be used for general purposes. The horizontal coil section operates as a full coil. It consists of a chilled water single serpentine with 6 rows. The validation exercises related to the cooling coil consists of both two sets of comparative and one single empirical test procedure. The simulation results that have been provided during the IEA project was running are from Technical University of Dresden, University of Liege, Vabi Software BV in Delft, ITG Dresden, and GARD Analytics from U.S. Tests and results are described in more detail in a separate paper (Felsmann et al., 2009).

HEATING WATER SYSTEM

The heating water system consists of a gas-fired condensing boiler supplying hot water to a hydraulic system that again serves several heating coils. These coils are either part of centralized air-handling units (AHU-1, AHU-A, AHU-B) or terminal re-heat units installed in the test rooms of the laboratory facility. Figure 4 shows a simplified scheme of the heating water piping system.

Under the scope of IEA Task34/Annex43 a comparative as well as an empirical test has been developed for both the boiler and one of the heating coils inside the AHU. The hydraulic network has been described only without offering a test procedure.

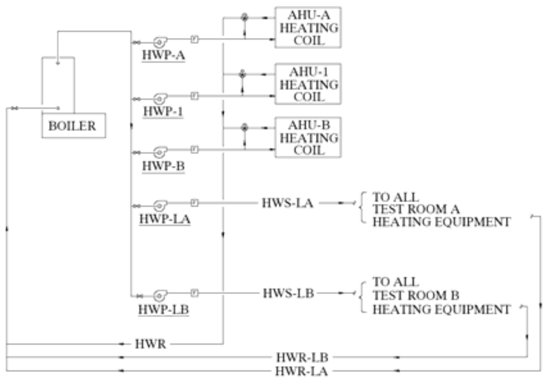

Figure 4: *Simplified heating water piping schematic*

Boiler

The gas fired hot water condensing boiler used for this validation task is designed for application in any closed loop hydraulic system. It relates the energy input directly to the fluctuating system load by an energy input modulation. When return water temperatures are low enough the boiler is capable to discharge flue gas condensate. From the experiments conducted at the ERS a lot of data have been recorded that allow to validate an appropriated simulation model of the boiler. Figure 5 schematically shows the built-in situation of the boiler with measuring points.

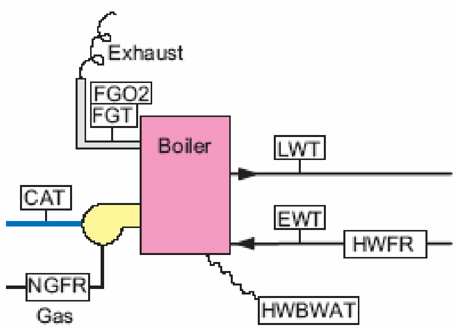

Figure 5: Scheme of the condensing boiler with measuring points

Some general data of boiler performance at nominal load taken from the manufacturer submittal are provided with the description of the test procedures. In addition to the nominal point also part load performance of the boiler depending on return temperature is known as depicted in Figure 6.

In the comparative test cases boiler performance during a heating season has to be calculated referring to two different control options: constant or variable supply water temperature. Supply water temperature set point, return water temperature, and hot water flow rate, respectively, are given depending on outside air temperature used as a heat load indicator.

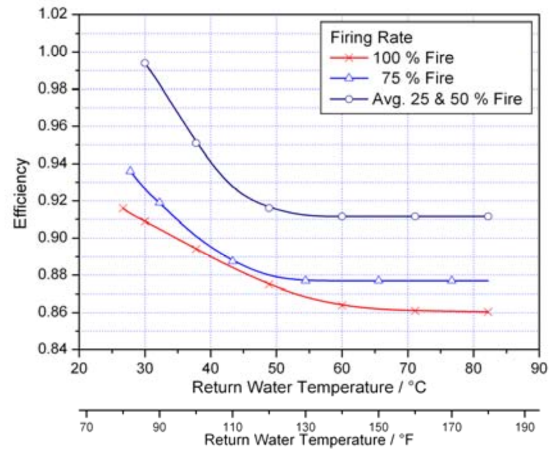

Figure 6: Efficiency curves of the boiler

Beside control options also combustion air intake and condensing effects have been varied during comparative test.

For empirical validation minute-by-minute experimental data collected during February 21-28, 2006 can be used as a reference. Figure 7 exemplary shows the comparison of an daily averaged heating load profile derived from experimental data and two of those predicted by simulation programs. The simulation results that have been provided during the IEA project was running are from Technical University of Dresden and the University of Liege.

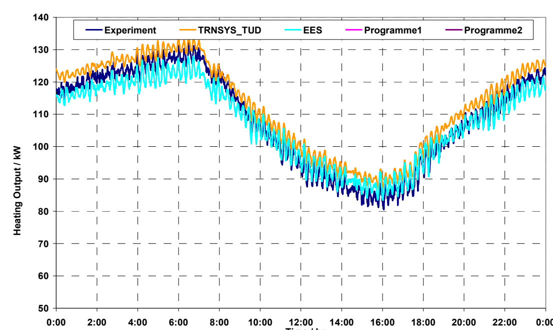

Figure 7: Boiler empirical test - heating output

Heating Coil

The high performance fin tube coil used for validation purposes is an integral part of a central station air-handling unit manufactured by Trane. The horizontal coil section operates as a full coil. It consists of a heating water single serpentine with 2 rows. Information about the performance of the heating coil can be taken from the equipment submittal. However the submittal available for this heating coil only describes one operating state rated with ARI Standard 410[1]. From this single state again only limited knowledge about the full range of coil performance can be extracted. For this reason some experimental data are given additionally, that can be used to adjust the heating coil model. The validation exercises related to heating coil consists of both a comparative and an empirical procedure. The simulation results that have been provided during the IEA project was running are from Technical University of Dresden, University of Liege, Vabi Software BV in Delft, ITG Dresden, and GARD Analytics. Tests and results are described in more detail in a separate paper.

Hydraulic system

In fact the hydraulic network investigated is only a small part of a more complex heating water system but the view to only this network keeps the exercise manageable. The modelling of the hydraulic system can be done either in a detailed way based on the information taken from a 3D-drawing of the hydraulic system or in a simplified way based on the scheme depicted in Figure 4. The aim of the task is to predict flow rate in the hydraulic system under given lift of the control valve taken into account performance of the circulation pump as presented in Figure 8.

CONCLUSIONS

Based on the lessons learned in this joint IEA SHC-Task34 / ECBCS-Annex43 some recommendation for future work in the field of validation of mechanical equipment and HVAC system models can be derived.

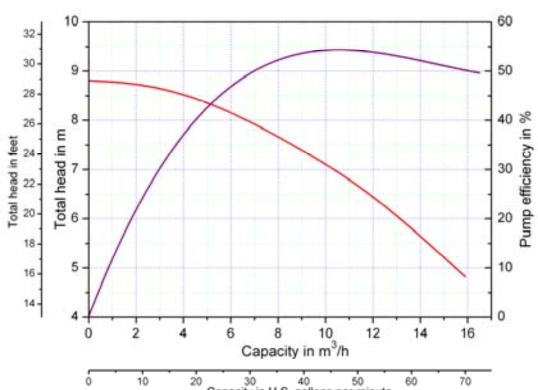

Figure 8: Heating water pump performance curve extract

At first the design of comparative test cases should be done particular with regard to strong diagnostic power of the test. This means:

- Nearly the full area of operation from low part load to peak load should be covered by the test conditions.
- The impact of certain design parameters on the performance of the HVAC system model should be analysed.
- The impact of variable inputs on the performance of the mechanical equipment should be analysed using standardised tests for controllers, i.e. step response.

Dynamic effects should be taken into account if they are relevant for the performance of the components. For that reason the tests should focus on a limited time-frame rather than a (half-) annual time period of simulation.

The design of empirical test cases depends on the opportunities given in the test facility. In a laboratory or in a test facility that offers conditions similar to a lab also artificial boundary conditions can be created that allow to operate the equipment apart from real world conditions but better covering the potential area of operation. This was done during this project in the Cooling coil empirical test II. Empirical tests should be performed in addition to comparative tests to show differences between theory and real world. It is obvious that a high effort must be undertaken to collect reliable experimental data suitable for empirical validation purposes.

A third aspect is related to a whole system approach that does not only target on the validation of certain components (i.e. chiller, cooling coil, boiler, heating coil) but also accounts for the simultaneous operation of the whole system. Doing this the interaction of components can be checked. Inaccurate predictions propagate from one component to the next and will be intensified or compensated.

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