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Hardware in the loop test bench using Modelica: A platform to test and improve the control of heating systems

Alberto Tejeda De La Cruz [a,b,*], Philippe Riviere [b], Dominique Marchio [b], Odile Cauret [a], Anamaria Milu [a]

[a] Energy Systems in Buildings Group, ENERBAT Department, EDF R&D, Moret sur Loing, France
[b] CES-Centre for Energy Efficiency of Systems, MINES ParisTech, PSL Research University, Paris, France

HIGHLIGHTS

- New HIL test bench to assess performances and control strategies for HVAC systems.
- Real time building simulation is connected to the HVAC system to be tested.
- Dynamic conditions inside the building are simulated using a Modelica building model.
- An AWHP is tested and several improvements of control strategies are highlighted.
- The methodology presented lowers the time to market of the development process.

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ABSTRACT

HVAC manufacturers make important investments to develop more efficient technologies for space heating (SH) and domestic hot water generation (DHW). Among these technologies, this article focuses on Double service air-to-water-heat-pumps (AWHP). The control of AWHP strongly impacts their performances, so that manufacturers of AWHP need to optimize the control of their systems to increase their performances. This paper presents the implementation of a Hardware-In-the-Loop – HIL – real time simulation test bench for AWHP. The new test bench proposed uses real weather conditions and simulates building's and occupants' response thanks to a virtual model. This test bench allows R&D departments and manufacturers to test several heating systems in parallel as well as different control options. It may also limit the need for field testing. It thus has the potential to reduce the cost and time required for AWHP development-to-market process. The test bench presented in this paper is used for a specific AWHP and a typical building in France. The analysis of the impact of the heat pump's control on the system dynamics and on the indoor thermal comfort enables to highlight control issues related to the heating curve, the DHW management and the defrost process of AWHP. Optimized control parameters throughout time are proposed in view of reaching lower consumption and better performances. This case study shows the potential of the HIL test benches for manufacturers to optimize the development of their products controls.

1. Introduction

In Europe, the increasingly restricting environmental regulations push the residential building sector to replace polluting fossil fuel boilers with more environmentally friendly technologies. For this purpose, manufacturers have made important investments in Research and Development (R&D) in order to develop more efficient technologies for space heating (SH) and domestic hot water generation (DHW). Double service air-to-water-heat-pumps (AWHP) are suitable for this purpose as they can supply space heating and domestic hot water while reducing CO_2 emissions [1]. However, AWHP performances are dependent on their control and commissioning [2], which pushes manufacturers to improve control systems embedded in their machines [3].

Energy management of double service AWHP systems (non-simultaneous generation of space heating and domestic hot water) is critical to avoid any discomfort and to ensure good performances [4]. Standard controls are not usually adapted either to all type buildings or to all kind of hot water tapping profiles [5]. Moreover, due to operating conditions, frost accumulates on the evaporator

* Corresponding author at: CES-Centre for Energy efficiency of Systems, MINES ParisTech, PSL Research University, 60 Boulevard Saint-Michel, 75006 Paris, France.
E-mail address: alberto.tejeda@outlook.com (A. Tejeda De La Cruz).

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Nomenclature

AWHP	air to water heat pump
DHW	domestic hot water
EDF	Electricité de France
GSHP	ground source heat pump
HIL	hardware in the loop
HP	heat pump
HVAC	heating ventilation and air conditioning
IP	internet protocol
OPC	OLE - Object Linking and Embedding - for Process Control
RTU	remote terminal unit
R&D	Research and Development
SH	space heating
TCP	transmission control protocol

forcing a defrost process. Thermal comfort and heat pump performances are negatively impacted [6].

In this context, this article presents a hardware-in-the-loop (HIL) test bench capable of evaluating the impact of different control parameters settings on the seasonal performances of an AWHP and on the occupants' comfort. We focus on investigating the impact of different parameters settings on the dynamics of the AWHP, the DHW tank and the building. The test bench presented allows R&D departments and manufacturers to test several of their products simultaneously by connecting them to virtual buildings, in order to test different control parameters settings under real weather conditions.

1.1. Development of residential heating systems: R&D current practices

Nowadays, heating technologies manufacturers invest field tests and prototypes validation in R&D before commercializing any system. After the design step, prototypes must be built in order to test performances and to check the viability of the system [7]. Once the prototype is validated, manufacturers pass through the step of testing their systems under real conditions. This step allows them to verify the adaptation of the product to the behaviour of both the buildings and the occupants as well as to try different parameters settings to improve their product's operation. These field tests are also an opportunity to identify design errors to be corrected in new prototypes.

However, field tests in real buildings, as stated in [8–11], are costly operations that need the authorization of the customers and which are usually not representative of the adaptability of the system to different buildings. Moreover, the parameters settings configuration cannot be freely tested, as they may affect the comfort of the occupants as well as the reliability of the system. In addition, when design errors are identified, manufacturers are forced to replace systems with the associated costs of decommissioning.

There is also a high interest in comparing different technologies or different catalogue or innovative products under the same boundary conditions, i.e. weather, building and occupants. However, during a field test campaign this is not feasible because the buildings and occupants differ. Even when a large field trial is performed, as the one done in the UK by Energy Saving Trust [12], it is difficult to compare systems performances installed in different houses and under different weather conditions. As a response to these challenges, this paper presents a solution for manufacturers and R&D laboratories to compare and test heating systems technologies under real weather conditions, yet using virtual models to represent the same building characteristics and behaviour of their occupants.

As presented in Fig. 1–1, the presented test bench improves the development process of heating systems by reducing and improving the validation steps: semi-virtual test benches increase the possibilities of testing products in a larger range of buildings and using different control parameter settings.

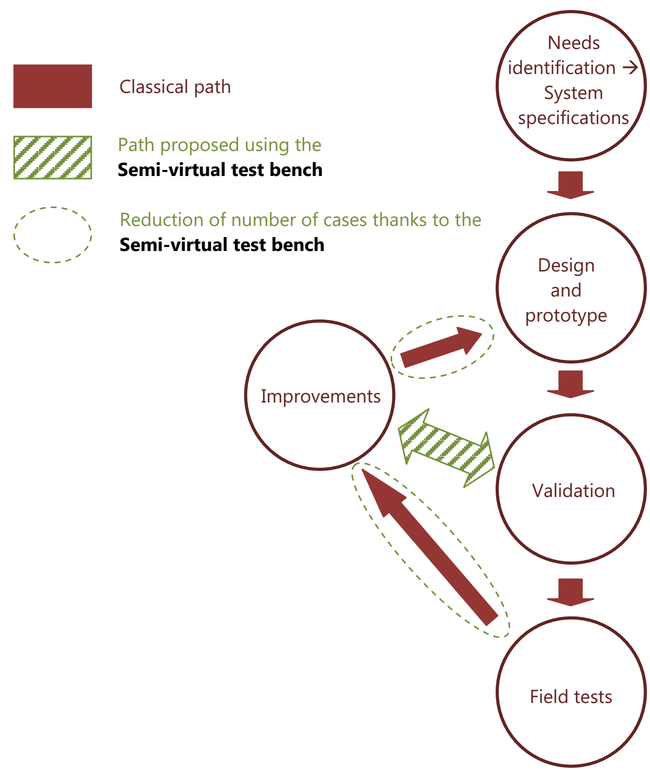

Fig. 1–1. Improvement of the development process of heating system technologies.

The current R&D roadmap for emerging HVAC technologies [13] focuses on innovative initiatives that accelerate the development of technologies; initiatives that produce near-term improvements as well as those which advance the development of next generation or transformational technologies. The test bench and methodology presented in this paper meet these expectations.

1.2. Current platforms

There are already existing platforms which are used for evaluating heat pumps seasonal performances and influence of control parameters. Table 1 shows a synthesis of different configurations: completely real systems (i.e. field tests), hybrid systems (as the HIL test bench presented in this document) or totally virtual systems.

Field tests are distinguished by using real systems installed in dwellings of customers. They are commonly carried out in order to assess heat pumps performances in real-life conditions as well as to evaluate the impact of installation practices and customer