Applied Energy 205 (2017) 976–990

Contents lists available at ScienceDirect

Applied Energy

journal homepage: www.elsevier.com/locate/apenergy

Development of a new dynamic test procedure for the laboratory characterization of a whole heating and cooling system

Diego Menegon*, Anton Soppelsa, Roberto Fedrizzi

EURAC Research, Institute for Renewable Energy, Viale Druso 1, 39100 Bolzano, Italy

HIGHLIGHTS

- A new dynamic procedure for heating and cooling system testing was developed.
- In the procedure a load is prescribed and the performance are directly extrapolated.
- The procedure is valid for different climates and loads.
- The effects of dynamics are evaluated experimentally.

ARTICLE INFO

Keywords:
Dynamic test procedure
Hybrid thermal systems
Seasonal performance
Clustering
Direct performance extrapolation

ABSTRACT

The performance of heating and cooling systems are affected by their dynamic operating conditions. As a consequence, a sound evaluation of system performance should be done through a dynamic test procedure. However, the complexity, the cost, and the time for such type of experimentation are obstacles to the diffusion of this test method.

A new whole system test procedure was developed to reduce its potential failure. The test method considers the emulation of system components that cannot be installed in the laboratory, while the selection of short-yet-significant test sequence is performed classifying the days of the year with clustering analysis.

The procedure was applied to a solar-assisted heat pump system in four different European climates. The seasonal performance figures are extrapolated from the test results and compared with the numerical simulations of the entire heating and cooling system. In all test cases the seasonal performance factors are lower than the simulated ones by approximately 10%. The results obtained with dynamic tests confirm the necessity of their implementation, since they provide useful information to improve the system layout and control. In this way, the manufacturers can introduce more efficient products into the market.

1. Introduction

In recent years, the need to slow climate changes has required several measures from different national and international institutions. As indicated in the Renewable Heating & Cooling (RHC) platform, the main challenges of European Union can be summarized by the reduction of greenhouse gas emissions, the improvement of security of energy supply, and development of clean technologies [1,2]. Renewable energy sources have a large potential to fulfil these aims, and their integration in residential buildings heating and cooling system could be crucial, since this sector makes up about half of all heat consumption in Europe. This heat consumption corresponds to the 51% of the final energy demand [1–4].

To help consumers to choose products that save energy and consequently push the market to develop more efficient products, the European Directive 2010/30/EU [5] requires the adoption of the "energy label" for all energy-related products. The products are rated in a category ranging from A (best) to G (worst), indicating the seasonal efficiency and the overall energy consumption represented by reference cases. The directive was implemented through different European Regulations as, for example, the Regulation N. 626/2011 (specific for air conditioners) [6] and the Regulation N. 811/2013 (generic for heating systems) [7].

To label a product, a standardized benchmark test is needed to compare the performance of different systems. However, the definition of a benchmark test procedure has to satisfy different requirements, such as the comparability and repeatability of results, simplicity and flexibility of test method, cost effectiveness, and so forth. In this

* Corresponding author.
E-mail address: diego.menegon@eurac.edu (D. Menegon).

http://dx.doi.org/10.1016/j.apenergy.2017.08.120
Received 30 March 2017; Received in revised form 9 June 2017; Accepted 11 August 2017
0306-2619/

Nomenclature

Nomenclature	[Unit]
$\dot{m}$	mass flow rate [kg/s]
m	mass [kg]
$\dot{Q}$	heat power [kW]
$\dot{W}$	electrical power [kW]
Q	thermal energy [kW h]
W	electrical energy [kW h]
E	energy (generic) [kW h]
T	temperature [K]
ΔT	temperature difference [K]
c_p	specific heat [J/(kg K)]
τ	time [s]
δ	deviation [–]
GHI	global horizontal irradiation [W h/m^2]
DHW	domestic hot water
SH	space heating
SC	space cooling
SPF	Seasonal Performance Factor
PF	Performance factor
SF	Solar Fraction
AF	Air Fraction
CTSS	Component test system simulation
WST	Whole system test
DST	Dynamic system testing
CCT	Concise cycle test
SCSPT	Short cycle system performance test
sup	supply
ret	return

context, it has to be considered that implementation of different energy sources often leads to a single hybrid system with complex architecture and sophisticated control strategies [8]. As an example, different solutions can be identified for implementing renewable energy sources [9], such as solar and heat pump system [10] or biomass [11]. Consequently, the working conditions are strongly time-varying during the operation.

In most cases, standard tests are based on steady-state approaches such as heat pumps (EN 14511-3:2011), biomass boilers (EN 303-5:2011) and solar collectors (EN 12975-2:2006) [12–14]. The characterization of performance under steady-state conditions is quite simple to reproduce in a laboratory, but it can differ substantially from realistic working conditions. Indeed, the effect of transient phases, the on/off cycles, the influence of layout and control strategy are not negligible [15–17], and hence have to be considered in the performances characterization.

The analysis of current standards shows that many of them focus on testing the components under stationary conditions. Specific standards for the characterization of complex or hybrid heating and cooling systems are not yet available.

The two standards methodologies used to assess the seasonal performance are based on the steady-state test: one is the bin method and the other is the so-called component test and system simulation (CTSS). The first one considers the cumulated frequency of the external air temperature and the corresponding load. The EN 14825 [18] describes the bin method for heat pumps; the component performance is extrapolated from a few tested points and is built for three reference heating conditions and one reference cooling condition. Instead, in the component testing and system simulation method, numerical models of components are defined from laboratory test and the system performances are evaluated from a numerical simulation. In many cases, tests are performed under steady state conditions and as a consequence the model is over-simplified. With the test of single components (i.e. heat pump, pellet-boiler, collector and so on), the hydraulic layout and control strategy is left to the modeller; moreover, not all the components available in the market have a corresponding testing standard.

The dynamic test of components enables the definition more reliable models, albeit at the expense of increased development time. For example, component dynamic tests are used for the implementation of dynamic models in the CTSS method in solar thermal driven system [19–21], while Carlon et al. have developed a load cycle of 8 h to validate a thermodynamic biomass boiler model [22]. Instead, we have developed a dynamic test procedure to characterize the component performances directly from the test results; these are representative of realistic working conditions [15,16].

The dynamic characterization of a single component is not enough to understand its behaviour when installed into a complex system. To overcome this limitation, dynamic whole system test approaches have been developed and applied in recent years to test small-scale and residential systems by several institutes: SPF in Switzerland [23–25], SERC in Sweden [26–28], and CEA INES in France [29,30]. A description of whole-system test procedures has been reported [23,31,32], while Schicktanz et al. [33] presented a classification of rating methods for solar heating and cooling system that also considered previous methodologies. These procedures followed a holistic approach in which the whole system was installed in a test bench that emulated the loads and the sources. These procedures have been originally developed for solar Combisystems, but they have also been used to test biomass-driven systems [11]. Within the EU FP7 funded project MacSheep [31], the three above-mentioned institutes have harmonized and simplified their procedures in order to define a common approach for benchmarking. In addition, they have extended their test methods to allow their application to solar thermal and heat pump systems. A major step forward in the harmonization of the methods was the application of a realistic dynamic behaviour of a building model coupled with a load file that fixes an energy target. In addition, the seasonal performance is defined with a direct extrapolation of results. However, the procedures adopt only one reference climate (Zürich) and consider only space heating system. Moreover, the procedures require the coupling of the laboratory control with a simulation software (TRNSYS) to emulate the behaviour of the loads and the sources; this can be an obstacle for the implementation of this approach since it can be performed only by skilled personnel. In addition, it does not consider the test of space cooling system.

In the literature [23–25,29], the definition of test sequence has followed two different approaches:

- Selecting reference days with an iterative procedure in order to maintain the proportionality of the sequence performance figure with the annual performance figure;
- Selecting reference days as the representative day within each month following some kind of averaging procedure.

The advantage of first approach is that the seasonal performance can be directly extrapolated. However, the complexity of this optimization process does not permit the definition of different sequences, since that is a long process. The second approach makes the definition of a test sequence simple, but this approach cannot perform a direct extrapolation of performance [25]. The extrapolation of seasonal performance is done validating a numerical model and running annual simulations; in this way, the post process of results requires a huge effort.

These considerations have motivated the development of a new dynamic procedure for the whole system tests. The procedure is