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A new test procedure for the dynamic laboratory characterization of thermal systems and their components

Diego Menegon[a,b,*], Alice Vittoriosi[a], Roberto Fedrizzi[a]

[a] EURAC Research, Institute for Renewable Energy, Viale Druso 1, 39100 Bolzano, Italy
[b] University of Udine, DIEGM, Via delle Scienze 208, 33100 Udine, Italy

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ABSTRACT

The need for energy labelling procedures applied to thermal systems requires new methods to assess their seasonal performance. Their typical dynamic operation and the interaction among components and control system restrict the possible use of stationary, component-oriented tests. New dynamic test methods addressing the system as a whole are now available in the open literature. Discussion is undergoing with respect to key issues such as test sequence definition and post-processing of the test results.

A new dynamic procedure was developed to address these points, based on the statistical selection of the test boundary conditions. The paper describes the procedure and its first validation at component level. The results of the dynamic test were compared with the values obtained for the entire season operation, showing a good agreement both in terms of seasonal performance figures and of instantaneous distributions of the performance indicators. The promising results obtained so far to motivate the application of the procedure to other components and a future adaption to test whole systems.

1. Introduction

With the adoption of the European Directive 2010/30/EU [1], all energy-related products should be labelled according to their energy consumption. Following the Directive, different European Regulations for heating and cooling systems were published, as, e.g., the Regulation N. 626/2011 [2] and the Regulation N. 811/2013 [3]. These documents establish that, for each system, seasonal performance figures should be provided, declaring its overall energy consumption and allowing the comparison with analogous systems.

The architecture of heating and cooling systems being currently proposed on the market tends to be significantly more complex than traditional installations, often exploiting renewable energy contributions, different active components and sophisticated control strategies, all together in a single system. As a result, the performance assessment of such arrangements is not trivial.

Specific standards for the characterization of complex or hybrid heating and cooling systems are not available yet. Contrarily, a variety of standards for single components, specific combinations of those or particular applications can be accessed. In general, different approaches for the seasonal performance evaluation can be identified: the Bin Method and the component-testing-system-simulation (CTSS) techniques are relatively consolidated, being based on the test of the single components. On the other hand, recent approaches, as the Concise Cycle Test (CCT), the Combitest and Short Cycle System Performance Test (SCSPT), move towards the Whole System Testing (WST).

The Bin Method is a handy procedure used to estimate the seasonal performance of heating and cooling systems, taking into account reference operating conditions. A description of the method can be found in the standard EN 15312-4-2 [4], which implements the results of the IEA Annex 28 [5] or in the standard EN 14825 [6], for the rating of electrically driven heat pumps. The main features of the procedure rely on the evaluation of the cumulative frequency of the outdoor air temperature and the corresponding load variation. This is used for the calculation of the seasonal performance parameters, along with performance figures retrieved in stationary tests at full and part load conditions. The mentioned standards are used with respect to heat pumps systems, but the application of the method to hybrid system is complicated, as the dynamics of the components and the control influence can hardly be considered.

With the CTSS approach, tests made on single components are used to validate a numerical model of the whole system, which is then used for the evaluation of the seasonal performance. The tests are usually performed under stationary conditions, again neglecting their dynamic behaviour. Loose et al. [7] proposed a solution

* Corresponding author at: EURAC Research, Institute for Renewable Energy, Viale Druso 1, 39100 Bolzano, Italy. Tel.: +39 0471055639.
E-mail address: diego.menegon@eurac.edu (D. Menegon).

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Nomenclature

C	number of classes [−]
N	dimension of events/classes [−]
NP	number of parameters [−]
n	number of divisions [−]
T	temperature [°C]
ΔT	temperature difference [K]
$\dot{m}$	mass flow [kg/s]
c_p	specific heat [J/kgK]
Q	thermal energy [kWh]
$\dot{Q}$	thermal power [kW]
EER	energy efficiency ratio [−]
SEER	seasonal energy efficiency ratio [−]
f	frequency [%]
u	measured uncertainty

Subscripts

A	parameter amplitude within an event
M	mean of the parameter within an event
avg	average
gen	generator
cond	condenser
evap	evaporator

Greek letters

τ	duration [min] [days]

to overcome this limitation by using dynamic tests to identify the parameters required to describe a detailed numerical model, while Uhlmann and Bertsch [8] experimentally investigated the effect of ON-OFF cycles on the performance of air-to-water geothermal heat pumps, to develop a more reliable numerical model of these components.

Nonetheless, the interactions among the components, as well as the role of the control strategy are accounted for only through simulations. Kerskes [9] and the standard EN 12977-2 [10] present the application of the procedure to solar thermal systems (space heating and domestic hot water). Based on this application, the procedure has been adopted as Australian Standard to test solar desiccant based air-conditioners [11,12]. The dynamic effects introduced by valves and pumps (that are not tested), as well as the losses related to the pipelines are still disregarded.

In order to take also these factors into account, a number of procedures considering systems as a whole, are being developed. These methods aim at testing the entire systems only for a representative part of the yearly operation, defining correspondence criteria to retrieve the seasonal performance parameters.

The Combitest method [13,14] consists of a 8 days test: 2 for preconditioning, 2 representing the average seasonal values for summer, 2 for winter and 2 for spring and autumn. From the experimental results, the annual space heating demand is calculated with a proportion based on the degree days of the location where the system is installed, while the annual domestic hot water energy demand is calculated by extrapolating the results to the entire year. A load file is used as a boundary condition to simulate the building space heating and the DHW consumption, in order to assure that all tested systems exchange the same amount of energy. As a drawback, the full coupling of the system with the building cannot be experienced.

During the CCT and SCSPT tests, building loads are emulated by calculating the return temperature from the building through a simulation run along with the test. In this case, the system behaves as it would do in the reality, but different systems cannot be compared on a common ground.

In the SCSPT method [15,16] 12-days representative of the 12 months in a year are selected to have heating demand and DHW consumptions in a proportion of 12/365. Yearly performance is then simply extrapolated from the short test results. A procedure suitable to extend the results to different climates and buildings is proposed in Leconte et al. [16].

In the CCT method [17], a 12-day sequence is selected representing the annual temperature and irradiation fluctuations; this is then used as a boundary condition to test the whole system. The seasonal performance cannot be assessed from the experimental results with a simple proportion, since the effects of thermal storages would not be correctly accounted for and the final solar fraction would not be the same. Seasonal evaluations are performed by means of an annual numerical simulation instead, which parameters are defined on the basis of the tests results. The numerical model is used also to extend the results to different climates and buildings.

A comparison of the three test methods used to rate solarcombi systems can be found in Haller et al. [18] and Papillon et al. [19]. Besides solarcombi systems, these methods have been used to test geothermal heat pump systems [20]; first results of the SCSPT used to evaluate a solar cooling system are reported in Boudéhenn et al. [21].

The described holistic methods allow a deep understanding of complex systems operation, since they take into account both their dynamic behaviour and the effect of the interactions between different components. Nonetheless, some questions still arise.

A first issue concerns the criteria used to select the representative test sequence. As already pointed out, a selection based on monthly or seasonal average weather data (CCT method) implies that the experimental data cannot be directly translated into seasonal performance, requiring instead annual simulations. On the other hand, the simplification of the seasonal performance calculation implies iterative procedures for the correct selection of the sequence (SCSPT method). These can be rather complicated for inexperienced users, especially in the perspective of translating the proposed methods into standards.

Moreover, the duration of the experimental sequences is decided a priori, reducing the potential representativeness of the obtained results.

Finally, the validity of the proposed methods is mainly based on the accordance between the average performance parameters (such as, auxiliary energy consumptions, fractional energy savings, overall solar gains, etc.) between the test and the corresponding annual values. This could result in misleading conclusions, since the same average performance may result from different instantaneous performance distributions: by chance, a steady stress can produce the same overall effect of an unsteady/fully-irregular one. Heading from these considerations, test procedures should not only be able to replicate the average performance of the considered systems but also provide more in-depth information on their instantaneous behaviour.

These considerations motivated the development of a new dynamic test procedure: it originates from mechanical fatigue analysis techniques applied to structural elements and tries to simplify and structure the selection of representative boundary conditions to be used in the dynamic test, by means of a statistical methods. Contrarily to the dynamic test procedures presented, the proposed method does not establish the duration of the test sequence in advance, which instead is gathered by statistical evaluations.

Moreover, boundary conditions are given as load file, as it is done in the Combitest, in order to simplify the test procedure and hardware employed (therefore the costs of the test).