Comparison of Two Whole System Test Methods: CCT and PLPE

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Abstract

To perform a reliable performance evaluation under realistic boundary conditions, in the last twenty years, different research institutes have developed and applied whole system test methods. The methodologies are based on a common approach but the literature presents several differences on the steps that compose the test methods. This leads to different advantages and drawbacks.

The paper compares two methodologies in order to investigate on the different results that could be obtained in the same conditions applying two different methodologies. In this paper, we analyze the difference between the CCT method and the PLPE method in terms of boundary conditions (test sequences and load) and present a common application case.

Despite the different procedures in the definition of test sequence and emulations, the two methods bring to similar results in the characterization of the seasonal performance of a solar and heat pump system. The CCT method estimates a SPF of 4.09 while the PLPE 4.13.

Keywords: dynamic test, whole system testing, solar assisted heat pump, CCT method, PLPE method.

1. Introduction

A reliable performance prediction is one of the key factors to increase the efficiency and the contribution of renewable energy sources of heating and cooling systems. If one (or more) renewable energy source is integrated in a heating system, the reliable performance evaluation is not a trivial task. In this case, there are several effects interacting with each other such as the control strategy, the operation of each component, the availability of renewable energy source, the dynamics of load and so on. The consequence is that the system works under dynamic working conditions. Therefore, it is very important to study the performance considering realistic and dynamic working conditions as well as interaction between components.

In the last years, different whole system test procedures have been developed (Haller et al., 2013) namely CCT (Haberl et al., 2009), PLPE (Menegon et al., 2017b), Combitest (Bales, 2004), SCSPT (Albaric et al., 2008), DST and so on. The common approach of these methods is the test of the whole system considering a short sequence (of 6 or 12 days) and the emulation of the boundary conditions. As general approach, the system is installed as a whole in the laboratory; a short sequence reproduces the boundary conditions that represents the entire year, the load and the components that are not installed are emulated in real time. The data recorded during the test is used to analyze the system performance. However, the different methods present several differences on:

- 1) the selection of the test sequence;
- 2) the definition of load;
- 3) the emulation of the components that cannot be installed in the lab;
- 4) the extrapolation of the seasonal performance from the test sequence;
- 5) the extrapolation of the seasonal performance to other climates;
- 6) the applicability of methodologies (climates, system typologies, loads).

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From the literature, a simple comparison between the test methods could be done, considering all steps that compose the test methods. Table 1 shows a brief comparison of the different methodologies.

Tab. 1: Comparison of main test methods presented in literature.

Method	Test sequence - Climate	Emulation	Extrapolations	Application
PLPE	6 day– clustering applicable for any climate	with simplified emulations, load files	Direct	Solar thermal system + heat pumps Solar cooling
CCT	6 day– Zurich	with TRNSYS	Direct	Solar thermal system + biomass Solar thermal system + heat pumps
Combitest	6 day - Zurich	with TRNSYS, load files	Direct	Solar thermal system + biomass
SCSPT	6 day– 3 climates	with TRNSYS	ANN	Solar thermal system + biomass Solar thermal system + heat pumps
DST	In situ	On field test	Simulation	Solar heating – DHW systems

The table has been compiled comparing different literature sources. (Chèze et al., 2015, Haberl et al., 2015b, Haller et al., 2013, Lazrak et al., 2015, Menegon et al., 2017b, Schicktanz et al., 2014).

From this table, it is not easy to understand which are the differences on the final results when different test methods are applied on the same system. As an example, the user can understand which method is the simplest one to be applied in his own laboratory, but there is a lack of any kind of quantitative comparison. To cover this gap, in this paper, we have compared the CCT method (Haberl et al. 2015) with the PLPE method (Menegon et al. 2017b).

The analysis performed in this paper compares the two test methods in terms of the different steps composing the methods (e.g. boundary conditions, load, emulations and results). To quantify these differences, a solar assisted heat pump system has been simulated comparing the short sequences of PLPE and CCT with the annual performance.

2. Method of comparison of CCT and PLPE

The CCT and the PLPE present several differences in the steps that compose the procedures. The main differences can be identified in the definition of test sequence, in the definition of load and in the emulation of not-installed components. These aspects are compared in the paper in the following sections:

- 2.1 Boundary conditions: definition test sequences for the climate of Zurich
- 2.2 Load: definition of load for the test sequence.
- 2.3 Emulation: definition of emulation performed during the test.
- 2.4 Simulation of the two test methods on one case study.

2.1. Boundary conditions

The first comparison is made on the methodology used to define the short test sequence and a comparison of the two boundary conditions that are used during the test.

The choice of the CCT method is to define the test sequence for the climate of Zurich. The CCT does not foresee any other climate in order to perform a benchmark test for the different systems that are tested. Differently, the PLPE applies a clustering methodology to define the short boundary condition for a climate that the user can choose (Menegon et al., 2017a). With this method, the user can also choose to variate the length of the test sequence. The motivation of this choice is to allow the redefinition of test boundary conditions for specific applications required by the manufacturer of the system.

Since the CCT has a fixed six-day sequence, in order to compare the two methods, a six-day sequence for the Zurich climate has been defined with the PLPE. The results of this comparison are presented in section 3.1,

The CCT sequence has reduced the original sequence of twelve days to six days (Chèze et al., 2016). This was developed with an iterative simulation that has minimized the deviation between a direct extrapolation of results and the annual performance and that have satisfied the requirements of the CCT method.

2.2. Load

The two test methods define two different approaches for the definition of the load.

The CCT method considers a load file coupled with the building emulation performed with the type 5897. the six-days sequence is simulated in order to get a load file. Then, during the test, the load file is limiting the heat input into the building within certain boundaries during the day, and to a fixed value at the end of the test-day. Thus, an equal amount of heating by all systems is guaranteed for the same day of the profile alhough the building is simulated in parallel and the correct return temperature from the building is supplied during the test.

The PLPE method considers a fixed load file that is coupled with the distribution system emulation. In the second case, an annual load file is calculated with the simulation of a reference building and the test sequence load profile is defined considering the load that occurs during the days selected with the clustering. In that case, the load is the same that occurs during the year as if during the test the annual days between two sequence days are simulated to precondition the building.

In other words we can say that the CCT adopts a “six-day simulated load” while the PLPE adopts a “load file from annual”.

The two test methods allow to extrapolate the corresponding annual load from the test sequences even if they present a different distribution of the load in the sequence. The load considered by the CCT and PLPE is different since they adopt a different reference building: the CCT considers a building with 140 m^2 and specific load of 60 kWh/m^2 while the PLPE considers a building with 180 m^2 and specific load of 70 kWh/m^2. The values of load are calculated for the climate of Zurich. The PLPE method considers also the cooling load when the climate conditions requires it.

Concerning the DHW consumption, the PLPE defines one daily profile of 7 kWh that is repeated each day of test (42 kWh for the whole sequence) while the CCT present a profile different for each day with a total sequence load of 50 kWh. To be able to compare the two methods, in this study the CCT profile has been scaled to reach the same energy extraction of the PLPE DHW profile.

2.3. Emulations

In the installation of the whole system, it is not possible to install all the component in the laboratory. That means that the laboratory should emulate the behavior of the components not installed.

Table 2 compares the emulations of the PLPE and the CCT test methods. In general, the PLPE performs emulation based on simplified emulation that can be implemented in the control system of the laboratory while the CCT couples the control of the lab with the TRNSYS types described in the table.

Tab. 2: Emulation of components.

Emulation	PLPE	CCT
Load	Load file defined with Type 56 and simplified emulation of distribution system	Non-Standard Type 5897 coupled with the load file
DHW	DHW load file	DHW load file
Solar collector	Equation based on the EN 12975-2.	Non-Standard Type 832
Air source	Linear regression based on the test of air unit Applicable in case of not availability of a climatic chamber	Not applicable.
Ground probes	Under development	Non-Standard Type 451

Sources: Type 5897: (Leconte et al., 2014). Type 832: (Haller et al., 2012); Type 451: (Wetter and Huber, 1997). Emulations of PLPE: (Menegon et al., 2017b).

2.4. Comparison on an application case

The differences presented in the section 2.1 and 2.2 have consequence on the variation of the boundary conditions. To understand how these factors influence the performance evaluation, the two test methods were compared considering the simulation of a solar assisted heat pump system.

Figure 1 shows the layout of the system that was considered in this study. The system model was developed in TRNSYS 17 (Klein and et al., 2012) and was validated with experimental data. This comparison allows to compare the two methods in terms of deviation on the direct extrapolation of the seasonal performance figures (load and energy sources, performance factors and so on).

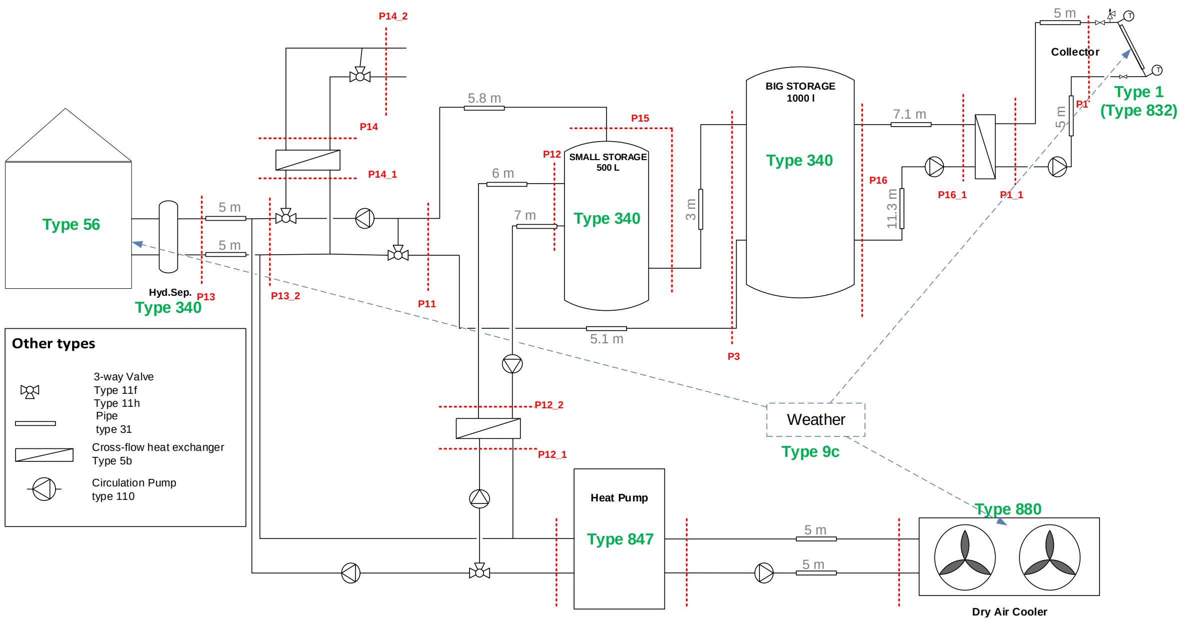

Fig. 1: Layout of the system considered for the comparison of PLPE and the CCT method.

From the short sequence, the annual energies are calculated with a direct extrapolation. The CCT scales the energies calculated with the test sequence with a direct proportion between the number of days of the sequence and the year (eq. 1) while the PLPE weights the daily energies with the cluster size of each day (N_i). In addition, the results obtained with the CCT sequence are adjusted according to the correction factors defined in the CCT method (Menegon, 2016).

$$Q_{a,CCT} = Q_{seq,CCT} \cdot \frac{365}{6} \cdot FC \qquad \text{(eq. 1)}$$

$$Q_{a,PLPE} = \sum_{i=1}^{6} Q_{i,PLPE} \cdot N_i \qquad \text{(eq. 2)}$$

Where Q represents the energies of load (space heating, DHW, total), the energy of sources (e.g. solar collector) and the consumptions (e.g. electric, gas or biomass). The subscript “a” indicates the annual value, “seq” the sequence, “i” the number of the day.

The values calculated with the eq. 1 and eq. 2 has been compared with the annual simulation calculating the deviation in the following way:

$$\delta = \frac{Q_{a,seq} - Q_a}{Q_a} \qquad \text{(eq. 3)}$$

Where the deviation δ is calculated for the space heating, DHW, total load, the collector yield, the electric consumption and the SPF. The subscript “seq” is valid for the CCT and PLPE values.

3. Results of comparison of CCT and PLPE

3.1. Boundary conditions

Figure 2 compares the temperature and irradiance profiles of the CCT and PLPE sequences. The CCT sequence spaces between the minimum temperature point of -8.9°C and the maximum temperature point of 20.3°C. The temperature profile of PLPE variates between -4.59°C and 25.7°C. Therefore, the CCT sequence reaches the minimum temperature while the PLPE reaches the maximum temperature. In both sequence, the coldest day present the lowest irradiation while the hottest day present the highest irradiation.

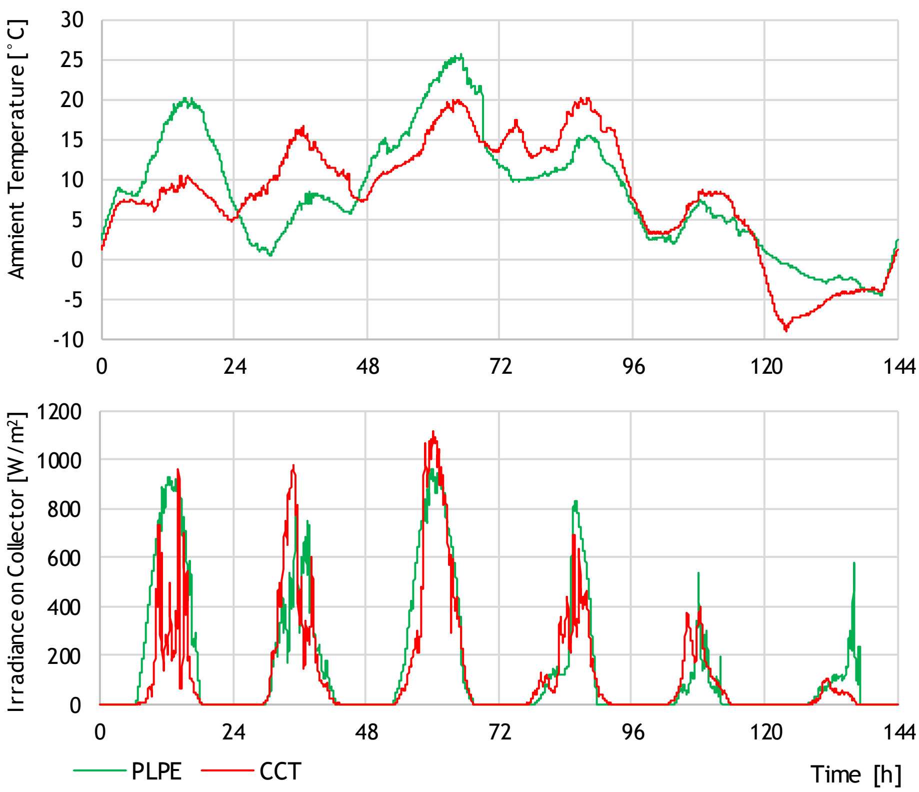

Fig. 2: Comparison of PLPE and CCT profiles of the ambient temperature and irradiation on the collector surface during the short test sequence.

To understand how the profiles are positioned and distributed in the test reference year, Figure 3 presents the position of the six-day sequences in the 365 days of the year. The left-hand figure presents the daily irradiation on horizontal as a function of the daily average temperature, while the right-hand figure presents the daily load as a function of daily average temperature distinguished into heating load (red points) and cooling load (blue points). The annual temperature spaces between -8.3°C and 26.04°C, the irradiation between 123 Wh/m^2 and 8245 Wh/m^2, the maximum heating load is 125 kWh.

From the figure, it can be noticed that the cooling load is not relevant if compared with the heating load. Both the sequence do not present any day with cooling load.

The points of the PLPE sequence are well-distributed in the graphs and that is a direct consequence of the clustering methodology. The PLPE sequence is closer to the border of the area identified with the days of the year.

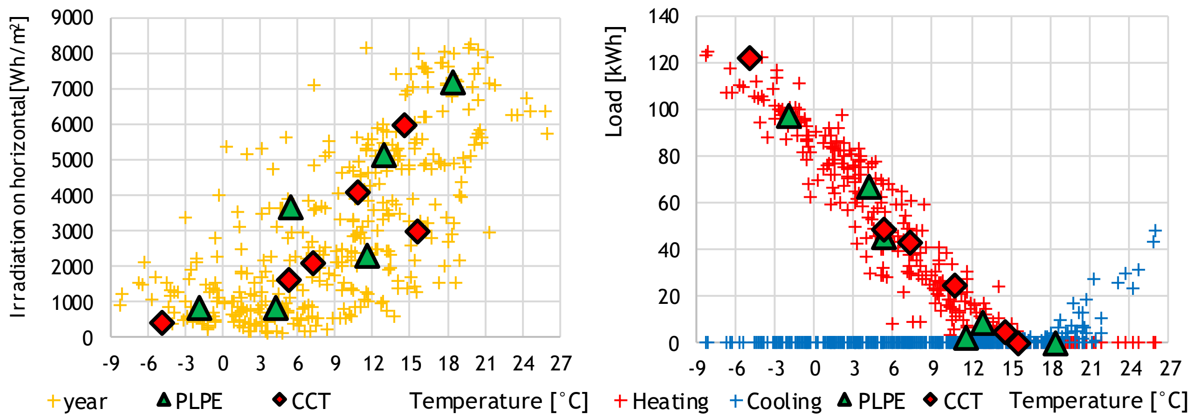

Fig. 3: Identification of six-days sequences of PLPE and CCT. Zurich Climate.

Figure 4 compares the two sequences in terms of daily average temperature, irradiation on horizontal and load. The figures present the average of the six-day profiles and of the annual average profile. Since the PLPE method uses a weight based on the size of clusters for the calculation of seasonal performance, also the average of temperature, irradiation and load has been calculated with a weighted average.

The comparison of the sequence average temperature and annual average temperature shows that the PLPE is closer to the annual average temperature. That is a direct consequence of the selection methodology. Indeed the difference between PLPE average temperature with the annual value is 0.2°C while the CCT is 0.9°C. The CCT sequence presents the coldest day closer to the minimum annual value. This day presents 3.4°C more than the annual coldest day, while the PLPE coldest day presents an average temperature 6.4°C higher than the coldest annual day. At opposite, the hottest day of PLPE sequence has an average temperature 7.7°C lower than the annual hottest day, while the CCT is further (10.4 lower). The motivation of this higher distance compared to the coldest day is that the colder conditions are more frequent than the warmer days. Therefore, these higher distances of the highest temperature days are not relevant for the system characterization with the two test methods.

The same trend is verified for the irradiation where the PLPE sequence presents an average irradiation higher than the annual average about 54 Wh/m^2 while the CCT presents an average irradiation 175 Wh/m^2 lower than the annual average value. The PLPE sequence represents better the annual average conditions for the motivation previously explained. Again, the day with the lowest irradiation of the CCT sequence presents an irradiation 289 Wh/m^2 higher than the annual minimum point while the PLPE 701 Wh/m^2. At opposite the day with the highest irradiation of CCT sequence is quite far from the day of the year with maximum irradiation (2235 Wh/m^2) while the PLPE is closer to the annual maximum (1040 Wh/m^2).

In the PLPE, the hottest day presents also the highest irradiation while in the CCT the two maximum points (temperature and irradiation) are distinguished into two different days.

As final comparison, the days selected in the two test sequence present different loads. In this graph, the load is the one that occurs during the year (note: it is not the load considered in the CCT method. The CCT considers the load coming from the sequence simulation). As for temperature and irradiation, also the heating load of PLPE sequence is close to the annual average value. The difference between the average load of the CCT days with the annual values is 8.2 kWh while the difference between PLPE average load and annual average load is 1.9 kWh.

Since the CCT considers one day of extreme condition, its load is very close to the maximum heating load required during the year (2.4 kWh lower) while the highest load in the PLPE sequence is 27.2 kWh lower than the maximum annual heating load.

The two sequences do not identify days with space cooling load (not indicated in the figure) while during the year there are few days with cooling load. The cooling load is not relevant.

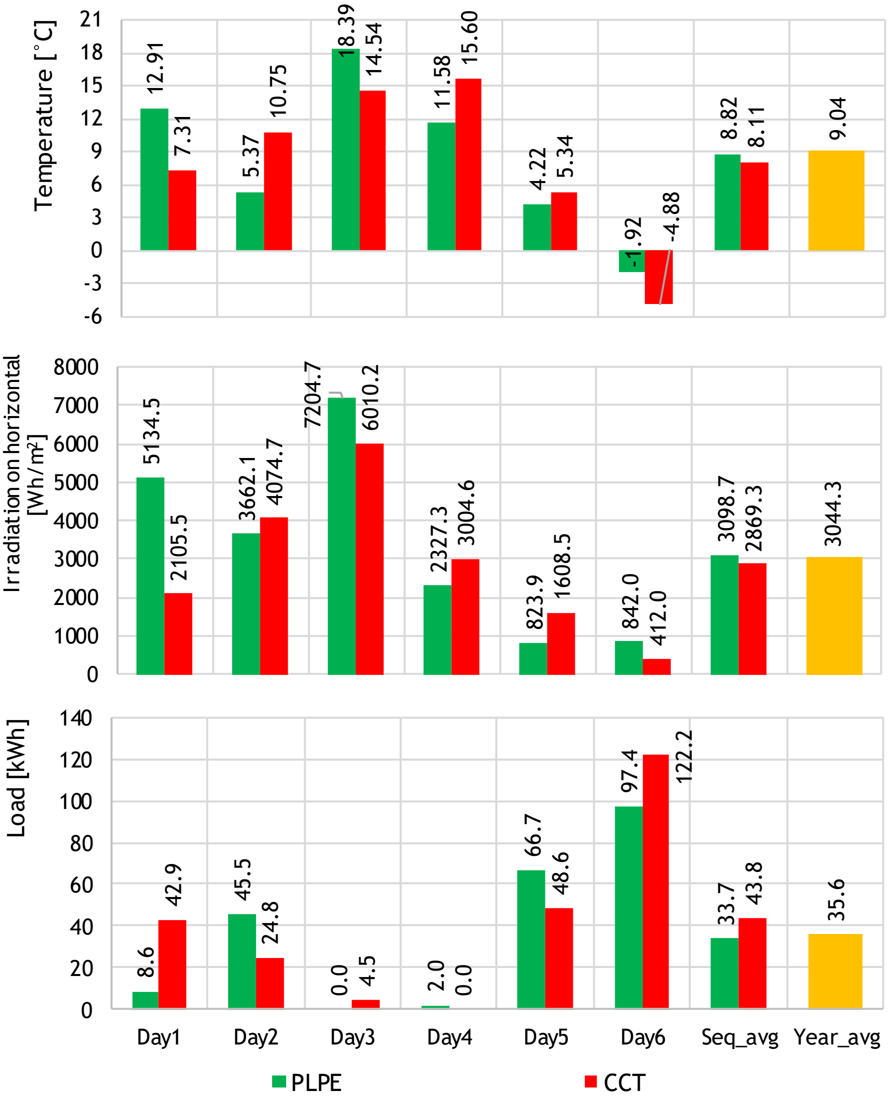

Fig. 4: Daily average temperatures and total irradiation on horizontal surface. Comparison of PLPE and CCT sequences.

In general, the PLPE sequence presents a profile closer to the annual average conditions. This outcome is a direct consequence of the clustering methodology. The CCT method presents the day with the extreme cold condition.

3.2. Load

As presented in the section 2.2, the CCT and PLPE follow two different approaches for the definition of load. In this way, the load resulting for the two test methods is different on the distribution of the load during the different days of the sequence. The motivation is given by the dynamics of the thermal load and the inertia of the building is accounted in different ways. For example, in the CCT the load of "day 6" is "preconditioned" by "day 5" and "day 4" while in the PLPE the load of "day 6" is preconditioned by the days that precede the "day 6" in the year.

As indicated in section 2.2, the CCT load could be called "six-day simulated load" while the PLPE called "load file from annual" and these two methods are compared in the Figure 5. Since the two methods have a different reference buildings, the load has been recalculated for the two methods with the two reference buildings. In addition, also the two test sequences are different and therefore the loads are defined considering the CCT sequence. That means that the load presented in the Figure 5 is not the one adopted in the PLPE method.

As a result, the daily loads are different and the maximum load can be reached only with the days taken from the annual load file ("load file from annual"), testing therefore the worst load condition. The average load of the "load file from annual" is higher than the "six-day simulated load" because the cold days are preconditioned by other cold days in the year. Since this comparison is made only on the approach of load definition (and not on the sequences), this does not mean that the extrapolated energy of the PLPE is higher. The PLPE method considers different days than the CCT.

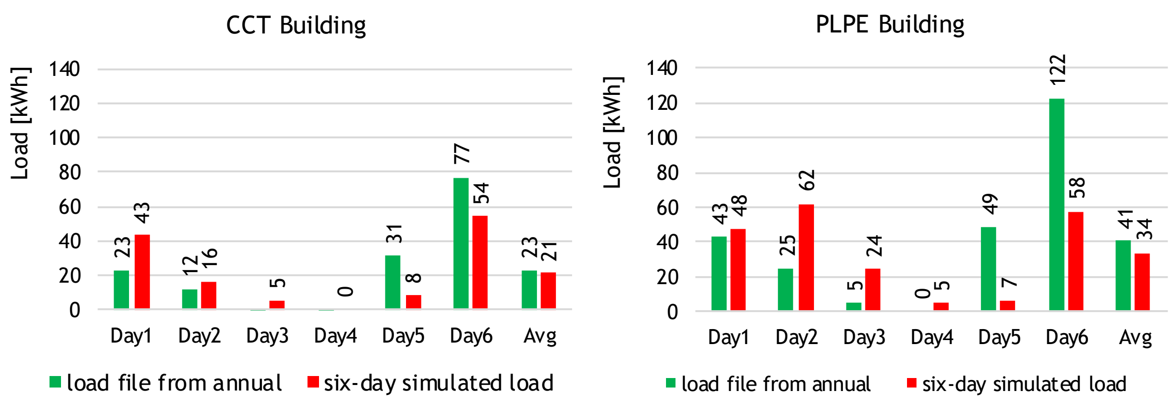

Fig. 5: Comparison of daily loads defined in the CCT and PLPE methods.

Note: the figure shows the average load instead of the sequence total load since it would have a different order of magnitude and the scale of graph would not be readable.

3.3. Simulation of sequences and loads

To understand the effect of applying the PLPE sequence and the CCT sequence, and the difference on the application of the two methods of load definition, the system indicated in the figure 1 has been simulated considering the "load file from annual" and the "six-day simulated load". In this case, one building should be considered to perform a coherent comparison. For this motivation the load has been defined with the PLPE reference building.

The table 3 presents the PLPE and CCT sequences simulated considering the two methods of load definition. In the first two rows the load has been defined according the PLPE method "load from annual file" while in the following two rows the load has been defined according the CCT method "six-day simulated load". The last row indicates the annual simulation that should be the objective function of the two test methods.

The table is combining the two sequences with the two methods of load definition that means that the row with "CCT sequence" and "load from annual file" is not coherent with the development of the CCT method and also the row with "PLPE sequence" and "six-day simulated row" is not coherent with the development of the PLPE method.

The table shows that the heating load required with the "CCT sequence" is higher than the heating load of the "PLPE sequence". That happens with the load definition with the "load from annual file" and with the "six-day simulated load". As we have seen in the previous section of selection of boundary conditions (3.1), the "CCT sequence" selects days colder than the PLPE method. From the table it is clear that is not possible to combine the PLPE sequence with the "six-day simulated load" and it is not possible to combine the CCT sequence with the "load from annual file".

For every combination of sequence and load, the collector yield identified with the sequence is lower than the annual simulation.

Tab. 3: Comparison of simulation of sequences defined with PLPE and with CCT with the load file defined according to PLPE.

Sequence	Load	Qheat [kWh]	Qdhw [kWh]	Wheat [kWh]	Wdhw [kWh]	Qcoll [kWh]
PLPE	load from annual file	12250	2565	3241	343	7722
CCT	load from annual file	15733	2456	4167	773	7710
PLPE	Six-day simulated load	11450	2565	3015	399	7570
CCT	Six-day simulated load	13595	2435	3376	546	7252
Test Reference Year	Annual load	12996	2546	3646	428	10095

Note: the energies indicated in this table are extrapolated according the (eq.1) and (eq.2)

3.4. Simulation of CCT and PLPE

As presented in the introduction, the PLPE defines the sequence with clustering and the load of each that is the same that occurs during the year, while the CCT considers the sequence defined with the optimization procedure and the load is simulated during the sequence. The results of CCT have been corrected with the correction factors defined in the procedure .

Table 4 presents the results of the seasonal performance evaluation calculated simulating the PLPE method, the CCT method and the annual profile. The CCT load has been scaled to reach the same level of the PLPE load.

Table 5 presents the deviation of the PLPE and the CCT method calculated in comparison with the annual simulation (eq. 3).

The results show to a similar deviation if compared to the annual simulation. The PLPE reaches a load 5% lower than the annual value while the CCT reached a load 5% higher than the annual value. Both results agree with the accuracy declared in the literature in the different test methods. In terms of SPF, the two sequences deviate about 1% one to each other and they deviate about 7% from the annual simulation.

The largest deviation is obtained in the calculation of DHW consumption.

Tab. 4: Comparison of simulations of PLPE and CCT methods. Performance figures

	Qheat [kWh]	Qdhw [kWh]	Qtot [kWh]	Wheat [kWh]	Wdhw [kWh]	Wtot [kWh]	Qcoll [kWh]	SPFt [-]
PLPE	12250	2565	14815	3241	343	3584	7722	4.13
CCT	13595	2435	16029	3376	546	3922	7252	4.09
Annual	12996	2546	15542	3646	428	4074	10095	3.82

Tab. 5: Comparison of simulations of PLPE and CCT methods. Deviation with annual simulation

	Qheat [kWh]	Qdhw [kWh]	Qtot [kWh]	Wheat [kWh]	Wdhw [kWh]	Wtot [kWh]	Qcoll [kWh]	SPFt [-]
PLPE	-5.7%	0.7%	-4.7%	-11.1%	-19.9%	-12.0%	-23.5%	7.6%
CCT	4.6%	-4.4%	3.1%	-7.4%	27.6%	-3.7%	-28.2%	7.1%

4. Conclusions

The paper has presented the comparison of two whole system test methods: the CCT method and the PLPE. The aim is to understand the qualitative and quantitative differences of the two methods. The paper compares the different steps composing the test methods in order to understand the effect of those steps. In addition, the paper compares the two methods on one application study.

At first, the boundary conditions were compared. The two methods test the system under different boundary conditions. The CCT method reaches the lowest external temperature and the PLPE method reaches the highest temperature. In addition, the PLPE presents a test sequence closer to the annual average conditions.

As second comparison, the methods used to define the load has been compared. The PLPE method considers the load of each day as it is during the year while the CCT simulates the load during the sequence. As a consequence the load profiles that came out during the test are different. For this motivation, the PLPE requires a higher load than the CCT.

The two effects given by the different sequences and the different loads mitigate each other and therefore the CCT and PLPE method result in a similar load: the deviation between the short sequence and the annual load is about 5% in both cases.

Despite the different approaches on the test boundaries and the emulations, the two methods result in similar seasonal performance factors determined for the investigated system. The annual simulation of the system was taken as a reference and best estimation of the true value with a SPF of 3.82. From the direct extrapolation performed with the two methods, the CCT estimation is 4.09, while the PLPE yields 4.13.

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