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Optimising test environment and test set up for characterizing actual thermal performance of building components and whole buildings

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Abstract

The development of mathematical models that can reliably simulate the energy performance of a whole building or a building component with minimal discrepancy between the real and simulated data is a major aim of Building Physics science. In order to create models that accurately represent real physical phenomena it is necessity to perform tests on buildings and building components, producing real data that can be used to adjust and validate these models. If these tests are not undertaken correctly, incorrect data sets, insufficient data sets or excessively complex and expensive experiments may be performed. Thus, depending on the aim and the accuracy needed for the mathematical models, the test environment and test set up must be chosen correctly.

This problem has been studied inside Subtask 2 of the Annex58 “Reliable building energy performance characterisation based on full scale dynamic measurements”. The aim was to come to a roadmap on how to measure the actual thermal performance of building components and whole buildings. This means under realistic boundary conditions (field exposure or artificial climate) and taking into account workmanship. Since there are many established methods and different Standards for different measurement purposes, the solution has been to organize the existing methods (both Standards and widely used non-Standard testing methods) into a decision tree. This decision tree begins with the question “What do you want to characterize?” and determines the context, environment, experimental design and analysis method being used by the user, terminating in a document reference. In a very simple format, following the decision tree and having a clear idea of what you need to characterize or model, you will reach an end branch of the decision tree where a testing Standard or testing method will be defined. The objective of this paper is to present the decision tree, its logic and the way it should be used.

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Keywords: thermal performance of buildings; optimal test set up; decision tree, IEA Annex58

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1. Introduction

Annex 58 of the International Energy Agency's 'Energy in Buildings and Communities Programme' is an international research collaboration on the topic of 'Reliable building energy performance characterization based on full scale dynamic measurements'. The goal of the Annex is to develop the necessary knowledge, tools and networks to achieve reliable in situ dynamic testing and data analysis methods that can be used to characterize the actual energy performance of building components and whole buildings.

In subtask 2 on the 'Optimizing full scale dynamic testing' a procedure on how to realize a good test environment and test set-up is carried out. The aim is to come to a roadmap on how to measure the actual thermal performance of building components and whole buildings that can be used by multiple audiences from both an academic and industry background. Although there are hundreds of papers describing specific measurement methods for energy assessment of buildings or building components, few papers as [1] are focused on classifying these different methods for existing building energy performance assessment. [2] has done something similar but focused only on the PASLINK methodology for testing building components. None of these papers result user friendly tools to decide for a proper testing method under certain testing necessity.

Since there are many different objectives when measuring the thermal performance of buildings or building components, the best way to treat this variety has been identified as constructing a decision tree. This decision tree will follow logic and if the decision tree user has a clear idea of the objective of the test to be carried out, the decision tree will give the information of a test procedure or a standard where this type of test is explained in detail.

Full scale testing requires quality on all topics of the process chain, starting with a good test infrastructure. Only when this is present can a good experimental set-up be designed with the capacity to produce reliable data that can be used for dynamic data analysis, arriving at a characterization and final use of the results. The data analysis methods used in the test facilities range from averaging and regression methods to dynamic approaches based on system identification techniques. In this paper we will focus on the explanation of the decision tree and how to use it to obtain a clear reference to a reliable document that will explain in detail how to perform the experiment that best fits the decision tree user.

IMPORTANT: This document must be used together with the decision tree, which is hosted in the *http://dynastee.info/* webpage and will be updated regularly by the webpage managers. The decision tree has been built with the software xmind. A free version can be downloaded in: *http://www.xmind.net/*. There are no references to specific testing methods inside this text, since all those references can be found in the decision tree itself in an ordered way. The authors do not claim ownership for any documents referenced within the decision tree and insist proper citation practices must be observed if these documents are used in further research activity. Document descriptions in attached notes are taken from the source material and are not the original work of the Decision Tree contributors – as such reference should be made to the original document concerned.

2. Decision tree

2.1. Why a decision tree?

There are different stages in the design, construction and use of a building component or a building. Thus, there are many different interests concerning the energy performance of them. As an example, many building codes only limit the U value of the building walls and windows without taking into account other important facts such as their thermal capacity. Moreover, some of these building codes do not consider the benefits of some solar passive components such as ventilated façades and green roofs.

This is why, historically, the measurement of the U value of the designed building components has been the main goal of manufacturers and researchers. This has led to several procedures and standards for describing the experimental set up, test procedures and data analysis methods to fulfill this goal.

With the new requirements of the building codes, the objective is to fulfill some limits in the energy demand of the building. Note that the Nearly Zero Energy Buildings objective is for 2020 in Europe for new built buildings. Limiting the energy demand of the building instead of limiting the U value of the building components means that the energy performance of the building envelope must be simulated in a much more precise way as the total energy demand of the building is an interrelation of the building envelope, building systems and the user behaviour.

It is clear that the understanding of designed building components must be deeper than just measuring its U value under steady-state laboratory conditions. The modelling and testing of the dynamic thermal behaviour of the buildings and building components must be more precise. Many different procedures have been developed to test the dynamic behaviour of building components and buildings *in situ* but few of them have become internationally accepted standards. Indeed, many of these procedures may never result in a standard, since the nature of dynamic testing causes testing on the same test component under different dynamic conditions to obtain different results in some cases.

In addition to individual building components, it is important to consider the energetic performance of an entire building. The poor energetic performance of the existing building stock paired with slow rates of new build completion necessitates building energy refurbishments to meet national energy target. To assess the effectiveness of any refurbishment, it is important to measure the energy performance before the refurbishment and, most importantly, after the refurbishment. With this in mind, many different experimental set ups and procedures have been developed to characterize the actual building performance.

Another important aspect that has led to the creation of different procedures is the buildings energy signature. New buildings require an energy signature and they should perform energetically as they were designed. To prove this fact it is mandatory to make some measurements in the building.

All the above problems (and others) have led to several procedures and standards inside the energy characterization of building components and whole buildings. There are so many procedures and standards available that it may become unmanageable for a researcher or a building sector professional to know which is the best procedure or standard for their specific aim.

After some discussion inside the Annex58, the idea of constructing a decision tree that copes with most of the actually available standards and procedures to characterize the energy behaviour of building components and buildings has been developed. A two dimensional decision tree structure has been chosen.

2.2. Logic of the decision tree

The next step in the definition of the decision tree has been to define the logic and thus, the main question to follow down the decision tree. The logic of the decision tree is closely related to the question that the user must follow to reach an end branch where the user will find a reference to a test standard or a test procedure.

After a deep discussion, the main question to be followed by the decision tree user has been chosen to be “**What do you want to characterize?**”. Although it seems a simple question it is a very precise way to reach to the best test procedure required by the decision tree user. Following this question the decision tree user will find three main branches as shown in Fig. 1. The decision tree user will find it obvious to expand the branch that is most appropriate for their research aim.

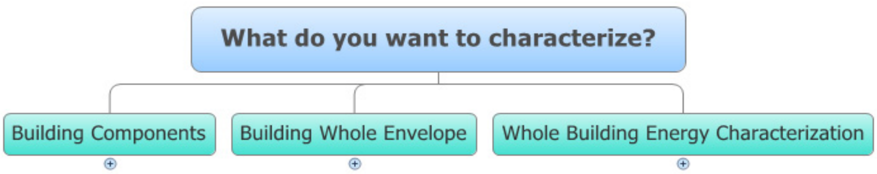

Fig. 1. Main question and main branches of the decision tree.

Once the main branch is chosen the second level will be shown to the decision tree user as shown in Fig. 2. Following again the main question “**What do you want to characterize?**” the decision tree user, should have no problem to check the most suitable case in the second level.

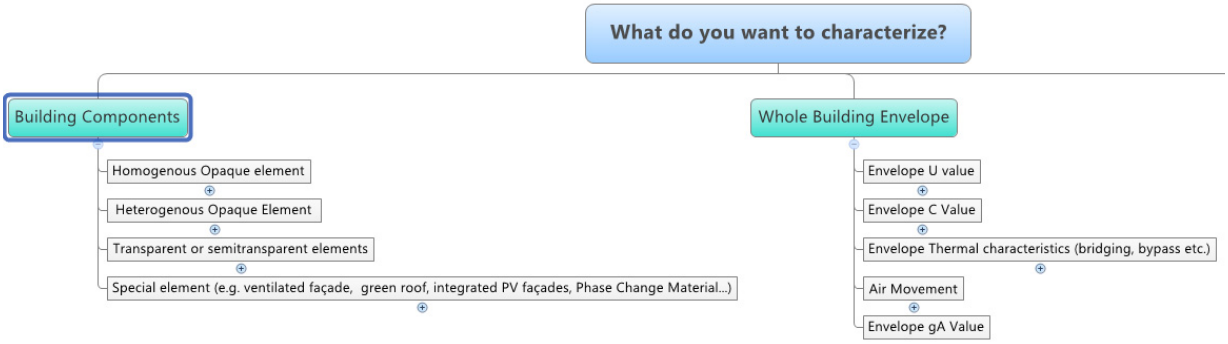

Fig. 2: Partial view of the second level of the decision tree.

As can be seen in Fig. 3, once the second level is chosen we find again the question "**What do you want to characterize?**". Following this question we will already be in the third level of the decision tree. Once the third level is chosen by the decision tree user, some more specific questions will appear until an end branch is reached.

Fig. 3 shows an example of how we can reach an end branch. In this example, once we are in the third level, we will find the question "**What is your test environment?**". The decision tree user must find it straight forward to know if the test environment is in situ or a controlled laboratory. This is the fifth level for the specific case shown.

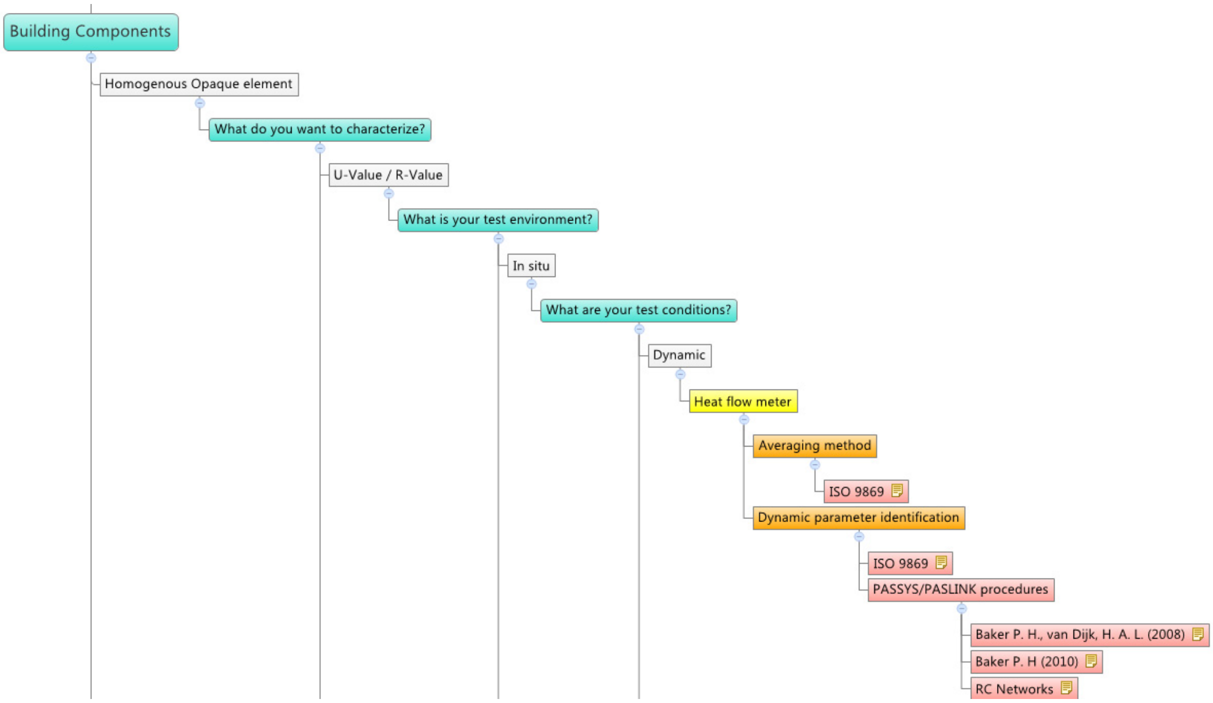

Fig. 3. Partial view of decision tree process

Once the fifth level is chosen we will find the next specific question "**What are your test conditions?**". Here the decision tree user will have to know if the problem that is being studied is going to be treated as a Dynamic or Steady State problem. In the Fig. 3 example the "Dynamic" case is chosen in the fifth level. Once the decision tree user checks for this case the name of the existing test procedure (or possible different procedures) to carry out the experiment is shown in the sixth level. Inside the sixth level we can find different data analysis procedures that could be used for this specific test procedure. Once the data analysis procedure is chosen in the seventh level the decision tree will arrive to an end branch where a link to a specific Standard or a widely proven test and data analysis procedure is referenced.

Depending on the branch followed there might be different questions to follow the path to the end branch. But the logic is similar to the above developed case.

As it can be seen in Fig. 3, inside the "ISO 9869" box, the decision tree user will find some notes inserted in some of the levels that will give support to the decision tree user to make the right choice. The decision tree user has to click over this note and will find useful information to follow the decision tree.

3. Description and use of the main branches of the decision tree

The general logic of the decision tree has been explained in section 2. This information is sufficient to understand how to use the decision tree successfully. This section will describe why these three branches have been considered as the main branches and then some details on the use of each of the branches will be given in the following subsections.

The first level of the decision tree has three choices: **Building components**, **Whole building envelope** and **Whole building energy characterization**. These are the main three levels where the different full scale testing is carried out in the building sector.

The building component branch is focused on how to test a building component in isolation, without considering the effect of the whole building. This branch primarily covers the U and gA value characterization of walls and windows under well-known standards, but also considers how to test and characterize special building components such as ventilated façades, green roofs etc.

The whole building envelope branch is focused on characterizing and/or modeling the main energy characteristics of the whole building envelope. The term 'characteristic' in this case stands for the envelope U, C and gA values and also for the buildings envelope special characteristics such as thermal bridging characterization and modeling and characterizing the air movement through and within the building envelope. These points are the main causes for the energy demand of the building due to the whole building envelope.

Finally the third main branch copes with the whole building energy characterization. This general characterization considers the three main reasons for the energy consumption in buildings: the buildings thermal envelope, the buildings systems and the user behavior. The end branches of this main branch end on different standards and methods currently available for whole building energy characterization under different building use assumptions. In the next three subsections a short explanation on each of the main branches is given.

3.1. Building component branch

During recent decades, much work has been carried out on building component energy characterization. As can be seen in Fig. 2, there are four options inside the main level of the "Building components" branch. The first three options consider the characterization of "common" building components, this is: Homogeneous opaque elements, Heterogeneous opaque elements and Transparent or Semitransparent elements.

The main thermal characteristics tested and modeled on these types of elements are the thermal transmittance value (U-value), the thermal capacity value (C-value) and the Solar Gain (g-value) or Solar Heat Gain Coefficient (SHGC).

Although the above three thermal characteristics are the main causes of the thermal behaviour of "common" building components, also these other important aspects are considered in the decision tree: the hygrothermal behavior, thermal bridging, reflective, absorptive, transmittance light aspects and air permeability.

Most of the test procedures considered in these three types of "common" building components are already standards but many of the new developed "special" building components cannot be tested correctly with the above standards. For example PV façades or façades containing PCM cannot be tested in a guarded hot box since they are passive solar components and the correct thermal characterization of these components requires tests carried out under real weather conditions or at least with a solar simulator.

Inside the research process realized during the construction of this decision tree a general procedure to test and characterize these types of “special elements” have been arranged. This general procedure divides the building component in two parts.

PART 1 considers the “common” layers (concrete, insulation, plaster…). These layers can be thermally characterized independently from the special part of the building component (green cover, ventilated façade…) by means of the standards or techniques that can be found inside the “common” building components branches. Once this part is characterized we only need a model of PART 2 that will provide the temperature in the interface of PART 2 with PART 1. With this we are able to simulate the energy requirements per square meter in the inner surface of this element. A detailed example on how to use the decision tree for the green roof is available in the webpage *http://dynastee.info/* together with the decision tree file.

3.2. Whole building envelope branch

In addition to understanding the performance characteristics of individual construction elements and materials in isolation, it is important to appreciate their interaction across the whole building envelope. In order to do this, the researcher may choose to conduct tests on the building post construction *in situ*.

As can be seen in Fig. 2, the whole building envelope branch follows a similar logic to the building components branch, with the second level of questioning exploring specific characteristics: Whole envelope U value, Whole envelope C value, Whole envelope gA value, Envelope special thermal characteristics (thermal bridging) and air movement. A detailed example on the further development of the branch ‘air movement’ is available in the webpage *http://dynastee.info/*. In this case, questioning distinguishes between internal/external air transfers (as opposed to internal air looping) before determining the environment and conditions of the research.

3.3. Whole building energy characterization branch

The whole building energy characterization branch seeks to present methodologies centered on monitoring the main contributors to energy use in whole buildings, namely the building envelope, building systems and users.

This branch seeks to define the environmental conditions at the first stage, as opposed to focusing on the research subject. This is because the impact of occupancy is highly significant and may limit the type of tests that are possible or permitted to be undertaken, so it is important to establish occupancy at an early stage. This is why the two main levels inside this branch are **unoccupied buildings** and **occupied buildings**.

Following occupancy assessment, further environmental considerations are explored as in the other branches. In addition to the environment and conditions, the whole building energy characterization branch also clarifies the usage of the building, splitting into **domestic** and **commercial properties**. This is important to distinguish as the two types often exhibit distinctly different features such as occupancy patterns, build typologies, system infrastructure and overarching research focus and rationale. From this stage the branch progresses as normal, with experimental and analysis options terminating in a guidance document supported by an attached note.

4. Conclusion

This decision tree approach has been found by the researchers participating in the Annex 58 to be a valuable tool to reduce literature review when a researcher or a building sector professional wants to thermally characterize a building component or a whole building. It is important to acknowledge that the Decision Tree is to be a live document and will need periodic updating to reflect changes in the state of the art and ensure the most recent versions of standards and reports are provided.

References

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[2] P.A. Strachan, L. Vandaele, Case studies of outdoor testing and analysis of building components, Build. Environ. 43 (2008) 129-142.