IEA Annex 58

Subtask 2 – Logic and use of the Decision Tree for optimising full scale dynamic testing

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2. SYMBOLS AND UNITS

A	m²	Area
A_{sol}	m²	Solar aperture
C	J/K	Effective heat capacity of a space or building
g	-	Total solar energy transmittance of a building element
H	W/K	Heat transfer coefficient
H_{tr}	W/K	Transmission heat transfer coefficient
H_{ve}	W/K	Ventilation heat transfer coefficient (including infiltration)
I_{sol}	W/m²	Solar irradiance
Q	J	Quantity of heat
q	W/m²	Heat flow density
R	m²K/W	Thermal resistance
T	K	Thermodynamic temperature
t	s	Time, period of time
U	W/m²K	Thermal transmittance
θ	°C	Centigrade temperature
Φ	W	Heat flow rate
Φ_P	W	Thermal power

3. 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.

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, producing reliable data that can be used for dynamic data analysis to come to 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 report 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. There are no references to other documents inside this text, since all those references can be found in the decision tree itself in an ordered way.

4. LOGIC OF THE DECISION TREE

4.1 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 limit only the U value of the building walls and windows without taking into account other important factors 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 component has been the main goal of manufacturers and researchers. This has led to several procedures and standards for describing the experimental set up, test procedure and data analysis method to fulfil this goal.

With the new requirements of the building codes, the objective is to fulfil 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. The majority of existing buildings do not have envelopes and/or building systems that meet modern requirements for energy performance. This means a huge stock of buildings will be refurbished in the coming years in order to meet national energy targets. In order to assess the effectiveness of any refurbishment, it is important to measure the energy performance before the refurbishment and 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 energy assessment procedures is the buildings energy signature. New buildings require an energy signature and they should perform energetically as they were designed. In order to prove this, it is necessary to obtain 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.

Initially a multiple dimension decision tree has been proposed as shown in Figure 4.1.

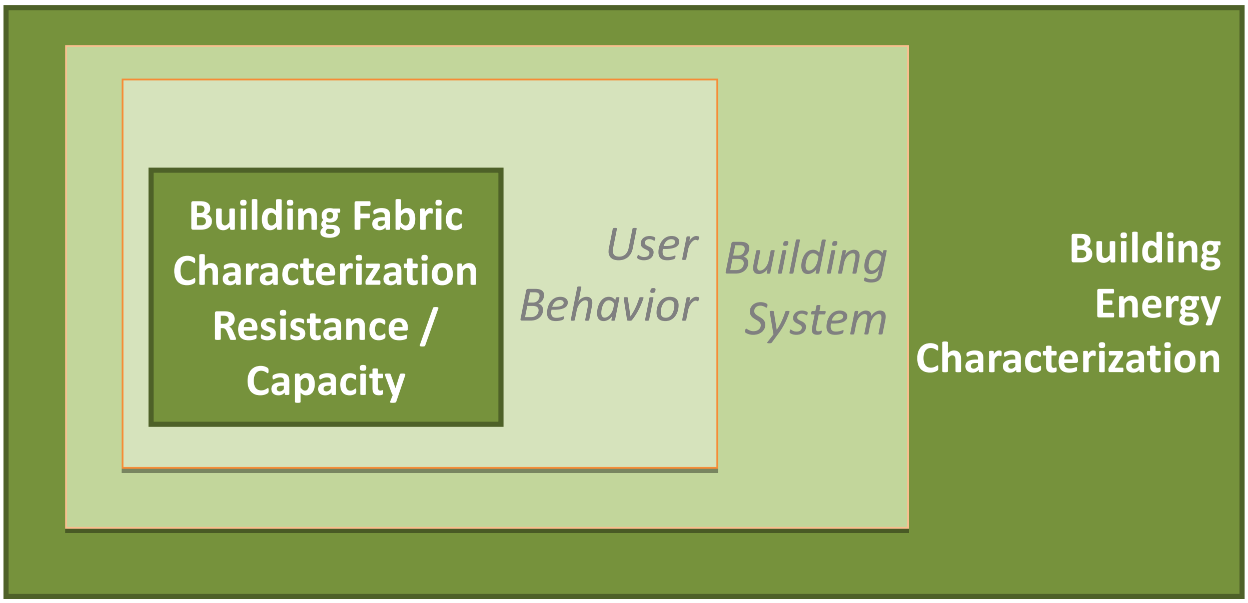

Figure 4.1: Initial structure of the decision tree.

The Figure 4.1 structure is a nested structure and cannot be plotted in two dimensions. An internet based wiki or a matrix based 'multiple entries multiple output' software would be required to follow this structure.

In order to avoid such a complex system, a two dimensional decision tree structure has been developed. This decision tree could be hosted in a webpage such as http://dynastee.info/ and 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/.

4.2 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.

Figure 4.2: Decision Tree logic

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 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 figure 4.3. The decision tree user will find it obvious to expand the branch that is most appropriate for their research aim.

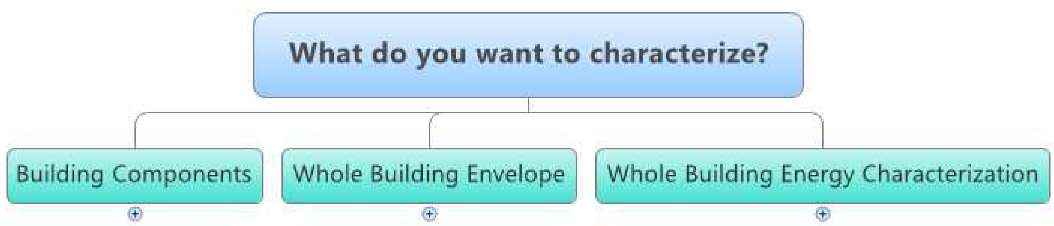

Figure 4.3: Main question and main branches of the decision tree.

Once the main branch is chosen the second level will be shown to the decision tree user as shown in Figure 4.4. 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.

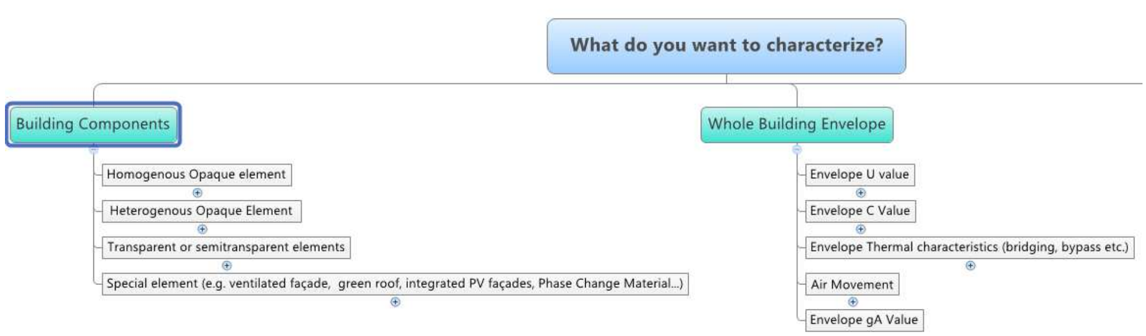

Figure 4.4: partial view of the second level of the decision tree.

As it can be seen in figure 4.5 once the second level is chosen we will 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.

Figure 4.5 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 know if the test environment is *in situ* or a controlled laboratory. This is the fifth level for the specific case shown.

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 figure 4.5 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.

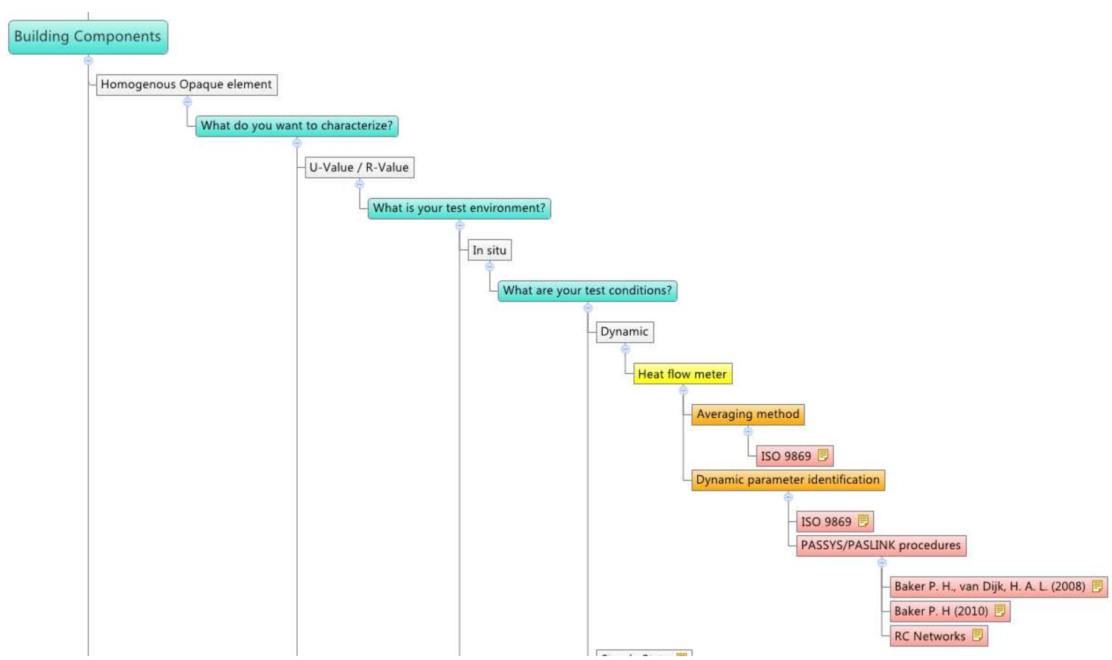

Figure 4.5: partial view of decision tree process

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 figure 4.5 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. This is illustrated in figure 4.6.

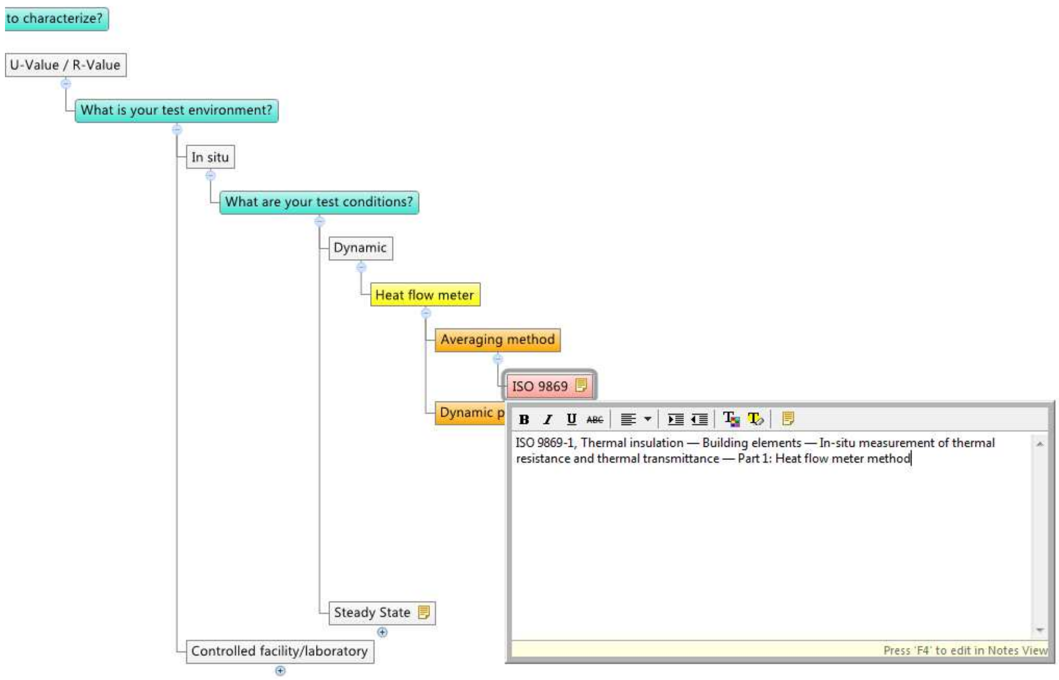

Figure 4.6: Supplementary note attached to reference document

5. DESCRIPTION AND USE OF THE MAIN BRANCHES OF THE DECISION TREE

5.1 INTRODUCTION

The general logic of the decision tree has been explained in section 4.2. 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 name of the Annex58 is “Reliable building energy performance characterization based on full scale dynamic measurements” and the second subtask of this annex is “Optimizing full scale dynamic testing”. It was clear that “optimizing full scale dynamic testing” is dependent on the objective of the researcher or manufacturer and the building component or whole building. It was also clear that many standards and procedures have already been developed and proven for many different objectives and thus a decision tree was the best option to order the large amount of standards and procedures with differing aims and scopes.

The first level of the decision tree has three choices:

- Building components
- Whole building envelope
- 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 on the building component. This branch primarily covers the U 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.

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.

5.2 BUILDING COMPONENTS BRANCH

During recent decades, much work has been carried out on building component energy characterization. As can be seen in figure 5.1, there are four options inside the main level of the "Building components" branch. The first three options consider the characterization of "common" building components (see figure 5.1), this is:

- Homogeneous opaque elements
- Heterogeneous opaque elements
- Transparent or Semitransparent elements

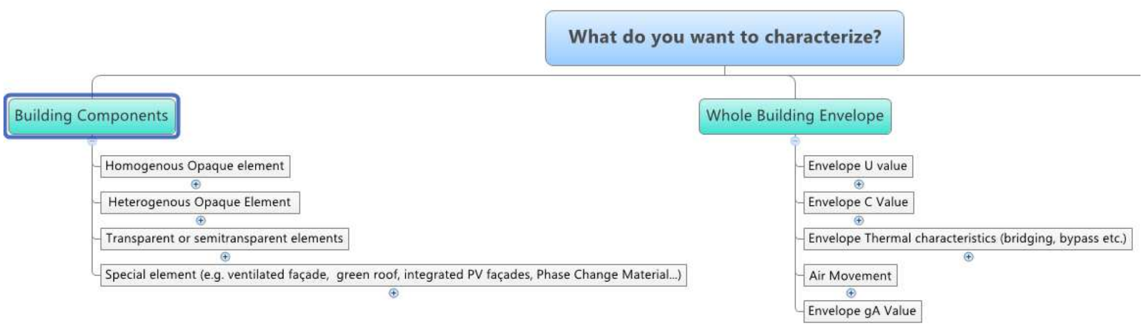

Figure 5.1: main levels of the "Building components" branch.

The main thermal characteristics tested and modelled on these types of elements are the ones presented in figure 5.2 and figure 5.3. The main thermal characteristics of these three "common" element branches are these ones:

- Thermal transmittance value (U-value)
- Thermal capacity value (C-value)
- 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 thermal aspects are considered in the decision tree, since many researchers and manufacturers consider them important (see figure 5.2 and 5.3):

- Hygrothermal behaviour
- Thermal bridging

- Reflective, absorptive and transmittance light aspects
- Air permeability

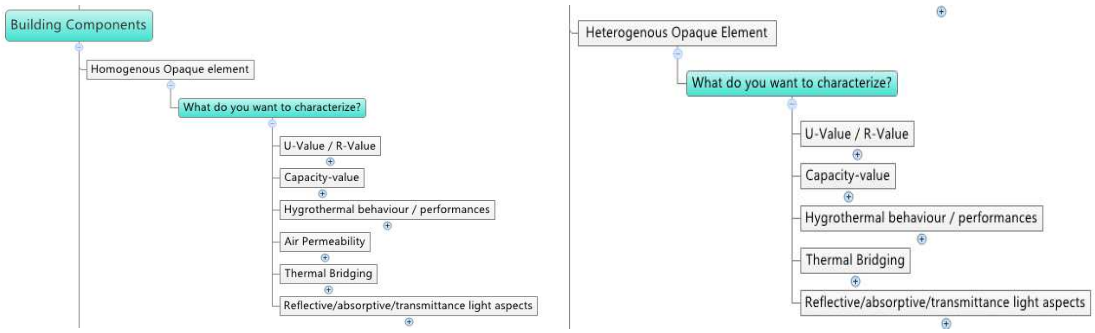

Figure 5.2: main levels inside the "Homogeneous opaque elements" and "Heterogeneous opaque elements" branches.

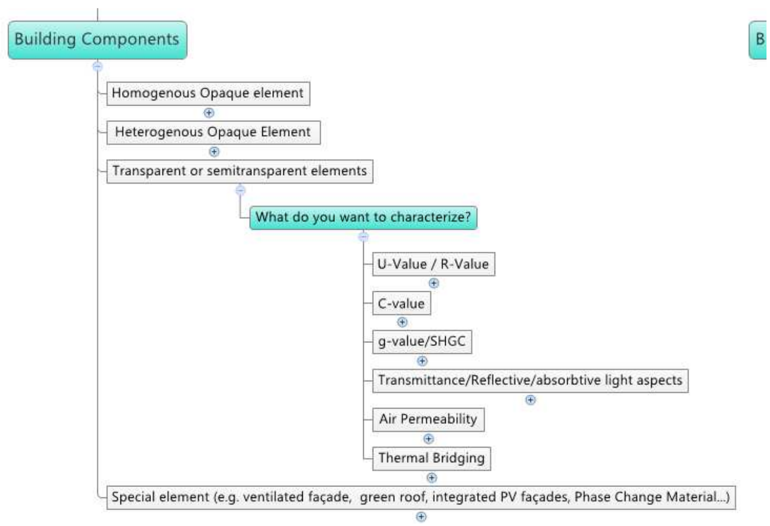

Figure 5.3: main levels inside the "Transparent or Semitransparent elements" branch.

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 a ventilated façade or a green roof 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 will be explained with a simple example. Consider the green roof presented in a schematic way on figure 5.4. The schematic on figure 5.4 distinguishes 3 parts on this building component:

- PART 1: considers the internal surface thermal resistance and the three “common” layers (concrete, insulation and concrete). These three layers can be thermally characterized independently from the green cover 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 and PART 3 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.
- PART 2: in this case the soil plus drainage layer will behave as a “common” element since only its thermal resistance and its thermal capacity will affect the energy behaviour of this component. Depending on the water content of this layer the thermal conductivity and the thermal capacity may vary. The procedure to cope with these variations is considered in the procedure presented at the end of the decision tree branch related to this type of “special” elements.
- PART 3: the PART three for this case is the model that will permit us to calculate hourly during a whole year and based on the meteorological data available for the specific place where we are interested on installing the green roof. The end branch of the decision tree regarding to green roofs will provide a procedure that will permit the decision tree user to characterize and model PART 2 and PART 3 of the green roof.

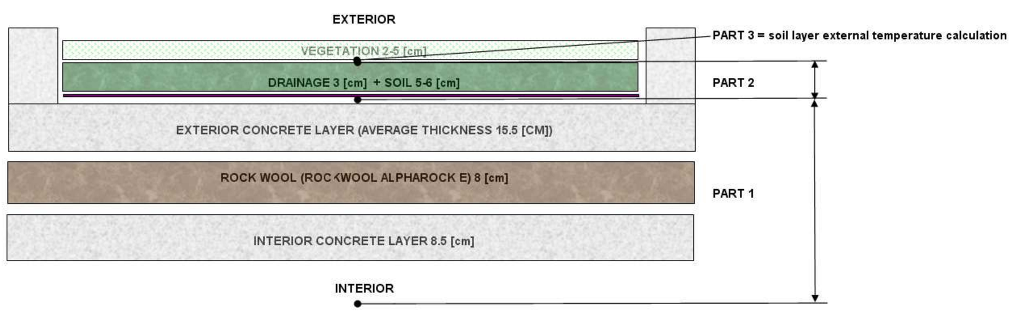

Figure 5.4: schematic of the possible green roof.

The decision tree treats the “special” elements as a conjunction of a “common” element and a “special” element. The link between the “common” part and the “special” part is the temperature of the interface between the special element and the common element. This way the common part of the building component can be characterized as a common element with the well-known standards or procedures of the first three main branches of the “Building component” main branch. The special element model will permit to characterize just the special process happening inside the special part of the element in a precise way. The link between the special part and the common part will be the temperature of the interface between both elements.

An example on how to use the decision tree for the green roof example will be presented. In figure 5.5 we would choose the “special” element choice and the question “Does the special component have a common construction part?” will appear.

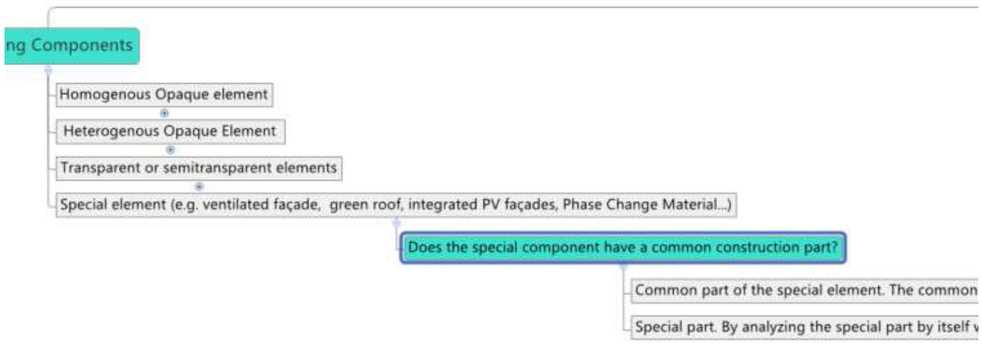

Figure 5.5: First question inside the "Special elements" main branch.

In the above green roof schematic there was a "common" part and two "special" parts of the element. In figure 5.6 we would choose both options since there are both the special and the common part.

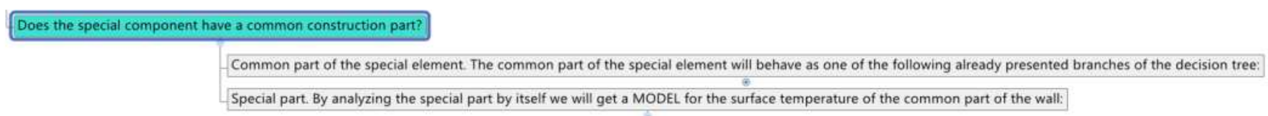

Figure 5.6: division of the special element into a "common" element and a "special" element.

Once both options are selected, we would obtain the figure 5.7 options. For the PART 1 of the figure 5.4 example we would choose the "heterogeneous Opaque element" of figure 5.7 to characterize this PART 1 of the whole green roof. In the other hand, we would choose the "evapotranspiration" branch to characterize the PART 2 and PART 3 of the figure 5.4 example.

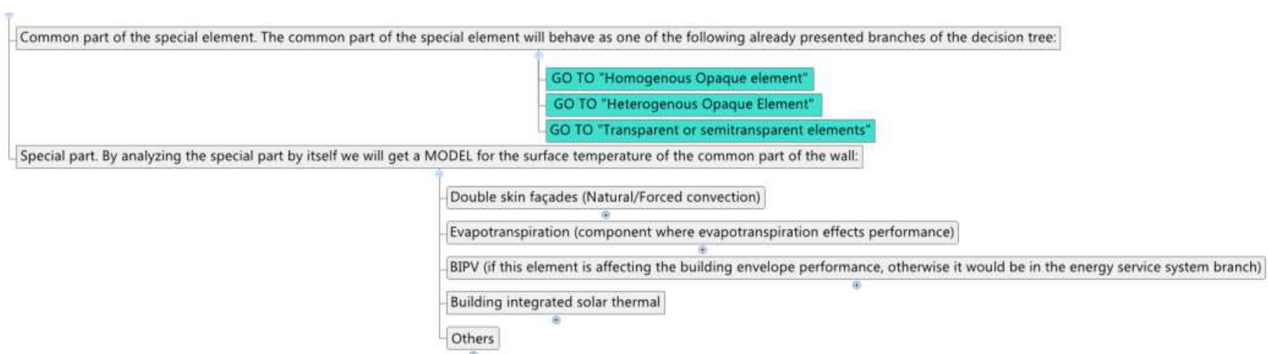

Figure 5.7: redirections to "common" element and options inside the "special" element.

Developing the decision tree for the "evapotranspiration" option, we will obtain the link to a modelling procedure for PART 2 and PART 3 of the figure 5.4 example.

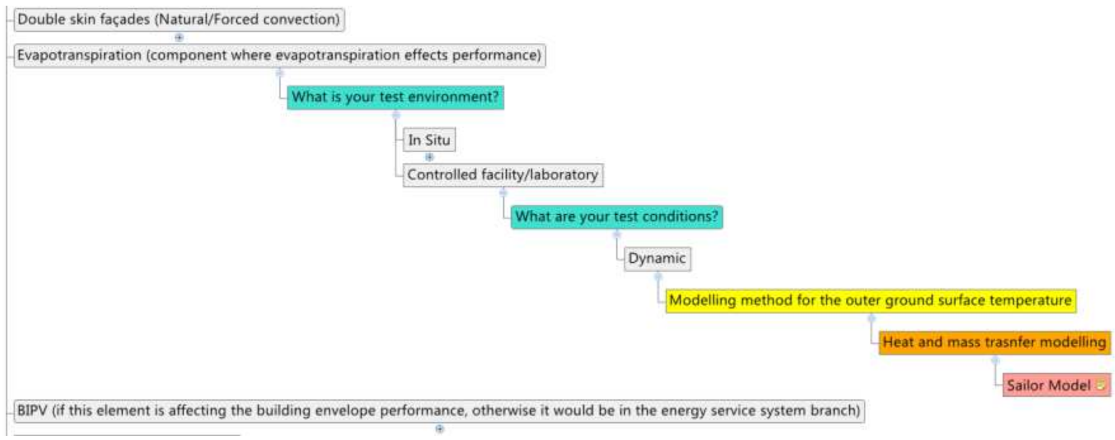

Figure 5.8: development of “special” part of a green roof until an end branch.

5.3 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 figure 5.9, the whole building envelope branch follows a similar logic to the building components branch, with the second level of questioning exploring the specific characteristic e.g. whole envelope U value.

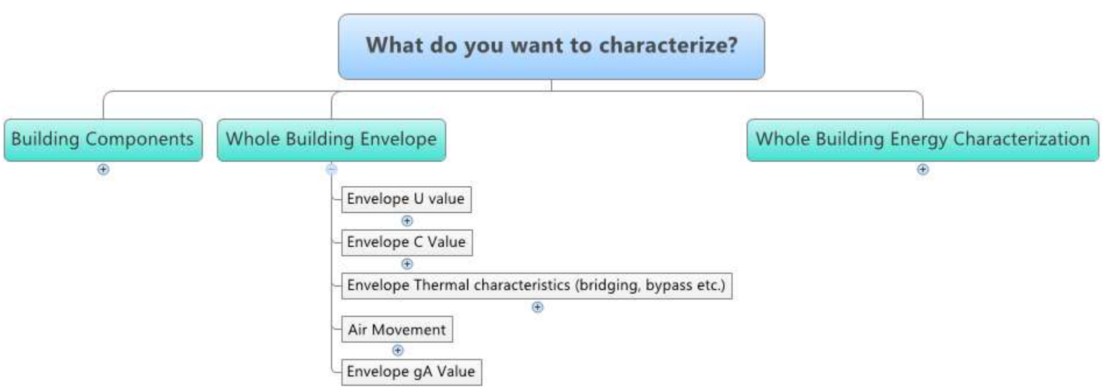

Figure 5.9: Main levels of “whole building envelope” branch

Figure 5.10 illustrates the further development of the branch using ‘air movement’ as an example. Questioning distinguishes between internal/external air transfers (as opposed to internal air looping) before determining the environment and conditions of the research.

Different equipment is then presented before refining the method and final documentation. As discussed above, each final document has an accompanying note which provides further information to the user to aid them in its use and ensure it is appropriate for their needs. For example, the guidance given by an ISO document differs greatly from the information provided by an academic journal and it is important that attached notes highlight this; ensuring users do not need to spend time reading the actual document to determine its usefulness for their purpose.

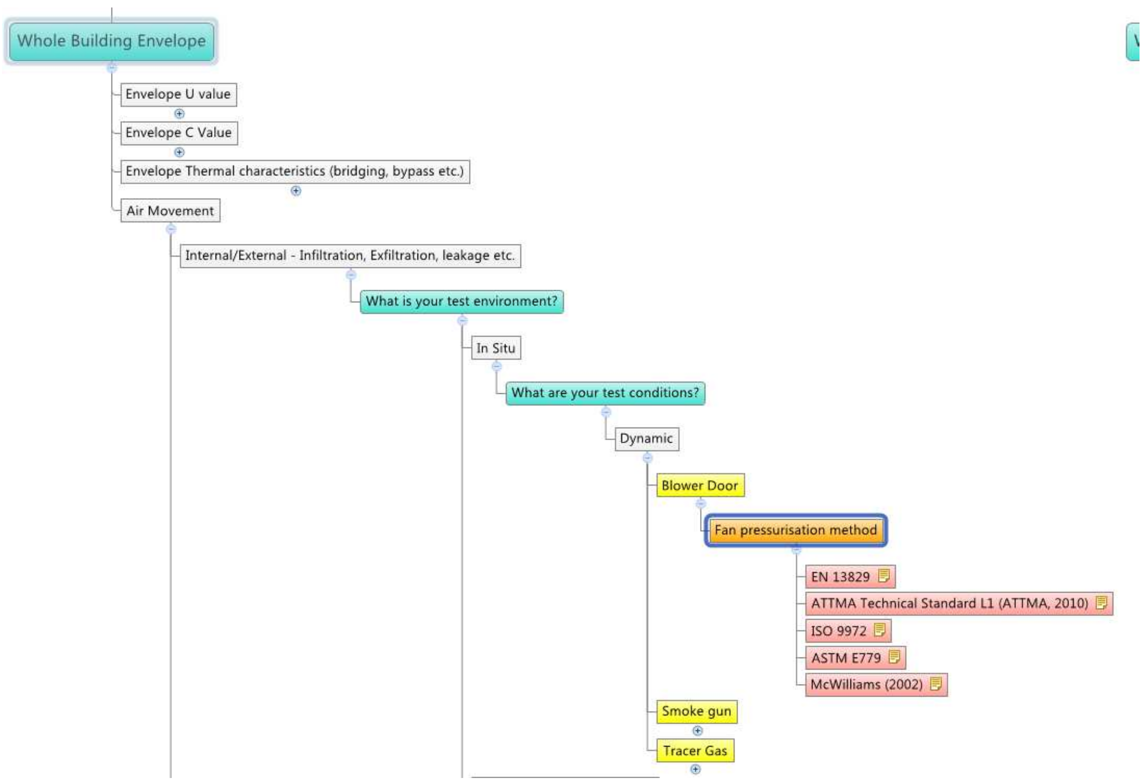

Figure 5.10: Example of process within whole building envelope branch

It was necessary to introduce a third option for test conditions when considering the whole envelope U value due to the recent developments in the field. In addition to steady state and dynamic conditions, transient state was also added to reflect the QUB test. This is shown in figure 5.11. 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.

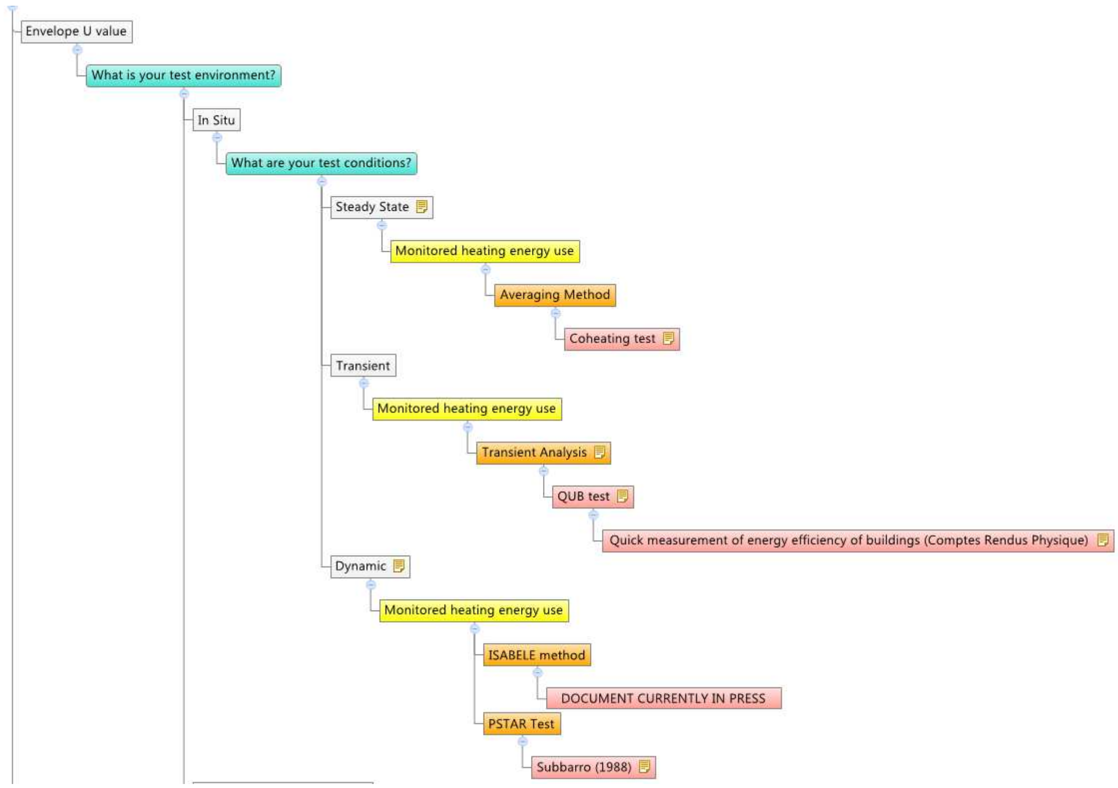

Figure 5.11: Whole envelope U value branch

5.4 WHOLE BUILDING ENERGY CHARACTERIZATION BRANCH

The whole building energy characterization branch seeks to present methodologies centred on monitoring the main contributors to energy use in buildings, namely the building fabric, services and users.

This branch seeks to define the environmental conditions at the first stage, as opposed to focussing 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 shown in figure 5.12.

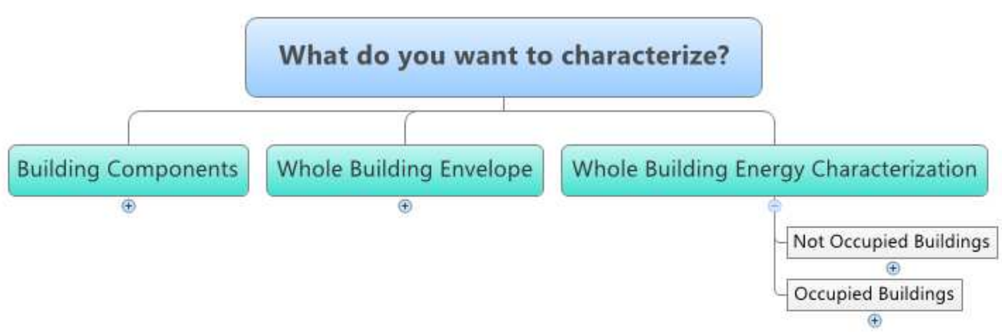

Figure 5.12: Main levels of "whole building energy characterisation" branch

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 as shown in figure 5.13. 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.

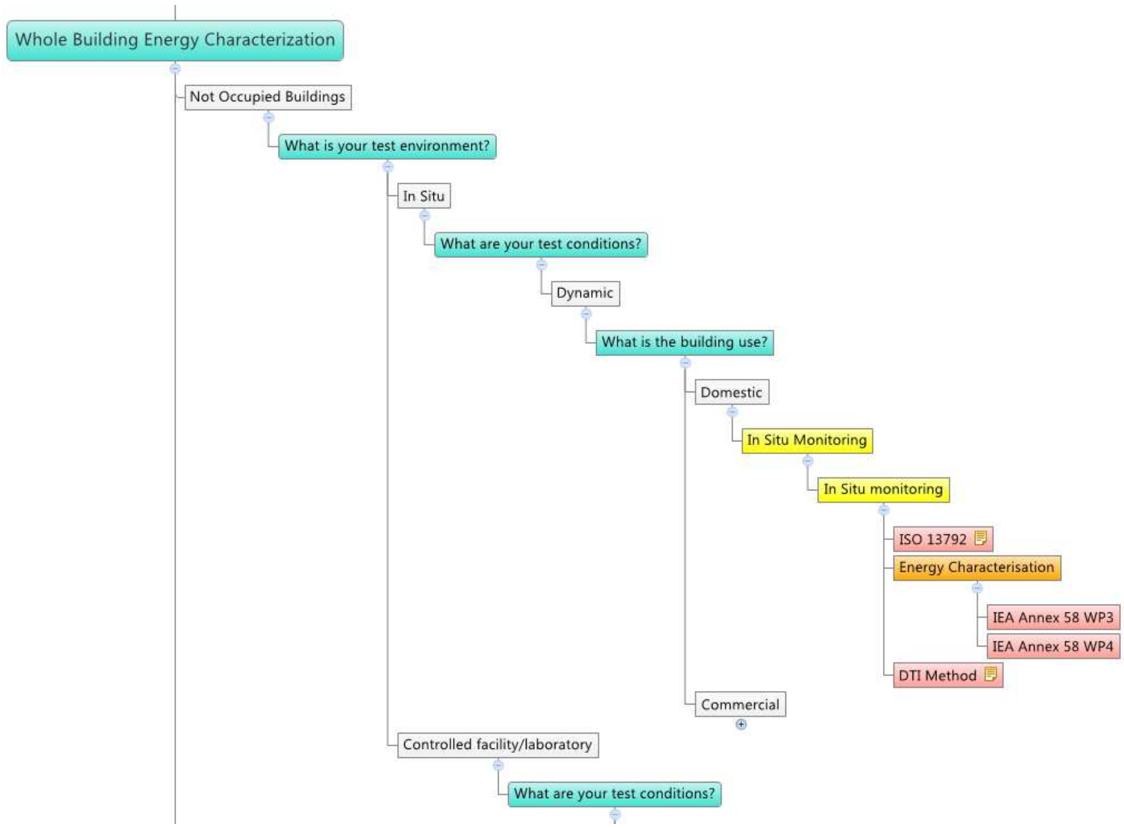

Figure 5.13: Example of whole building energy characterization branch