International Energy Agency, EBC Annex 58

Reliable building energy performance characterisation based on full scale dynamic measurements

Report of Subtask 2: Logic and use of the Decision Tree for optimizing full scale dynamic testing

Aitor Erkoreka, Chris Gorse, Martin Fletcher, Koldobika Martin

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cover picture: Tailored heating experiment performed for one of the industrial partners of the Annex 58-project to determine the overall heat loss coefficient of a newly built dwelling based on on-site measured data. (source: Geert Bauwens, KU Leuven)

Preface

The International Energy Agency

The International Energy Agency (IEA) was established in 1974 within the framework of the Organisation for Economic Co-operation and Development (OECD) to implement an international energy programme. A basic aim of the IEA is to foster international co-operation among the 29 IEA participating countries and to increase energy security through energy research, development and demonstration in the fields of technologies for energy efficiency and renewable energy sources.

The IEA Energy in Buildings and Communities Programme

The IEA co-ordinates international energy research and development (R&D) activities through a comprehensive portfolio of Technology Collaboration Programmes. The mission of the Energy in Buildings and Communities (EBC) Programme is to develop and facilitate the integration of technologies and processes for energy efficiency and conservation into healthy, low emission, and sustainable buildings and communities, through innovation and research. (Until March 2013, the IEA-EBC Programme was known as the Energy in Buildings and Community Systems Programme, ECBCS.)

The research and development strategies of the IEA-EBC Programme are derived from research drivers, national programmes within IEA countries, and the IEA Future Buildings Forum Think Tank Workshops. The research and development (R&D) strategies of IEA-EBC aim to exploit technological opportunities to save energy in the buildings sector, and to remove technical obstacles to market penetration of new energy efficient technologies. The R&D strategies apply to residential, commercial, office buildings and community systems, and will impact the building industry in five focus areas for R&D activities:
– Integrated planning and building design
– Building energy systems
– Building envelope
– Community scale methods
– Real building energy use

The Executive Committee

Overall control of the IEA-EBC Programme is maintained by an Executive Committee, which not only monitors existing projects, but also identifies new strategic areas in which collaborative efforts may be beneficial. As the Programme is based on a contract with the IEA, the projects are legally established as Annexes to the IEA-EBC Implementing Agreement. At the present time, the following projects have been initiated by the IEA-EBC Executive Committee, with completed projects identified by (*):

Annex 1:   Load Energy Determination of Buildings (*)
Annex 2:   Ekistics and Advanced Community Energy Systems (*)
Annex 3:   Energy Conservation in Residential Buildings (*)
Annex 4:   Glasgow Commercial Building Monitoring (*)
Annex 5:   Air Infiltration and Ventilation Centre
Annex 6:   Energy Systems and Design of Communities (*)
Annex 7:   Local Government Energy Planning (*)
Annex 8:   Inhabitants Behaviour with Regard to Ventilation (*)
Annex 9:   Minimum Ventilation Rates (*)
Annex 10:   Building HVAC System Simulation (*)
Annex 11:   Energy Auditing (*)
Annex 12:   Windows and Fenestration (*)
Annex 13:   Energy Management in Hospitals (*)
Annex 14:   Condensation and Energy (*)
Annex 15:   Energy Efficiency in Schools (*)

IEA EBC Annex 58: Reliable Building energy performance characterisation based on full scale dynamic measurements

Annex 58 in general

To reduce the energy use of buildings and communities, many industrialised countries have imposed more and more stringent requirements in the last decades. In most cases, evaluation and labelling of the energy performance of buildings are carried out during the design phase. Several studies have shown, however, that the actual performance after construction may deviate significantly from this theoretically designed performance. As a result, there is growing interest in full scale testing of components and whole buildings to characterise their actual thermal performance and energy efficiency. This full scale testing approach is not only of interest to study building (component) performance under actual conditions, but is also a valuable and necessary tool to deduce simplified models for advanced components and systems to integrate them into building energy simulation models. The same is true to identify suitable models to describe the thermal dynamics of whole buildings including their energy systems, for example when optimising energy grids for building and communities.

It is clear that quantifying the actual performance of buildings, verifying calculation models and integrating new advanced energy solutions for nearly zero or positive energy buildings can only be effectively realised by in situ testing and dynamic data analysis. But, practice shows that the outcome of many on site activities can be questioned in terms of accuracy and reliability. Full scale testing requires a high quality approach during all stages of research, starting with the test environment, such as test cells or real buildings, accuracy of sensors and correct installation, data acquisition software, and so on. It is crucial that the experimental setup (for example the test layout or boundary conditions imposed during testing) is correctly designed, and produces reliable data. These outputs can then be used in dynamic data analysis based on advanced statistical methods to provide accurate characteristics for reliable final application. If the required quality is not achieved at any of the stages, the results become inconclusive or possibly even useless. The IEA EBC Annex 58-project arose from the need to develop the necessary knowledge, tools and networks to achieve reliable in situ dynamic testing and data analysis methods that can be used to characterise the actual energy performance of building components and whole buildings. As such, the outcome of the project is not only of interest for the building community, but is also valuable for policy and decision makers, as it provides opportunities to make the step from (stringent) requirements on paper towards actual energy performance assessment and quality checking. Furthermore, with the developed methodology it is possible to characterise the dynamic behaviour of buildings, which is a prerequisite for optimising smart energy and thermal grids. Finally, the project developed a dataset to validate numerical Building Energy Simulation programs.

Structure of the project

Successful full scale dynamic testing requires quality over the whole process chain of full scale testing and dynamic data analysis: a good test infrastructure, a good experimental set-up, a reliable dynamic data analysis and appropriate use of the results. Therefore, the annex-project was organised around this process chain, and the following subtasks were defined:

Subtask 1 made an inventory of full scale test facilities available all over the world and described the common methods with their advantages and drawbacks for analysing the obtained dynamic data. This subtask produced an overview of the current state of the art on full scale testing and dynamic data analysis and highlighted the necessary skills.

Subtask 2 developed a roadmap on how to realise a good test environment and test set-up to measure the actual thermal performance of building components and whole buildings in situ. 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. With a clear idea of the test objective, the decision tree will give the information of a test procedure or a standard where this type of test is explained in detail.

Subtask 3 focused on quality procedures for full scale dynamic data analysis and on how to characterise building components and whole buildings starting from full scale dynamic data sets. The report of subtask 3 provides a methodology for dynamic data analysis, taking into account the purpose of the in situ testing, the existence of prior physical knowledge, the available data and statistical tools,… The methodologies have been tested and validated within different common exercises, in a way that quality procedures and guidelines could be developed.

Subtask 4 produced examples of the application of the developed concepts and showed the applicability and importance of full scale dynamic testing for different issues with respect to energy conservation in buildings and community systems, such as the verification of common BES-models, the characterisation of buildings based on in situ testing and smart meter readings and the application of dynamic building characterisation for optimising smart grids.

Subtask 5 established a network of excellence on 'in situ testing and dynamic data analysis' for dissemination, knowledge exchange and guidelines on testing.

Overview of the working meetings

The preparation and working phase of the project encompassed 8 working meetings:

Meeting	Place, date	Attended by
Kick off meeting	Leuven (BE), September 2011	45 participants
Second preparation meeting	Bilbao (SP), April 2012	46 participants
First working meeting	Leeds (UK), September 2012	44 participants
Second working meeting	Munich (GE), April 2013	53 participants
Third working meeting	Hong-Kong (CH), September 2013	26 participants
Fourth working meeting	Gent (BE), April 2014	49 participants
Fifth working meeting	Berkeley (USA), September 2014	37 participants
Sixth working meeting	Prague (CZ), April 2015	39 participants

During these meetings, working papers on different subjects related to full scale testing and data analysis were presented and discussed. Over the course of the Annex, a Round Robin experiment on characterising a test box was undertaken, and several common exercises on data analysis methods were introduced and solved.

Outcome of the project

The IEA EBC Annex 58-project worked closely together with the Dynastee-network (www.dynastee.info). Enhancing this network and promoting actual building performance characterization based on full scale measurements and the appropriate data analysis techniques via this network is one of the deliverables of the Annex-project. This network of excellence on full scale testing and dynamic data analysis organizes on a regular basis events such as international workshops, annual training,... and will be of help for organisations interested in full scale testing campaigns.

In addition to the network of excellence, the outcome of the Annex 58-project has been described in a set of reports, including:
Report of Subtask 1A: Inventory of full scale test facilities for evaluation of building energy performances.
Report of Subtask 1B: Overview of methods to analyse dynamic data
Report of Subtask 2: Logic and use of the decision tree for optimizing full scale dynamic testing.
Report of Subtask 3 part 1: Thermal performance characterization based on full scale testing: physical guidelines and description of the common exercises
Report of Subtask 3 part 2: Thermal performance characterization using time series data – statistical guidelines.
Report of Subtask 4A: Empirical validation of common building energy simulation models based on in situ dynamic data.
Report of Subtask 4B: Towards a characterization of buildings based on in situ testing and smart meter readings and potential for applications in smart grids
IEA EBC Annex 58 project summary report

<u>Participants</u>

In total 49 institutes from 17 countries participated in Annex 58. The different participants are listed below:

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	Susanne Metzger, Vienna University of Technology
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	Guillaume Lethé, Belgian Building Research Institute
	Luk Vandaele, Belgian Building Research Institute (subtask 5 co-leader)
	Paul Steskens, Belgian Building Research Institute
	Gabrielle Masy, Haute Ecole de la Province de Liège
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	Dirk Saelens, KU Leuven (subtask 4 co-leader)
	Geert Bauwens, KU Leuven (secretary)
	Glenn Reynders, KU Leuven
	Ruben Baetens, KU Leuven
	Roel De Coninck, KU Leuven
	Staf Roels, KU Leuven (operating agent)
	Frédéric Delcuve, Knauf Insulation
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	Henrik Madsen, Technical University of Denmark (subtask 3 co-leader)
	Kyung Hun (Peter) Woo, Technical University of Denmark
	Peder Bacher, Technical University of Denmark
France	Bouchie Remi, Centre Scientifique et Technique du Bâtiment
	Pierre Boisson, Centre Scientifique et Technique du Bâtiment
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	Xavi Cipriano, Centro Internacional de Métodos Numéricos en Ingeniería
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IEA, EBC Annex 58, Report of Subtask 2

Logic and use of the Decision Tree for optimizing full scale dynamic testing

Aitor Erkoreka, Christopher Gorse, Martin Fletcher, Koldobika Martin

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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

1. Preface

This report summarizes the activities that were carried out in the framework of Subtask 2 of IEA Annex 58. Subtask 2 dealt with the challenge of optimizing full scale dynamic testing. The aim was to arrive at a roadmap presenting the user with reliable methods used to measure the actual thermal performance of building components and whole buildings. The roadmap (using a decision tree logic) is aimed at multiple audiences from both academic and industry backgrounds.

The present report focuses on the development of the Decision Tree and how it changed throughout the course of Annex 58, giving an overview of the presented work.

The general outline of the report is listed below:

Chapter 1: Preface

Chapter 2: Introduction

Chapter 3: Definitions of key terms

Chapter 4: Evolution of the Decision Tree

Chapter 5: Logic of the Decision Tree

Chapter 6: Description and use of the Decision Tree

Chapter 7: Summary of Subtask 2

2.   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.

Annex 58 is composed of 5 subtasks, of which Subtask 2 focusses on 'Optimizing full scale dynamic testing'. The aim was to arrive at a roadmap presenting the user with reliable methods used to measure the actual thermal performance of building components and whole buildings. The roadmap (using a decision tree logic) is aimed at multiple audiences from both academic and industry backgrounds.

Since there are many different objectives when measuring the thermal performance of buildings or building components, the method considered most appropriate to address the options was to map out a decision tree to guide the user through defined options. The decision tree's logic was informed by the scientific expert group of the annex, and is aimed at the users need to understand a building, component or element behavior. Where the user of the decision tree has a clear idea of the objective of the test to be carried out, the decision tree will provide information on test procedures and standards where information is available, and will provide a link or reference to the detail of the test.

To ensure a good test set up, the full scale testing requires informed decisions, based on previous experience at every stage of the process, starting with a good test infrastructure. Only when the most current information is considered and the influencing factors taken into account can a good experimental set-up be designed. It is essential that optimal set-up conditions are achieved in order to produce reliable data that can then be used for dynamic data analysis, achieving understanding to inform the final results and characterization. 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 the   focus will be on the explanation of the decision tree and how to use it to obtain reference to reliable documentation that will detail how to perform the experiment that best fits the user requirements.

IMPORTANT: This document must be used together with the decision tree. There are no references to other documents inside this text, since the references can be found in the decision tree itself. The references are presented in a systematical way following the logic of the decision tree.

3. Definitions of Key Terms

The Decision Tree is intended to be accessible to a broad audience, and effort has been made to ensure the language used is as non-technical as possible. Where technical language is unavoidable, notes are provided to give a brief definition to guide the reader. There are however several key terms that appear throughout the Decision Tree which it is worthwhile defining in this ReadMe Document.

Conditions – The state in which the test is occurring, with the following 3 options presented to the user:

> **Steady State** – Conditions of the test do not change over time.

> **Dynamic** – The period between two different steady state stages following the change of one or more variables.

> **Transient** – Conditions are capable of constant change over time.

Element – A single component that exists independently, and when considered in a whole building context forms part of the composite construction.

Envelope – The part of the building that forms a physical barrier between the internal and external space; this is typically the walls, roof and floor.

Environment – The setting of the research. When considering the environment, two options will be given:

> **In situ** – Tests that are conducted 'in the field'. In other words, the test is taking place in a real world setting, with limited control of the environment.

> **Controlled facility/laboratory** – Tests are conducted in a setting which allows the researcher to accurately control the environment.

4.   Evolution of the Decision Tree

Throughout the duration of the Annex 58 collaboration the decision tree underwent several iterations reflecting the changing conception of how best to represent such a large body of literature so that it is accessible and useful to a diverse variety of users. The original Subtask outline specified the creation of a roadmap document to aid in the correct set-up and analysis methods to be used when conducting physical tests on buildings and their constituent elements. After discussion amongst the Annex 58 scientific committee, it was determined that the best way to achieve this was to develop a decision tree which allows the user to follow a linear path that adheres to a typical research approach – namely defining the aims, context and environment before considering experimental design, analysis methods and finally specific methodological approach. Alternative approaches that were considered included a large document covering methodologically specific approaches which could be navigated using an index, and a matrix style 'wiki' through which the user utilizes embedded links to move through the appropriate contextual pages. Whilst these alternatives have their merits, in order to reach the widest audience and generate a useable tool given the time and resource available, a decision tree was found to offer the best solution.

In order to gather the required information with which to begin the population of a tool capturing the key literature related to the physical testing of building elements and whole buildings, a questionnaire was distributed to all Annex 58 participants with the invitation extended to share this with their colleagues working within the field. Feedback from this exercise was unfortunately insufficient to create a truly comprehensive document, but using the questionnaires that were returned in addition to individual knowledge of the topic, Subtask 2 leaders were able to create the first version of a roadmap document, the front cover of which can be seen in figure 4.1. This was a 37 page document that provided an outline of available test methods and equipment required for the in situ testing of whole buildings, with specific focus on the determination of the whole house heat loss coefficient though the co-heating method. Although useful, the formation of such a document was not compatible with the overall goal of Subtask 2. Even with an advanced indexing system in place, when complete the final document would be overly large and the likelihood of such a document capturing all necessary information for the accurate set-up and analysis of dynamic testing would be unlikely due to the wide range of available methods.

Discussions amongst the scientific committee at the Annex 58 meeting in Holzkirchen led to the development of a nested structure similar to a 'wiki', which placed the information in interlinked zones and can be viewed in figure 4.2. It was quickly determined that this structure would also prove to be overly detailed in addition to requiring significant resources to realize in practice. A nest structure would provide a good system of storing layers of information; however, some of the logic of the decision tree approach would be lost.

*Figure 4.1: First iteration of the roadmap document*
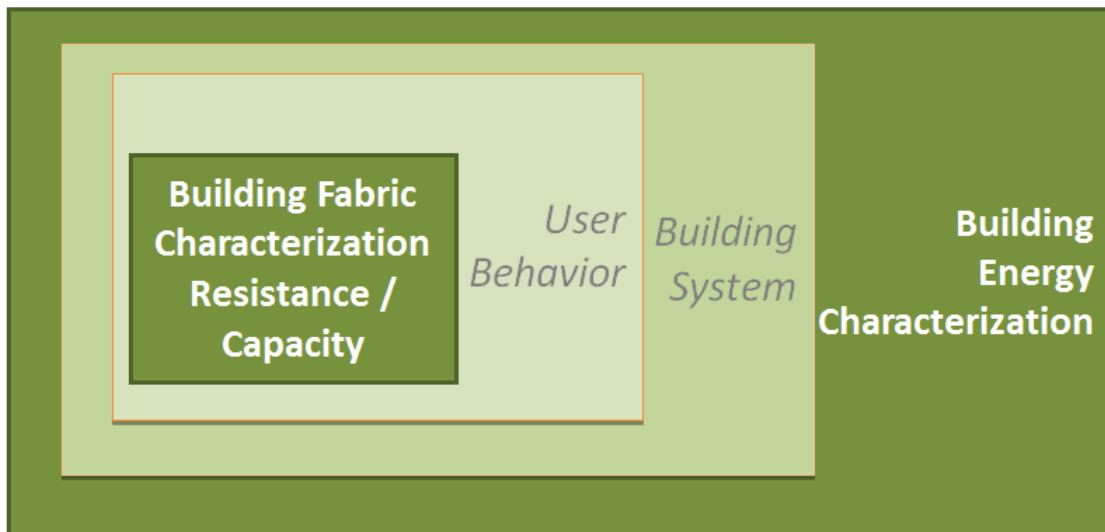
Figure 4.2: Wiki concept structure

A rationalized linear approach was then adopted, which allowed the information that had been collected about testing methods to be broken down in a logical order that could be subsequently reconstructed through direct questioning. Key aspects of testing and analysis methods were drawn from core texts, for example equipment requirements, environmental conditions and practical limitations. These were then used to apply a filtration process whereby the user of the decision tree may answer questions on their personal aims and limitations and receive guidance specific to their given contextual situation. The first version of this breakdown process can be seen in figure 4.3. The standardized questions and resulting documents were then applied to the freeware mind mapping tool Xmind, as can be seen in figure 4.4.
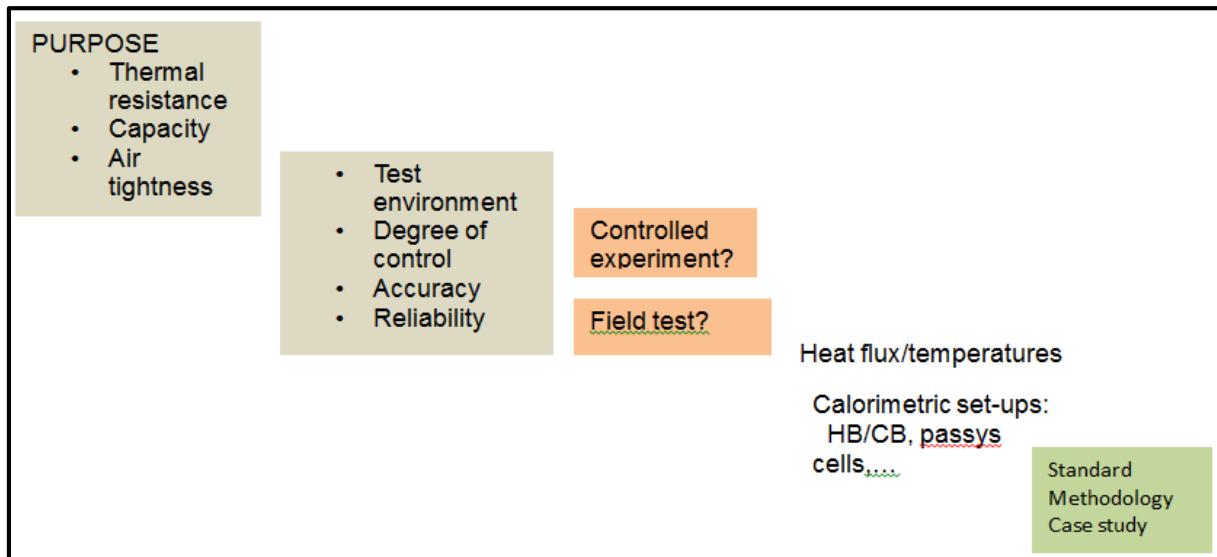

Figure 4.3: Breakdown of linear path for the decision tree
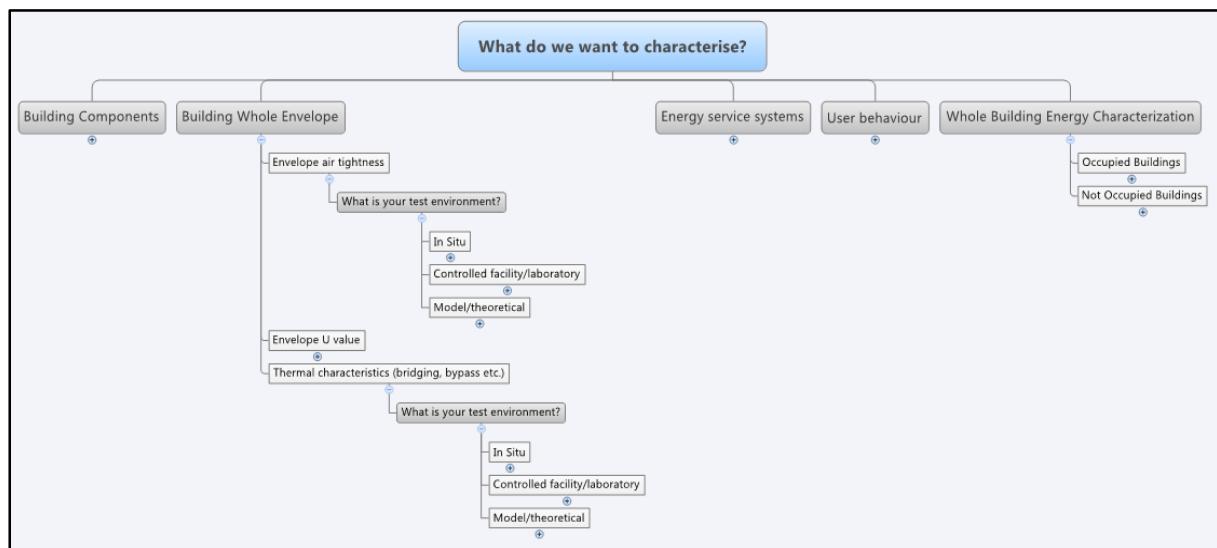
Figure 4.4: Early iteration of the decision tree in Xmind

The conversion to a decision tree and the adoption of a linear approach greatly improved the usability of the information, using the core characteristics of state of the art methods as the

basis for a standard set of contextual questions. As can be seen in figure 4.4, the earlier iterations of the decision tree considered 5 factors affecting energy and performance of building:

- Building components
- Building whole envelope
- Energy service system
- User behavior
- Whole building energy characterization

In order to return to the original focus of Annex 58, aspects of building energy characterization related to services and users were removed. Although these issues are fully acknowledged as significant when considering energy performance of buildings, they were deemed out of scope for the Subtask 2 exercise.

Subsequent meetings and feedback led to further revision of the decision tree logic, an example of which can be seen in figure 4.5. As the overall framework was set, the final task was to populate the decision tree with references that had sufficient academic credibility to warrant inclusion, namely ISO documents, peer reviewed articles and established test protocols. Additionally, notes and clarifications were added to the decision tree so that users unfamiliar with the field-specific language could engage more easily with the tool.
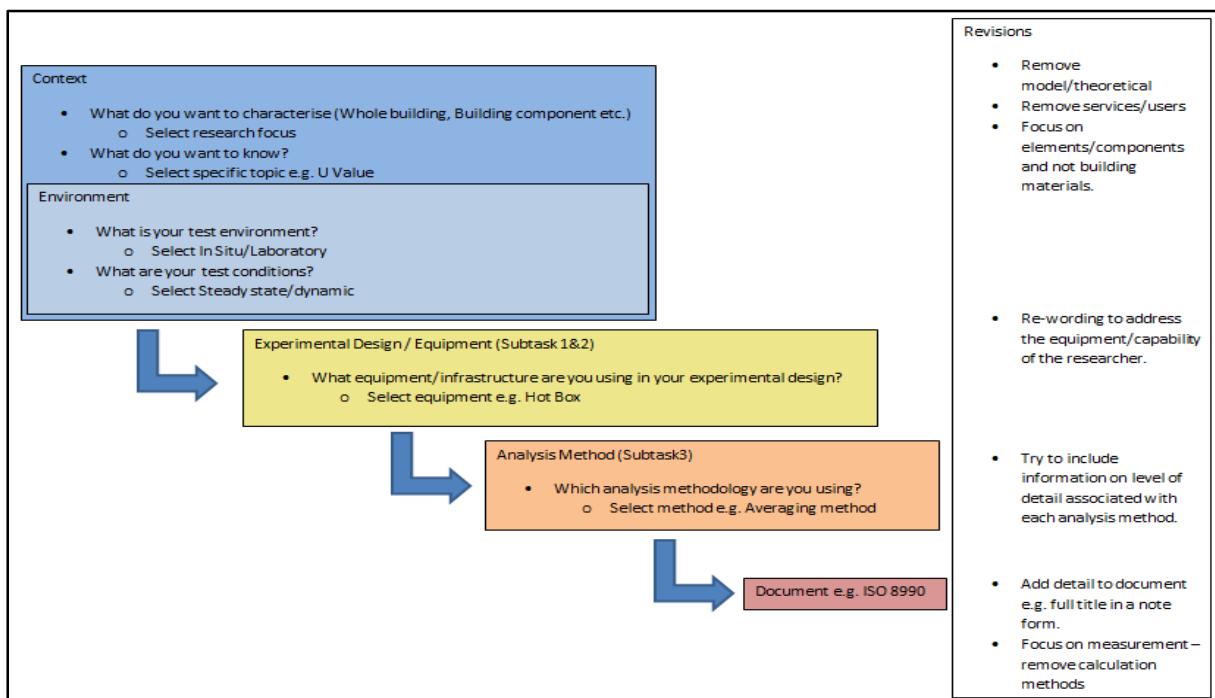

Figure 4.5: Refined logic of the decision tree

5.   Logic of the decision tree

5.1 Why develop 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 their behaviour and energy related performance. 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. While many other factors are taken into consideration, research largely tends to follow building codes and methods used to validate related performance. This is why, historically, the measurement of the U value of the designed building component has been the main goal of manufacturers and researchers. As a result of code driven research there are 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 limit and better define the energy demand of the building. The Nearly Zero Energy Buildings objective for 2020 in Europe for new built buildings emphasises the need to understand, limit and control. 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 understood. The energy behaviour must be simulated in a much more robust and precise way. The total energy demand of the building will be dependent on the interrelationship and controlled behaviour of the building envelope, building systems and the user.

Clearly it is necessary that the knowledge of components and their expected performance must go beyond U value measurements under steady-state laboratory conditions. Research must be undertaken so that the understanding of performance in real world 'dynamic' conditions is known. The modelling and testing of the dynamic thermal behaviour of the buildings and building components must be more precise. Stemming from this need, there are many different procedures which have been developed to test the dynamic behaviour of building components and buildings *in-situ*. Unfortunately, at this juncture few of them have gone beyond scientific research and have not become part of the international body of accepted standards. Indeed, many of these procedures may never be developed for use as an international standard. Furthermore, for some of the dynamic tests cause testing on the same test component under different dynamic conditions to obtain different results. While the results of these tests may still be valid, they represent results and phenomena which although are found to occur cannot easily be replicated, due to the variability in test conditions, test samples and exposure. There is much to understand with regard to the nature of dynamic tests, especially those conducted under real world conditions.

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 buildings to be upgraded and refurbished, with the aim of becoming more energy efficient. The majority of existing buildings do not have envelopes and/or building systems that meet modern requirements for energy performance. There is a huge variability in the performance of the existing building stock. This means that almost the entire building stock requires thermal and energy efficient improvements if they are 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. Building energy signatures, can represent many different aspects of energy behaviour, in this document we are referring to the aspects of the buildings energy behaviour that are used to demonstrate that a building has met a mandatory standard or code. New buildings are required to be energy efficient; they require an energy signature that reflects their expected behaviour, so that they perform as they were designed. In order to prove that the behaviour of the building corresponds with that expected, it is necessary to measure the building's performance. The performance is measured to show that performance has been achieved.

As researchers have attempted to measure and characterise building performance, different test, monitoring procedures and standards have evolved. In each situation, the tests attempt to characterize building components and whole buildings, in order to understand an aspect of their behaviour. There are so many different procedures and standards that it is difficult for a researcher or a building sector professional to know which is the best procedure or standard for their specific aim.

Following expert led workshops and discussions, to address what had become an unmanageable and non-scientific approach to the selection of tests and measurement, a decision was made to construct a guide and roadmap. The decision tree and the common methods cited address most of the standards and procedures, available at the time, to characterize the energy behaviour of building components and the whole buildings.

5.2 Logic of the decision tree

In order to encourage engagement across a wide spectrum of potential users, specific attention has been paid towards keeping the logic of the decision tree simple and consistent, so that engagement and experience will be broadly similar regardless of the user's particular research interest. With this in mind, Figure 1 displays the linear path that the user should expect to follow when engaging with the decision tree:

Figure 5.1: Decision Tree logic

The main question to be followed by the decision tree user is "**What do you want to characterize?**" Although a simple question, it is a very precise way to reach to the optimal test procedure. Following this question the user will find three main branches as shown in figure 5.2. The user can expand the branch that is most appropriate for their research aim by clicking the '+' icon.
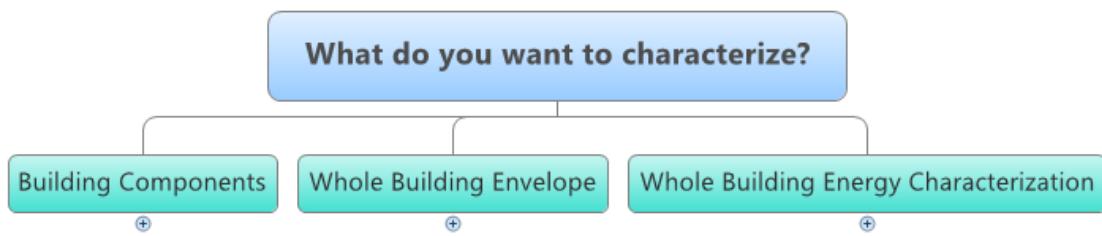
Figure 5.2: Main question and main branches of the decision tree.

Once the main branch is chosen the second level will be shown to the user, as shown in Figure 5.3 Following again the main question "**What do you want to characterize?**" the user should then check the most suitable situation or case from the options displayed in the second level.
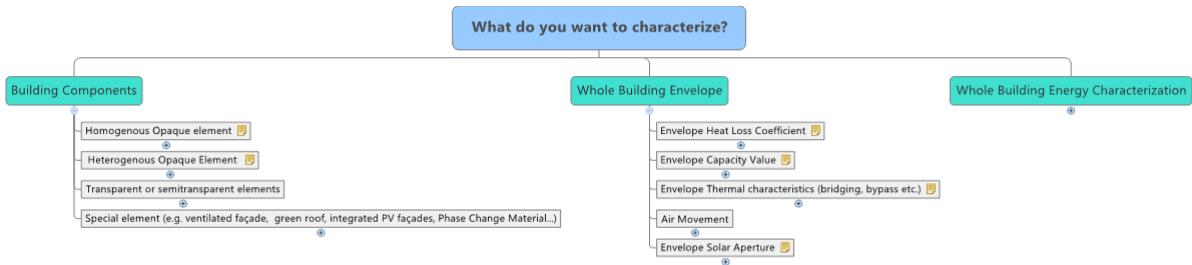

Figure 5.3: partial view of the second level of the decision tree.

As it can be seen in figure 5.4 once the second level is chosen we will find again the question "**What do you want to characterize?**" Following this question, the user is now at the third level of the decision tree and a reasonable level of the experiment context is set and much of the purpose defined. Once the third level is chosen by the user, some more specific questions will appear until an end branch is reached. Where technical language is used, notes have been added to the node to provide definitions, aiding the application of the decision tree for a non-technical audience.

Figure 5.4 shows an example of how we can reach an end branch. In this example, once the user is in the third level, the question "**What is your test environment?**" is raised. The user must know if the test environment is *in situ* (taking place in the field where the building, element or component is being used) or in a controlled laboratory setting. 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 user will have to know if the problem that is being studied is going to be treated or considered as a 'Dynamic' or 'Steady State' problem. In the figure 5.4 example the 'Dynamic' case is chosen in the fifth level. Once the user checks for this case the name of the existing test procedure (or possible different procedures) to carry out the experiment are 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, the user will arrive at an end branch where a link to a specific Standard or a widely proven test and data analysis procedure is referenced.

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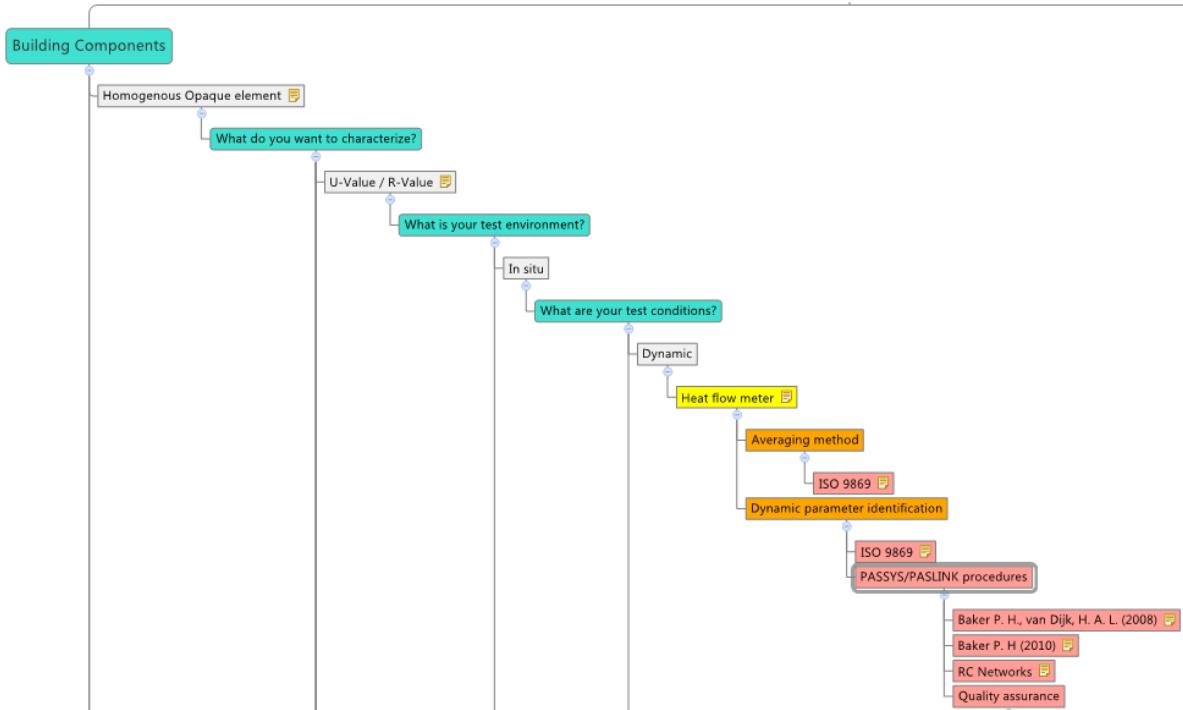
Figure 5.4: partial view of decision tree process

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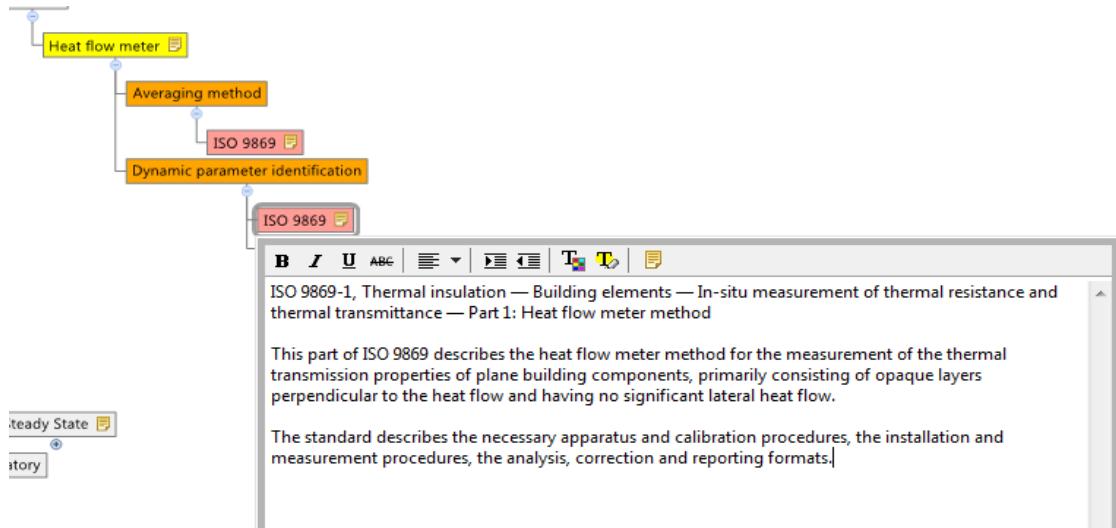

Figure 5.5: Supplementary note attached to reference document

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

The general logic of the decision tree has been explained in section 4 and 5. This information is sufficient to understand how to use the decision tree successfully, and can be used with the decision tree companion document (or ReadMe). 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 International Energy Agency Annex 58 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, C and g 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 cumulative effect of multiple aspects contained in both the two earlier branches and also factors not covered in high detail (e.g. users). In the next three subsections a short explanation on each of the main branches is given.

6.1 Building components branch

During recent decades, much work has been carried out on building component energy characterization. As can be seen in figure 6.1, 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 6.1), this is:

- Homogeneous opaque elements

- Heterogeneous opaque elements

- Transparent or Semitransparent elements
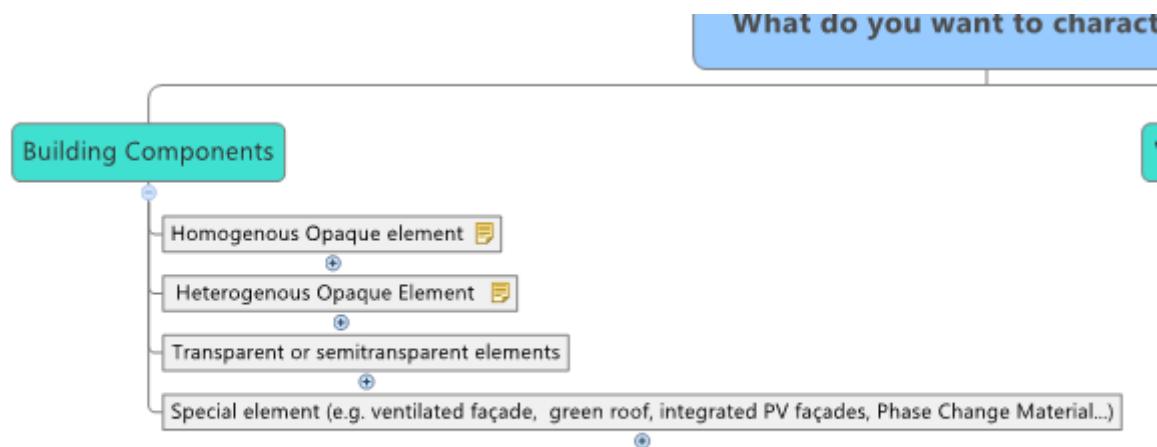
Figure 6.1: main levels of the "Building components" branch.

The main thermal characteristics tested and modelled on these types of elements are the ones presented in figure 6.2 and figure 6.3. 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 6.2 and 6.3):

- Hygrothermal behaviour

- Thermal bridging

- Reflective, absorptive and transmittance light aspects

- Air permeability

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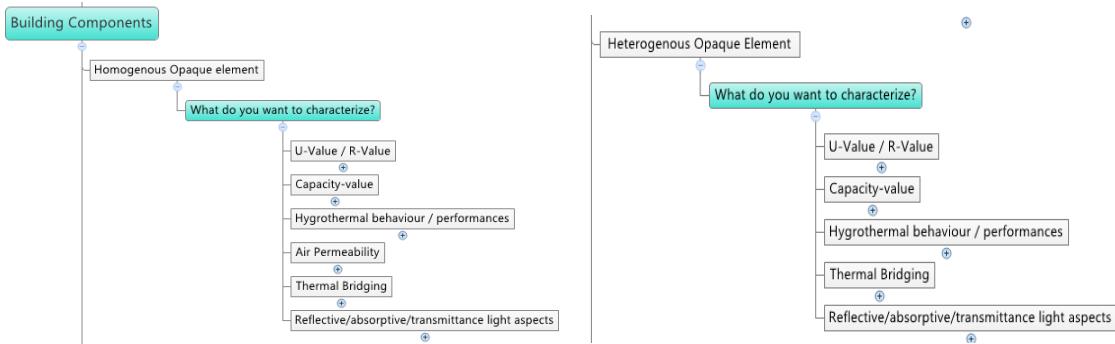
Figure 6.2: main levels inside the "Homogeneous opaque elements" and "Heterogeneous opaque elements" branches.
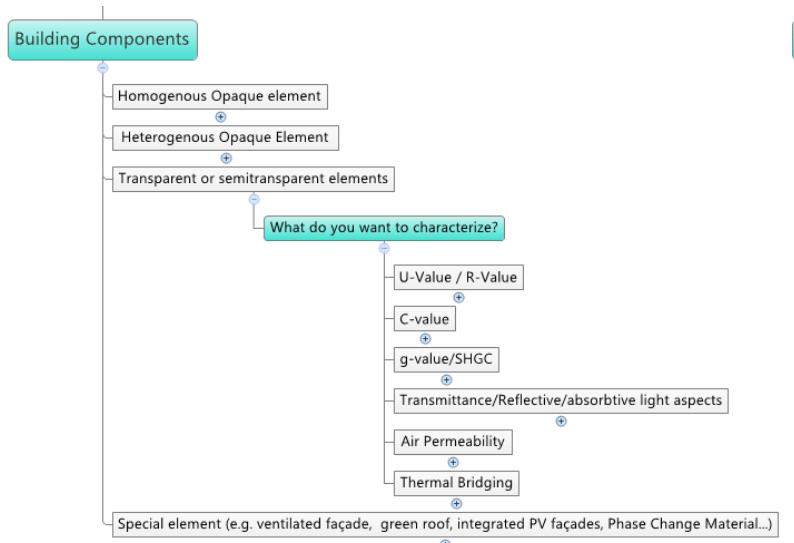
Figure 6.3: main levels inside the "Transparent or Semitransparent elements" branch.

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 6.4. The schematic on figure 6.4 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 (despite its "special element" nature) 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 hourly calculations during a whole year and based on the meteorological data available for the specific place where there is interest in 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.
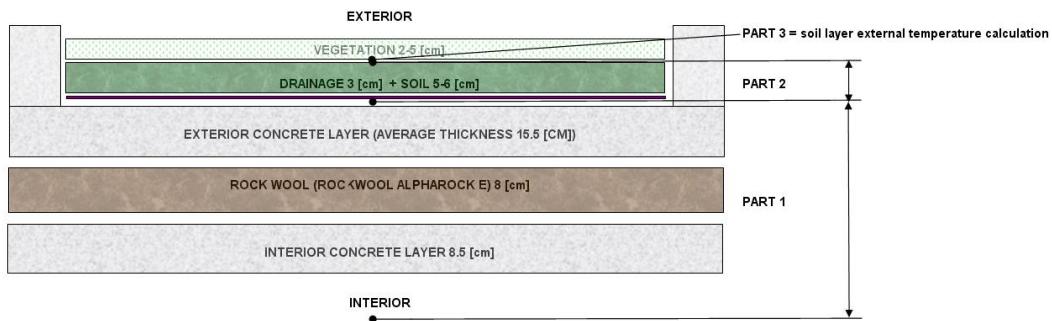
Figure 6.4: schematic of the possible green roof.

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 the characterization of the special process within 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 is presented. In figure 6.5 we would choose the "special" element choice and the question "Does the special component have a common construction part?" will appear.
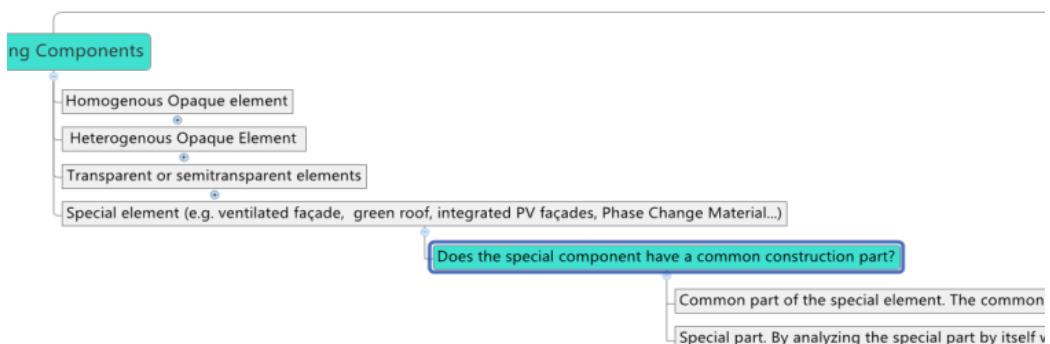
Figure 6.5: First question inside the "Special elements" main branch.

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In the above green roof schematic there was a "common" part and two "special" parts of the element. In figure 6.6 we would choose both options since there are both the special and the common part.
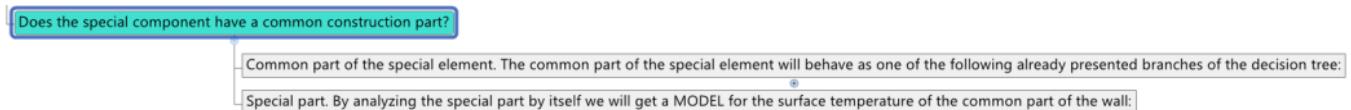
Figure 6.6: division of the special element into a "common" element and a "special" element.

Once both options are selected, we would obtain the figure 6.7 options. For the PART 1 of the figure 6.4 example we would choose the "heterogeneous Opaque element" of figure 6.7 to characterise this PART 1 of the whole green roof. Alternatively, the "evapotranspiration" branch would be used to characterize the PART 2 and PART 3 of the figure 6.4 example.
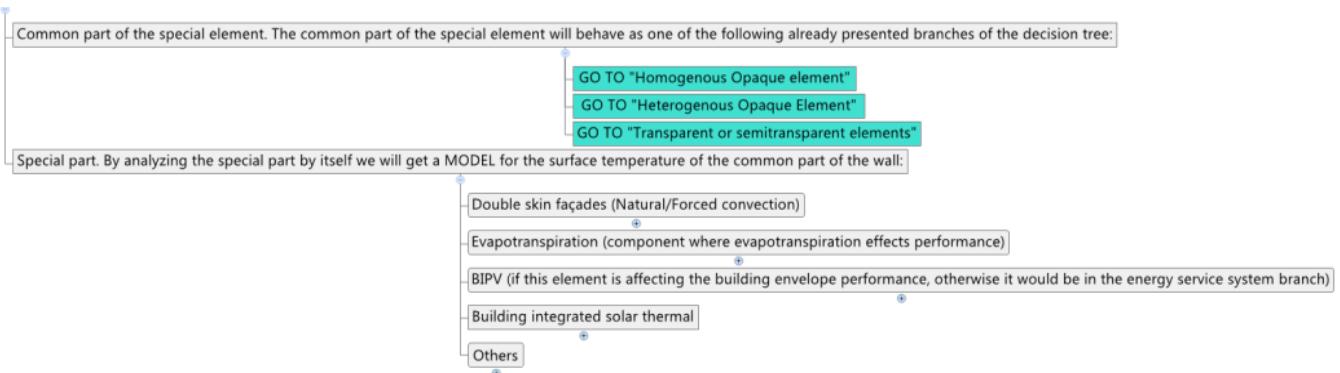
Figure 6.7: redirections to 'common' element and options inside the 'special' element.

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 6.4 example.
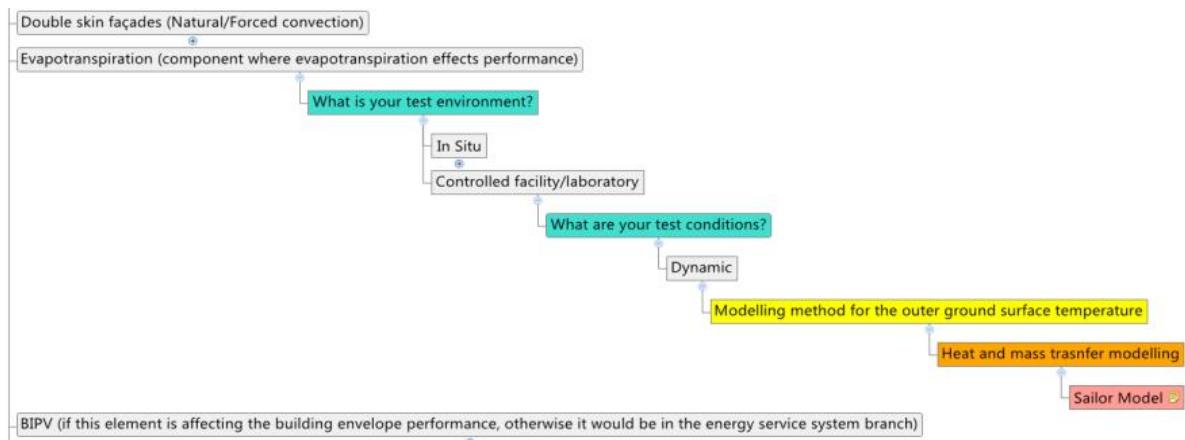
Figure 6.8: development of 'special' part of a green roof until an end branch.

6.2 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 figure 6.9, 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 Heat Loss Coefficient (HLC).
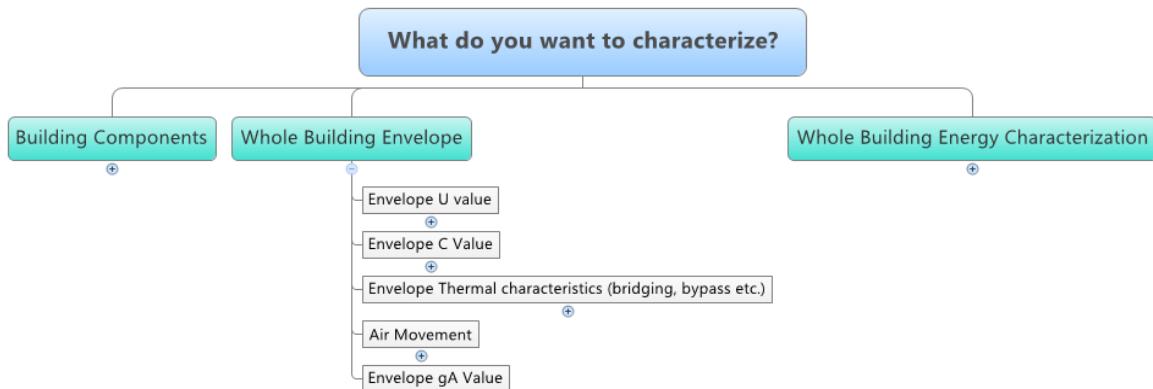

Figure 6.9: Main levels of 'whole building envelope' branch

Figure 6.10 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 full document to determine its usefulness for their purpose.
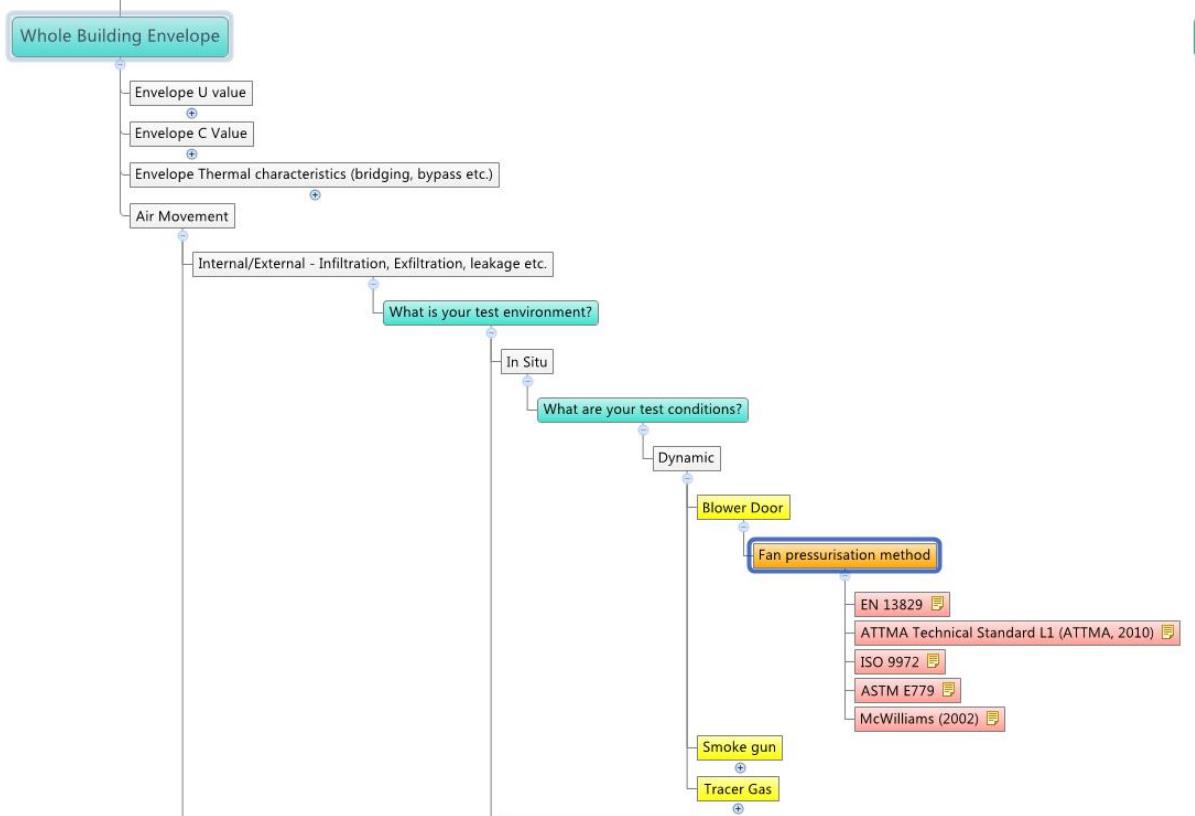
Figure 6.10: Example of process within whole building envelope branch

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 Quick U-value of Buildings (QUB) test. This is shown in figure 6.11.
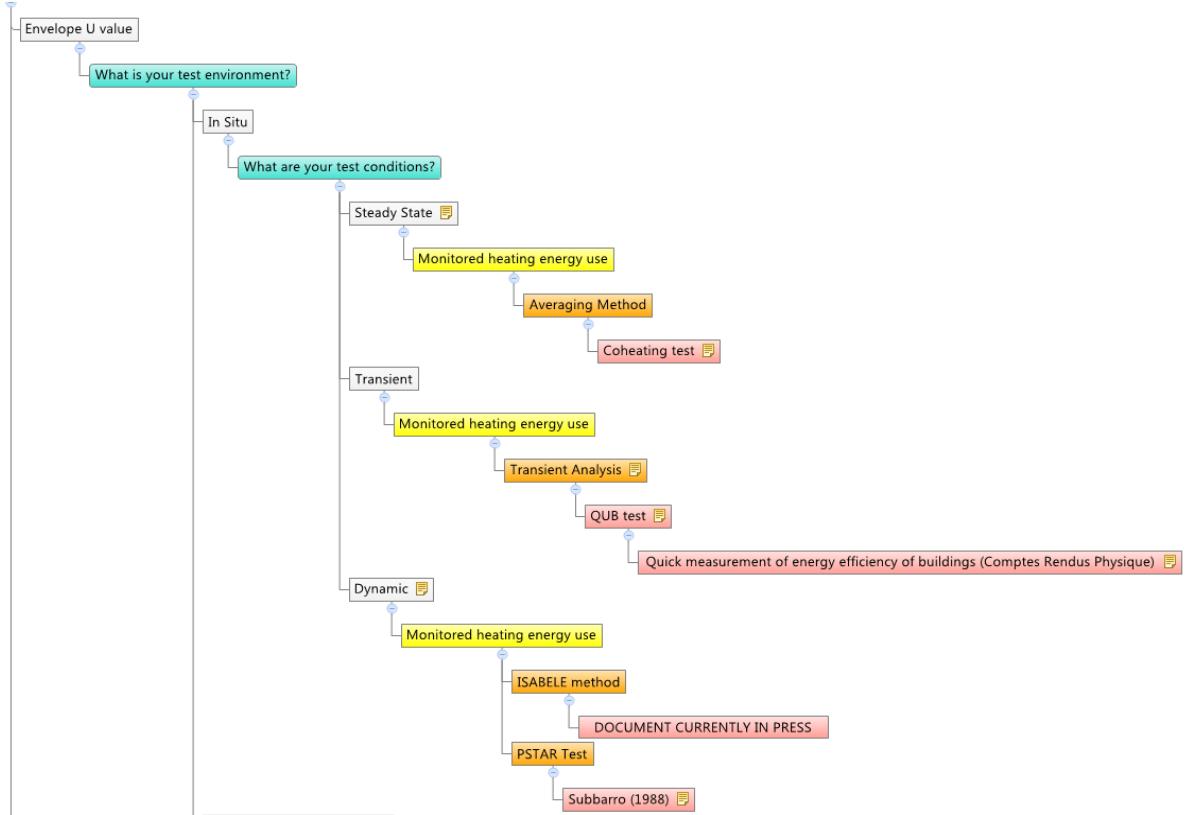
Figure 6.11: Whole envelope U value branch

6.3 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 and their interactions with the building elements.

This branch defines 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 understand occupancy at an early stage. This is shown in figure 6.12.
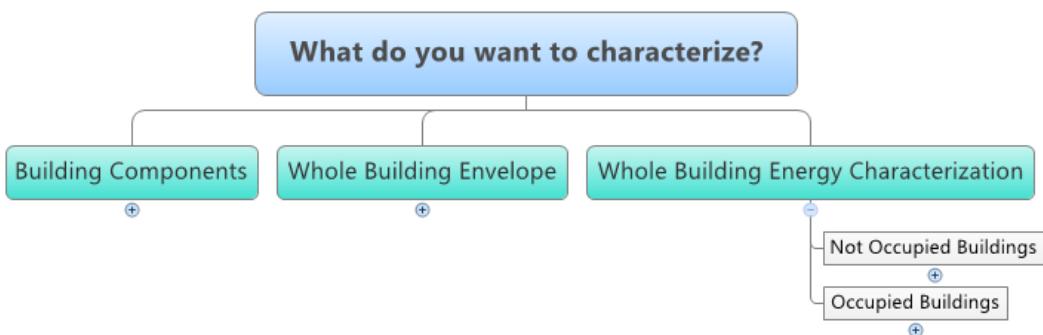

Figure 6.12: Main levels of 'whole building energy characterization' branch

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 6.13. 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.
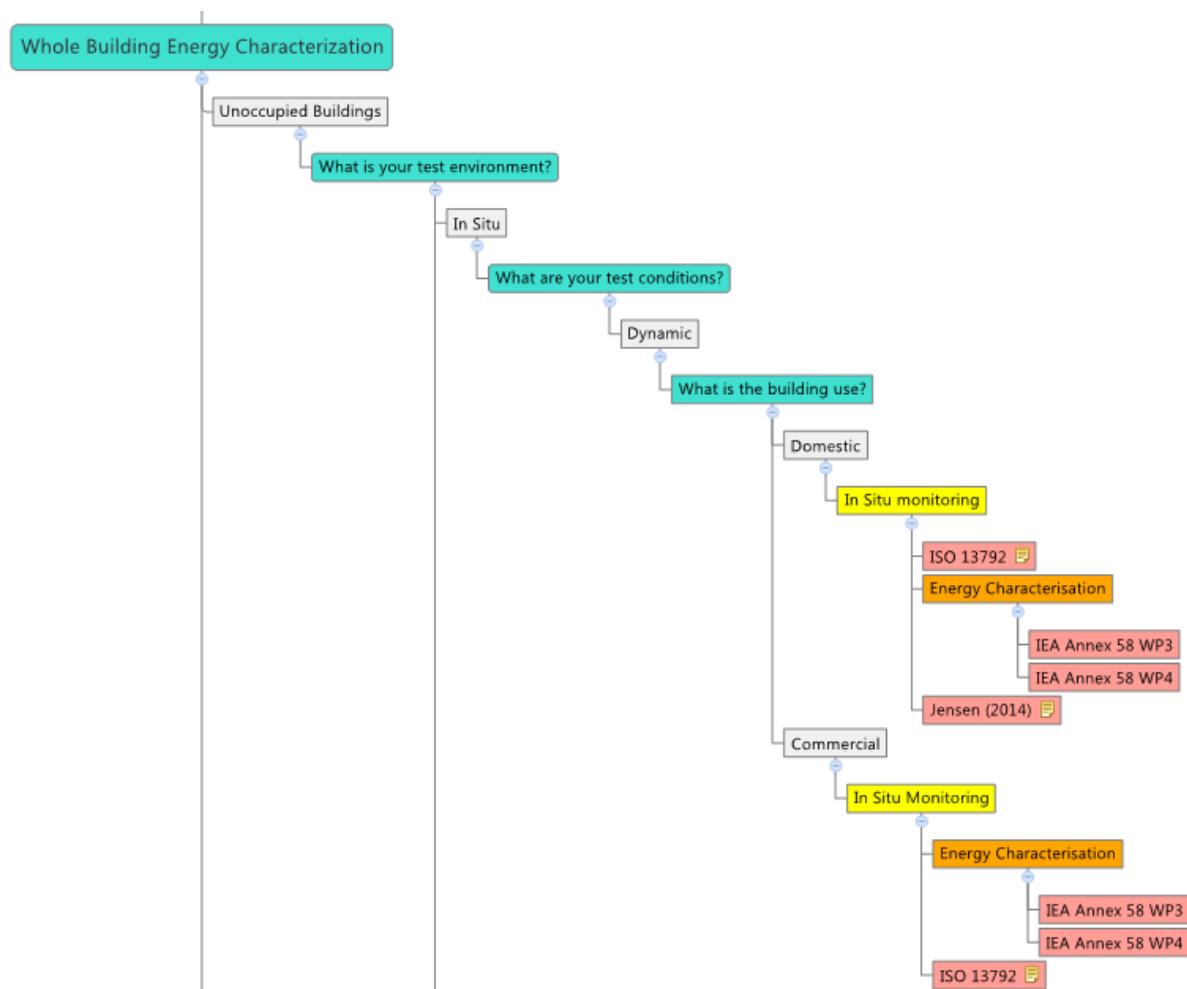

Figure 6.13: Example of whole building energy characterization branch

7. Summary of Subtask 2

Within Annex 58, the aim of Subtask 2 was to provide a roadmap tool to assist users from multiple backgrounds in the design, set-up and execution of in-situ building performance testing. The approach taken to achieve this aim was the development of a decision tree presenting the reliable methods used to measure the actual thermal performance of building components and whole buildings.

To assist the user, this broad topic was broken into sub-categories:

- Building Components
- Whole Building Envelope
- Whole Building Energy Characterization

These sub-categories were then expanded upon by presenting the user with questions to determine the nature of their research. The result of this filtering process was to present a relevant reference document which the user could access for detailed guidance on their specific research.

The decision tree will hopefully provide a valuable source of information for a range of potential users from both industry and academic backgrounds, and by following the guidance contained in the reference documents will assist in the capture of robust data sets.

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. The most recent version of the Decision Tree and the accompanying ReadMe companion document will be hosted at http://dynastee.info/ .