POLITECNICO DI MILANO

Dipartimento BEST

Scienza e Tecnologie dell'Ambiente Costruito

Building Environment Science & Technology

DOTTORATO DI RICERCA TEPAC

TECNOLOGIA e PROGETTO PER L'AMBIENTE COSTRUITO

Coordinatore del Dottorato: Anna Mangiarotti

XXIV ciclo

Chiara Ducoli, matr. 738767

ENERGY, MATERIAL, TIME

Retrofit strategies in a Life Cycle Assessment

2009-2011

RELATORI: Adriana Angelotti
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ABSTRACT

A ABSTRACT

In the contemporary scenario, the focus on the energy consumption in the use phase of buildings prevails over an interest concerning the environmental impacts linked to all the other phases of the construction process. The interest in reducing energy consumption during the use phase could lead to a shift of the environmental impacts from one stage to another, simply by spreading the total environmental load in a different way. Thus, it is clear the importance of combining the study of strategies to improve the energy efficiency in the use phase with life cycle assessments.

Starting from these issues, the aim of the research is to propose a methodology to assess the effects of retrofit strategies in the life cycle assessment. Particular emphasis will be given to the aspect of lifetime, of both buildings and materials, which play a key role since the choice of appropriate technology is strongly related to life expectancy and conditions of use of buildings.

The field of investigation is the building environment, which contributes significantly to the production of environmental impacts and energy consumption at a regional, national and global level.

The case study is a representative hall of the Milan Trade Fair, which presents several interesting characteristics such as the discontinuous use period during a year, the high values of the internal loads due to the relevant number of users and to the electric equipments and finally the significant internal height, that could lead to thermal stratifications.

SOMMARIO

Nello scenario contemporaneo l'interesse per la riduzione dei consumi energetici degli edifici legati alla fase d'uso tende a prevalere rispetto ad un interesse per gli impatti ambientali relativi a tutte le fasi del processo edilizio. Focalizzare le strategie di intervento solo su azioni finalizzate alla riduzione dei consumi in fase d'uso potrebbe portare ad uno spostamento degli impatti ambientali da una fase all'altra del processo edilizio, semplicemente ridistribuendo il carico ambientale complessivo. Emerge quindi l'importanza di abbinare lo studio di strategie per il miglioramento dell'efficienza energetica in fase d'uso a valutazioni ambientali nel ciclo di vita.

A partire da queste considerazioni, l'obiettivo della ricerca è l'elaborazione di una metodologia per valutare gli effetti di strategie di retrofit nel ciclo di vita. Particolare importanza viene data all'aspetto della durata della vita utile sia degli edifici e sia di materiali e componenti. Questo tema assume un ruolo chiave nella valutazione ambientale, poiché la scelta della tecnologia adeguata è fortemente relazionata all'aspettativa di vita e alle condizioni d'uso degli edifici.

Il campo di indagine della ricerca è il patrimonio edilizio esistente, che contribuisce significativamente alla produzione di impatti ambientali e consumi energetici a scala regionale, nazionale e globale.

Il caso studio oggetto d'analisi è un padiglione del Polo Fieristico di Rho Pero, complesso edilizio del settore terziario/commerciale. Questo padiglione è rappresentativo di una serie di criticità, tra le quali elevati valori di consumi energetici, elevato valore di energia incorporata, elevati valori di carichi interni dovuti al consistente numero di visitatori e alle apparecchiature elettriche, periodi di utilizzo discontinui durante l'anno e un'altezza netta interna significativa, che potrebbe portare a stratificazioni termiche interne.

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I INTRODUCTION

Up to now, literature has shown how the energy consumption during the use phase of a building (for heating and cooling) was so relevant that in a few years it exceed the energy spent for the construction of the building.

Since the new mandatory regulations on energy saving encourage the increasing of low-energy buildings, the construction phase has acquired a growing role: in view of these considerations, the embodied energy calculation can help to achieve an energy balance, comparing the energy saving in the use phase of low-energy buildings and the energy spent to realize the building.

Official statistics (ENEA, 2008) support the need for energy saving policies that incorporate the life cycle approach. In fact, the use of buildings in Italy roughly corresponds to 31% of the final energy use and greenhouse emissions throughout the country, but when the manufacturing of construction materials (cement, bricks, glass, ceramics, etc.) is included and when building activities are considered, the final energy use and greenhouse emissions rise to 37 and 41%, respectively.

Current regulations, economic and social sensitivity are increasing the interest in reducing energy consumption, in zero-emission buildings and passivhaus. The interest in reducing energy consumption during the use phase may lead to shift environmental impacts from one phase to another and from one kind of impact to another, simply by redistributing the total environmental load. The information extracted from environmental assessments on the life cycle can make the designers aware of all the environmental impacts related to the design choices and can support them in their decision making.

Starting from these considerations, the focus of the thesis concerns the strategies to reduce energy consumption in the use phase and the assessment of the environmental impacts of these strategies in the life cycle.

The aim of the research is to suggest a methodology to assess the effects of retrofit strategies in a life cycle assessment. The analysis is based on the relationship between the energy saving got in the use phase and the environmental impacts in the life cycle. It has been carried out through the dynamic simulation of a case study and the assessment of the energy spent in the other phases of the life cycle. The case study is an exhibition building, a “sample hall” in the Milan trade fair, a particular building type with some features, such as the discontinuous use period during a year, the high values of the internal loads due to the relevant number of users and to the electric equipments and finally the significant internal height, that could lead to thermal stratifications.

The research is organized in a theoretical part (chapters 1 and 2), in an experimental one (chapter 3, 4, 5) and finally in a propositive part (chapter 6).

Chapter 1 deals with an analysis of the meaning of the simulation and its declination in architecture, with some reflections about the building performance simulation, the simulation methods and the role of the architect within the simulation process and in the decision making.

Chapter 2 investigates the relationship between the study of strategies aimed at reducing the energy consumption in the use phase and the assessment of the environmental impacts of these strategies in the life cycle. A focus is made on the uncertainties linked to the LCA and to their management. At last, some consideration concerning three main issues: lifetime of buildings and materials, optimization of products and materials, use intensity of spaces.

Chapter 3 introduces the tools that will be used in the analysis, the application, limits and potential.

Chapter 4 deals with the analysis of the energy performance of the envelope of a building. The analysis is carried out through a dynamic energy simulation model, a “sample exhibition hall” was modeled, calibrated and simulated during a year, considering a typical annual schedule. Different strategies were simulated, considering both energy retrofit solutions on the envelope and system management strategies. Then, a simple economical evaluation was implemented to verify the payback times.

Chapter 5 starts analyzing the solutions of energy savings in a life cycle assessment to see the relationship between the benefits got in the use phase and the environmental impacts developed during all the life cycle. Besides, the embodied energy of the representative hall and other environmental impacts were calculated and compared to the energy consumption in the use phase considering different temporal scenario. Finally, a proposal for a building envelope redesign was suggested to reduce both the value of embodied energy and the energy consumption.

Lastly, chapter 6 suggests a general methodology to assess the effects of retrofit strategies during the life cycle that could lead to define a dashboard to support the designer’s decision.

I INTRODUZIONE

Fino ad oggi la letteratura scientifica ha messo in evidenza come i consumi energetici di un edificio in fase d'uso dovuti alla climatizzazione siano così rilevanti che in pochi anni possono eguagliare l'energia spesa per la sua costruzione.

Dal momento in cui sono cominciati ad affermarsi edifici a basso consumo energetico, la cui costruzione è sollecitata e incentivata dalle recenti normative sul risparmio energetico, l'energia spesa per la fase di costruzione ha acquisito un ruolo sempre più importante. A fronte di queste considerazioni, la stima dell'energia incorporata può essere utile per realizzare un bilancio energetico complessivo che metta a confronto l'energia risparmiata in fase d'uso e l'energia spesa in fase di realizzazione dell'edificio.

Statistiche ufficiali (ENEA, 2008) sostengono la necessità di politiche indirizzate al risparmio energetico che tengano contemporaneamente conto anche dell'approccio "life cycle". Infatti, in Italia, l'energia spesa in fase d'uso dagli edifici ammonta a circa il 31% del consumo finale di energia e di emissioni di anidride carbonica ma se si considera anche la produzione dei materiali da costruzione e le attività necessarie, si passa rispettivamente al 37% riguardo il consumo finale di energia e al 41% riguardo le emissioni.

Normative vigenti e una crescente sensibilità sociale tendono a far prevalere un interesse legato alla riduzione dei consumi energetici in fase d'uso. Focalizzare le strategie di intervento solo su azioni finalizzate alla riduzione dei consumi in fase d'uso potrebbe portare tuttavia ad uno spostamento degli impatti ambientali da una fase all'altra del processo edilizio semplicemente ridistribuendo il carico ambientale complessivo; le indicazioni estraibili da valutazioni ambientali sul ciclo di vita, invece, possono rendere consapevole il progettista di tutte le ricadute ambientali relative alle proprie scelte progettuali e supportarlo nella decisione della strategia da adottare.

A partire da queste considerazioni, l'interesse centrale della tesi è legato alle strategie per la riduzione dei consumi energetici in fase d'uso e alla valutazione degli impatti ambientali che esse producono nel ciclo di vita.

L'obiettivo della ricerca è l'elaborazione di una metodologia per la valutazione degli effetti di strategie di retrofit nel ciclo di vita. L'analisi è basata sul rapporto tra i risparmi energetici ottenuti in fase d'uso e gli impatti ambientali prodotti nel ciclo di vita ed è stata effettuata tramite la simulazione a regime dinamico di un caso studio e la successiva valutazione dell'energia spesa nelle altre fasi del ciclo di vita. Il caso studio è un padiglione del Polo Fieristico di Rho Pero, complesso edilizio del settore terziario/commerciale. Questo padiglione è rappresentativo di una serie di criticità, tra le quali elevati valori di consumi energetici, elevato valore di energia incorporata, elevati valori di carichi interni dovuti al consistente numero di visitatori e alle apparecchiature elettriche, periodi di utilizzo discontinui durante l'anno e un'altezza netta interna significativa.

La ricerca è organizzata in una parte teorica (capitoli 1 e 2), in una parte sperimentale (capitoli 3, 4 e 5) e infine in una parte propositiva (capitolo 6).

Il capitolo 1 riguarda l'analisi del significato di simulazione e delle sue declinazioni in ambito architettonico, con alcune riflessioni riguardo la simulazione delle prestazioni degli edifici, i metodi di simulazione e il ruolo dell'architetto all'interno del processo di simulazione e di decisione.

Il capitolo 2 indaga le relazioni che intercorrono tra i risparmi energetici in fase d'uso ottenibili grazie all'attuazione di strategie di retrofit e gli impatti ambientali che queste strategie producono nel ciclo di vita. Particolare attenzione è stata data al tema dell'incertezza e ai metodi di gestione dell'incertezza nella valutazione LCA. Infine, alcune considerazioni riguardo tre questioni: la durata di vita di edifici e materiali, l'ottimizzazione di prodotti e materiali, l'intensità d'uso degli spazi.

Il capitolo 3 introduce gli strumenti che verranno utilizzati nell'analisi, la loro applicazione in relazione al contesto in esame, i loro limiti e le loro potenzialità.

Il capitolo 4 riguarda l'analisi delle prestazioni energetiche dell'involucro di un caso studio, effettuata tramite l'elaborazione di un modello di simulazione a regime dinamico precedentemente calibrato. Sono state studiate e simulate diverse strategie di riqualificazione energetica cercando di migliorare da un lato le prestazioni dell'involucro e dall'altro la gestione degli impianti. Infine è stata effettuata una valutazione economica per verificare i tempi di ritorno degli investimenti.

Il capitolo 5 è finalizzato all'analisi delle strategie di retrofit nel ciclo di vita confrontando i benefici ottenuti in fase d'uso e gli impatti prodotti nel ciclo di vita. E' stata calcolata l'energia incorporata del padiglione ed è stata confrontata con l'energia consumata in fase d'uso considerando diversi scenari temporali. Successivamente, è stata elaborata una proposta di riprogettazione del padiglione al fine di ridurre sia i consumi energetici in uso e sia l'energia incorporata.

Infine, il capitolo 6 propone una metodologia generale per la valutazione di strategie di riqualificazione energetica nel ciclo di vita, che potrebbe portare a definire un cruscotto decisionale a supporto delle decisioni del progettista.

P1

PART 1

THEORETICAL GROUNDS: SIMULATION AND LIFE CYCLE ASSESSMENT IN THE DECISION MAKING

1 Simulation, Assessment, Decision making

1.1. BACKGROUND TO SIMULATION

This chapter deals with the topic of simulation, the central issue of this research. The aim is to provide a theoretical framework to the next experimental section, which uses simulation as a tool to assess or verify different retrofit strategies in the decision making. Thus, to start, it is necessary to clarify the meaning of some of the main keywords that will be used, such as simulation, model and system.

Different definitions of the term simulation have been proposed[1]. A definition of simulation synthesized from relevant literature describes it as “a virtual experiment that involves the reproduction of the physical behaviour of a system to create a virtual abstracted equivalent behavioral model of the building and provide transient simulations of energy transfers within it” (Wilde, 2004; Augenbroe, 2002; Morbitzer, 2003).[2]

Simulation can therefore in general be considered an analytical and predictive process that attempts to emulate future reality of the behaviour of a building (Hensen, 1994).

Shannon (1998), in the paper “Introduction to the art and science of Simulation”, defines simulation as “the process of designing a model of a real system and conducting

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[1] Different authors have dealt with topic of simulation; the following are some suggested references, intended to deepen the issue:

Banks J. (1998), *Handbook of Simulation: Principles, Methodology, Advances, Applications, and Practice,* John Wiley, New York.

Baudrillard J. (1994), *Simulacra and Simulation*, University of Michigan Press, Ann Arbor, MI.

Bennett B. (1995), Simulation Fundamentals, Hertfordshire, Prentice Hall.

Gardner F. and Baker J. (1996), *Simulation Techniques*, Wiley, London.

Guba E.G. and Lincoln, Y.S. (1989), *Fourth Generation Evaluation*, Sage, Newbury Park, CA, pp. 236–243.

[2] As rightly expresses in the article “Predicted building performance: the ethics of computer simulation” (Williamson, 2010), to fully understand the meaning of simulation, it is necessary to know that there are different ontological positions about the nature of the world and different epistemological beliefs about the nature of knowledge and about the possibility to know the world. The following is a brief summary of the main historical currents of thought regarding these issues. The simulation is steeped in an empiricist/positivist tradition which believes that the external world is essentially knowable and that it is possible to discover the true nature of external reality through the application of the methods of science. Therefore, the simulation is a tool to get closer to the external reality. Knowledge is thus the representation of what there is in the external reality today and in the future. A post-modern tradition believes that there is no possibility of theory without foundational knowledge and no special epistemic privilege can be attached to any particular method. Similarly, no external referent that would allow to adjudicate different knowledge is available. In a constructivist view, the knowledge of the external world is temporary and it depends on the context: there are some different subjective constructions of reality produced by different individuals. Therefore, shared knowledge is acknowledged as a social and historical product. These views have significant implications for thinking about and assessing the use of performance simulation to inform the design. That is, the truth of a matter is what a group has worked out from within; it is not relative to any truth that is “out there” in an epistemological or metaphysical “reality”. Accordingly, a project to assess the appropriate truth of simulation could begin with criteria that a reflective judge could use.

experiments with this model for the purpose of understanding the behavior of the system and/or evaluating various strategies for the operation of the system".

Another possible definition, suggested by Williamson (2010) in "Predicting building performance: the ethics of computer simulation", could be "the science of estimating future states of single or multiple physical phenomena within an existing or proposed built environment".

The terms *model* and *system* are the key words of the definition of simulation:

- *Model* means a representation of a group of objects or ideas in some form other than they really are; a model could also be a simplified representation of a system at some particular point in time or space intended to promote understanding of the real system itself. *Modeling* can be described as the process of developing a model that faithfully represents a complex system (Hensen, 1994), of which buildings are one type. A classification scheme for models proposed by Page distinguishes various dimensions of characterization and accordingly lists several typologies which are listed in the following table (Page, 1994).

Table 1-1. Model typology classification scheme (source: Page, 1994)

DIMENSION OF CHARACTERIZATION	TYPE	DESCRIPTION
A MODEL REPRESENTATION	ABSTRACT MODEL	THE MODEL IS REPRESENTED THROUGH SYMBOLS. THIS MAY EITHER INVOLVE A VERBAL/WRITTEN DESCRIPTION OR A MATHEMATICAL MODEL THAT IS DESCRIBED IN THE SYMBOLOGY OF MATHEMATICS.
	PHISICAL MODEL	THIS USES SCALED REPLICA REPRESENTATIONS OF THE SYSTEM AND MAY ALSO BE REFERRED TO AS AN ICONIC MODEL.
THE STUDY OBJECTIVE UNDERLYING THE MODEL	DESCRIPTIVE MODEL	DESCRIBES THE BEHAVIOUR OF A SYSTEM WITHOUT ANY VALUE JUDGEMENT ON THE QUALITY OF SUCH BEHAVIOUR.
	NORMATIVE MODEL	DESCRIBES THE BEHAVIOUR OF A SYSTEM IN TERMS OF THE QUALITY OF SUCH BEHAVIOUR. WHEN SOLVED, THESE MODELS PROVIDE A DESCRIPTION OF THE SOLUTION AS OPTIMAL, SUBOPTIMAL, FEASIBLE, INFEASIBLE...ETC.
TEMPORAL PROPERTIES IN THE MODEL	STATIC MODEL	DESCRIBES RELATIONSHIPS THAT DO NOT CHANGE WITH RESPECT TO TIME AND MAY BE EITHER ABSTRACT OR PHYSICAL.
	DYNAMIC MODEL	DESCRIBES TIME-VARYING RELATIONSHIPS.
THE SOLUTION TECHNIQUE	ANALYTICAL MODEL	PROVIDES CLOSED-FORM SOLUTIONS USING FORMAL REASONING TECHNIQUES, SUCH AS MATHEMATICAL DEDUCTION.
	NUMERICAL MODEL	SOLVED BY APPLYING COMPUTATIONAL PROCEDURES, MAY ALSO BE REFERRED TO COMPUTATIONAL/MATHEMATICAL MODELS.

- *System* means a group or collection of interrelated elements that cooperate to accomplish some stated objective; a system exists and operates in time and space[3]. A system can also be defined as a structured set of related and have the

[3] To study in deep the concept of “model” and “system”, it is suggested:

Bossel H. (1994), *Modeling and Simulation*, Wellesley, A.K. Peters.

Ciribini, G. (1979), *Introduzione alla tecnologia del design. Metodi e strumenti logici per la progettazione dell’ambiente costruito*, Franco Angeli, Milano.

Ciribini, G. (1984), *Tecnologia e progetto*, Celid, Torino.

Cloud D. J. and Rainey L. B. (1998), *Applied Modeling and Simulation: an integrated approach to development and opaeration*, McGraw-Hill, New York.

Law A. L. and D. W. Kelton, (2000), *Simulation Modeling and Analysis*, 3rd Edition, McGraw-Hill, Boston, MA.

Nelson B., *Stochastic Modeling: Analysis & Simulation*, McGraw-Hill, New York.

Morin E. (2007), *Il metodo (3), la conoscenza della conoscenza*, Cortina Raffaello, Milano.

Morin E. (1993), *Introduzione al pensiero complesso, gli strumenti per affrontare la sfida della complessità*, Sperling & Kupfer, Milano.

property of being analyzed considering structured sets of lower order (Ciribini, 1979). The analysis of the systems consists in the study of the structure and behavior of sets of interacting elements. The elements and their interactions can be essentially abstract, as in mathematical representations, or solid, as in astronomy or in communication systems.

Modeling and simulation are the practice to develop a level of understanding of the interaction of the parts of a system, and of the system as a whole.

A system is understood to be an entity which maintains its existence through the interaction of its parts. A model is a simplified representation of the actual system intended to promote understanding[4].

Whether a model is a good model or not depends on the extent to which it promotes understanding. Since all models are simplifications of reality there is always a trade-off as to what level of detail is included in the model. If too little detail is included in the model, it is possible to run the risk of missing relevant interactions and the resultant model does not promote understanding. If too many details are included in the model the model may become overly complicated and actually preclude the development of understanding[5]. Thus it is necessary to follow different steps: to develop a model, to simulate it, to learn

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Page E. (1994), *Simulation Modelling Methodology: Principles and Etiology of Decision Support*, PhD Thesis, Virginia Tech, Virginia, USA,

Rubinstein R. and Melamed B. (1998), *Modern Simulation and Modeling*, Wiley, New York.

Senge P. M. (1990), *The Fifth Discipline: The Art & Practice of The Learning Organization*, Currency Doubleday, New York.

Severance F. (2001), *System Modeling and Simulation: An Introduction*, Wiley, New York.

Xu X., Wnag J., Ma Y. (2008), "An Exploration on the Simulation System Theory of the Discipline of Simulation Science and Technology", *Proceedings of the 2008 Asia Simulation Conference — 7th Intl. Conf. on Sys. Simulation and Scientific Computing.*

Zeigler B., Praehofer H., Kim T. G. (2000), *Theory of Modeling and Simulation: integrated discrete event and continuous complex dynamic systems*, Academic Press, Boston.

[4] In this PhD thesis, model and system are the main keywords. The energy and environmental analysis is based on a case study. Thus, the system is the building that has to be analyzed and the model is the simplified representation of the system, on which the energy analysis is made. Processing and developing the model, it has been possible to better understand the complexity of the system and to reproduce, through the simulation, its behavior (see Chapter 4, Paragraph 4.2).

[5] In this PhD thesis the model presents some simplifications. For example the geometry of the analyzed building has been redesigned because of its complexity, that has caused some interface problems between different software. Moreover, the modeling of the heating and cooling systems has been simplified by entering an ideal system able to satisfy the indoor comfort condition imposed by the user. On the other hand, considering the data essential for the aim of the research, the level of detail has been very high: for example all the envelope has been described in a thermal-phisical level considering all the specific features of the real materials of the envelope; internal loads have been described in an hourly step and so on. What needs to be considered is that all these simplifications that have been made are not in contrast with the final goal, indeed they can be considered useful because they allow to overlook to many details not relevant for the purpose of the work (see Chapter 4, Paragraph 4.2).

from the simulation, to revise the model and to continue the iterations until an adequate level of understanding is developed, depending on its complexity.

Peter Senge, in “The Fifth Discipline: The Art & Practice of the Learning Organization” talks about two types of complexity, detail and dynamic. Detail complexity is associated with systems which have many component parts. Dynamic complexity is associated with systems which have cause and effect separated by time and or space. The understanding is that it is dynamic complexity that we have great difficulty dealing with because we are unable to readily see the connections between the parts of the system and their interactions. One of the great values of simulation is its ability to effect a time and space compression on the system, essentially allowing one to perceive, in a matter of minutes, interactions that would normally unfold over very lengthy time periods.

Thus, the underlying purpose of simulation is to shed light on the underlying mechanisms that control the behavior of a system. Perhaps most importantly, simulation should be used when the system under consideration has complex interactions and requires the input from multiple disciplines. In this case, it is difficult for any one person to easily understand the system. A simulation model can act as the framework to integrate the various components in order to better understand their interactions. As such, it becomes a management tool that keeps you focused on the “big picture” without getting lost in unimportant details.

That is, simulation can be used to predict the way in which the system will evolve and respond to its surroundings, so that you can identify any necessary changes that will help make the system perform the way that you want it to.

Simulation is a decision analysis and a support tool. Simulation allows to evaluate, compare and optimize alternative designs, plans and policies. As such, it provides a tool for explaining and defending decisions to various stakeholders.

Simulation should be used when the consequences of a proposed action, plan or design cannot be directly and immediately observed (i.e., the consequences are delayed in time and/or dispersed in space) and/or it is simply impractical to test the alternatives directly: it provides a way in which alternative designs, plans and/or policies can be evaluated without having to experiment on a real system, which may be prohibitively costly, time-consuming or simply impractical to do. That is, it allows to ask “what if?” questions about a system without having to experiment on the actual system itself.

1.1.1. ADDRESSING RISK AND UNCERTAINTY: DETERMINISTIC AND PROBABILISTIC SIMULATIONS

Although simulation can be a valuable tool to better understand the underlying mechanisms that control the behavior of a system, it could be difficult to use simulation to make predictions of the future behavior of a system[6]. This is because, for most real world systems, at least some of the controlling parameters, processes and events are often stochastic, uncertain and/or poorly understood[7].

The objective of many simulations is to identify and quantify the risks associated with a particular option, plan or design. To simulate a system considering uncertainties means the estimation of risks that have to be calculated.

There are two main approaches to simulation[8]:

- *Deterministic approach*. In a deterministic simulation, the input parameters for a model are represented using single values (which typically are described either as "the best guess" or "worst case" values). This kind of simulation, while it may provide some insight into the underlying mechanisms, cannot quantitatively address the risks and uncertainties that are inherently present.
- *Probabilistic approach*. Probabilistic simulation is the process of explicitly representing these uncertainties by specifying inputs as probability distributions. If the inputs describing a system are uncertain, the prediction of future performance

[6] To know more about the theme of simulation, uncertainties and predictions, some references are suggested:
Dorini G., Kapelan Z., Azapagic A. (2010), "Managing uncertainty in multiple-criteria decision making related to sustainability assessment", *Clean Technologies and Environmental Policy 2011*, v. 13, n. 1, pp. 133-139.
Evans J. and Olson D. (2002), *Introduction to Simulation and Risk Analysis*, Prentice Hall, NJ.
Kleijnen,J.P.C. (1974), *Statistical Techniques in Simulation, Part I*, Marcel Dekker, New York.
Liu D., Wang Q., Xiao J. (2009), "The Role of Software Process Simulation Modeling in Software Risk Management: a Systematic Review", *Proceeding of the 3thInternational Symposium on Empirical Software Engineering and Measurement*, pp. 302-311.
Matloff N. (1988), *Probability Modelling and Computer Simulation*, PWS-Kent pub. Co., Boston.
Raisnen J. and Palmer T.N. (2001) "A probability and decision model analysis of a multimodel ensemble of climate change simulations", *Journal of Climate 14*, pp. 3212–3226.
Rorty R. (1991), *Objectivity, Relativism, and Truth*, Cambridge University Press, Cambridge.
Smithson, M. (1989) *Ignorance and Uncertainty: Emerging Paradigms*, Springer, New York.
Strauch R. (1974), *Squishy Problems and Quantitative Methods, The Rand Corporation*, available at: http://www.rand.org/pubs/papers/2006/P5303.pdf.
[7] The issue about the authenticity of the input data is very relevant. In this analysis not all the data needed by the simulation software were available or reliable, for example some information about the features of the materials of the building or some others about the air change per hour due to natural infiltration and ventilation. What is important is to declare it and to assume reasonable values taken from literature and/or regulations.
[8] Relevant readings on deterministic and probabilistic approaches:
Danesh I. (1989), "Deterministic Simulation versus Probabilistic Simulation Approaches to Scientific Educational Problem Solving", *Journal of Computers in Mathematics and Science Teaching*, v.8 n.4, pp. 64-72.
Mavris D. M., Bandte O. (1997), "A Probabilistic Approach to Multivariate Constrained Robust Design Simulation", *presented at the 2nd World Aviation Congress and Exposition*, Anaheim, CA, October 13-16.

> is necessarily uncertain. That is, the result of any analysis based on inputs represented by probability distributions is itself a probability distribution. Hence, whereas the result of a deterministic simulation of an uncertain system is a qualified statement the result of a probabilistic simulation of such a system is a quantified probability. In order to compute the probability distribution of predicted performance, it is necessary to propagate the input uncertainties into uncertainties in the results. A variety of methods exist for propagating uncertainty. One common technique for propagating the uncertainty in the various aspects of a system to the predicted performance is Monte Carlo simulation.

Nowadays public discussions, policy decisions and scientific results are frequently based on deterministic analysis and without explicit evaluation of the uncertainties involved.

1.1.2. THE SIMULATION PROCESS

The simulation could follow different ways, also depending on the finality of the analysis[9]. Below, some of the main steps which should be present in any simulation study are collected:

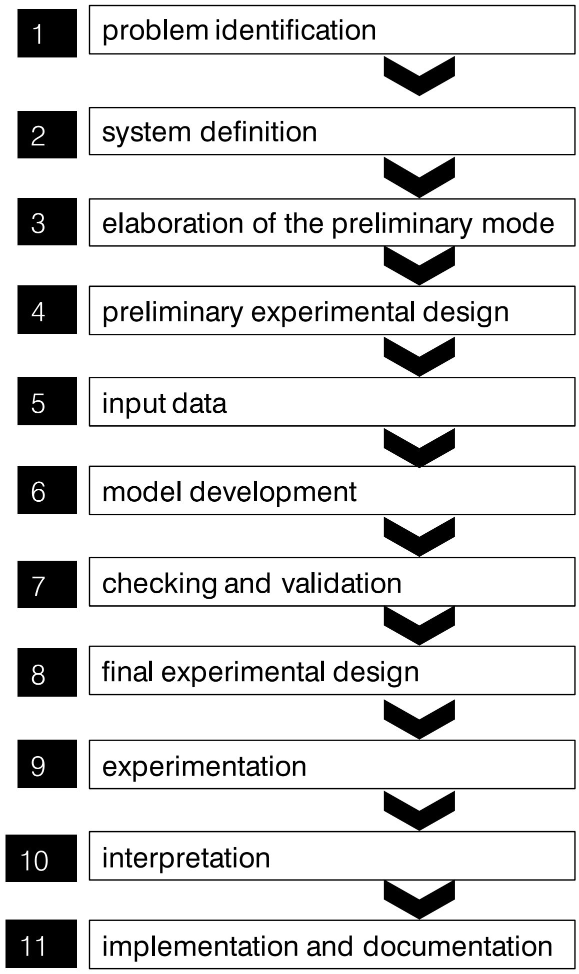

Figure 1-1. The main steps of the simulation process.

Each step consists of the following actions:

1. *problem identification*: identification of the aims of the analysis;
2. *system definition:* determination of the boundaries to be used in defining the system and survey on how the system runs;

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[9] Suggested reading:
Yi J. J. and Lilja D. J. (2006), "Simulation of computer architectures: simulators, benchmarks, methodologies, and recommendations", *IEEE transactions on computers*, v. 55, n. 3.

3. *elaboration of the preliminary mode:* develop of a preliminary model to define the components, the variables, and the interactions within the system;
4. *preliminary experimental design*: selection of the data that need to be gathered from the model, in what form, and to what extent;
5. *input data:* identification and collection of the input data needed by the model;
6. *model development:* process of the model in an appropriate simulation language;
7. *checking and validation:* attestation that the model operates in the correct way and that the output of the model is believable and representative of the output of the real system;
8. *final experimental design:* design of an experiment that will yield the desired information and determining how each of the test runs specified in the experimental design is to be executed;
9. *experimentation:* executing the simulation to obtain the required data;
10. *interpretation*: analysis of the output data;
11. *implementation and documentation*: reporting the results, putting the results to use, recording the findings, and documenting the model and its use.

In the simulation it is possible to acknowledge a great number of advantages over analytical or mathematical models for analyzing systems. First of all, a simulation model could be more realistic because its behavior has been compared to the one of the real system.

Besides, it is possible to obtain some information about how a modeled system actually works to understand which variables are most important.

Simulation tools also allow to test new designs without committing resources to their implementation; they let to test hypothesis about how or why certain phenomena occur in the system. Another important advantage is that simulation allows to control time: thus it is possible to operate the system for several months or years of experience in few seconds allowing to quickly look at long time horizons or we can slow down phenomena for study.

Even though simulation has many strengths and advantages, it is not without drawbacks. First of all it is evident that simulation modeling is a practice that requires specialized training and therefore skill levels of practitioners vary widely. Moreover, gathering highly reliable input data can be time consuming and the resulting data is sometimes highly questionable. Simulation cannot compensate for inadequate data or poor management decisions[10].

Finally, simulation models are input-output models, i.e. they yield the probable output of a system for a given input. They do not yield an optimal solution, rather they serve as a tool for analysis of the behavior of a system under conditions specified by the experimenter.

1.2. THE ASSESSMENT OF SIMULATION

1.2.1. THE CRITERIA FOR A QUALITATIVE EVALUATION OF THE SIMULATION

One of the principal benefits of using a model to replicate a process is that it is possible to begin with a simple approximation of the process and gradually refine it as understanding of the process improves. This stepwise evolution with systematic variation of parameters to find out the most important factors enables us to achieve good approximations of very complex problems surprisingly quickly. As refinements are added, the model becomes more and more accurate. At this point, the question that arises is the degree to which it is necessary to go to get an accurate simulation with acceptable results. To be able to assess different design alternatives, it is evident that in the simulation process all the simulation criteria must be declared, in order to better understand if the final results are reliable or not.

The critical aspect in the design - but also in the operational phase of a building, when renovation or retrofit actions are needed - is the evaluation and adjustment of the alternative strategies based on a set of criteria such as energy consumption, environmental performance, investment cost, operational cost, indoor environment quality, security, social factors... Examining the literature on methods of enquiry, it becomes clear that views about the criteria to judge the built environment performance simulation will be heavily influenced by the assumptions of the person making the judgment. It is evident that these paradigms and assumptions influence which particular principles and criteria are favored in making decision.

The criteria for “trustworthiness” for qualitative evaluations are credibility, transferability, dependability and confirmability (Guba and Lincoln, 1989)[11]:

[10] The importance to have adequacy data in the simulation process is evident is the aim of this thesis is to reproduce the behavior of a system. For example in the energy simulation the basic weather file inserted as input in the software is relative to the area of Milan-Linate; in order to make a more refined calibration, the file has been integrated with data retrieved from the Meteorological Center Lombard related to Rho, the place where the analyzed building is located. Running the simulation with the default weather file or with the modified file, the results obtained are heavily different.

Credibility and absence

Credibility is related to how the simulation fits the realities and to the views the participants express in the process of the inquiry. The credibility of an application of simulation will be derived by reference to an appropriate authority to establish the match between the constructed realities of the simulation and those realities that will be the built environment in the real world. Credibility will be lacking when some key elements of a problem definition are missing or when a simulation tool is use inappropriately.

Transferability and confusion.

Transferability refers to the possibility that what was found in one context by a simulation is applicable to another context. Transferability is the use of simulation results beyond the intended range of contexts (explicit or implicit), or the application of aspects beyond the proposed scope of the underlying analytical model. Key questions on transferability therefore include the extent to which authoritative knowledge should be scientific, to the exclusion of other forms of knowledge, and related to this, the problem of how to bring together different knowledge into a coherent decision-making rationality. Because of distortion in the use of the simulation results, significant resources may well be expended without achieving the desired aim.

Dependability and uncertainty.

Dependability relates to the uncertainties in using simulation results. It depends on how the changing conditions of the phenomena simulated are taken into account, as well as how changes in the design (created by an increasingly refined understanding of the setting) are handled[12].

Confirmability and inaccuracy.

Confirmability is concerned with the constructions, assumptions, and facts (data) behind a simulation model and the possibility to use the model to draw general conclusions[13].

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[11] To study in deep this item it is suggested the reading of:
Guba E.G. and Lincoln, Y.S. (1989), *Fourth Generation Evaluation*, Sage, Newbury Park, CA, pp. 236–243.
Heap J. L. (1995), “Constructionism in the rhetoric and practice of fourth generation evaluation”, *Evaluation and Program Planning*, v. 18, n. 1, USA, Pergamon, pp. 51-61,
Williamson T. J. (2010), “Predicting building performance: the ethics of computer simulation”, *Building Research & Information 38:4*, pp. 401-410.

[12] In this PhD thesis, as the model is a simplification of the real system, the results of the energy simulation are related to the detail level that has been considered. Of course if the model will be refined, the results could change. What is important is to take into account all the assumptions and simplifications that have been considered in the construction of the model.

[13] In this PhD research the final aim is to process a general methodology to make and energy and environmental analysis. Therefore, the frameworks and the assumptions concerning the elaboration of the model are not linked to the specific case study but they can be generalizable.

1.2.2. THE METHODOLOGIES FOR A QUANTITATIVE EVALUATION OF THE SIMULATION

Accuracy or validity of a simulation model is precisely described as the degree to which the model corresponds to the reality.

Three methodologies are adopted in simulation in order to satisfy the accuracy/ validity criteria to predict a real behavior[14]:

- analytical validation: the output of a program, a subroutine or an algorithm are compared with the analytical solution of the ideal test cases, characterized by simplified boundary conditions;
- empirical verification: the output of a program, a subroutine or an algorithm are compared with the data monitored and recorded in a real physical construction, in cell test, or laboratory experiments;
- intermodal comparison, which compares the output of one program with the results of other similar programs[15].

The following table synthetically shows advantages and disadvantages of each validation technique.

[14] Relevant readings on this topic:
Schruben L. (2008), "Analytical simulation modeling", *Proceedings of the 2008 Winter Simulation Conference S. J. Mason, R. R. Hill, L. Mönch, O. Rose, T. Jefferson, J. W. Fowler eds.*

[15] In this PhD thesis the results of the simulation have been compared with the monitored and measured energy consumption of the building. Of course the empirical validation allows to verify whether the model is able to reproduce the real behavior of the building. However, because of the complexity of the process (it is very expensive in terms of time), the model has been calibrated only in two periods of the year, both in winter and summer (see Chapter 4, Paragraph 4.2.2).

Table 1-2. Validation technique: advantages and disadvantages.

TECNIQUE	ADVANTAGE	DISADVANTAGE
EMPIRICAL (TESTING THE MODEL AND THE PROCESS OF RESOLUTION)	▪ APPROXIMATION OF THE TRUE REALITY WITHIN THE LIMITS OF EXPERIMENTAL PRECISION; ▪ ANY LEVEL OF COMPLEXITY;	• EXPERIMENTAL UNCERTAINTY (CALIBRATION OF INSTRUMENTS, SPACE-TIME DISCRETIZATION, IMPERFECT KNOWLEDGE OF THE SIMULATED OBJECTS); • DETAILED AND HIGH-QUALITY MEASUREMENTS AND TIME-CONSUMING; • ONLY A LIMITED NUMBER OF TESTS ARE FUNCTIONALLY.
ANALITICAL (TESTING THE PROCESS OF RESOLUTION)	• NO UNCERTAINTY IN THE INPUT DATA; • EXACT MATHEMATICAL SOLUTION FOR THE GIVEN MODEL; • ECONOMIC;	• IT IS NOT POSSIBLE T VERIFY THE VALIDITY OF A MODEL; • LIMITED TO HIGHLY CONSTRAINED CASES FOR WHICH IT IS POSSIBLE TO OBTAIN AN ANALYTIC.CAL SOLUTION
INTERMODAL (COMPARISON TEST OF THE MODEL AND THE RESOLUTION PROCESS)	• NO UNCERTAINTY IN THE INPUT DATA; • ANY LEVEL OF COMPLEXITY; • THERE ARE SEVERAL POSSIBLE DIAGNOS TIC COMPARISONS; • ECONOMICAL AND FAST; • IT IS POSSIBLE TO IDENTIFY AREAS REQUIRING FURTHER EMPIRICAL INVESTIGATI ON.	• THE APPROXIMATION OF REALITY IS NOT TRUE (IT IS ADVISABLE TO USE MORE THAN ONE TOOL USING DIFFERENT MODELS TO REPRESENT THE SAME PHENOMENON)

1.3. ARCHITECTURE AND SIMULATION

The complexity of the operations and the relationships between the operators of the design and construction process makes it impossible to think of the project as a result of a choice made only by the designer. More realistically, the project is the result of convergence of all the competences able to ensure the technical feasibility of an idea. The project no longer appears as a definitive solution to a problem but, on the contrary, it provides a solution that can be realized in different ways, with different techniques and different materials: an intermediate solution which must be developed during the process considering the synergic contribution of different operators, from designers to the upstream industry. Within a complex system, in which it is increasingly difficult to predict the result that a specific choice causes on the whole system, the most suitable solution is presented as the one that allows the greatest number of degrees of freedom for the subsequent choices. Thus, it is possible to understand why the result of the project can no longer be thought in terms of single choice but, on the contrary, it should admit a large number of options that will be the developed during the process (Campioli, 1993).

As rightly shown in the paper of Sam C. M. Hui “Simulation Based Design Tools for Energy Efficient Buildings in Hong Kong” (Hui, 1998), it is possible to schematize the relationship between the design and simulation:

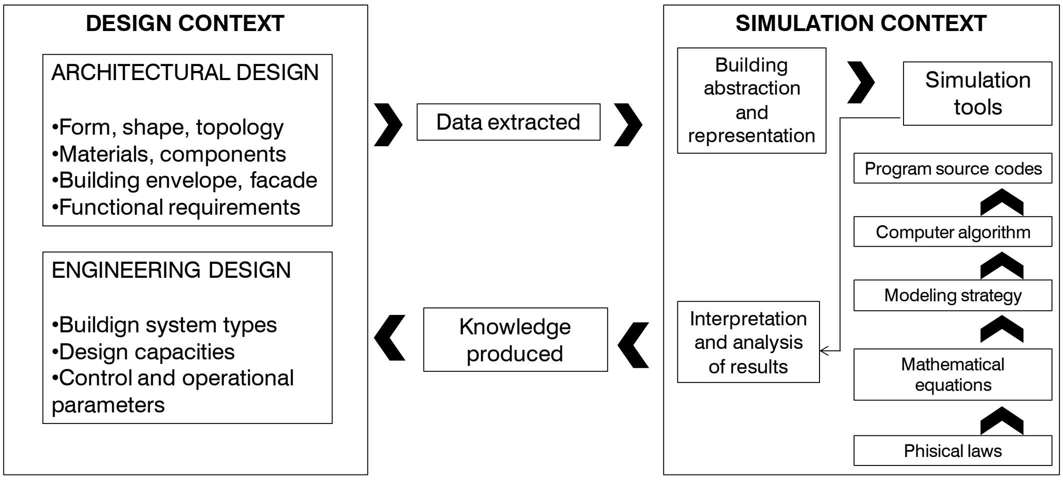

Figure 1-2. Relationship between design and simulation (adapted from Hui, 1998).

Regarding the architectural field, simulation can be utilized for the main following functions[16]:

- to evaluate design options and investigate design optimization;
- to facilitate the investigation of new ideas (cognitive);
- to check compliance with building energy codes;

[16] On the topic of building simulation and architecture the following readings are suggested:
Augenbroe G. (2001), “Building simulation trends going into the new millennium”, *Proceedings of the 7th International IBPSA Conference*, Rio de Janeiro, August 13-15, pp. 15-28.
Augenbroe G. (2002), “Trends in Building Simulation”, *Building and Environment 37 (8-9),* pp. 891-902.
Bloomfield D.P. (1986), “The influence of the user on the results obtained from thermal simulation”, *Proceedings of the 5th International Symposium on the Use of Computers for Environmental Engineering Related to Buildings*, Bath, UK.
Cetica P. (1993), *L’edilizia di terza generazione. Breviario di poetica per il progetto nella strategia del costruire*, Franco Angeli, Milano.
Hensen J. (1994), “Energy related design decisions deserve simulation approach”, *Proceedings of the International Conference on Design and Decision Support Systems in Architecture & Urban Planning*, Vaals, Eindhoven University of Technology, August 15-19.
Morbitzer C. (2003), Towards the Integration of Simulation into the Building Design Process, PhD Thesis, University of Strathclyde.
Seletsky P. (2005), “Digital Design and the age of Building simulation”, available at http://aecbytes.com/viewpoint/2005/issue_19.htm l viewed on 10 October 2008.
Williamson T. J. (2010), “Predicting building performance: the ethics of computer simulation”, *Building Research & Informatio, 38:4*, pp. 401-410.

- to perform economic analysis for determining the impact of energy conservation measures[17].

In the design process, simulation can be introduced inside a continuous back-and-forth process, where the designer synthesizes the outcomes of decisions in relationship with different parameters and constraints.

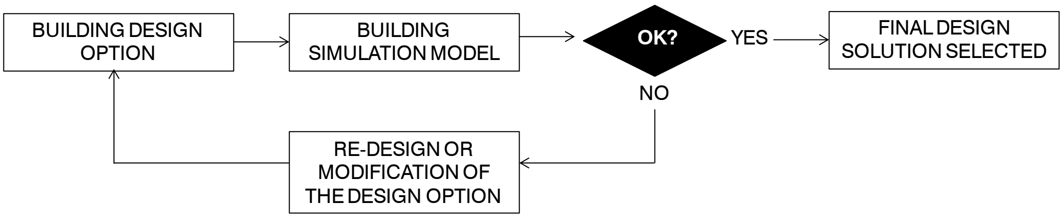

Figure 1-3. Simplified scheme of the role of the building simulation in the design process.

Today the role of simulation within the design process is particularly important, as it becomes an increasingly essential tool to support the designer, especially regarding the field of energy behavior[18]. Non only designers but also manufacturers have to confront with the need to address the energy consumption and the environmental impacts; so, designing sustainable buildings requires to all the operators a greater awareness of environmental issues and tools to simulate the energy behavior of building depending of the adopted strategy[19].

[17] In this PhD research the energy saving potential of some retrofit and system management strategies for the case study were evaluated by means of dynamic simulations. Thus, simulation is mainly used to evaluate different design options and t investigate design optimization (see Chapter 4, Paragraph 4.4).

[18] Relevant readings on this topic:

Bambardekar S., Poerschke U. (2009), "The architect as performer of energy simulation in the early design stage", *Proceedings of the 11th International IBPSA Conference*, Glasgow, July 27-30, pp. 1306-1316,

Diakaki C., Grigoroudis E., Kabelis N., Kolokotsa D., Kalaitzakis K., Stavakakis G. (2010), "A multi-objective decision model for the improvement of energy efficiency in buildings", *Energy 35 (2010)*, pp. 5483-5496.

Wilde P. (2004), *Computational Support for the Selection of Energy Saving Building Components*, PhD Thesis, DUP Science, Delft The Netherlands.

Williamson T.J., Radford A. and Bennetts H. (2003), *Understanding Sustainable Architecture*, Spon, London.

[19] The traditional architectural design has finished its life cycle: the long period in which the design has found its justification in the quality of architecture is finished. Today this quality is still necessary but no longer sufficient; the legitimacy of an architecture comes from the quality of its strategic goals. As Cetica stated, today we are in the third generation of the construction process: the first one is based on the idea of *construction* (linked to the invention of architecture and how to design), the second one is based on the idea of *production* (linked to the industrial process) and the third one is based on the idea of *strategy* (also linked to the new tools and technologies) (Cetica, 1993).

1.3.1. THE ROLE OF THE ARCHITECT

The movement toward building simulation will reinstall the understanding that architects indeed play a central position in the design and construction processes and it confers their leadership status on the process. The incorporation of digital design into the world of architecture will help to remark the principle that it is not sufficient just to design but if architecture is the blending of science and art, it will be important for architects to be able to conceive and develop their ideas not only through artistic treatise but also with building simulation data that validates design intents.

The architectural projects do not just begin and end with architects; any given project environment extends to a larger collaborative core team[20]. The opportunity to contact specialized consultants who know how to use specific methods and tools drives the designer to expand the design team.

About the simulation of the energy behavior of buildings, three are the main figures that have to collaborate:

- the specialist consultant, the operator with specific technical expertise that deals with the implementation of the operational part of the simulation, since it operates from the construction of the model to analyze;
- the energy manager, the person with technical expertise related to the knowledge of systems, heat transfer and other techniques to evaluate the efficiency of the property. The energy manager is involved in the facilities management of the property and, therefore, he is aware of the challenges that are relevant from the point of view of the survey;
- the architect, the entity that supports the energy manager in the choices of technological interventions about the energy efficiency and that coordinate all the subjects. In particular, in case of new achievements, his contribution is very important in order to anticipate critical issues at the planning phase: otherwise they would arise only during the use phase.

Anyway, the simultaneous presence of several individuals who work within the simulation process is difficult to organize and to manage, such as simulation specialists, project managers, design teams with engineers and/or architects and clients. (Prazeres, Kim & Hand, 2009).

[20] To study in deep this item it is suggested:
Prazeres L., Kim J., Hand J. (2009), “Improving communication in building simulation supported project”, *Proceedings of the 11th International IBPSA Conference*, Glasgow, July 27-30, pp.1244-1251.

What is important to state is also that the prevalence of a figure rather than another is driven by the final aim of the energy analysis and consequently by the kind of the used tool. In fact, despite the software developments intended to facilitate the use of energy simulation programs by architects in the early design stage, a very limited guidance is available, leading to a limited uptake (Bambardekar and Poerschke, 2009). Of course the required skills depends on the level of detail of the energy analysis: the degree of specificity is determined by the needs of the person requesting the execution of the analysis and obviously it heavily influences the execution time of the project. Some energy assessment could required a not very refined level of detail, usually when they concern many buildings or entire neighborhoods. Of course the results will not be so close to reality but anyway they lead to a first initial evaluation and they have some advantages, such as the less time and cost, and they also could be performed by architects. Therefore, it also emerges as the usage of the tool and the involved subjects have to be calibrated against the application context to prevent the use of an inappropriate method, not able to outline the problems of a property.

With the advent of these resources, it may ultimately be appropriate to enforce a formal agreement between design team and building simulation expert, concerning the model assumptions that underlie a delivered design analysis. Model specifications that are suitable for such formal agreement do not exist in current practice. Research in this area should deal with certification and expert calibration, based on approaches that use uncertainty and risk analysis.

At last, as well expressed by Paul Seletzky, it must be acknowledged that “the age of digital design and digital building simulation has arrived and is more than just the introduction of a new set of computer tools that architects can use to better coordinate their construction documents. It belies the future of the architectural profession itself” (Seletsky, 2008).

1.4. SIMULATE TO ASSESS – ASSESS TO DECIDE

To decide which design alternative has to be chosen, it is necessary for the designer to have the possibility to compare different scenario. Simulation is one of the most powerful tools available for decision-makers responsible for the design and operation of complex processes[21]. It makes possible the study, analysis and evaluation of situations that would not be otherwise possible. The simulation process can be used to create different scenario in the design phase, for both the new design and the redesign of the built environment and it addresses all stages of a project, i.e. from early conceptual design to commissioning, through to operation and, finally deconstruction of the facility.

However before any ranking can be carried out, each evaluation has to be characterized for a number of decision criteria defined, e.g. technical, economic, environmental etc. Various models and tools can be used for these purposes, estimating, for example, costs, environmental impacts and technical performance of the options.

As shown by R. T. Clemen in his article "Making hard decisions with decision tools" (Clemen, 2001), there are four main reasons why decisions are hard[22]:

- complexity of the problem;
- uncertainty of the situation and future events;
- multiple objectives to be achieved;
- the fact that a problem is framed differently depending on who is solving it.

The basic elements of a decision problem are:

- decisions to be made;

[21] Suggested readings on the simulation and decision process:
De Wilde P., Van Der Voorden M. (2004)," Providing computational support for the selection of energy saving building components", *Energy and Buildings 36*, pp. 749–758.
Petersen S., Svendsen S. (2010), "Method and simulation program informed decisions in the early stages of building design", *Energy and Buildings 42*, pp. 1113–1119.
Reichard G., Papamichael K. (2005), "Decision-making through performance simulation and code compliance from the early schematic phases of building design", *Automation in Construction 14*, pp. 173– 180.
Robinson S., Edwards J.S. and Yongfa, W. (1998), "An Expert Systems Approach to Simulating the Human Decision Maker", *Proceedings of the Winter Simulation Conference 1998* (D.J. Medeiros, E.F. Watson, M. Manivannan, J. Carson, eds.), *The Society for Computer Simulation*, San Diego, CA, pp. 1541-1545.
Simon H. A. (1988), *Le scienze dell'artificiale*, Il mulino, Bologna.
Wetter M. (2011), "A View on Future Building System Modeling and Simulation", in *Building Performance Simulation for Design and Operation*, Jan L. M. Hensen and Roberto Lamberts (editors), Routledge, UK.

[22] In this PhD thesis, the energy analysis has been hard because of the complexity of the building type considered, that is not easy to be modeled because of its particular construction. Moreover, also the decision of the strategy to adopt was difficult because it has to answer to a large amount of aims. There are many uncertainties in the model: for example, having modeled the hall considering a representative year, it is necessary to take into account that the exact data about occupants, electric equipment environmental conditions change every year.

- uncertain events;
- valuing the outcome.

According to Herbert Alexander Simon, the decision making is organized in 5 phases[23]:

- intelligence: problem definition and problem understanding;
- design: searching of different solutions;
- choice: assessment and choice of a solution;
- implementation: implementation of the choice;
- control: control of the results and corrections.

A designer must map the effects of the decisions he makes at the project level to the achievement of these multiple business goals. Also, he must somehow model the decision problem and the relationship between his decisions and the project outcome. For modeling the decision, usually one can use decision trees, influence diagrams, or other representation approaches. For valuing the outcome, according to the decision maker preference, techniques for conflicting attributes trade-off can be used. Several approaches have been suggested in order to support decision-making in tool development, such as performing empirical studies and collecting data and building models as a results of the data analysis; building knowledge bases and experience bases and augment them with the appropriate technology for acquisition, storage, retrieval and dissemination (for example expert systems or knowledge management systems). All of these systems are meant to support and not to replace their users, the final decision still being made by the humans.

[23] In this PhD thesis, the decision making began with the definition of all the problems, secondly different retrofit strategies –with their advantages and drawbacks- have been studied and suggested and finally the strategy able to answer to the greater number of aims has been chosen.

2 Energy and Material: simulation in the use phase and life cycle assessment

2.1. THE USE PHASE AND THE LIFE CYCLE

As mentioned in Chapter 1, nowadays simulation in architecture is a powerful tool that allows the designer to model different energy retrofit strategies in the use phase in order to visualize their savings. In the contemporary scene, the focus on the energy consumption in the use phase of a building is increased by regulations and by a growing social awareness and it prevails over an interest regarding the environmental impacts linked to all the other phases of the construction process. The interest in reducing energy consumptions during the use phase, however, could lead to a shift of the environmental impacts from one stage to another, simply by spreading the total environmental load in a different way. Contrariwise, a Life Cycle Assessment may make the designer able to assess all the environmental impacts of different design strategies, supporting him in the final decision.

Even if to improve the environmental sustainability of buildings it is reasonable to start from the phases that require more energy, it should be evident that not only the use phase is a source of environmental concern.

The difficulty of analyzing environmental aspects and impacts along the life cycle of the products or buildings often lead to perform analysis on a single phase, with the risk of neglecting phases or impacts that are most critical. Trying to improve from an environmental point of view only a step of the building process or trying to reduce the impacts associated with a single environmental indicator can only lead to shift impacts from one phase to another and from one type of impact to another.

Other point concerns the fact that it is not sufficient to consider life cycle and the single phases: going into detail, also each phase of the construction process has inside itself several activities that produce environmental impacts and that have to be managed. For example, in the use phase, the major environmental impacts are due to the energy consumptions: refurbishments are necessary to minimize them, but they also could generate other environmental impacts and so on. And it is the designer who has the task of finding the balance between the benefits produced within each phase (or activity) of the construction process and the ones produced during the entire life cycle.

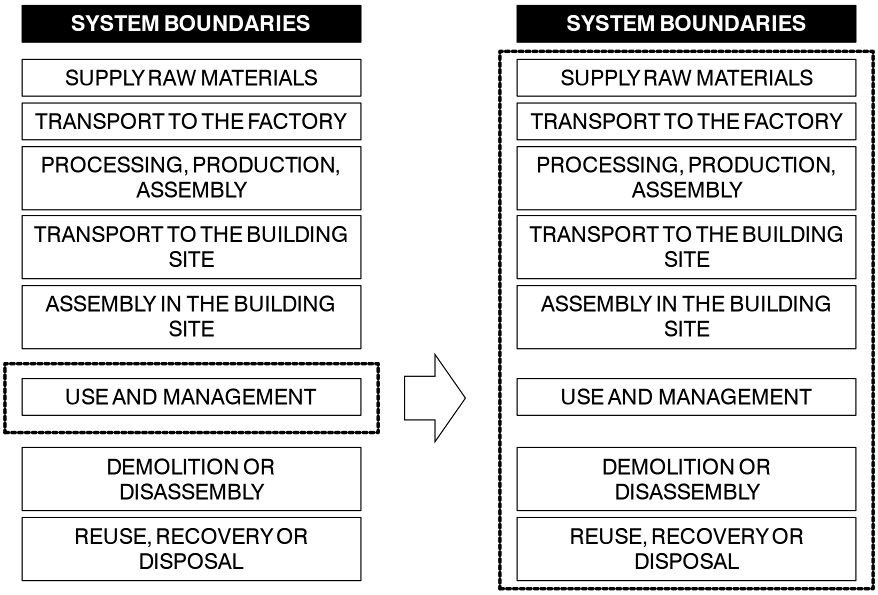

Figure 2-1. The building process phases: the LCA methodology takes into account not only the use phase (left) but the whole life cycle (right).

The importance of considering all the phases in the evaluation of the environmental impacts is also due to the fact that life cycle impacts are highly inter-dependent, as one phase can influence one or more of the others (Blengini, 2010). For example, the choice of building materials can decrease the energy need, but may also increase the embodied energy and the energy due to transport or affect the use phase of the building and the waste production. Thus, the interest in understanding energy use, consumption of natural resources and pollutant emissions in a life cycle perspective is growing, as acknowledged in a number of studies[24]: while in some of these it has been confirmed that operation energy is by far the most important contributor to life cycle impacts of conventional buildings, in some other cases it has been pointed out that, especially for new and low energy buildings, the relative role and the importance of life cycle phases are changing. According to Huberman and Pearlmutter, the embodied energy can be up to 60% of the life cycle energy (Huberman & Pearlmutter, 2008). Therefore, the lower is the energy in the use phase, the more important it is to adopt a life cycle approach, because low values of energy consumption in the use phase can for example mean a large amount of

[24] Suggested readings on this topic:
Blengini G. A., Di Carlo T. (2010), "The changing role of life cycle phases, subsystems and materials in the LCA of low energy buildings", *Energy and Buildings 42 (2010),* pp. 869–880.
Huberman N., Pearlmutter D. (2008), "A life-cycle energy analysis of building materials in the Negev desert", *Energy and Buildings 40*, pp. 837‐848.
Zabalza I., Aranda A., Scarpellini S., Díaz S. (2009), "Life cycle assessment in building sector: state of the art and assessment of environmental impact for building materials", *Proceedings of the 1st International Exergy, Life Cycle Assessment, and Sustainability Workshop Symposium (ELCAS),* Nisyros, Greece.

insulation, that leads to an increasing of embodied energy. It is not said that at the end of the energy balance the better solution in absolute terms is found; on the contrary, each intervention will be more likely to cause more or less significant impacts at different stages in the life cycle. Hence the responsibility of the designer in choosing the design strategy that optimizes the use phase with the awareness of its environmental impact in the life cycle.

Below is a graph where the relationship between simulation, assessments and decision is shown.

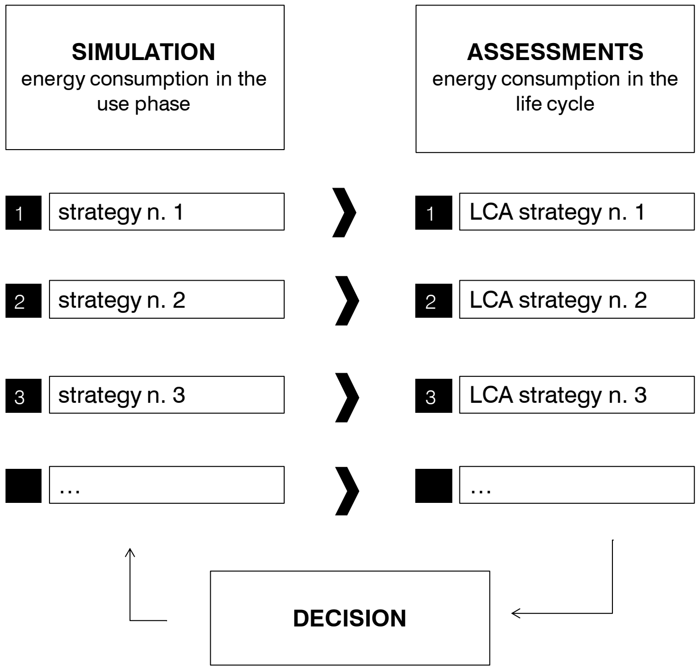

Figure 2-2. The decision process: simulation, assessments, decision.

2.2. ENERGY CONSUMPTION IN THE BUILDING SECTOR

The rapidly growing of the world energy use has already raised concerns over supply difficulties, exhaustion of energy resources and heavy environmental impacts (ozone layer depletion, global warming, climate change, etc.). The International Energy Agency (IEA) has gathered frightening data on energy consumption trends. During the two decades (1984-2004) primary energy has grown by 49% and CO_2 emissions by 43%, with a respectively average annual increase of 2% and 1.8%.

Inside this scenario, the building sector contributes significantly to environmental impacts regionally, nationally and globally: the residential and tertiary sector, the major part of which are buildings, accounts for more than 30% of the final energy consumption in the

European Community and it is expanding, a trend which is bound to increase its energy consumption and hence its carbon dioxide emissions[25]. The construction sector is one of the main protagonists of the environmental issue because of the exploitation of renewable resources, materials, land use, energy consumption related to all the phases of the building process and waste production. The increasing competitiveness in markets and the drive toward sustainability continue to lead industries to improve their processes to achieve higher levels of economic and environmental efficiency. The construction industry is also in a similar situation: "While buildings have a large positive economic impact on society, they also account for a major share of material and energy consumption and for the generation of environmental emissions, both nationally and globally" (Kibert, 2005; United States Dept. of Energy, 2009).

In the setting outlined, civil sector represents an important energy user, demanding all the types of energy and, therefore, contributing in a significant measure also to the carbon dioxide emissions (Table 2-1).

Table 2-1. Final consumptions in Italy for sector and for type of energy in 2007 in Mtep (Source: Data MiSE, synthetic balance sheet 2007, elaborated by ENEA).

	Consumpiton (Mmtep)	Oli (%)	Gas (%)	Carbon (%)	Electricity (%)
Transportation	44.65	97	1		2
Industry	41.02	19	40	12	29
Residential and Non Residential	43.41	11	55	4	30
Total	144.1	48	29	5	18

In particular, within the civil sector, large non residential buildings represents an important part of the construction industry: in Italy in year 2007 (considering only the industrial, the commercial and the hospitality buildings) more than 7000 new building has received the building permit for an amount of more than 90 million cubic meters (ISTAT, 2009). The average volume is significantly larger in urban areas with more than 100000 inhabitants (more than 33000 cubic meters per each building) so the impact for the environment of these new buildings is even higher than it is in small towns.

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[25] Statements of this kind are found in:
Casals X. G., "Analysis of building energy regulation and certification in Europe: Their role, limitations and differences", *Energy and Buildings 38 (2006)*, pp- 381–392.
Commission of the European Communities, *Green Paper (2000), Towards a European Strategy for the Security of Energy Supply*, Brussels.
EU Directive 93/76/CEE of the Council of 13 September 1993 on the limitation of the carbon dioxide emissions through the improvement of energy efficiency (SAVE).
EU Directive 2002/91/CE of the European Parliament and of the Council of 16 December 2002 on the energy performance of buildings.
Lombard L. P., Ortiz J., Pout C. (2008), "A review on buildings energy consumption information", *Energy and Buildings 40*, pp. 394–398

Non residential buildings account for 34% of the energy consumption in the civil sector and 11% of the total consumption of end uses (ENEA, 2006). The demand for comfort inside non residential buildings both in winter and particularly in summer has been largely growing in the last years, also in relation both with innovations in working practices and with climate conditions rapidly changing and hardly predictable; the final effect is the constant growing of energy consumption for different activities.

Table 2-2. Energy consumption (electrical) in non residential sector in GWh (Source TERNA).

	1998	1999	2000	2001	2002	2003	2004	2005
Total	37.088	39.243	41.361	43.654	46.284	49.905	52.011	55.644

Furthermore, as Figure 2-3 shows, energy consumption in non residential buildings grows much faster than in residential ones.

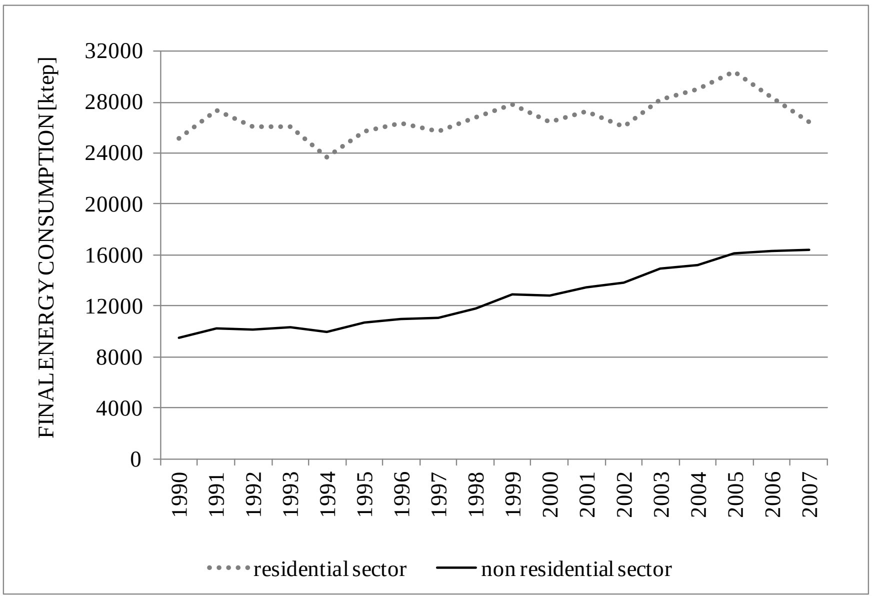

Figure 2-3. Final energy consumption trend of residential and non residential buildings in Italy (source: ENEA, 2009).

Besides, it is important to underline the fact that nowadays an important volume of non residential buildings constructed in the sixties and in the seventies is still in use. They are buildings characterized by more and more inefficient energy behaviors, often with exterior façades and roofs not or insufficiently insulated, with large surfaces of light curtain walls highly dissipating in winter and unprotected from solar radiation in summer, with obsolete equipments, generally deficient both in solar gain systems and in any kind of attention for energy saving solutions.

All these aspects carry to highlight some pressing problems:

- both in new buildings and in energy rehabilitation interventions it is possible to notice the general lack of strategies able to consider simultaneously many aspects, such as: improvement of energy performances both in winter and in summer; implementation of technical solutions adapted to the specific ways of using buildings; reduction of impacts both on costs in use and on environment resources considering the life cycle of materials and components adopted; the influence of different and alternative project choices on CO_2 emissions, etc.
- frequently, choices adopted to improve energy behavior of buildings seem to be fragmented, able to consider only particular aspects, ignoring synergic and indirect effects; concurrently mainly methodologies and tools developed to evaluate and simulate the effects of choices tend to isolate particular aspects and performances not considering for example the energy consumption and the environmental impact during all the life cycle of the building;
- operations in non residential buildings produce high costs both on economic and on environment;

Nowadays it is important to orient a sector of sustainability and energy saving researches in the direction of tools supporting the strategic decisions giving a synthetic vision of the interactions of the different influences of various aspects (environment, energy, money, etc.) and on numerous dimensions of space and of time. This need arises in the phase in which many alternatives must be evaluated and confronted in relation with different parameters and with various policies (Paganin, Talamo, Ducoli, 2010).

Official statistics[26] support also the need for energy saving policies that incorporate the life cycle approach. In fact, the use of buildings in Italy roughly corresponds to 31% of the final energy use and greenhouse emissions throughout the country, but, when the manufacturing of construction materials (cement, bricks, glass, ceramics, etc.) is included, and when building activities are considered, the final energy use and greenhouse emissions rise to 37 and 41%, respectively.

[26] ENEA (2008), *Rapporto Energia e Ambiente 2007*, ENEA, Roma.

2.3. THE BUILDING PROCESS AND THE LIFE CYCLE

As mentioned above, the rapidly growing demand for better energy performance in buildings in the use phase is leading to an ongoing development of strategies and technologies to improve energy efficiency without compromising on comfort, cost, aesthetics and other performance considerations.

The strategies employed to save energy and the decision maker are thus required to establish an optimal solution, taking into account multiple and usually competitive objectives such as energy consumption, financial costs, environmental performance, etc. In other words, the decision maker is facing the challenge to solve a multi-objective optimization problem; the common practice usually employs different methods like simulation and multiple criteria decision analysis techniques that exploit possibly many but in any case limited alternative options.

The building process is divided into different phases:

- raw material supply or extraction;
- transportation to factory;
- processing, production and assembly;
- transportation to yard;
- installation and assembly;
- use, management and maintenance;
- demolition or disassembly;
- reuse, recycling, energy recovery or disposal in landfill.

All the phases help to increase environmental impacts in terms of material and energy[27].

Thus, it would be necessary a holistic approach, able to consider the environmental impacts of the building process in all its phases, in its life cycle. Contrariwise, the building process is divided into well-defined phases where each operator is involved in the construction process and tries to optimize, in terms of energy, the phase of its jurisdiction; moreover, there is not a solely responsible for the entire building process and that regulatory policies are focused on the energy efficiency in the use phase of the building,

A “Life Cycle Assessment” definition, according to SETAC (Society of Environmental Toxicology and Chemistry), is: “a process to evaluate the environmental burdens associated with a product, process, or activity by identifying and quantifying energy and

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[27] Suggested reading on this topic:
Bilec M. M., Ries R. J., Matthews H. S., ASCE A.M., (2010), “Life-Cycle Assessment Modeling of Construction Processes for Buildings”, *Journal of Infrastructure Systems © ASCE*, pp. 199-205.

materials used and wastes released to the environment; to assess the impact of those energy and materials used and releases to the environment; and to identify and evaluate opportunities to affect environmental improvements. The assessment includes the entire life cycle of the product, process or activity, encompassing, extracting and processing raw materials; manufacturing, transportation and distribution; use, re-use, maintenance; recycling, and final disposal" (SETAC, 1993).

The life cycle analysis is a systematic analysis that evaluates the flows of matter and energy throughout the life of a product (or service); the overall aim of the life cycle analysis is to assess the environmental impacts associated with the various phases of the life cycle of a product, from the perspective of an environmental improvement of processes and products.

The key feature of LCA is the totally new approach to the analysis: the traditional approach, which focuses on the separate study of the individual elements of the production processes, is replaced by an overview of the production system, in which all processes transformation are considered as participating in the function for which they are designed.

The information got from the environmental life cycle assessments can make designers and construction professionals aware of the environmental effects related to their design choices and make them able to make decisions in an conscious way, evaluating the life cycle impacts of building materials, components and systems and finding the most appropriate solutions that reduce the building's life cycle environmental impact.

The actual interest in using LCA in construction decision making is evident from the amount of ongoing research in this area. The attention towards sustainability aspects in construction decision making is likely to continue in the future, in view of increasing concerns about the environment in society. LCA can provide a useful decision framework to incorporate such sustainability concerns into construction and can potentially improve current green building assessment methods.

Incorporating energy efficiency and sustainable green design features into new and existing buildings has become a top priority in recent years for building owners, designers, contractors, and facility managers. The delivery of an energy efficient building is not just the result of applying one or more isolated technologies. Rather, it can best be obtained using an integrated whole building process throughout the entire project development process, which leads building designers to generate a large amount of data during energy simulations (Kim, Stumpf, Kim, 2011). However, while LCA is a powerful tool, creating an accurate and inclusive model is not so simple. Some of main problems discussed below are related to the source of data for the inventory, to the impacts assessments methods and to the selection of the boundaries of the analysis.

2.3.1. THE TEMPORAL AND SPATIAL BOUNDARIES OF THE LIFE CYCLE ASSESSMENT

Although the life cycle assessment was born with the purpose to evaluate the whole life cycle ("from cradle to grave"), partial assessments are actually possible[28].

The definition of the phases that will be analyzed leading to the system boundaries tracking: for example, if the purpose is to assess the environmental behavior during production, it is possible to perform studies such as "from cradle to gate" thus also involving the stages of supply materials or eco-balances "from gate to gate", thus limiting the assessment of what happens in the factory. Modular construction is also possible to carry out an analysis of information "from gate to grave" (out by the factory to grave), or of the scenarios for the use phase of buildings "service life scenarios" and end of life "end of life scenarios".

Cradle-to-grave

It is an LCA of the materials used in making a product, from the extraction of materials and energy to the return of the materials to earth when the product is finally discarded.

Cradle-to-gate

It is the LCA of the efficiency of a product or service until it is produced or delivered. It shows the environmental performance as it is in its manufactured state. It is often used for environmental product declarations (EPD).

Gate-to-gate

It is an LCA carried out for a manufacturing process. Some companies use it to calculate the burden to the environment that their particular step in the supply chain has.

Cradle-to-cradle

It is a way of thinking about life cycles. If the grave of one cycle can be the cradle of its own or another, the life cycles are called cradle-to-cradle.

What is important in a life cycle assessment is the clear and explicit definition of all the boundaries conditions depending of the aims. In this way it is possible to understood and to compare different environmental assessments[29].

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[28] The boundary of the life cycle assessment are described in:
ISO 14040 (2006), *Environmental management, Life cycle assessment, Principles and framework*, International Standard Organization, Geneva.

2.4. UNCERTAINTY IN LIFE CYCLE ASSESSMENT

It is stated that LCA is supposed to play a role in environmental decision making, even if the quality of the decision support should be made clear. Although concerns about the quality of LCA-results have been raised at an early stage of LCA-development, assessment of this quality is still not shared and a systematic and comprehensive treatment is still lacking in most guidebooks, databases and software for LCA.

Life cycle assessment practitioners build models to quantify resource consumption, environmental releases, and potential environmental and human health impacts of systems. Most often, practitioners define a model structure, assign a single value to each parameter and build deterministic models to approximate environmental outcomes (Shannon & Ries, 2007). This approach fails to capture the variability and uncertainty inherent in LCA. To make good decisions, decision makers need to understand the uncertainty and the divergence between LCA outcomes for different systems: decisions made regarding design development and improvement, strategic planning, public policy making or product marketing without recognizing this uncertainty may potentially be flawed.

When speaking on uncertainties, one of the first things that could be defined is the notion of uncertainty itself. Although a fully satisfying definition may be difficult to agree upon, in this paragraph a mere reference to the problem of using information that is unavailable, wrong, unreliable, or that show a certain degree of variability is suggested [30].

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[29] In this PhD thesis a life cycle assessment has been made considering the environmental impacts of the added materials of the energy retrofit strategies. In the assessment, the pre-production phase, the production phase, the transport phase and the use phase have been considered. The end of life has been neglected because of the multiple scenarios that could be outlined (see Chapter 5, Paragraph 5.1).

[30] Suggested readings on uncertainty in LCA:

Basson, L., and Petrie, J. G. (2007), "An integrated approach for the consideration of uncertainty in decision making supported by Life Cycle Assessment", *Environmental Modelling & Software 22*, pp.167-176.

EPA (1995), *Guidelines for assessing the quality of life-cycle inventor analysis, US Environmental Protection Agency*, EPA 530-R-95-101, April.

Geisler, G. (2007), "Uncertainties in LCA of Plant- Growth Regulators and Implications on Decision- Making", in *Transactions of the 2nd Biennial Meeting of the International Environmental Modelling and Software Society*, iEMSs, Manno, Switzerland.

Heijungs R., Huijbregts M. A. J. (2004), "A review of approaches to treat uncertainty in LCA", *Proceedings of the 2nd Biennial Meeting of iEMSs, Complexity and integrated resources management*, , Osnabrück, Germany, Orlando, June 14-17, pp. 332-339.

Huijbregts, M. A. J. (2001), "Framework for Modeling Data Uncertainty in Life Cycle Inventorie"s, *International Journal of Life Cycle Assessmen, 6(3)*, pp. 127-132.

Lenzen, M. (2006)," Uncertainty in Impact and Externality Assessments - Implications for Decision- Making", *The International Journal of Life Cycle Assessment 11(3)*, pp. 189-199.

Lloyd S.M., Ries R (2007), "Characterizing, propagating, and analyzing uncertainty in life-cycle assessment: A survey of quantitative approaches", *Journal of Industrial Ecology 11 (1)*, pp. 161- 179.

2.4.1. DEFINITIONS AND TYPES OF UNCERTAINTY

Variability and uncertainty in LCA may cover different issue, as shown in Figure 2-4.

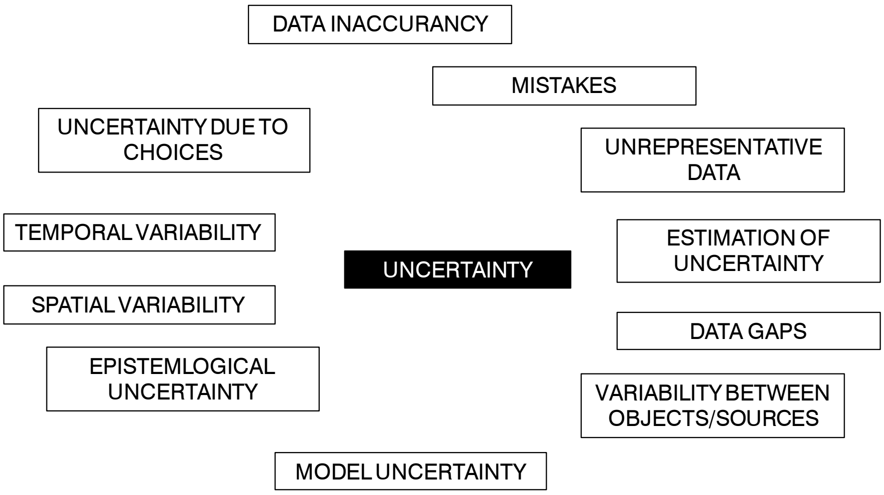

Figure 2-4. Types of uncertainties (adapted from Bjorklund, 2002.

A proper framework to distinguish types of uncertainty in LCA has not been agreed yet. The U.S. Environmental Protection Agency (U.S.EPA) defines types of uncertainty and variability in models:

- parameter uncertainty[31]. Uncertainty in observed or measured values used in a model is called parameter uncertainty. Parameters can be inherently variable and random, that is, not maintain a single value over time; they may be difficult to measure precisely; or precise values may be unavailable. Different applications of parameter uncertainty exist in literature and different techniques are employed, such as Monte Carlo analysis, Bayesian statistics, analytical uncertainty propagation methods. Many authors make use of statistical methods, likely because they are well known and they are integrated in most of the LCA software;

Porta P. L., Buttol P., Zamagni A., Buonamici R. and P. Masoni, (2008), "A survey on uncertainty aspects in LCA", *Proceedings of the SETAC Europe 18th Annual Meetin*g, Warsaw, May 25-29, p.165.
Shannon M. L., Ries R. (2007), "Characterizing, Propagating, and Analyzing Uncertainty in Life-Cycle Assessment - A Survey of Quantitative Approaches", *Journal of Industrial Ecology, v. 11, n. 1*, pp. 161-179.

[31] In the energy analysis of the case study, parametric uncertainties are for example in measured data (e.g. f energy consumption, of internal load…) or in hypnotized data because they were unknown, such as the exact number of occupants during the hour of the days or the flow rate of natural infiltration (see Chapter 4, Paragraph 4.2.2). In the assessment of the environmental impact in the life cycle, parametric uncertainties are for example the embodied energy values found in different databases.

- model uncertainty[32]. Models themselves may add uncertainty and there may be variability between models because of the structure and mathematical relationships in the models. Whether ambiguity in model results is caused by variability or uncertainty significant implications may arise in the decision making. The importance of a quantified analysis of model uncertainty is highlighted because it is recognized that these uncertainties can alter the results by several order of magnitude. However, very few studies includes such analysis and discuss strategies to identify model uncertainties;
- scenario uncertainty[33]. Scenario uncertainty relates to, for example, the normative choices in constructing scenarios and the inherent variability in scenario characteristics given various geographical locations or situations. These uncertainties cannot be neglected but could be made operational with the help of scenario analysis, probabilistic simulation and cultural theory perspectives. Due to the complexity and variety of choices and sources of uncertainties, scenario uncertainty is less accessible to quantitative analysis but, depending on the contexts, also a rule of empiric method could be useful to evaluate case studies where quantitative uncertainty analysis is infeasible.

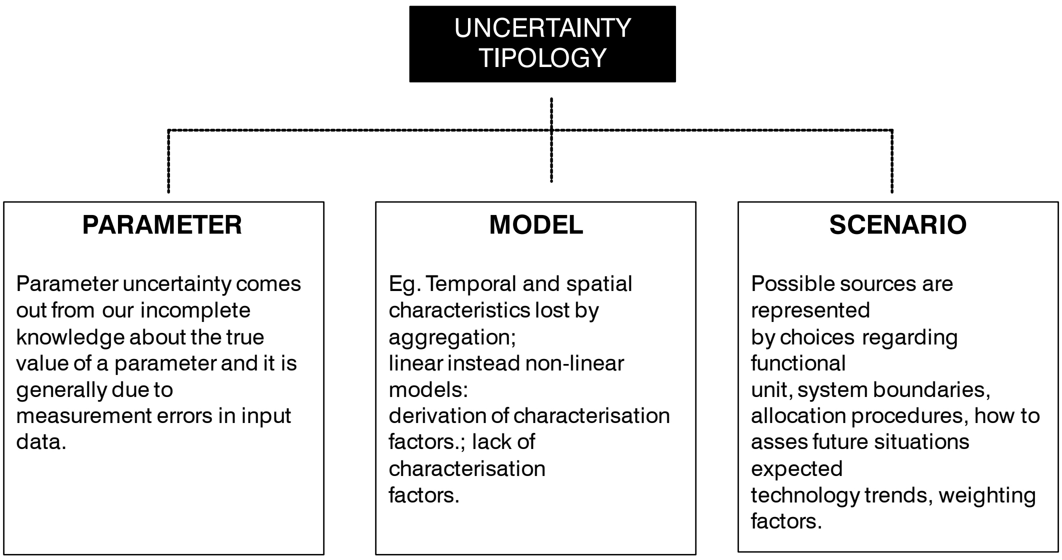

Figure 2-5. Typologies of uncertainty (adapted from Lloyd & Ries , 2007).

[32] In the energy analysis of the case study, model uncertainties are due to some simplification of the model than the real system, such as the geometrical construction of the sample hall in DesignBuilder (see Chapter 4, Paragraph 4.2.1.4).

[33] In the energy analysis of the case study, scenario uncertainties are due to the variability of the external climate conditions, such as the temperature and relative humidity, that influence the results of the energy simulations.

Table 2-3 lists examples categorized by the LCA modeling components listed in the top row as defined by the USEPA and by sources of uncertainty and variability listed in the first column as defined by Morgan and Henrion (1990).

Table 2-3. Sources of variability and uncertainty in life-cycle assessment (adapted from Shannon & Ries, 2007).

SOURCES OF UNCERTAINTY AND VARIABILITY	**LCA MODELING COMPONENT**		
	PARAMETER (INPUT DATA)	**SCENARIO** (NORMATIVE CHOICE)	**MODEL** (MATHEMATICAL RELATIONSHIPS)
RANDOM ERROR AND STATISTICAL VARIATION	PARAMETER MEASUREMENT ERROR	IMPERFECT FIT OF DATA TO REGRESSIONS FOR EVALUATING TRENDS AND FORECASTING	MEASUREMENT ERROR IN PHYSICAL CONSTANTS OR MODELED RELATIONSHIPS
SYSTEMATIC ERROR AND SUBJECTIVE JUDGMENTS	METHODS FOR ESTIMATING MISSING DATA	DEVELOPING SCENARIOS BASED ON PAST TRENDS, USING VALUE JUDGMENT	EXTRAPOLATING RELATIONSHIPS FROM WELL-STUDIED PROCESSES TO SIMILAR PROCESSES
LINGUISTIC IMPRECISION	ASSIGNING QUANTITATIVE PARAMETER ESTIMATES BASED ON QUALITATIVE DESCRIPTORS	DEVELOPING SCENARIOS BASED ON QUALITATIVE DESCRIPTIONS	BUILDING MODELS BASED ON QUALITATIVE DESCRIPTIONS OF RELATIONSHIPS
VARIABILITY	INHERENT GEOGRAPHICAL, TEMPORAL AND TECHNOLOGICAL VARIABILITY IN PARAMETER DATA	INHERENT VARIABILITY IN SCENARIO CHARACTERISTICS	INHERENT VARIABILITY IN PROCESS RELATIONSHIPS
INHERENT RANDOMNESS AND UNPREDICTABLY	SIMPLIFICATIONS OF FLUCTUATIONS IN MEASURED VARIABLES	A SCENARIO IN WHICH SIMPLIFIED CHARACTERISTICS ARE USED	INCONSISTENT PROCESS CHARACTERISTICS
EXPERT UNCERTAINTY AND DISAGREEMENT	A SINGLE PARAMETER VALUE IS NOT WIDELY ACCEPTED	ESTIMATES OF SCENARIO CHARACTERISTICS	DISAGREEMENT ABOUT PROCESS MECHANISMS AND SYSTEM BEHAVIOR
APPROXIMATION	CHARACTERIZING PARAMETERS BY A FEW IMPORTANT PROPERTIES	CHOICE OF FUNCTIONAL UNIT, ALLOCATION RULES, SYSTEM BOUNDARIES, CUT-OFF CRITERIA	SIMPPLIFICATIONS OF REAL-WORLD SYSTEMS, SUCH AS SYSTEM BOUNDARIES

The choice of the type of data used in LCA study is one of the main critical points. Nowadays the discussion on the reliability of databases used for LCA evaluations is opened, in particular the problem concerns the extension of data from one specific case to the general ones. Based on the type of study, simplified or detailed, secondary data (from the database) or primary data (collected directly in relation to the specific case) should be chosen. Clearly the primary data collection is only for studies of specific products, related to a specific production site and for the purpose of a product certification (such as EPD). Instead, if the study aims to support the design, general databases may be sufficient. At the same time using primary data could greatly alter the results of assessments to support the design: to use of a specific product that applies the best available technology (resulting in a drastic reduction of environmental impacts compared to other products of its sector) can significantly change the results of an assessment made with average data taken from the database. Furthermore, it is difficult to understand how data were built and what aspects have been considered. The databases are useful tools to have access to environmental data, but it would be desirable to spread a more transparency and accessibility to specific environmental data, related to specific products in specific contexts[34]. These are aspects that significantly disrupt the results of the evaluation: it is useless to be detailed in the definition of processes, if not contextualized data are used[35].

Reviewing all the types of uncertainty, it is reasonable to ask if a typology of uncertainties is useful at all. It appears that all uncertainties should be dealt with in the appropriate way: a typology is useful if it provides a distinction between sources and sorts of uncertainty. Moreover, it is the sorts of uncertainty that should be emphasized, because it ought to orient the approach taken to deal with uncertainty. Another underemphasized aspect of uncertainty is that there are different levels of uncertainty, relating to the role of the person that experiences the uncertainty. This distinction may be of critical importance in the choice of methods to deal with uncertainty (Heijungs & Huijbregts, 2004).

Summarizing, several methods for the quantification of the uncertainties are available to cover the full range of needs, but the identification of the various type of uncertainty and the reason why a specific uncertainty is chosen is not always clear and terminology is

[34] Suggested readings on this topic:
Dimitrokali E., Hartungi R., Howe J. (2009), "LCA Application in the Built Environment", *Proceedings of the 1st International Exergy, Life Cycle Assessment, and Sustainability Workshop Symposium (ELCAS,)* Nisyros, Greece.

[35] In this PhD thesis two different kind of data have been used: to study the environmental impacts of the retrofit strategies in the life cycle, primary data have been used taken from the EPD of each material, since in case of renovation of the hall, those specific products have been chosen. Contrariwise, to estimate the embodied energy of the hall, data taken from a general database have been used, because the specific products were not known (see Chapter 5, Paragraph 5.1 and 5.2).

confusing. Most of authors deal with parameter - more than scenario - and model uncertainty. At a general level, for all types of uncertainty identified, more guidance is needed on how to define uncertainty in LCA, together with an increased number of good practices. Below is a guideline (suggested by Porta et al) necessary to help practitioners on the definition of important aspects.

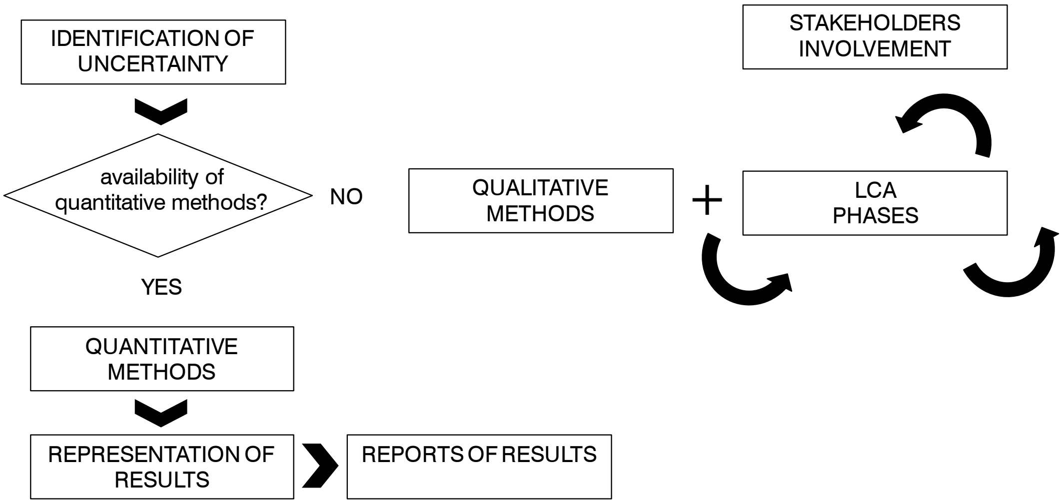

Figure 2-6. Guidelines to define uncertainty in LCA (adapted from Porta P.L. et al, 2008.

2.5. TIME DIMENSION AND USE INTENSITY IN A LIFE CYCLE ASSESSMENT

Designing in an environmentally responsible way means dealing with the issue of "lifetime", since the choice of appropriate technology is strongly related to life expectancy and conditions of use of buildings[36]. In fact, the time dimension can be read according to a double point of view:

- the lifetime of the building and its components is linked to sustainability because the reduction of maintenance and replacement is itself a reduction of environmental impacts;
- the different way of using the building over time in the use phase of the building.

[36] Suggested readings on this topic:
Ashby M., Hohnson K. (2002), *Materials and Design*, Elsevier, Oxford.
Dimitrokali E., Hartungi R., Howe J. (2009), "LCA Application in the Built Environment, *Proceedings of the 1st International Exergy, Life Cycle Assessment, and Sustainability Workshop Symposium (ELCAS,)* Nisyros, Greece.
Lavagna M. (2008), *Life Cycle Assessment in edilizia – Progettare e costruire in una prospettiva di sostenibilità ambientale*, Hoepli Editore, Milano.

In both cases, reducing or extending the time dimension leads to different energy consumption and environmental impacts. That is why it is necessary to clarify these two points, as the incidence in the final results is heavy.

2.5.1. INFINITE LIFETIME OR OPTIMIZATION?

The topic of lifetime is a controversial issue from an environmental perspective. It is stated that a durable product dilutes the impacts over time and it prevents the new ones, contributing to a saving of raw materials; however, at the same time, the rapid evolution of technology, more energetically efficient, calls for a continuous change in order to reduce energy consumption. These choices can be driven by an LCA, which defines the cost-benefit balance of replacing, evaluating whether the savings obtained by substitution compensates for the impacts from waste products and new resources collected. LCA also allows the evaluation to estimate the payback-time of the impacts produced by the production of a product.

When working an overall energy balance, and then counting both energy and impact generated by production and construction of the building, both energy and impacts generated during the use of the building, it is necessary to define the lifetime that has to be considered in the evaluation of the use phase. The choice usually is to estimate the useful life of the building, but it does not coincide with the lifetime of its materials and components. Nowadays few information are available than the lifetime of materials and this is one the most critical aspects, because it can significantly change the assessment.(Lavagna, 2008).

To compare the energy consumption in the production and use phase, it is necessary to consider different temporal scenarios and to relate the impact indicators with the years when the product is used (considering both the lifetime of the building and of the components) and with the concerned surface: in this way it is emphasized the need to use durable products in case of a long lasting buildings and products with reduced embodied energy in the temporary buildings[37].

For some buildings, which have greater impacts during the use phase, it may happens that there is an optimal limit to their lifetime[38]. And the same is for the building

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[37] In this PhD thesis, the time dimension plays a key role. First of all in the assessment of the lifetime of the refurbishments: different lifetime of each material have been hypothesized and the amortization years have been estimated. Secondarily, after calculating the embodied energy of the hall, different lifetime of the whole building have been hypothesized to see how quickly the energy used in the production phase matches the energy consumed during use (see Chapter 5, Paragraph 5.1.3 and 5.2.2).

[38] Suggested reading on this topic:
Manzini E., Vezzoli C. (1998), *Lo sviluppo di prodotti sostenibili*, Maggioli Editore, Rimini.

components and materials: giving the same performance, if the technological development offers the opportunity to have products with better environmental efficiencies (lower consumption of energy and materials and reduce emissions), there will be a time when the fact of having built, used and disposed a product will be paid off (in terms of balancing the environmental impact) with best performance during the use phase (Manzini, Vezzoli, 1998). Thus, there is a potential limit to the lifetime of a product, a break-even point, where its replacement with a new one (which guarantees the same performance) have an overall minor impact. In other words, the greatest impact due to the production and distribution of new products and the disposal of the old ones is less than the reduction of impact caused by an increased environmental efficiency of the new product during use.

As mentioned, the first candidates for a long life are products that require few resources (in terms of energy and material) during use. Otherwise, products that consume a lot of resources in use and in maintenance cannot find an efficient answer in an sustainable design of long lasting products. And it is because of the existence of this last category of products that is more correct to speak of “optimization” rather than “durability” of all.

In general, it is important to understand the peculiarity of each product or component. Some interventions can extend the life of a product without necessarily using more resources. In other cases, however, the extension of life is linked to an increased consumption of resources, and when this happens, the impacts resulting from this increased consumption of resources should be considered assessing the estimated time extension, in order to consider and evaluate them based on time and use. Environmental impacts should be compared with respect to a functional unit.

2.5.2. THE RELEVANCE OF THE USE INTENSITY

Energy use in buildings is closely linked to the occupancy of spaces and to the behavior of the occupants[39].

User behavior has a relevant influence due to:

- their presence of people in the building;
- their activities in the building;
- the control actions that aim to improve indoor environmental conditions (thermal, air quality, light, noise).

[39] Suggested readings on this item:
Hoes P., Hensen J. L. M., Loomans M. G. L. L., De Vries, Bourgeois D. (2009),” User behavior in whole building simulation”, *Energy and Buildings 41*, pp. 295-302.

For a standard type of non residential building, for example, the internal heat gain was found to be an important and sensitive input parameter when applying a building performance simulation tool to assess the building performance[40]. The internal heat gain has a direct relation with user presence and behavior, it is assumed that user behavior is one of the most important input parameters influencing the results of building performance simulations models.

Also the use intensity of a building is an important aspect concerning the use behavior and it is strictly linked to the building type[41]. This issue clearly emerges if considering some Energy Certification which compare annual energy consumption of different building type only considering annual values. Matching annual values of energy consumptions of buildings used in different way could be misleading and it could suggest that a building is more performing of another one while it is simply used fewer days per year[42]. Hence, the need to clarify some indicators that take into account this issue, in particular for non residential buildings, which have a discontinuous use period during a year.

However, in current building performance simulation tools, user behavior generally is imitated in a very static way[43]. General assumptions are applied to describe user presence in a building or room. This also relates to the user actions in the building. User profiles represent the presence and user actions, e.g., describing the use of lighting from

[40] In this PhD thesis the internal gains, and in particular those due to the presence of people, significantly affect the energy demand for heating and cooling. A sensitivity analysis concerning the presence of people has been done (see Chapter 4, Paragraph 4.2.2).

[41] In this PhD thesis, one of the main issue is that the exhibition hall analyzed is used only 52 days per year. Increasing the effective use of the exhibition halls, by considering the possibility of adapting this spaces to different activities, such as sport events, theatre events or concerts, would make the building more used during the year avoiding the construction of additional buildings to overcome these needs. Often, however, this suggestion is not compatible with the exhibitions activities, which require long periods for both the event preparing and disassembling (see Chapter 5, Paragraph 5.2.2).

[42] For this reason, analyzing an exhibition building, it was necessary to clarify an indicator that expresses the average daily energy consumptions rather than annual ones. In this way it is possible to compare it with the ones of the other building types; of course considering the whole year the energy consumption of the exhibition hall are fewer but it is necessary to be aware of the reason (see Chapter 5, Paragraph 5.3.1).

[43] One of the calibration parameter of the analysis of this PhD thesis is the people distribution during the day. From the measured total number of visitors in a day, two profiles giving the people distribution during the day were created. One profile was derived assuming that all the visitors recorded in a day are in the hall during the central hours, while 1/3 of the total is assumed to be there in the opening and closing hours. Instead a second profile was derived assuming that the sum of the people present every hour is equal to the total daily number of visitors. Therefore in the winter representative event a larger number of people decreases the heating rate, because it means a higher internal load. The opposite is found in the summer event. However the kind of people distribution seems to be more important in winter than in summer. This could be understood also considering that, during the winter event, internal loads due to the people and to the electric equipment are similar, while during the summer event, internal loads due to the people are about 1/3 of the electric loads (see Chapter 4, Paragraph 4.2.2).

8 o’clock in the morning till 8 o’clock in the afternoon. In reality user behavior is much more complex.

Developments are ongoing to allow for a better assessment of user behavior in building performance simulations, improvements of behavior models still are possible. This will result in more complex models, however, there is no guideline that supports the efficient use of this type of higher resolution models for user behavior in building simulation.

P2

PART 2

ENERGY ANALYSIS IN THE USE PHASE AND ENVIRONMENTAL ASSESSMENTS IN THE LIFE CYCLE

3 Analysis tools: limits and potentiality

3.1. THE TOOLS FOR THE ENERGY ANALYSIS: DESIGNBUILDER AND ENERGYPLUS

The dynamic simulation tool used to calculate the energy consumptions is the software EnergyPlus, while DesignBuilder is the interface software only used to draw the three-dimensional model of the case study with the thermal-physical description of the envelope.

3.1.1. THE DYNAMIC SIMULATION OF BUILDINGS

Recent decades have witnessed the proliferation of simulation software for a broadening range of building performance assessments; nowadays they are routinely used by many designers and their équipe to guide and assess the design decision-making.

Simulation software provide techniques aimed at predicting, with some hypothesis, future states that could have a direct impact on the decision processes; many of simulation models are now used by many designers to guide and assess design decision-making.

The building simulation software are based on two principal methods[44]. The first one is based on the quasi-steady method, which calculates the thermal balance on a long period of time (typically a month or a season) neglecting the heat stored and released from the walls and which takes into account dynamic effects through an empirically determined factor of loss or gain.

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[44] To learn more about simulation methods, the following readings are suggested:
Barlas Y. (1989), "Multiple tests for validations of system dynamics type of simulation models", *European Journal of Operational Research 42 (1),* pp. 59-87.
Beattie K. H. (1999), "The advantages of building simulation for building design engineers", *Proceedings of Building Simulation 1999, IBPSA, Volume II*, September 13-15, Kyoto, pp. 1079-1084.
Clarke J. A. (2001), *Energy simulation in building design*, Butterworth-Heinemann, Oxford.
Dyner I., Smith R. and Pena G. (1995), S"ystem dynamics modeling for energy efficiency analysis and management", *Journal of Operational Research, 46 (10)*, pp. 1163–1173.
Forrester, J.W. (1961), "The model versus modeling process", *System Dynamics Review 1 (2)*, pp. 133-134.
Lomas K. J., Heppel H., Martin C. J., Bloomfeld D. P. (1997), "Empirical validation of building energy simulation programs", *Energy and Buildings 26*, pp. 253-275.
Oliva R. (2003), "Model calibration as a testing strategy for system dynamics models", *European Journal of Operational Research 151*, pp. 552–568.
Sterman J. D. (2000), *Business Dynamics: Systems Thinking and Modeling for a Complex World*, McGraw-Hill, New York,
Van Der Veken J., Saelens D., Verbeeck G., Hens H. (2004), "Comparison of steady state and dynamic building energy simulation programs", *Proceedings of the international Buildings IX ASHREA conference on the performance of exterior envelopes of whole buildings*, Clearwater Beach, Florida.

The second model is based on a dynamic method, and it calculates the thermal balance on a relatively short period (typically one hour) and, unlike the first model, it takes into account the heat stored and released from the mass construction. Unlike the static approaches mentioned above, dynamic process simulation is able to capture the evolution in time from the beginning to the end of the project; project behavior is determined by the structure of the process and relationships between its variables; it allows representation of feedback loops; it allows representation of uncertainty, by using probability distributions. Simulation allows performing sensitivity analysis (one parameter or a combination of parameters can vary, while the others are kept constant) to determine which attributes have a significant influence on the outcome under study. However, using dynamic simulation software, one of the main problems concerns the construction phase of the model in order to start the simulation, that should define a very detailed description of the building to make the results closer to reality.

Simulation models in general and system dynamics type simulation models in particular have become increasingly popular in the analysis of important policy issues in business organizations. The usefulness of these models is predicated on their ability to link patterns of behavior of a system to the underlying structures of the system. Despite their capabilities, the acceptance of system dynamics simulation models by the broader community of modelers and decision makers is limited.

EnergyPlus is a powerful dynamic software in developing proposals dealing with improving the energy performance of new and existing buildings, since it can generate data needed in feasibility studies. Both in new buildings and in energy rehabilitation interventions it is possible to notice the general lack of strategies able to consider simultaneously many aspects, such as:

- the improvement of energy performances both in winter and in summer;
- the implementation of technical solutions adapted to the specific ways of using buildings;
- the reduction of impacts both on costs in use and on environment resources considering the life cycle of materials and components adopted;
- the influence of different and alternative project choices on CO_2 emissions.

Using dynamic simulation tools it is possible to have an answer to the first two points, while to answer to the other, a complementary LCA evaluation is needed.

The output of the energy simulation could be a support for the strategic decisions in the phase in which many alternatives must be evaluated and confronted in relation with different parameters and with various policies.

3.1.2. ENERGYPLUS STRUCTURE

EnergyPlus is a new building energy simulation program that builds on the strengths of BLAST and DOE-2[45]. Based on the user's description of the building envelope associated to a mechanical system, the EnergyPlus program can calculate the energy need for heating and cooling of a building using a variety of systems and energy sources as well as many other simulation details that are necessary to verify that the simulation is performing as the actual building would (EnergyPlus-Getting Started, 2009).

EnergyPlus software is organized in a list of inputs and outputs. The input required for EnergyPlus is a detailed description of the building (such as the geometrical and thermal-physical description of the envelope and the operational profile) and the underlying mechanical system. It is also necessary to enter the weather file which includes hourly environmental conditions of the building location. The output is produced in a text that can be viewed and manipulated using spreadsheets.

Down in detail, the dynamic simulation of the energy behavior of a building, as already mentioned, is characterized by the exploitation of the operational characteristics varying over time. The data used for the calculation are grouped into four main categories:

- the structural/geometric/thermal-physical characteristics;
- the plants properties;
- aspects concerning the use profile;
- climatic conditions.

The structural features consist primarily in the description of:

- orientation and inclination of the sides;
- overall size and all the individual components (external walls, roofs, floors, windows, doors, overhangs, internal partition);
- stratigraphy of opaque surfaces;

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[45] Suggested readings about the EnergyPlus structure and the main applications:
Crawley D. B., Lawrieb L. K., Winkelmannc F.C., Buhlc W.F., Huangc Y. J., Pedersend C.O., Strandd R. K., Liesend R.J., Fishere D. E., Michael J. W., Glazerf J. (2001), "EnergyPlus: creating a new-generation building energy simulation program", *Energy and Buildings 33 (2001),* pp. 319-331.
Crawley D. B., Lawrieb L. K., Winkelmannc F.C., Buhlc W.F, Erdem A. E., Pedersen C.O., Liesen R.J., Fisher D.E. (1997), "The next-generation in building energy simulation-a glimpse of the future", *Proceedings of Building Simulation 1997, IBPSA, Vol. II*, Prague, Czech Republic, September, pp. 395-402.
EnergyPlus, "Energy Simulation Software, DOE Energy Efficiency & Renewable Energy", Building Technology Program, available at http://www.eere.energy.gov/buildings/energyplus.
Melki S., Hayek M. (2009), "Building simulation tools and their role in improving exinsting building design", *Proceedings of the International conference on advances in computational tools (ACTEA*), Zouk Mosebeh, Lebanon.
Wasilowski H. A., and Reinhart C.F. (2009), "Modelling an existing building in DesignBuilder/EnergyPlus: custom versus default inputs", *Proceedings of Building Simulation 2009, IBPSA*, Glasgow, July 27-30.

- stratigraphy of transparent surfaces (glass type);
- types of frames and dividers (frame type, frame material…).

The structural features of the building are completed by the attributes of technological features of the heating/cooling systems:

- heating/cooling system: the heat source (fuel type, efficiency, power…) and the cooling generation units (configuration, absorption, accessories…);
- AHU (Air Handling Units) system: fans, heat exchangers, heat recovery, dehumidification, humidification, type and location of distribution terminals.

The third group of data concerns the use of the building. The categories of data to be taken into account are as follows:

- intended use of the building;
- crowding (maximum and minimum density of people);
- use of heating/cooling system.

The last group is represented by the climate data. Unlike quasi steady state simulation programs, which are only used to settle the monthly mean data, the tool require the presence of dynamic data in an hourly basis for a period of one year. The main information of this weather file, for all 8760 hours of the year, are:

- temperature;
- relative and absolute humidity;
- speed and wind direction;
- solar radiation;
- atmospheric pressure.

Because of the huge number of input data required by the program, it is important to state that simulating in EnergyPlus, the user can choice the level of detail by editing the fields he is interested in and omitting the ones he doesn't need; obviously, the simulation result is close to reality as much detailed are the input data.

3.1.3. CRITICAL ASPECTS

Summarizing it is possible to recognize some main drawbacks of the EnergyPlus tool:

- EnergyPlus is not an architect or design engineer replacement, it does not check input, verify the acceptability or range of various parameters (expect for a limited number of very basic checks), or attempt to interpret the results; it only indicates errors that help the user in fine-tuning and correcting input mistakes;

- without a graphical interface tool it is very complicated to use, as it is difficult to describe analytically a building entering the coordinates of each of its vertices;
- an EnergyPlus input, while readable, is cryptic and not user-friendly; it is not intended to be the main interface for typical end-users;
- EnergyPlus is currently not a life cycle cost analysis tool; it produces results that can then be fed into an LCC program. In general, calculations of this nature are better left to smaller “utility” programs which can respond more quickly to changes in escalation rates and changes to methodologies as prescribed by state, federal, and defense agencies.

3.2. THE TOOL FOR THE ENVIRONMENTAL ANALYSIS: THE LIFE CYCLE ASSESSMENT

3.2.1. LCA FRAMEWORK

According to ISO 14040, Life Cycle Assessment can be divided into four distinct phases[46]:

- goal and scope definition, in defining the scope of an LCA study a clear statement on the specification of the functional unit of the study shall be made;
- inventory, which involves data collection and calculation procedures to quantify relevant inputs (raw materials and fuels) and output (liquid, solid, and air wastes) of a product system;
- life cycle impact assessment, aimed at evaluating the significance of potential environmental impacts using the results of the life cycle inventory analysis;

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[46] Relevant readings suggested about the structure of LCA:
Baldo G., Marino N., Rossi S. (2005), *Analisi del ciclo di vita LCA - materiali, prodotti, processi*, Edizioni ambiente, Milano.
De Santoli L. (2006), *Analisi del ciclo di vita del sistema edificio impianto*, Palombi Editore, Roma.
Lavagna M. (2008), *Life Cycle Assessment in edilizia – Progettare e costruire in una prospettiva di sostenibilità ambientale*, Hoepli Editore, Milano.
Lavagna M. (2005), *Sostenibilità e risparmio energetico: soluzioni tecniche per involucri eco-efficienti*, Clup Editore, Milano.
Neri P. (2008), *Verso la valutazione ambientale degli edifici – Life Cycle Assessment a supporto della progettazione eco-sostenibile*, Alinea Editrice, Firenze.
UNI EN ISO 14041 (2004), *Gestione ambientale - Valutazione del ciclo di vita - Definizione dell'obiettivo e del campo di applicazione e analisi dell'inventari*o, Ente Nazionale di Unificazione, Milano.
UNI EN ISO 14042 (2006) *Gestione ambientale - Valutazione del ciclo di vita - Valutazione dell'impatto del ciclo di vita*, Ente Nazionale di Unificazione, Milano.
UNI EN ISO 14043 (2000) *Gestione ambientale - Valutazione del ciclo di vita - Interpretazione del ciclo di vita,* Ente Nazionale di Unificazione, Milano.
SETAC (1993), *Guidelines for Life-Cycle Assessment: a code of practice*, SETAC, Brussels.

- interpretation and improvement, in which the results from the inventory analysis and the impact assessment are combined together, consistent with the defined goal and scope, in order to reach conclusions and recommendations.

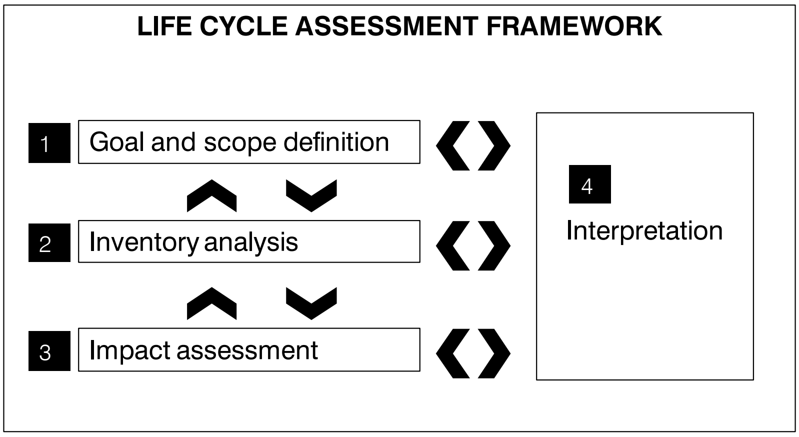

Figure 3-1. Stages of LCA.

LCA methodology has a dynamic character and the four phases are interrelated, so that the original hypothesis can be reconsidered or the data used can be refined in any one of the phases.

3.2.2. LCA METHODOLOGY APPLIED TO BUILDINGS[47]

The minimization of costs, which LCA permits, includes the environmental costs, the use of energy, materials and water which all play a relevant. Consideration for the environment continues to gain respect in the marketplace and businesses operating in the construction sector have to modify their strategies and differentiate their buildings by taking advantage of the widespread possibilities that LCA has to offer.

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[47] Reading suggested on the application of LCA in the built environment:
Dimitrokali E., Hartungi R., Howe J. (2009), "LCA Application in the Built Environment", *Proceedings of the 1st International Exergy, Life Cycle Assessment, and Sustainability Workshop Symposium (ELCAS,)* Nisyros, Greece.
Erlandsson M., Borg M. (2003), "Generic LCA-methodology applicable for buildings, constructions and operation services – today practice and development needs", *Building and Environment 2003, 38*, pp. 919–938.
Haapio A., Viitaniemi P. (2008), "A critical review of building environmental assessment tools", *Environmental Impact Assessment Review 2008, 28*, pp. 469–482.
Zabalza I., Aranda A., Scarpellini S., Díaz S. (2009), "Life cycle assessment in building sector: state of the art and assessment of environmental impact for building materials", *Proceedings of the 1st International Exergy, Life Cycle Assessment, and Sustainability Workshop Symposium (ELCAS,)* Nisyros, Greece.
Zabalza I., Aranda A., Scarpellini S. (2009), "Life cycle assessment in buildings: State-of-the-art and simplified LCA methodology as a complement for building certification", *Building and Environment 44 (2009),* pp. 2510–2520

Nowadays it is a necessity for decision makers, architects, engineers, and consultants to consider the environmental consequences of their decision. By integrating LCA in the methodology of building design, it is possible to assess the life cycle impacts of building materials, components and systems and to choose the best solutions that reduce the environmental impact. (Dimitrokali, 2009).

Following, a table that shows the mail typologies of users of the LCA methodology, the stage of the process of their potential and the purpose of the life cycle assessment. The last two lines refer in particular to the use of the LCA methodology to the building scale.

Table 3-1. LCA methodology: users, phases, aims.

TYPE OF USER	PHASE OF THE PROCESS	AIM OF LCA USE
Consultants municipalities, urban designers	Preliminary phases	Setting targets at municipal level Defining zones where residential/office building is encouraged or prohibited Setting targets for development areas.
Property developers and clients	Preliminary phases	Choosing a building site Sizing a project Setting environmental targets in a program
Architects	Early design (sketch) and detailed design in collaboration with engineers. Design of a renovation project.	Comparing design options (geometry / orientation, technical choices)
Engineers / **Consultants**	Early design in collaboration with architects, and detailed design Design of a renovation project	Comparing design options (geometry, technical choices)

When applied to decision making, Life Cycle Assessment contributes to each of the major processes of decision support:

- the identification of problem;
- the identification of the alternatives;
- the assessment of the best alternative;
- the determination of evaluation indicators of the chosen alternative.

In general, the Life Cycle Assessment approach can provide a support to decision making, mostly about:

- the comparison of different alternatives for the technological design of a product focusing on improving the impacts of the product over its life span;
- the development of improvement strategies focusing on the reduction of energy and material consumption;
- the analysis for ecolabelling or ecomarketing in relation to overall environmental impacts of a specific product;
- the evaluation of the environmental efficiency focused on technological innovation, resource utilization in specific sectors such as waste treatment and road transport;
- the elaboration of a set of indicators for environmental decision making comparing different activities in a specific territory.

3.2.3. THE INFORMATION TOOLS FOR THE LIFE CYCLE ASSESSMENT

There are several information tools that provide information about the environmental impacts in the life cycle.

Following, a brief description of those used for the analysis.

3.2.3.1. THE ENVIRONMENTAL PRODUCT DECLARATION (EPD)

An Environmental Product Declaration presents quantified environmental data for products or systems based on information from a LCA conducted according to the ISO-standards. EPD is voluntarily developed information and the purpose is to provide quality assured and comparable information regarding environmental performance of products.

A declaration is based on a Life Cycle Assessment: it includes information about the environmental impacts, such as raw material acquisition, energy use and efficiency, content of materials and chemical substances, emissions to air, soil and water and waste generation. It also includes product and company information. Environmental product declarations are usually based on a cradle-to-gate assessments.

EPDs can reflect the continuous environmental improvement of products over time and are able to communicate and add up relevant environmental information along a product's value chain. EPDs also add new market dimensions to inform about environmental performance of products and services - objectivity, comparability and credibility.

EPDs can be described as being:

- objective, due to the requirement to use internationally accepted and valid methods for life cycle assessment in order to identify and focus the environmental work on the most significant environmental aspects leading towards continuous improvement;

- credible, due to the requirements for critical review, approval and follow-up by an independent verifier;
- neutral, due to the absence of claims of environmental preferability, valuations and predetermined environmental performance levels that must be met;
- comparable, through the establishment of “Product-Specific Requirements” for selected product groups and services, describing harmonized LCA rules for data collection, methodology, calculations and presentation of the results;
- open to all products and services, through its neutral character and non selectivity, thereby having the widest range of applicability to all products and services;
- open to all interested parties, through easily accessible information on the Internet;
- environmental impact oriented, through the possibility to include assessments of potential environmental impacts;
- instructive, by the possibility to provide explanations of terms, definitions and concepts, as well as general information on relevant environment issues to help interpret the information.

The main data regarding the estimation of the environmental impacts taken by the EPD in this analysis are:

- the embodied energy, namely the primary energy consumption (PEC, also primary energy content or requirement). It is the overall consumption of energy resources required to manufacture a product or a service. Primary energy consumption therefore also includes the energy used to obtain the raw materials or energy loss through waste heat, for example. It is divided into energy from non-renewable resources (oil, natural gas, lignite and coal, nuclear power) and energy from renewable sources (biomass, hydroelectric power, solar energy and wind energy). The primary energy consumption is calculated from the highest calorific value of all the energy resources deployed;
- some of the main environmental impact indicators (shown in the table below), such as the acidification potential, the eutrophication potential, the global worming potential, the ozone depletion potential and the photochemical ozone creation potential.

Table 3-2. Environmental impact categories.

Abbreviation	Technical Term	Example Impact
AP	Acidification Potential	Acid rain
EP	Eutrophication Potential	Nutrient loading to stream
GWP	Global Warming Potential	Greenhouse gas emitted
ODP	Ozone Depletion Potential	Ozone hole over polar ice caps
POCP	Photochemical Ozone Creation Potential	Smog
PED	Primary Energy Demand	Electricity & fuel needed
Water	Total volume used	Irrigation water
ETP	Eco-Toxicity Potential	Animal health
HTP	Human Toxicity Potential	Human health

Following, a list of the categories that have been taken into account has been made:

- the global warming potential (GWP). It describes the contribution made by a trace gas to the greenhouse effect relative to carbon dioxide. For each greenhouse gas, an equivalent amount of carbon dioxide is calculated in kilograms. This enables their direct impact on global warming to be expressed as a single impact indicator. Global warming potential can be determined for various time horizons (20, 100 or 500 years). A shorter integration period (span of time during which the input signal is sampled and the average value calculated) of 20 years is crucial for predicting short-term changes due to an exacerbated greenhouse effect, as can be expected for land. This means that it can be used if the temperature rise is to be limited, for example, to 0.1°C per decade. By contrast, longer integration periods of 100 and 500 years are appropriate for evaluating the long-term rise in ocean levels and serve, for example, to weight the greenhouse gases by limiting the total anthropogenic temperature rise to, say, 2°C;
- the ozone depletion potential (ODP). The depletion of the stratospheric ozone layer is caused by the catalyst effect of halogens in specific climatic conditions The increased amount of ultraviolet radiation penetrating to the earth's surface raises the risk of skin cancer and cataracts. It also causes damage to crops and phytoplankton, which is at the bottom of the food chain in the oceans. Chlorofluorocarbons (CFC) are chiefly responsible for the depletion of the ozone layer in the stratosphere. In the lower atmosphere, these act in the same way as noble gases, and are thus completely non-toxic and inert. Being inert, they arrive in the stratosphere unaltered and are then split up by the strong ultraviolet radiation. The chloratomes which are released as a result have the ability to break down the ozone by acting as a catalyst for its conversion into normal atmospheric oxygen.

Since catalysts speed up chemical reactions but emerge from the process virtually unchanged themselves, one single chloratome can ultimately destroy many thousands of ozone molecules. Even if CFC emissions ended abruptly today, the ozone belt in the stratosphere would only return to today's level in another 40-60 years. Since early 1995, the production and use of CFCs has been strictly prohibited in the European Union. This prohibition affects only the most potent ozone destroyers, fully halogenated CFCs. Partly halogenated CFCs and HFCs (HCFCs and HFCs) are only prohibited in a few European countries (e.g. in Austria, where a transition period has been granted for HFCs). By looking at the dwell time and the forecast concentration of emissions, the ozone depletion potentials, or ODPs, were determined in relation to the substance CFC R 11 (trichlorfluoromethane);

- the photochemical ozone creation potential (POCP). Photosmog in towns and their immediate vicinity is caused by the formation of photooxidants in the lower troposphere. This refers to the mixture of harmful, highly reactive gases which forms when sunlight comes into contact with anthropogenic emissions (especially nitric oxide compounds and hydrocarbons from car exhausts). The more highly reactive gases react within the space of a few hours close to the source of the emissions, while the less reactive constituents may spread before forming oxidants. Ozone is the principal product of this photochemical reaction and is also the chief cause of smog-related ocular irritation and respiratory problems, as well as of damage to trees and crops. The photochemical ozone creation potential (POCP) refers to the propensity of a substance to form photooxidants (summer smog). The photochemical ozone creation potential is measured in relation to the reference substance ethylene;
- acidification is caused mainly by the interaction of nitric oxides (NO_x) and sulphur dioxides ($S0_2$) with other constituents of the air. These gases can be converted in the space of just a few days into nitric acid (HNO_3) and sulphuric acid (H_2SO_4), both substances which are instantaneously soluble in water, by means of any number of reactions, such as combination with the hydroxyl radicals (OH* radicals). The acidified water droplets then precipitate as acid rain. Unlike the green house effect, acidification is a regional, not a global, phenomenon. Knowledge of the impact of acidification is still only fragmentary. One of the clearly attributed consequences is the acidification of lakes, rivers and streams, which is decimating fish stocks in terms both of quantity and diversity. Acidification can have the effect of mobilizing heavy metals, which then become available to plants and trees. Moreover, acid deposits may play a role in the observed damage to forests. Overacidification of

the soil can impact the solubility and thus the availability to plants of nutrients and trace elements. Corrosion on buildings and outdoor art works is another consequence of acidification. The unit of measurement for the tendency of a constituent to acidify is the acidification potential, AP;

- the eutrophication (EP). Fertilisation is the application of additional nutrients to soil and water in order to raise farming production. Excessive fertilisation can affect the environment in a variety of ways. For example, it can cause a shift in the diversity of the ecosystem. At present, eutrophication is calculated solely on the basis of substances which contain neither nitrogen nor phosphorous. The potential contribution of a substance to the production of biomass is expressed as in terms of eutrophication potential, EP.

3.2.3.2. ICE (INVENTORY OF CARBON & ENERGY)

Professor Geoff Hammond and Craig Jones from the Department of Mechanical Engineering (University of Bath) have been working on a database to determine the embodied energy and carbon of a large number of building materials. The database has been used to release an Inventory of Carbon & Energy (ICE), a life cycle dataset representing a wide range of building and construction materials and represents both the carbon emissions and the embodied energy of a product/material – the total primary energy consumed before operational use. With a few exceptions, the life cycle analysis boundaries represented within the ICE database are designated as cradle-to-gate (which includes all energy, in primary form, until the product leaves the factory gate). The authors advise that, even within these boundaries there are many possible variations that affect the absolute boundaries of each material analysis. This arises predominantly from the use of secondary data resources which represent variable boundaries. The Inventory of Carbon and Energy is freely available.

The dataset represents over 300 individual materials, including metals (e.g. aluminium, iron, steel), plastics, insulation, mineral-based materials (e.g. aggregate, cement, concrete, glass, stone), and organic materials (soil, timber) as well as manufactured composite materials such as carpets, photovoltaic cells, roads and windows. Each material is differentiated into a range of specific subtypes, and, in many cases, distinct representations of “virgin” versus “recycle” variants of materials are available. For each type of material, the database provides measures of the embodied energy (i.e. MJ) and CO_2 emissions (i.e. kg) which are related to specific unit quantities of the material. The bulk of the materials in the dataset are represented as mass quantities - that is, the embodied energy and CO_2 emissions are represented on a “per kg” basis. Calculations are made, in these cases, by multiplying a mass quantity for the material by the appropriate factors. In some cases, materials are represented on an area basis (i.e. m^2), for example, carpets, roads and paint (kg [CO_2] per m^2). In these cases, calculations are made by providing area quantities.

Hereafter, the five selection criteria for ICE data building energy are summarized:

- source: extracted from studies that are compliance with approved methodologies/standards (e.g., ISO 14040 series compliant);
- system boundaries: chosen to comply with cradle-to-gate embodiment;
- origin (country) of data: the best available embodied energy data from around the world has been adopted, although a preference has been given to good quality UK sources;
- age of data: modern sources has been employed (wherever possible), because the fuel mix and carbon coefficients associated with power generators has changed over time;
- embodied carbon: preference has been given to data from LCA studies, but otherwise estimates has been made on fuel split.

3.2.4. CRITICAL EVALUATION OF LCA

All the assessment and decision support tools provide guidance related to their specific field of inquiry but the complexity of the project requires a capacity for synthesis that no tools can have.

Undertake an evaluation of buildings in the life cycle should be the current and future focus, but LCA is a complex methodology and there are many uncertainties and limitations in current practices. For this reason, LCA cannot be taken as the single tool able to guide the choice of a material or a technological solution. LCA overlooks many aspects at the macro scale (the relationship between building and environment) and at the micro scale (internal health). It is not always easy to get enough information for more indicators or even for all the life cycle processes. That’s why LCA has been described as a scalable concept where it is possible to choose how precise you want to be. Thus, it is an environmental assessment to complement others, in order to get an overview.

LCA is a quantitative evaluation tool that allows an objective check even though the reference to numerical values is not synonymous with reliability and all the assessments, especially with the degree of reliability of data now available, may have a margin of uncertainty. Environmental information arising from the LCA are used to pick up some guidelines and allow to redirect wrong strategies. One of the main issue of integrating

LCA in the construction sector is how to collect the appropriate data needed, which impact indicators to examine, which life cycle phases and elements to include and how to set system boundaries.

Summarizing it is possible to observe that LCA methodology has both advantages and drawbacks. The main reasons for using this tool in buildings is to investigate how building materials, systems and equipments impact the environment. However, life cycle assessment has also many limitations and uncertainties, such as the difficulty to collect and find all the suitable data needed taking into account all the environmental impact indicators and all the life cycle phases. It should be looked as a holistic approach in order to examine the full life cycle of the building and to promote sustainable integrated solutions.

Of course it must be remembered that the tool is adjusted in relation to the use that the operator does, so it is important to become aware of the method, of the procedures and types of data that LCA allows to obtain, of its limitations and its potential.

4 Energy analysis in the use phase

4.1. THE CASE STUDY: FIERA MILANO S.P.A.

This study focuses on exhibition centers, taking the case study of the Milan Trade Fair, whose new seat was inaugurated in 2005.

From an energy point of view, this kind of buildings shows several interesting characteristics, which may be grouped into the following issues:

- morphological aspects: compact shape, single volume with considerable height, low height to basement surface ratio;
- materials and construction techniques: mainly prefabricated components;
- use aspects: high internal loads due to electric equipments and people, short and fragmented use period during the year.

The complex consists of 8 buildings, divided into 20 pavilions, 6 of them are one-storey buildings (164.5 m x 224.31 m and clear height 13 m) and 2 of them are two-storey buildings, for a total of 345 000 m^2 and 60 000 m^2 of gross exhibition space outdoor.

The whole area is heated by district heating through two 15 MW heat exchangers. The hot water comes from the Waste To Heat Plant located in Figino through an underground network of about 3.5 km. 5 auxiliary gas heaters with a total power of 42.5 MW are also installed for peak demand supply. According to Fieramilano S.p.A., approximately 95% of the yearly heating demand of the area is supplied by district heating, while 5% comes from the gas heaters.

The cooling of the entire district is carried out through 10 cooling generation units. Specifically, the halls and the service center are served by 4 units, each consisting of three 5.2 MW centrifugal chillers coupled with cooling towers. From the cooling and the heating generation units the underground distribution networks provide hot and cold water to the Air Handling Units of the halls. The climatization system of a one-storey hall is a fixed air volume system made up of 9 AHU, each of them handling 55000 m^3/h, with a variable mix of indoor and outdoor air.

Considering a representative year, it is possible to estimate about 70 events, with an overall consumption of about 50 GWh for electric energy and 15 GWh for heating, 150000 m^3 for drinking water and 600000 m^3 for hot water.

The monitoring system of the trade fair measures the cooling and heating energy provided to the AHU of each hall, in terms of cold/hot water, as well as the electricity consumption of the hall. Moreover the total number of people entering the hall in a day is recorded. These data are shown in Table 4-1 for each event that took place in 2009 in a typical hall. It is worth to notice that a cooling demand may be present also within the heating period, as shown in the case of event n. 10.

Table 4-1. Events calendar of a typical hall, year 2009.

Events hall 5-7 year 2009					
n°	Period	energy need for cooling	energy need for heating	electric consumption	number of users
		kWh	kWht	kWh	n°
1	16/01 to 19/01	-	99473	97860	3462
2	04/02 to 07/02	-	68125	84757	6927
3	19/02 to 22/02	-	90675	73997	6667
4	04/03 to 07/03	-	58610	95914	2813
5	24/03 to 28/03	-	35189	102867	8571
6	22/04 to 27/04	60443	-	158744	22143
7	04/09 to 07/09	112275	-	54612	3000
8	16/09 to 19/09	90542	-	91542	2813
9	05/10 to 10/10	165308	-	177249	6061
10	23/10 to 27/10	18738	-	98229	4364
11	06/12 to 12/12	-	107004	198984	27778

Figure 4-1 shows the total and daily heating/cooling energy consumption per unit volume of the typical hall for each event reported in Figure 4-1. In Figure 4-2 and Figure 4-3 the daily average internal loads per unit area respectively for electric equipments and people are shown. People average loads were estimated starting from the recorded total number of people entering the hall, by assuming a reasonable distribution during the day and by considering a sensible heat rate per person of about 90 W (the hypothesis about the distribution provides a constant flow of people up in the three central hours of each event, equal to the known number of visitors per day, and a third of people in the first and last three hours).

A shown in Figure 4-1, daily heating/cooling energy consumption may vary significantly for different events. As an example, events n. 1 and 11, taking place in a similar period of the winter, have a specific heating daily consumption respectively of 50 and 31 Wh/m^3. This difference can be understood looking at the average daily internal loads in Figure 4-2 and Figure 4-3, which are 28 W/m^2 for event n. 1 and up to 32 W/m^2 for event n. 11; considering the UNI-TS 11300, exhibition buildings, libraries and commercial buildings have medium internal loads due to electric equipment of about 8 W/m^2. In general it is worth to notice that average internal loads per unit area are large, mainly due to the electric equipments, but in some events also the people contribution may be relevant, as for instance in events n. 6 and 11.

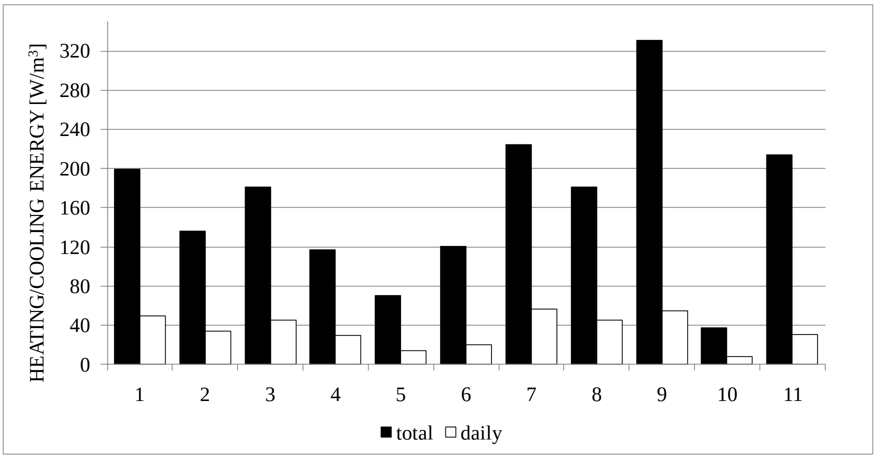

Figure 4-1. Total and daily heating/cooling energy consumption per unit volume for each event in a typical hall.

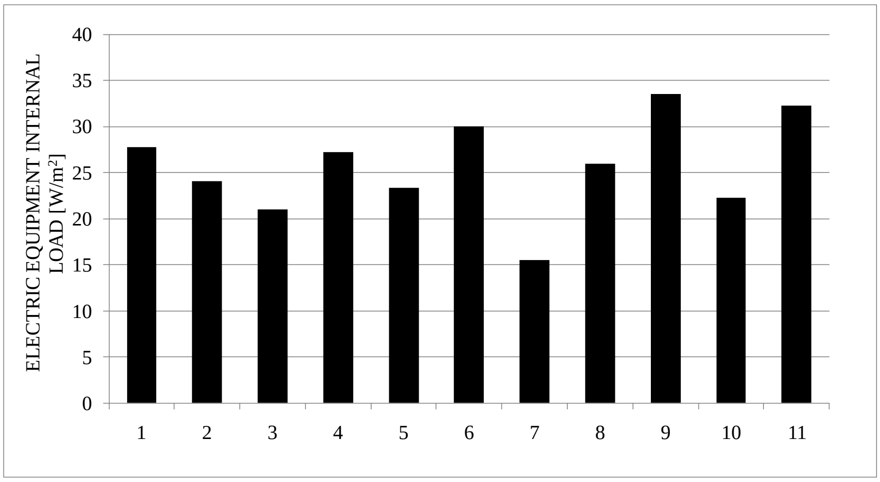

Figure 4-2. Daily average electric equipments internal gains per unit area for each event in a typical hall.

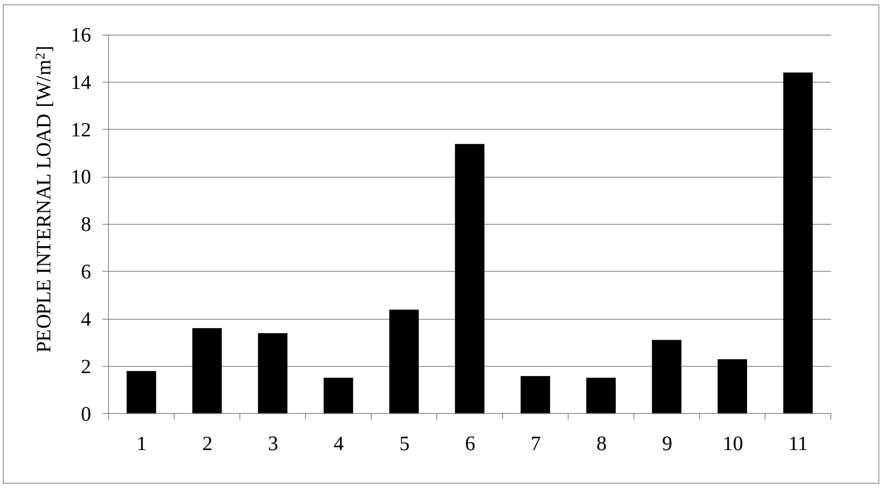

Figure 4-3. Daily average people internal gains per unit area for each event in a typical hall.

4.2. SIMULATION MODEL

4.2.1. SAMPLING AND MODELING IN DESIGNBUILDER

The first step is the construction of the 3D model of the building processed in DesignBuilder. This model is entered in EnergyPlus to elaborate the simulation model. Both tools were described in 3.1.

4.2.1.1. THE IDENTIFICATION OF THE SAMPLE HALL

The approach proposed is based on the identification and analysis of a "sample hall" (Figure 4-4). The geometric characteristics, the construction techniques and the orientation of the sample hall are similar to most of the halls of the whole exhibition center. In this way the assessments made on the "sample building" can be transferred to the other halls of the same area. The sample hall is the pavilion 5-7.

Figure 4-4. The identification of the “sample hall”.

Following is the plan of the hall: it is a parallelepiped with an exhibition area of 37242 m^2. On the roof there are two skylights shaped like truncated cones.

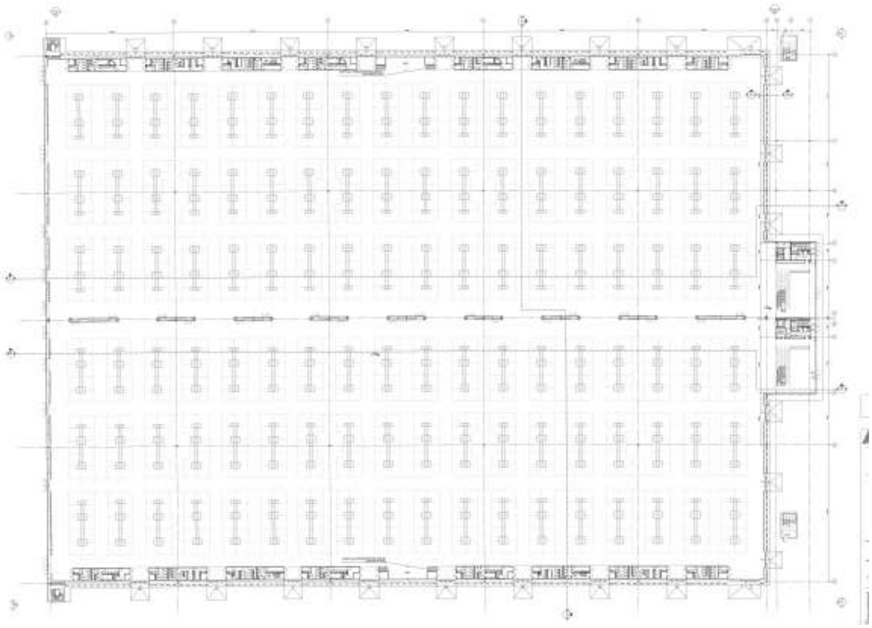

Figure 4-5. The plan of the sample hall.

The façades of the hall are shown in Figure 4-6 and following.

Figure 4-6. East façade.

Figure 4-7. West façade.

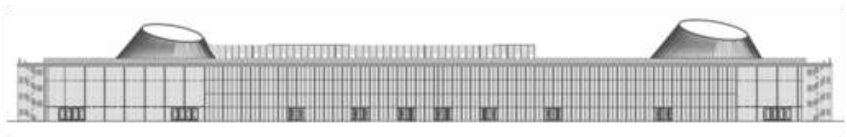

Figure 4-8. North façade.

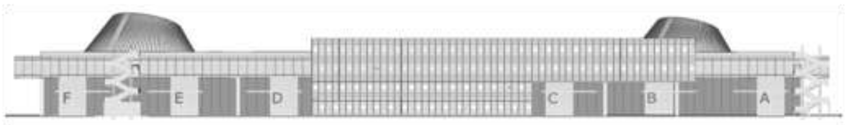

Figure 4-9. South façade.

Following are some photographs of both the district and the halls.

Figure 4-10. The main façade of the sample hall (east side, equal to west side).

4.2.1.2. THE IDENTIFICATION OF THERMAL ZONE

The objective of this analysis is to verify the temperature uniformity inside the hall in the vertical direction to evaluate the possibility of dividing the volume into several vertical thermal zones. To achieve this goal measurements of temperature at different heights (4m, 5m, 7m, 11m, 13m) have been made with data logger (EasyLog model EL-USB, with an accuracy of half a degree) during the winter and summer representative events.

Figure 4-11. The data logger in the hall.

The maximum vertical temperature difference measured during a representative day is less than 2 °C, as shown in the next figures.

Horizontal temperature differences were also found to be less than 2 °C; the survey was executed with the same tool by detecting the temperature in different parts of the hall, along the perimeter to the center.

Below are the detail of the data measured for each day of the winter and summer representative event. After the first day of the “MADE” event, where temperatures tend to be lower than in the next days, temperature levels and stratifications are almost the same during each event. The same considerations are true also considering the summer event, therefore, only the first and second day data are reported in the following figures.

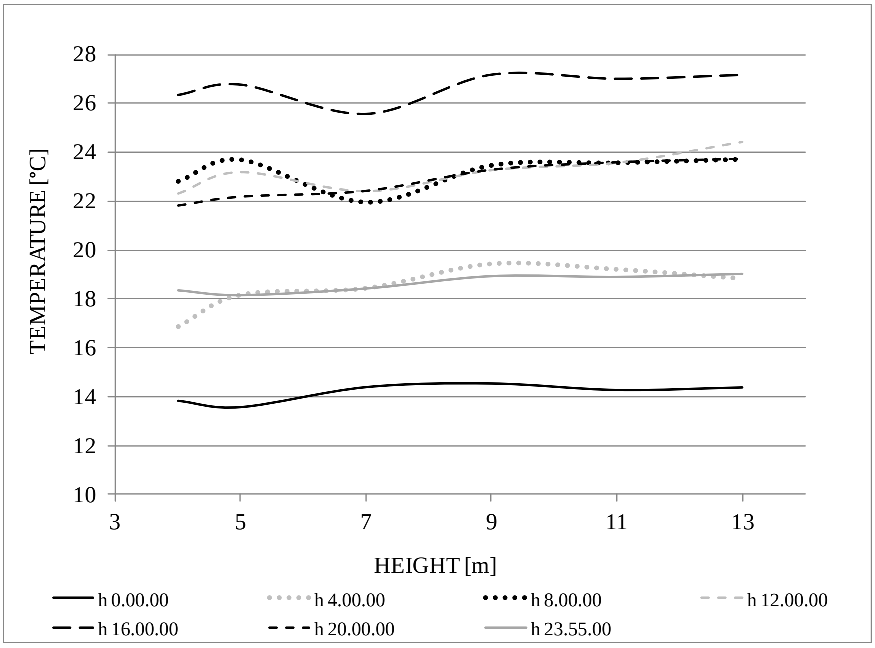

Figure 4-12. Temperature stratification during the first day of “MADE” (3 February 2010).

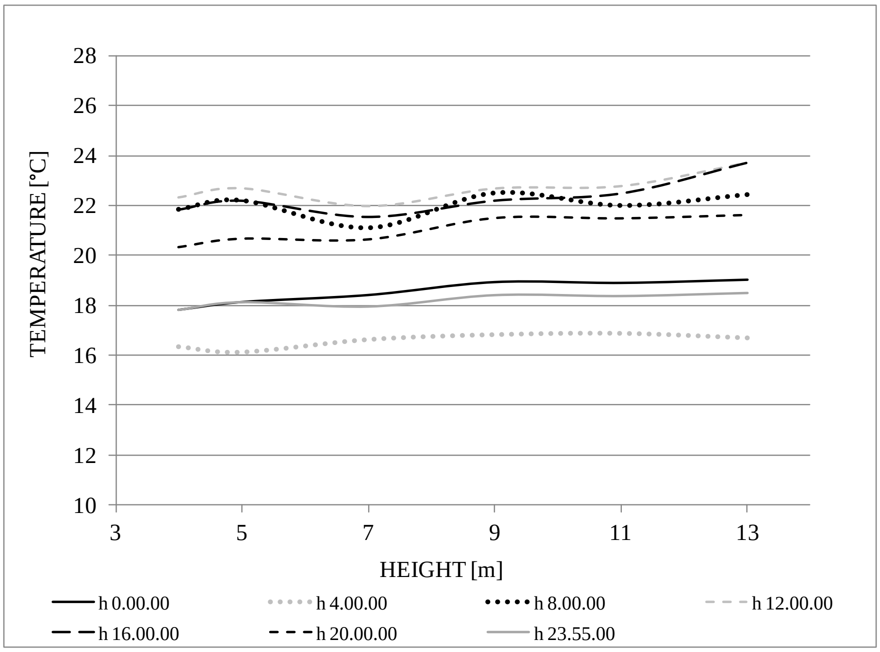

Figure 4-13. Temperature stratification during the second day of “MADE” (4 February 2010).

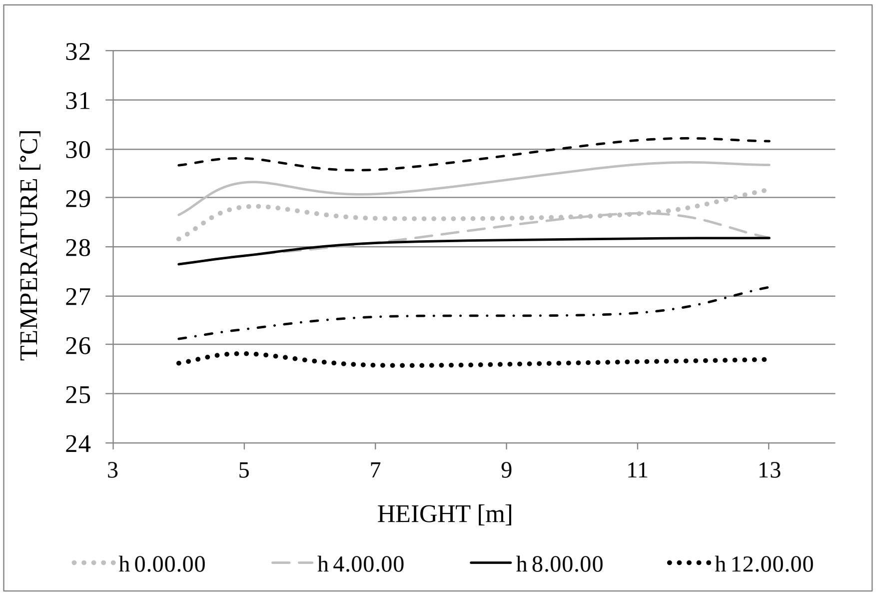

Figure 4-14. Temperature stratification during the first day of “TUTTO FOOD” (10 June 2009).

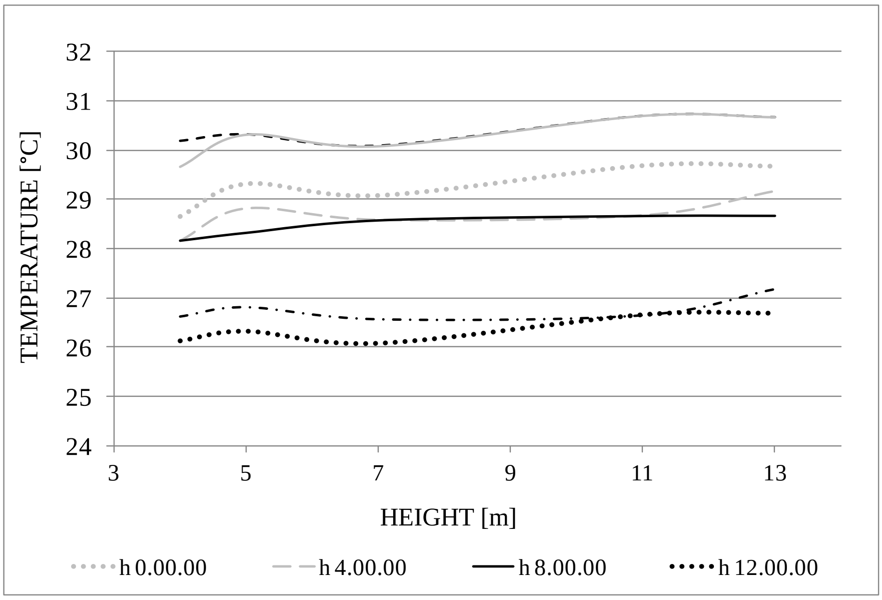

Figure 4-15. Temperature stratification during the second day of “TUTTO FOOD” (11 June 2009).

After this analysis, it seemed a reasonable approximation to model the hall as a single thermal zone.

4.2.1.3. THE IDENTIFICATION OF THE THERMAL-PHYSICAL CHARACTERISTICS

The starting point of this phase is the finding and elaboration of all the data about the envelope. In particular the information provided by the building owner are:

- plans, façade and sections of the sample hall;
- different layers and materials of the opaque envelope;
- technical data about the transparent envelope.

The next stage was the elaboration of these information:

- identification of the thermal-physical characteristics of each material (specific heat capacity, density, conductivity);
- computation of the thermal transmittance of the transparent and opaque components;
- assessment of the thermal bridges;
- evaluation of the critical parts of the envelope.

The composition and the U value of the opaque and transparent components of the envelope are shown in the following tables. It must be noted that the concrete panel is a sandwich panel with an insulation layer embedded in the concrete. In order to describe this panel in DesignBuilder, an equivalent homogeneous layer was defined. The thermal conductivity and specific heat capacity of this fictitious layer were assessed on the basis of a parallel thermal network, as reported more in detail in Appendix 1.

Table 4-2. The thermal-physical characteristics of the envelope components.

FLOOR					
Material	**Thickness (m)**	**Specific heat capacity (J/kgK)**	**Conductivity (W/mK)**	**Density (kg/m^3)**	**Resistance (m^2K/W)**
compacted granular mix	0.35	1045	2	1950	0.18
compacted concrete mix	0.3	1000	1	1800	0.30
structural concrete screed	0.2	1000	1.8	2400	0.11
					R (m^2K/W)
Internal surface resistance					0.17
External surface					0.04
Total thermal resistance					0.80
					U (W/m^2K)
Transmittance U=					1.26

ROOF					
Material	**Thickness (m)**	**Specific heat capacity (J/kgK)**	**Conductivity (W/mK)**	**Density (kg/m^3)**	**Resistance (m^2K/W)**
aluminium cladding	0.0009	890	209	2700	0.00
glass wool	0.14	840	0.04	14	3.50
corrugated sheet	0.001	1999	52	7800	0.00
mineral wool	0.02	840	0.035	150	0.57
					R (m^2K/W)
Internal surface resistance					0.10
External surface					0.04
Total thermal resistance					4.21
					U (W/m^2K)
Transmittance U=					0.27

STEEL PANEL (HALL UPPER PART)					
Material	**Thickness (m)**	**Specific heat capacity (J/kgK)**	**Conductivity (W/mK)**	**Density (kg/m^3)**	**Resistance (m^2K/W)**
steel	0.0005	2000	52	7800	0.00
polyurethane foam	0.079	1600	0.035	35	2.26
aluminium sheet	0.0005	2000	52	7800	0.00
					R (m^2K/W)
Internal surface resistance					0.13
External surface					0.04
Total thermal resistance					2.43
					U (W/m^2K)
Transmittance U=					0.41

ALUMINIUM PANEL (NORTH FACADE/AUXILIARY BUILDING)					
Material	**Thickness (m)**	**Specific heat capacity (J/kgK)**	**Conductivity (W/mK)**	**Density (kg/m^3)**	**Resistance (m^2K/W)**
painted aluminium	0.0025	890	209	2700	0.00
air	0.065				0.18
rockwool	0.12	840	0.038	120	3.16
plasterboard	0.0125	1090	0.21	900	0.06
					R (m^2K/W)
Internal surface resistance					0.13
External surface					0.04
Total thermal resistance					3.57
					U (W/m^2K)
Transmittance U=					0.28

CONCRETE PANEL (HALL LOWER PART)					
Material	**Thickness (m)**	**Specific heat capacity (J/kgK)**	**Conductivity (W/mK)**	**Density (kg/m^3)**	**Resistance (m^2K/W)**
concrete	0.05	880	1.16	2000	0.04
concrete-polystyrene	0.14	1199	0.52	30	0.27
concrete	0.06	880	1.16	2000	0.05
					R (m^2K/W)
Internal surface resistance					0.13
External surface					0.04
Total thermal resistance					0.53
					U (W/m^2K)
Transmittance U=					1.87

FLOOR AUXILIARY BUILDING					
Material	**Thickness (m)**	**Specific heat capacity (J/kgK)**	**Conductivity (W/mK)**	**Density (kg/m^3)**	**Resistance (m^2K/W)**
flooring	0.02	840	1.3	2300	0.02
concrete screed	0.08	880	0.9	1800	0.09
lightweight concrete	0.06	880	0.16	500	0.38
cast in concrete	0.14	1000	2.3	2300	0.06
corrugated sheet	0.001	1999	52	7800	0.00
					R (m^2K/W)
Internal surface resistance					0.17
External surface					0.04
Total thermal resistance					0.75
					U (W/m^2K)
Transmittance U=					1.33

ROOF AUXILIARY BUILDING					
Material	**Thickness (m)**	**Specific heat capacity (J/kgK)**	**Conductivity (W/mK)**	**Density (kg/m^3)**	**Resistance (m^2K/W)**
aluminium cladding	0.0009	890	209	2700	0.00
glass wool	0.04	840	0.04	40	1.00
malta	0.05	1000	0.8	1600	0.06
structural concrete screed	0.13	1000	1.8	2400	0.07
cast in concrete	0.13	1000	2.3	2300	0.06
corrugated sheet	0.001	1999	52	7800	0.00
					R (m^2K/W)
Internal surface resistance					0.10
External surface					0.04
Total thermal resistance					1.33
					U (W/m^2K)
Transmittance U=					0.75

The Table 4-3 shows the characteristics of the transparent envelope, frame and divider.

Table 4-3. Areas and thermal transmittance of the transparent envelope.

	GLASS LAYER		**FRAME**		**n°**	**U_W(W/m^2K)**	**n° UPRIGHTS**	**n° CROSSPIECES**
	AREA (m^2)	Ug (W/m^2K)	AREA (m^2)	Uf (W/m^2K)				
EAST								
glass doors	85.25	1.40	21.59	8.15	8	2.76	3+2	1+2
external glass door	12.34	1.40	2.70	8.15	1	2.61	3+2	1+2
window building 2	6.23	1.90	1.50	5.17	10	2.54	0	0
window building 1	6.23	1.90	1.50	5.17	10	2.54	0	0
WEST								
glass doors	85.25	1.40	21.59	8.15	8	2.76	3+2	1+2
external glass door	12.34	1.40	2.70	8.15	1	2.61		
window building 1	11.84	1.90	2.85	5.17	19	2.54	0	0
NORTH								
window building 2	6.85	1.90	1.65	5.17	11	2.54	0	0
window building 1	9.97	1.90	2.40	5.17	16	2.54	0	0
glass - left	358.99	1.40	40.06	9.75	1	2.24	23+2	3+2
glass - right	149.58	1.40	18.47	9.68	1	2.31		
SOUTH								
glass doors	63.94	1.40	16.19	8.15	6	2.76	3+2	1+2
window building 2	14.95	1.90	3.60	5.17	24	2.54	0	0
window building 1	37.38	1.90	9.00	5.17	60	2.54	0	0
glass - corridor left	195.34	1.40	23.73	9.55	1	2.28	25	2
glass - corridor right	74.93	1.40	9.24	9.62	1	2.30	11	2
HORIZONTAL								
skylights 1 min	135.01	2.70	18.75	9.74	1	3.56	7	7
skylights 1 max	169.54	2.70	20.90	9.74	1	3.47	7	7

At this step, the assessment of thermal bridges was elaborated referring to the technical standard UNI EN ISO 14683.

Each typology of thermal bridge was considered, those due the morphological features and those due to the combination of different materials.

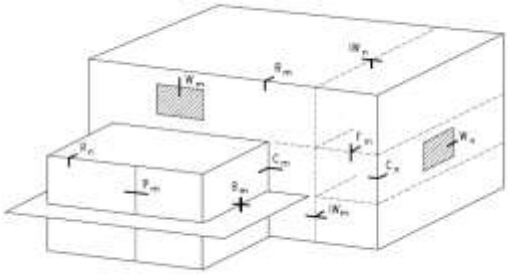

Figure 4-16. Different typologies of thermal bridges due to the morphology of the building.

Figure 4-17. Examples of thermal bridges due to the morphology of the building in the representative hall.

The length “l” of each thermal bridge was measured in the 3D model and a transmittance per unit length “Ψ” was associated. Finally the product of these two factors was estimated.

Table 4-4. Assessment of the incidence of the thermal bridge.

EVALUATION THERMAL BRIDGE	UNI EN ISO 14683			
THERMAL BRIDGE TYPOLOGY	**EXPOSITION**	**Ψ [W/(mK)]**	**l [m]**	**Ψ*l [W/K]**
morfology/different type material	north/south/east/west	UNI EN ISO 14683	measured	product

The incidence of all the thermal bridges on the heat losses of the hall was estimated considering the ratio $\frac{\sum_{i=n}^{n}\Psi l}{\sum_{i=n}^{n}AU}$ (where U indicates the thermal transmittance and A the area to which it refers). The ratio results less than 3%, so the effects of the thermal bridges were not considered in the simulation model.

The preliminary assessment of the critical parts of the envelope is given (Table 4-5) and it is based on the identification of those parts characterized by a high value of the product of thermal transmittance and its surface, compared to the total. In fact, the parts of the envelope which have a high value of $AU/(AU)_{tot}$, are responsible, in steady state, of most of the heat losses. The results show the critical role of the floor, the roof and the vertical concrete panels. It should be stressed that the floor is in thermal contact with the ground and not directly with the outside air; for this reason, it has been considered the corrective factor (0.45) in the ratio Area/Transmittance because of the different temperature condition of the adjacent space, the ground (UNI TS 300-1: 2008). Finally, it may also be noted the modest influence of the transparent parts.

Table 4-5. The preliminary assessment of the most critical parts of the envelope.

	AREA (m^2)								
VERTICAL ENVELOPE	**EAST**	**WEST**	**SOUTH**	**NORTH**	**Total Area (m^2)**	**U (W/m^2K)**	**Corrective factor**	**A*U (W/K)**	**(AU/AUtot)**
concrete panel	1465	1465	777	0	3707	1.87		6923	**15.0%**
steel panel	1197	1197	61	0	2454	0.41		1011	2.2%
aluminium panel	229	229	959	1694	3111	0.28		872	1.9%
opaque doors	143	143	117	84	488	0.44		214	0.5%
glass doors	123	123	81	0	328	2.76		906	2.0%
glass - left	0	0	0	399	399	2.24		893	1.9%
glass - right	0	0	0	168	168	2.31		388	0.8%
glass corridor - left	0	0	219	0	219	2.28		500	1.1%
glass corridor - right	0	0	84	0	84	2.30		194	0.4%
windows	15	15	65	21	116	2.52		293	0.6%
HORIZONTAL ENVELOPE					**Total Area (m^2)**	**U (W/m^2K)**		**A*U (W/K)**	**(AU/AUtot)**
floor					37424	1.26	0.45	21154	**45.9%**
floor auxiliary building					559	1.33		745	1.6%
roof					36322	0.27		9807	**21.3%**
roof auxiliary building					1317	0.75		989	2.1%
skylights 1 min					154	3.56		547	1.2%
skylights 2 max					190	3.47		661	1.4%
	EAST	**WEST**	**SOUTH**	**NORTH**	**Total Area (m^2)**			46098	0.53
total	3173	3172	2363	2366	87040				
	EAST	**WEST**	**SOUTH**	**NORTH**	**horizontal**	**Total Area (m^2)**			
transparent envelope	139	138	449	588	344				
opaque envelope	3034	3034	1914	1778	75622	85381.91			

4.2.1.4. THE 3D MODEL

This phase has the purpose to create a three dimensional model of the representative hall in DesignBuilder to be used as input for the simulation in EnergyPlus. The thermal-physical characteristics of the envelope have been associated with the geometric model. Outside elements belonging to the hall, such as stairwells have been described only as shading elements, while the skylights have been described as part of the volume, with a glass surface on the top.

A first modeling of the hall has maintained a high level of geometric detail in the description, as shown in Figure 4-18.

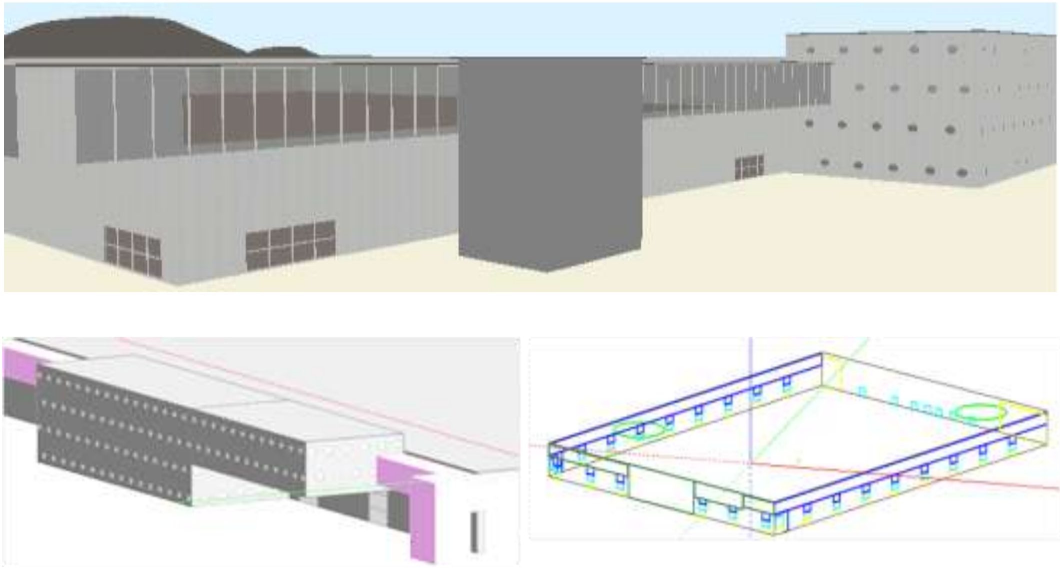

Figure 4-18. The detailed 3D model of the sample hall.

However it has been necessary to simplify the model because of interface problems between the two software. Figure 4-19 shows the 3D model where some simplifications were made, such as the grouping of glass surfaces and doors for each orientation, in order to reduce the number of surfaces.

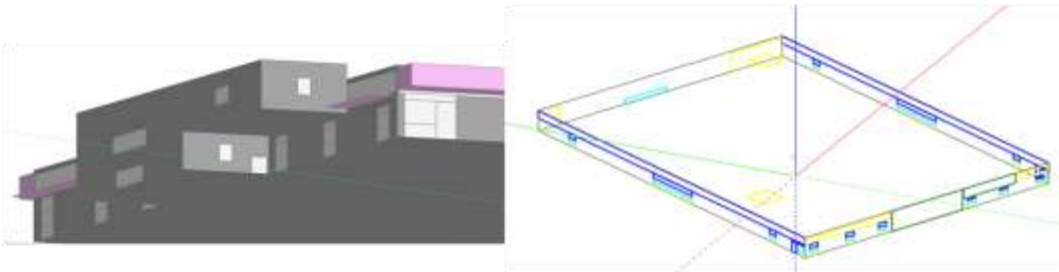

Figure 4-19. The simplified 3D model of the sample hall.

Below it is possible to see how each area has been associated with the corresponding stratigraphy in DesignBuilder.

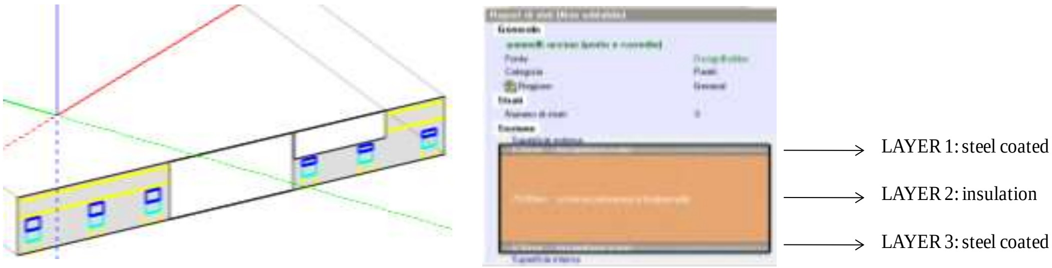

Figure 4-20. Identification of the stratigraphy of the steel panel in the 3D model.

4.2.2. MODEL CALIBRATION IN ENERGYPLUS

The geometrical model and all the necessary data, such as the operating schedule of the AHU, the electricity internal loads, the occupancy profiles and the local weather data, were entered in the EnergyPlus simulation model. Since the research focus was on the envelope retrofitting strategies and on some simple system management strategies, the AHU was not included in the model. In turn the Ideal Load Air System, that is an ideal system that can be used to calculate in EnergyPlus the ideal envelope thermal loads, was adopted.

In a calibration process the results of the simulation are compared with measured data and the simulation is tuned until its results closely match the measured data. In this analysis, a calibration of the model during a representative winter and summer events was done. These two events are called “Made” (3-6 February 2010) and “Tutto Food” (10-13 June 2009).

The Ideal Load Air System Heating/Cooling Rate was compared with the measured heating/cooling rate provided to the AHU. The calibration parameters chosen were the ventilation and infiltration rate (Air Changes per Hour, ACH) and the occupants distribution during the day. In fact, since the AHU was not included in the model but measured consumption refers to the AHU level, the ACH in the simulation model represent the sum of the infiltration air changes of the envelope and the ventilation air changes handled by the real system. The monitoring system of the trade fair does not measure the proportion of indoor/outdoor air flow rates handled by the system. However it is known that the ventilation air changes range between a minimum of 0.4 vol/h to a maximum of 2 vol/h.

4.2.2.1. WINTER EVENT MODEL CALIBRATION

The following graphs illustrate the electrical and thermal consumption rate measured in the representative winter event "MADE" (3-6 February 2010), averaged on an hourly basis.

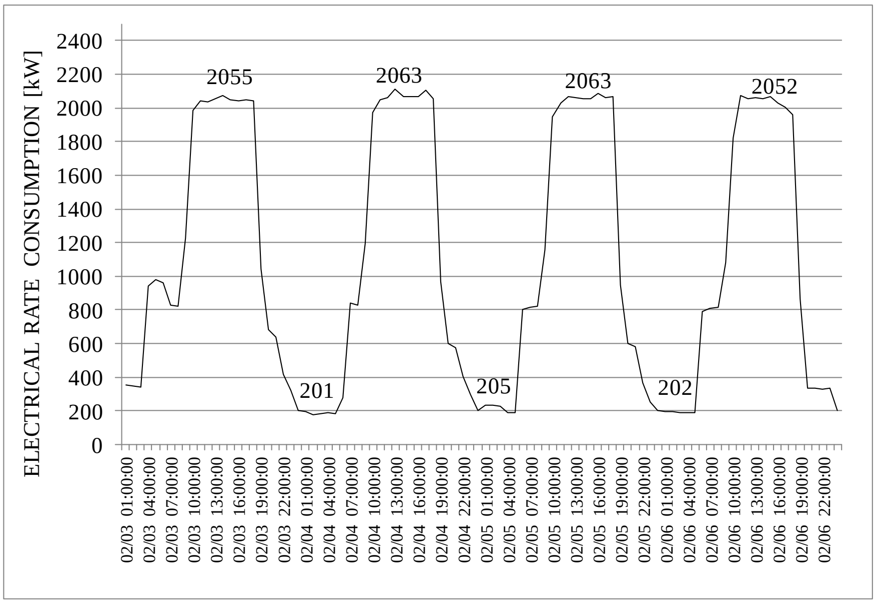

Figure 4-21. Electrical rate consumption, “MADE”, 3-6 February 2010.

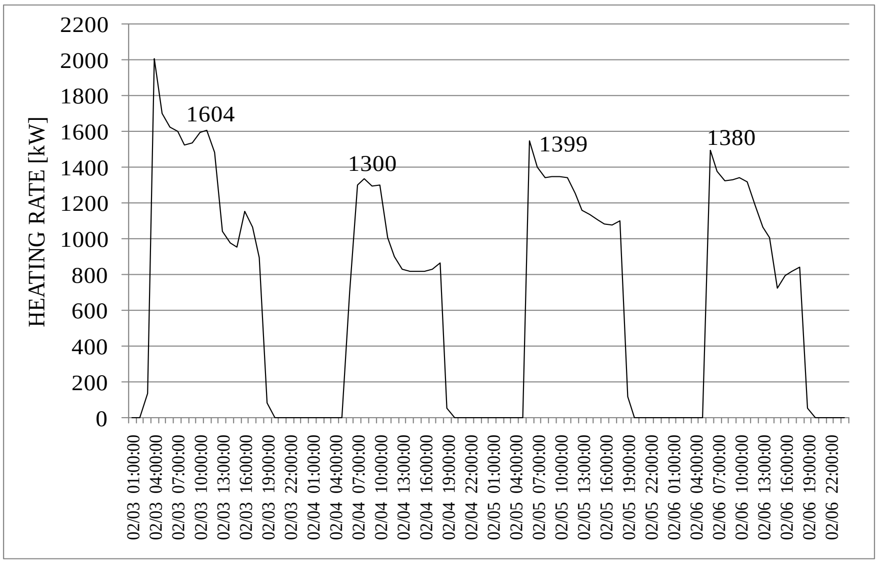

Figure 4-22. Heating energy need, “MADE”, 3-6 February 2010.

In order to calibrate the model with the winter event, the following inputs data have been entered in EnergyPlus:

- geometry and thermal zone: using the 3D model just developed;
- schedule: description of the working schedule of the hall in an hourly step (the operating schedule of the AHU, the set temperature…). The switch on time of technical plants is different in the first day (from 4:00 to 6:00 p.m.) with respect to the other days of the event (from 6:00 to 18:00 hours), the temperature set point is 21 °C, as shown in Figure 4-23. In EnergyPlus, the temperature set when technical plants are switched off is 0°.

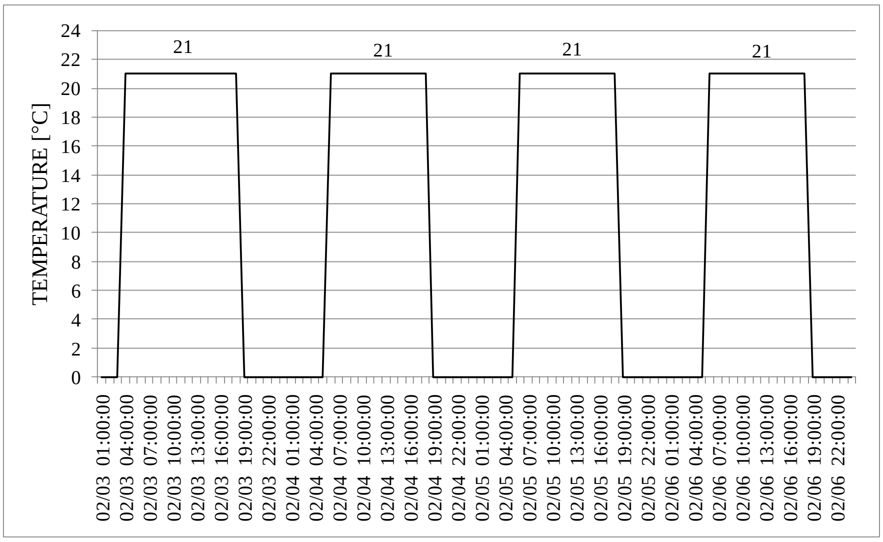

Figure 4-23. The set temperature during "MADE", 3-6 February 2010.

- Internal load: People distribution. One of the calibration parameter is the people distribution during the day. From the measured total number of visitors in a day, two profiles giving the people distribution during the day were created. Figure 4-24 shows the simulated heating rate for the two people distributions. Curve 1 was derived assuming that all the visitors recorded in a day are in the hall during the central hours, while 1/3 of the total is assumed to be there in the opening and closing hours. Instead Curve 2 was derived assuming that the sum of the people present every hour is equal to the total daily number of visitors. Therefore in the winter representative event a larger number of people (Curve 1) decreases the heating rate, because it means a higher internal load. The kind of people distribution seems to be important in winter: this could be understood considering that internal loads due to the people and to the electric equipment are similar. The people distribution corresponding to Curve 1 was chosen for a better match with measured data.

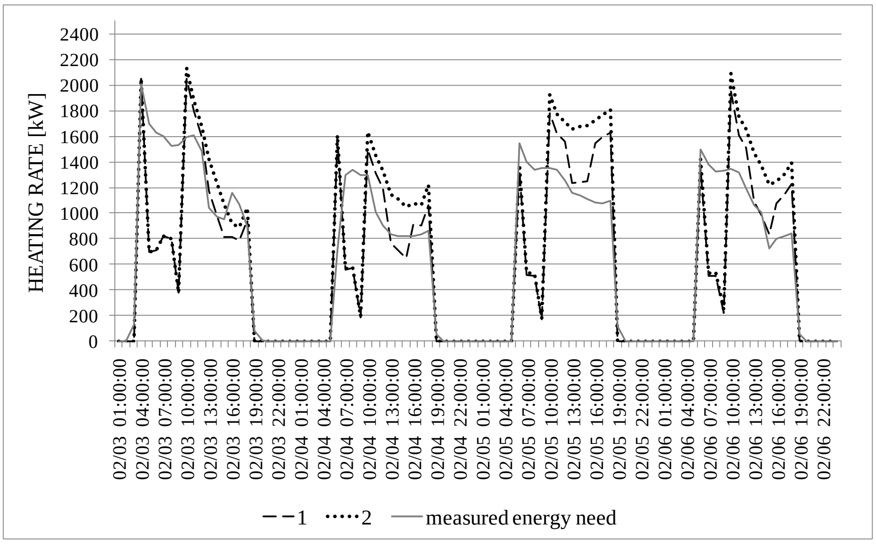

Figure 4-24. Sensitivity of the heating rate to the people distribution during the representative event in winter.

The assumption adopted about the distribution provides a constant flow of people up in the three central hours of the event (equal to the total number of visitors per day) and a third of people in the first and last three hours. Following the Figure 4-25 shows people distribution during the first day of the event.

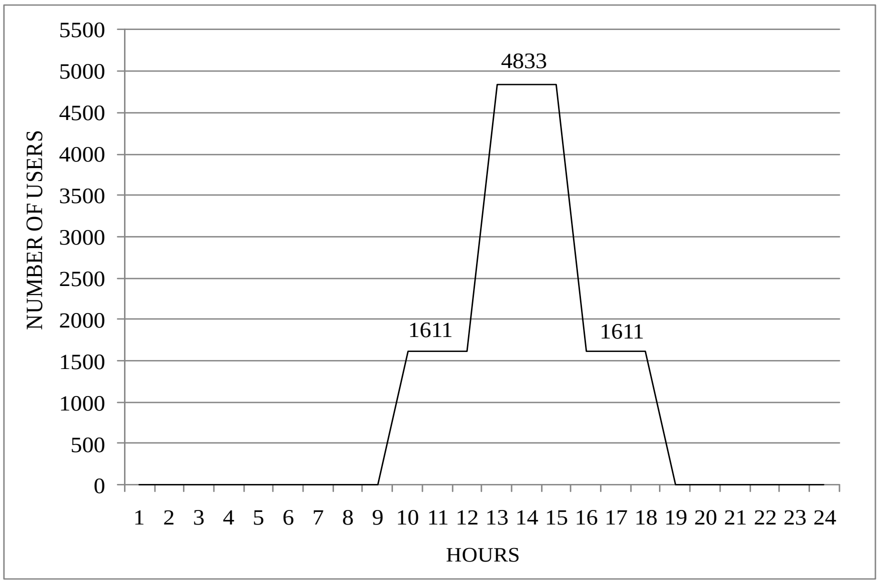

Figure 4-25. People distribution assumed during the first day of "MADE", 3-6 February 2010.

- Internal load: Electric equipment. The hourly data recorded by Fiera Milano were entered (excluding the consumption of AHU).
- Air Change per Hour, due to natural infiltration and ventilation: different values of Air Change per Hour were assumed during the day and night, because greater

ventilation of the hall during the day can be expected because of the frequent opening of the doors by the visitors. Figure 4-26 shows then the great sensitivity of the simulated heating rate to the ACH during the day in winter.

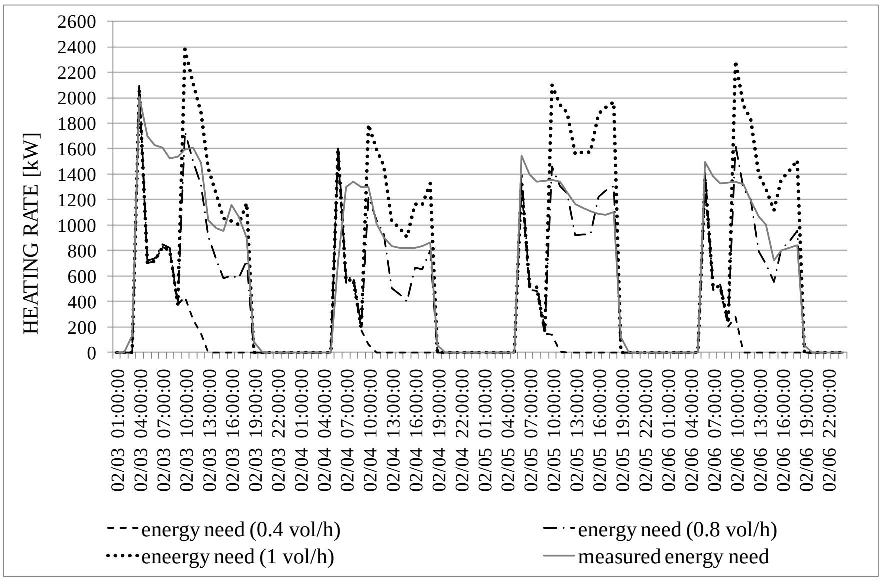

Figure 4-26. Sensitivity of the heating rate to the infiltration during the representative event in winter.

By comparing the simulation data with the measured ones, a variable ACH during the 24 hours was chosen, in order to take into account the on/off of the mechanical ventilation system and the effects of the visitors presence. During the night the value was set to 0.1 vol/h, while during the day the air changes were modulated following the curve of the presence of people in the hall: 0.9 vol/h in the 3 central hours of the day and 0.8 vol/h in the first and last 3 hours. In the 3 hours before the start of the event 0.4 vol/h have been hypothesized due to the presence of the staff (see Figure 4-27).

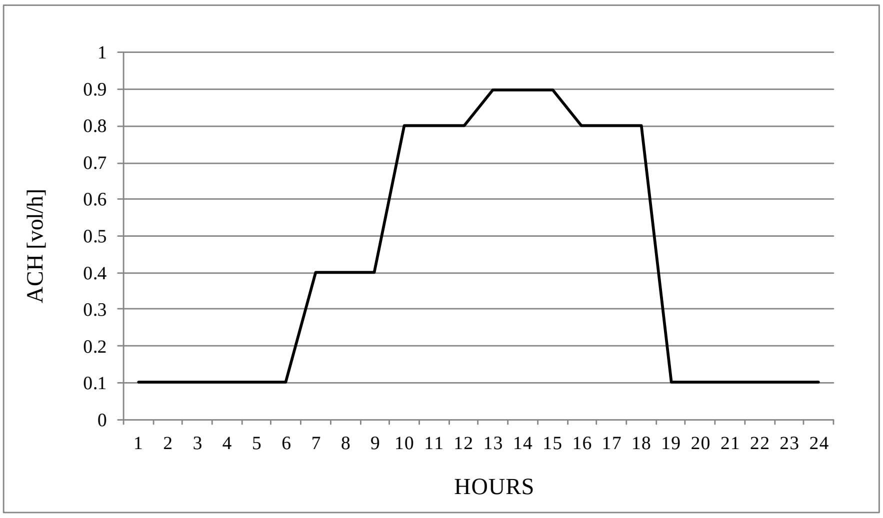

Figure 4-27. ACH during the first day of “MADE”, 3-6 February 2010.

- Weather file: the basic weather file inserted as input in EnergyPlus is relative to the area of Milan-Linate; in order to make the calibration, the file has been integrated with data retrieved from the Meteorological Center Lombard related to Rho and related to the event time period. In particular, the data modified were relative humidity, solar radiation and wind speed, while the outside temperature data was obtained from the weather station of the Milan Trade Fair.

The simulated heating rate achieved with the calibrated model is reported in Figure 4-28, where also the measured heating rate is shown.

The difference between the measured and the simulated overall energy is 4.2%.

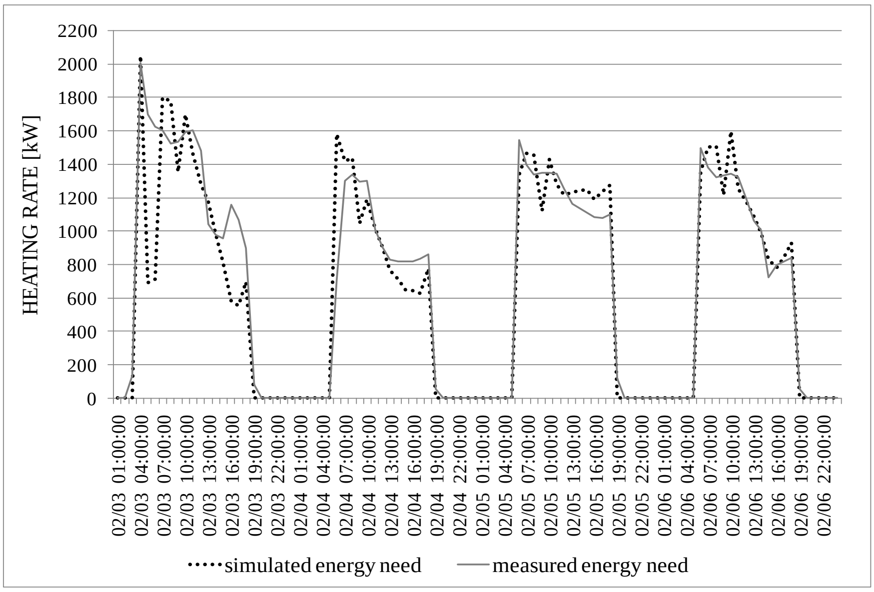

Figure 4-28. Measured and simulated heating rate during "MADE", 3-6 February 2010.

4.2.2.2. SUMMER EVENT MODEL CALIBRATION

The following graphs illustrate the electrical and thermal energy consumption measured in the representative summer event "TUTTO FOOD" (10-13 June 2009), averaged on an hourly basis.

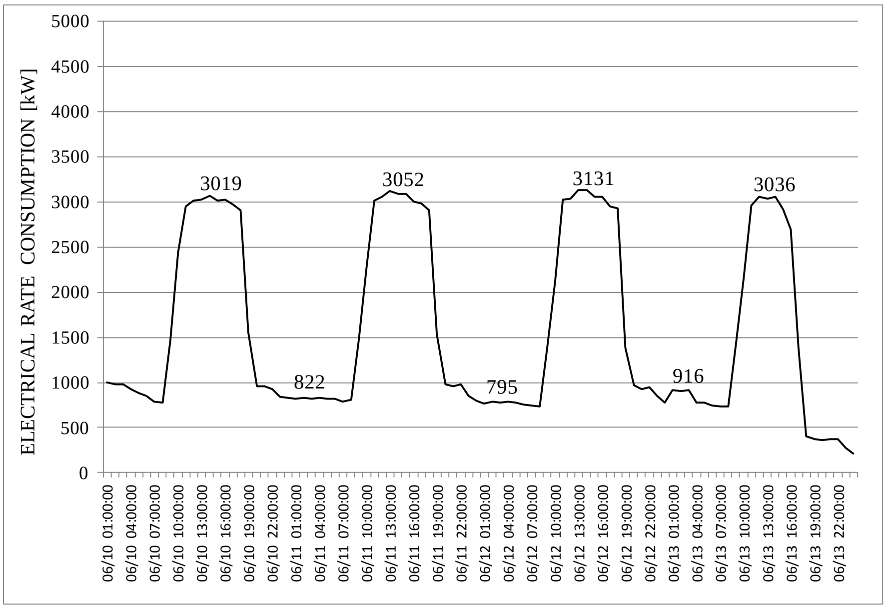

Figure 4-29. Electrical rate consumption, "TUTTO FOOD", 10-13 June 2009.

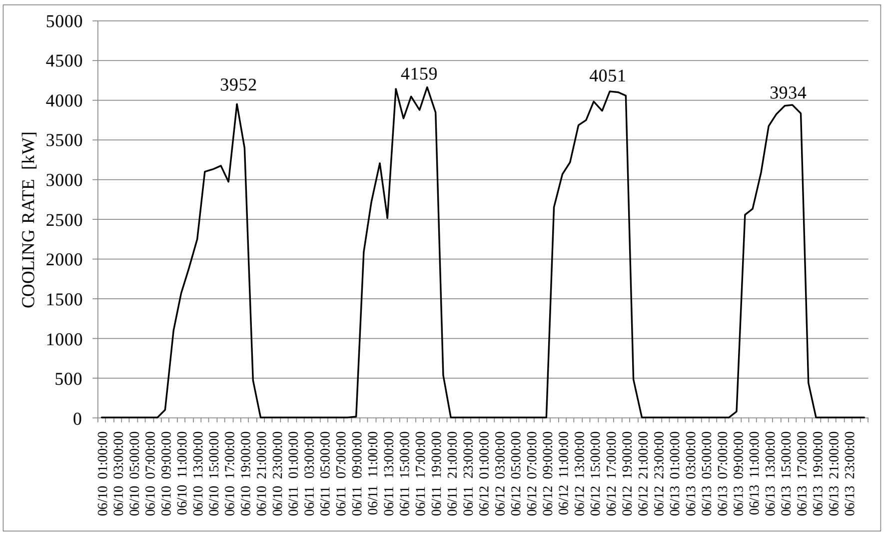

Figure 4-30. Cooling energy need, “TUTTO FOOD”, 10-13 June 2009.

In order to calibrate the winter event, the following input data have been entered in EnergyPlus:

- Geometry and thermal zone: using the 3D model just developed;
- Schedule: description of the working schedule of the hall in an hourly step (the operating schedule of the AHU, the set temperature…). The switch on time of technical plants in the first day is from 7:00 a.m. to 19:00 p.m., in the second and third days is from 9:00 a.m. to 17:00 p.m. and in the last day from 7:00 a.m. to 19:00 p.m. The temperature set point is 23 °C. As in the previous case, the temperature set in EnergyPlus when technical plants are switched off is 0°.

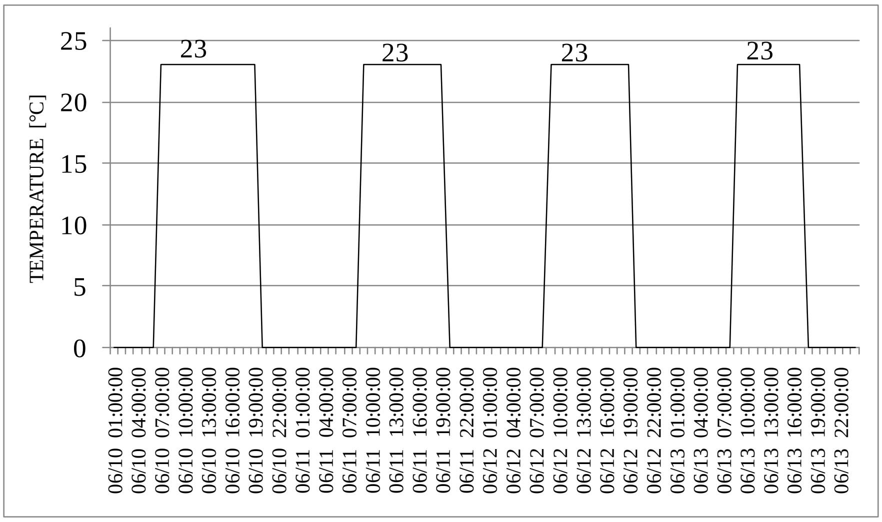

Figure 4-31. The set temperature during “TUTTO FOOD”, 10-13 June 2009.

- Internal load: People distribution. As for the winter event, the data provided is the total number of visitors per day and following the sensitivity analysis due to the two profiles about people distribution is shown. In the summer event, a larger number of people (Curve 1) increases the cooling rate, because it means a higher internal load. The kind of people distribution seems to be less important than in winter; this could be understood considering that in the summer event, internal loads due to the people are about 1/3 of the electric loads (and not similar, as in the winter event). The people distribution corresponding to Curve 1 was chosen for a better match with measured data.

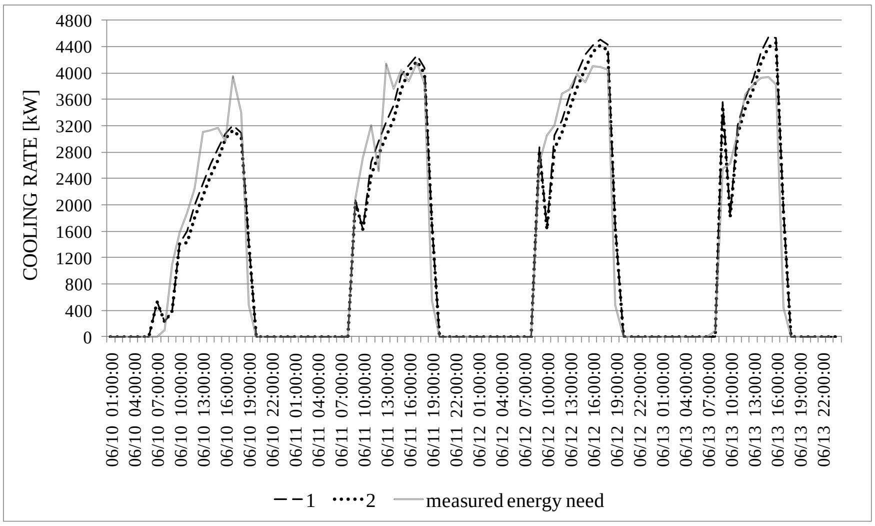

Figure 4-32. Sensitivity of the cooling rate to the people distribution during the representative event in summer.

In this case, the hypothesis about the distribution provides a maximum and constant flow of people up in the first five central hours of the event (equal to the total number of visitors per day) and a third of people in the last three hours. Following, the Figure 4-33 shows people distribution during the first day of the event. The different distribution of the people with respect to the winter event is due to the particular theme of the event, that causes a maximum rate of users during the lunch time.

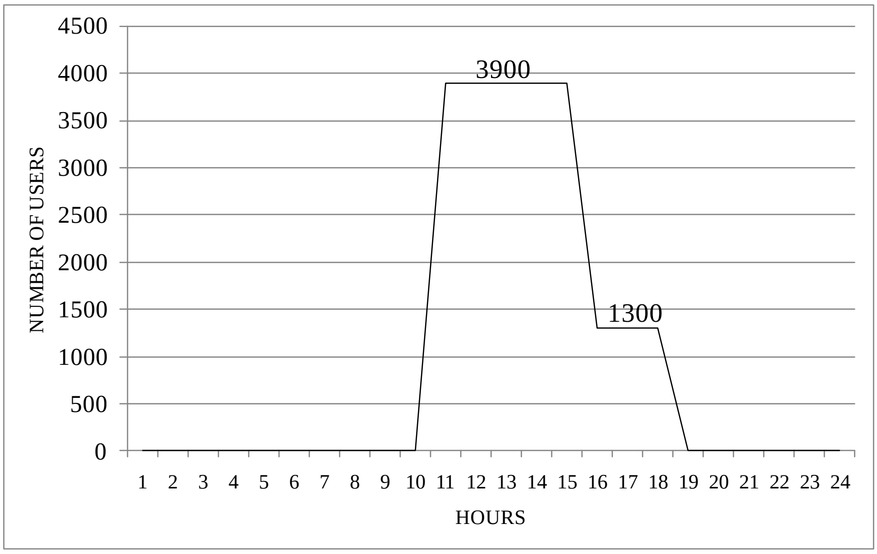

Figure 4-33. People distribution during the first day of “TUTTO FOOD”, 10-13 June 2009.

- Internal load: Electric equipment. The hourly data recorded by Fiera Milano were entered (excluding the consumption of AHU).
- Air Change per Hour, due to natural infiltration and ventilation. As for the winter event, following a sensitivity analysis to the ACH is shown.

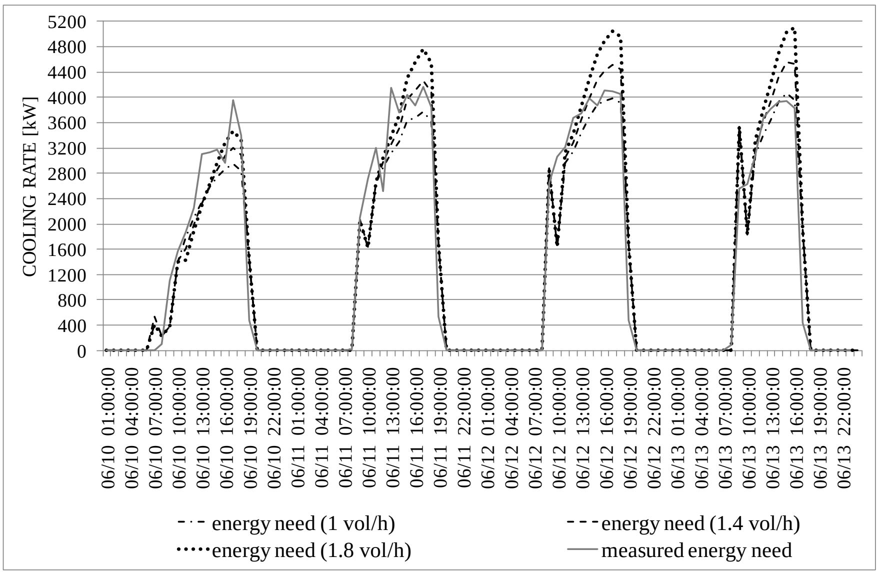

Figure 4-34. Sensitivity of the cooling rate to the infiltration during the representative event in summer.

Different values of air change per hour were assumed: during the night the value was set to 0.1 vol/h, while during the day the air changes were modulated following the curve of the presence of people in the hall: 1.4 vol/h in the first 5 hours of the day and 1.3 vol/h in the last 3 hours. In the 3 hours before the start of the event 0.7 vol/h have been hypothesized due to the presence of the staff (see

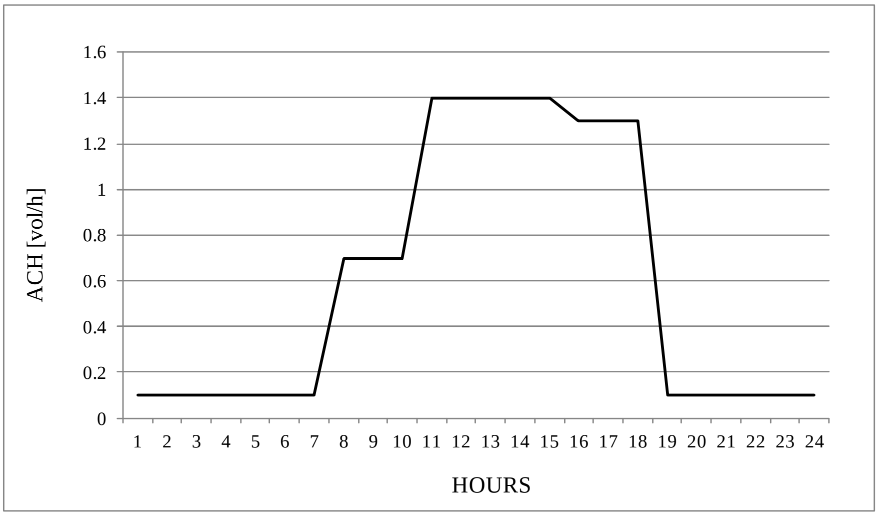

Figure 4-35. ACH during the first day of "TUTTO FOOD", 10-13 June 2009.

- Weather file: the same used in the winter calibration.

The simulated heating rate achieved with the calibrated model is reported in Figure 4-36, where also the measured heating rate is shown.

The difference between the measured and the simulated overall energy is 2.7%.

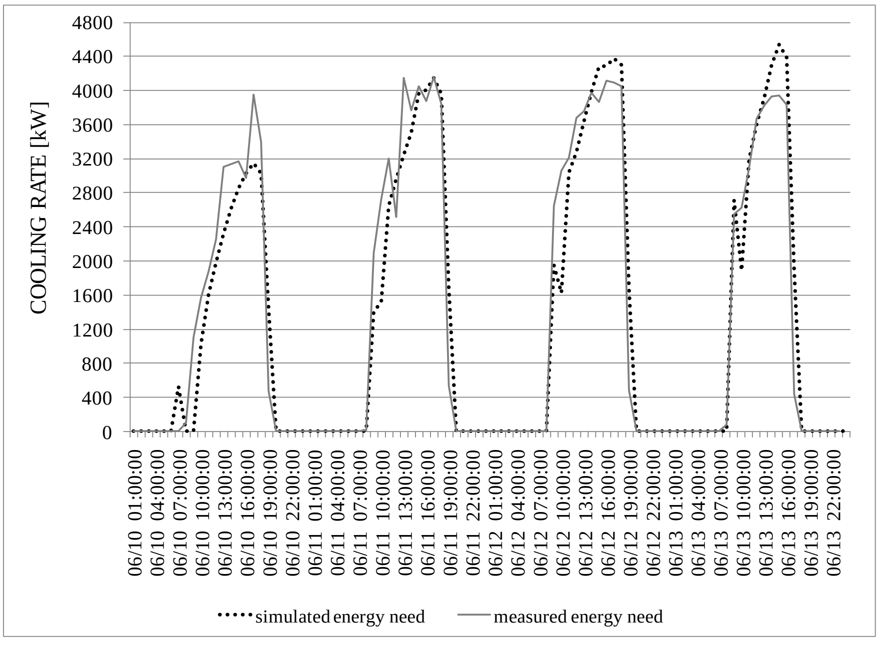

Figure 4-36. Measured and simulated heating rate during "TUTTO FOOD", 10-13 June 2009.

To calculate the energy demand for cooling the hypothesis to estimate the latent heat rate has been considered, as the AHU may sometimes provide dehumidification (see Appendix 2). In this case, during the day, the air change per hour has been set equal to 1 vol/h at the peak of users and 0.9 in the last 3 hours of the event.

The simulation output has returned as an overall energy need for the four-day event that deviates from the real situation recorded by Fiera Milano for a value equal to 4.5% (Figure 4-37). The two models, corresponding to the assumption that only the sensible load or the sensible and the latent load are supplied, provide similar results with regard to the agreement with the measured data.

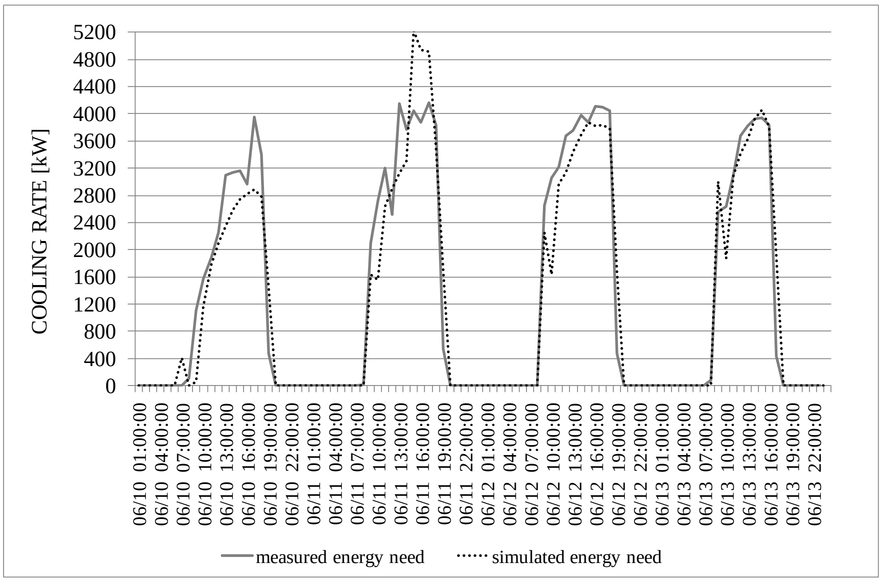

Figure 4-37. Measured and simulated heating rate (sensible+latent) during "TUTTO FOOD", 10-13 June 2009.

4.3. REFERENCE ENERGY CONSUMPTION

After calibrating the model, a dynamic simulation of a representative year was performed.

Below are the input data:

- Geometry and thermal zone: using the 3D model just developed;
- Schedule: description of the working schedule of the hall in an hourly step (the operating schedule of the AHU, the set temperature…). The switch on time of technical plants in the winter events is from 5:00 a.m. to 18:00 p.m., in the summer events from 8:00 a.m. to 18:00 p.m. The set temperature is 21 °C in winter and 23 °C in summer.

- Internal load: People distribution. A description of the hourly number of people in the hall during each events was done. The data provided is the total number of visitors per day. The hypothesis about the distribution provides a maximum and constant flow of people in the central hours of the event (equal to the total number of visitors per day) and a third of people in the first and last three hours.
- Internal load: Electric equipment. The hourly data recorded by Fiera Milano were entered (excluding the consumption of AHU).
- Air change per hour, due to natural infiltration and ventilation: the values of air change per hour were assumed following the curve of people distribution. The values used in the winter events are the same used in MADE and the values used in the summer events are the same used in TUTTO FOOD.
- Weather file: the basic weather file inserted as input in EnergyPlus is relative to the area of Milan-Linate.

The heating and cooling energy results were converted into primary energy considering the efficiency of the heating system (Waste To Heat efficiency 37%, heating distribution grid efficiency 90%, gas boilers efficiency 85%) and of the cooling system (COP 6, national electrical efficiency 41%).

4.4. ENERGY SAVING MEASURES

4.4.1. STUDY AND SIMULATION OF STRATEGIES TO IMPROVE THE ENERGY EFFICIENCY

The aim of this phase is to highlight the solutions able to reduce the primary energy demand for heating and cooling of the typical hall. The proposed intervention strategies were chosen in relation to the particular kind of building and to the real feasibility. The solutions include retrofit interventions on the envelope (considering the present Italian regulation regarding the maximum values of thermal transmittance (DM 11/3/2008 and DM 7/4/2008) to achieve an economic incentive) and simple management strategies of the heating/cooling system.

The simulated solutions regarding the energy performance of the envelope are:

- internal insulation of the vertical panels (so that thermal transmittance passes from U=1.87 W/m^2K to U'=0.24 W/m^2K), as shown in Table 4-6.

Table 4-6.Thermal-physical characteristics of the concrete panel with internal insulation.

INTERNAL INSULATION CONCRETE PANEL (HALL LOWER PART)					
Material	**Thickness (m)**	**Specific heat capacity (J/kgK)**	**Conductivity (W/mK)**	**Density (kg/m^3)**	**Resistance (m^{2}K/W)**
concrete	0.05	880	1.16	2000	0.04
concrete-polystyrene	0.14	1199	0.52	2000	0.27
concrete	0.06	880	1.16	2000	0.05
rockwool	**0.13**	**1030**	**0.036**	**90**	**3.61**
					R (m^{2}K/W)
Internal surface resistance					0.13
External surface resistance					0.04
Total thermal resistance					4.15
					U (W/m^{2}K)
Transmittance U= (1/Rtot)					0.24

- external insulation of the vertical panels (from U= 1.87 W/m^{2}K to U'= 0.24 W/m^{2}K), as shown in Table 4-7.

Table 4-7. Thermal-physical characteristics of the concrete panel with external insulation.

EXTERNAL INSULATION CONCRETE PANEL (HALL LOWER PART)					
Material	**Thickness (m)**	**Specific heat capacity (J/kgK)**	**Conductivity (W/mK)**	**Density (kg/m^3)**	**Resistance (m^{2}K/W)**
rockwool	**0.13**	**1030**	**0.036**	**90**	**3.61**
concrete	0.05	880	1.16	2000	0.04
concrete-polystyrene	0.14	1199	0.52	2000	0.27
concrete	0.06	880	1.16	2000	0.05
					R (m^{2}K/W)
Internal surface resistance					0.13
External surface resistance					0.04
Total thermal resistance					4.15
					U (W/m^{2}K)
Transmittance U= (1/Rtot)					0.24

- roof insulation (from U=0.27 W/m^{2}K to U'=0.10 W/m^{2}K), as shown in Table 4-8.

Table 4-8. Thermal-physical characteristics of the insulated roof.

INSULATED ROOF					
Material	**Thickness (m)**	**Specific heat capacity (J/kgK)**	**Conductivity (W/mK)**	**Density (kg/m^3)**	**Resistance (m^{2}K/W)**
aluminium cladding	0.0009	890	209	2700	0.00
glass wool	**0.05**	**800**	**0.038**	**100**	**1.32**
expanded polistyrene	**0.09**	**1340**	**0.036**	**18**	**2.50**
expanded polistyrene	**0.075**	**1340**	**0.036**	**18**	**2.08**
glass wool	0.14	840	0.04	14	3.50
corrugated sheet	0.001	1999	52	7800	0.00
mineral wool	0.02	840	0.035	150	0.57
					R (m^{2}K/W)
Internal surface resistance					0.10
External surface resistance					0.04
Total thermal resistance					10.11
					U (W/m^{2}K)
Transmittance U= (1/Rtot)					0.10

- floor insulation (from U=1.26 W/m^{2}K to U'=0.26 W/m^{2}K), as shown in Table 4-9.

Table 4-9. Thermal-physical characteristics of the insulated floor.

INSULATED FLOOR					
Material	**Thickness (m)**	**Specific heat capacity (J/kgK)**	**Conductivity (W/mK)**	**Density (kg/m^3)**	**Resistance (m^{2}K/W)**
compacted granular mix	0.35	1045	2	1950	0.18
compacted concrete mix	0.3	1000	1	1800	0.30
structural concrete screed	0.2	1000	1.8	2400	0.11
structural concrete scree	**0.08**	**1000**	**1.8**	**2400**	**0.04**
expanded polistyrene	**0.12**	**1340**	**0.04**	**25**	**3.00**
					R (m^{2}K/W)
Internal surface resistance					0.17
External surface resistance					0.04
Total thermal resistance					3.84
					U (W/m^{2}K)
Transmittance U= (1/Rtot)					0.26

- clear painting of the roof (so that the albedo passes from A=0.5 to A'=0.1);
- clear painting of the vertical panels (from A=0.5 to A'=0.1).

The simulated interventions at the system management level are instead:

- summer night ventilation (free cooling);
- variation of the set point temperature (passing from 21°C to 20°C in winter, and from 23°C to 24°C in summer);
- early switch off of the system (1 hour in advance).

After simulating individual solutions, the most promising individual solutions were combined.

4.4.2. COMPARISON OF SIMULATION RESULTS

The total primary energy savings resulting from each intervention were calculated and compared. They are reported in Table 4-10 and Figure 4-38 (retrofit interventions), in Table 4-11 and Figure 4-40 (system management strategies) and finally in Table 4-13 and Figure 4-41 (combined solutions).

Figure 4-38 shows that roof and walls insulation lead to a significant primary energy saving during the year. In the case of the walls insulation the yearly energy saving results from a decrease of the heating demand and an increase of the cooling demand. The roof insulation instead has a positive impact on both the heating and cooling energy., as can be seen in Table 4-10, where beside the annual primary energy consumption, the primary energy consumption for heating and the primary energy consumption for cooling are shown separately.

Table 4-10. Results of simulated strategies of energy retrofit.

ENERGYPLUS SIMULATIONS	Total primary energy consumption [kWh]	% Saving	Total primary energy consumption for heating [kWh]	% Saving (heating)	Total primary energy consumption for cooling [kWh]	% Saving (cooling)
Present energy behaviour	545667	-	318508	-	265320	-
SIMPLE SIMULATION ON THE ENVELOPE						
roof insulation	515923	5.5%	299565	5.9%	257422	3.0%
walls internal insulation	510532	6.4%	292665	8.1%	270368	-1.9%
walls external insulation	515741	5.5%	296644	6.9%	269009	-1.4%
floor insulation	564430	-3.4%	325000	-2.0%	292948	-10.4%
clear painted roof	594048	-8.9%	359235	-12.8%	237045	10.7%
clear painted panels	548358	-0.5%	320967	-0.8%	262945	0.9%

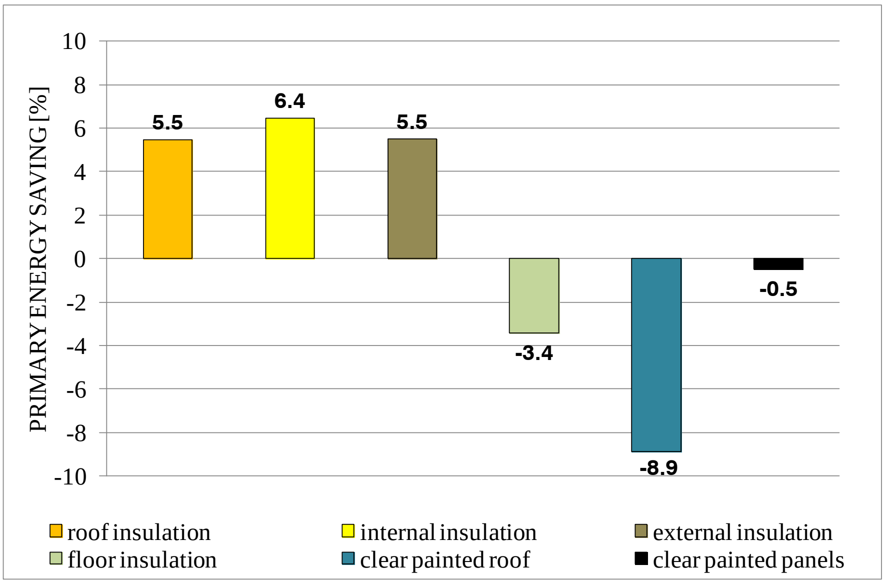

Figure 4-38. Results of simulated strategies of energy retrofit.

Otherwise it is interesting to notice that reducing the floor thermal transmittance, by adding an insulation layer on the inside, leads to an increase in the primary energy consumption resulting for both an increase in winter and in summer. In order to understand this outcome, the inside face conduction heat flow (named "dynamic") calculated by EnergyPlus is reported in Figure 4-39 for the base floor and for the insulated floor, during a winter event. Moreover, a steady state heat flow is shown, calculated by taking the product of the surface temperatures difference and the floor thermal conductance $(T_{surf,outside} - T_{surf,inside})\,C$.

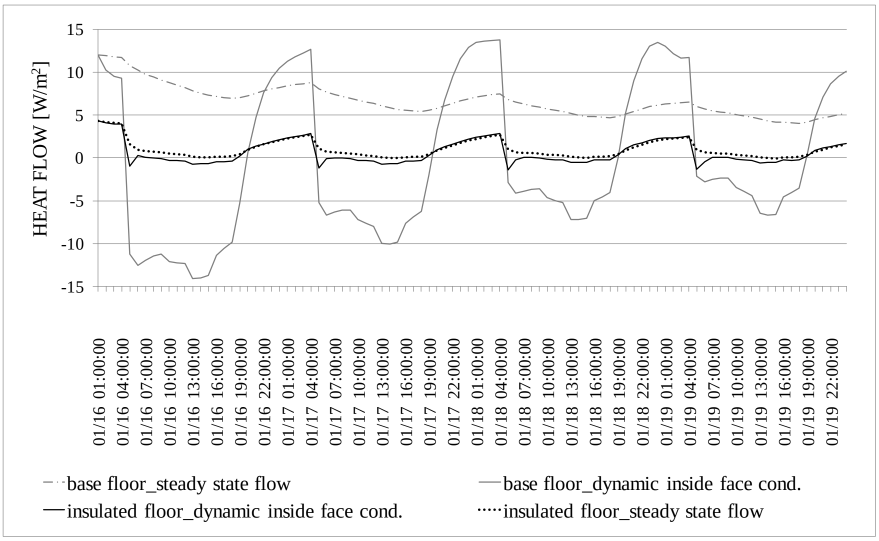

Figure 4-39. Heat flow through the floor.

Observing the dynamic heat flux of the base floor it is possible to see that during the day it represents a heat loss from the hall, while during the night it turns into a heat gain (the floor releases heat to the indoor environment). Considering the insulated floor, the dynamic and the steady heat fluxes are quite similar, meaning that the floor thermal inertia is dramatically reduced by the insulation layer. In this case, the heat flux is a thermal loss most of the time. Therefore, since in this kind of buildings during the day important internal gains are produced, the floor thermal inertia helps using these gains to reduce the energy demand.

Increasing the albedo of the roof and of the walls has a negative impact on the primary energy consumption, since the reduction in the cooling energy does not overcome the increase in the heating energy.

Table 4-11. Results of system management strategies.

ENERGYPLUS SIMULATIONS	Total primary energy consumption [kWh]	% Saving	Total primary energy consumption for heating [kWh]	% Saving (heating)	Total primary energy consumption for cooling [kWh]	% Saving (cooling)
Present energy behaviour	545667	-	318508	-	265320	-
SIMPLE MANAGEMENT ACTIONS						
T setpoint wint 20°C/sum 23 °C	469866	13.9%	265379	16.7%	265320	0.0%
T setpoint wint 21°C/sum 24 °C	527187	3.4%	318508	0.0%	211584	20.3%
T setpoint wint 20°C/sum 24 °C	451386	17.3%	265379	16.7%	211584	20.3%
early switch off plant (1 hour)	520506	4.6%	308330	3.2%	234383	11.7%
free cooling (8 hours)	595610	-9.2%	318508	0.0%	247140	6.9%
free cooling (4 hours)	569850	-4.4%	318508	0.0%	253938	4.3%

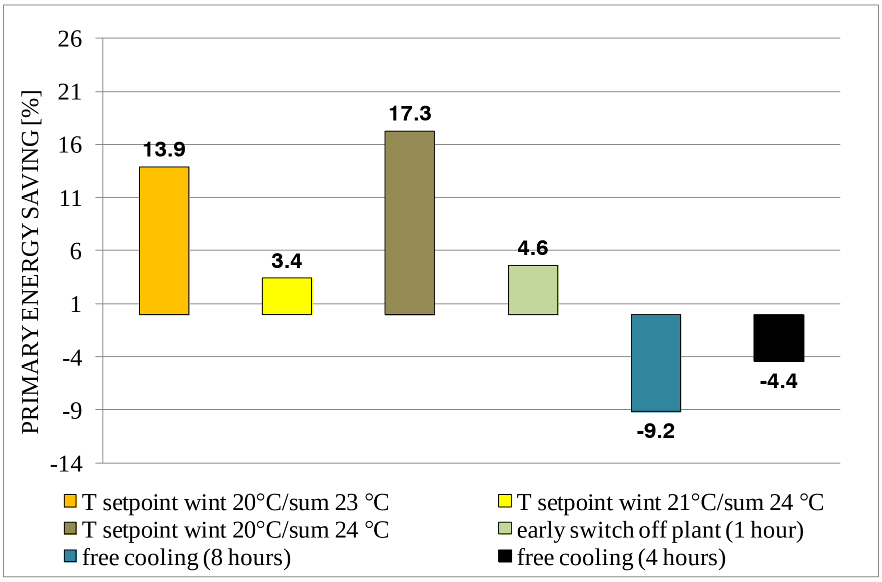

Figure 4-40. Results of system management strategies.

Among the system management strategies, the variation of the set point temperature leads to an important energy saving, up to 17% if both the winter and the summer setpoints are modified by only 1 °C.

Another strategy that leads to an energy saving of about 5 % regards the possibility to switch off the plant one hour before the closing of the event. In this case it was verified that in the 98% of the time the temperature maintains an acceptable value (the difference between the indoor temperature and the setpoint value is lower than 2 °C).

Adopting a free cooling strategy in summer events, through mechanical ventilation eight hours per night, would reduce the electricity consumption for cooling. The calculation of the energy consumption due to a summer night mechanical ventilation were calculated taking into account the power and the number of AHU in the hall, the number of nights of the summer events and the hours when free cooling is assumed.

Table 4-12. Electrical energy consumption of the AHU.

Event	Power AHU [kW]	Number AHU	N. hours free cooling	N. nights	Electrical energy consumption (kWh)
1	8	18	8	5	5760
2	8	18	8	3	3456
3	8	18	8	3	3456
4	8	18	8	5	5760
5	8	18	8	4	4608
				tot. Energy need	23040
				tot. Primary Energy	**56195**

If the energy consumption for AHU were not considered, the summer night ventilation of 8 hours would lead to annual savings of 3% in terms of primary energy (PE= 539 415 kWh). Having also considered the energy consumptions of fans (56 195 kWh), there is an increase in energy demand by 9.2%. The increase in the electricity consumption of the presently installed fans overcomes the savings, so that this strategy is not advantageous, also considering only four hours of free cooling per night.

In Figure 4-41 the results of the combined solutions are shown.

Table 4-13. Results of combined simulated strategies.

ENERGYPLUS SIMULATIONS	**Total primary energy consumption [kWh]**	**% Saving**	**Total primary energy consumption for heating [kWh]**	**% Saving (heating)**	**Total primary energy consumption for cooling [kWh]**	**% Saving (cooling)**
Present energy behaviour	545667	-	318508	-	265320	-
COMBINED SOLUTIONS						
roof ins+int ins	480886	11.9%	273913	14.0%	261962	1.3%
T setp var+roof ins	424938	22.1%	248528	22.0%	204585	22.9%
T setp var+int ins	420571	22.9%	242583	23.8%	216551	18.4%
roof ins+int ins+T setp var	392193	28.1%	224451	29.5%	209257	21.1%
T setp var+early sw off plant	431145	21.0%	257214	19.2%	186601	29.7%
roof ins+int ins+early sw off plant	457315	16.2%	264694	16.9%	231666	12.7%
roof ins+int ins+T setp var+early sw off plant	373853	31.5%	217490	31.7%	184808	30.3%

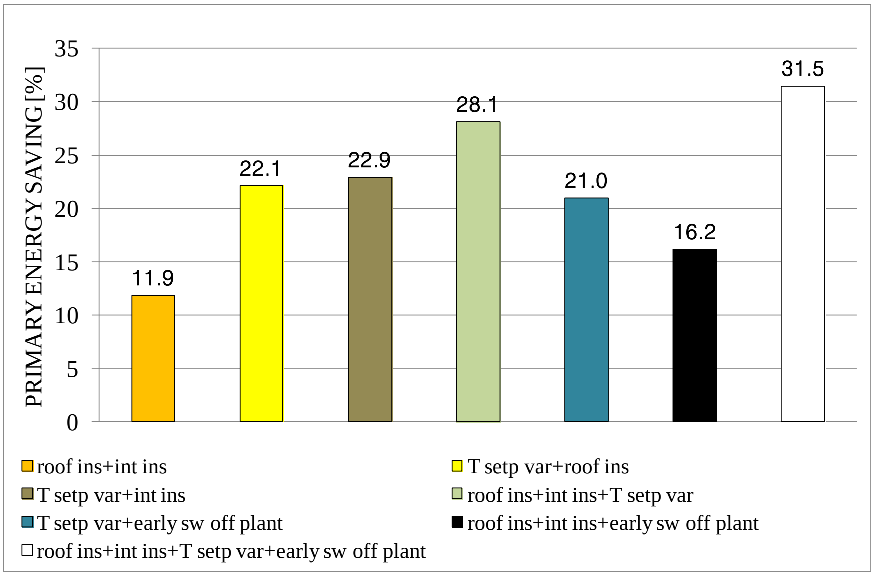

Figure 4-41. Results of combined simulated strategies.

Combining roof insulation, walls insulation, the variation of the set point temperature and the early switch off of plant, an annual saving of 31.5% can be achieved.

4.4.3. SIMPLE PAYBACK TIME ASSESSMENT

Below are the estimated simple payback time for the retrofit strategies.

Internal insulation

Considering the price list for the execution of public works and maintenance (Comune di Milano, 2010), the price list of public works (Regione Lombardia, 2009) and the structural characteristics of the market for public works (Regione Lombardia, 2004), the original investment was estimated in 235303 €. Considering a cost of 0.05 €/kWh$_t$ and of 0.11 €/kWh$_e$, that corresponds to the present costs for the heating and electricity supply of the Milan Trade Fair, it is possible to get an annual saving of 1343 €, that is clearly too small compared to the initial investment. This trade off is mainly due to the short use period of the exhibition hall, that is only 52 days in a year, as shown in the schedule of a representative year. If it were used as a common office /commercial building (5 days a week), the annual saving would be 6716 €, with a payback time of about 35 years (refurbishment cost/annual saving). Considering also the deduction of 55% (DM 11/3/2008 and DM 7/4/2008), the payback time would reduce to about 16 years.

External insulation

Considering the original investment was estimated in 235303 €, it is possible to get an annual saving of 1147 €. If it were used as a common office /commercial building (5 days a week), the annual saving would be 5735 €, with a payback time of about 41 years. Considering also the deduction of 55%, the payback time would reduce to about 18 years.

Roof insulation

The original investment was estimated in 2091420 € and it is possible to get an annual saving of 1197 €. If it were used as a common office /commercial building (5 days a week), the annual saving would be 6000 €. Considering also the deduction of 55%, the payback time would reduce to about 130 years. Considering environmental and economic benefits, this intervention could hardly be carried out.

This analysis ended in a scientific publication (Angelotti et al., 2011).

5 Environmental assessments in the life cycle

5.1. EVALUATIONS OF THE RETROFIT STRATEGIES IN THE LIFE CYCLE

This chapter starts analyzing the solutions of energy savings in a life cycle assessment to see the relationship between the benefits got in the use phase and the environmental impacts developed during all the life cycle.

Besides, the embodied energy of the representative hall and other environmental impacts were calculated and, finally, a proposal for a redesign of the building envelope was suggested to reduce both the value of embodied energy and the energy consumption.

5.1.1. ASSESSMENT OF THE EMBODIED ENERGY OF THE RETROFIT STRATEGIES AND OTHER ENVIRONMENTAL IMPACTS INDICATORS

The environmental indicators, such as the embodied energy, can be used for example to compare alternative products or materials, in order to choose the least impactful.

The literature values on the embodied energy of the materials are “unit values”, namely expressed in relation to the weight or volume and then in relation to the mass of material. In a first instance it would seems appropriate to use this data directly to select materials with lower embodied energy. But this statement is misleading, because such a comparison does not take into account the amount of material required to achieve the required performance. Operating comparisons between materials, it is necessary to define a “functional unit” of reference and, consequently, the amount of material that carries out a specific performance. For example, if the thermal transmittance is the functional unit set, it is necessary to consider the embodied energy of the amount of material which allows to reach the established value of transmittance.

The aim of this paragraph is the evaluation of the embodied energy and other impacts indicators of the added materials of the retrofit strategies, such as the insulation of the inner/external coat and the insulation of the roof.

Following are the tables with the parts of the envelope involved in the renovation. The thermal transmittance calculation before and after the refurbishment and the thickness of the juxtaposed materials are shown.

- internal insulation:
  - from U=1.87 W/m^{2}K to U’=0.24 W/m^{2}K;

- from thickness t=0.25 m to thickness t'=0.38 m.

Table 5-1. Thermal-physical characteristics of the concrete panel with internal insulation.

INTERNAL INSULATION CONCRETE PANEL (HALL LOWER PART)					
Material	**Thickness (m)**	**Specific heat capacity (J/kgK)**	**Conductivity (W/mK)**	**Density (kg/m^3)**	**Resistance (m^{2}K/W)**
concrete	0.05	880	1.16	2000	0.04
concrete-polystyrene	0.14	1199	0.52	2000	0.27
concrete	0.06	880	1.16	2000	0.05
rockwool	**0.13**	**1030**	**0.036**	**90**	**3.61**
					R (m^{2}K/W)
Internal surface resistance					0.13
External surface resistance					0.04
Total thermal resistance					4.15
					U (W/m^{2}K)
Transmittance U= (1/Rtot)					0.24

- external insulation:
  - from U=1.87 W/m^{2}K to U'=0.24 W/m^{2}K;
  - from thickness t=0.25 m to thickness t'=0.38 m

Table 5-2. Thermal-physical characteristics of the concrete panel with external insulation.

EXTERNAL INSULATION CONCRETE PANEL (HALL LOWER PART)					
Material	**Thickness (m)**	**Specific heat capacity (J/kgK)**	**Conductivity (W/mK)**	**Density (kg/m^3)**	**Resistance (m^{2}K/W)**
rockwool	**0.13**	**1030**	**0.036**	**90**	**3.61**
concrete	0.05	880	1.16	2000	0.04
concrete-polystyrene	0.14	1199	0.52	2000	0.27
concrete	0.06	880	1.16	2000	0.05
					R (m^{2}K/W)
Internal surface resistance					0.13
External surface resistance					0.04
Total thermal resistance					4.15
					U (W/m^{2}K)
Transmittance U= (1/Rtot)					0.24

- roof insulation:
  - from U=0.27 W/m^{2}K to U'=0.10 W/m^{2}K;
  - from thickness t=0.16 m to thickness t'=0.38 m.

Table 5-3. Thermal-physical characteristics of the insulated roof.

INSULATED ROOF					
Material	**Thickness (m)**	**Specific heat capacity (J/kgK)**	**Conductivity (W/mK)**	**Density (kg/m^3)**	**Resistance (m^{2}K/W)**
aluminium cladding	0.0009	890	209	2700	0.00
glass wool	**0.05**	**800**	**0.038**	**100**	**1.32**
expanded polistyrene	**0.09**	**1340**	**0.036**	**18**	**2.50**
expanded polistyrene	**0.075**	**1340**	**0.036**	**18**	**2.08**
glass wool	0.14	840	0.04	14	3.50
corrugated sheet	0.001	1999	52	7800	0.00
mineral wool	0.02	840	0.035	150	0.57
					R (m^{2}K/W)
Internal surface resistance					0.10
External surface resistance					0.04
Total thermal resistance					10.11
					U (W/m^{2}K)
Transmittance U= (1/Rtot)					0.10

For each retrofit strategy, a specific material (with technical data sheets and EPD) has been chosen: in this case the materials that need to be analyzed are:

- rock wool, used for both internal and external insulation;
- glass wool and expanded polystyrene (EPS) for the insulation of the roof.

To begin the computation it has been necessary to summarize all the information about the added materials for each retrofit strategy, such as:

- square meters (m^2);
- thickness (m);
- volume (m^3);
- orientation (N-S-E-W);
- density (Kg/m^3);
- weight (Kg);
- conductivity (W/mK);
- specific heat capacity (J/KgK).

This task is necessary because all the information about the environmental impacts produced by materials refers to the physical and thermal-physical characteristics of each material itself.

Below the summary table is shown.

Table 5-4. Summary table with all the necessary information to calculate the embodied energy.

retrofit strategy and materials	orientation and area (m^2)			tot area (m^2)	thickness (m)	volume (m^3)	density (Kg/m^3)	weight (Kg)	conductivity (W/mK)	specific heat capacity (J/kgK)
internal insulation										
	EAST	WEST	SOUTH							
rock wool	1465	1465	777	3707	0.13	482	90	43369	0.036	1030
external insulation										
	EAST	WEST	SOUTH							
rock wool	1465	1465	777	3707	0.13	482	90	43369	0.036	1030
roof insulation										
glass wool	horizontal	horizontal	horizontal	36322	0.05	1816	100	181610	0.038	850
expanded polystyrene	horizontal	horizontal	horizontal	36322	0.17	5993	18	107876	0.036	1340

All the data concerning the evaluation of the environmental impacts have been taken from the EPD of each material and they are the embodied energy (the renewable and not renewable primary energy consumption of the pre-production and production phases - PEI-) and some of the main environmental impact indicators, such as the acidification potential, the eutrophication potential, the global worming potential, the ozone depletion potential and the photochemical ozone creation potential[48].

Hereafter, the table with all the impact indicators for each materials is shown. It has to be noted that the EPD shows the value of the indicators per kilogram, therefore, to obtain the complex value, the total amount of each material has been considered.

Table 5-5. The indicators of the environmental impacts of the materials of the retrofit strategies and the embodied energy.

units (/Kg)	**(/Kg)**			**total**		
	EPS	glass wool	rock wool	EPS	glass wool	rock wool
PEI ren [MJ]	1.8	1.3	0.1	194177	243357	4337
PEI non ren [MJ]	110.7	28.8	12.9	11941911	5223104	559454
GWP_{100} [g CO_2 eq]	4500.0	1770.0	1160.0	485443530	321449700	50307468
ODP [g CFC_{11} eq]	0.0000	0.0001	0.0001	0	16	4
POCP [g C_2H_4 eq]	24.4	0.3	0.5	2636977	61747	22552
AP [g SO_2 eq]	16.8	6.7	7.5	1809925	1216787	325264
EP [g PO_4 eq]	1.6	1.1	0.8	173801	199771	35996
	EMBODIED ENERGY (MJ/Kg)			**EMBODIED ENERGY (tot MJ)**		
	EPS	glass wool	rock wool	EPS	glass wool	rock wool
	112.5	30.1	13.0	12136088	5466461	563791

Below there are some graphs that show the comparison between all these indicators of environmental impacts for each material. The figures illustrate both the environmental impacts per kilogram of material and the complex value related to the total amount.

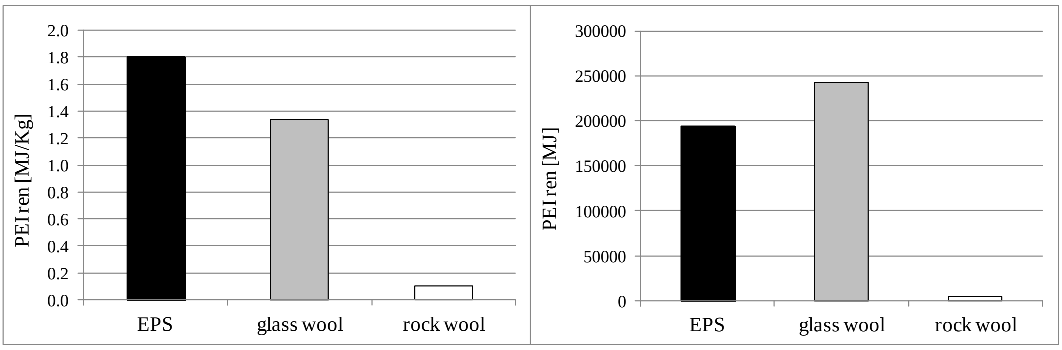

Figure 5-1. Renewable primary energy of EPS, glass wool and rock wool.

[48] All the data have been taken from EPDs of the insulating materials, even if the names of the manufactory companies are not mentioned. Therefore, the results are not absolute but they are referred to the specific context in analysis.

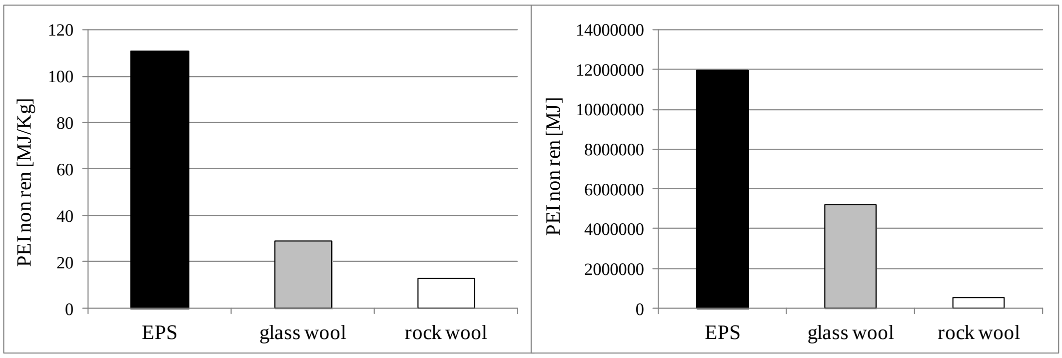

Figure 5-2. Non-renewable primary energy of EPS, glass wool and rock wool.

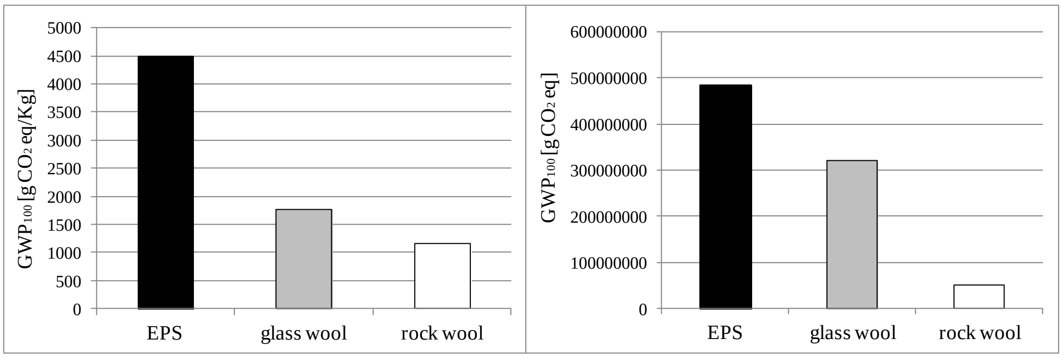

Figure 5-3. Greenhouse potential of EPS, glass wool and rock wool.

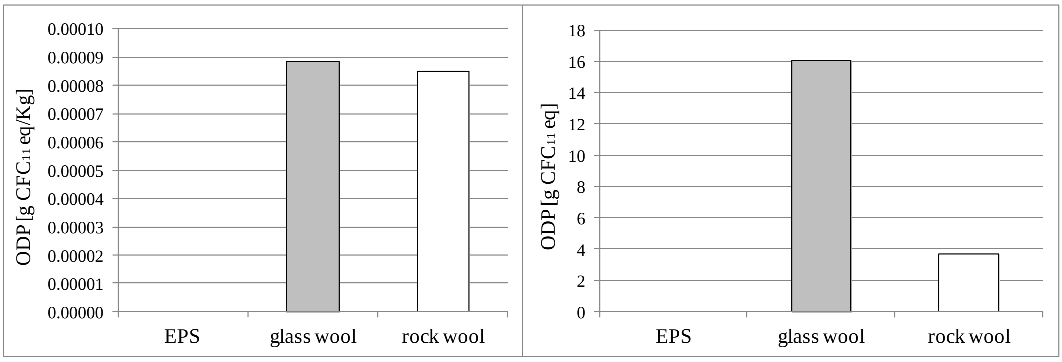

Figure 5-4. Ozone depletion potential of EPS, glass wool and rock wool.

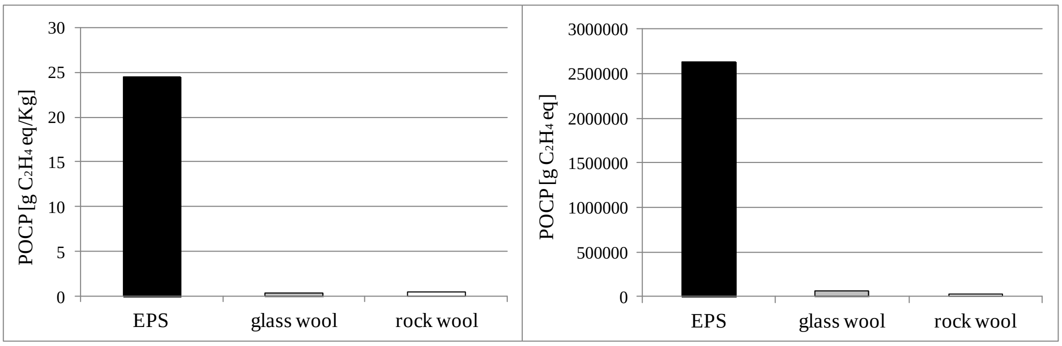

Figure 5-5. Photochemical ozone creation potential of EPS, glass wool and rock wool.

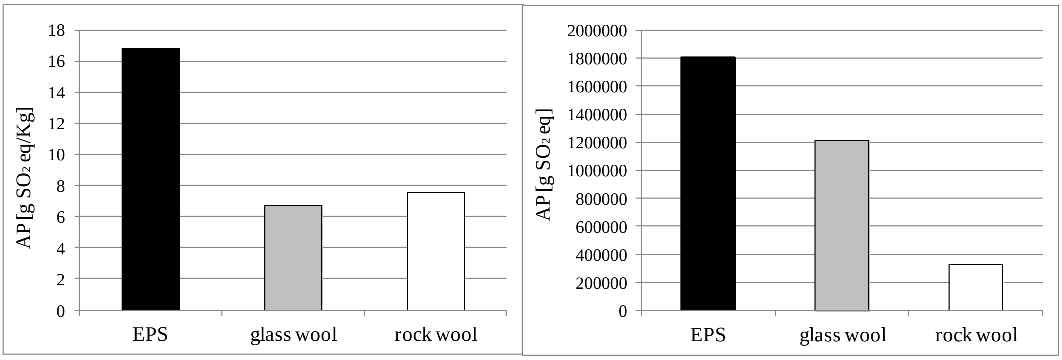

Figure 5-6. Acidification potential of EPS, glass wool and rock wool.

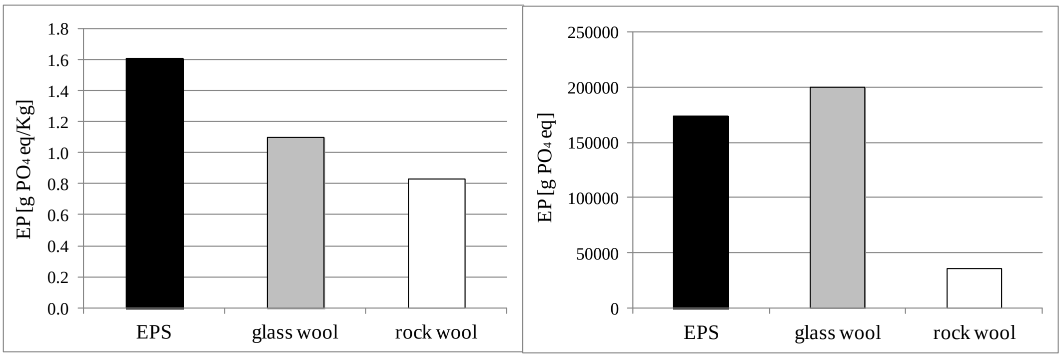

Figure 5-7. Eutrification potential of EPS, glass wool and rock wool.

The previous graphs show the environmental impacts due to the retrofit strategies; comparative conclusions should not be made in absolute terms.

5.1.2. ASSESSMENT OF THE ENERGY DUE TO TRANSPORT

Another very important issue concerns the transport sector, whose impacts are not negligible. The designer has at the disposal a high variety of materials from all over the world thanks to globalization of markets favored by the economy and ease of transport.

Trips made by the materials and building components can lead to a significant increase in environmental impacts; however, it is not easy to realize the long journey undertaken by each building component.

During the entire life cycle of the product it is necessary:

- the transport of raw materials from the extraction site to the place of production;
- the transport of the finished products from the place of production to the construction site;
- at the end of life, the transport of the product to the dump or to the recycling plant.

In this analysis, having considered the indicators of the EPD of each materials, impacts related to the transport to the place of production are already included; the following impacts are calculated for the transport of materials from the factory to the building site.

First of all, the factories closer to the building site for each kind of material have been assumed, with the aim of reducing environmental impacts and CO_2 emissions (even though the data have been taken from the EPD, different factories have been considered. The choice to take the data from EPD is driven by the fact that data are more truthful than those of a generic database);

After the identification of the factories closer to the building site for each materials, the calculation of the indicator "tKm" (ton per kilometer).

Table 5-6. Materials, location of the factories, "tKm" indicator.

material	**location of the factory**	**distance from Rho (Km)**	**t tot (t)**	**(tKm)**
glass wool	Vidalengo di caravaggio (Bergamo, ITALY)	63	182	11441
rock wool	Potpicàn (CROATIA)	520	43	22552
expanded polystyrene	Verolanuova (Brescia, ITALY)	172	108	18555

Afterwards, it has been hypothesized a transport by truck to the building site considering the impact indicators of a medium truck per 1 tKm.

Table 5-7. Environmental impacts of a transport by truck (source: Ecoinvent v.1.3).

indicator	**units**	**truck 32t** environmental impacts 1 truck (32t) per 1tkm
PEI	MJ	3.71
PEI ren	MJ	0.06
GWP	Kg CO_2 eq	0.22
AP	g SO_2 eq	1.22
EP	g PO_4 eq	0.26
POCP	g C_2H_4 eq	0.21
ODP	mg CFC eq	0.04

Finally, the environmental impacts of the transport by truck considering 1 tKm, have been multiplied for the total tKm of each material.

Table 5-8. Total environmental impacts due to the transport by truck.

indicator	**units**	**truck**			
		environmental impacts 1 truck (32t) per 1tkm	total glass wool	total rock wool	total expanded polystyrene
PEI	MJ	3.71	42459	83689	68857
PEI ren	MJ	0.06	641	1263	1039
GWP	Kg CO_2 eq	0.22	2551	5029	4138
AP	g SO_2 eq	1.22	13959	27513	22637
EP	g PO_4 eq	0.26	2929	5773	4750
POCP	g C_2H_4 eq	0.21	2403	4736	3896
ODP	mg CFC eq	0.04	412	812	668

5.1.3. COMPARISON BETWEEN THE ENERGY SAVINGS IN THE USE-PHASE AND THE ENVIRONMENTAL IMPACTS IN THE LIFE CYCLE

In the analysis the comparison between the environmental impacts of the retrofit strategies during the life cycle and the energy savings in the use phase has been done.

In particular have been considered:

- the pre-production and production phases impacts (source data: EPD);
- transport phases impacts (calculated);
- energy savings in the use phase (calculated).

The end of life has been neglected because of the multiple scenarios that could be outlined.

Table 5-9. Energy consumptions and energy savings.

RETROFIT STRATEGY AND MATERIALS	LIFE REFURBISHMENT	ENERGY CONSUMPTIONS		ENERGY SAVINGS
	1 year	embodied energy (MJ/y)	energy due to transport (MJ/y)	energy savings in use phase (MJ/y)
rock wool (internal insulation)		563791	84952	265637
rock wool (external insulation)		563791	84952	225743
EPS+glass wool (roof insulation)		17602549	112996	204598
	10 year	embodied energy (MJ/y)	energy due to transport (MJ/y)	
rock wool (internal insulation)		56379	8495	
rock wool (external insulation)		56379	8495	
EPS+glass wool (roof insulation)		1760255	11300	
	20 year	embodied energy (MJ/y)	energy due to transport (MJ/y)	
rock wool (internal insulation)		28190	4248	
rock wool (external insulation)		28190	4248	
EPS+glass wool (roof insulation)		880127	5650	
	30 year	embodied energy (MJ/y)	energy due to transport (MJ/y)	
rock wool (internal insulation)		18793	2832	
rock wool (external insulation)		18793	2832	
EPS+glass wool (roof insulation)		586752	3767	

In this comparison, it is possible to find the “amortization years” of each refurbishment. When working on a total energy balance, comparing the energy spent in the construction phase of the building and the energy spent during the use of the building, a common indicator has been considered, the MJ/m^2 y.

Different scenarios regarding the life of the interventions have been proposed and for each of them energy consumptions (embodied energy + energy due to transport) and energy savings in the use phase have been calculated.

The results are shown in the following graphs.

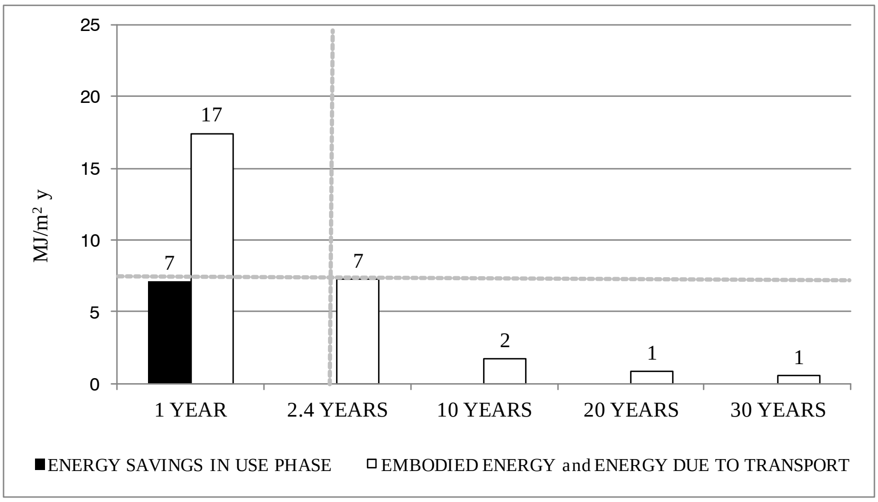

Figure 5-8. The amortization years of the internal insulation.

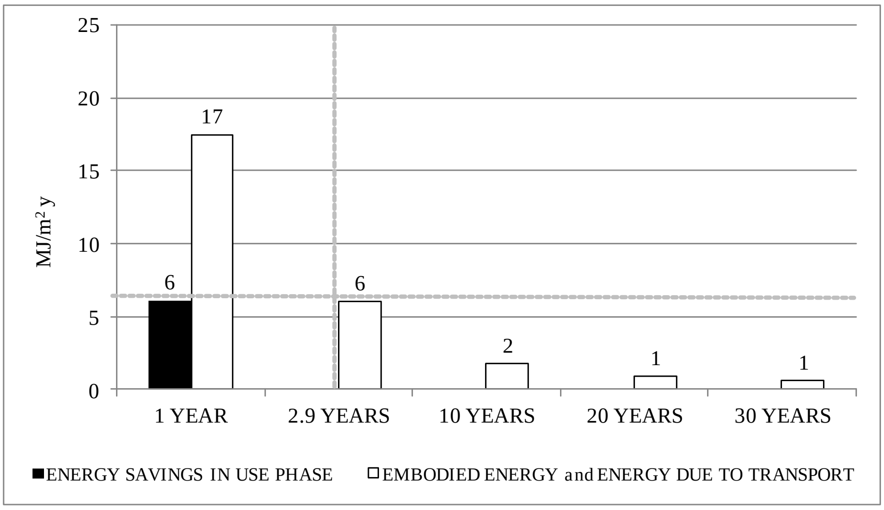

Figure 5-9. The amortization years of the external insulation.

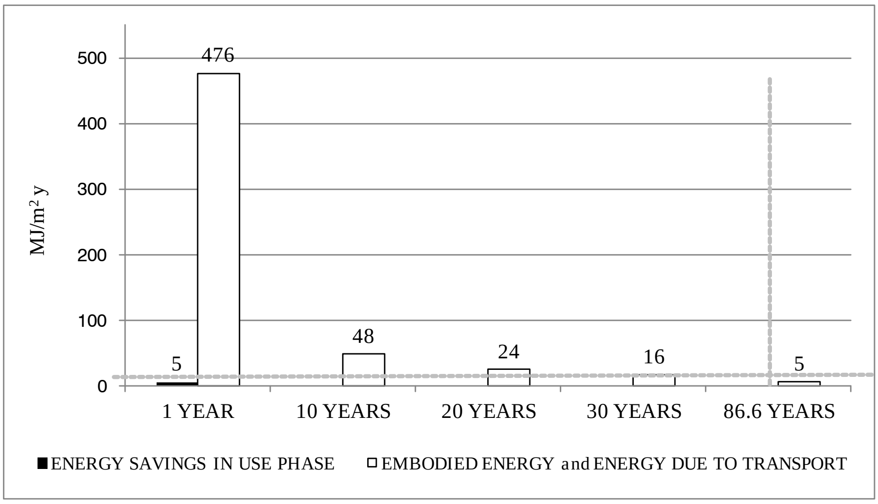

Figure 5-10. The amortization years of the insulated roof.

Summarizing, considering the internal and external insulation it is possible to state that there is a significant decrease of the thermal transmittance (from 1.87 W/m^2K to 0.24 W/m^2K) with 0.13 m of insulation material while considering the roof, there is not a so relevant reduction of the thermal transmittance (from 0.27 W/m^2K to 0.10 W/m^2K) despite the thickness of the material is considerably greater (0.22 m). Moreover it is important to notice that insulate the panel involves a quantity of material almost 7 times lower than isolate the roof, because of the density of the material and the extension of the area involved. That's why the amortization years of internal and external insulation are significantly lower (approximately 3 years) than the ones of the insulated roof (more than 80 years).

As the following graph shows, starting from an high value of thermal transmittance, it is possible to decrease it significantly with a not so relevant increasing of the thickness of insulating material. Otherwise, to reduce the value of the thermal transmittance from a low value in an even lower, a significant thickness is needed and, consequently, many years to amortize the refurbishment.

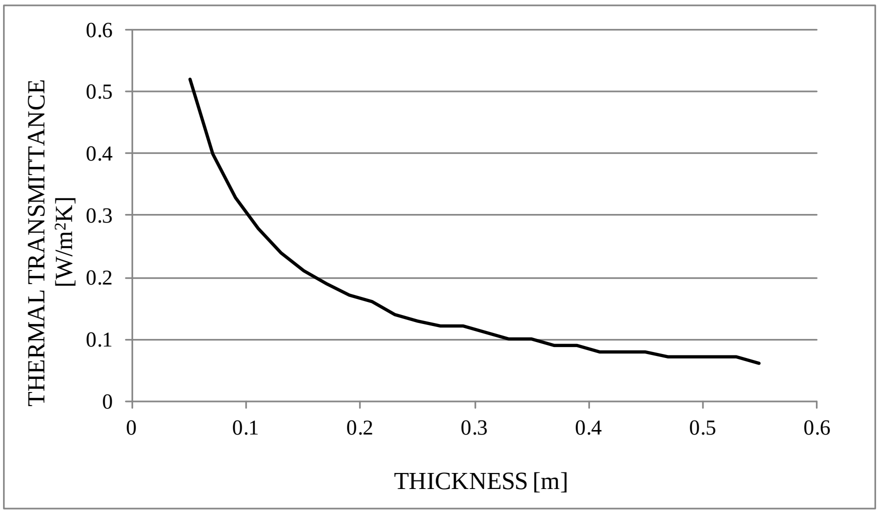

Figure 5-11. Variability of thermal transmittance changing the thickness of the insulating material (cases: internal and external insulating).

5.2. EVALUATIONS OF THE EMBODIED ENERGY OF THE REPRESENTATIVE HALL

5.2.1. THE EMBODIED ENERGY OF THE HALL

After calculating the embodied energy of the retrofit strategies, the embodied energy of the envelope and structure of the hall has been estimated to see the relationship between the energy consumed in the construction phase and the energy consumed in the use phase.

It has been considering the values proposed by the ICE database (Hammond, Jones 2011). The value of embodied energy is expressed in the database in MJ/Kg and it is specified as “Cradle to Gate”.

Starting from the thermal physical characteristics of each part of the envelope already drawn up (thickness, area, density), the first step is to calculate the volume of each layer (Table 5-10), the weight and finally the embodied energy (Table 5-11).

The embodied energy of the plants has been neglected.

Table 5-10. Thermal-physical characteristics of the materials of the envelope of the sample hall.

envelope part	material	thickness (m)	area (m^2)	density (kg/m^3)	volume (m^3)
CONCRETE PANEL	concrete	0.05	3707	2000	185
	polystyrene	0.14		30	519
	concrete	0.06		2000	222
ROOF_HALL	aluminium coating	0.0009	35015	2700	32
	glass wool	0.14		14	4902
	corrugated steel sheet	0.001		7800	35
	mineral wool	0.02		150	700
FLOOR	structural concrete slab	0.2	37242	2400	7448
STEEL PANEL	steel	0.0005	2454	7800	1
	polyurethane foam	0.079		35	194
	corrugated aluminium sheet	0.0005		2700	1
ALUMINIUM PANEL	aluminium coating	0.0025	3112	2700	8
	air	0.065		1.3	202
	rock wool	0.12		120	373
	plasterboard	0.0125		900	39
STRUCTURE	steel				
FOUNDATION STRUCTURE	compacted granular mix	0.35	37242	1950	13035
	compacted concrete mix	0.3		1800	11173
ROOF_SERVICE BUILDING	aluminium coating	0.0009	1317	2700	1
	glasswool	0.04		40	53
	mortar	0.05		1600	66
	structural concrete slab	0.13		2400	171
	cooperative cast of reinforced concrete	0.13		2300	171
	corrugated sheet steel	0.001		7800	1
FLOOR_SERVICE BUILDING	ceramic	0.02	559	2300	11
	concrete slab	0.08		1800	45
	lightweight concrete	0.06		500	34
	cooperative cast of reinforced concrete	0.14		2300	78
	corrugated steel sheet	0.001		7800	1
GLASS PARTS	glass	0.016	1436	2400	22.976
FRAME AND DIVIDER	aluminium	0.05	218	2700	10.9

Table 5-11. The calculation of the embodied energy of the sample hall.

envelope part	weight (Kg)	EE (MJ/Kg)	EE tot (MJ)	EE (MJ) envelope part	EE (GJ) envelope part
CONCRETE PANEL	370700	0.8	278025		
	15569	86.4	1345196		
	444840	0.8	333630	1956851	1957
ROOF_HALL	85087	155.0	13188475		
	68630	28.0	1921634		
	273119	20.1	5489683		
	105046	16.6	1743757	22343549	22344
FLOOR	17876160	4.5	80442720	80442720	80443
STEEL PANEL	9571	20.1	192369		
	6785	102.1	692780		
	3313	155.0	513500	1398649	1399
ALUMINIUM PANEL	21003	155.0	3255501		
	263	0.0	0		
	44807	16.8	752756		
	35005	6.8	236286	4244543	4245
STRUCTURE	3500000	20.1	70350000	70350000	70350
FOUNDATION STRUCTURE	25417665	0.1	2109666		
	20110680	1.0	19909573	22019239	22019
ROOF_SERVICE BUILDING	3200	155.0	495973		
	2107	28.0	58993		
	105344	1.3	140108		
	410842	4.5	1848787		
	393723	4.5	1771754		
	10271	20.1	206448	4522062	4522
FLOOR_SERVICE BUILDING	25714	10.0	257140		
	80496	1.3	107060		
	16770	1.3	22304		
	179998	4.5	809991		
	4360	20.1	87640	1284135	1284
GLASS PARTS	55142.4	15	827136	827136	827
FRAME AND DIVIDER	29430	155	4561650	4561650	4562

The value of the embodied energy of the whole hall is reported in the table below.

Table 5-12. The total embodied energy of the hall.

EE tot (MJ)
213950535
EE tot (MJ/m²)
5745
EE tot (GJ/m²)
5.7
EE tot (GJ/m³)
0.43

Hereafter two graphs are shown: the first one shows the embodied energy (GJ) of each part of the envelope, the second one shows the embodied energy only of the parts of the envelope that could be improve (omitting the structure, the foundation structure and the floor).

The Figure 5-12 highlights the main role of the floor and of the structure; however this parts cannot be refurbished.

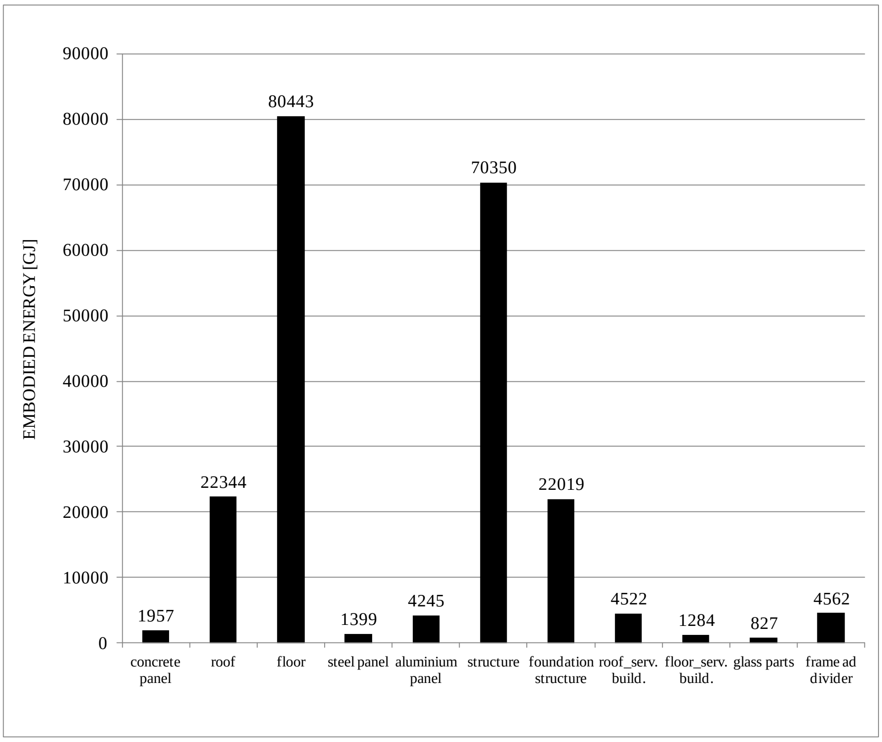

Figure 5-12. The embodied energy of the hall, considering of the envelope part.

In the Figure 5-13 emerges the relevant role of both the roof and the aluminum panel; the other parts of the envelope are not so relevant.

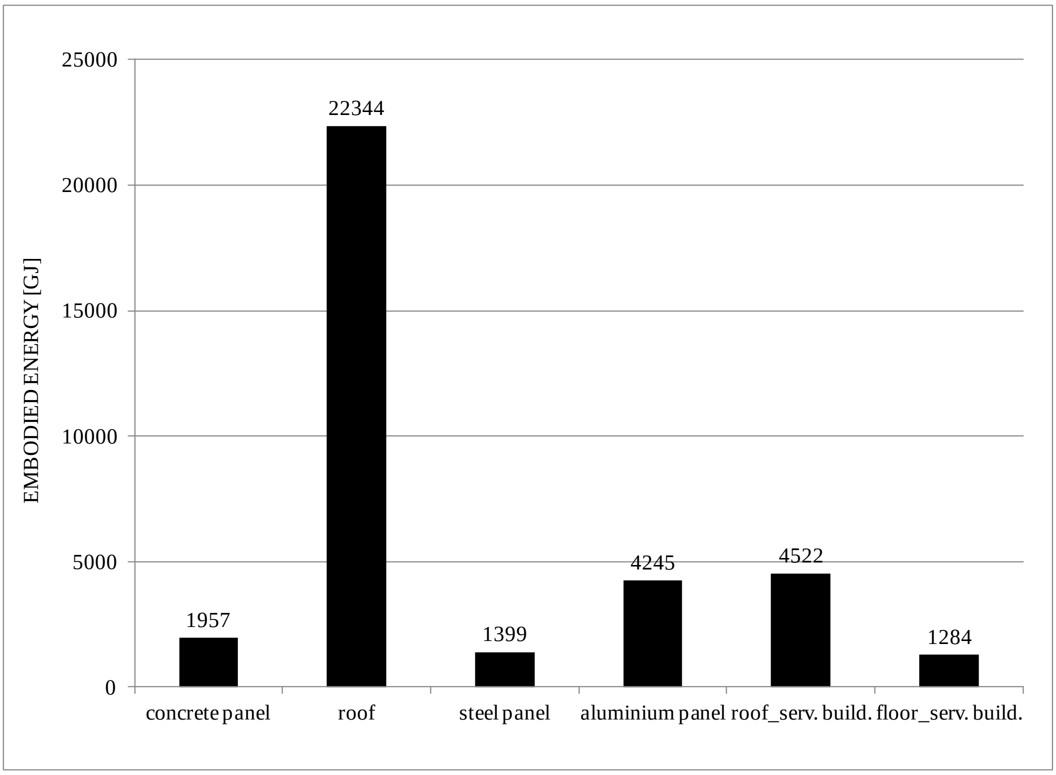

Figure 5-13. The embodied energy of the hall, not considering the parts that cannot be refurbished.

To compare the total value of embodied energy with the one of other building types, a reference value of the embodied energy of the envelope and structure[49] of a residential building was found in literature and it is 2.6 GJ/m^2 (to be compared with 5.7 GJ/m^2 of the exhibition building in analysis). In a first assessment, it seems that the embodied energy of the hall is more than two times that of the residence. Considering the significant internal height of the halls, it seems interesting to compare the values per cubic meter: the embodied energy of the residential building is 0.87 GJ/m^3 (considering 3m of interplane) and those of the exhibition building 0.43 GJ/m^3.

5.2.2. COMPARISON BETWEEN THE EMBODIED ENERGY AND THE PRIMARY ENERGY CONSUMPTION

After calculating the embodied energy of the hall, it seemed reasonable to compare it with the energy consumption in the use phase to see the relationship between the energy

[49] This value has been recovered in "Protocollo ITACA Marche - Manuale strumenti di calcolo", a manual drawn up by the Marche region on a software for calculating the embodied energy of buildings, available at: http://www.ambiente.regione.marche.it/Portals/0/Ambiente/Bioedilizia/2011_Manuale_strumenti_di_calcolo_020511.pdf

spent for the construction of the building and the energy used during the useful life of the building.

The following graph shows that a little more than 57 years are needed before the embodied energy equalizes the energy consumption in the use phase.

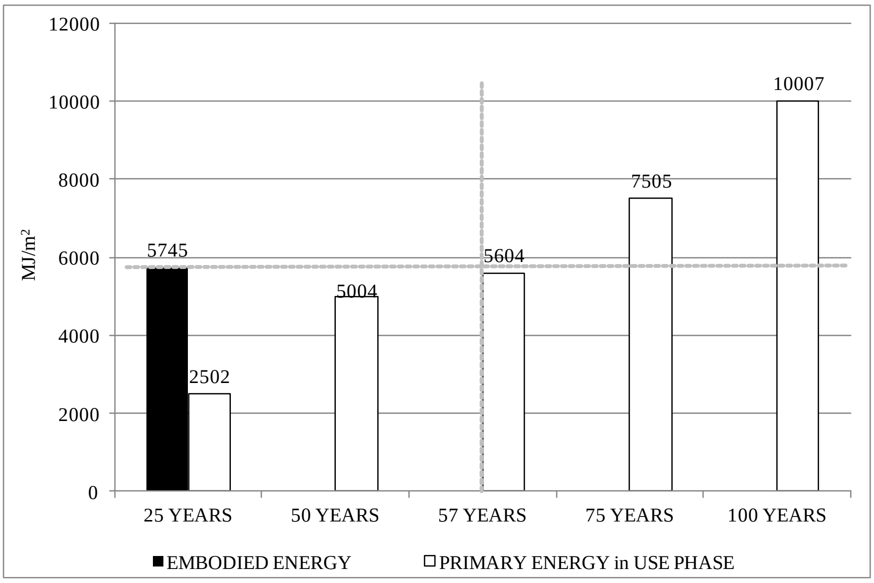

Figure 5-14. The relationship between embodied energy and primary energy in the use phase.

By analyzing the graph above, it has to be noted that the 57 years required to balance embodied energy and energy consumption in use are not fully exploited, because the hall is used only 52 days per year. If the hall were used 365 days per year, as shown in the next paragraph, in 8 years the embodied energy would equalize the energy consumption in the use phase.

This issue is relevant also comparing the energy consumption of the exhibition hall with other building types or to draft the energy certification: it should be made clear that the low annual energy consumption is caused by the low intensity of use and not for example by the fact that the building has a particularly high performance envelope.

5.3. A CRITIQUE OF THE ENERGY CERTIFICATION

To match the energy consumption of the exhibition hall to other building of the same type or also to other building types, it seemed to be appropriate to make a comparison between the energy classes identified in the regional Energy Certifications[50].

For each building type, different energy classes are marked for both primary energy for heating and thermal energy for cooling.

In the table below there are the following indicators:

- EP_H: primary energy for heating;
- ET_C: thermal energy for cooling.

All the values in the table are referred to non residential buildings[51] (as the exhibition building in analysis) and they are expressed in kWh/m^3 y. The exhibition hall is in zone E.

Table 5-13. Limit values of the energy classes for primary energy for heating in non-residential buildings in kWh/m^3 y (source: DGR VIII 8745 Lombardia, 2009).

Classe	*Altri edifici*		
	Zona E	*Zona F1*	*Zona F2*
A+	$EP_H < 3$	$EP_H < 4$	$EP_H < 5$
A	$3 \le EP_H < 6$	$4 \le EP_H < 7$	$5 \le EP_H < 9$
B	$6 \le EP_H < 11$	$7 \le EP_H < 15$	$9 \le EP_H < 19$
C	$11 \le EP_H < 27$	$15 \le EP_H < 37$	$19 \le EP_H < 46$
D	$27 \le EP_H < 43$	$37 \le EP_H < 58$	$46 \le EP_H < 74$
E	$43 \le EP_H < 54$	$58 \le EP_H < 73$	$74 \le EP_H < 92$
F	$54 \le EP_H < 65$	$73 \le EP_H < 87$	$92 \le EP_H < 110$
G	$EP_H \ge 65$	$EP_H \ge 87$	$EP_H \ge 110$

Table 5-14. Limit values of the energy classes for thermal energy for cooling in non-residential buildings in kWh/m^3 y (source: DGR VIII 8745 Lombardia, 2009).

Classe	*Altri edifici*		
	Zona E	*Zona F1*	*Zona F2*
A+	$ET_C < 2$	$ET_C < 2$	$ET_C < 2$
A	$2 \le ET_C < 4$	$2 \le ET_C < 4$	$2 \le ET_C < 4$
B	$4 \le ET_C < 8$	$4 \le ET_C < 8$	$4 \le ET_C < 8$
C	$8 \le ET_C < 12$	$8 \le ET_C < 12$	$8 \le ET_C < 12$
D	$12 \le ET_C < 16$	$12 \le ET_C < 16$	$12 \le ET_C < 16$
E	$16 \le ET_C < 20$	$16 \le ET_C < 20$	$16 \le ET_C < 20$
F	$20 \le ET_C < 24$	$20 \le ET_C < 24$	$20 \le ET_C < 24$
G	$ET_C \ge 24$	$ET_C \ge 24$	$ET_C \ge 24$

[50] All this information can be found in DGR VIII 8745 Lombardia (2009), "Determinazioni in merito alle disposizioni per l'efficienza energetica in edilizia e per la certificazione energetica degli edifici."
[51] According to DPR 26 agosto 1993, n. 412 (G. U. n.96 del 14/10/1993).

Considering the primary energy for heating and the thermal energy for cooling, it is possible to state that the hall is in class A+ in both cases: the first value is 1.85 kWh/m^3 y and the second one is 0.53 kWh/m^3 y.

Table 5-15. The energy class for primary energy for heating of the exhibition hall considering the regional Energy Certification in kWh/m^{3}y.

Classe	*Altri edifici*		
	Zona E	*Zona F1*	*Zona F2*
A+	$EP_H < 3$	$EP_H < 4$	$EP_H < 5$
A	$3 \leq EP_H < 6$	$4 \leq EP_H < 7$	$5 \leq EP_H < 9$
B	$6 \leq EP_H < 11$	$7 \leq EP_H < 15$	$9 \leq EP_H < 19$
C	$11 \leq EP_H < 27$	$15 \leq EP_H < 37$	$19 \leq EP_H < 46$
D	$27 \leq EP_H < 43$	$37 \leq EP_H < 58$	$46 \leq EP_H < 74$
E	$43 \leq EP_H < 54$	$58 \leq EP_H < 73$	$74 \leq EP_H < 92$
F	$54 \leq EP_H < 65$	$73 \leq EP_H < 87$	$92 \leq EP_H < 110$
G	$EP_H \geq 65$	$EP_H \geq 87$	$EP_H \geq 110$

Table 5-16. The energy class for thermal energy for cooling of the exhibition hall considering the regional Energy Certification in kWh/m^{3}y.

Classe	*Altri edifici*		
	Zona E	*Zona F1*	*Zona F2*
A+	$ET_C < 2$	$ET_C < 2$	$ET_C < 2$
A	$2 \leq ET_C < 4$	$2 \leq ET_C < 4$	$2 \leq ET_C < 4$
B	$4 \leq ET_C < 8$	$4 \leq ET_C < 8$	$4 \leq ET_C < 8$
C	$8 \leq ET_C < 12$	$8 \leq ET_C < 12$	$8 \leq ET_C < 12$
D	$12 \leq ET_C < 16$	$12 \leq ET_C < 16$	$12 \leq ET_C < 16$
E	$16 \leq ET_C < 20$	$16 \leq ET_C < 20$	$16 \leq ET_C < 20$
F	$20 \leq ET_C < 24$	$20 \leq ET_C < 24$	$20 \leq ET_C < 24$
G	$ET_C \geq 24$	$ET_C \geq 24$	$ET_C \geq 24$

As already mentioned, the low annual energy consumption is caused by the low intensity of use and not for example by the fact that the building has a particularly high performance envelope.

Thus, the Energy Certification is not suitable for buildings of this type, with a discontinuous use: the problem is to define a different reference value in order to make comparisons.

5.3.1. THE "USE INTENSITY" INDICATOR

Following these considerations, the necessity to clarify an indicator that takes into account the annual intensity of use of a building was born. Starting from this issue, the proposed solution is to spell out a normalized value on the day (rather than on the year). The comparison with the classes of the Energy Certification can be made only considering the primary energy for heating, because the regional legislation[52] gives precise indication about the period of heating but not for cooling: the thermal energy for cooling is not considered in specific months (as for heating) but is it stated that the calculation is performed for all months of the year, particularly for internal thermal zones of commercial buildings in which it is possible have a cooling load even in winter.

Thus, the values of the previous table related to the primary energy for heating have been divided for the number of days of heating[53] during the year, and the same has been made for the annual energy consumption of the hall, considering the real number of days of heating: 1.85 kWh/m^3 y have been divided for the 28 days of heating, finding the daily value of energy consumption (0.07 kWh/m^3 d).

In this way it is possible to compare daily values and to find the more appropriate class for the building, as shown in the following table.

Table 5-17. The energy class for primary energy for heating of the exhibition hall considering the daily indicator of energy consumption in kWh/m^{3}d.

classe	Altri edifici		
	zona E	**zona F1**	**zona F2**
A+	$EP_H<0.01$	$EP_H<0.02$	$EP_H<0.02$
A	$0.01\leq EP_H<0.03$	$0.02\leq EP_H<0.03$	$0.02\leq EP_H<0.04$
B	$0.03\leq EP_H<0.05$	$0.03\leq EP_H<0.07$	$0.04\leq EP_H<0.09$
C	$0.05\leq EP_H<0.13$	$0.7\leq EP_H<0.18$	$0.09\leq EP_H<0.22$
D	$0.13\leq EP_H<0.20$	$0.18\leq EP_H<0.28$	$0.22\leq EP_H<0.35$
E	$0.20\leq EP_H<0.26$	$0.28\leq EP_H<0.35$	$0.35\leq EP_H<0.44$
F	$0.26\leq EP_H<0.31$	$0.35\leq EP_H<0.41$	$0.44\leq EP_H<0.52$
G	$EP_H\geq 0.31$	$EP_H\geq 0.41$	$EP_H\geq 0.52$

The building, considering the daily values, belongs to class C instead of class A+.

The importance of clarify the intensity of use of a building during the year is significantly evident if considering the hypothesis to use the exhibition hall 365 days per year: in Figure 5-15, as already mentioned, it is possible to see that using the hall 52 days per year, it takes 57 year to make the embodied energy equal to the primary energy in the use phase.

[52] Decreto n. 5796 del 11 giugno 2009 “Aggiornamento della procedura di calcolo per la certificazione energetica degli edifici”

[53] Range found by the regional legislation for the zone E: from the 1th of October to the 30th of April (Decreto n. 5796 del 11 giugno 2009 “Aggiornamento della procedura di calcolo per la certificazione energetica degli edifici”).

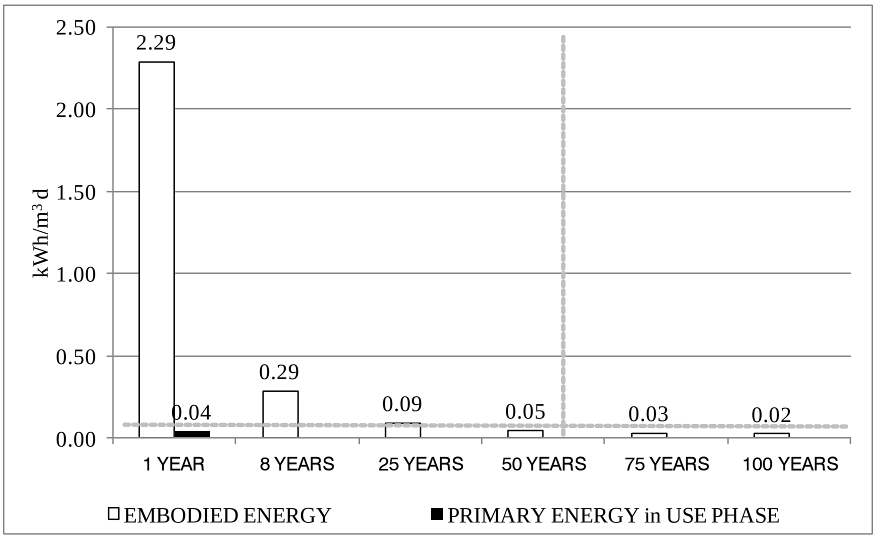

Figure 5-15. Embodied energy and primary energy in use phase, considering the real annual intensity of use (52 days.

Otherwise, considering the hypothesis of using the hall 365 days per year (Figure 5-16), only 8 years will be needed.

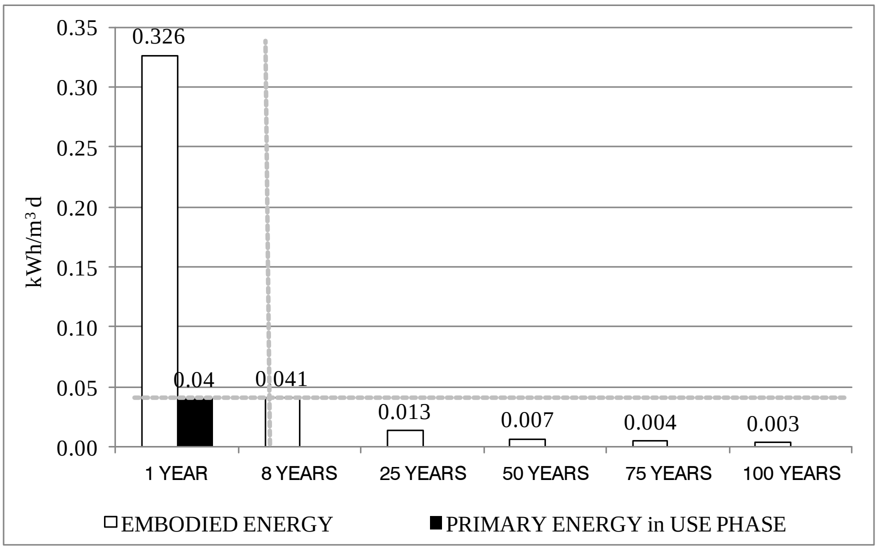

Figure 5-16. Embodied energy and primary energy in use phase, considering an annual intensity of use of 365 days.

Finally, the graph below shows the relationship between the embodied energy in both cases, always considering different scenario of the building lifetime.

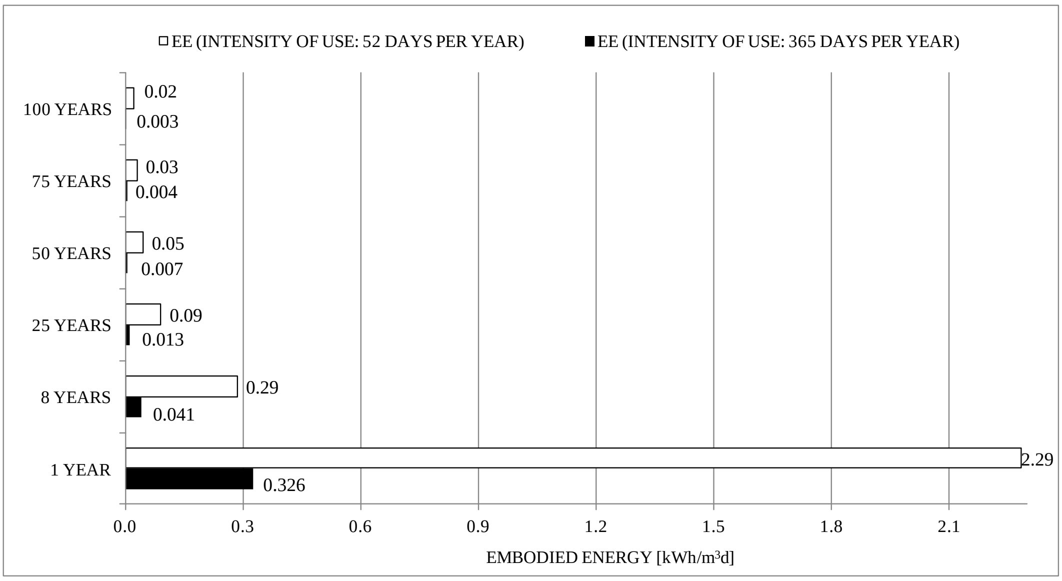

Figure 5-17. The embodied energy of the hall, considering different annual intensity of use.

As the building is used for about one seventh of year, the ratio between embodied energy and primary energy in use, considering the two different scenarios, is always 1:7.

5.4. CRITICAL ISSUES OF THE EVALUATION

Undertaking an evaluation of buildings or materials in the life cycle should be the current and future focus, even if LCA is a complex methodology and there are many uncertainties and limitations in current practices: it is not always easy to get enough information for more indicators or even for all the life cycle processes. For this reason, LCA cannot be taken as the single tool able to guide the choice of a material or a technological solution.

Following are some of the main critical issues of the life cycle assessment that emerge by this analysis.

5.4.1. SENSITIVITY ANALYSIS TO DATA OF EPD AND OTHER DATABASE

LCA is a quantitative evaluation tool that allows an objective check even though the reference to numerical values is not synonymous with reliability and all the assessments (especially with the degree of reliability of data now available) may have a margin of uncertainty. Environmental information arising from the LCA are used to pick up some guidelines and allow to redirect wrong strategies.

One of the main issue of integrating LCA in the construction sector is how to collect the appropriate data, which impact indicators to examine, which life cycle phases and elements to include and how to set system boundaries.

For example, considering the embodied energy of the materials such as in the previous analysis, it is possible to have different values depending on the database: the problem is that EPD is not mandatory and is difficult to understand how the data were built in other database, how to compare them, which impacts have been considered and which processes (for example it is often difficult to understand if packaging is included or not).

The following graph shows the embodied energy of EPS, glass wool and rock wool considering different database.

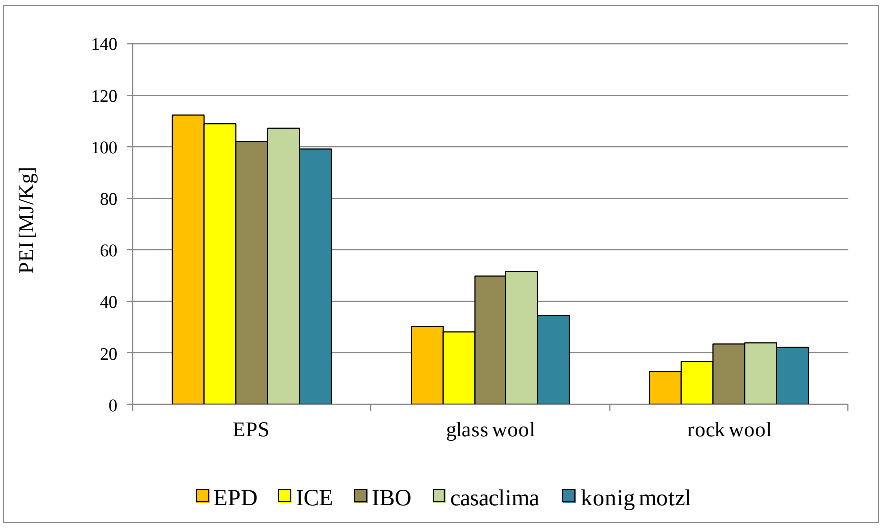

Figure 5-18. The values of embodied energy of the insulating materials considering different database (source data: Lavagna, Paleari, Mondini, 2011).

The choice of the type of data is critical in an LCA analysis. Depending on the type of study, detailed or simplified, it should be choose whether to use secondary data from the database or primary data collected in relation to a specific case. Even in case of collection of primary data, it is necessary to define if they are collected only for the main work or also for the entire production chain. In this analysis, as already mentioned, data taken from EPD were chosen because specific retrofit solutions have been hypothesized. As the previous graph shows, the assessments may change greatly if data from other sources have been taken. Thus, the debate on the reliability of the databases to process LCA remains opened, above all the issue about the exporting of data from a specific context to all the other situations.

It would be appropriate that the designer requires the EPD of the materials, so the companies would be encouraged to draw it: in this way the comparisons between materials would be easier because all the data would be comparable to each other.

5.4.2. SENSITIVITY ANALYSIS TO THE TRANSPORTATION SYSTEM AND TO THE DISTANCE OF THE FACTORIES

The impact due to the transport of building materials and components from the factory to the site is not negligible. However, it is difficult to control and calculate all the environmental impacts due to transport, also because the designer provides the technical specifications for products but he does not address the choice of suppliers, which is a task of the construction company.

Two important considerations have to be taken into account: the transportation system and the location of the factory of the chosen material.

Currently, road transport is often chosen because it lets to achieve with only a means a decentralized locations, as the plants are usually located, but road transport is significantly more impacting than the transportation by train and by ship (the ratio is about 1:10).

The other issue concerns the place where the factory is located and the distance that materials and components have to cover.

The first part of this paragraph concerns the possibility of a rail transport.

It has been hypothesized a transport by train to the building site considering the impact indicators per 1 tKm.

Table 5-18. Environmental impacts of a transport by train (source: Ecoinvent v.1.3).

indicator	units	environmental impacts rail transport per 1tkm
PEI	MJ	0.30
PEI ren	MJ	0.31
GWP	Kg CO_2 eq	0.01
AP	g SO_2 eq	0.07
EP	g PO_4 eq	0.01
POCP	g C_2H_4 eq	0.01
ODP	mg CFC eq	0.00

Then, the environmental impacts of the transport considering 1 tKm, have been multiplied for the total tKm of each material.

Table 5-19. Total environmental impacts due to the transport by train.

indicator	units	rail transport			
		environmental impacts rail transport per 1tkm	total glass wool	total rock wool	total expanded polystyrene
PEI	MJ	0.30	3410	6720	5529
PEI ren	MJ	0.31	3558	7014	5771
GWP	Kg CO_2 eq	0.01	157	309	254
AP	g SO_2 eq	0.07	781	1540	1267
EP	g PO_4 eq	0.01	141	277	228
POCP	g C_2H_4 eq	0.01	103	203	167
ODP	mg CFC eq	0.00	15	29	24

Comparing the energy consumption of the two transportation system, it is evident as the rail transport is more advantageous, both in terms of energy (Figure 5-19) and emissions.

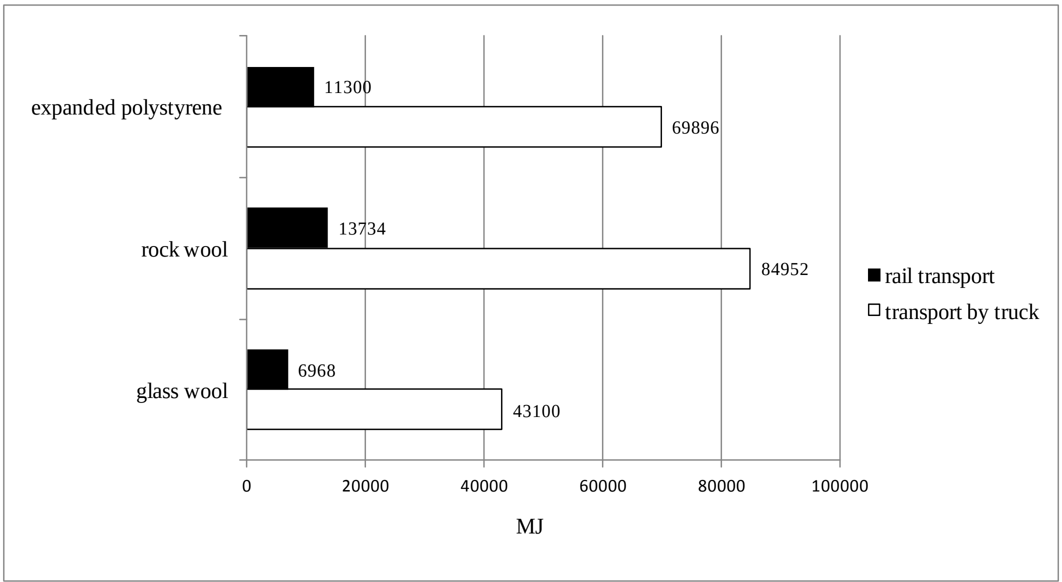

Figure 5-19. Comparison between the energy consumption due to transport by truck and by train.

Following, the assessment of the environmental impacts due to transport considering furthest factories for each materials are shown; the aim of this analysis is to see the incidence of the choice of the materials and their origin.

Table 5-20. Materials, location of the factories, "tKm" indicator.

material	location of the factory	distance from Rho (Km)	t tot (t)	(tKm)
glass wool	Billesholm (SWEDEN)	1481	182	268964
rock wool	Tapolca (HUNGARY)	846	43	36690
expanded polystyrene	S. Vito al Tagliamento (Pordenone, ITALY)	354	108	38188

First of all it has been taken into account the transport by truck and then the rail transport.

Table 5-21. Total environmental impacts due to the transport by truck (different factories).

indicator	units	truck			
		environmental impacts 1 truck (32t) per 1tkm	total glass wool	total rock wool	total expanded polystyrene
PEI	MJ	3.71	998127	136156	141717
PEI ren	MJ	0.06	15062	2055	2139
GWP	Kg CO_2 eq	0.22	59979	8182	8516
AP	g SO_2 eq	1.22	328137	44762	46590
EP	g PO_4 eq	0.26	68855	9393	9776
POCP	g C_2H_4 eq	0.21	56483	7705	8020
ODP	mg CFC eq	0.04	9683	1321	1375

Table 5-22. Total environmental impacts due to the transport by train (different factories).

indicator	units	rail transport			
		environmental impacts rail transport per 1tkm	total glass wool	total rock wool	total expanded polystyrene
PEI	MJ	0.30	80151	10934	11380
PEI ren	MJ	0.31	83648	11411	11877
GWP	Kg CO_2 eq	0.01	3685	503	523
AP	g SO_2 eq	0.07	18370	2506	2608
EP	g PO_4 eq	0.01	3308	451	470
POCP	g C_2H_4 eq	0.01	2421	330	344
ODP	mg CFC eq	0.00	342	47	48

The graph below shows the difference of the two ways of transport: the rail transport consumes about seven times less than road transport.

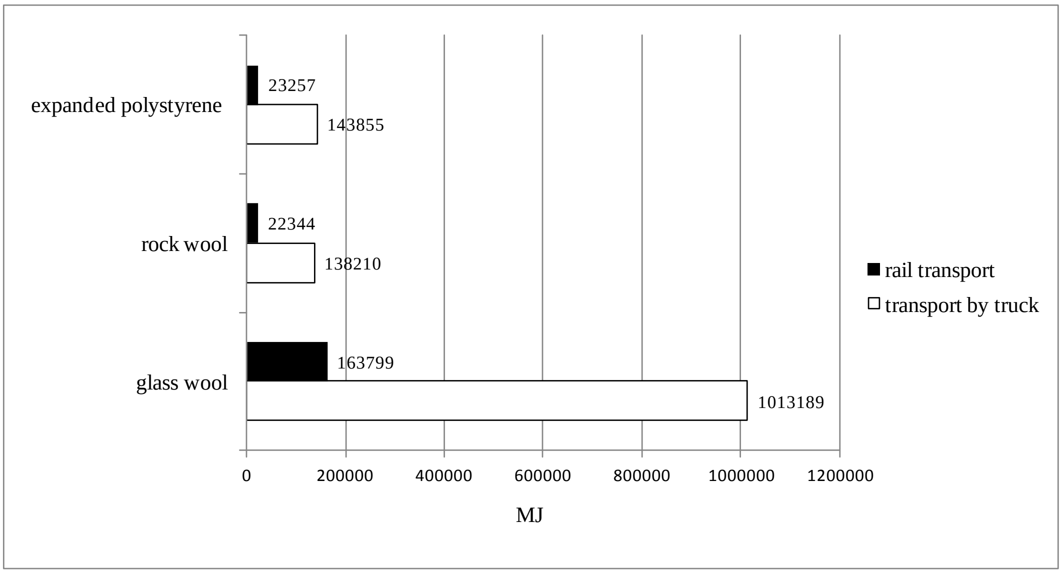

Figure 5-20. Comparison between the energy consumption due to transport by truck and by train (different factories).

Finally, a comparison considering the same transport system, nearest and furthest factories for each materials is shown.

The following graphs and the previous ones are displayed to show that it would be necessary that the designer gives some directions about the transportation system of the materials and, for example, a maximum distance of the factories from the project site.

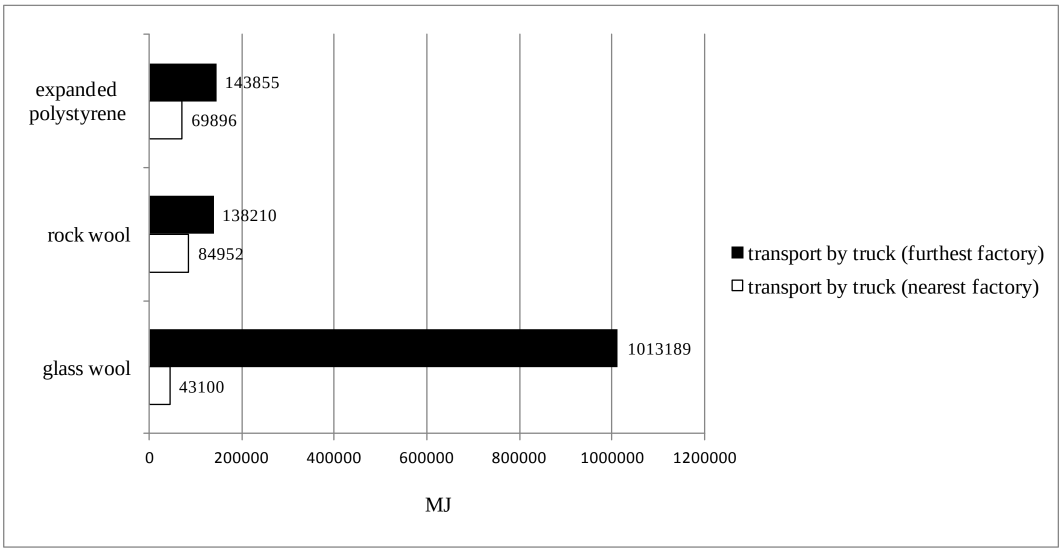

Figure 5-21. Energy consumption due to transport by truck considering different factories.

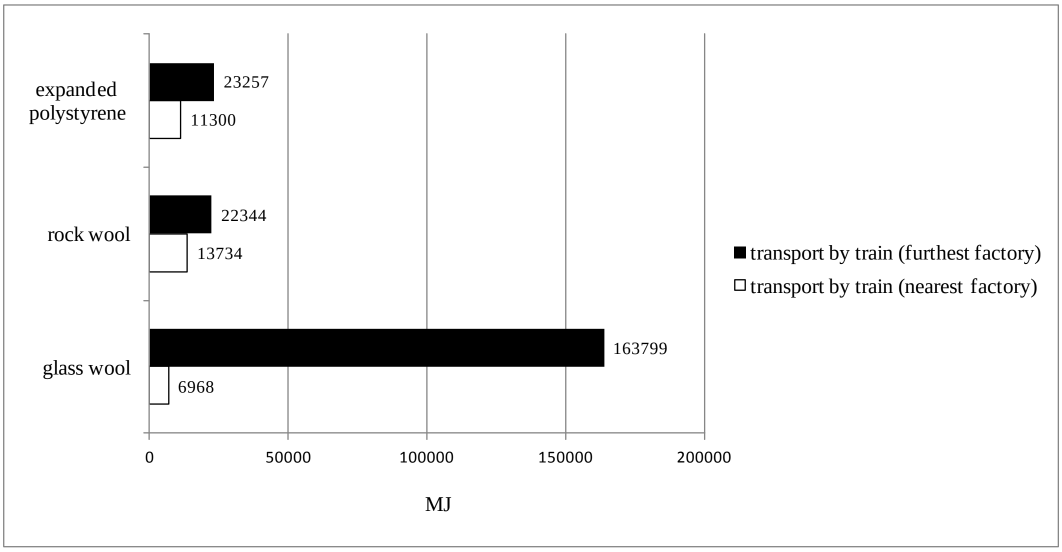

Figure 5-22. Energy consumption due to transport by train considering different factories.

In general, the environmental assessment tools and the environmental criteria for sustainable design promote the choice of local materials to reduce impacts due to transport. The purchase of products is often done by local dealers that, however, can supply very far away. Furthermore, the products can come from plants that produced the finished component, assembly or operating the latest work, but the network of supply of materials and semi-finished products can be articulated and the material can come from far away. Consequently the local origin should be demonstrated throughout the supply chain and not only in the last steps; this demonstration is often very difficult because of the paucity of information available from producers. Finally it should be emphasized that the local origin is not synonymous with reduction of environmental loads in absolute terms because of the impacts also affect the weight of the materials and the dimensions of transport. For example may be more advantageous a product with enhanced modes of transport (compressed load) from a distant factory rather than a product with non-optimized mode of transport coming from a near factory. These considerations demonstrate once again the need for an environmental balance in the life cycle linked to the specific case, that allows to compare alternatives in relation to real amount of material to be transported, the weight, compact dimensions, distances and transport.

The importance to choose the best transportation system is not to be overlooked in a project that aims to optimize energy consumption and the environmental impacts, however, the assessment of the impacts due to transport is not so easy to forecast and estimate. As already mentioned, the designer has the task to choose products and materials combining so many aspects, including just the place of production.

It would be hoped that the designer put limits and conditions on the origin of materials in order to have the ability to manage and reduce impacts in this field. This would also greatly influence the actions of the companies, which would have an incentive to structure and make transparent all the information about the environmental impacts of all the phases of the construction process.

5.4.3. SENSITIVITY ANALYSIS TO THE TYPES OF INSULATION

Comparing and evaluating different materials, it is important to take into account the performance required. For example, if a comparative evaluation of insulating materials has to be set, the performance of thermal insulation is achieved by a number of different products depending on the thermal conductivity and density of different materials, so the comparison should not be at the same weight but at the same performance. For this reason it becomes necessary to set the study clarifying the expected performance of the products, which is the functional unit of reference.

Following, an example of sensitivity analysis to different types of insulation is shown considering the thermal transmittance as functional unit. This analysis has been made, as an example, for the internal insulation.

The values of the thermal physical characteristics of the insulations and the embodied energy have been taken from different database (Lavagna, 2008).

INTERNAL INSULATION

In the retrofit strategies proposed, the internal insulation is made of 0.13 m of rockwool, leading to a thermal transmittance of 0.24 W/m^{2}K. Below, the same value of transmittance is achieved changing the insulation materials; the thickness of the different materials has been changed in each specific case.

Table 5-23. The wood fiber in the internal insulation: to obtain a thermal transmittance of 0.24 W/m^{2}K, a thickness of 0.145 m is necessary.

Material	Thickness (m)	Specific heat capacity (J/kgK)	Conductivity (W/mK)	Density (kg/m^3)	Resistance (m^{2}K/W)
concrete	0.05	880	1.16	2000	0.04
concrete-polystyrene	0.14	1199	0.52	2000	0.27
concrete	0.06	880	1.16	2000	0.05
wood fiber	**0.145**	**2300**	**0.04**	**100**	**3.63**
					R (m^{2}K/W)
Internal surface resistance					0.13
External surface resistance					0.04
Total thermal resistance					4.16
					U (W/m^{2}K)
Transmittance U= (1/Rtot)					0.24

Table 5-24. The glass wool in the internal insulation: to obtain a thermal transmittance of 0.24 W/m^{2}K, a thickness of 0.14 m is necessary.

Material	Thickness (m)	Specific heat capacity (J/kgK)	Conductivity (W/mK)	Density (kg/m^3)	Resistance (m^{2}K/W)
concrete	0.05	880	1.16	2000	0.04
concrete-polystyrene	0.14	1199	0.52	2000	0.27
concrete	0.06	880	1.16	2000	0.05
glass wool	**0.14**	**800**	**0.038**	**100**	**3.68**
					R (m^{2}K/W)
Internal surface resistance					0.13
External surface resistance					0.04
Total thermal resistance					4.22
					U (W/m^{2}K)
Transmittance U= (1/Rtot)					0.24

Table 5-25. The EPS in the internal insulation: to obtain a thermal transmittance of 0.24 W/m^{2}K, a thickness of 0.13 m is necessary.

Material	Thickness (m)	Specific heat capacity (J/kgK)	Conductivity (W/mK)	Density (kg/m^3)	Resistance (m^{2}K/W)
concrete	0.05	880	1.16	2000	0.04
concrete-polystyrene	0.14	1199	0.52	2000	0.27
concrete	0.06	880	1.16	2000	0.05
expanded polistyrene	**0.13**	**1340**	**0.036**	**18**	**3.61**
					R (m^{2}K/W)
Internal surface resistance					0.13
External surface resistance					0.04
Total thermal resistance					4.15
					U (W/m^{2}K)
Transmittance U= (1/Rtot)					0.24

Table 5-26. The cellular glass in the internal insulation: to obtain a thermal transmittance of 0.24 W/m^{2}K, a thickness of 0.18 m is necessary.

Material	Thickness (m)	Specific heat capacity (J/kgK)	Conductivity (W/mK)	Density (kg/m^3)	Resistance (m^{2}K/W)
concrete	0.05	880	1.16	2000	0.04
concrete-polystyrene	0.14	1199	0.52	2000	0.27
concrete	0.06	880	1.16	2000	0.05
cellular glass	**0.18**	**830**	**0.05**	**100**	**3.60**
					R (m^{2}K/W)
Internal surface resistance					0.13
External surface resistance					0.04
Total thermal resistance					4.13
					U (W/m^{2}K)
Transmittance U= (1/Rtot)					0.24

Table 5-27. The cork in the internal insulation: to obtain a thermal transmittance of 0.24 W/m^{2}K, a thickness of0.145 m is necessary.

Material	Thickness (m)	Specific heat capacity (J/kgK)	Conductivity (W/mK)	Density (kg/m^3)	Resistance (m^{2}K/W)
concrete	0.05	880	1.16	2000	0.04
concrete-polystyrene	0.14	1199	0.52	2000	0.27
concrete	0.06	880	1.16	2000	0.05
cork	**0.145**	**1800**	**0.04**	**150**	**3.63**
					R (m^{2}K/W)
Internal surface resistance					0.13
External surface resistance					0.04
Total thermal resistance					4.16
					U (W/m^{2}K)
Transmittance U= (1/Rtot)					0.24

In the graph below, the different values of thickness of the insulations to achieve the fixed value of thermal transmittance are shown.

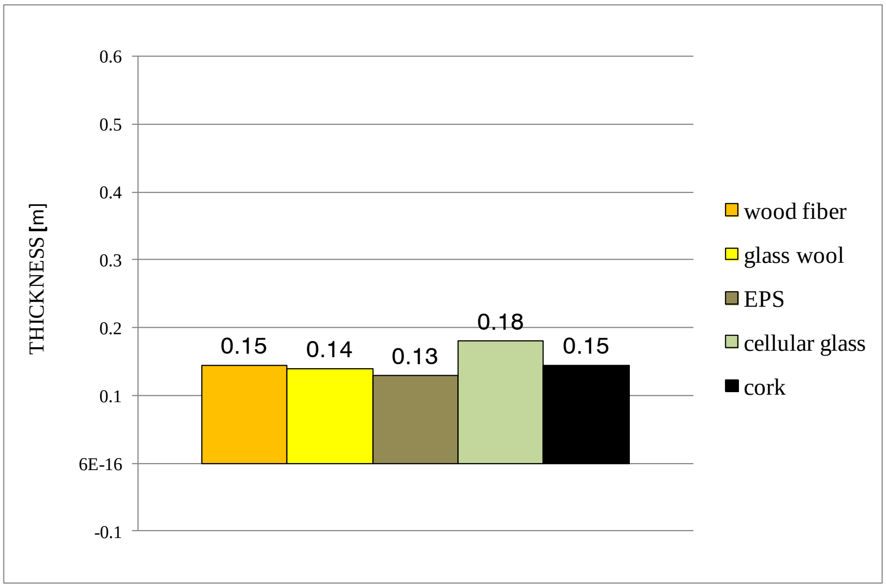

Figure 5-23. The variability of thickness considering different insulations to achieve the fixed value of thermal transmittance.

As already mentioned, considering the thermal transmittance as functional unit, the amount of materials changes and, if it happened, also the impacts due to transport would change and so on: all the aspects of uncertainty and all the variables depend on each other.

At this stage, what is interesting is to calculate the total amount of each materials (the weight) in order to see the differences in terms of embodied energy.

It has to be noted that also considering the same material, different values of density can be found and also different values of embodied energy per kilogram can be found: these are other aspects of uncertainty that have to be added to the previous ones. The values of embodied energy per kilogram have been taken by ICE.

Table 5-28. Assessment of the embodied energy of the insulations.

insulations	area (m^2)	thickness (m)	volume (m^3)	density (Kg/m^3)	weight (Kg)	EE (MJ/Kg)	EE (Kg)
rockwool	3707	0.13	482	90	43369	13	563791
wood fiber	3707	0.145	537	100	53747	20	1074946
glass wool	3707	0.14	519	100	51894	28	1453030
EPS	3707	0.13	482	18	8674	109	947168
cellular glass	3707	0.18	667	100	66721	27	1801461
cork	3707	0.145	537	150	80621	4	322484

Figure 5-24 shows the embodied energy per kilogram, while Figure 5-25 shows the total amount.

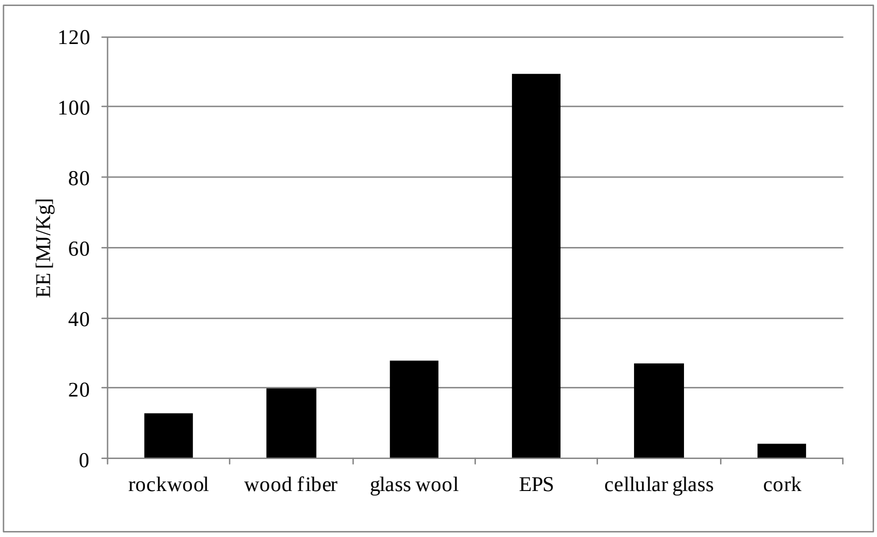

Figure 5-24. The embodied energy of the insulations per kilogram.

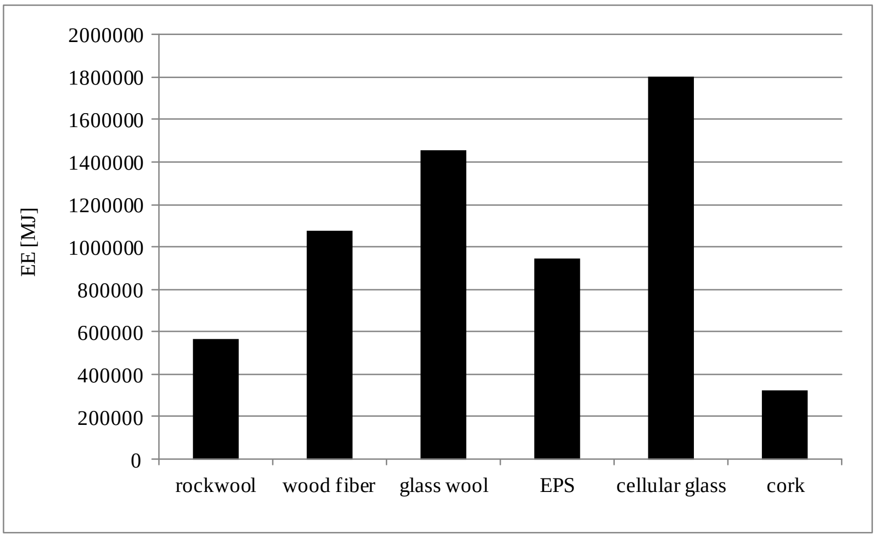

Figure 5-25. The total embodied energy of the insulations.

Operating benchmarks, it is also essential to consider also that the material works simultaneously to multiple performances, so if the functional unit is set differently, the result of the environmental assessment changes. Thus, the difficulty of the designer in the choice of the materials is further complicated, because of the many factors that he has to take into account.

5.5. PROPOSAL TO REDESIGN THE HALL

The suggested method for the analysis of the construction and use phase and has been tested concerning retrofit strategies. Following is an example of application of the methodology also in new building. After analyzing the existing hall, considering the energy consumptions in use and the embodied energy, the next step is to propose a new exhibition building better from both the two points of view.

The constraints are the square meters of exhibition, the internal height (which cannot be reduced because of the size of the means of transport that prepare the events), the structure (and the foundation structure), the floor and the place where the AHU are located.

The strategies to minimize the impacts both in construction and use phases have not to be considered in absolute terms but they are referred to the specific case study.

5.5.1. THE STRATEGIES TO MINIMIZE THE EMBODIED ENERGY OF THE ENVELOPE AND THE ENERGY CONSUMPTIONS

The strategies to redesign a new hall have to take into account the reduction of energy consumptions in the use phase and the embodied energy of the envelope. Considering the energy savings during the use phase, the strategies are related to the reduction of the thermal transmittance; simultaneously it has been necessary to consider the materials with reduced values of embodied energy.

A steel panel has been proposed to replace the concrete panel and the aluminum panel, and a different kind of roof to replace the roof of the hall and the roof of the service building.

Following are the thermal-physical characteristics of both the steel panel and the redesigned roof.

Table 5-29. The thermal-physical characteristics of the steel panel.

STEEL PANEL (proposal)					
Material	**Thickness (m)**	**Specific heat capacity (J/kgK)**	**Conductivity (W/mK)**	**Density (kg/m^3)**	**Resistance (m^{2}K/W)**
corrugated iron	0.001	1999	52	7800	0.00
mineral wool	0.140	670	0.04	16	3.50
air	0.040				0.06
steel	0.001	1999	52.0	7800	0.00
					R (m^{2}K/W)
Internal surface resistance					0.13
External surface resistance					0.04
Total thermal resistance					3.73
					U (W/m^{2}K)
Transmittance U= (1/Rtot)					0.27

Table 5-30. The thermal-physical characteristics of the redesigned roof.

ROOF (proposal)					
Material	**Thickness (m)**	**Specific heat capacity (J/kgK)**	**Conductivity (W/mK)**	**Density (kg/m^3)**	**Resistance (m^{2}K/W)**
steel	0.001	1999	52	7800	0.000
glass wool	0.120	840	0.04	14	3.000
corrugated steel sheet	0.001	1999	52	7800	0.000
mineral wool	0.020	840	0.035	150	0.571
					R (m^{2}K/W)
Internal surface resistance					0.10
External surface resistance					0.04
Total thermal resistance					3.71
					U (W/m^{2}K)
Transmittance U= (1/Rtot)					0.27

The next graph shows the transmittance values after the hall redesign.

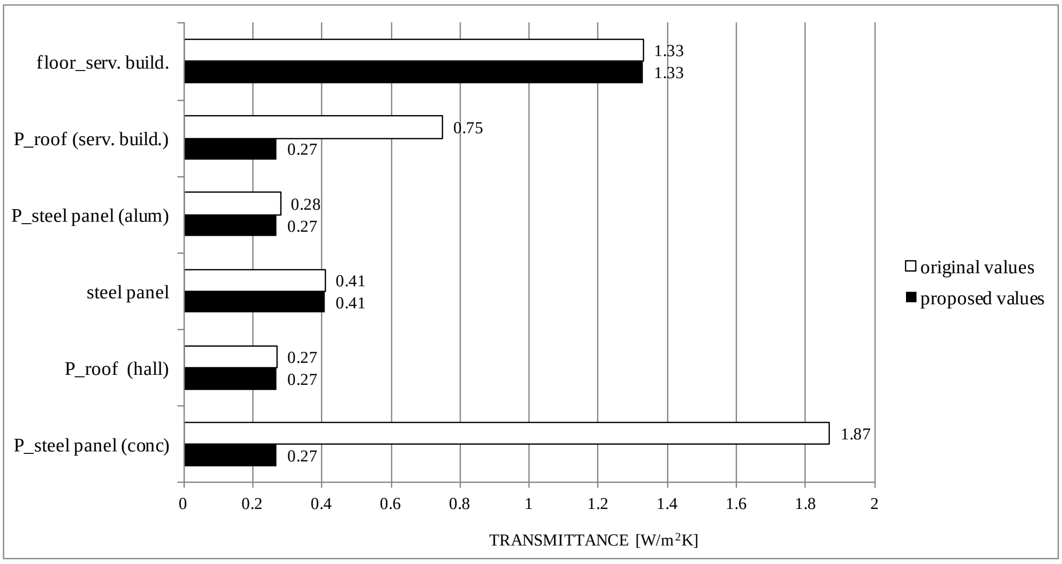

Figure 5-26. The original and proposed transmittance values.

Following are the embodied energy values of the redesigned panels and roof.

Table 5-31. The embodied energy of the redesigned panels and roof.

envelope part	material	thickness (m)	area (m^2)	density (kg/m^3)	volume (m^3)	weight (Kg)	EE (MJ/Kg)	EE tot (MJ)	EE (MJ) envelope part	EE (GJ) envelope part
	corrugated iron	0.001	3707.0	7800	4	28915	20.1	581183		
STEEL PANEL	mineral wool	0.14		16	519	8304	16.6	137841		
(proposal in subst. the conc panel)	air	0.04					0.0	0		
	steel	0.001		7800	4	28915	20.1	581183	1300208	1300
	steel	0.00	36332.0	7800	36	283390	20.1	5696131		
ROOF	glass wool	0.12		14	4360	61038	28.0	1709057		
(proposal in subst. the hall roof)	corrugated steel sheet	0.00		7800	36	283390	20.1	5696131		
	mineral wool	0.02		150	727	108996	16.6	1809334	14910653	14911
	corrugated iron	0.001	3111.6	7800	3	24270	20.1	487835		
STEEL PANEL	mineral wool	0.14		16	436	6970	16.6	115701		
(proposal in subst. the alum. panel)	air	0.04		1	124	162	0.0	0		
	steel	0.001		7800	3	24270	20.1	487835	603536	604
	steel	0.00	1317.0	7800	1	10273	20.1	206479		
ROOF	glass wool	0.12		14	158	2213	28.0	61952		
(proposal in subst. the serv. build. roof)	corrugated steel sheet	0.00		7800	1	10273	20.1	206479		
	mineral wool	0.02		150	26	3951	16.6	65587	540497	540

The next table shows the difference (%) of embodied energy between the original envelope and the redesigned one.

Table 5-32. Embodied energy values of the original envelope and the redesigned one.

ENVELOPE	PROPOSAL VALUES (GJ)	ORIGINAL VALUES (GJ)	DIFFERENCE (%)
P_steel panel (conc)	**1300**	**1957**	**33.6%**
P_roof (hall)	**14911**	**22344**	**33.3%**
floor	80443	80443	
steel panel	1399	1399	
P_steel panel (alum)	**604**	**4245**	**85.8%**
structure	70350	70350	
foundation structure	22019	22019	
P_roof (serv. build.)	**540**	**4522**	**88.1%**
floor_serv. build.	1284	1284	

Summarizing, the redesigned panel and roof have lower value on both thermal transmittance and embodied energy:

- steel panel (proposal): U= 0.27 W/m^{2}K, EE= 1300 GJ, in replacement of concrete panel: U= 1.87 W/m^{2}K, EE= 1957 GJ;
- steel panel (proposal): U= 0.27 W/m^{2}K, EE= 604 GJ, in replacement of aluminum panel: U= 0.28 W/m^{2}K, EE= 4245 GJ;
- hall roof (proposal): U= 0.27 W/m^{2}K, EE= 14911 GJ, in replacement of hall roof: U= 0.27 W/m^{2}K, EE= 22344 GJ;
- hall service building (proposal): U= 0.27 W/m^{2}K, EE= 540 GJ, in replacement of hall service building: U= 0.75 W/m^{2}K, EE= 4522 GJ.

Considering only the parts of the envelope that can be refurbished, the next graph shows the decreasing of the embodied energy of each redesigned part.

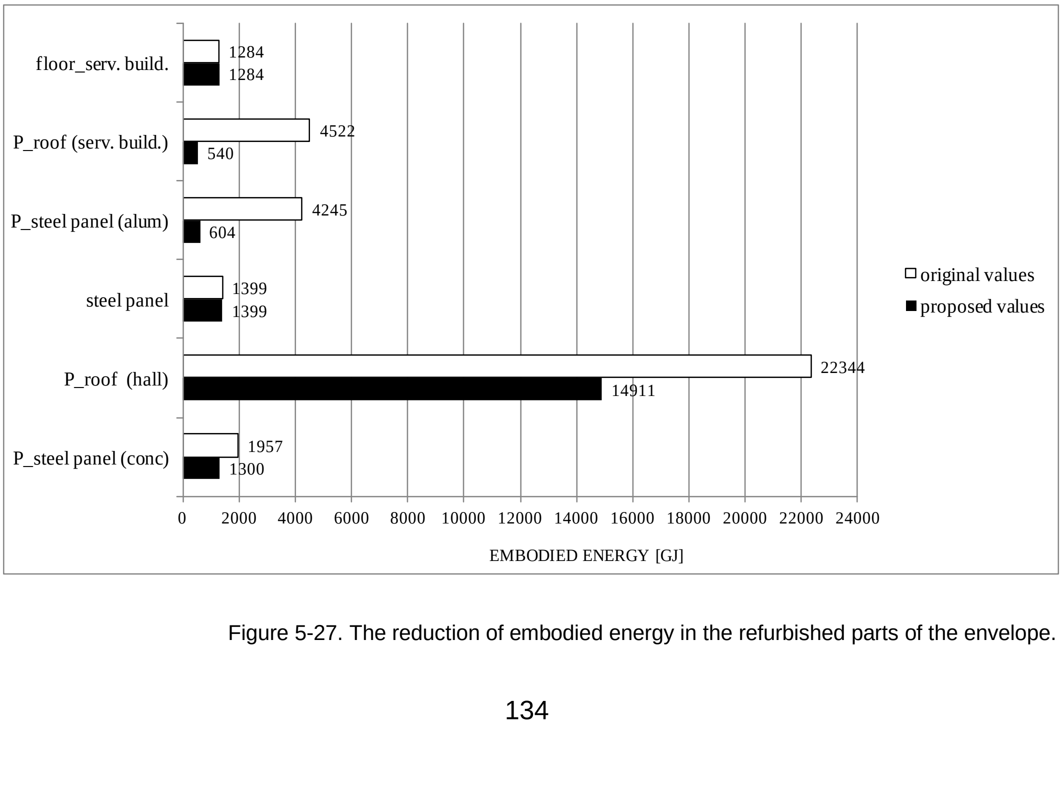

Figure 5-27. The reduction of embodied energy in the refurbished parts of the envelope.

The total embodied energy of the envelope is decreased by 7.5%. Simulating the redesigned hall in EnergyPlus, the energy annual consumptions are decreased by 11%.

This application of the method has many limits and critical aspects. First of all it is not possible to state, in absolute terms, that a material produces less impacts rather than another: in addition to considering the performance provided, there are many other factors that come into play, like his lifetime, the maintenance needed, its origin and so on. The exercise presented only gives some guidelines that still need further study. Secondly it was not possible to know if the materials used had a percentage of recycled material or not, and also this factor has a significant influence on the outcome of the evaluation. Therefore, it is important that the final result must not be misunderstood and generalized.

P3

PART 3

METHODOLOGY AND PROCEDURE

6 Stages, expertises and timing in the process of energy analysis in the life cycle

6.1. THE REQUIRED INFORMATION

To launch an energy analysis, it is necessary to conduct a pre-audit phase to list all the information needed; this process is necessary to define qualitative and quantitative knowledge of the property in examination.

It is emphasized that this phase appears to be one of the most critical steps of the process because of difficulties in finding information related to buildings, often absent or incomplete. There are several criteria that converge to define goals and aspects that characterize this stage:

- the gradualism. The process requires the implementation of a "strategy of gradualism", that is the statement of pre-defined criteria and the prioritization of the information needed in order to control the timing of the gradual acquisition in relation to available resources. Therefore, it is necessary a preliminary analysis aimed at defining what are the basic information needed to start the process and which can be acquired in a deferred;
- the dynamism. The audit phase should be a process that is constantly updated, organized in such a way as to define at any time the status of the property;
- the level of detail in relation to needs. It must has been conducted a preliminary analysis to define the level of detail of the trial and, therefore, the degree of detail of the required information, this level is defined according to the needs of the subject who orders the study.

The information needed can be organized into four categories:

- general documentation on the property, such as historical analysis, register data, technical information concerning the characteristics of the property, plant details, etc..;
- documentation acquired through surveys, photographic surveys, geometric measurements, tests on materials with heat flow and coring, etc..;
- technical data relating to the description of external walls, floors, interplane, roofs, partitions, windows and frames;
- information about the embodied energy of the materials, the ways of transportation of materials and means of transport.

Table 6-1. Phases, actions, descriptions and formalization.

PHASE	ACTION	DESCRIPTION	FORMALIZATION
1	DOCUMENT SEARCH AND CATALOGING	GENERAL DOCUMENTATION ON THE PROPERTY, SUCH AS HISTORICAL ANALYSIS, REGISTER DATA, TECHNICAL INFORMATION CONCERNING THE CHARACTERISTICS OF THE PROPERTY, PLANT DETAILS, ETC..;	REPORT AND TABLES
2	MEASUREMENTS	SURVEYS, PHOTOGRAPHIC SURVEYS, GEOMETRIC MEASUREMENTS, TESTS ON MATERIALS WITH HEAT FLOW AND CORING, ETC..;	PHOTO BOOK, TABLES AND DRAWS IN CAD
3	DESCRIPTION OF TECHNOLOGICAL ELEMENTS	TECHNICAL DATA RELATING TO THE DESCRIPTION OF EXTERNAL WALLS, FLOORS, INTERPLANE, ROOFS, PARTITIONS, WINDOWS AND FRAMES	TABLES AND DRAWS IN CAD

All data obtained must be organized and collected in reports (in tabular form, written or graphic table) to make the consultation of the information easier and immediate.

Moreover, it is desirable to create a format that collects all the information needed for the work, useful to provide a complete picture of the characteristics of the building- Following the one related to the geometrical and thermal-physical description of the building is shown.

The format proposed is organized in sections:

- geometrical description of the building;
- geometrical and thermal-physical description of the opaque envelope;
- geometrical and thermal-physical description of the transparent envelope;
- geometrical and thermal-physical description of frames and dividers;
- assessment of the embodied energy of the retrofit strategies;
- assessment of the environmental impacts due to transport.

Following the format-tables developed are shown.

Table 6-2. The information format about the geometry of the building.

GEOMETRY of the building	
	File Format
building	AutoCAD 3D
Ground plan	AutoCAD 2D
First floor plan	AutoCAD 2D
Second floor plan	AutoCAD 2D
…	AutoCAD 2D
Roof plan	AutoCAD 2D
Sections	AutoCAD 2D
Elevations	AutoCAD 2D

Table 6-3. The information format about the opaque envelope of the building.

OPAQUE ENVELOPE	**Thermophysical and geometrical properties**						
Technological detail	Material [name]	Thickness [m]	Color of the external layer	Conductivity [W/(mK)]	Specific heat capacity [J/(Kg*K)]	Density [Kg/m^3]	location in plant
CEILING/ROOF							
layer 1	…	…	…	…	…	…	…
layer 2	…	…		…	…	…	…
…	…	…		…	…	…	…
WALL 1							
layer 1	…	…	…	…	…	…	…
layer 2	…	…		…	…	…	…
…	…	…		…	…	…	…
WALL 2							
layer 1	…	…	…	…	…	…	…
layer 2	…	…		…	…	…	…
…	…	…		…	…	…	…
WALL 3							
layer 1	…	…	…	…	…	…	…
layer 2	…	…		…	…	…	…
…	…	…		…	…	…	…
GROUND FLOOR							
layer 1	…	…	…	…	…	…	…
layer 2	…	…		…	…	…	…
…	…	…		…	…	…	…

Table 6-4. The information format about the transparent envelope of the building.

TRANSPARENT ENVELOPE									
		SOLAR PROPERTIES					VISIBLE PROPERTIES		
WINDOWS LIST	Gas type	Solar Transmittance	Outside solar reflectance	Inside solar reflectance	Coating type	Color	Visible Transmittance	Outside visible reflectance	Inside visible reflectance
WINDOW 1									
outermost pane		...	...	...	...	...	...	...	...
window gas 1	...								
pane 2		...	...	...	...	...	...	...	...
window gas 2	...								
...	...	...	...	...	...	...	...	...	...
innermost pane	...	...	...	...	...	...	...	...	...
WINDOW 2									
outermost pane		...	...	...	...	...	...	...	...
window gas 1	...								
pane 2		...	...	...	...	...	...	...	...
window gas 2	...								
...	...	...	...	...	...	...	...	...	...
innermost pane	...	...	...	...	...	...	...	...	...
WINDOW 3									
...									

	Glazing	Name product	Location in plant	Glass area [m^2]	Frame and divider (frame 1, frame 2…)	Transmittance [W/m^{2}K]	Solar gain factor
WINDOW 1	1	...	...	...	...	...	...
WINDOW 1	2	...	...	...	...	...	...

Table 6-5. The information format about the frame and dividers.

Frame	Thickness	Thermal break	Area [m^2]	Transmittance [W/m^{2}K]	Divider type
FRAME 1 (material)	...	...	...	...	... (divider 1, 2 ..)
FRAME 2	...	...	...	...	...
FRAME 3	...	...	...	...	...
DIVIDER 1	...	...	...	...	
DIVIDER 2	...	...	...	...	
DIVIDER 3	...	...	...	...	

Table 6-6. The information format about the embodied energy of materials, envelope and structure.

envelope part	material	thickness (m)	area (m^2)	density (kg/m^3)	volume (m^3)	weight (Kg)	EE (MJ/Kg)	EE tot (MJ)	EE (MJ) envelope part	EE (GJ) envelope part
STRUCTURE	layer 1									
	layer 2									
	layer 3									
FOUNDATION STRUCTURE	layer 1									
	layer 2									
	layer 3									
FLOOR	layer 1									
	layer 2									
	layer 3									
ROOF	layer 1									
	layer 2									
	layer 3									
VERTICAL PANEL 1	layer 1									
	layer 2									
	layer 3									
VERTICAL PANEL 2	layer 1									
	layer 2									
	layer 3									
…	layer 1									
	layer 2									
	layer 3									

Table 6-7. The information format about the assessment of the environmental impacts due to transport.

material	location of the factory	distance from Rho (Km)	t tot (t)	(tKm)
material 1				
material 2				
material 3				

indicator	units	truck			
		environmental impacts 1 truck (32t) per 1tkm	material 1	material 2	material 3
PEI	MJ	3.71			
PEI ren	MJ	0.06			
GWP	Kg CO_2 eq	0.22			
AP	g SO_2 eq	1.22			
EP	g PO_4 eq	0.26			
POCP	g C_2H_4 eq	0.21			
ODP	mg CFC eq	0.04			

indicator	units	rail transport			
		environmental impacts rail transport per 1tkm	material 1	material 2	material 3
PEI	MJ	0.30	80151	10934	11380
PEI ren	MJ	0.31	83648	11411	11877
GWP	Kg CO_2 eq	0.01	3685	503	523
AP	g SO_2 eq	0.07	18370	2506	2608
EP	g PO_4 eq	0.01	3308	451	470
POCP	g C_2H_4 eq	0.01	2421	330	344
ODP	mg CFC eq	0.00	342	47	48

6.2. THE EXPERTISES INVOLVED IN THE SIMULATION PROCESS

When a process of analysis is beginning, it is necessary to take into account the necessary expertise to achieve their goals. The process to ensure the competence of those involved requires identification of the knowledge and expertise necessary to achieve the objectives and the choice of those who constitute the working group (so that the totality of knowledge and expertise are present in the group itself).

Therefore, it is possible to identify the people responsible for each stage:

- Designer, the entity that supports the Energy Manager in the choices of technological interventions in energy efficiency. In particular, in case of new achievements his contribution is very important in order to anticipate critical issues at the planning phase: otherwise they would arise only during the use phase;
- Energy manager, the person with technical expertise related to the knowledge of systems, heat transfer and other techniques to evaluate the efficiency of the property. The Energy Manager is involved in the facilities management of the property and, therefore, he is aware of the challenges that are relevant from the point of view of the survey;
- Specialist consultant, the subject with specific technical expertise that deals with the implementation of the operational part of the analysis, since it operates from the construction of the model to analyze.

These statements allow to define the resources necessary to carry out a preliminary form of the analysis project.

Table 6-8. Indication of the figures involved in the process with its moment of action.

PHASE	DESCRIPTION	EXPERTISE	TIME FOR ACTION
1	Data acquisition and information retrieval	ENERGY MANAGER	Preliminary phase
2	Sampling	ENERGY MANAGER	Preliminary phase
3	Three-dimensional modeling in DesignBuilder or other interface program	SPECIALIST CONSULTANT	Operative phase
4	Dynamic simulation of the sample building	SPECIALIST CONSULTANT	Operative phase
5	Study of strategies for energy saving	DESIGNER ENERGY MANAGER	Operative phase
6	Simulation of strategies for energy saving	SPECIALIST CONSULTANT DESIGNER ENERGY MANAGER	Operative phase
7	Calculation of the embodied energy of the materials of the retrofit strategies proposed	SPECIALIST CONSULTANT	Operative phase
8	Comparison of the embodied energy of the retrofit strategies and the energy saving	DESIGNER	Operative phase
9	Calculation of the embodied energy of the building	SPECIALIST CONSULTANT	Operative phase
10	Comparison of the embodied energy of the building and the energy saving in the use phase	DESIGNER SPECIALIST CONSULTANT	Final phase

Table 6-9. Summary plan of the figures involved in the process for each phase and timing.

PHASE		1	2	3	4	5	6	7	8	9	10
SKILL	DESIGNER										
	ENERGY MANAGER										
	SPECIALIST CONSULTANT										
TIMING (days)			2	7	20	15	20	10	10	15	15

6.3. THE METHOD SUGGESTED FOR THE ANALYSIS

The aim of this paragraph is to give some guidelines aimed at developing a methodology for structured and articulated energy retrofit projects.

6.3.1. THE OPERATIONAL PHASES

In order to apply the procedure of the method proposed in this research, the activities have been identified and divided into phases. These are organized as follows.

Building energy dynamic simulation

- Data acquisition and information retrieval. In the audit phase, the documents and the information necessary to begin the analysis need to be obtained.
- Sampling. Phase during which it has to be chosen a “sample” building, or portion of a building (such a cell), considered representative for the evaluation in terms of location and orientation, relationship between opaque and transparent surfaces, geometrical and thermal-physical features, number of occupants, types and characteristics of the technological plant.
- Three-dimensional modeling in DesignBuilder or other interface program. Elaboration of a three-dimensional model of the sample building to be used as input for the next dynamic simulation in EnergyPlus. It is empathized that the stratigraphy and the thermophysical characteristics of the materials constituting the housing are associated with previously processed elements of the graphical mode made DesignBuilder. At this stage it is also necessary to identify the thermal zones within the cell or the sample building in order to verify the possible

horizontal/vertical stratification of temperature. It is emphasized that this can be verified by precise measurements by placing sensors directly in the building.

- Dynamic simulation of the sample building. The three-dimensional model and the thermal-physical description of its materials have to be imported in EnergyPlus to carry out the dynamic simulation; the model defined, properly calibrated, will be used as a yardstick to evaluate the energy behavior of the same building after the refurbishments. Moreover, it is also necessary to define:
  - the boundary conditions, defined by the climate files of the area concerned;
  - the temporal operational mode of the building, such as the density of occupation, the use of lighting, power plants ...;
  - the volume of air entering in the building by natural infiltration and ventilation;
  - the ideal system for heating and cooling, with infinite capacity.

  Once calibrated the model, it is possible to require the outputs necessary for the energy analysis, it is also possible to proceed with further processing of the data obtained in tables or graphs to make immediate understanding of the results and evaluation.

Retrofit strategies simulation

- Study of strategies for energy saving. The strategies could regard the envelope and system management levels. The first category is mainly refers to the reduction of the transmittance of both the opaque and transparent surfaces. Some of the main actions could be:
  - internal insulation;
  - external insulation;
  - roof insulation;
  - ventilated façade;
  - more performing windows;
  - application of horizontal shading “brise soleil” in winter and summer;
  - application of vertical shading “brise soleil” in winter and summer;
  - application of overhang;
  - spring/summer night ventilation (free cooling).
  - The second category, about system management, could regard for example the variation of the set temperature and the early switch off of the system.
- Simulation of strategies for energy saving. Dynamic annual energy simulations of different interventions (at the envelope and system management levels) have to be

carried out as well as the relative economic assessment through the calculation of the payback time. First of all individual interventions have to be simulated and after combined solutions. The aim is the search for improvements for both heating and cooling demand. The total primary energy savings resulting from each intervention have to be calculated and compared.

Retrofit strategies assessment in the life cycle

- Calculation of the embodied energy of the materials of the retrofit strategies proposed. The embodied energy and the energy due to transportation of the materials of the retrofit strategies have to be calculated and also the estimation of the payback years.

Comparison of the embodied energy of the retrofit strategies and the energy saving

- The embodied energy of the retrofit strategies has to be calculate to see the relationship between the embodied energy and the energy savings before and after the retrofit design, considering different scenarios in different periods.

Building embodied energy calculation

- Calculation of the embodied energy of the envelope and the structure of the building.

Comparison of the embodied energy of the building and the energy consumption in the use phase.

- The embodied energy of the building has to be calculate to see the relationship between the energy consumed in the construction phase and the energy consumption in use, considering different scenarios in different periods.

6.3.2. THE ORGANIZATION OF THE DECISION MAKING WITHIN THE COMPANY

The experimental analysis on the assessment of the energy behavior of existing buildings is developed in steps which start from the decision of the top manager to undertake a redevelopment project. Therefore, it is with the top manager that begins and finishes the decision process, because also all the final outcomes must be reported to him.

The diagram below shows the scenario corresponding to the decision-making process before the entry of the energy manager.

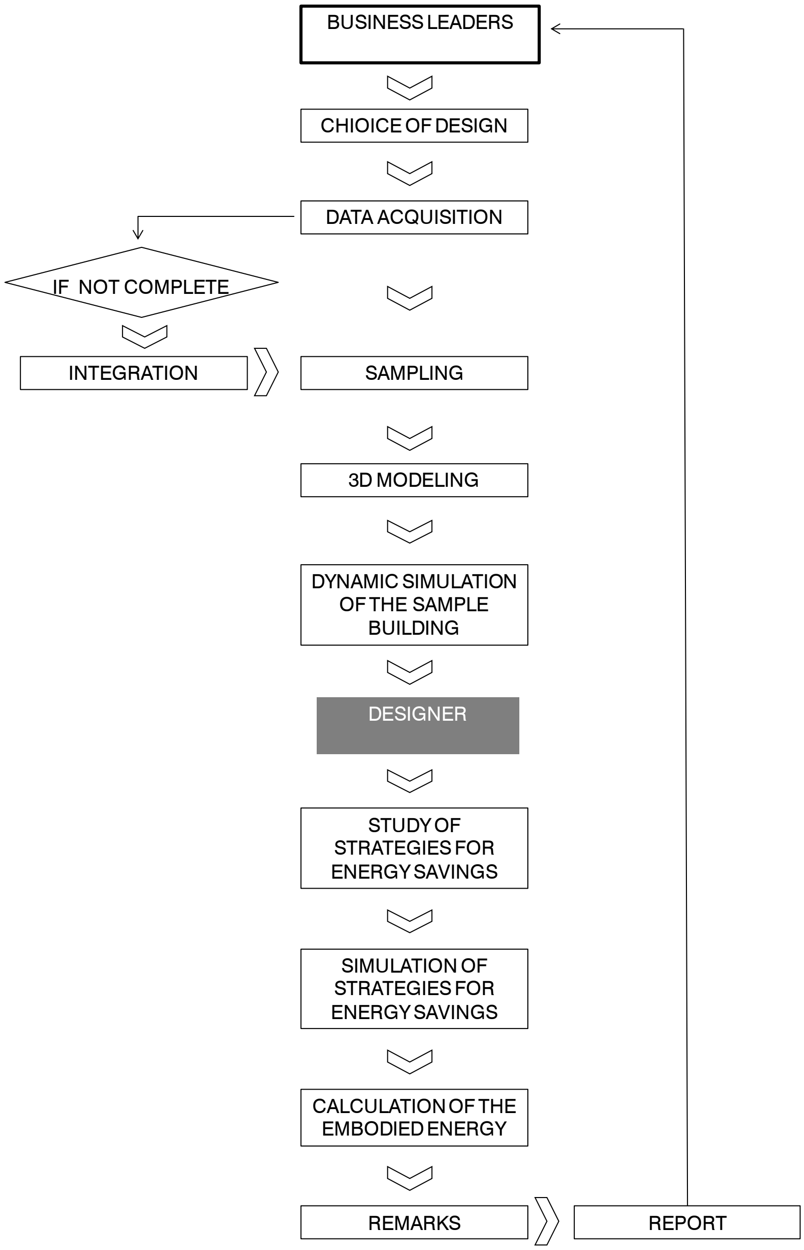

Figure 6-1. Methodological framework of the decision-making process.

The presence of an energy manager within a company is a strategic advantage since he is able to propose to the top manager smarter choices that can merge policies with corporate environmental policies thanks to his technical training. In this case, the choice to take on the project is evaluated not only from an economic point of view but also considering the energy savings. Therefore, the task of the top manager becomes to evaluate the strategic and economic costs in relation to company policies and not to carry out energy assessments.

The diagram below shows the scenario corresponding to the presence of the energy manager in the decision-making process.

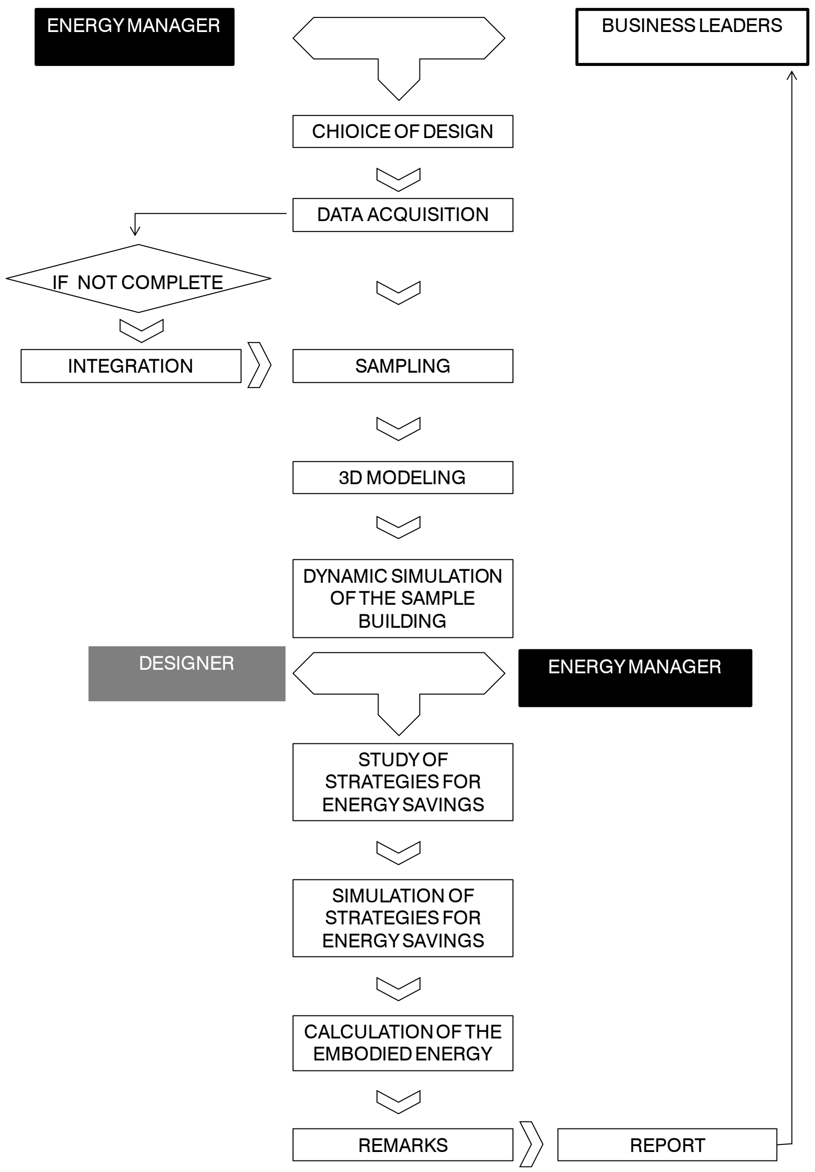

Figure 6-2. Methodological framework of the decision-making process with the introduction of the energy manager.

As can be seen from the previous table, the energy manager must interface with the different parties during the course of the process, such as:

- the top manager: figure to whom it is necessary to refer to both input and output, since the trial will develop by his decision; the energy manager task is to propose to him new experiments and projects;

- the designer, with whom the energy manager has to discuss to select that choice of the technological interventions about the energy efficiency. It is important that these two entities interact, since the energy manager knows energy issues related to the property, while the designer has expertise on technological solutions.

C CONCLUSION AND REMARKS

In recent years, technical innovations in the construction industry have led to an increasingly rapid evolution of construction methods. Materials, techniques, skills and roles within the construction process tend to specialize and to break down the process into phases with too much autonomy. The environmental design, however, requires an integrated approach because the environmental criteria fall into all the phases of the construction process and because the reduction of impacts and of energy consumption is the result of synergies between the many issues of the project.

The complexity of the information flowing between different subjects exposes the process to an infinite possibility of error, endangering the quality of the process (Lavagna, 2008). In this research some critical issues and uncertainties that can significantly affect the final result were found as shown in the first two chapters, where issues related to the knowledge and uncertainty were investigated, both in the simulation process and in the life cycle assessment. The unresolved questions, highlighted in the thesis, could be the starting point for the development of future researches.

This study leads to the definition of a methodology for the analysis of design strategies in the life cycle. Three are the main focus points of the thesis:

- the dynamic simulation of retrofit strategies to reduce the energy need. In the first part of the this analysis, the energy saving potential of some retrofit and system management strategies for an exhibition center have been evaluated by means of dynamic simulations. The calibration of the model put in evidence the role played by the high internal loads and by the infiltration rates, also related to the visitors, in the resulting climatization energy demand of this kind of buildings. The most relevant energy saving solutions have to take into account both retrofit and management strategies. The best combined intervention, which leads to an annual saving of about 32%, tries to find a balance between expensive solutions and those at no cost. The economical assessment, associated to the environmental one, shows that the short use period during the year of each exhibition hall in the fair center makes the retrofit solutions less attractive than the management ones;
- the life cycle assessment of the environmental impacts of the retrofit strategies. Having integrated this analysis on the use phase with the life cycle assessment, it

has been possible to evaluate the environmental impacts of the refurbishments also in the other phases. The computation of the embodied energy of the hall has allowed to compare it with the energy consumption in use (considering different lifetime of the building) and to see the relationship between the energy spent for the construction of the building and the energy used during the life. 57 years are required to balance embodied energy and the energy consumption in use: this result is due to the fact that the hall is not fully exploited, in fact, the hall is used only 52 days per year. If the hall were used 365 days per year, in 8 years the embodied energy would equalize the energy consumption in the use phase.

- the development of a procedure to analyze retrofit strategies in the use phase and in the life cycle.

Finally, another important issue. In the case study, increasing the effective use of the exhibition halls, by considering the possibility of adapting this spaces to different activities, such as sport events, theatre events or concerts, would make energy retrofit strategies more economically advantageous. Moreover, also considering the life cycle perspective, adapting a building to multiple functions reduces the need to build more buildings for the different functions, and this means the reduction of the environmental impacts and an energy saving.

The low use of the hall during the year took it to class A+ in the regional Energy Certification (considering the annual energy consumption) but this must not be misleading, as the building is used only few days per year. The necessity to clarify an indicator that takes into account the annual intensity of use of a building was born and, starting from this issue, the proposed solution was to spell out a normalized value on the day (rather than on the year). In this way, considering the real number of days used, the building belongs to class C. Thus, the classification proposed by the Energy Certification is not suitable then types of building used in a discontinuous way. Often, however, the suggestion to increase the use of the hall is not compatible with the exhibitions activities, which require long periods for both the event preparing and disassembling.

All these considerations could help the designer and the energy manager in the choice of the best strategy to reduce both the energy consumption in use and the environmental impacts in the life cycle: in the last chapter, a general methodology has been drawn and the procedure can be followed for any kind of buildings.

Considering the many variables and the different subjects involved in the process of analysis, a perspective for a future research could involve the development of a tool that involves on the one hand the customer, which accounts in the policies and objectives defining the final environmental strategies and secondly the designer, who has the ability to make contractually mandatory requirements aimed to reduce some of these elements of uncertainty, such as the request of the EPDs of the materials to make informed choices, information about the origin of materials and components used and so on.

C CONCLUSIONI E OSSERVAZIONI

Le innovazioni tecniche nel settore delle costruzioni hanno portato, negli ultimi anni, ad un'evoluzione sempre più rapida delle modalità costruttive ed esecutive. Materiali, tecniche, competenze e ruoli all'interno del processo edilizio tendono a specializzarsi e a scomporre l'intero processo in fasi spesso dotate di eccessiva autonomia. La progettazione ambientale invece richiede un approccio integrato, sia perché i criteri ambientali rientrano in tutte le fasi del processo edilizio e sia perché la riduzione degli impatti e dei consumi energetici è il risultato di sinergie tra i molteplici aspetti del progetto.

La complessità delle informazioni che circola tra i diversi soggetti espone il processo ad un'infinita possibilità di errore, mettendo a rischio la qualità dell'intero processo (Lavagna, 2008). In questa ricerca emergono una serie di aspetti critici e incerti che influenzano significativamente il risultato finale, come illustrato nei primi due capitoli, dove si indagano in chiave epistemologica tematiche relative alla conoscenza e ai fattori di incertezza, sia nella simulazione e sia nelle valutazioni nel ciclo di vita. Le questioni che oggi rimangono ancora aperte, evidenziate all'interno della tesi, potrebbero essere il punto di partenza per lo sviluppo di future ricerche.

La sperimentazione elaborata ha portato alla definizione di una metodologia per l'analisi di strategie progettuali nel ciclo di vita. Riassumendo, i punti principali su cui si focalizza la tesi sono i seguenti:

- la simulazione dinamica di strategie di retrofit per ridurre il fabbisogno energetico. Nella prima parte dell'analisi sono stati stimati i potenziali risparmi energetici di alcune strategie di retrofit e di gestione in un edificio espositivo mediante la costruzione di un modello di rappresentazione del comportamento energetico reale dell'edificio esistente. La calibrazione del modello ha messo in evidenza il ruolo significativo dei carichi interni e delle infiltrazioni d'aria nella stima del fabbisogno energetico per la climatizzazione. Gli interventi che portano a risparmi energetici maggiori tengono in considerazione sia strategie mirate al miglioramento delle prestazioni dell'involucro e sia strategie gestionali: l'intervento più significativo, che combina le due categorie di strategie, porta ad un risparmio del 32%. La valutazione economica degli interventi di retrofit, associata a quella ambientale, mostra che l'utilizzo ridotto e discontinuo del padiglione durante l'anno rende le strategie di retrofit meno convenienti rispetto a quelle gestionali.

- la valutazione nel ciclo di vita degli impatti ambientali delle strategie di retrofit. Integrando l'analisi relativa alla fase d'uso con la valutazione nel ciclo di vita, è stato possibile valutare gli impatti ambientali prodotti dagli interventi anche nelle altre fasi e stimare gli anni di ammortamento delle diverse soluzioni. Il calcolo dell'energia incorporata del padiglione ha reso possibile un confronto con i consumi energetici in fase d'uso ipotizzando diversi scenari di vita utile dell'edificio, rendendo trasparente la relazione tra l'energia spesa in fase di costruzione e l'energia consumata in fase uso. Gli anni necessari per bilanciare l'energia incorporata con l'energia consumata in uso sono 57: questo risultato è dovuto al fatto che il padiglione non è sfruttato a pieno durante l'anno, infatti è utilizzato solo 52 giorni. Se fosse utilizzato 365 giorni all'anno, l'energia incorporata verrebbe bilanciata in soli 8 anni;
- l'elaborazione di una procedura per analizzare strategie di retrofit in fase d'uso e nel ciclo di vita.

Infine, un'altra questione centrale. Nel caso studio, l'intensificazione dell'uso effettivo dello spazio considerando la possibilità di adattare lo spazio anche ad attività differenti (come eventi sportivi, spettacoli o concerti) renderebbe le strategie di retrofit più convenienti dal punto di vista economico. Inoltre, considerando anche l'ottica del ciclo di vita, adattare uno spazio ad una molteplicità di attività evita la costruzione di altri edifici portando alla riduzione di impatti ambientali e ad un risparmio energetico.

L'utilizzo limitato e discontinuo del padiglione durante l'anno colloca l'edificio in classe A+ nella certificazione energetica regionale (considerando i consumi energetici annuali) ma ciò non dev'essere frainteso in quanto è dovuto proprio al fatto che l'edificio è in funzione pochi giorni all'anno. Da qui è sorta la necessità di esplicitare un indicatore che tenga in considerazione l'intensità annuale di utilizzo di un edificio e la soluzione proposta è la normalizzazione dei consumi energetici a livello giornaliero. In questo modo, considerando il numero effettivo di giorni di utilizzo dell'edificio, il padiglione risulta appartenere alla classe C, pertanto, è emerso come la classificazione proposta dalla certificazione energetica non risulti adeguata a edifici usati in modo limitato e discontinuo durante l'anno. Spesso, tuttavia, la proposta di incrementare l'uso dei padiglioni non è compatibile con le attività relative alle manifestazioni, che richiedono lunghi periodi per l'allestimento e lo smantellamento degli stand.

Tutte queste considerazioni possono aiutare progettisti e energy manager nella scelta delle strategie progettuali finalizzate alla riduzione sia dei consumi energetici in fase d'uso e sia gli impatti ambientali nel ciclo di vita: nell'ultimo capitolo è stata elaborata una metodologia di ordine generale e una procedura che può essere seguita per l'analisi di qualsiasi tipologia edilizia.

Considerate le molteplici variabili in gioco e i diversi soggetti coinvolti nel processo di analisi, una prospettiva per una futura ricerca potrebbe riguardare la messa a punto di uno strumento che coinvolga da un lato il committente, che incide nelle politiche e negli obiettivi finali definendo le strategie ambientali e dall'altro il progettista, che ha la possibilità di rendere cogenti a livello contrattuale alcune prescrizioni finalizzate alla riduzione di questi elementi di incertezza, come ad esempio la richiesta delle EPD dei materiali per poter operare scelte consapevoli, di informazioni relative alla provenienza di materiali e componenti utilizzati e così via.

A APPENDIX

APPENDIX 1. THE THERMAL TRANSMITTANCE OF THE SANDWICH PANELS.

The real configuration of the panel includes a heterogeneous layer is impossible to describe in the software DesignBuilder and EnergyPlus, so the creation of an "equivalent" layer was necessary.

The concrete panel is actually composed of:

- a homogeneous section of concrete;
- a heterogeneous layer of concrete and insulation;
- a layer of concrete, as shown in Figure 6-3.

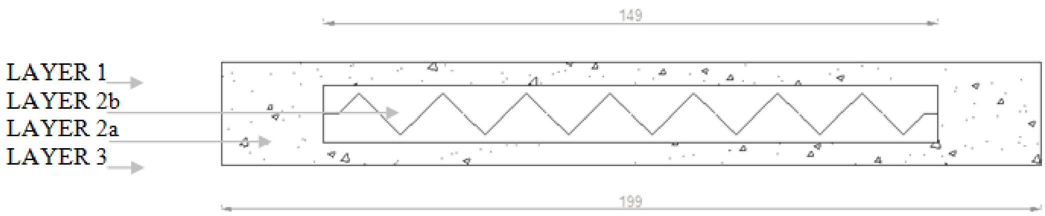

Figure 6-3. Horizontal section of the concrete panel.

To calculate the thermal transmittance of the concrete panels it has been referred to the UNI EN ISO 6946.

The total thermal resistance of the panel is calculated as the arithmetic mean of the upper and lower limit of thermal resistance.

The lower limit of the total thermal resistance is determined assuming that all the planes parallel to the surfaces of the component are isothermal planes. The resistance of the heterogeneous element is calculated by reference to the "electrical analogy," according to the diagram below.

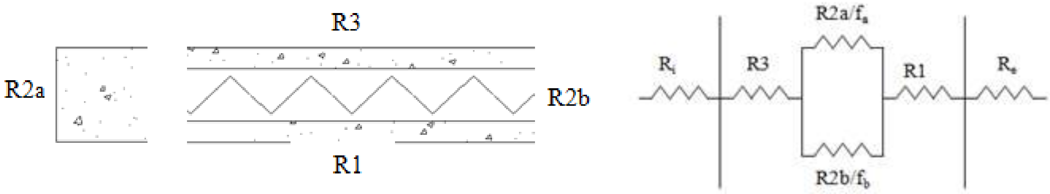

Figure 6-4. Diagram of the electrical analogy to calculate the lower limit of the thermal resistance.

In Figure 6-4, $f_a=A_a/A$, $f_b=A_b/A$, A_a is the area of the concrete section and A_b is the area of the insulation section. A indicates the area of the whole panel. The lower thermal resistance is 0.46 (m^2K)/W.

The upper limit of the total thermal resistance is determined by considering the heat flow as one-dimensional and perpendicular to the surfaces of the layers. Therefore, the surfaces perpendicular to the layers are considered adiabatic.

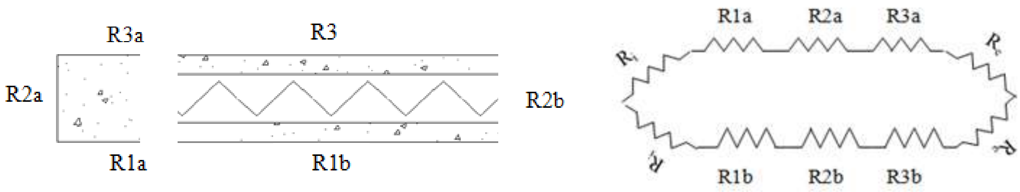

Figure 6-5. Diagram of the electrical analogy to calculate the upper limit of the thermal resistance.

The upper thermal resistance is 0.60 (m^2K)/W.

The total thermal resistance is 0.54 (m^2K)/W and the thermal transmittance 1.87 W/(m^2K).

The same method was followed to calculate the thermal capacity: the final value is 302352 J/m^2K and the specific heat capacity considered is 1079 J/KgK.

APPENDIX 2. THE ESTIMATION OF THE LATENT HEAT.

The thermal energy demand of the building is calculated as the sum of the sensitive thermal energy demand, related to the maintenance of the desired temperature, and the latent one, linked to the maintenance of the conditions of humidity.

The estimate of the latent heat for the calibration of the model during the summer week was necessary because, although the humidity control was not set, it could be possible that the treated air is sometimes dehumidified by the cold air exchanger.

To obtain the overall need for cooling. the methodology adopted is shown.

- estimate of the sensible heat:
- estimate of the latent heat;
- estimate of the total energy need for cooling.

To estimate the latent heat, the procedure adopted includes the following steps:

- collection of the external data: external temperature and relative humidity of Rho (data collected at the Centro Meteorologico Lombardo);
- calculation of external absolute humidity and external enthalpy through the following relations:

  $X = 0.622 \frac{U_R p_{sat}(t)}{p - U_R p_{sat}(t)}$ [$Kg_{vap}/Kg_{dry\ air}$]

  $p_{sa}t$= saturated vapor pressure at a given temperature t, p_{sat} = 610.5•e^A

  $A = \frac{17.269t}{t+237.3}$ if t>= 0°C

  $A = \frac{21.875t}{t+265.5}$ if t < 0°C

  p= atmospheric pressure (101325 Pa)

- calculation of external enthalpy:

  $h = c_{pa}t + X(c_{pv}t + \lambda_v)$ [$KJ/Kg_{dry\ air}$]

- collection of the internal data: indoor/ input temperature and relative humidity (data measured by Fiera Milano);
- calculation of internal absolute humidity and internal enthalpy;
- calculation of the enthalpy and absolute humidity of the mix air by varying the flow of outside air;
- calculation of the enthalpy and absolute humidity of the input air input varying the by-pass factor of the cooling coil;

- calculation of the relative humidity of the input air by varying the air changes by ventilation and infiltration and estimation of the hours in which the condensation takes place (reasonably assumed if RH> 98%);
- calculation of the latent heat due to the people and to the air infiltration and ventilation (latent heat only added in the hours when condensation occurs).

Assessment of the latent heat due to the air infiltration.

The latent heat for ventilation and air infiltration was calculated as the product of the ventilation mass flow rate, the difference between indoor and outdoor absolute humidity and the enthalpy of the water vapor:

$Q_v= m_e(X_e-X_i)\lambda_e$ [KW]

(λ_e=2501.3 [KJ/Kg])

Assessment of the latent heat due to the people.

$Q_p= \lambda_e \cdot n°$ persons [KW]

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