A MODEL TO FORESEE BUILDING HEAT PERFORMANCE

By

Alex GRANDGIRARD

Master Thesis

Master of Civil and Architecture Engineering

KTH

2018
In the last decades, the rehabilitation market has become increasingly significant in France. In particular, the renovation of university sites and hospitals from the 1970s, this is a fast growing segment of the French construction market. In parallel, the office and residential buildings construction sector is becoming a lot more environmentally friendly, with more efficient buildings and more advanced sustainable systems such as better design and implementation of renewable energy sources. This Master thesis, carried out in France with the company Elioth, focuses exclusively on the renovation market.

The goal of this thesis is to determine a model that delivers forecast consumption for an existing building. The efforts during this Master Thesis project have been put to one typology of building in situation of an energetic performance commitment at Elioth. Rehabilitation projects on university campuses are the most ongoing and urgent demand from the company. So university as a based building has been chosen to support the thesis.

The result of this Master thesis is a practical supporting protocol along with an operative tool named “Estim’ELIOTH”. It enables environmental engineers to define the data in their possession in order to determine the energy consumption of the building studied. This feature aims to provide information for energy performance commitment management in the early stages of the design. Nowadays, this is essential for renovation projects in France.
# TABLE OF CONTENT

List of Figures ........................................................................................................ 4

List of Tables ........................................................................................................... 5

Acknowledgment .................................................................................................... 6

Glossary .................................................................................................................... 7

Chapter 1 - Introduction ......................................................................................... 8
  Reasons for the Study 8
    THE CONTEXT ........................................................................................................ 8
    THE NEED .............................................................................................................. 11
    THE COMPANY .................................................................................................... 12
  Current State of Knowledge 14
    Common Methods .................................................................................................. 14
  Aims of the Thesis 15
    Forecasting a Building's Energy Behaviour ....................................................... 15
    Building a Mathematical Model ............................................................................. 16
    Development of an Operative Tool ................................................................. 16

Chapter 2 – The Method ......................................................................................... 17
  The Investigation Process 17
    The Research Question .......................................................................................... 17
    The Theory ........................................................................................................... 20
    The Empirical Feedback ...................................................................................... 24
  The Prerequisites 26
    A Resilient Database .......................................................................................... 26
    An Advancement Procedure ............................................................................... 28
  The Model Production Process 30
    A Mathematical Model ....................................................................................... 30
    A Deterministic Model ....................................................................................... 32
    A Model Adjusted to Site Observation ............................................................... 39
    An Algebra Model ............................................................................................... 43
  The Tool Development 45
    Requirement Analysis .......................................................................................... 45
    System Design ....................................................................................................... 46
    Architecture Design ............................................................................................. 47
    Module Design ...................................................................................................... 50
    Implementation ...................................................................................................... 51

Chapter 3 – The Results ........................................................................................ 52
  Model Testing 52
    Accuracy ............................................................................................................... 53
    Stability ............................................................................................................... 55
Chapter 4 – Discussion ........................................................................................................ 61
RESULT ANALYSIS 61
STRENGTHS ......................................................................................................................... 61
WEAKNESSES .......................................................................................................................... 62
LIMITATIONS ........................................................................................................................... 62
FUTURE RESEARCHES 63
DEVELOPMENT ....................................................................................................................... 63
EVOLUTION ............................................................................................................................... 64

BIBLIOGRAPHY ......................................................................................................................... 65

APPENDIX .................................................................................................................................. 66
TOOL PRESENTATION ............................................................................................................... 66
TEST INPUTS AND OUTPUTS ..................................................................................................... 66
LIST OF FIGURES

Figure 1 – Different levels of heat exchange ................................................................. 1
Figure 2 – Building life cycle ......................................................................................... 8
Figure 3 – Energy commitment actors ......................................................................... 9
Figure 4 – The Egis group story .................................................................................... 12
Figure 5 – ELIOTH divisions ....................................................................................... 13
Figure 6 – Approach suggested by the project ............................................................... 15
Figure 7 – Principal entities of the thesis ..................................................................... 16
Figure 8 – Schematic comparison between a mono-zone and a multi-zone model ..... 17
Figure 9 – Different “objects” defined within the report .............................................. 18
Figure 10 – The system approach .................................................................................. 20
Figure 11 – Results of the dispersion study .................................................................. 27
Figure 12 – The V model procedure .............................................................................. 28
Figure 13 – Illustration of heat equation parameters relative influence ....................... 33
Figure 14 – French meteorological zone distribution .................................................... 40
Figure 15 – Clim’ELIOTH outputs ................................................................................ 40
Figure 16 – SADT A0 of the project .............................................................................. 44
Figure 17 – System workflow ....................................................................................... 45
Figure 18 – Tool’s sheets identification and synergy ..................................................... 49
Figure 19 – ID card of a building given by Estim’ELIOTH ........................................... 50
Figure 20 – Coupling system diagram ......................................................................... 51
Figure 21 – NRMSD result distribution for both S1 and S2 ........................................... 53
Figure 22 – Stability test results .................................................................................... 54
Figure 23 – ERE result distribution for both S1 and S2 ................................................. 55
Figure 24 – Results toward consumption and its relative error for the Lyon sample .... 56
Figure 25 – Results toward total consumptions in term of absolute value and relative error for the Rennes sample ........................................................................... 57
Figure 26 – Results toward heating consumptions in term of absolute value and relative error for the Rennes sample ........................................................................... 57
Figure 27 – Results toward heating consumptions in term of absolute value and relative error for the Rennes sample ........................................................................... 58
Figure 28 – Results toward relative error for the total consumption distribution between the non-heating systems for the Rennes sample ........................................................................... 58
Figure 29 – Estim’ELIOTH ......................................................................................... 65
Figure 30 – Input data and test results ......................................................................... 65
LIST OF TABLES

Table 1 – Criterion limits ................................................................. 19
Table 2 – Weighting values for laboratory reference .................................. 34
Table 3 – Weighting values for experiment reference ................................... 34
Table 4 – Weighting values for teaching reference .................................... 34
Table 5 – Weighting values for office reference ........................................ 34
Table 6 – Reference heating consumption ............................................ 35
Table 7 – Correlation determinant values .............................................. 36
Table 8 – Reference lighting consumption ............................................ 36
Table 9 – Reference ventilation consumption ........................................ 37
Table 10 – Reference auxiliaries consumption ....................................... 38
Table 11 – Reference process consumption .......................................... 38
Table 12 – Normalized root-mean-square deviation for S1 ....................... 53
Table 13 – Normalized root-mean-square deviation for S1 ....................... 53
Table 14 – Energy relative error for S1 ................................................ 55
Table 15 – Energy relative error for S2 ................................................ 55
ACKNOWLEDGMENT

This Master thesis would not have been possible without the support of many people. First, I would like to thank Raphael MENARD and Sebastian DUPRAT for giving me the opportunity to carry out my Master thesis at Elioth. I would also like to express my gratitude to Thierry DEBERLE, my local supervisor at Elioth for his crucial assistance and his precious guidance throughout this Master thesis.

I also wish to thank Kjartan GUDMUNDSSON, my supervisor at the Royale Institute of Technology for his kind cooperation and the valuable feedback he gave from Sweden through our Skype meetings.

Thanks also to Aurélie HENNEQUIN, Jean ABAGLO, Aymeric ANQUETIN and Paola PUISEGUR for having shared their knowledge and for their help during the different missions I was involved in.

I finally wish to express my appreciation to KTH for the quality of the education I received during my Master of Civil and Architecture Engineering.
GLOSSARY

**Model**: Representation of a target that could be too complex by its nature or its lack of data

**Energy system**: All the machines that ensure a convenient indoor environment for the user in terms of temperature, humidity, air quality and lighting

**Process**: All the mechanical parts of the energy systems that consume electricity

**Auxiliaries**: Refers to both heating-cooling and ventilation mechanical component consumption

**Heating load**: Corresponds to all the parameters that participate in heating and cooling consumptions

**Non-heating**: Corresponds to all the parameters that participate in lighting, ventilation, auxiliaries and process consumptions

**Electricity**: Refers to the source of energy that participate totally or partially in heating, cooling, lighting, ventilation, auxiliaries and process consumptions

**Off-electricity**: Refers to the source of energy that participate totally or partially in heating and cooling consumptions such as gas or fuel

**Treatment group**: Refers to buildings under study

**Distribution**: The significance of each energy system regarding each other in terms of consumption share
REASONS FOR THE STUDY

THE CONTEXT

In France, the "Grenelle 1" law asks of public buildings that they reduce their energy consumption by 40% by 2020 [1]. An energetic performance contract is made to ensure the long-term improvement of a building's or a set of existing buildings' energy efficiency. Improving energy efficiency refers to the reduction of energy consumption regarding a specific usage. An energy consumption reduction goal is expressed as a percentage and focuses on primary energy.

The "baseline" [1] is the starting situation to perform energy performance calculations. It is a modeled and a functional representation based on validated data that facilitates its adjustment thereafter. The differential energy consumption between the adjusted baseline and the real building is determined in the contract agreements. The adjusted baseline reflects changes in the level of service and operating conditions made to the original baseline at the beginning. It takes into account the evolution from the operation to the mutation time according to Figure 2 – Building life cycle. The energy consumption measurements of the real building are done at each periodical performance evaluation during the warranty period. It constitutes one of the essential parts of the contract [2].

The operator may be a consortium of complementary skills. It can be the design team, the contractor or the owner. In many cases, it is the contractor that provides the guarantee of energy savings. It can cover all or part of the expenditure initially granted to the project. The actions implemented by the operator can concern the structure, the technical equipment - terms of use and user behaviour included -, the maintenance or multiple areas at once, within the limits set by the tender regulations. Some examples of actions are listed below - a non-exhaustive list of actions that could be included in a performance contract are given in the Excel sheet “Improvement list” - :
. Improve energy system efficiency
. Rehabilitate building enclosure
. Use double flow air system with heat recovery
. Implement mechanical regulation of lighting components

Once an operator has been selected, the client signs off on a defined and measurable level of energy savings. However, achieving this performance and controlling its implementation, does not guarantee a performance level on the long term. The client has, under the responsibility of the operator, to define the actions to be implemented in terms of energy performance – see examples above -, how to implement these actions and finally the performance guarantee period.

The client includes, in the tender documents given to the operator, a program designed to improve energy efficiency. In many projects, the client is helped by an environmental organization that develops a green chart defining quantitative and qualitative targets with respect to different environmental objectives such as:

- Energy monitoring
- Water monitoring
- Indoor air quality monitoring
- Materials’ organic emissions limitation
- Thermal limitation towards enclosure performance

It ensures a reduction of the global energy consumption for a defined level of service - this means that the contract is flexible in the sense that it takes into

Figure 3 – Energy commitment actors
account that the function of the building may change within time. It also indicates the foreseeable development of the area and the foreseeable development of factual conditions of use relative to existing conditions, knowing that the contract must provide possibilities for adjustment procedures if the reality differs from the forecast. The contract and the minimum performance requirement should be included in the notice of public solicitation and the tender regulations. The compensation is included in the compensation of all studies conducted in order to obtain the contract or the partnership agreement. The commitment is defined in terms of both primary energy and final energy. The ratio between final energy and primary energy from thermal regulations is part of the contract and should be annexed. The contract also provides compensation for the operator in the form of a penalty in the case of underperformance and a premium for outperformance.

In the event of underperformance, the operator is accountable to the client for the cost of the surplus of energy consumption compared to the contractual commitment. This amount is deducted from the rent paid by the public person or deducted from the payment of operating and maintenance services.

In the event of outperformance, the client is accountable to the operator for the money saved thanks to the extra energy savings compared to the contractual commitment. This amount takes the shape of an increase in the rent paid by the client or an increase in the payment of operating and maintenance services.
THE NEED

Nowadays, companies that are part of a consortium have difficulty dealing with the different terms of an energy performance contract. The main reason is that it is a new concept that clients are asking for. Energy consumption data, or more precisely a building's energy behaviour, are not available most of the time. This is due to the lack, or absence in worst case scenarios, of monitoring and captors in ancient buildings. Hence, the operator does not have a tool to model the baseline with sufficient insurance given that it is not based on real consumption but on theoretical simulated values. These consumptions cannot take into account all the parameters that govern a building's energy behaviour such as how it has been used over time.

It would also be beneficial to include a measurement protocol and a performance verification procedure to take into account the strict terms of the contract. These protocols must be enforceable for each of the contracting parties during and at the end of the contract.

Some protocols exist, such as the IPMVP - International Performance Measure and Verification Protocol -, a protocol managed by the EVO Association, a non-governmental American-born, non-profit organization dedicated to creating protocols for the measurement and verification of a construction project’s energy performance. However, this sort of protocol remains marginal, and most companies create their own non-enforceable procedure to get a project. The consequences could be dramatic for the operator if the building appears to underperform through the years of operation.
THE COMPANY

The Egis Group is a French company specialized in engineering and consulting expertise. It is involved in several fields such as civil engineering, building construction, transport infrastructure, water treatment, urban development and environmental certification.

It was created in 2007 with the merger of three major engineering firms (Isis, SEMALY and SCETAROUTE) and was expanded in early 2011 with the addition of the major French construction firm IOSIS to the group. By combining their knowledge and their resources, they are now able to provide their clients with a full range of services from the design to the construction field including project management and consulting expertise.

Elioth, alias Egis Concept, is a subsidiary of the Egis Group. It is a design office of around 40 engineers located in Montreuil, France. The company provides its expertise both for the group and direct clients. It is essentially specialized in contract development related to green buildings. To do so, it is divided in four specific business units.

This Master thesis has been carried out within the Energy & Environment field of the company (Elioth_EE) under the management of its director, Thierry DEBERLE. Elioth_EE aims at designing energy efficient and low-impact buildings for new constructions, as well as for renovated buildings. Its activity focuses on winning public-private projects. Elioth_EE provides expertise right from the initial stage of the project, supporting the design teams, the architects and the clients to achieve highly efficient buildings.
After discussing with both the company and KTH, a research topic concerning building energy performance was found.
COMMON METHODS

For a couple of years now in the energy sector, some methods have been used to calculate a building’s consumption value during the design phase. In France, there are different techniques to do so. There are also some legislative methods recognized by every stakeholder.

The aim of a baseline is to describe a building’s energy performance so that possible actions for improvement may be investigated. It permits the in-depth investigation of the current state of a building and gives an inventory of the different elements of a building, such as the envelope composition, the building technologies used to assemble the different parts of the construction or the consumption systems installed. The most commonly used method in France is the “3CL”. It is processed by software that calculates building behaviour in terms of energy. The limits of this type of software are multiple. It is not flexible, seeing as it is necessary to have all of the entry data to run calculations. And collecting this information takes time. Furthermore, its results are not accurate as it does not consider building lifetime and usage. Nowadays, with all of the field and audit feedbacks, it is established that these two parameters are the most impacting in terms of energy consumption. It is therefore not adapted to renovation but is nonetheless a good starting point.

Dynamic thermal energy simulation software also exists. They are numerous but the most common in France are Virtual Environment (IES VE), TYRNYS and TAS. They are used to forecast a building's consumption more accurately during the design stage. The calculation core is more complete and precise than the one used to perform thermal regulation calculations. Nonetheless, this solution also has its weaknesses and the results obtained are inaccurate since a building’s situation is complex. Companies are therefore cautious when it comes to taking the responsibility of an energy performance. They develop “home-made” methods to obtain more precise values by crossing the usual results with field reports. But this way of working is archaic and not based on real knowledge.

It is thus necessary to establish an optimized protocol in line with the project phase, in order to be faster and more accurate right from the start. Creating a dynamic energy simulation model from the starting point of the project is impossible because the assumptions of both the architects and the technical teams are not fixed. Furthermore, the introduction of this type of heavy-handed approach is not economically viable for companies.
AIMS OF THE THESIS

FORECASTING A BUILDING'S ENERGY BEHAVIOUR

The purpose of this Master Thesis is to offer both an approach and an operative tool to determine the energy consumption of an existing building. To narrow the field of study, it has been decided, together with Elioth, to focus on university constructions or a campus. This addresses one of the company’s current needs.

The work begins with empirical consumption feedbacks on existing university buildings depending on their age, functionality, location and usage. Hence it is possible to build up a behaviour model that reflects the manner in which the building components are interacting with each other and the resulting impact on the energy consumption of the building. This Master thesis project ends with an accurate deterministic approach to estimate the different energy consumptions using adjustment consumption formulas based on parameters such as weather data, envelope characteristics or functionalities within the building.

The protocol has been designed in order to simplify the current way of running a project that requires an energetic performance commitment. The simplification is based on time saving and standardization. It should save timework at the beginning of a project by avoiding building a 3D model to run initial calculations as illustrated below.

This period at an early stage is time consuming. It is also a crucial step to build up the most creative and innovative renovation project. It is therefore absolutely necessary to be as efficient as possible.

Standardization is a specific way of thinking that matches this problematic perfectly. The protocol should serve as a standard for future projects. It should be flexible enough to be adaptable to other sets of input data. It should also be robust to fulfill its simplification goal.
BUILDING A MATHEMATICAL MODEL

A model must be developed to represent the building under study and forecast its consumptions as described previously: the BASELINE. This project aims at establishing a simple description of the physics phenomena that govern a building's energy behaviour. The model must use as few equations as possible and characterize energy consumption using a limited number of inputs. The purpose of this Master thesis is not to use the complex and heavy equations that thermal simulation software is working with. The different steps of the model establishment will be developed in “the production process” section of chapter 2.

DEVELOPMENT OF AN OPERATIVE TOOL

A “material” tool will be necessary to use the model developed in this project. This means that the aim of this thesis is not limited to defining a theoretical model and testing its different equations. The project will go one step further by implementing the model to something “usable” such as a Matlab application, an Excel sheet or any other kind of software. The support will be chosen and argued in “the tool development” section of chapter 2.

The company needs a tool to get useful results for design and strategic meetings. Time has thus been allocated to turn the theory into a business reality during this Master thesis. The different steps of the tool's conception will be developed in “the tool development” section of chapter 2.

As a conclusion, the timing diagram below outlines the different phases that guided the project to reach the goals stated above.

Figure 7 - Principal entities of the thesis
Chapter 2 – The method

THE INVESTIGATION PROCESS

THE RESEARCH QUESTION

The following research question has guided all the work done during this master thesis to determine whether the model and the tool that will be developed, satisfy the aims of the project. The pre investigations conducted to answer the problematic have led to state the following hypothesis and the observable consequence that could be depicted from it.

- **Question** - “Could an existing building's energy behaviour be foreseen by a deterministic model through as little data as possible?”
- **Hypothesis** - “A building can be represented by a mono-zone model.”
- **Consequence** - “It is possible to reduce the amount of measured data to foresee building consumptions using reference buildings.”

This report will expose the construction of the model to test whether the observable consequence stated above is valid or not. It will allow accepting or rejecting the hypothesis by demonstrating that the effects of some parameters on global building consumption are sufficient to determine accurate consumption values. Such a result will imply that the thermal behaviour of a building can be foreseen thanks to reference existing buildings using a deterministic mono-zone model. An illustration of the mono-zone concept is given below.

![Diagram of Mono-Zone and Multi-Zone Models]

Hence, the model will be based on mathematics and physics. It will provide a deterministic representation of the existing building energy performance. A database will be developed using company empirical feedback to develop a
deterministic approach. It is further explained in the report of “the experiment feedback” section and the “a resilient database” section.

A summary of the different objects dealt by the project is given below to simplify the understanding of the report:

- **Data**: information from experiment studies about parameters that influence energy performance – measurement on site by captors
- **Database**: arrangement of data to develop the model towards deterministic forecast
- **Reference**: made-up building created using the database to develop the deterministic approach in order to have something to compare to. It gives the referenced values in terms of heating, cooling, ventilation, lighting, auxiliaries and process consumptions.
- **Model**: mathematical deterministic representation, using equations, of the target that gives the baseline
- **Baseline**: representative building given by the model to determine the target energy behaviour
- **Target**: real building that will be modelled to determine its energy behaviour

The figure above also illustrates the different steps to obtain the baseline as a representation of a real building. The mono-zone model will be developed through the reference given by the use of the database. It is generic in the sense that the database, the reference and the equation are independent from the building under study. It is the entry data fed to the model that changes the coefficients and delivers a specific baseline for each target. The inputs characterize the outputs in a deterministic way. It means that the same set of inputs must give the same set of outputs.

Hence, the model needs to be tested in order to ensure its viability. It is the crucial part of the project to validate the hypothesis conjectured at the beginning of the project. It will be tested through three complementary epistemic virtues: accuracy, reliability and precision. To do so, the model will process some university buildings. The consumptions of these buildings are known in advance thanks to a past study conducted by the company. In addition, these buildings were not used to create the database. This means
that there are totally independent from the model, as it would be the case in a real use situation. Hence, the known consumptions will be compared to the consumptions of the baseline given by the model. The testing procedure is described in detail in chapter 3 – the results.

The accuracy of the model will be measured by the normalized root-mean-square deviation RMSD.

\[
NRMSD = \sqrt{\frac{\int (X - X_{ref})^2 dt}{\int max(X_{ref}) - min(X_{ref})}}
\]

It is a frequently used measure of the differences between values predicted by a model and the values actually observed. It means that the consumption value given by the model i.e. the baseline will be compared to the consumption value measured by captors on site i.e. the target. It has been agreed with the company that the NRMSD of the model must be less than 10 percent.

The reliability of the model means that it must provide the same baseline for the same set of inputs after a certain time interval. If the baseline remains the same over time, then the test is reproducible, which means that the model stays consistent throughout testing and re-testing.

The precision of the model will be measured by the standard criteria of the energy relative error ERE.

\[
ERE = 100 \times \frac{\int X dt - \int X_{ref} dt}{\int X_{ref} dt}
\]

It means that the difference between the real and the foreseen consumptions must not be larger than a limit value determined in advance. In other words, the test amounts to comparing the consumption values of the baseline with those of the target. It has been agreed with the company that the ERE of the model must be less than 10 percent.

The criterion limits, based on the ASHRAE guideline limits, are presented in the Table 1 below.

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Limit</th>
</tr>
</thead>
<tbody>
<tr>
<td>ERE</td>
<td>([-10%; 10%])]</td>
</tr>
<tr>
<td>NRMSD</td>
<td>&lt; 10%</td>
</tr>
</tbody>
</table>

Table 1 - Criterion limits [3]
THE THEORY

Some pre studies have been conducted to determine whether a mono-zone model is realistic. A lot of information is required to describe building thermal properties. Hence, it is complex to fully understand the interactions within a building.

To do so, the vision focuses on a system approach to building technology and the utility of building science to understand the physical behaviour of the building as a system and how it impacts the energy efficiency. Indeed, traditional analytical techniques rely on the elaborate isolation of the smallest possible component of the subject under study. In many cases, this fails to provide a suitable description of the behaviour of the subject as a whole. It is particularly true when there are strong and complex interactions between the various components of a building. That is the reason why it was essential to look at the building as a “system”. The system approach added two parameters compared to the traditional approach as illustrated below [4].

The system approach adds an “evaluation criteria” and “modelling” parameters to the traditional diagram. It considerably increases the number of relations between the overall parameters. The “evaluation criteria” consideration implies outlining several concepts for a building and fundamentally understanding how they interact [5]:

- Boundary Criterion - Building system extends to the outer reaches of what it impacts, and what impacts the building
- Flows and Storage Criterion - Inhabitants, energy, water, sewage, and data are examples of the flows and storage characteristics of the building as a system
Occupant behaviour - It is among the most difficult flows to accurately predict in energy models

Transformations Criterion - Users modify the age buildings, not always in a beneficial way

Feedback and Control Loops Criterion - Buildings rely on many forms of cybernetics to control the indoor environment

Defining a building this way allows narrowing the amount of entry data needed to translate both its evolution over time and its resulting energy consumption.

i. Boundary criterion

1. Building enclosure: type of glazing, gap between panels, roof, floor, wall insulation degree and area, height slab to slab, number of storeys and percentage of glazing area
2. External environment: referenced exterior temperature and associated DJU0, party wall (north, south, east and west), natural lighting capacity
3. Site: n° region, city and geographical zone

ii. Flow criterion

1. Inhabitants usage: people, lighting, equipment and others, interior temperature
2. Activity within the building: laboratory, experimentation, teaching, and office
3. Systems: heating and cooling equipment area and efficiency (COP & EER), ventilation equipment (air renew debit, usage time, type of ventilation, heat recovery ratio, grid quality, ventilator efficiency, natural ventilation capacity)

iii. Transformation criterion

1. Building services: structure, roof, floor, wall and window state and air tightness
2. Building time period: date of construction, period of construction

The feedback criterion is not taken into account because the buildings under study are too old to have any form of cybernetics controlling the indoor environment.

The system approach allows reducing the amount of data processed by the tool to 55 elements. The operational approach described in the next chapter is used to categorize the data.
. CRITICAL Project value - Required data to get results
. EXTRA Project value - Data to get more precise results
. FIXED Project value – Data that does not need to be changed

This operation reduced the number of entry data elements needed to run a viable calculation from 55 to 21.

Basically, the building is a living structure that continuously exchanges with its outdoor and indoor environments. These exchanges can be divided into four categories [4]. Heat flow characterizes conductive, convective and radiation flows of heat throughout the building. Airflow within the building enclosure characterizes leakages due to building permeability and its ventilation system. Moisture flow is the flow of water and vapor across and within the building enclosure. Solar radiation refers to the influence of sunlight on the indoor building environment through the insulation of opaque and transparent enclosure components.

Moisture flow has not been taken into account during this project due to a lack of information about it and the difficulty to isolate its impact on heating load.

The heating and cooling load is determined by the difference between losses and gains as explained below [6]:

\[ \text{Total load} = \text{Losses}(\Pi) - \text{Gains}(\Omega) \]

There are two types of losses, the envelope losses and the internal air treatment losses, which can be formulated mathematically:

\[ \Pi = \Pi_{\text{env}} + \Pi_{\text{air}} = [U \times S_t + 0,34Q] \times \text{grad}(T) \]

With:

- \( U \): Enclosure mean U-value (thermal performance) -W/m²/K-
- \( S_t \): total loss area -m²-
- \( Q \): air renew and leakage debit -m³/h-
- \( \text{Grad} \ (T) \): temperature gradient = T outside - T inside °C-

Is should be noted that the linear losses and the inertia losses are neglected because, respectively, of a lack of information and too complex a data processing. Hence, the envelope losses correspond to the surface thermal deficit characterized by the heat transfer toward a surface with a temperature difference at its extremities.
Meanwhile, the gains are divided into two sections: the internal and the external gains. The external gain resulting from solar heat gain is:

$$\Omega_e = I \times S \times F$$

With:
- $I$: total solar irradiation -W/m$^2$.
- $S$: total irradiated area -m$^2$.
- $F$: glazing solar factor

The internal gains are the heat generated by the users, the lighting and the equipment within the building as indicated below:

$$\Omega_i = \Omega_i^p + \Omega_i^e + \Omega_i^l = \sigma \times J_p \times S_p + J_e \times S_e + J_l \times S_l$$

With:
- $\sigma$: People density -pers/m$^2$.
- $J_i$: Intensity of respectively people, equipment and lighting systems - W/m$^2$.
- $S_i$: Surface of respectively people, equipment and lighting systems within the building -m$^2$.
THE EMPIRICAL FEEDBACK

The operational approach focuses on using a large amount of data regarding:

- Typology, university, site, date of construction
- Total floor area, number of levels, density of inhabitants
- Global, heating, air conditioning, lighting, ventilation, auxiliaries and process consumptions
- Structure, roof, floor, facade and window area, thermal bridge values and state
- Indoor and outdoor temperatures
- Heat gain from users, solar irradiation and equipment
- Heat loss by space air treatment
- Equipment efficiency and state

This data comes from a consulting study ran by Elioth in Rennes to advise a private client on the refurbishment of a large set of university buildings.

The different steps to build the model explained previously in “the research question” section are: collect the data described above, arrange it into a functional database, exploit it to obtain the reference and insert it in the equation to have a model ready for input. The empirical approach defines another parameter to deal with in order to take into account the use of a university building more precisely. It is the activity accommodated by the building. There are four principal activities in universities according to a study ran by the company. These building facilities are described below:

- The laboratory space – corresponds to the room where chemical experiments are conducted with its specificity in air treatment
- The experimentation space – corresponds to the room where physical experiments are conducted, such as optic or electric tests, with its specificity in process use
- The teaching space – corresponds to the room where lectures are conducted with its specificity in internal gains
- The office space – corresponds to the room where a person, such as a teacher or an administrator, is working with its specificity in indoor heat transfer

This approach led to introduce a weighting parameter in order to conserve the mono-zone model. It will be developed further in the “a deterministic model” section. Hence the model continues modelling the building as one zone with its internal, external and limit parameters but from now it weights these factors between the four activities. For example, if a building is composed of 50% of office space and 50% of teaching space, the model will consider the following factors to run calculations:
. A laboratory factor of 0
. An experimentation factor of 0
. A teaching factor of 0,5
. An office factor of 0,5

In conclusion, the baseline is the combination of the four reference activities adjusted by the inputs entered in the model. It means that the baseline is the default reference when there are no inputs.

The type of results expected has been discussed with the company. Indeed, the possible outputs given by a model to explain a building's energy behaviour are multiple. It has been decided to focus on consumption values i.e. how much energy the building is consuming to behave in a defined outdoor and indoor climate. In accordance with the French energy regulation, the consumptions are expressed in primary energy i.e. the energy used in nature to produce the energy actually consumed in the building. Hence, the model should give a target in the form of six energy system consumptions: heating, cooling, ventilation, lighting, auxiliaries and process. The definition of these terms is given in the GLOSSARY. The total consumption is the sum of the six energy system consumptions.

\[ C_T = H + C + L + V + A + P \]

With:
. \( H \) : Heating load
. \( C \) : Cooling load
. \( L \) : Lighting load
. \( V \) : Ventilation load
. \( A \) : Auxiliaries load
. \( P \) : Process load
. \( C_T \) : Total load
THE PREREQUISITES

A RESILIENT DATABASE

Database resilience is defined as "the ability to return to a previous state after the occurrence of an event or action which may have changed that state." In general, resiliency is about flexibility, it should bend but not break. The database built for the thesis is able to counteract most human failures without resulting in systemic tool overriding:

- A data element within the base (from one column or one line) is deleted
- A data element within the base (from one column or one line) is modified
- A data element within the base (from one column or one line) is added

In this case, it means reacting to modification in a way that is non-disruptive to the overall system. The database has been set up using the large amount of data available within the company. It is composed of over a hundred parameters for one hundred buildings. It enables to create a reference for each type of activity that characterizes the building as described in the previous section. Office space concerns teaching and administration rooms. Experimentation space concerns workshop rooms. Teaching space concerns lecture rooms and amphitheater. Laboratory space concerns research and chemistry rooms. All the data resulting from this analysis is available in the “Reference building” sheet in the tool.

The disparity of consumption values is tested to figure out whether the data is relevant enough to be used as a reference. The process is repeated for each building of the database and the results for the different energy systems - heating, cooling, ventilation, lighting and process - are given by activity. The first and second quartile, the minimum and the maximum value and the median are calculated to determine the distribution of the data.
In general, the results depict that the dispersion between values is limited. It means that the median value is a good indicator of the reference consumption of the treatment group. Nonetheless, it can be observed that the heating distribution is broader. Hence, the median value must be considered with provision. The last observation that can be made from this study is that there are few extreme values. It concerns either the maximum or the minimum value for some energy systems. This data will not be taken into account to constitute the reference.

Figure 11 – Results of the dispersion study
AN ADVANCEMENT PROCEDURE

The V-model [7] is a simple and easy use industrial life cycle methodology (SDLC) to design tools. It is particularly appropriate for software development. That is why this conceptual process has been used to build the protocol of this Master thesis project.

The V-model is based on nine steps as described below:

- **Requirement analysis**: a first feasibility assessment is performed. It lists all the system’s functionalities (tool’s interface, performance, data, security...)

- **System design**: the software specifications from the previous step are analyzed to figure out possibilities by which it could be implemented

- **Architecture design**: the general structure of the tool is defined as well as its modules and their functionalities. A high-level design architectural diagram is performed at this stage

- **Module design**: the database tables with their type and size, all the interface details and dependency issues and complete inputs and outputs are designed on the chosen programming interface

- **Implementation**: the tool is completed on the selected program

- **Unit testing**: it verifies that each entity is working correctly when it is isolated from the other units

- **Integration testing**: it verifies that the links between all the units previously created and tested independently are interacting correctly
. **System testing:** the functionality and the interdependency of the tool are tested to ensure it meets all the requirements expressed previously.

. **User acceptance:** it verifies that the delivered application meets the user requirements. It states whether the tool is ready for use.

This methodology is a well-organized mechanism and a disciplined process to develop an application for a specific user. Each step is directly associated with a testing phase so it enables identifying and efficiently correcting any problem detected at any time during the development process.
THE MODEL PRODUCTION PROCESS

In this section, the construction of the model will be explained. It is the generic model described in the previous section based on the database, the four references - one for each activity - and equations that will be outlined. The scope of this part is to work out a generic linear algebraic relation between the reference and the baseline. Hence, this formula will give the same outputs for the same inputs whereas it will give other outputs if any changes are made to the inputs. The division into three subsections is voluntary but only one model, and not three models, has been developed in this project. This choice was driven by the desire to clearly expose the three aspects of the model: physics through mathematics, statistics through determinism and algebra.

A MATHEMATICAL MODEL

The model is based on mathematics exposing building physic equations. The model of this project must result in an Excel sheet that will be manipulated to foresee the building energy consumption level. Three key steps are needed to build this mathematical representation:

. Isolate the real phenomena that affect the common energy use of a building
. Describe the target result using building physics equations
. Predict the target consumptions based on real building data within a database

Building's energy balance results from heating, cooling, lighting, ventilation and its auxiliary properties. The model takes into account each of these parameters. By using physics equations it is therefore possible to isolate the different parameters that influence the result towards energy use. The argument uses the equations below:

i. Heating load

\[ H = COP \times (\Pi - \Omega) \]

With:

. COP: heating system performance

ii. Cooling load

\[ C = EER \times (\Pi - \Omega) \]
With:

. EER: cooling system performance

iii. **Lighting load [8]**

\[ L = 0.33 + 0.67 \times \left[ (1 - \rho) \times (\sigma_l \times \theta_l \times P) \right] \]

With:

. \( \rho \): Natural lighting rate
. \( \sigma_l \): Use of artificial lighting -h/year-
. \( \theta_l \): Artificial lighting rate
. \( P \): Power of the entire artificial lighting systems -W/m²-

iv. **Ventilation load [9]**

\[ V = \frac{\sigma_v \times Q}{3600} \times \left[ \omega_1 \times \Delta P_{out} + \omega_2 \times \xi \times \left( \Delta P_{out} + \Delta P_{in} \right) \right] \]

With:

. \( \sigma_v \): Use of ventilation system -h/year-
. \( Q \): Ventilation debit -m³/h-
. \( \omega_1, \omega_2 \): Ratio of respectively simple flow and double flow air treatment within the building
. \( \Delta P_{out}, \Delta P_{in} \): Pressure gradient of respectively extraction and pulsing -Pa-
. \( \xi \): Heat recovery capacity of the ventilation system

v. **Auxiliaries load [9]**

\[ A = \frac{\sigma_v \times Q}{3600} \times (v \times \phi) \]

With:

. \( v \): Performance of the ventilation system
. \( \phi \): Ventilator efficiency -W/m³/h-
A DETERMINISTIC MODEL

It means the model must give an identical representation of the target for identical entry data sets. Some coefficients have been introduced to compare the target with the references. First of all, the target is decomposed into the four activities to depict its distribution. It gives the set of activity coefficients $[\gamma_o; \gamma_e; \gamma_i; \gamma_t]$ for respectively the office, the experimentation, the laboratory and the teaching spaces. These coefficients will impact the baseline to represent the target as correctly as possible.

i. **Heat loss formula**

$$\Pi = F_D \times \omega_{env} \times \tau_{env} \times \alpha_{env} + \omega_{air} \times \tau_{air} \times \alpha_{air}$$

\[
\begin{align*}
\alpha_{env} &= \frac{\Pi_{env}^M}{\Pi_{env}^T} \\
\alpha_{air} &= \frac{\Pi_{air}^M}{\Pi_{air}^T}
\end{align*}
\]

With:

- $[\text{env; air}]$: losses due to respectively the envelope and the air treatment
- $F_D$: Damages factor
- $\omega_i$: Weighting coefficient from the database
- $\tau_i$: Use rate
- $\alpha_i$: Comparison coefficient per type of loss
- $\Pi_{env}^M, \Pi_{env}^T$: Respectively measured and calculated envelope loss
- $\Pi_{air}^M, \Pi_{air}^T$: Respectively measured and calculated air loss

ii. **Heat gain formula**

$$\Omega = \omega_l \times \tau_l \times \alpha_l + \omega_p \times \tau_p \times \alpha_p + \omega_e \times \tau_e \times \alpha_e + \omega_s \times \alpha_s$$

\[
\begin{align*}
\alpha_l &= \frac{\Omega_l^M}{\Omega_l^T} \\
\alpha_p &= \frac{\Omega_p^M}{\Omega_p^T} \\
\alpha_e &= \frac{\Omega_e^M}{\Omega_e^T} \\
\alpha_s &= \frac{\Omega_s^M}{\Omega_s^T}
\end{align*}
\]

With:
The weighting coefficient represents the relative influence of each impacting parameter towards heat transfer. The different events occurring in heat gain and loss are pondered. Considering that they have the same significance would be wrong. The outputs from the database analysis are illustrated below:

![Figure 13](image-url)

Figure 13 – Illustration of heat equation parameters relative influence for respectively experiment, laboratory, office and teaching spaces

The results from the database studies for the four activities are presented in the tables below. It allows stating the coefficient values that have been used during this project.
Table 2 – Weighting values for laboratory reference

<table>
<thead>
<tr>
<th>Heat sources</th>
<th>Weighting coefficient $w_i$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Envelope</td>
<td>0.687</td>
</tr>
<tr>
<td>Air flow</td>
<td>0.374</td>
</tr>
<tr>
<td>Solar radiation</td>
<td>0.227</td>
</tr>
<tr>
<td>People</td>
<td>0.056</td>
</tr>
<tr>
<td>Lighting systems</td>
<td>0.208</td>
</tr>
<tr>
<td>Equipment</td>
<td>0.096</td>
</tr>
</tbody>
</table>

Table 3 – Weighting values for experiment reference

<table>
<thead>
<tr>
<th>Heat sources</th>
<th>Weighting coefficient $w_i$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Envelope</td>
<td>0.812</td>
</tr>
<tr>
<td>Air flow</td>
<td>0.217</td>
</tr>
<tr>
<td>Solar radiation</td>
<td>0.044</td>
</tr>
<tr>
<td>People</td>
<td>0.048</td>
</tr>
<tr>
<td>Lighting systems</td>
<td>0.103</td>
</tr>
<tr>
<td>Equipment</td>
<td>0.033</td>
</tr>
</tbody>
</table>

Table 4 – Weighting values for teaching reference

<table>
<thead>
<tr>
<th>Heat sources</th>
<th>Weighting coefficient $w_i$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Envelope</td>
<td>0.880</td>
</tr>
<tr>
<td>Air flow</td>
<td>0.237</td>
</tr>
<tr>
<td>Solar radiation</td>
<td>0.308</td>
</tr>
<tr>
<td>People</td>
<td>0.141</td>
</tr>
<tr>
<td>Lighting systems</td>
<td>0.247</td>
</tr>
<tr>
<td>Equipment</td>
<td>0.127</td>
</tr>
</tbody>
</table>
Table 5 – Weighting values for office reference

<table>
<thead>
<tr>
<th>Heat sources</th>
<th>Weighting coefficient ( w_i )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Envelope</td>
<td>0.902</td>
</tr>
<tr>
<td>Air flow</td>
<td>0.236</td>
</tr>
<tr>
<td>Solar radiation</td>
<td>0.072</td>
</tr>
<tr>
<td>People</td>
<td>0.068</td>
</tr>
<tr>
<td>Lighting systems</td>
<td>0.134</td>
</tr>
<tr>
<td>Equipment</td>
<td>0.084</td>
</tr>
</tbody>
</table>

iii. Heat equation

\[
H = (F_s^e + F_s^o) \times \left[ \sum_{j=1}^{4} \gamma_j \times C_j^h \times K_j \times F_c^h \times (\Pi_j - \Omega_j) \right]
\]

With:

- \( j \in [1 \text{ to } 4] \): Distribution between the four activities - experiment, laboratory, teaching and office -
- \( F_s^e, F_s^o \): Severity factor for respectively electrical part and non-electrical part of heating energy source
- \( \gamma_j \): Distribution between activities -
- \( C_j^h \): Referenced heating consumptions -kWh\(_{pe}\)/m\(^2\)/year - for each activity
- \( K_j \): Correlation determinant for each activity
- \( F_c^h \): Climatic heating corrective factor for each activity

The numerical values of consumption used in this project resulting from the database analysis are given in the table below.

Table 6 – Reference heating consumption

<table>
<thead>
<tr>
<th>Activity</th>
<th>Consumption kWh/m(^2)/year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Laboratory</td>
<td>106</td>
</tr>
<tr>
<td>Experiment</td>
<td>198</td>
</tr>
<tr>
<td>Teaching</td>
<td>83</td>
</tr>
</tbody>
</table>
The correlation determinant is the ratio between theoretical and captor-measured consumptions. The real consumption of the reference building takes into account all the types of gain and loss whereas the model of this thesis does not. It allows correlating theoretical equations with the measurement in the database to describe reality.

\[ K_j = \frac{C_j^{HM}}{C_j^{RT}} \]

With:

. \( j \in \{1 \text{ to } 4\} \): Distribution between the four activities - experiment, laboratory, teaching and office -
. \( C_j^{HM} \): Measured heating consumption -kWh/m²/year- for each activity
. \( C_j^{RT} \): Calculated heating consumption -kWh/m²/year- for each activity

The numerical values used in this project resulting from the database analysis are given in the table below.

<table>
<thead>
<tr>
<th>Activity</th>
<th>Correlation determinant ( K_j )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Laboratory</td>
<td>2,107</td>
</tr>
<tr>
<td>Experiment</td>
<td>1,247</td>
</tr>
<tr>
<td>Teaching</td>
<td>3,398</td>
</tr>
<tr>
<td>Office</td>
<td>1,282</td>
</tr>
</tbody>
</table>

iv. Lighting equation

\[ L = \sum_1^4 \gamma_j \times C_{j}^{l} \times F_{c}^{l} \times \alpha_j^{l} \]

\[ \alpha_j^{l} = \frac{C_j^{lM}}{C_j^{lT}} \]

With:

With:
\( j \in [1 \text{ to } 4] \): Distribution between the four activities - experiment, laboratory, teaching and office -

\( \gamma_j \): Distribution between activities -\%-

\( C^l_j \): Referenced lighting consumptions \(-\text{kWh}_{pe}/\text{m}^2/\text{year}\) for each activity

\( F^h_{c, j} \): Climatic lighting corrective factor for each activity

\( \alpha^l_{j, v} \): Lighting comparison coefficient for each activity

\( C^l_{j, v} \): Measured lighting consumption \(-\text{kWh}_{pe}/\text{m}^2/\text{year}\) for each activity

\( C^l_{j, r} \): Calculated lighting consumption \(-\text{kWh}_{pe}/\text{m}^2/\text{year}\) for each activity

The numerical values of consumption used in this project resulting from the database analysis are given in the table below.

**Table 8 – Reference lighting consumption**

<table>
<thead>
<tr>
<th>Activity</th>
<th>Consumption k(\text{W}h/\text{m}^2/\text{year})</th>
</tr>
</thead>
<tbody>
<tr>
<td>Laboratory</td>
<td>30</td>
</tr>
<tr>
<td>Experiment</td>
<td>23</td>
</tr>
<tr>
<td>Teaching</td>
<td>26</td>
</tr>
<tr>
<td>Office</td>
<td>21</td>
</tr>
</tbody>
</table>

\( V = \sum_{1}^{4} \gamma_j \times C^v_j \times F^v_{c, j} \times \alpha^v_j \)

\( \alpha^v_j = \frac{C^v_{j, v}}{C^v_{j, r}} \)

With:

\( j \in [1 \text{ to } 4] \): Distribution between the four activities - experiment, laboratory, teaching and office -

\( \gamma_j \): Distribution between activities -\%-

\( C^v_j \): Referenced ventilation consumptions \(-\text{kWh}_{pe}/\text{m}^2/\text{year}\) for each activity

\( F^v_{c, j} \): Climatic ventilation corrective factor for each activity

\( \alpha^v_j \): Ventilation comparison coefficient for each activity
. $C^M_j$: Measured ventilation consumption -kWh/ m²/year- for each activity
. $C^{TF}_j$: Calculated ventilation consumption -kWh/ m²/year- for each activity

The numerical values of consumption used in this project resulting from the database analysis are given in the table below.

<table>
<thead>
<tr>
<th>Activity</th>
<th>Consumption kWh/m²/year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Laboratory</td>
<td>45</td>
</tr>
<tr>
<td>Experiment</td>
<td>20</td>
</tr>
<tr>
<td>Teaching</td>
<td>9</td>
</tr>
<tr>
<td>Office</td>
<td>10</td>
</tr>
</tbody>
</table>

vi. **Auxiliaries equation**

$$A = \sum_{j=1}^{4} y_j \times C^a_j \times F^a_{c j} \times \alpha^a_j$$

$$\alpha^a_j = \frac{C^{aM}_j}{C^{aT}_j}$$

With:
- $j \in [1 \text{ to } 4]$: Distribution between the four activities - experiment, laboratory, teaching and office -
- $y_j$: Distribution between activities %-
- $C^a_j$: Referenced auxiliaries consumptions -kWh/ m²/year- for each activity
- $F^a_{c j}$: Climatic auxiliaries corrective factor for each activity
- $\alpha^a_j$: Auxiliaries comparison coefficient for each activity
- $C^{aM}_j$: Measured auxiliaries consumption -kWh/ m²/year- for each activity
- $C^{aT}_j$: Calculated auxiliaries consumption -kWh/ m²/year- for each activity

The numerical values of consumption used in this project resulting from the database analysis are given in the table below.
### Table 10 – Reference auxiliaries’ consumption

<table>
<thead>
<tr>
<th>Activity</th>
<th>Consumption kWh/m²/year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Laboratory</td>
<td>5</td>
</tr>
<tr>
<td>Experiment</td>
<td>19</td>
</tr>
<tr>
<td>Teaching</td>
<td>5</td>
</tr>
<tr>
<td>Office</td>
<td>10</td>
</tr>
</tbody>
</table>

vii. **Process equation**

\[ P = \sum_{1}^{4} \gamma_j \times C^p_j \times \pi_j \]

With:
- \( j \in [1 \text{ to } 4] \): Distribution between the four activities - experiment, laboratory, teaching and office -
- \( \gamma_j \): Distribution between activities - % -
- \( C^p_j \): Referenced process consumptions - kWh/m²/year - for each activity
- \( \pi_j \): Process determinant for each activity

The numerical values of consumption used in this project resulting from the database analysis are given in the table below.

### Table 11 – Reference process consumption

<table>
<thead>
<tr>
<th>Activity</th>
<th>Consumption kWh/m²/year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Laboratory</td>
<td>176</td>
</tr>
<tr>
<td>Experiment</td>
<td>40</td>
</tr>
<tr>
<td>Teaching</td>
<td>48</td>
</tr>
<tr>
<td>Office</td>
<td>10</td>
</tr>
</tbody>
</table>

### A MODEL ADJUSTED TO SITE OBSERVATION

Some factors have been developed to ensure that the theoretical model stated below is consistent with the observations, the feedback and the knowledge of the company. The different factors are explained below:
i. Severity factor

The DJU literally means unified degree-days. All things being equal, they can estimate a hot or cold consumption according to a given set point temperature. The DJU\(_{18}\) (set point temperature of 18°C) are generally used to estimate the heating loads of a building’s needs in France [10].

\[
f(t) = T_c - \frac{T_{\min}(t) + T_{\max}(t)}{2}
\]

\[
h(t) = \begin{cases} 
0 & \text{if } t < 0 \\
1 & \text{if } t > 0 
\end{cases}
\]

\[
DJU = \int f(t) \times h(t) \, dt
\]

With:

- \(T_c\): Set point temperature
- \(t\): Time step

Hence,

\[
F_s^e = 1 - p_e + p_e \times \frac{DJU}{DJU_0}
\]

\[
F_s^o = 1 - p_o + p_o \times \frac{DJU}{DJU_0}
\]

With:

- \(p_o\): Coefficient from table for non-electric heating source
- \(p_e\): Coefficient from table for electric heating source
- \(DJU_0\): Referenced DJU

The different consumptions are calculated for each climate zone defined by the French regulation RT 2012. It has been chosen to divide the French country into eight meteorological zones to take into account the climate variations more precisely. An illustration of this distribution is given below.
The intern simulation tool Clim’ELIOTH was used to determine the different reference consumptions. The process was repeated for the four activities and for the five construction periods. The baseline zone is h2a as all the data refers to this area. Hence, the ratio between this area and the others gives the climatic factor needed to correct the heat loads of this area.

Clim’ELIOTH [11] is a mono-zone dynamic thermal simulation tool that is simple, fast and responsive. It allows to easily implementing all project inputs, to perform a quick calculation and process the results in order to appreciate the overall energy attribute of a building. In terms of calculation, it computes the balance of energy exchanges hour by hour. It is defined by the input data and meteorological data on the defined area. It offers a variety of charts to observe the thermal behaviour of the building on an annual basis.

ii. **Climatic factor [12][13]**

A climatic factor has been created to modulate the target’s energy loads according to its geographic location. Indeed, there are different climates within the country and more precisely different balances between heating and cooling loads. So the heating and cooling auxiliaries’ part differs from an area to another. Moreover, the lighting
needs are different in the north and the south. To adjust the model as
described in the “mathematical model” section, corrective factors
have been introduced. They were determined using the
Clim’ELIOTHT software described previously. It enabled calculating a
coefficient for each energy system compared to the Paris reference
which presents the medium microclimate in France. All the results of
this study are given in the “geographic factor” spreadsheet of the tool.
Its implementation within the calculations is done in the “geographic
calculation” spreadsheet accessible within the tool.

iii. Damage factor [12]
A damage factor has been created to modulate the target’s energy
loads according to its state. It concerns the state or the level of
damage of its structure, envelope, roof, floor and slab. As damages
impact the losses due to enclosure, they have a repercussion on the
heating and cooling load. The state of the reference buildings is taken
as a basis to determine whether the target state is better or worse than
the reference one. To do so, a quantification scheme has been set
based on confidential company knowledge. This scale allows
transforming a qualitative statement into a quantitative assessment.
For example, a good state for the structure corresponds to a five
percent reduction in the structural performance given by the
regulation. Hence, the constructive period is crucial to figure out
which regulation to use. The equivalent grid for regulation is given
below:

- Constructing period “< 1974” corresponds to RT 1974
- Constructing period “1974 to 1988” corresponds to RT 1988
- Constructing period “1988 to 2000” corresponds to RT 2000
- Constructing period “2000 to 2005” corresponds to RT 2005
- Constructing period “> 2005 corresponds to RT 2012

All the results of this study are given in the “damage factor” spreadsheet of
the tool. Its implementation in the calculations is done in the “damage
calculation” spreadsheet accessible within the tool.
AN ALGEBRA MODEL

The thorough check that has been developed above allows condensing the model into algebra matrix relations between the building sample and the target [14].

\[ M[t] = (z_{kq}^i)[t] = (\varphi_{kp}^i)[t] \times \sum_j (\lambda_{kp}^{ij})[t](z_{kj}^{ij}) \]

With:

. \( i \in [1 \text{ to } 6] \): Refers to the six energy systems - heating, cooling, lighting, ventilation, auxiliaries and process -
. \( j \in [1 \text{ to } 4] \): Refers to the four activities - office, teaching, experiment and laboratory -
. \( k \in [1 \text{ to } 6] \): Refers to the line of the matrix
. \( p \in [1 \text{ to } 6] \): Refers to the column of the square matrix
. \( q \in [1 \text{ to } 1] \): Refers to the column of the column matrix
. \( t \): Treatment group
. \( M[t] \): Algebra model
. \( (\varphi_{kp}^i)[t] \): Corrective matrix
. \( (\lambda_{kp}^{ij})[t] \): Adjustment matrix
. \( (z_{kq}^i)[t] \): Forecast matrix
. \( (z_{kj}^{ij}) \): Reference matrix

i. **Forecast matrix**

\[ (z_{kq}^i)[t] = \begin{pmatrix} H \\ C \\ L \\ V \\ A \\ P \end{pmatrix}[t] \]

With:

. \( t \): Treatment group i.e. target
. \( H \): Heating consumption
. \( C \): Cooling consumption
. \( L \): Lighting consumption
. \( V \): Ventilation consumption
. \( A \): Auxiliaries consumption
. \( P \): Process consumption

ii. **Corrective matrix**
\[
(\varphi^i_{\text{kp}}) = \begin{pmatrix}
COP(F^e_s + F^p_s) & 0 & 0000 \\
0 & EER(F^e_s + F^p_s) & 0000 \\
0 & 0 & 1000 \\
0 & 0 & 0100 \\
0 & 0 & 0010 \\
0 & 0 & 0001
\end{pmatrix}
\]

iii. **Adjustment matrix**

\[
(\lambda^i_{\text{kp}}) = \begin{pmatrix}
\gamma_f K_f F^h_j \left( \Pi_j - \Omega_j \right) & 0 & 0 & 0 & 0 & 0 \\
0 & \gamma_f K_f F^h_j \left( \Pi_j - \Omega_j \right) & 0 & 0 & 0 & 0 \\
0 & 0 & \gamma_f F^l_j \alpha_j^l & 0 & 0 & 0 \\
0 & 0 & 0 & \gamma_f F^p_j \alpha_j^p & 0 & 0 \\
0 & 0 & 0 & 0 & \gamma_f F^a_j \alpha_j^a & 0 \\
0 & 0 & 0 & 0 & 0 & \gamma_f \pi_j
\end{pmatrix}
\]

iv. **Reference matrix**

\[
(x^i_{\text{qa}}) = \begin{pmatrix}
C^h_j \\
C^f_j \\
C^l_j \\
C^p_j \\
C^a_j \\
C^p_j
\end{pmatrix}
\]

Below, the final equation of the project’s linear model concludes this section. It is the model that will be implemented in a tool and explained in the next section.

\[
M[t] = \Phi[t] \times \sum \Lambda[t] \times Z
\]
THE TOOL DEVELOPMENT

REQUIREMENT ANALYSIS

The general goal of the project, as stated in the Master thesis proposal, is the following:
“Implement a model to determine the energy performance of an existing building”.

To narrow this topic, a case study on the renovation of university buildings with an energy performance commitment was chosen. The protocol is composed of the evaluating procedure, which proposes a vision in the determination of a building’s energy performance, and the associated tool which can be used to carry out the evaluation.

The tool must be ergonomic in the sense that it should be difficult to make mistakes by choosing the wrong entry data. It should also be accessible so that people can use it easily, even during the different phases of a competition when knowledge about the energy performance calculation can be limited. In that way it will be a workable operative tool. It should also be composed of a limited number of layouts and options so it is easy to learn how to use it.

All these requirements are necessary for the tool to be efficient as a supporting instrument for Elioth. To be consistent with the operational application and aims of this Master thesis, it was named Estim’ELIOTH. All the environmental engineers and project managers in charge of a project or competition with an energy performance commitment will use the protocol. It is a single-user tool that will be stored on the server of the company to make it accessible to every engineer of Elioth_EE. As a supporting design and decision approach, the client, the architect, any other design teams and any other entity involved in the project will not use the tool. The protocol is implemented with Microsoft Excel and relies on Visual Basic programming language when necessary.

Figure 16 – SADT A0 of the project
SYSTEM DESIGN

A protocol has been developed to fulfill the demands of the requirement analysis. The user must answer four basic questions:

- Is data about the target consumptions available?
- Is data about the target morphology available?
- Is data about the target envelope available?
- Is data about the target energy systems and their uses available?

The tool must then process each scenario depending on whether the answer is Yes/No. The logic is synthesized below:

The tool is based on a Boolean procedure that induces the result. Basically, the first parameter is about initial consumption. The model can determine the distribution between energy systems if the target consumptions are known. If information is not available, it will require entering a minimum number of data about the target morphology to start processing. These are the CRITICAL values described in the “Theory” section. This data is compulsory since the model gives the reference as a baseline without any inputs. Hence, the more information about the target enclosure, system and use is available, the more the model gives a result close to reality. These are the EXTRA values, described in the “Theory” section, to get a more accurate result in terms of consumption. If they are not accessible, the tool gives results largely based on the database. In this case, the consumption is less realistic and more theoretical.
ARCHITECTURE DESIGN

Three major sections compose the tool: the user interface, the calculator and the database. It cannot work correctly without connections between these three components.

The user interface consists of the following sheets:

- **Notice**: This spreadsheet explains to the user how the different spreadsheets of the tool work. It is completely independent from the rest of the tool.

- **Protocol**: This spreadsheet explains to the user how the protocol works. It depicts the process that was followed when the tool was developed. It should be used primarily as a clue to know which project scenario the user is in. It also gives the user an overview of both the data in his possession and the missing data at the very beginning of the project.

- **Entry data**: This spreadsheet collects all the entry information required to run the tool. It permits to collect some basic information about the project range from the typology of the building to its geographical properties. This data is essential for the tool core since all the mathematical formulas rely on it. Exclusively for scenario 1 and scenario 2, it also allows to manually entering the reference consumption data of the building. This step is crucial since these values are used in the next sections to determine the initial consumptions.

- **Results**: This spreadsheet allows the user to create the building reference card. It summarizes all the important and useful information to make an energy performance commitment for the studied building. To create this card, just press the button “Generate” and the button “Create PDF” to export this file as a PDF.

- **Improvement list**: This spreadsheet gives a non-exhaustive list of potential improvements for each energy consumption category.

The calculator consists of the following sheets:

- **Calculation table**: It contains all the calculations processed by the tool. It adjusts the coefficient in real time for every modification made by the user in the entry data sheet. It operates the computation for the
four activities at the same time. The user does not need to look at this spreadsheet.

- **Graphics**: It regroups all the diagrams used to create the building ID card. The user cannot see this spreadsheet.

- **Technology calculation**: It contains all the mechanisms needed to determine the coefficient regarding building technology enclosure in terms of both insulation and glazing.

- **Climate calculation**: It contains all the mechanisms to determine the climate factor depending on the construction period and the geographic location of the building under study.

- **Damage calculation**: It contains all the mechanisms to establish the damage factor. It characterizes the state of the enclosure for the structure, roof, facade, slab and floor. It converts a qualitative quotation into a quantitative coefficient.

- **Characteristic calculation**: It regroups all the calculations needed to translate the properties of the target into numeric coefficients. It deals with the adjacencies, natural light potential, ventilator performance, window frame state, insulation material, air treatment technology, and ventilation grid quality.

The database consists of the following sheets:

- **Technology factor**: It centralizes all the data used to complete the technology calculation.

- **Climate factor**: It centralizes all the data used to complete the climate calculation.

- **Damage factor**: It centralizes all the data used to complete the damage calculation.

- **Geographic factor**: It centralizes all the data used to calculate the geographic factor.

- **Severity factor**: It centralizes all the data used to calculate the severity factor.

- **Guidance envelope**: It concentrates all the French legislative thermal building properties over the different construction periods. It gives

. **Reference building:** It synthesizes the results of the database analysis. It permits to assemble the four reference buildings used by the deterministic model.

. **Outputs:** It is the analysis of the database for the four activities. It goes from consumption distribution between energy appliances to state weighting between the different components of the enclosure. The user can find more details about this in this sheet.

. **Database:** It centralizes all the information that has been used to build the deterministic model. There is one general spreadsheet that regroups all the data and there is one compiled sheet per activity.
MODULE DESIGN

The sheets work in accordance with each other. The database set of sheets assembles all the information required to run a calculation or to determine the coefficients and factors that impact the building’s final energy consumption. The engineer can explore the tool, learn how to manipulate it and exchange information thanks to the user interface. The calculator set of sheets regroups every calculation necessary to establish the energy consumption of the building under study. It compiles the information from the database and the knowledge from the user interface entry data. The synthetic diagram below depicts the connections between these three entities.

Figure 18 – Identification and synergy of the tool’s sheets
IMPLEMENTATION

The tool is implemented in Excel and can be found in the APPENDIX. The tool’s output is a building ID card. It gathers all of the results in terms of energy consumption and its distribution between the different energy systems. It also sums up the main information that characterizes the target concerning location, typologies and state. An example of an ID card is given below.

![Figure 19 – ID card of a building given by Estim’ELIOTH](image-url)
Chapter 3 – The results

MODEL TESTING

The test protocols were based on the system coupling diagram description developed by Lawson, H [15].

The parameters are defined as:

- **Situation System** – A problem or opportunity situation. In any case, in order to assess the situation, a response is required.
- **Respondent System** – The system created to respond to the situation. The parallel bars above indicate that this system interacts with the situation and transforms the situation into a new situation.
- **System Assets** – The sustained assets of an enterprise that are used in responding to a situation.

In this project, the situation system is an existing building on a university campus. The situation is to determine its consumption, using its set of information. The respondent system is the operative tool. It will respond to the input data to calculate the consumption of the target. The system asset is the model itself which allows performing calculation. It is translated to the respondent system thanks to the “calculation table” function.

A data sample is used to run the tests. The data comes from a refurbishment project, conducted by Elioth in the past, on a set of existing buildings from two university campuses – Lyon Tech la Doua and Rennes UR2. These buildings were not used to construct the database of the model. The sample and the model are totally independent to guarantee the acceptability of the tests presented in the “Research question” section. The data used to test the model, from enclosure properties to final energy consumption, corresponds to real values measured on site by captors.

The first sample characteristics, labeled S1, are listed below:
5 buildings - Joseph JACQUARD, Antoine de ST EXUPERY, Sadi CARNOT, Blaise PASCAL 501 and Blaise PASCAL 502 -
2 activities - office and teaching -
Constructing period before 1974
Geographic zone H1c (c.f. Figure 13 – French meteorological zone distribution)

The second sample characteristics, labeled S2, are listed below:
8 buildings - UR A, UR B, UR B', UR E, UR I, UR L, UR N and UR P -
3 activities - office, laboratory and experiment -
Constructing period before 1974
Geographic zone H2a (c.f. Figure 13 – French meteorological zone distribution)

The tests were run multiple times to ensure that the results are consistent. The tests only concern global consumption for S1 because its repartition between the different energy systems was not available. However, the tests concern both global consumption and its distribution between the six energy systems for S2. All the inputs are given in the Excel file “Results” in the APPENDIX.

The following sections gives the results of the three epistemic testing virtues – accuracy, reliability and precision – as described in section “Research question”.

**ACCURACY**

In order to determine whether the model is accurate, the normalized root-mean-square deviation NRMSD has been calculated for each target of S1 and S2. The results are given in the tables below.

**Table 12 – Normalized root-mean-square deviation for S1**

<table>
<thead>
<tr>
<th>Target</th>
<th>NRMSD</th>
</tr>
</thead>
<tbody>
<tr>
<td>JACQUARD</td>
<td>14,7%</td>
</tr>
<tr>
<td>ST EXUPERY</td>
<td>7,0%</td>
</tr>
<tr>
<td>CARNOT</td>
<td>2,5%</td>
</tr>
<tr>
<td>PASCAL 501</td>
<td>3,9%</td>
</tr>
<tr>
<td>PASCAL 502</td>
<td>1,3%</td>
</tr>
</tbody>
</table>
Table 13 – Normalized root-mean-square deviation for S2

<table>
<thead>
<tr>
<th>Target</th>
<th>RMSD</th>
</tr>
</thead>
<tbody>
<tr>
<td>UR A</td>
<td>5.9%</td>
</tr>
<tr>
<td>UR B</td>
<td>2.6%</td>
</tr>
<tr>
<td>UR B'</td>
<td>3.2%</td>
</tr>
<tr>
<td>UR E</td>
<td>1.8%</td>
</tr>
<tr>
<td>UR I</td>
<td>4.9%</td>
</tr>
<tr>
<td>UR L</td>
<td>9.6%</td>
</tr>
<tr>
<td>UR N</td>
<td>4.7%</td>
</tr>
<tr>
<td>UR P</td>
<td>1.2%</td>
</tr>
</tbody>
</table>

The limit criterion was NRMSD < 10%, as defined in table 1 – Criterion limits, to validate the accuracy of the model. The results demonstrate that the NRMSD is fewer than 10% for 75% of the targets in S1 and for 100% of the targets in S2.

The results are satisfying don’t allow to conclude on the accuracy of the model. It can be depicted that the response of the model is relatively accurate. Indeed, most of the NRMSD results are well within the criterion limit as illustrated in the graphic below.

![NRMSD result distribution for both S1 and S2](image)

Figure 21 – NRMSD result distribution for both S1 and S2
STABILITY

The model itself guarantees the stability of the tool. Indeed, the model is based on stable equations. It is implemented in the “calculation table” sheet. The different parameters and coefficients described in the investigation process are stable over time and do not need to be changed so the matrix $\Lambda$ and $\Phi$ are resistant to any exterior disruption. Only the matrix $Z$ will change over time when new sample buildings are added to the database. It is the aim of the tool to evolve and update itself as more and more manipulations are made and studies run. This does not affect its stability in any way. So the model $M$ itself is stable.

The formulas have been fixed within the tool to ensure that no wrong manipulation could affect the integrity of the equations. Some tests have been conducted to confirm that the calculation core gives the same results over time. A set of entry data has been defined and stated as permanent. The tool has been launched from ten times to one hundred times with a step of ten. The tests have been made at different time intervals - every minute, every hour, every day and every week -. The results are illustrated below and confirm that the model is stable.

Figure 22 – Stability test results
PRECISION

In order to determine whether the model is precise, the energy relative error ERE has been calculated for each target of S1 and S2. The results are given in the tables below.

Table 14 – Energy relative error for S1

<table>
<thead>
<tr>
<th>Target</th>
<th>ERE</th>
</tr>
</thead>
<tbody>
<tr>
<td>JACQUARD</td>
<td>-9.4%</td>
</tr>
<tr>
<td>ST EXUPERY</td>
<td>-6.5%</td>
</tr>
<tr>
<td>CARNOT</td>
<td>3.8%</td>
</tr>
<tr>
<td>PASCAL 501</td>
<td></td>
</tr>
<tr>
<td>PASCAL 502</td>
<td></td>
</tr>
</tbody>
</table>

Table 15 – Energy relative error for S2

<table>
<thead>
<tr>
<th>Target</th>
<th>ERE</th>
</tr>
</thead>
<tbody>
<tr>
<td>UR A</td>
<td>-8.7%</td>
</tr>
<tr>
<td>UR B</td>
<td>-3.8%</td>
</tr>
<tr>
<td>UR B'</td>
<td>-3.0%</td>
</tr>
<tr>
<td>UR E</td>
<td>-6.1%</td>
</tr>
<tr>
<td>UR I</td>
<td>-4.8%</td>
</tr>
<tr>
<td>UR L</td>
<td>-11.4%</td>
</tr>
<tr>
<td>UR N</td>
<td>-5.1%</td>
</tr>
<tr>
<td>UR P</td>
<td>1.2%</td>
</tr>
</tbody>
</table>

The limit criterion to validate the accuracy of the model was \(-10\% < \text{ERE} < 10\%\), as defined in table 1 – Criterion limits. The results demonstrate that the ERE is under 10% for 100% of the targets in S1 and for 87.5% of the targets in S2.

The results are satisfying but don’t allow concluding on the accuracy of the model. It can be depicted that the response of the model is relatively accurate. Indeed, most of the ERE results fit well within the criterion limit as illustrated in the graphic below.
An in-depth study has been conducted regarding the results for both samples S1 and S2.

i. **Testing S1**

The results of the tests are illustrated below.

They are meaningful. The mean relative error on total consumption values of these five targets is about 6%. It is less than the 10% aimed. In conclusion, this first generic test gives encouraging results in terms of precision. They must be confirmed by a second test to state whether the model is as precise as aimed.

ii. **Testing S2**

The results obtained are significant. For these eight targets, the mean relative error on the global consumption value is about 5%. It is less than the 10% aimed. The results concerning the energy system are very satisfying. The precision on consumption distribution between the energy systems ranges from 2% to 7%. It is less than the 10% required. The details of all the results are illustrated below.
The above diagrams confirm the tendency for global consumption values. Indeed, the relative error in terms of forecast is less than 10% for 90% of the treatment group elements.

These two figures show that the mean relative error for the foreseen heating consumption values is less than 10% for 75% of the treatment group. It implies that the model is not precise enough to satisfy the ambition of the project in terms heating foreseen consumptions. Nonetheless, it should be noted that the values exceeding the limit only represent about 12% of the total values. It is not that far from the target.
These two figures show that the mean relative error of non-heating foreseen consumption values is less than 10% for 90% of the treatment group. It implies that the model is not precise enough to satisfy the ambition of the project in terms of foreseen heating consumptions. Nonetheless, it should be noted that the only exceeding value is about 13% over the limit. It is not that far from the target.
The illustrations above demonstrate that the model provides a trustable distribution between energy systems. No system presents a share that is too large or too thin compared to the others. The mean relative error is about 2% for the all targets. It means, for example, that for a building with the following distribution - 15% for lighting, 10% for process, 20% for ventilation and 10% for auxiliaries - the tool will deliver this distribution:

- Lighting: [13% to 17%]
- Process: [8% to 12%]
- Ventilation: [18% to 22%]
- Auxiliaries: [8% to 12%]

In conclusion, the precision tests outline that the tool gives encouraging results. They have demonstrated, for two different and independent treatment groups, that respectively 100% and 85% of the targets present a result under the 10% aimed. Nonetheless, these results don’t allow stating that the model satisfies the objective. However, the results in terms of total consumption distribution between the energy systems are very promising.
RESULT ANALYSIS

STRENGTHS

The strengths of the model are various and can be divided into different categories:

i. Asset toward assumption

- The limited amount of data necessary to obtain a result is a real strength. It gives a perfect answer to the company which needed a tool as little time-consuming as possible while still effective and able to give adequate orientation at an early stage of a rehabilitation project.

- Considering the results, the decision to focus on one building typology - universities - is strength for the model as it permits to obtain relatively good results.

ii. Asset toward model

- The tool is reproducible for other building typologies due to its model. Indeed, it is possible to change the database without modifying the model. It allows duplicating the model as many times as there are databases available. This is a real advantage because there are a lot of different types of buildings with their own specificities in terms of activities.

- The model can be implemented to another support than Excel since it is an algebraic formula. In this sense, the model is flexible in its application. It is therefore possible to create different tools from one model.
WEAKNESSES

The weaknesses of the model are various and can be divided into different categories:

i. **Deficiency toward assumption**
   - Heat gain resulting from the inertia of the building has been neglected. Experiment feedbacks demonstrate that it is a non-negligible term of the equation.
   - Heat loss corresponding to linear exchange around the building has been neglected. This lack of information is prejudicial to the model as it makes it incomplete.

ii. **Deficiency toward determinism**
   - The linear deterministic model is limited to a stochastic simulation. “A deterministic model assumes that its outcome is certain if the model’s input are fixed. No matter how many times one recalculates, one obtains exactly the same result. It is arguable that the stochastic model is more informative than a deterministic model since the former accounts for the uncertainty due to varying behavioral characteristics. In nature, a deterministic model is one where the model parameters are known or assumed. Deterministic models describe behavior on the basis of some physical law.” [16] It means that if the needs of the company change, the tool cannot process randomness. It remains an approximation while the natural world is full of stochastic events.

LIMITATIONS

The limitations are various and can be divided into different categories:

i. **Restraint toward data**
   - The limited number of buildings - over a hundred - to create the database. The more samples the database contains, the more robust the model is.
   - The number of buildings used to test the model is not sufficient to state any truth. The analysis of the results can only allow for a trend to be detected.

ii. **Restraint toward diversity**
   - Considering the decision to focus on one typology of buildings - universities – as one of the model’s strengths is also a weakness. Indeed, the tool's application scope is reduced. It could be a problem if the company does not get any more university campus projects. Nonetheless, it is not prejudicial on the short-term.
FUTURE RESEARCHES

DEVELOPMENT

The model could be developed in various ways.

i. **Update toward assumption**
   . Research regarding information to determine a linear coefficient. It would enable to strengthen the model. It would also decrease the impact of the correlation determinant by increasing information concerning the treatment group.
   . A study to develop a subsidiary model for the inertia parameter could be done. It would enable to reintroduce this parameter in the heat equation. Hence, the model would be more complete in terms of building theory. Nonetheless, this is complicated to apply as there is no measurement of it. This absence is prejudicial to the model implementation.

ii. **Update toward database**
   . Organize the company in terms of data collection and capitalization. A large amount of data is available in the company resources. However, it is very hard to find it and use it for another purpose. By developing big data management, it could be possible to significantly increase the amount of data and the quality of the information used for the model’s database. Maybe the tool itself could act as a support instrument for data organization.
   . Develop the database so as to get buildings from everywhere in France. Hence, the four reference buildings will be based on a more diversified set of data. It will permit to create a global guide representing all French climatic areas.

iii. **Update toward function**
   . By collecting information about other building typologies, such as for instance office and hospital, a tool could be developed for each of them, using the same pattern as for university buildings. The changes would be minimal. It would mean redefining the activities taken into account in the building and changing the lines in the database.
EVOlUTION

The model could evolve in various ways.

i. **Change toward function**
   - In the future, it would be great to add a unit for respectively the “saving actions” and “saving assets” parts of the procedure described in chapter 1. It would permit to give a final and global response in design meetings with both energy and money saving considerations. At this stage, the tool only gives the user indications about different solutions to reduce the consumptions calculated by the model.
   - The database could evolve in another way than collecting “external” data. Indeed, we could imagine using the targets that are processed by the model itself to increase the size of the database. So, for each application of the tool, the database would update itself and generate new reference buildings.

ii. **Change toward determinism [17]**
   - Replace the linear deterministic model by a stochastic model using the Krigeage method. It would enable to interpolate the target with all the relevant buildings from a reference group around its location. It means that the tool would no longer be “static” but dynamic. It would make its own choices and the results would not be the same for the same inputs. It would allow characterizing both the reliability of the tool and the quality of the database.
   - From the Krigeage method, we could imagine developing a unit within the tool to locate geographically all the elements of both treatment and sample groups. Hence, we would have a map of France with all the necessary information regarding energy and savings. It could be very useful to output general tendencies in the country and determine which geographic location is critical in terms of consumption. The French energy and environment department could engage refurbishment plans and actions by level of importance based on the tool’s map. It could finally help our country to further reduce its energy use in order to meet to the COP 21 goals.


APPENDIX

TOOL PRESENTATION
The hyperlink below grants access to the Excel tool.

![Model.xlsx](model.xlsx)

Figure 29 – Estim'ELIOTH

TEST INPUTS AND OUTPUTS
The hyperlink below grants access to the entry data used to run the tests. It also gives the results and the graphics used in chapter 3.

![Results.xlsx](results.xlsx)

Figure 30 – Input data and test results