smart living lab

Building 2050
State-of-the-art and preliminary guidelines

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Haute école d'ingénierie et d'architecture Fribourg
Hochschule für Technik und Architektur Freiburg
UNI FR
UNIVERSITÉ DE FRIBOURG
UNIVERSITÄT FREIBURG
EPFL
ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

Impressum

Authors	**Thomas JUSSELME**, Building 2050 Project Manager, EPFL-FR **Dr. Arianna BRAMBILLA**, Postdoctoral Researcher, EPFL-FR **Dr. Endrit HOXHA**, Postdoctoral Researcher, EPFL-FR **Dr. Yingying JIANG**, Postdoctoral Researcher, EPFL-FR **Stefano COZZA**, Master thesis, EPFL-FR **Dr. Didier Vuarnoz**, Scientific Collaborator, EPFL-FR
Supervision	**Prof. Marilyne Andersen**, Head of the Interdisciplinary Laboratory of Performance-Integrated Design, Dean ENAC, EPFL **Prof. Emmanuel Rey**, Head of the Laboratory of Architecture and Sustainable Technologies LAST, Scientific committee President, EPF **Dr. Anne-Claude Cosandey**, Operational Director of the EPFL Fribourg Outpost, smart living lab coordinator, EPFL
Scientific committee	**Prof. Emmanuel Rey**, Head of the Laboratory of Architecture and Sustainable Technologies LAST, President, EPFL **Prof. Marilyne Andersen**, Dean ENAC EPFL **Prof. Alexandre Blanc**, Associate Professor ENAC IA MANSLAB1, EPFL **Prof. Thomas Keller**, Full Professor ENAC IIC CCLAB, EPFL **Prof. Jean-Louis Scartezzini**, Full Professor ENAC IIC LESO-PB, EPFL **Prof. Jean-Philippe Bacher**, Head of the smart living lab program for EIA-FR **Prof. Jacques Bersier**, Head of applied research and development, EIA-FR **Prof. Elena Lavinia – Niederhauser**, Head of the iEnergy laboratory, EIA-FR **Prof. Florinel Radu**, Head of the TRANSFORM laboratory, EIA-FR **Prof. Daia Zwicky,** Civil Engineering professor at iTEC, HEIA-FR **Prof. Stephanie Teufel**, UniFR Head IIMT, Dean SES Faculty, UNIFR **Prof. Jean-Baptiste Zufferey**, Administrative Law Professor, UNIFR **Dr. Dennis Lalanne**, Senior researcher, UNIFR **Dr. Peter Richner**, Deputy Director, EMPA
Language proof	**Veronica Cubarle**, Administrative Assistant EPFL-FR
Editor	**EPFL Fribourg** Rte de la Fonderie 8 CH-1700 Fribourg www.smartlivinglab.ch

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1. Summary

After the shutdown of the Swiss Beer Factory Cardinal located in Fribourg, the state and the city of Fribourg decided to transform this industrial site in an innovation quarter called BlueFACTORY. The Swiss Federal Institute of Technology in Lausanne (EPFL) was invited to join the project for the creation of a national center for technological innovation in the built environment. This is how, together with the University of Fribourg (UNIFR) and the School of Architecture and Engineering of Fribourg (HEIA-FR), the smart living lab was born in 2014.

One of the projects of the smart living lab is the design and construction of its own building, at the cutting edge of research and best practice on sustainability. Before the construction of the smart living lab, a preliminary research program has been set-up to define the scientific specifications to be faced by the future designers and the way to integrate them into the construction. This project, called Building 2050, proposes to study different aspects such as the architectural quality, the climate changes, the environmental performances, the flexibility and the local economy.

The planned smart living lab is a mixed-use building (residential, offices and experimental lab at the same time). This construction must correspond to the intermediate objectives of the vision of the 2,000-Watt Society model by the middle of the 21st century. The present report is the first deliverable of the Building 2050 project.

The Kaya identity is usually used to identify the main contributor of CO2 emissions by human activity. By applying it, we propose the means to achieve sustainability. As a result, the three main components of this well-known relation are the main topics discussed, namely the Life Cycle assessment (LCA), the flexibility and the energy strategy. In this report, these aspects are being contextualized thanks to a state-of-the- art, followed by a rough strategy for the building design process, and proposal of scientific research topics that could be investigated during the Building 2050 project.

The Life Cycle Assessment Chapter

A Life Cycle Assessment (LCA) evaluates environmental impacts attributed directly to a product, goods or service throughout its lifecycle. Environmental impacts as a whole consist of contributors such as building, mobility, food, consumption and infrastructure. An extensive review of the literature is conduct to put the design of the smart living lab building in the context of LCA research fields. In this way, different preliminary issues are solved.

Methodologies, databases and software, which are usually used when assessing environmental impacts, are presented. Nowadays, the difficulties linked to LCA are the databases and the software; their inherent limits are pointed out. One of the major problems in LCA is the significant expansion of the boundaries of a considered problem, e.g. from a single product to a district or even a city. Conducting a LCA study could become then very complex, especially for a system or a service.

Out of the huge amount of different indicators used in LCA, the 2,000-Watt Society model suggests three relevant indicators. They are namely the cumulative energy demand, the non-renewable cumulative energy demand and the Global Warming Potential (GWP) indicator. Their respective targets are 2000W, 500W and 1t of CO2-eq. Based on these goals, together with the present key repartition between the different contributors, a top-down approach is used to determine the targeted values that the smart living lab would have to reach to have environmental outstanding performances (the 2050’s objectives). These targets are specified according to the space functionalities.

In current literature, no environmental impact study of urban area having considered all contributors has been found. Only embodied and operational impacts have been usually evaluated. Out of 200 buildings reported in the literature and based on some defined criteria, 20 buildings have been selected. However, none of them are able to reach the 2050's objectives.

Based on the state-of-the-art, paths to improve environmental impacts of material or elements used in the construction of buildings have been identified. Despite the current possibilities to develop low/zero energy consumption buildings, the main issue is the minimization of embodied primary energies and greenhouse gases.

An identification analysis has been conducted to determine the importance of the environmental impact of each element and material present in a building. According to their impact, a classification of these elements and materials is proposed. This process identifies which elements and materials must be firstly improved, and which others could be put aside when simplifying an LCA model. For example, ceilings and materials such as concrete and polystyrene have very high embodied impacts. Therefore, they cannot be neglected during the LCA study and must request high attention from architects and engineers.

No strong correlations have been found between the three major indicators or between the embodied and operational environmental impacts. Yet, a very strong correlation between the non-renewable energy and the GWP indicators for the building's elements has been identified. The level of difficulty to reach the GWP goal is higher than the goal for cumulative non-renewable energy demand. These conclusions would then enable us to consider in the future only two impacts, namely the cumulative energy demand and the global warming potential.

Methodology, databases and software that will be used during the next research phase of the project have been emphasized. The main objective of the Building 2050 is the development of an LCA methodology for the design of a building able to reach the 2050's targets. To succeed in this challenging task some specific research topics must be envisaged. These are as follows:

- the simplification of the LCA model thanks to different strategies;
- the identification of potential reductions of environmental impacts;
- the optimization/improvement of high environmental impact of buildings part;
- the investigation of the lifespan in building LCA;
- the correlation between the improvement of the embodied impacts with better operation's impacts;
- the interaction between users, building and public space and understand how to improve the environmental impacts of the building.

The Flexibility study chapter

The main purpose of the flexibility is to optimize the ratio between the building volume and population of users. This definition leads to keeping the building usability performance at high level during the whole life cycle. This is, of course, connected to the users, their behavior and to the needs and requirements of the built environment.

A review of 116 cases, where the usability is increased by the flexibility, is proposed and helps the reader understand the concept of building flexibility. Strategies and methods vary depending on each particular situation. This literature review covers various types of buildings including residential, educational, healthcare, and mixed-use buildings. Usual approaches and relevant practices are disclosed in order to achieve flexibility.

Involved flexibility strategies concern usually components (foldable, movable, detachable and modularized), rooms (polyvalent/multifunctional, multi-access) and zones (open space with zones, space extension reservation, and space modularization). Two main classes of strategies are described. The "hard" one provides designated changeable or movable components, products, or technology as a part of a completed building and its future possibilities. The second called "soft", allows to keep a certain indeterminacy in design and construction, thus waiting for more precise information in the future.

The estimated lifespan of the current buildings induces the need to introduce the idea of flexibility into the entire building lifecycle. It is suggested that the changes of the short-lifespan products should influence the ones with longer lifespan as little as possible. Making irreversible decision more reversible or postponing uncertain decisions until more information becomes available, may be used to support the decision-making. The needs and requirements strongly contribute to the final value of the space usability. The availability of this information on needs and requirements determines the design and construction methods that would apply.

Based on this review, a methodology for designing flexible building is proposed. At first, two questions must be answered:

1) When is the right time to fix the design of each component and how it is it possible to postpone decision-making?
2) What must be the right components or equipment and facilities of the building?

The method proposes to divide the construction process into two independent parts: Project A and Project B, according to the available information about needs and requirements. Project A corresponds to the already fixed information coming from macro contexts. Functional space units of the whole building could be designed first as a part of the primary building. Project B should be designed in a second phase and must respond strictly to the needs and requirements of the users. It could include more specific design of the floor plan, arrangement of internal partition walls, layout of rooms, technical services at the room levels and some specific furniture and equipment.

Based on the review of the collected cases, some recommendations that may enhance building flexibility are proposed. These recommendations involve:

- The layout of the building (regular pattern, small grid frame and universal space dimension);
- The number of functions a volume could support;
- The accessibility of space units, facility components and vertical ducts;
- The increase of the usable building space, story height and bearing capability;
- The facility components (the use of universal types and ability to disconnect them);
- The independence of volume layers and zones, but also of walls and skins from the building structure;
- The neutralization of space units and structures.

Some scientific research topics for the flexibility study have been identified. These are as follows:

- The interaction between users and the construction components;
- The correlation between users, lifespan and environmental impacts of the construction components;
- The possibility to integrate a building flexibility criteria into the whole building lifecycle design.

The Energy strategy chapter

In the first part, the internal comfort requirements are defined, depending on the affectation of the volumes. The limits for the parameters playing an important role for the sensation of comfort are reviewed, as well as the ones that cause health or technical problems.

The external context, e.g. the climatic conditions is exposed. The low temperature and relatively high humidity are the parameters that characterize the Fribourg area and make the site critical to moisture problems. Analyzing the future trends towards 2050, stronger summers and rising temperatures will be more frequent, as well as sky coverings, due to greenhouse gas emissions. The humidity and rainy days will increase and the peaks of direct radiation will be shifted to other period. These changes will therefore affect the passive strategies potential.

The kind of energy resources that could be exploited on the construction site is investigated. The solar resource is strongly present but not distributed evenly (almost 50% of the radiation is concentrated from May to July). The shift between the energy production potential and the energy demand makes it difficult to cover the thermal needs of the building without seasonal energy storage. Because of this shift, and the unclear challenge to store electricity, photovoltaics is also handicapped.

The wind's average annual speed is too low to use it efficiently as a source of energy. The hydroelectric potential in the Fribourg region is already saturated. On the other hand, waste heat availability and easiness to implement geothermal probes could become an advantageous solution. The proximity of the railways could play in favor of a biomass power plant with power generation and heat recovery. To be efficient, this kind of energy availability could be useful, not only to the smart living lab, but also to other buildings of the BlueFACTORY.

To understand the state of the art of the Minergie® houses, a deep analysis on case studies is addressed. Thermal loads are nowadays the main issue in Switzerland but more accurate assessment will be done to see if, with future climate, cooling may become an issue. For providing energy to the building, the wise use of current technologies is preferred to particularly innovative or complicated technologies. It is suggested to follow this path but to keep the possibility to combine innovative systems for the research and development.

The full energy concept must be based on the sensitivity analysis related to climate, use and requirements changes. The concept should be an optimum between the operation phase energy and the embodied energy.

Finally, a number of scientific research topics have been identified. These are as follows:

- The implementation of thermal inertia regarding the life cycle target values;
- The users/occupants interaction and their influence on the operating energy demand;
- The components with limited lifespan and their influence on users' comfort with passive strategies.

2. Introduction

The vision of the smart living lab project is to create, in the heart of the blueFACTORY (Fribourg, Switzerland)*, a living and working space ahead of its time – i.e., the building itself - housing an interdisciplinary, inter-institutional center of excellence in the field of innovative concepts and technologies linked to the built environment – i.e., the contents of the building*[1]*.*

The building will, therefore, have to be in the forefront of the current practices, and will be an experimental support center for the future research teams it will house.

The exceptional nature of the smart living lab project justifies the setting up of a preliminary research program, whose first objective is to define a brief with the scientific specifications to be faced by the future designers. The way to integrate these specifications into the construction process is also part of the research.

This is the state-of-the-art report, the first deliverable of the Building 2050 research program. As defined in the previous report, next deliverables will be:

2. Scientific concept: technical solutions and methodologies usable for the smart living lab building
3. Workshops: scientific concept proofing by building professionals and scientists
4. Scientific program (draft): translation of the scientific concept and the workshops into a brief for the future smart living lab designers
5. Experimentations: prototypes construction, performance monitoring and feedback
6. Scientific program: the definitive program that will be submitted to the smart living lab designers and that will include technical and performance specifications and recommendations.

The report allows to understand the gap that we have to fill between the current best practices and the future 2050 objectives.

As it was previously proposed in the first report, we apply the kaya equation to the building environment in order to divide this complex issue into key drivers (Figure 1). Kaya's equation shows, however, the interdependence of each one of these fields, since each research field depends on another one.

[1] EPFL | UniFR | EIA, « smart living lab, Summary document, Version 6 », février 2014.

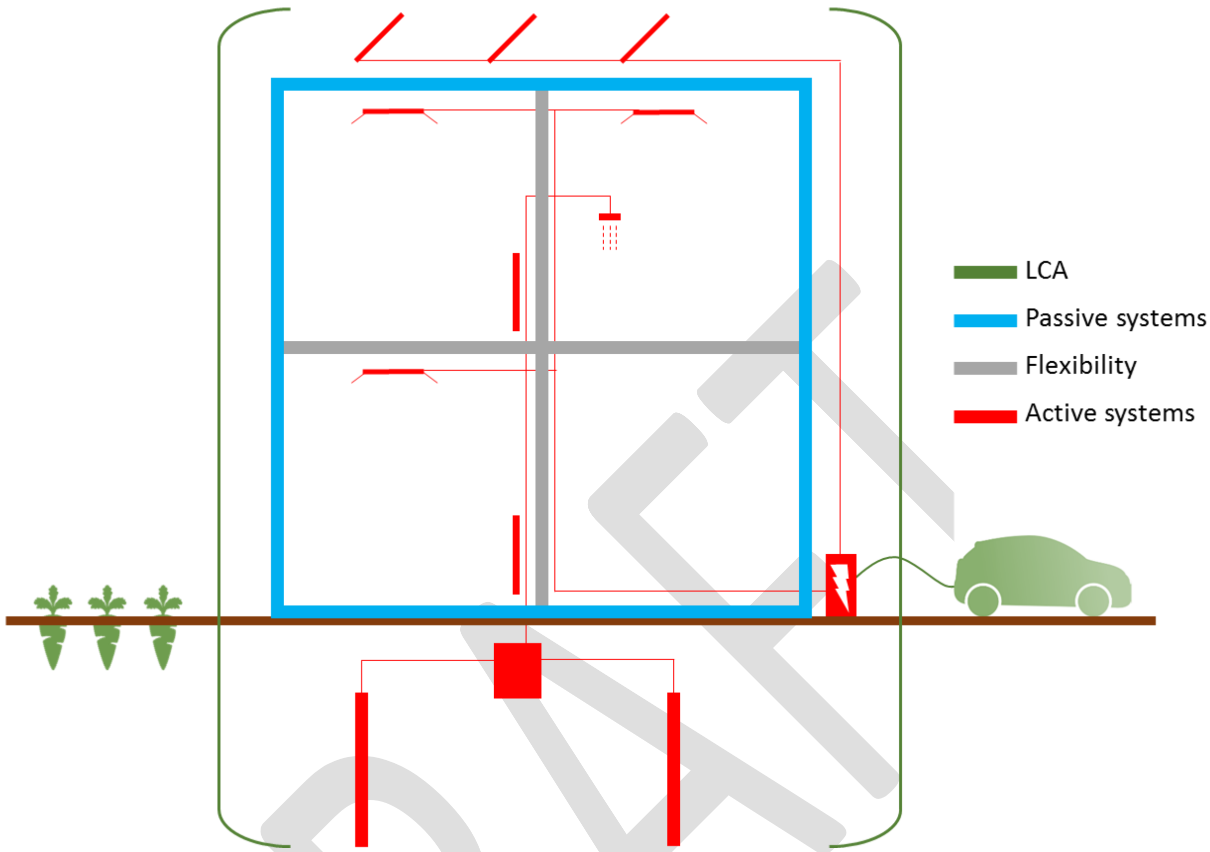


Figure 1 : Technical diagram of research field programs

Based on this proposition, this report consists of three parts:

- Part 1 introduces the current best practices and the environmental objectives that we will have to reach in 2050 from a life-cycle analysis point of view,
- Part 2 defines flexibility based on literature review and the best strategies to develop a flexible building for the smart living lab,
- Part 3 provides an extensive overview of what energy strategies (active and passive systems) will have to face.

Even if the framework is divided by three different research fields, a strong interdisciplinary approach has been developed to keep the coherence of the global project.

3. Lifecycle assessment: objectives, key parameters and methodology

Authors: Endrit Hoxha, Thomas Jusselme

3.1. List of abbreviations

PE	Primary energy
NRE	Non-renewable energy
CED	Cumulative energy demand
CEDnr	Cumulative non-renewable energy demand
GWP	Global warming potential
EI	Embodied impact
TI	Total impact
OI	Operation impact
R	Coefficient of correlation
w/p/y	Watts per person per year
kg CO_2-eq/p/y	Kilogram carbon dioxide equivalent per person per year
SIA	Société des ingénieurs et achitectes
ERA	Energy reference area
PR	Project
MJ/p/y	Mega joule per person per year

Table 1: List of abbreviations in LCA

3.2. Introduction

The tendency of economy, the concentration of crude oil in the Near East, the overexploitation of non-renewable resources and the damage caused to the environment will compel developed nations to use energy and materials more efficiently. Much effort from researchers, government, designers and enterprises has been made for realizing efficient use of materials and energy. In 1998, the Board of the Swiss Federal Institute of Technology promoted the vision of a "2000 Watts per capita society by the middle of the 21th century" [1]. This vision is founded for a sustainable use of energy resources and it aspires to a sustainable and equitable use of the world's raw materials. According to this vision, which must be reached by 2150, the 2005's impacts per person of primary energy (6500 watts), non-renewable energy (5800 watts) and greenhouse gases (8.6 t CO_2-eq) have to be reduced respectively to 2000 watts primary energy, 500 watts non-renewable energy and 1000 kg CO2-eq. This vision is well established and can be presented in an understandable way.

To respond to this vision, different norms and rules have been developed. The society of engineers and architects (SIA-société des ingénieurs et achitectes) [2] laid the foundations in the field of residential building, schools and offices. It proposes target values that have to be respected during the conception of the building in order to respond to the 2000-watt society's vision. Additionally, intermediate objectives can be identified by using the information of Switzerland's actual impacts of building system (embodied impacts, operation impacts, mobility, food, consumption and infrastructure) and those implies by 2000 watts society's vision [3].

One of the objectives of the smart living lab project, is to respond to these intermediate visions. To develop the smart living lab's capability to respond to these requirements, the report of embodied energy consumption per built volume EE/B_{vol} in the Kaya's equation has to be optimized. The optimization of report consists in the optimization of both parameters EE and B_{vol}. To do so in this state of the art we will identify:

- The intermediate smart living lab's objectives;

- The elements to be firstly improved;
- And the methodology and software to be used.

For these reasons the top-down, bottom-up and identification analysis, will be used for responding to the following questions:

- Which will be the target values of smart living lab?
- Does the actual urban area reach the 2050's goals?
- Does the actual building reach the 2050's goals?
- Which part of the building and for which case have been reached 2050's goals?
- Are the indicators correlated with each other?
- Which building element has the biggest influence to the whole impacts?
- Which methodology, database and software have to be used for the assessment of the impacts?

In Figure 2 are summarized the methodology followed in this state of the art for responding to the questions.

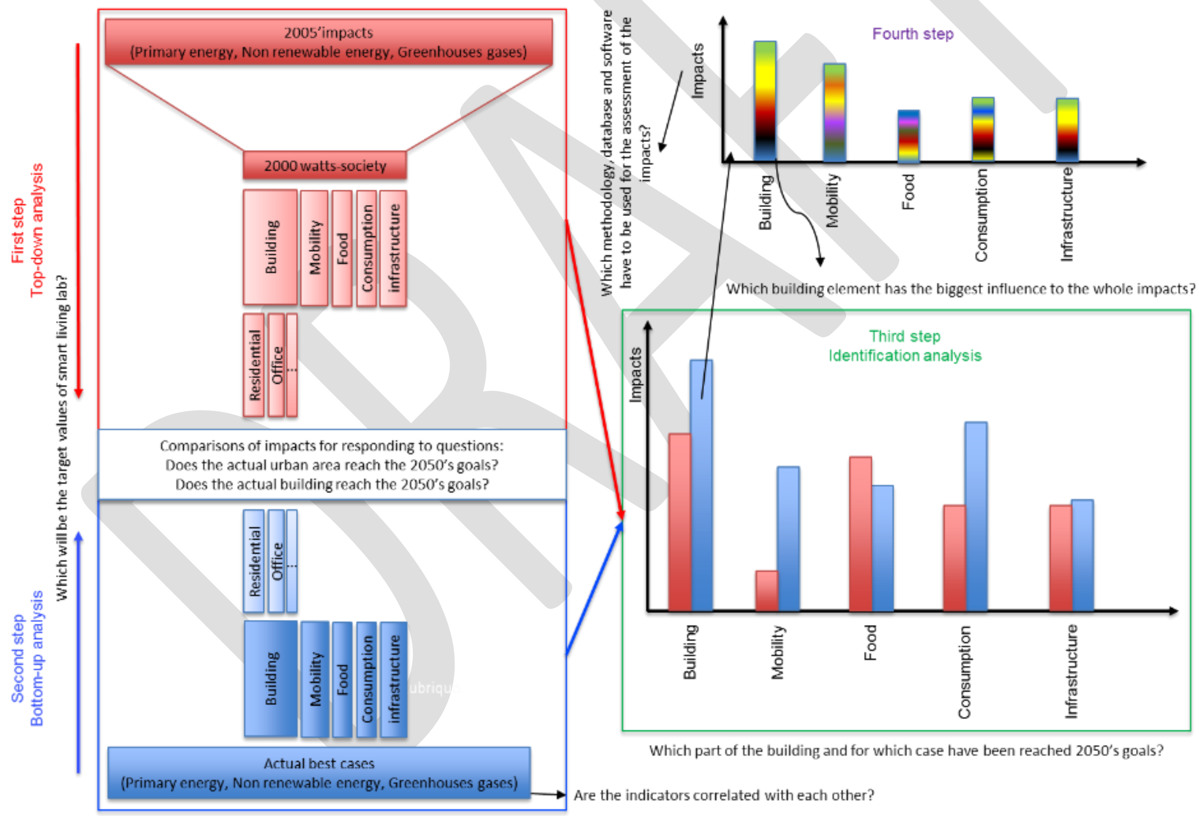


Figure 2 : Methodology followed for responding the questions asked in the state of the art

3.3. Path to 2000-watt society

The Swiss consumed about 6500 watts of primary energy (PE) in 2005 among which, 5800 Watts of non-renewable energy (NRE) and reject 8.6 t of CO_2-eq (GHG) per capita per year. In Switzerland these are assessed by the indicators of cumulative energy demand (CED) that is the sum or the primary energy required for the production utilization and disposal of a product [4], non-renewable cumulative energy demand (CEDnr) and global warming potential (GWP). The 2000-Watt society implies the improvement of the CED, CEDnr and GWP indicators respectively by a factor of 3.25, 11.6 and 8.6. Because of many constraints these objectives couldn't be reached immediately. This is why SIA has developed and recommended intermediate targets for the residential building, schools and offices that must be reached by 2050. These targets are calculated by a linear interpolation between 2150's objective and 2005's impacts. Using the same methodology Kellemeberger et al [5] have developed the target values for hotels, restaurants, specialized shops, food shops and shopping malls. These values have been evaluated only for the construction elements, operation phase of the building and the mobility without considering the food, consumption and the infrastructure. Using the additional information about the 2005's impacts given by Leuthart et al [6] we have developed the target values that the building system have to reach by 2050 and 2150. The assessment of the target values are based by using the information of the PE demand by Switzerland citizens in 2005 (1800 watts for buildings, 1700 watts for mobility, 750 watts for food, 750 watts for consumption and 1500 watts for the infrastructure). After SIA2040 [2] and Kellenberger et al [5], the 2050's target values for the building and mobility are respectively 1275 watts and 395 watts. According to SIA norms [2] the 2050's target value for the PE is defined to be 3500 watts. So the 6500 watts PE consumed in 2005 have to be reduced by a factor of 1.85. Using this reduction coefficient the target values for the food, consumption and infrastructure will be reduced respectively to 435 watts, 435 watts and 960 watts. So, the overall sum of PE needed for the goods and services is equal to 3500 watts. The most detailed information about the mobility and the building are given by the SIA 2040 [2] norm and Kellenberger et al [5]. In the same way, using the reduction factor we have evaluated the 2150's target values. The target values presented in MJ/m²/year have been converted in Watts/person/year assuming that the energy reference area will not change. The information about the energy reference area per capita in Switzerland are presented in Table 2**Erreur ! Source du renvoi introuvable.** [7].

	Residential	Office	School	Hotel	Restaurant	Specialized shop	Food store	Commercial center
ERA (m²/p)	60	5	2.5	1	0.5	1.6	0.3	0.13

Table 2: Energy reference area (ERA) per capita

Concerning the NRE, the Swiss used 5800 watts in 2005. By 2050 this value has to be reduced to 2000 watts (coefficient of reduction equal to 2.9) and by 2150 to 500 watts (coefficient of reduction equal to 11.6. According to SIA2040 [2] and Kellenberger et al [5], the 2050's target values for the building and mobility are respectively 762 watts and 375 watts. For simplicity and without deteriorating the target values for the NRE we have accepted that the rest of impacts (2000 -762 -375 = 863) will be distributed to the food, consumption and infrastructure in the same rapport as in the PE.

In the 2000 watts of PE that have to be reached by 2150 only 500 watts have to be NRE. The difference of 1500 watts must, therefore, be renewable primary energy. The evaluation of target values for the GWP indicator has assumed that the distribution of the impact will have the same range as that of NRE. First, the values given by SIA 2040 [2] and Kellenberger et al [5] have been used for the part of building and mobility, and then the distribution of the impacts for the food, consumption and infrastructure has followed the same distribution of impact as that of NRE. The information about the target values is summarized in Figure 3.

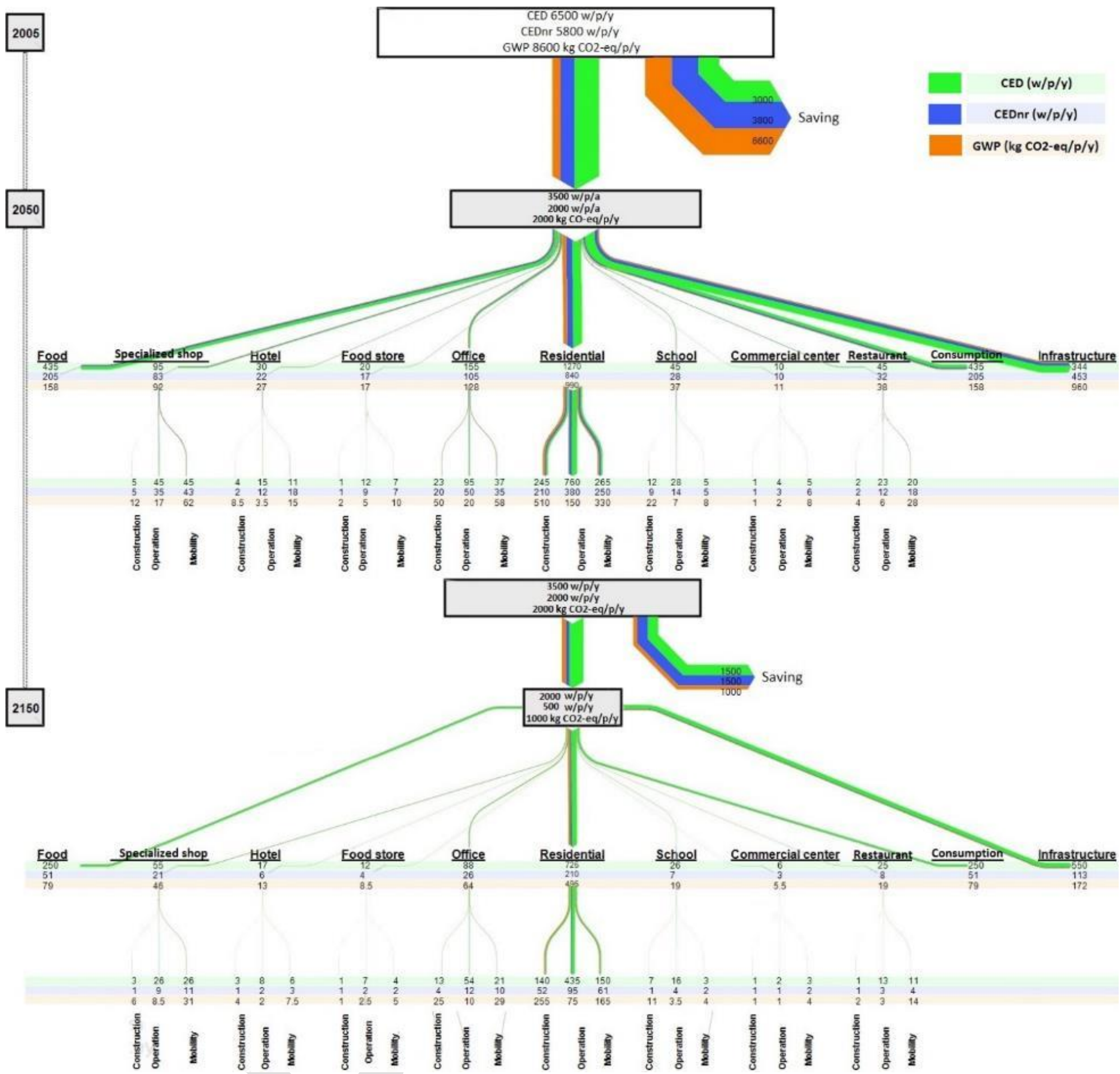


Figure 3 : Annual need of primary energy: The progress of target values from 2005 to 2150)

The calculation of targets for building elements, operation, mobility, food, consumption and infrastructure is very useful. Since the targets are not dependent from each other, the minimization of impacts of all goods and services can be made independently. The values previously presented in Figure 3 aren't precise in the strict sense, but they can be considered as a good path towards objectives. The target values presented by other authors and norms [2], [8], [9], [10], [11] differ from each other. Even though the values presented in the previous figures aren't distributed correctly, at the end of the project the overall impacts of building components, operation phase, mobility, food, consumption and infrastructure will be considered and the sum of impacts have to be lower than the global values defined by the 2000 Watt-society. In the case of a possible conflict between the objectives of CED and GWP indicators, the GWP indicator has first to be improved [3].

Before fixing the goal of the smart living lab project, an identification analysis of the best case studies published in literature is very precious. The definition of goals the smart living lab project has to reach will be based on this work. On one hand, this work will allow to identify the level of environmental performances the actual building is able to reach and on the other hand, an identification analysis will identify the part of the goods and services that have to be first improved.

3.4. Environmental impacts: an overview

This section will provide the results identified by an overview of literature about the environmental impacts of neighborhoods and building. The objectives of this section are the identification of the actual impacts of neighborhoods and building to help us fix the objective the smart living lab project has to reach. Another objective of this literature review is to better trace the footsteps of the smart living lab by identifying the pertinent and most sensitive aspects of the goods and services. In order to do so, it is fundamental to accurately quantify which part of the life cycle and which service or product is the main contributor to the environmental impacts. For this purpose, we conducted a literature review of case studies published in scientific articles, PhD and scientific reports published within the context of the research program. The reviewing has been focused on searching on different sites of scientific journals, universities sites, scientific programs and has identified a big number of case studies that widely differ from each other in term of materials used for construction, types of energy used in the operation phase of the building, location in different city and country of the world, etc. Completeness, availability and transparency of the inputs (database used, hypothesis considered, etc) and outputs (environmental impacts) are other factors that differentiate the case studies.

3.4.1. Environmental impacts of urban areas

After a literature review, we have identified a large number of eco-neighborhoods (around 250 cases) that are or were being built or in the design phase, most of them in Europe. The most famous are the BedZED (Beddington Zero fossil Energy Development) [12] situated in London-England, Vauban [13] situated in Freibourg- Germany, Vesterbro [14] situated in Copenhague-Danmark, Eco-Viikki [15] situated in Helsinki-Findland, EVA-Lanxmeer [16] situated in Culemborg-Netherland, etc. Also in Switzerland, as in the rest of the world, a large number of eco-neighborhoods are being built or in the design phase. In western Switzerland only, there are 23 projects of new eco neighborhoods, among which blueFactory [17]. All eco-neighborhoods have been subject to the environmental problematic. After Salmon [18], the results of environmental impacts of neighborhoods are mostly evaluated by the feedback. The environmental problematic was at least addressed but it has not been an easy task to find information about the results. Salmon [18] has reached the same conclusion. The results found on literature about the impacts of neighborhoods are presented in Figure 4.

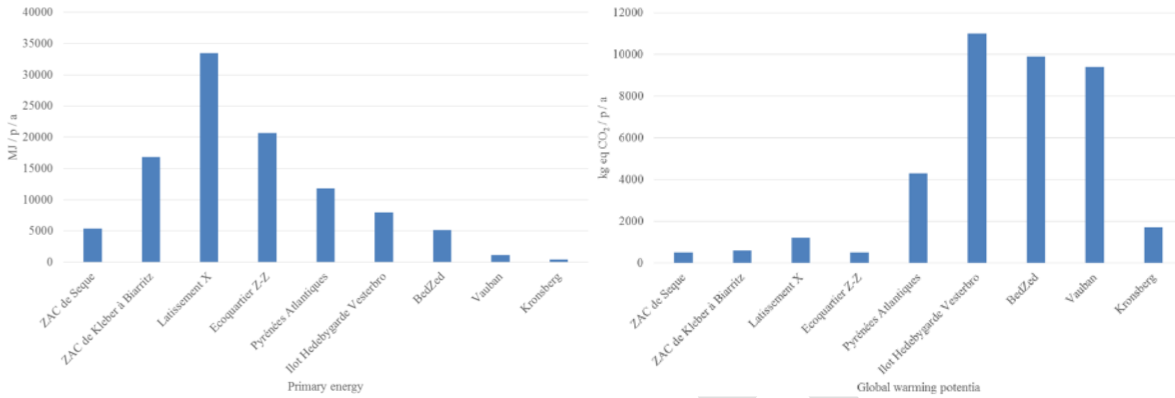


Figure 4 : Environmental impacts of neighborhoods for the primary energy and global warming potential indicator [18]

The application of the identification analysis was not possible, due to the lack of data on this scale. This lack of data made also impossible the application of a detailed analysis for identifying the part of the goods and services consider in the assessment of the environmental impacts of neighborhoods and the part of urban area and elements which need to be improved for the minimization of impact. For these reasons, the results identified in the literature about the environmental impacts of building, are presented in the next paragraph.

3.4.2. Environmental impacts of buildings

After a literature review, we identified about 300 case studies of environmental impacts at building scale. Information details of environmental impacts of embodied impacts (EI) and operation impacts (OI) or the mobility of the persons vary from one case to the other, even though the impacts of mobility aren't often considered in the assessment of impacts studies. Gustavsson et al [19] has analyzed an eight-story wood-frame apartment building to identify the heating system that has minimal impacts. Following this, the authors have presented a very detailed analysis about the environmental impacts of the operation phase but not of the EI. In the HQEperformance [20] the environmental impacts of 24 offices, 17 residential buildings and 22 individual houses was presented. The objective of this study was the identification of the parts of building having the biggest influence on the impacts. The results are presented in the form of box plots that made impossible the exploitation of the results project by project. Ramesh et al [21] has presented an overview of the environmental impacts of 26 offices, 46 residential buildings and individual houses, but not a single detailed analysis of the environmental impacts was found for the cases, even by consulting references cited by authors. The objective of these authors was to identify the importance of the operation phase in the overall impacts for the indicator of primary energy. In the ensclic Building [22] project, the environmental impacts of 4 houses, 9 residential buildings and 5 offices has been analyzed. The objective of this evaluation was also to investigate the environmental impacts of operation phase and building materials, and the phases of the buildings. For some projects, the information on impacts has been very detailed, but it wasn't the case for some others. In the €CO2 [23] project, the environmental impacts of 7 residential buildings have been presented. The objective of the presentation of this case study was to represent the environmental impacts of the operation phase and embodied phase and the amount of carbon storage by the use of wood material. For none of the projects, any detailed information about the impacts was presented. Berggren et al [24] reviewed 154 case studies present in the literature and added 11 Minergie cases. Their objective was the identification of the importance of the operation impacts compared to the embodied impacts for the primary energy indicator. This objective was close to those of Ramesh et al and they have used more or less the same cases presented above. Their objectives were also to compare the impacts of low energy building, and Net ZEB[2] building. The environmental information wasn't provided. Passer et al [25] presented the environmental impacts of 5 Austrian residential buildings. Their objective was the identification of the influence that the technical equipment has in the overall impacts of building. The environmental impacts of buildings or construction wasn't provided, but detailed information was found on his PhD rapport [26]. The information about the operation and embodied impacts have been detailed and by a decomposition of the embodied impact by materials. John [27] presented in her PhD a detailed environmental impacts' analysis of 12 Swiss residential buildings. The objective of this study was the reduction of the complexity of the LCA of the residential buildings. The results for all case studies are very detailed and a decomposition of the embodied impacts by component has been presented. Wyss et al [8] have presented 32 cases of residential building, offices, schools and single houses. Some of these cases are presented by John [27] and some others are building renovation projects. The objective of this work was the calculation of the 2050's target values for the indicator of the CEDnr, GWP and UBP. Due to a limited description of the projects and their environmental impacts the cases are not exploitable. Lehman [28] has presented the detailed environmental impacts of a Swiss office. The objective of her study was to improve the LCA methodology of the building by the use of a default database.

To derive efficient results and conclusion we have accepted only cases that fulfill certain criteria. These criteria are:

- The database used for the assessment of the environmental impacts of building is representative in Switzerland. The cases will be used for the Switzerland context, so the environmental impacts of buildings assessed with databases that are not representative in Switzerland can derive the results and conclusions of the study.
- The case studies are published in the last 5 years and the buildings have been built during the 2005 and 2015 period. A lot of effort have been made by the scientists in these last years for the minimization of the building's impacts. Therefore, the buildings presenting lower impacts can be found in the literature of the recent years. So, this criteria eliminate old case studies by accepting only those that are supposed to have minimal environmental impacts. Also the database used for the evaluation of impacts of old case studies is not relevant nowadays.
- The transparency of information about the inputs and hypothesis for the evaluation of the impacts. This criteria is linked with the information about the inputs consider in the calculation, database used for evaluation of environmental impacts and the hypothesis considered in the study. This criteria eliminate the cases that have a reduced boundary of the study, non-complete models and specific hypothesis that have a significant impact to the results.
- At least the indicators of CED and GWP were assessed in the study. After the 2000-Watt society concept the goods and services have to reach the goal for the indicator of CED, CEDnr and GWP. This criteria will be useful in the comparisons of the environmental impacts of case studies with the target values evaluated present in the previous section. If the studies haven't evaluated all indicators but only two of them, we can judge if the case study has reach the goals at least for these two indicators.
- The study has presented detailed results about the environmental impacts of goods and services and not a global results of the case study. This criteria is useful in the case of identification analysis. This identification will allow to know the major contributor to the environmental impacts.

[2] *The Net ZEB concept is a building where the weighted supply of energy form the building meets or exceeds the weighted demand and interacts with an energy supply system*.

Application of these criteria has led to the acceptance of 21 case studies presented by John [27], Passer [26], Lehmann [28], and CIRCE [22]. The above presented case studies by John, Passer, Lehmann and CIRCE are respectively Suisse, Austrian, Suisse and Spanish.

3.4.3. Comparisons of environmental impact of cases with target values

In the last 20 years, many databases and software that can be used in the assessment of environmental impacts of goods and services were developed. The database used by this software and also the methodology and hypothesis considered for assessing the impacts differs from one software to another. These differences are generated in general by the parameter of the energy mix produced in each country and considered in each software, fabrication method and transportation. Conversions have been made for making possible the comparison of environmental impacts of case studies found in literature with the 2050's targets. As the target values are evaluated for the Swiss society, environmental impacts of the cases are increased or decreased in function of environmental impacts of energy mix of states where the cases are located with those of energy mix of Switzerland. For example, the cases presented by Passer et al [25] that are located in Austria have been minimized by the report of impacts of energy mix of Switzerland with those of energy mix of Austria. Only the environmental impacts of operation phase have been reevaluated because the environmental impact of components have been assessed with the SimaPro software [29] using Ecoinvent database [30] respecting also the Switzerland representation. The other case studies have been converted in the same way, using the information about the energy mix found at Itten et al [31]. The environmental impacts of 20 projects of residential buildings are presented in Figure 5.

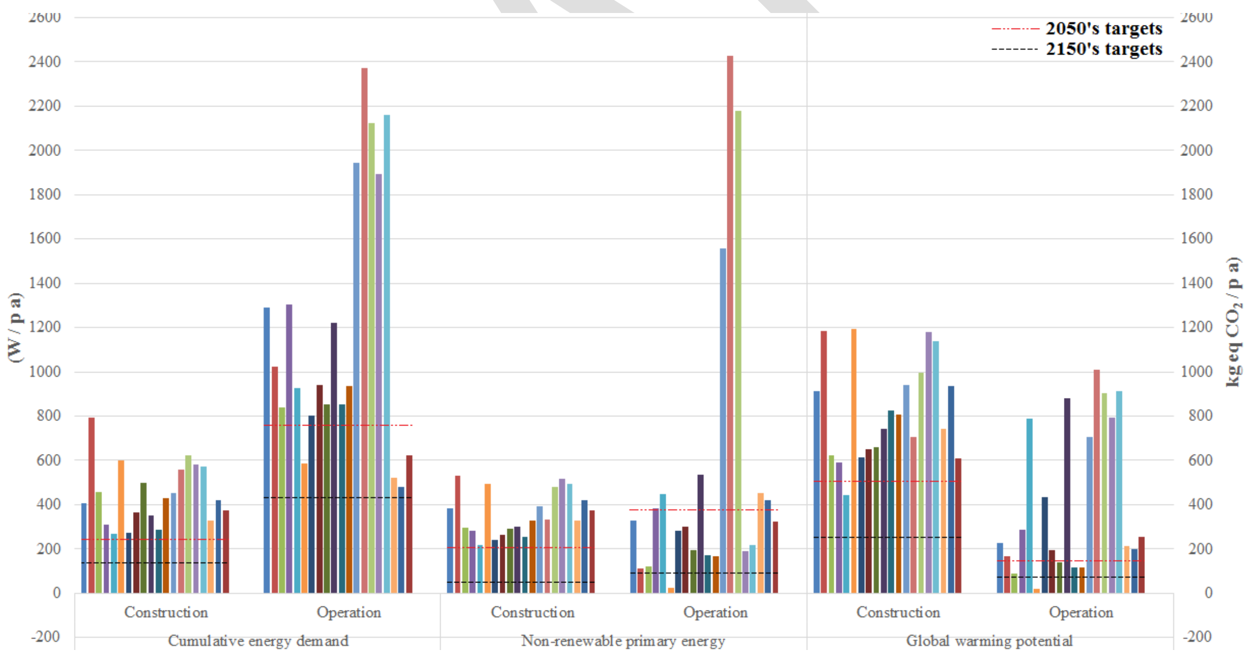


Figure 5 : Comparison of 20 building's impacts with 2050's and 2150's targets values (cumulative energy demand, non-renewable energy and global warming potential indicators)

In order not to complicate the Figure 5 we haven't presented the environmental impacts of an office project. Following the direction of presentation of the results in the Figure 5 the corresponding results of the office are: 18 watts / p a, 177 watts / p a, 18 watts / p a, 123 watts / p a, -2.4 kg CO_2-eq / p a, 50 kg CO_2-eq / p a. Comparing these impacts with the corresponding target values defined for the offices, we see that the impacts are very far from the 2050's objectives.

The analysis of the comparisons of the environmental impacts of cases and 2050's target values can be done in two different directions: one in the direction of indicators and one in the direction of embodied and operation impact. The results obtained by these comparisons allow the identification of the results presented in the Figure 6.

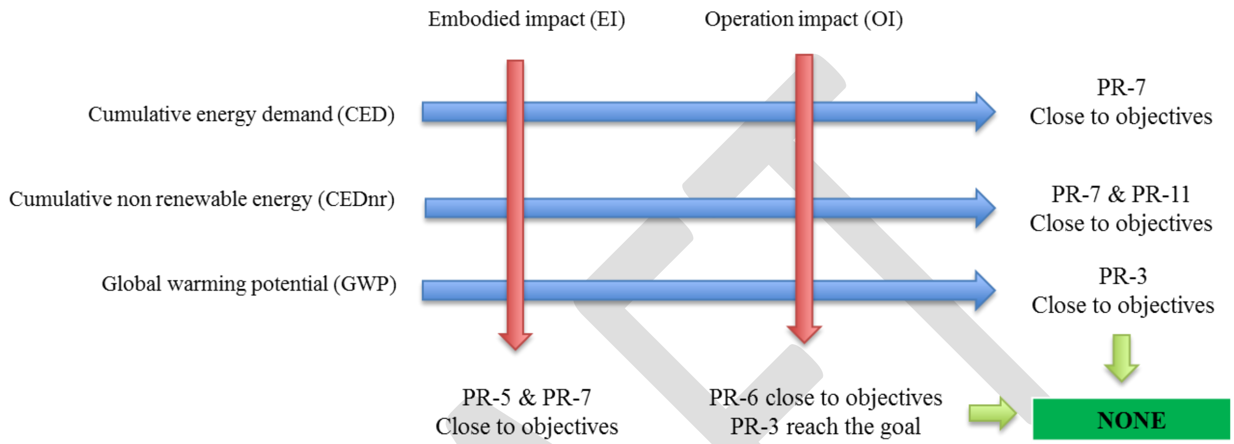


Figure 6 : Results of the comparisons of the targets values with embodied and operation impacts for each and all indicators

The comparisons of the environmental impacts of buildings with the 2050's and 2150's targets values (Figure 5) show that none of the projects has reached the 2050's goals. As result of a possible transfer of damages, the comparisons of total impact with the target values have also been made. These two comparisons conclude that nowadays none of the projects has reached the 2050's objectives. This conclusion is in accordance with the conclusion of Kaspar [2] and Ott et al [32]. After a comparison of the environmental impacts of an office projects (NuOffice I) which has received the platinum certification by LEED with the highest score on the planet that was previously given for an office with 2050's targets values he concluded that the project can reach the goal for one part of the building but it couldn't reach the final goal. In addition, they have considered the environmental impacts of food, consumption and infrastructure in the study. Ott et al [32] obtained the same results. They have analyzed five residential case studies situated in Zurich by considering the environmental impacts of building components, operation phase, mobility and food. The results of the study have shown that the actual buildings can reach intermediate goals between 2012 and 2050, but they couldn't reach the 2050's goals.

3.5. Smart living lab's objectives

The literature review has shown that at present not a single building has reached the 2050's environmental goals. Certainly we have identified building projects that have indeed reached the 2050's objectives for one specific indicator, or building projects that are not far from the 2050's objectives, but none of the projects has reached the goal. In addition, the literature review showed that in the assessment of environmental impacts of buildings, the mobility, food, consumption and infrastructure haven't' been considered. Also, the building projects have no level of flexibility. In the case of the smart living lab project, everything will be considered: goods and services (construction, operation, mobility, food, consumption and the infrastructure) for the assessment of the environmental impacts. The smart living lab project will reach in addition, a level of flexibility, and this will increase the impacts of projects. The particularity of the smart living lab relies also on the diversity of the construction project. The expected floor area of the smart living lab is the sum of the area of offices, experiment hall, meeting and training seminar rooms and housing. Comparing the projects that have been published in literature with our projects we can conclude that the 2050's objectives can be defined as our goals.

To conclude, in the smart living lab project, we have accepted to reach the target values of 2050.

3.5.1. 2050's target values of smart living lab

In the previous paragraph we have defined the 2050's targets for each type of building separately that couldn't be directly useful in the smart living lab as a mix project. This requires the identification of the target values for the smart living lab. The expected gross floor area for the smart living lab is around 4,000 m² and divided in office area, experimental hall area, meeting area and housing area.

Considering the area of the experimental hall, training and seminar rooms equivalent to the area of school, the target values for the smart living lab will be evaluated according to the equation:

$$T_{mix} = N_o \cdot T_o + N_s \cdot T_s + N_h \cdot T_h$$

Where: T_{mix} are the target values for the smart living lab for the indicator of CED, CEDnr and GWP.
T_o, T_s, and T_h are respectively the target values of offices, school and houses.
N_o, N_s, and N_h are respectively the number of capita that smart living lab can host in the area of offices, school and houses. This parameter depends from ERA of smart living lab and ERA per capita in Switzerland.

Using this information and the target values defined in the previous paragraph, we are able to evaluate the target values of the smart living lab. Since the corresponding number per capita for offices, school and houses for smart living lab will be a parameter that will vary until the identification of the best architectural project consequently the target values will also vary. The conditions the environmental impacts of smart living lab have to reach are:

$$I_{sll} \leq T_{mix}$$

The conditions given by the equation have to be reached for each part of the goods and services and for the whole environmental impact in order to reach the 2050's goals.

3.5.2. Definition of target values at component level

In the previous sections we have described and identified the target values for the building (embodied and operation), mobility, food, consumption and infrastructure that a system has to respect in order to reach the 2050 or 2150 objectives. A more detailed identification at components level of the targets values is possible. To do so, we have used the cases of residential building presented in the section 3.4.2. The first step to undertake for the calculation of targets at a components level, has been done by averaging the values of impacts components have on all projects. Secondly, for the residential building, these values have been reduced with reduction coefficients in a way that the sum of the component's impacts was equal to the target values described in section 3.3. For offices and schools, the information about the quantity of building's elements and their impacts presented by CIRCE [22] and Wyss et al [8] has been used as verification information. This verification has been made to make sure that the target values of components of offices, residential buildings and schools don't differ a lot from one typology to the other. The target values for the residential building, offices and school are summarized in Figure 7.

Figure 7 : 2050' target values for residential, offices and school at component level

As demonstrated in section 3.4.3 none of the projects has reached the 2050' goals, so further improvement in the building sector is necessary. To be able to focus on the pertinent and most sensitive aspects of the building sector, it is fundamental to accurately quantify which part of the life cycle of which element is the main contributor to the environmental impacts. In the next section we have performed an identification analysis that will be helpful in the identification of the part of the building that has to be firstly improved for reaching the objectives defined for the smart living lab project.

3.6. Identification analysis

This part of the state of the art was devoted to the identification analysis. In this work, we will show the capacity to reduce the embodied impacts and operation impacts by analyzing 21 case studies. Then the correlation between the embodied and operation impacts will be analyzed. The correlation between the indicators will also be part of the identification analysis. In the end, the identification analysis has been applied with the objectives to rank the building's materials and elements according to their influence to the building's impacts.

3.6.1. Embodied or operation impacts

In this part of the study, the objectives of the identification analysis is to analyze today's abilities for reducing the impacts of goods and services. Since none of the cases has considered the environmental impacts of mobility, food, consumption and infrastructure, the identification analysis will be focused only in the embodied and operational impacts. To do so, in Figure 8, Figure 9 and Figure 10, we have summarized the operation phase's impacts (OI) and the embodied impact (EI).

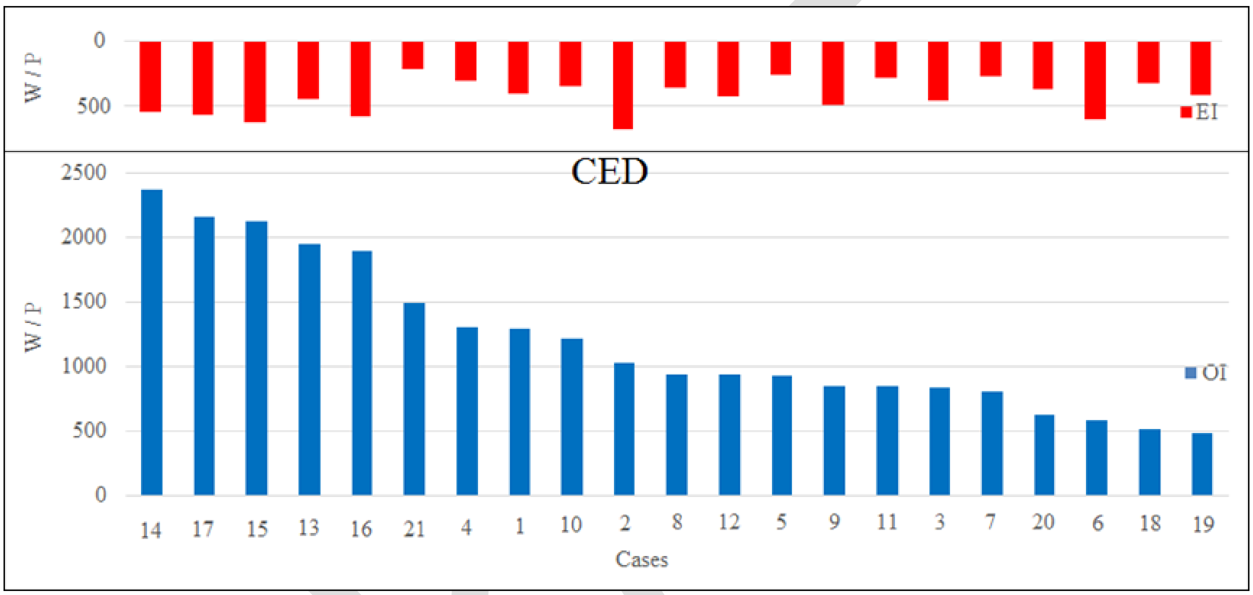


Figure 8 : Variation of embodied impacts (EI) and operation phase impacts (OI) for the indicator of cumulative energy demand.

Analyzing the results of Figure 8, we notice a large absolute variation (1890 w/p/y) of the operation's impacts (480-2370 w/p/y) comparing to (569 w/p/y) the embodied impacts (221-790 w/p/y). These results show that today the improvement of the OI is much easier than the improvement of the EI. Another interesting result noticed in the Figure 8 is that the improvement of the OI has not influenced the EI and vice versa. We notice that the projects that have the minimal EI don't have large OI.

The variation of OI and EI for the indicator of the CEDnr are presented in the Figure 9. For this indicator, we notice a variation of EI between 100 w/p/y to 530 w/p/y and a variation of the OI between 20 w/p/y to 2430 w/p/y. These results show the same conclusion as in the case of CED indicator. For the GWP indicator the variation of OI and EI are shown in the Figure 10. The EI vary between 440 and 1190 kg CO_2-eq/p/y (except the negative value of -3 kg CO_2-eq/p/y) and the OI vary between 20 kg CO_2-eq/p/y to 1350 kg CO_2-eq/p/. The results of GWP indicator don't differ from those of CED and CEDnr indicators, except one case, where the value of GWP indicator is negative. This is the case of an office's project where the principal material used in the construction is the wood. Considering that the wood material has storage CO_2 during the time, the author has consider this material with negative impacts for the GWP indicator. Other authors [23], [33], [34] and database [30], [35] consider wood with negative impacts. But, according to TRADA [36], Werner et al [37] etc, in the end of the life of building the quantity of the CO_2 storage in the wood will be return to the atmosphere. So, the wood couldn't be consider having negative impacts. Other authors refuse to consider the wood with negative impacts, even as carbon neutrality [38]. Further research is needed for the development of the conditions to consider material of wood as carbon neutrality and then with negative impacts. In conclusion, this first analysis of the 21 cases shows that nowadays the improvement of the environmental impacts of operation phase of the building is easier to achieve than the improvement of the environmental impacts of building components. Thus, the improvement of the environmental impacts of buildings must start by improving the environmental impacts of components. These conclusions are in accordance with the cases where buildings have been designed for low or net-zero energy [39], [40].

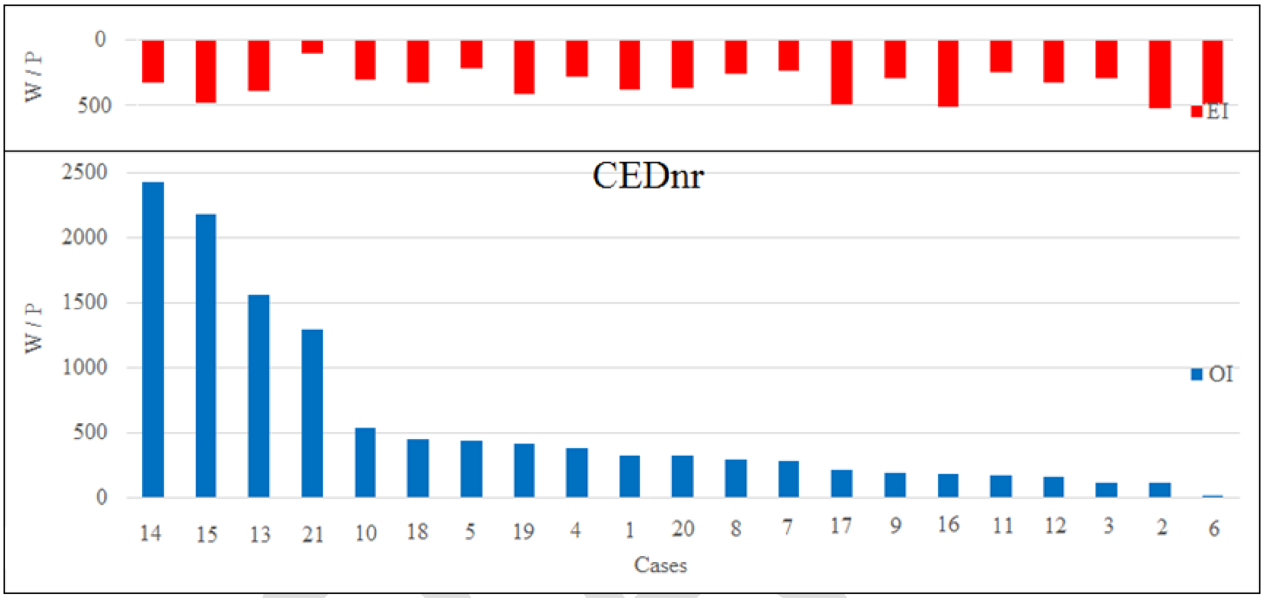


Figure 9 : Variation of embodied impacts and operation phase impacts for the indicator of cumulative non-renewable energy demand.

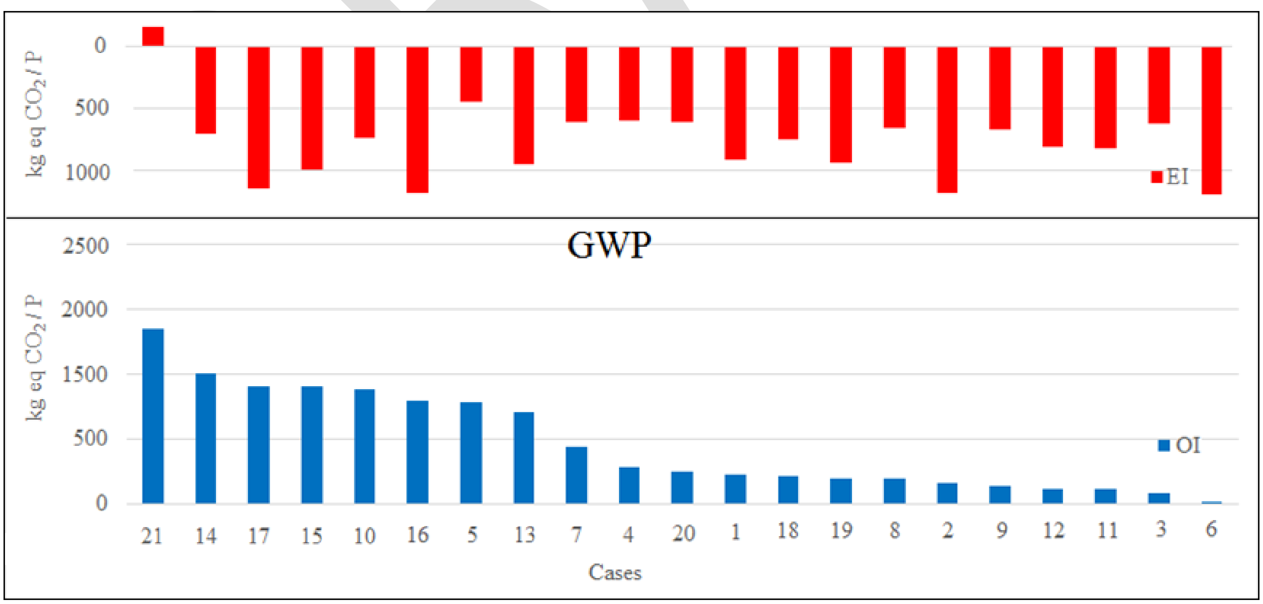


Figure 10 : Variation of embodied impacts and operation phase impacts for the global warming potential indicator.

In order to make sure that the improvement of the EI will not affect or influence the OI, we have to apply the identification analysis to analyze the correlation of these two parts of the building.

3.6.2. Correlation of Embodied and operation impacts

In order to assess the correlation of two parameters, the theory of probability and statistic proposed the coefficient of correlation. In function of the values of these coefficients we can obtain the information about the intensity of the correlation of two parameters.

Figure 11 summarized the information about the intensity of correlation in function of the values of correlation coefficient.

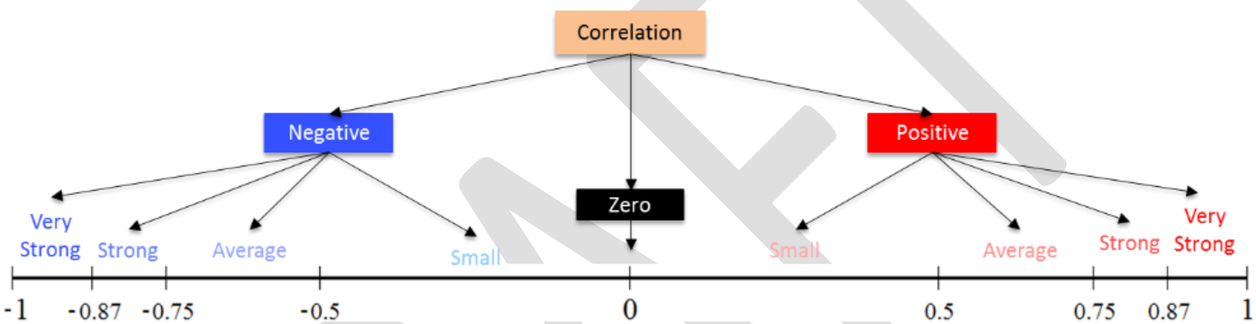


Figure 11 : Information on the intensity of correlation in function of the correlation coefficient R [41], [42].

Based on this theory, we have calculated the coefficient of correlation for testing the correlation between the embodied and operation's impacts.

The results obtained by this identification, are summarized in Figure 12.

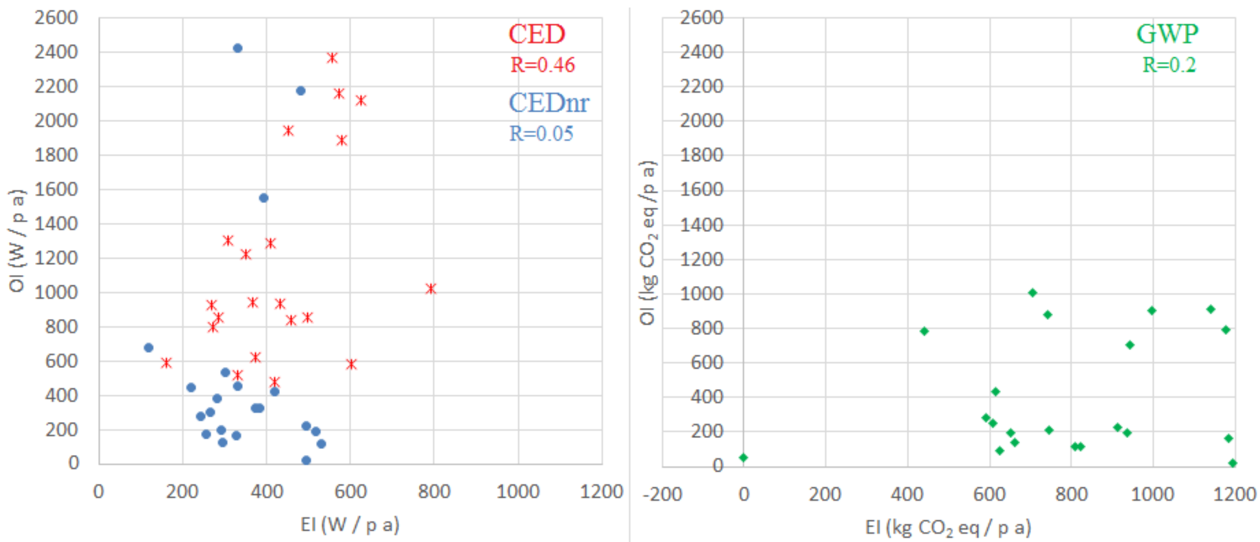


Figure 12 : Embodied and operation's impacts correlation

The results of the Figure 12, show that the EI and OI are not correlated with each other. Coupling the results obtained in the section 3.6.1 with those of Figure 12, we can conclude that the minimization of EI doesn't influence significantly in the OI. This result allows to analyze separately the environmental impacts of building components and operation phase. Another very important step is to analyze the correlation between the indicators.

3.6.3. Correlation of impacts

In this paragraph we have presented the results about the level of correlation that the whole impacts or part of building has with each other. This work will identify the indicator that has to be first improved. The results that we have about the correlation analysis are presented in the Figure 13.

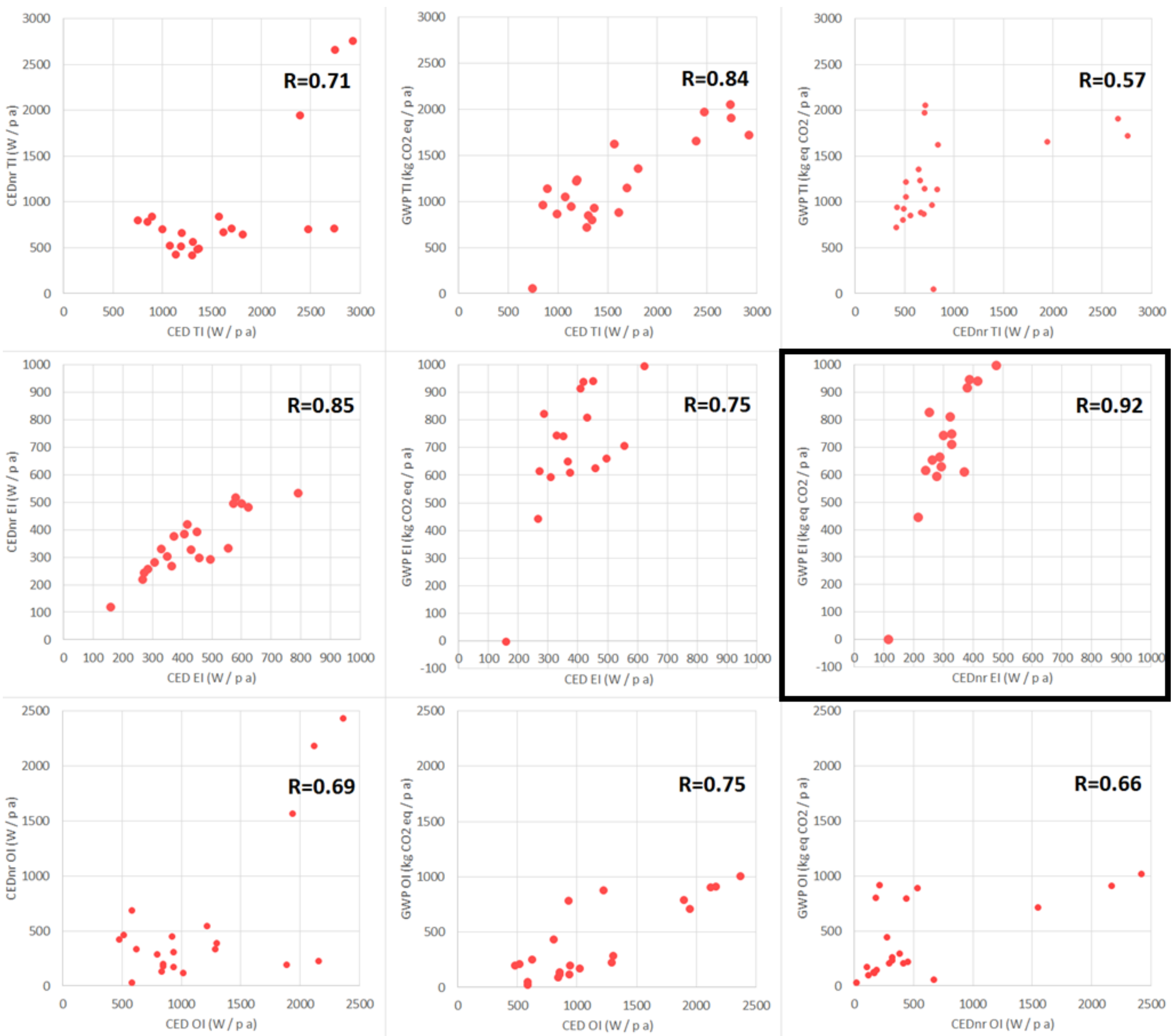


Figure 13 : Variation of embodied impacts and operation phase impacts for the global warming potential indicator.

These analysis show that there aren't any strong correlations between the indicators when the total impacts of buildings are analyzed. We obtain the same results when the impacts of the operation phase are analyzed. Only in the case (framing with black in Figure 13) of the environmental impacts of building components the results show that the correlation becomes very strong.

3.6.4. Identification analysis at component level

The objective of the last step of the identification analysis is to identify the influence of inputs to the environmental impacts. For reaching the 2050's goals the first indicator that has to be improved is the GWP. So, in this section we have applied the identification analysis only for this indicator. The method that has been applied for the identification analysis is by the Pareto's principle whereby 20% of causes implies 80% of effects.

A detailed application of the Pareto's principle in the environmental impacts of building would consist in the application of this principle for a decomposition of the project:

- In different phase (product stage, construction stage, use, end of life, benefits and loads beyond the system boundary) as present in Figure 14.
- In different components, goods and service. This decomposition allows the identification of the component and product that has the biggest influence in the environmental impact of building (figure 10).

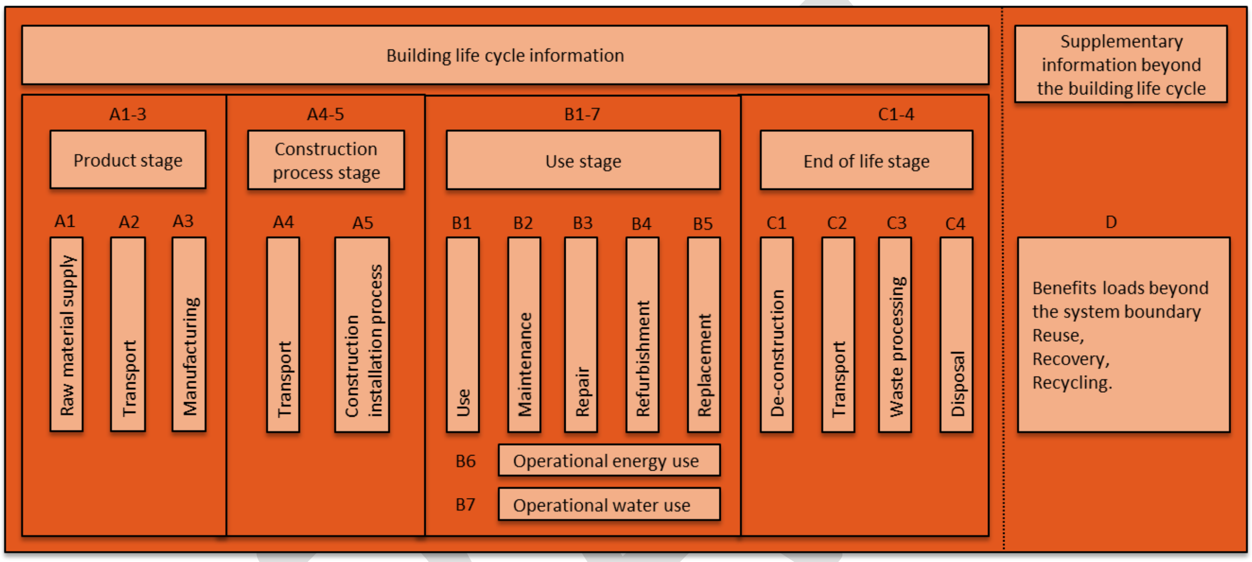


Figure 14 : Building assessment stages according to the (EN 15978, 2011)

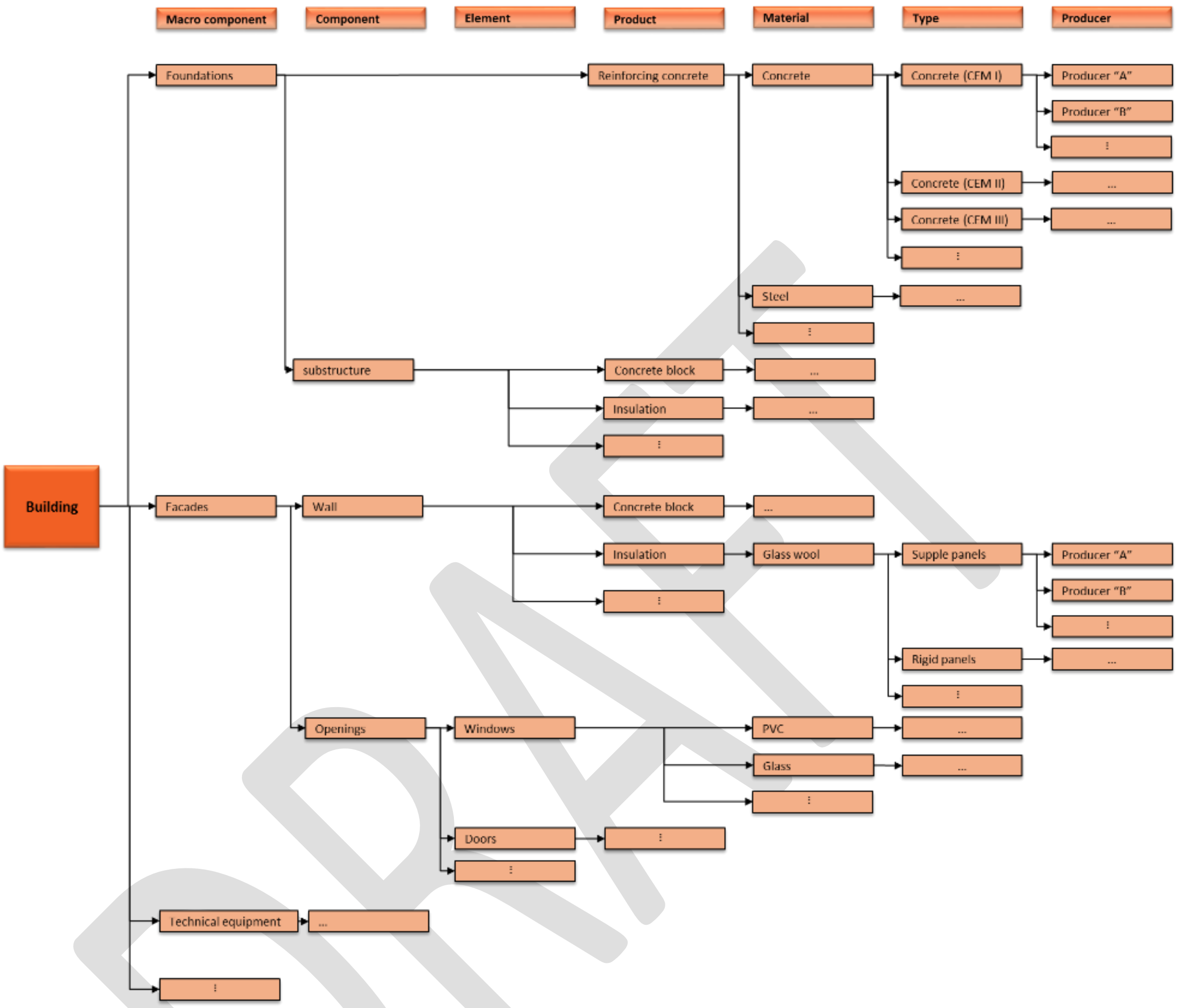


Figure 15 : Building decomposition according to the (EN 15804, 2011) and improved by (HOXHA, 2015)

As it can be noticed on the Figure 14 and Figure 15 there are different types of decomposition of the building. The definition of the decomposition depends on the objectives of the study but mostly from the availability of the inputs in the databases, the time of calculation, etc. Assessment of the environmental impacts of 21 case studies has been done by a decomposition of the building in a different way. This makes difficult the application of the identification analysis because the results couldn't be converted in a unique decomposition. Nevertheless, we have applied the identification analysis for a different type of decomposition and we have tried to couple the results together. The decomposition by macro component of the project presented by Lehman [28] is very limited. This type of decomposition hasn't allowed to reach any conclusion. CIRCE [22] has used a decomposition by products. Passer et al [25] have also used a decomposition by materials and products, and has/have additionally to CIRCE [22], presented the results by phase, even though this last wasn't complete.

John [27] has decomposed the building by macro components. In this part we have applied the identification analysis only in the cases presented by John [27] and Passer [25]. The cases presented in CIRCE [22] and by Lehman will not carry additional information. The sum of the percentage of influence that the macro component has in each project is used as the parameter for ranking the macro component according to their influence in the GWP indicator.

$$\text{Sum of influences (\%)} = \sum_i RC_i$$

Where i: represent the number of projects

RC_i influence of macro component in the environmental impact in project i.

The results obtained for the 12 cases of John are presented in the Figure 16 : Influence of building's macro components in GWP indicator.

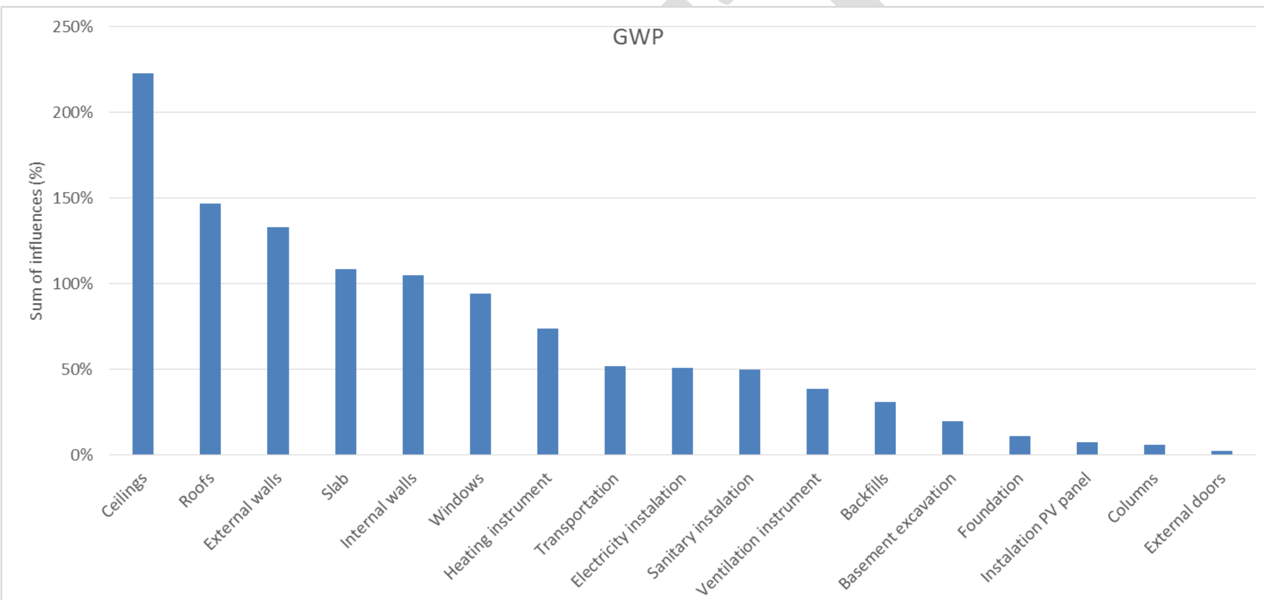


Figure 16 : Influence of building's macro components in GWP indicator

This identification ranks the ceilings as the macro component that has the highest influence to the GWP indicator, the roofs the second, external walls the third and so on. In the case of projects presented by Passer [26] the identification analysis has given the results presented in the Figure 17.

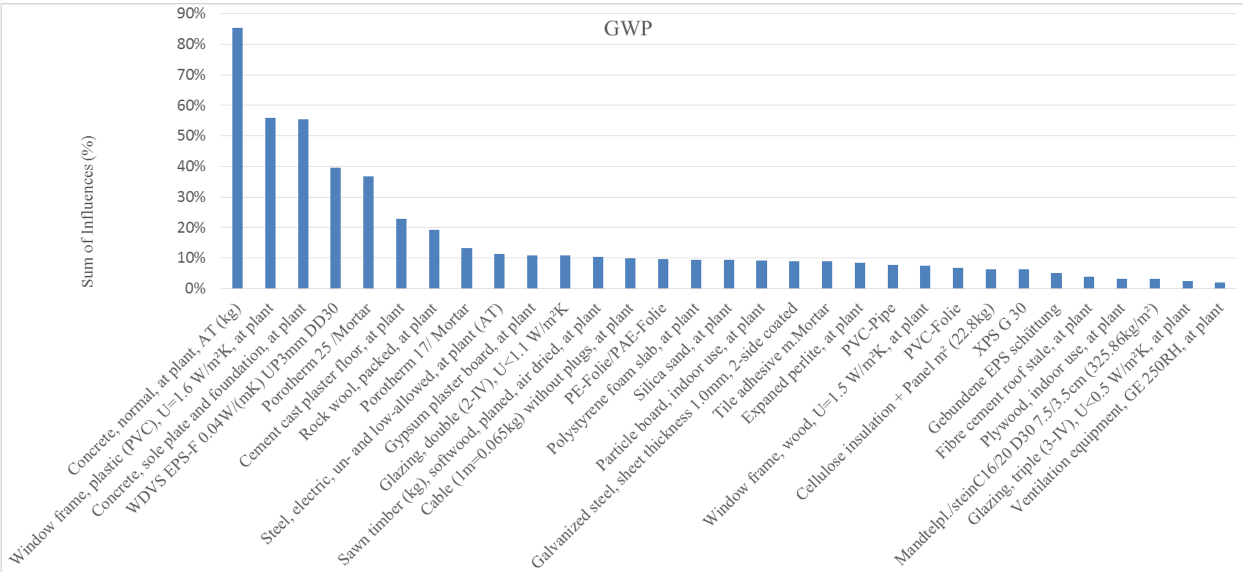


Figure 17 : Influence of building's materials in GWP indicator

In this case the identification analysis ranks the concrete as the material having the highest influence to the GWP, second the PVC windows frame, the third polystyrene and so on.

Coupling the results of identification analysis presented in Figure 16 and Figure 17 we obtained the information about the macro components that have to be first improved (ceilings) and the materials that have to be avoided or reduced in the improvement of this macro components (concrete, polystyrene, etc.).

3.7. Environmental impacts assessment methodology

3.7.1. Life cycle assessment methodology

According to the ISO-14040 [43] the life cycle assessment (LCA) is defined as a compilation and evaluation of the inputs, outputs and the potential environmental impacts of a product system throughout its life cycle. LCA consists of four components or steps: Goal and Scope Definition, Inventory Analysis, Impact Assessment, and Interpretation (Figure 18).

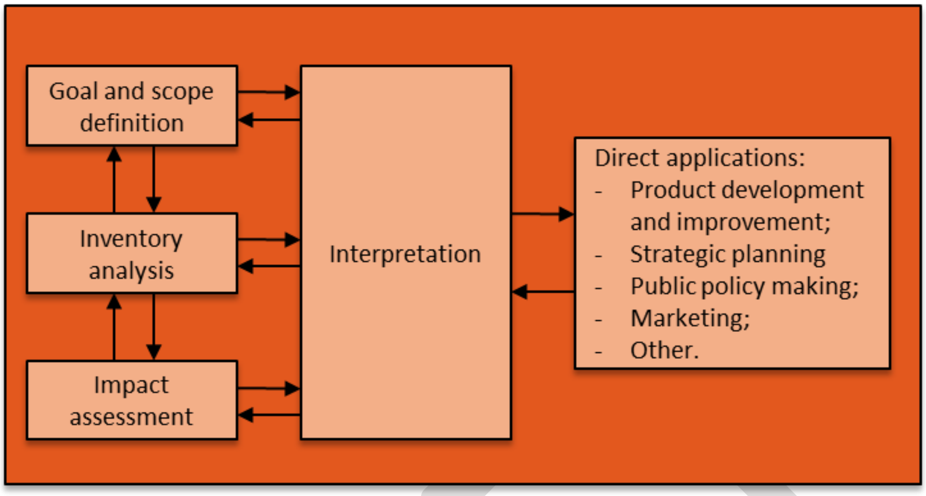


Figure 18 : Phases of an LCA according to ISO-14040

Goal and scope definition is the phase of LCA that consists of the definition of the functionality and the functional unit of the product or system that will be analyzed. The boundary of the system, the impact categories to be evaluated, and set of data that need to be collected are identified and defined in this step. According to the European norm EN15804 [44] and EN15978 [45] in the case of building a detailed description of the building is required. This description has to include the information about the functionality of the building, the geographic location, the lifespan of the building, hours of work and the building's elements and material to consider in the study, etc. The quality of this description will influence directly the time required for the evaluation and final results.
Inventory analysis is the second step of the LCA, where the data necessary for the completion of the analysis may be collected and processed. The life cycle inventory (LCI) helps to quantify the flows of energy and raw materials used through the system and related to the functional basis. In the case of the building, the problem of the collection of the data and calculation of the quantity of building's elements and materials has to be resolved.

Impact Assessment is third step of the LCA having for objective to translate the flows of energy and raw materials of the system in damages. In the case of buildings the environmental impacts are function of the phases (Figure 14):

$$I_{buidling} = \mathrm{f}(A1-3;\ A4-5;\ B1-7;\ \ C1-4;\ \ D)$$

A1-3 represents the product phase (raw material, supply, transport, manufacturing)
A4- represents the construction process stage (transport, construction-installing process)
B1-7 represents the use stage (use, maintenance, repair, refurbishment, replacement of building's elements, operational energy use, operational water use)
C1-4 represents the end of life stage (de-construction, transport, waste processing, disposal)
D represents the benefits and loads beyond the system boundary (reuse, recovery, recycling)

In a simplified approach the impacts can be presented as function of three parameters:

$$I_{buidling} = \mathrm{f}(quantity;\ caracterization\ factors; number\ of\ use\ of\ elements)$$

The number of use of elements is proportional to the lifespan of the building and disproportional with the lifespan of building's elements. This equation demonstrates the possibility of four ways of minimizing the environmental impacts of building. The first is the elimination or the minimization of the quantity of material used in the building. The second is the minimization of the characterization factor by using eco material, material with low impacts of recyclable material.

The third is by implementing during the lifespan of building, technologies and building's elements that can improve the impacts of building. And the fourth is by using building's elements that have long lifespan. In the end the last factors the lifespan depends on is the degradation of the building elements which depend significantly on the use condition (humidity, UV, temperature, etc...). The third and fourth are linked with each other and the minimization of the impacts require the development of an optimum solution.

Interpretation of results occurs in each of the preceding steps. It allows the validation of the various phases including identifying potential problems and putting forward modeling crucial points.

For the smart living lab, the LCA methodology described by Europeans norms EN15804 [44] and EN15978 [45] will be used for assessing the environmental impacts.

3.7.2. LCA databases and software

As a result of a large number of input data required in LCA, in the last 20 years many databases and software were developed to make possible the assessment of environmental impacts of products, goods and services. This software improves the efficacy and the time of calculation. There are at present many tools that have been developed at a national and international scale using general or specific databases. The rate of evaluation of this software varies from the assessment of impacts of a product to the assessment of impacts of a city. Among all the databases, the most useful are: Ecoinvent [30], Gabi [46], Ivam [47], US LCI database [48], European life Cycle Database [49], CPM LCA Database [50], JEMAI [51], etc which have been implemented in generic software. The generic software most widely used in the world are: SimaPro [52], Gabi software [53], CMLCA [54], openLCA [55], Quantis SUITE [56], MiLCA [57], EarthShift [58], CleanMetrics [59], UMBERTO [60] etc. The use of these databases and software has a number of advantages and disadvantages. The large number of data make possible the assessment of the environmental impacts of all types of goods and services. These databases and software are useful in the development and research field. The flexibility and the possibility to use this large amount of data have been used in the development of new materials and products with the lowest environmental impacts. Another strong advantage of this software and databases is the fact that they allow the assessment of the impacts of buildings including the other goods and services (mobility, food, infrastructure, textile product, etc) in all possible forms of decomposition and schemas (decomposition by phase: product stage, construction stage, use, end of life and benefits and loads; or decomposition by product: foundation, walls, ceilings, roof, etc; or by material: concrete, steel, wood, plaster, glass, insulations, etc). Certain software, make also possible to consider the uncertainties in the assessment of the environmental impacts. The Ecoinvent database generate uncertainties form the PEDIGREE matrix [61] which characterize the quality of the data. However, these databases and software have the time parameter as a disadvantage. The assessment of the environmental impacts of buildings, goods and services related to her required a lot of time. The time consumption becomes even greater when the uncertainties calculation have to be considered. These, due to the iteration calculation made by Monte Carlo method and the large amount of inputs considered in the assessment of impacts.
The necessity for the reduction of the environmental impacts has led to the development of the new databases and software in different sectors. One of them is the sector of construction including all the goods and services (mobility of people, food, textile consumption, etc) linked to it. Databases and software (Table 3) have been developed for the assessment of the environmental impacts of only one good or service (example: only food, or only mobility, etc) or

some of them (example: only building component, mobility and food, or building component, operation phase, mobility and infrastructure), but none of them is able to assess the environmental impacts of building components, operation, mobility, food, consumption and infrastructure. Obviously, there's other software that may be used for the assessment of the impacts of building system. In Table 3**Erreur ! Source du renvoi introuvable.** we have presented only the most widely known software, whose information was available.

State	Software	EI*	OI*	MI*	FI*	CI*	II*	Database
Australia	Building Greenhouse Rating [62]	x	x					?
Australia	LISA [63]	x	x				x	?
Australia	eToolLCD [64]	x	x					AusLCI
Belgium	Instant LCA [65]					x		OD**
Canada	Impact estimator [66]	x	x					Athena [67]
Germany	Legep [68]	x	x					ÖKOBAU [69]
Switzerland	Eco-bat [70]	x	x					KBOB [71]
Switzerland	LTE OGIP [72]	x	x					Ecoinvent
France	EIME [73]	x	x	x		x		EIME [74]
Switzerland	Mobitool [75]			x				Ecoinvent
Switzerland	Quartiers durables [76]	x	x	x				OD**
Switzerland	Lesosai [77]	x	x					KBOB
United states	Bees [78]	x						?
Netherland	Eco-Quantum [79]	x	x				x	IVAM
Italy	EcodEX [80]				x			?
UK	CCaLC2 [81]				x			?
Germany	Trainee [82]			x				?
Sweden	EcoEffect [83]	x	x					?
France	FoodPrint [84]				x			OD
France	EcoTransIT world [85]			x				?
France	Carbonostic [86]				x			?
France	ELODIE [87]	x	x	x				INIES [35]
Germany	GEMIS [88]	x	x	x				OD**
France	Spin it [89]					x		OD**
France	e-licco [90]	x	x					OD**
France	EGES [91]				x			OD**
UK	CORINE [92]	x	x	x				ELCD et EcoInvent
France	novaEquer [93]	x	x	x				INIES & ecoinvet
USA	Eiolca [94]	x	x	x	x	x	x	OD
Netherland	GreenCalc [95]	x	x	x				?
Canada	VOIRVERT [96]	x						Athena

*EI: Embodied impacts, OI: Operation impacts, MI: Mobility impacts, FI: Food impacts, CI: Consumption impacts, II: Infrastructure impacts
**OD: Own data

Table 3: LCA software for building, food, mobility, consumption and infrastructure

All these programs differ widely from each other, from the database point of view, from the assumptions and hypothesis that they consider in the calculation, from the methodology used for the evaluation of the impacts and from the results that they are able to evaluate, etc. Unlike the generic software, the parameter time is improved in these programs. They are easier to use and contain data in the product scale (example: if in the generic software the user has to assess himself the environmental impacts of a window, the impacts for windows are assessed before and the user has to give only the information about the quantity of product). But in the context of flexibility and improvement and development of the new solution the software has been deteriorated. The user can only use the data available in the software and cannot improve these data or his solution (example: the user has to use the data of window given by software but he couldn't improve the impacts). The level of uncertainties in the assessment of the impacts by this software is higher, as result of the linear assessment (example: in the case of PVC window the rapport of glass and PVC is linear, something that is not true). To conclude, none of these programs can be used for the assessment of the uncertainties of the impacts.

During the last years, new software for the assessment of environmental impacts of neighborhood and cities has been developed. Among this new software, the most used are NEST [97], TRACE [98], Citycad [99], Smèo [100], etc. These software solutions consider large hypothesis in the calculation, which implies large uncertainties in the results (example: the user has to give only the information about the area of the construction, the type of building and the area of the road etc, for the assessment of the environmental impacts of neighborhoods and cities). On the other hand, the flexibility of these software solutions are much more deteriorated compare to the previous software. At the moment, most of the software available is able to evaluate the impacts only for one or several goods and services of the neighborhoods or cities, but it is not able to evaluate all the impacts by considering all the goods and services. The time parameter used by this software is reduced significantly.
In this description of the software, we noticed that the time parameter and the flexibility of the assessment of impacts go in the opposite sense, when the time is improved the flexibility is deteriorated and vice versa (Figure 19).

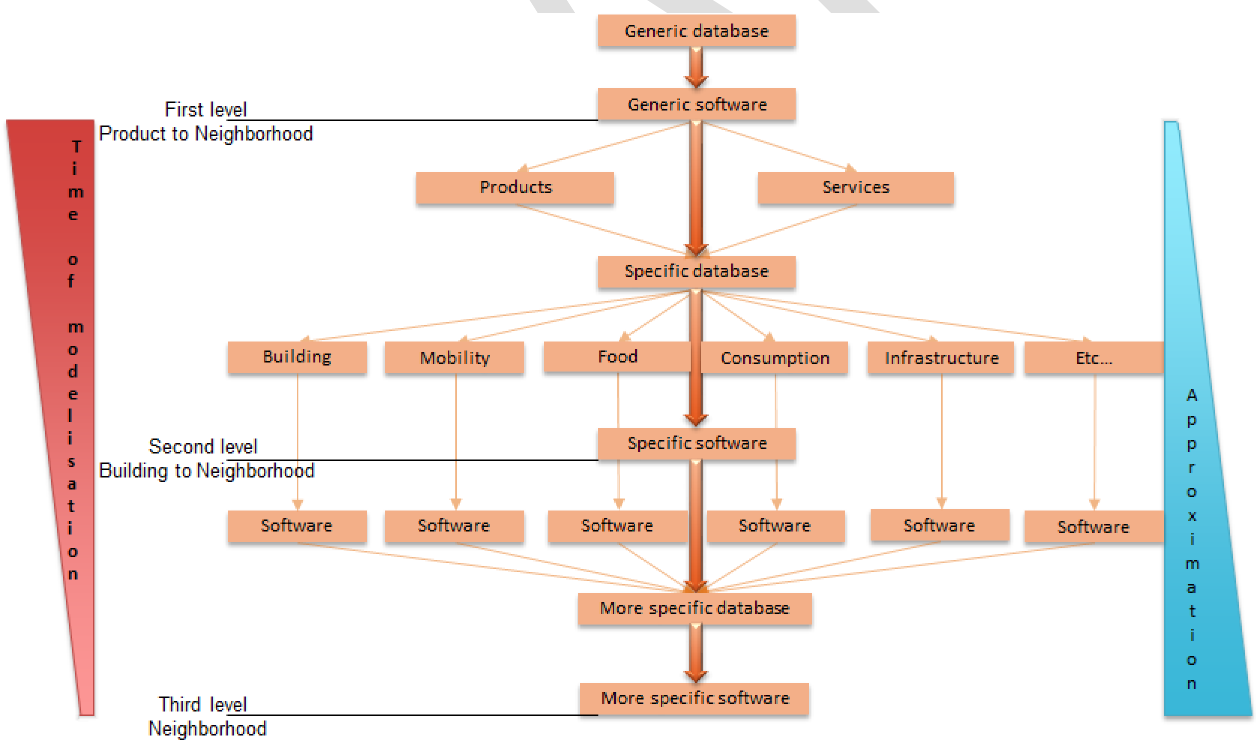


Figure 19 : The software development scheme and the relation time-approximation

This is due to the fact that the software is useful for different purposes. The third group of software is useful in the sketching phase of the neighborhoods and cities, by helping the designer to find the optimal way of placing the building, roads, and other goods and services in the neighborhoods and cities plans. The second group of software is useful in the design phase of the goods and services. They help the designer to find the optimal way to plan the project and the optimal quantity of materials and elements to be used for construction. The first group of software is useful in the detailed phase of goods and services. They can help the designer to develop the goods and services and to find the best solution with minimum environmental impacts.

Using this information about the databases and software, the software's purposes and the way of the assessment of impact by optimizing the interaction "time-flexibility" of software in the next section we have described the method and software to be used for the assessment of the environmental impacts of smart living lab.

3.8. Environmental impacts assessment methodology of smart living lab

As presented in the previous section, there is a large number of databases and software available for assessing the environmental impact from a product to a city. Each one of them has different purposes, uses a national or international database, a specific assumption and hypothesis and a methodology for assessing different impacts. Among the databases and software, we will select those for assessing the environmental impacts of smart living lab that fulfill the criteria:

- Is able to assess the environmental impacts from cradle to the grave ;
- Is representative in Switzerland's context ;
- Provides the possibility for the assessment of the primary energy, non-renewable primary energy and global warming potential indicators.

In the assessment of the environmental impacts of building component, operation, mobility, consumption, food and infrastructure we will try to include in the boundary of the study as much input as possible. The assessment of the environmental impacts of smart living lab will be done in two times. Initially, we will assess the environmental impacts using different databases and software that fulfill the above criteria. For this step we have identified the software presented in the Figure 20**Erreur ! Source du renvoi introuvable.**.

Figure 20 : The software development scheme and the relation time-approximation

In the cases where the database and the software accepted for the assessment of the impact lack input, we will try to compensate the lack of input by using other database even if they will not fulfill the above criteria.

After a sensitivity analysis, we will identify the materials, goods and services that have the biggest influence to the impacts. The improvement of these materials, goods or services will be done by using the specific software. Once we have achieved the goals and found the best solution, the specific software will be used for the assessment of the impacts in a more precise and detailed way. SimaPro (Goedkoop & Oele 2004) has been identified as the most appropriate software for assessing the environmental impacts of the buildings, operation phase, mobility, food, consumption and infrastructure. This last assessment will allow to validate the intermediate results and the robustness of the evaluation. The assessment of the uncertainties will be a complementary step that will allow to validate the robustness of the results.

During this scientific work, the main objective will be the achievement of the 2050's objectives. Also we will try to answer other problematics. One objective is the simplification of the LCA, by identifying the indicators that have to be always evaluated. Identifying the indicators that are correlated, the indicators that change in the same sense during the minimization phase of the impacts, and the indicator that are not correlated and don't respect any changing sense are the indicators that have to be always considered during a LCA process. Other scientific problematic is the identification of the optimal lifespan of the building and its components in the environmental impacts points of view. The problematic of the method used for the assessment of the impact remains another scientific topic to be developed.

3.9. Conclusions

Firstly, in this state of the art, we have defined the path to the 2000-Watt society by the definition of target values that the building, mobility, food, consumption and infrastructure have to respect in order to achieve the 2000 watts' objectives. Intermediate objectives that correspond to the year 2050, have also been defined for the cumulative energy demand, non-renewable cumulative energy demand and global warming potential indicator. The definition of target values makes possible to minimize the impacts of building, mobility, food, consumption and infrastructure separately without any influence to each other.

Secondly, a literature review of the environmental impacts of urban area case studies shows that there are no cases to have considered embodied, operation phase, mobility, food, consumption and infrastructure in the evaluation of impacts. In addition, an overview of best building case studies has been performed where only embodied and operation phase impacts have been assessed. The comparison of the target values and the environmental impacts of buildings concluded that none of the projects has reached the intermediate (2050's objectives) goals of 2000 Watt society. The 2050's objectives have been accepted as the goals the smart living lab project has to reach, as a relevant and outstanding performance. These targets are defined for both cases: for a flexible building where the surface can be changed during the lifespan of building and for the case of a mix building (residential, office and school).

Thirdly, we have performed an identification analysis with objectives to identify which are the part of the building to be improved for reaching the 2050's goals and for simplification of the LCA model. This work has permitted to identify the fact that the embodied impacts and the operation phase's impacts aren't correlated to each other. The minimization of the operation impacts will not influence significantly the embodied impacts. The state of the art has demonstrated that it is actually possible to minimize the operation's impacts by the development of building with low energy consumption or zero energy consumption. So, the more the operation's impacts are reduced, the more the embodied impacts are heavy to reduce. This is due to the fact that the more a project is efficient with low operation's impacts, the more the used technology to saved building's energy consumption has to be efficient with a low embodied impacts.

An identification for a possible correlation between the indicators has demonstrated that the cumulative energy demand, non-renewable cumulative energy demand and global warming potential's indicators in general aren't correlated with each other. Only a very strong correlation between the non-renewable and global warming potential's indicators for the building's elements has been identified. By the identification analysis we have classified the building's elements and materials according to their influence in the impact.

These results, useful in the design phase of the smart living lab, allow to identify that the work of the improvement of impacts should be focused more in the minimization of the embodied impacts because the operation phase impacts are easier to be reached. This can be reached by focusing firstly on the improvement of the environmental impacts of ceilings. In order to reach the goals in the project, materials such as concrete and polystyrene have to be avoided as they have been identified as having big impacts. Finally, the main issue is the minimization of the embodied primary energy and greenhouse, since the embodied non-renewable energy and green houses are strongly correlated.

Even though the LCA methodology presents difficulties and limits the assessment of the environmental impacts of product, goods, and services and consequently for the entire impacts buildings, mobility, food, consumption and infrastructure, it appears today as an indispensable tool for the assessment of impacts. In this state of the art, we have identified that there are no generic databases or software for the assessment of the environmental impacts of building, mobility, food, consumption and infrastructure. This explains the reason why we haven't found a thorough work on today's literature. However, for the next research phase we have defined the methodology, generics databases and software that will be used for the assessment of the environmental impacts of all goods and services. This will allow to identify the optimal mass of elements and materials to be used in the smart living lab for reaching the goals. The specific databases and software useful in a second and last step of the smart living lab design, will allow to improve the environmental impacts of certain elements and to validate the overall results in the sense of uncertainty.

3.10. Research topics

Despite all the research conducted in these recent years, the LCA's experts, architects, engineers, etc., have not been able to develop a building that has reached the 2050's objectives. So, the main objective of the scientific concept step is the development of a project able to reach the 2050's targets. In doing that, we will try different topics of work and improvement. Firstly, we will try to develop and improve the environmental impacts of ceiling, identify way that correlate the improvement of the embodied impacts by the improvement of the operation's impacts. The influence of the parameter of lifespan in the improvement of environmental impacts of building will be tested. The interaction of users-building-public space is another topic to be tested for improvement of the environmental impacts of building.

On the other hand, the complexity to conduct an LCA, still remains a very hot topic of the research, especially when the boundaries of the studies expand significantly. It becomes a real problem when passing from the evaluation of the environmental impacts of a product to the environmental impacts of district or cities.

The part of this scientific work will be to develop and provide an answer to these problems. The first objective will be the development of the scientific concept for reaching 2050's objectives. During this work we will try to simplify the LCA model.

In general for all the models and consequently in the LCA model, there are three paths of simplifications:

- Simplification of the model by the elimination of the input that does not have a significant influence to the output's results;

- Simplification of the model by the development of a comprehensible and simple methodology for the users or by the identification of part of the method that can be taken in the consideration in the form of fixed rates.
- Simplification of the model by the elimination of the outputs, the results of which can be obtained by the others outputs as a result of possible correlations that may exist between them.

These simplifications should be made so as not to minimize the robustness of the outputs results.

In the case of smart living lab project the first path of simplification will have as objective the identification of the inputs that do not have a significant influence in the outputs results. On the other hand, the inputs that have a significant influence in the outputs results and require improvement in the future, will be identified. The objective of the second path of simplification will be the simplification of the LCA methodology. The two-direction sensitivity analysis will identify the phases of products which have a significant influence in the overall impacts.

The third path is linked to the simplification of the indicators that have to be evaluated during the assessment of the environmental impacts of products, goods and services. In this third path, the first step of simplification is the elimination of the indicators that are correlated. Next one is the identification of the indicators that are not correlated but change in the same direction or in a different direction. And finally, there's the rest of indicators that aren't correlated and don't change in the same direction and those identified as problematic for the building sector.

During this work, the identification of the potential savings in the future will constitute another research topic to be tested.

4. Building Flexibility

Authors: Yingying JIANG, Thomas Jusselme

4.1. Introduction

The concept of the building flexibility comes from the Kaya Equation. The indicator $\frac{Bvol}{POP}$ in the whole equation demonstrates that to optimize the correlation between the built volume and user population would benefit the environmental impact of the building in terms of CO2 emission and energy consumption. In other words, the more the building would be efficiently used by the inhabitants, the better the building would perform with the other indicators, and the better the building would respond to the project target in the future. Accordingly, this research field is made up of the design of the building and the social study of the future users in two aspects:

- To enhance the usability of the building based on users' needs, and
- To maintain or even improve the usability of the building throughout its entire lifespan by means of flexibility.

Hereby, this state of the art report for the smart living lab is going to respond to the questions:

- What are the definitions of usability and flexibility for the smart living lab?
- What are the feasible specific solutions for the usability and flexibility of the smart living lab?
- What are the general recommended strategies for flexibility that can be used in the smart living lab?

4.2. Flexibility and usability for the smart living lab

Built environment matching the needs of users with certain acceptable performance levels is a key issue in building design and construction [1]. Certain studies have demonstrated that the quality of built environment can influence user behaviors and their efficiency of achieving goals in the buildings, which will also impact the effectiveness and efficiency of buildings [1][2][3]. Regarding to the smart living lab, the indicator $\frac{Bvol}{POP}$ refers that the way to optimize the indicator is to increase the population of users in the building, which can be explained in other words as to let occupants use the building more. This means the building's performance should be with high usability to its users during its entire life cycle.

4.2.1. Usability

The concept of usability was proposed at the very beginning as a quality attribute that assesses how easy user interfaces are to use in the field of engineering[4]. With the growth of the research body in this and other relevant fields, the concept has been extended to the building and construction field, which implies a change on the attitude towards buildings from the traditional property perspective to a product with functional performance.

General definition of usability

The general definition of usability is stated as "the extent to which a system can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use" [5]. This definition includes two parts:

- The specification is emphasized as specified users, goals and context of use, and
- The key factors for description are:
    - Effectiveness: accuracy and completeness with which users achieve specified goals;

- Efficiency: resources expended in relation to the accuracy and completeness with which users achieve goals, and
- User satisfaction: freedom from discomfort, and positive attitudes towards the use of the product.

Widely discussed and studied in the engineering and computer science, this definition was then introduced to the building and construction field by Keith Alexander when he argued that usability is one of the most important aspects of building and workplaces [6]. His proposal triggered the development of the original definition in the field of building and construction, namely as the usability of buildings, which is described as the performance of a building "depending on how well they support the users' activities, our physical surroundings contribute to efficiency, effectiveness and satisfaction in the user organization" [7]. In the other words, building usability is a kind of concept focusing on the human being interface based on certain physical environmental comfort which would be defined by the passive and active energy system of a building.

Impacts to usability

A series of studies on the theoretical frame and practical cases state that four impacts should be taken into consideration when referring to the usability of a building is [8]: special context [6], cultural context [9], situated action[10] and user experience [6], which is shown in Figure 21. More specifically, these impacts include the following contents:

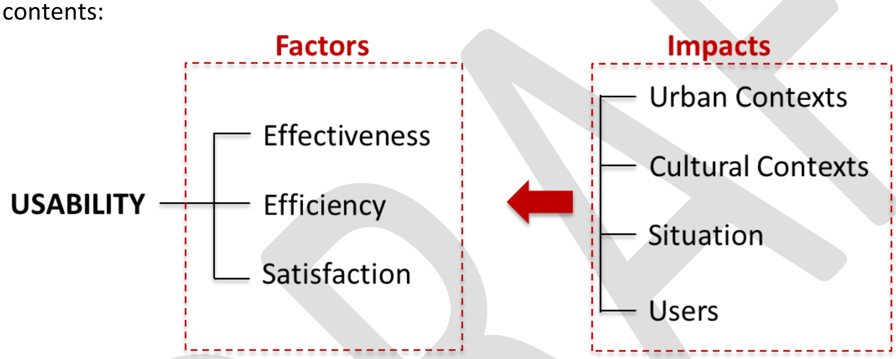


Figure 21: Factors and impacts of building usability

- Special context: understanding buildings as part of the urban fabric, creating physical infrastructure for the development of communities, and considering buildings in the urban context in terms of both region and ethnicity.[8]
- Cultural context: understanding activities with relation to specific collection of norms and values for user groups, and considering the specification in the built environment. [8]
- Situated action: understanding users' actions influenced by specific situations and circumstances, and considering user's specific requirements and needs in the peculiar circumstances, including specific physical environment of the built space. [8]
- User experience: understanding users' experience encompassing all interactions, and considering user-centered design as a design philosophy and process. [8]

One case study on the user-feedback system was implemented in 2010 evaluating the usability of the office building for the Department of Engineering and Building Technology at the Helsinki University. It demonstrated that different user groups in the building would assess the usability of the same building differently as it is shown in Figure 22. This result indicates deviations in user experience among various groups, and further endorses the statement that design based on users experience and taking their particular opinion can produce a better and positive design outcome and meet organization and users' goals[11][12], which is shown by Figure 23.

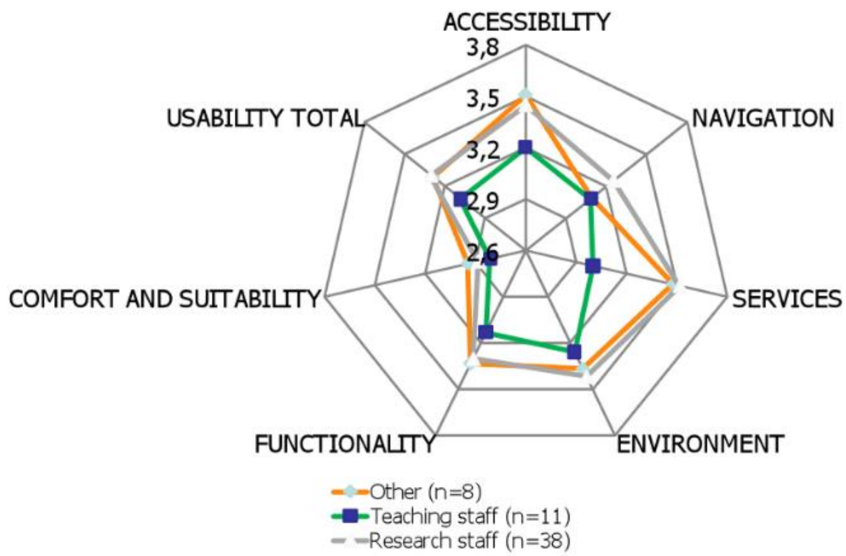


Figure 22: Comparison of the results of usability assessment feedback based on different groups in Helsinki University of technology

Figure 23: Strong link between building usability and users

4.2.2. Flexibility

General definition of flexibility

The appearance of the term flexibility in building can be tracked back to the beginning of the twentieth century, when a group of architects began to study and experiment the functionality of dwelling buildings with small areas after the First World War. They intended to provide as many functions as possible to buildings, primarily dwelling buildings, to realize the long-term efficiency in the daily use within limited building areas. The theoretical and technical backgrounds are the variation of space use pattern in different periods of time, and the separation of building components according to their roles in the building structure, i.e. load-bearing or non-load-bearing [13]. An early description given by Nabeel Hamdi [14], considered two major aspects of building flexibility, architectural design and construction:

- In regard to architectural design, flexibility describes the capacity, designed for buildings, building programs or building technologies, to ensure an initial good fit and enable the buildings or technology to respond to subsequent change.
- In regard to construction, flexibility expresses freedom to choose among options or devise programs that fit individual needs and aspirations, whether for building, finance, ownership, or management.

Based on the current major literature sources and questionnaire feedback from architects, Stephen Kendall integrates the definition of building flexibility as a kind of capability that a building is able to adapt to different requirements from both the external environment and users over time. In other words, a building with flexibility suggests openness to variety and changes to improve the usability of the building over time [15]. This includes the possible changes of a building in the perspectives of:

- Indoor space dimension
- Functional transformation
- Use pattern changes
- Building components renew
- Building volume changes

Approaches to building flexibility

A number of more specific strategies can be summarized from the cases adopted from certain significant studies and relevant research on the topic as well as the study conducted by Schneider and Till[13]. These include 116 cases (see the Annex) from 1965 till now with various types, the majority of which are residential buildings in Europe. The criteria of the selection are:

- Realized projects, excluding those simulated cases for study or architectural design competition;
- Projects completed in the last 50 years, as the recognition and study on the necessity of building flexibility appeared systematically around 1965.
- Information availability of projects.

Generally speaking, the strategies for building flexibility from these cases can be summarized as:

- Foldable component: components or products that can be folded or unfolded in the use phase, such as foldable furniture.
- Movable component: components or products that can be moved easily in the use phase, such as sliding walls. The components can be either within the built space or on the external surface of the building.
- Detachable component: components or products that can be removed or installed easily in the use phase.
- Modularized component: components or products that are modularly manufactured which can be decided and changed from one another.
- Polyvalent/multifunctional room: a single enclosed completed space by internal or external walls without identified function, which can support more than one functions or using purposes decided by users without any physical change. By this mean, the layout of the building floor is almost fixed, and the flexibility can only be realized by changing the particular function of the room.

- Multi-access room: a group of enclosed built space by internal or external walls with more than one access that can be opened or closed according to the layout of the space which could be decided according to the users. By this mean, the layout the building floor would be determined partly based on the needs of the space, and the flexibility can be realized by arranging the connection between the rooms.
- Open space with fixed facilities: an open built surface or area with all the utilities, such as vertical shafts, toilets, kitchens or other relevant appliances, fixed at one area of the surface. The layout and the functions of this surface would be decided by users later. By this mean, the flexibility can be realized by the particular design on the layout of the open space with specific requirements and equipment.
- Open space with zones: an open built surface or area with a certain zone for the installation of facilities and utilities. The location of the facilities and utilities can be determined within the zone along with the layout of the space by users. By this mean, the flexibility can be realized with even more freedom.
- Space extension reservation: reserving certain space volume as buffer in one completed building for the future extension when it is needed. By this mean, the flexibility can be realized by enlarging the built surface.
- Space modularization: a built space cell with integrated function and related techniques or equipment. The cell is allowed to be plugged into the existing structure or building when it is needed to support some other function required by the users. By this mean, the flexibility can be realized by the connection of the space cells with varied numbers of the cells.

These strategies for building flexibility were carried out in the existing cases by various techniques or methods in accordance with the particular situation of the projects in terms of construction schedule, budget, and human sources. For instance, the design of the open space can be completed by customized internal building design as NEXT 21 Complex in Japan (Case 47) as Figure 24, by providing options on the space layout as Arabianranta Project in Finland in Figure 25(Case 101), or even by users' self-building as Wohnregal in Germany as Figure 26(Case 60). On the other hand, these approaches and their means are usually combined in one single projects. Table 4below shows the application of the strategies in the adopted cases.

Figure 24: NEXT 21 Complex, Japan, 1994

Figure 25: Arabianranta Project in Finland. Source: http://infillsystemsus.com/open-building-projects

Figure 26: Wohnregal in Germany. Source: http://www.baunetz.de/meldungen/Meldungen-Zum_Tod_von_Peter_Stuerzebecher_2489451.html

Building flexibility strategies	Cases
Foldable components	41, 87, 92, 94, 95
Movable components	21, 39, 41, 42, 53, 87, 89, 94, 95, 96, 97
Detachable components	13, 18, 21, 22, 30, 35, 40, 43, 52
Component modularization	6, 12, 19, 22, 25, 54, 57, 60, 70, 75, 79, 81, 90, 112
Polyvalent/multifunctional room	7, 9, 18, 32, 50, 55, 66, 89, 92, 105, 110, 114
Multi-access room	1, 5, 8, 10, 14, 15, 18, 27, 46, 48, 49, 50, 51, 59, 63, 67, 68, 69, 80, 86, 98, 102, 105, 109, 113,
Open space with fixed facilities	2, 4, 11, 17, 19, 20, 21, 24, 28, 29, 30, 34, 37, 38, 40, 44, 47, 56, 58, 62, 67, 73, 74, 77, 83, 84, 85, 99, 100, 101, 103, 106, 107, 108, 109, 112, 115
Open space with zones	3, 7, 11, 15, 16, 22, 26, 31, 45, 46, 50, 51, 52, 55, 61, 64, 65, 68, 71, 72, 75, 76, 78, 81, 88, 89, 90, 91, 93, 102, 104, 110, 111, 113, 114, 116
Space modularization	5, 14, 21, 23, 33, 36, 79
Space extension reservation	81, 82

Table 4: Flexibility strategies and application in cases

According to the information on flexible houses and building projects, realized or not, around the world in the last century, Tatjana Schneider and Jeremy Till [13] use two simply word to describe the classification of the strategies for building flexibility as:

- Hardness: providing designated changeable or movable components, products, or technology as a part of a completed building for the possibility in the future; and
- Softness: reserving or allowing certain indeterminacy in design and construction waiting for more precise information in the future.

Coincidently, from the standpoint of project management, Nile O.E.Olsson also proposes that building flexibility can be achieved through along with these two directions theoretically [16]:

- Considering buildings as completed products and providing possibility for physical changes, including components changes, functional changes and building volume changes.
- Considering buildings as processes and providing possibility to locking into the decision-making process, according to the availability of information.

These can be explained as physical assemblage of maximum techniques and building lifecycle separation respectively. Hereby, following these two idea, the above major strategies are mentioned specifically as it is shown in Table 5:

<table>
<tr><th>Way</th><th>Major strategy</th><th>Description</th></tr>
<tr><td rowspan="3">Physical assemblage of maximum techniques</td><td>Foldable components</td><td rowspan="3">Providing designated technology or products for future possibility of use</td></tr>
<tr><td>Movable components</td></tr>
<tr><td>Detachable components</td></tr>
<tr><td rowspan="7">Lifecycle separation</td><td>Polyvalent/multifunctional room</td><td rowspan="5">Dividing the project into two or more steps, designing and building step by step according to the availability of information.</td></tr>
<tr><td>Multi-access room</td></tr>
<tr><td>Open space with fixed facilities</td></tr>
<tr><td>Open space with zones</td></tr>
<tr><td>Space extension reservation</td></tr>
<tr><td>Component modularization</td><td rowspan="2">Plugging in necessary functional products with independence</td></tr>
<tr><td>Space modularization</td></tr>
</table>

Table 5: Classification of major strategies for building flexibility

4.2.3. Usability-Flexibility tradeoff

In this section, the relationship between usability and flexibility is going to be addressed in order to explain the reason why building flexibility is needed to improve the usability of buildings. This is going to be conducted by discussion on the performance and lifespan of buildings, as well as the description of certain flexible building cases. The discussion on the lifespan and performance of buildings relates to the question of whether or not it is necessary to consider flexibility in the project, while the studied cases intends to show what scheme of building flexibility can be applied in the smart living lab based on our own objectives for the project.

Lifespan of buildings

The life span of a building is an important factor for discussing whether or not flexibility is necessary in the field of building and construction. Certain relevant studies have been found around the world.

The study on the building and infrastructure stock in China mentions that although the lifespan of the existing Chinese building stock is comparatively shorter than that in the European countries because of the high new construction rate resulted from quick urbanization and materials, the assumed standard service life time of massive buildings is generally 50 years [17]. In the US, the statistical analysis of the residential building lifetime seems to suggest that the average building life time is 61 years and a linearly increasing trend can be discovered [18].

The report presenting the economic and social value of the construction in the United Kingdom uses three factors, i.e. the total dwelling building stock, the growth rate of total dwelling building stock, and the demolishment rate of the total dwelling building stock, to analyze the longevity of the housings in England. Their study suggests the increasing tendency of average service life time in the dwelling building section from 46 years to 53 years, and the replacement rate is 133 years [19]. This study also states that the estimated replacement rate of building stock in the US and France is respectively78 years and 103 years [19].

There is also a study on the current building stock in the Switzerland based on official records. The estimated lifespan of the current buildings and relevant information are demonstrated as Table 6 below[20] :

Evaluation	Age (years)
Average age of the current buildings *Regarding to the cumulative construction proportion of each year, how old the buildings were from the media construction year to 2000. The media construction year refers to the year that half of the existing building stocks have been completed.*	47
Estimated average age of the current buildings *The average age of the current buildings based on the hypothesis that Switzerland would remain 40,000 historical buildings constructed before 1919.*	52
Estimated lifespan of the current building via the estimated average age *The estimated lifespan based on the hypothesis that the number of building, the construction and demolition rate of building remain constantly.*	>>104
Average age of the current residential buildings	42
Replacement rate of the building stock *How long each building has to last if each new building replaces a unit of existing building stock without any growth in demands*	94
Survival rate in 2000 of existing homes built in 1919 *The estimated reminded houses rate to the whole dwelling stock based on the hypothesis that the rate of demolition were the same before and after 1980, and each house built before or around 1919 was occupied by a single household.*	73 to 80%

Median life span of existing residential buildings built in 1919 *The estimated lifespan of residential buildings built in 1919 based on the assumption of the survival rate, replacement rate and estimated mean age of building as 40 years.*	>>121

Table 6: Estimated lifespan of buildings in Switzerland [20]

Most of these above mentioned studies on the estimated lifespan of the current building stocks, especially residential buildings suggest the slightly increasing trend of the service life time of buildings in the last century. However, how this trend is going to be developed is much more difficult to be detected as Mequignon [21] concludes in his study that a number of factors can alter this trend dramatically, such as final user behaviour, demographics situation, regulation or policies, quality of construction, and development of new technologies in both construction and materials [22][18].

Advantage and disadvantage of building flexibility

Besides the studies on the building lifespan, another question was risen according to the development of the understanding on the building life cycle performance, which can be illustrated as Figure 27 below

Figure 27: Relations between building process and the development of contexts and user requirements

In the conventional building process, the design and construction are conducted based on the understanding of certain contexts and user requirements. With the completion of the design and construction process, the building is manufactured as a static product without any possibility on future evolution. However, the contexts and user requirement remain constantly changing and development without stop. Hereby, a gap between the static building product and the dynamic changing progress of contexts appears.

The study on the life-cycle performance cited by ISO 15686 [23] (Figure 28) demonstrates that on the one hand the requirements from the users of a construction would change or increase through the use of the building because of the development of technology and society; on the other hand, due to the wear and tear of the materials and components, or even simple aging issue, the performance of the construction would decrease during the operation. Some actions have to be taken as maintaining, correcting or upgrading to the construction and its components in order to keep up the building performance at a required level[23]. This study indicate that during the lifecycle of a building, changes of two aspects have to be taken into account in the life cycle:

- Physical changes on the building elements and components, and
- Requirement changes based on the needs of the user

Certain arguments are also proposed on balancing expectancy of building lifetime, lifecycle performance, building energy consumption, and environmental impact. Aktas argues that building structures lasting for a long time might be not the best solution to the building environmental impact, as those buildings could not match trends in the use of knowledge and technology that would be better to replace by newer designs that suit the future needs of occupants[18]. At the end, the study points out that in reality, the lifespan of a building is an elusive characteristic which is not able to be foreseen precisely. Based on the research, it is often obsolescence determined by social or economic values rather than structural problems that leads to the demolition of the building [18][24][22], while providing flexibility in the design and construction can to some extern delay the obsolescence process in the building.

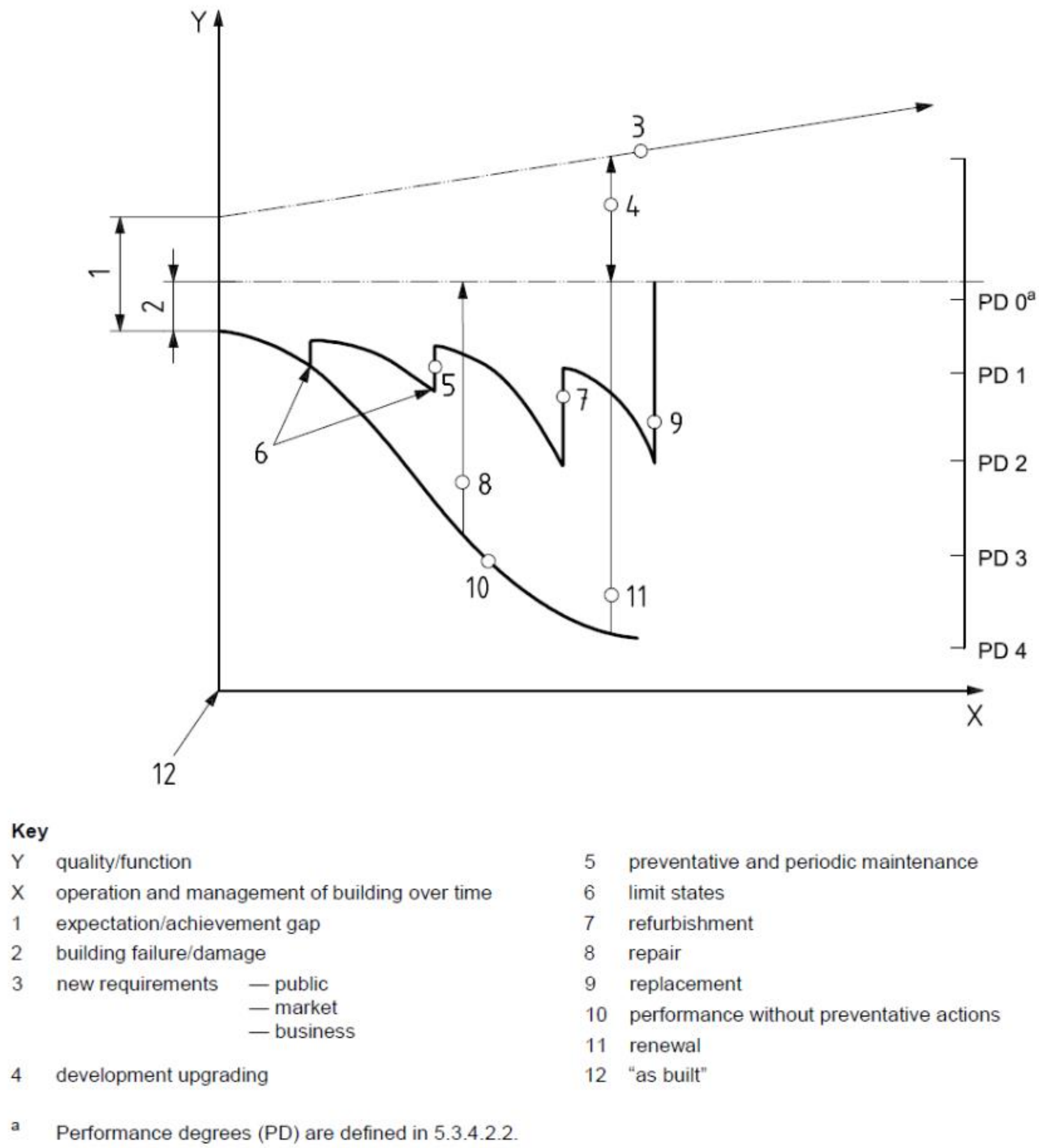


Figure 28: Building lifecycle performance illustration by ISO 15686-7

By considering change as the norm of the world, Olsson points out that it is necessary to have the so-called "room to manœuvre" in construction projects for both project owners and final users to be able to adjust projects following their needs in certain particular context [16]. A number of research shows that flexibility is necessary to face the changes and the challenge of uncertainty from either users or the environment [13][25][26][15][27]. Olsson further states that flexibility is primarily an approach to improve effectiveness of projects rather than efficiency, and a project with sufficient flexibility to utilize opportunities to increase the value for owners and users might, in the end, prove to be more effective [16].

But the other side of the coin is that, some studies also point out that the drawback of flexibility is less efficient than inflexible buildings in the aspects of design, construction and even use, with the costs in terms of complexity, time and money [28][29]. Aiming at the uncertainty of the user anticipation and future situation, flexibility would anyway experience the shift to the specialization along with pictures of user needs becoming more and more clear, which process is observed in all systems [28]. These idea imply that due to the long lifecycle of buildings, the outcomes or benefits of flexibility in building only appear periodically when changes or uncertainty rise, and as soon as these changes or uncertainty are fixed, the advantage of the flexibility would vanish and would be replaced by stable use. This also explains the reason why most of the so-called flexible buildings have not presented any change in the use phase without any external force.

Take some cases for instance. Jia's Flat in Hong Kong as Figure 29 (Case 97) was designed with the intention of creating a dynamic living environment for the family with a new born baby. With a group of movable panels, this idea worked well at the first decades, while as the baby growing up, the flat turned to be more and more stable without any changes in the last 10 years. Another typical case is the Micro Apartment in Hong Kong in Figure 30(Case 94), which was designed to assemble most possible living and recreation functions in a 32 square meter flat by foldable and movable furniture and construction products. However, behind this great concept is the truths that the owner spent much more money on installing these products than buying the flat and he used the flat as showroom rather than his home.

Figure 29: Jia's Flat in Hong Kong [30]

Figure 30: Hong Kong Micro Apartment

Being interpreted in the terms of building energy consumption and environmental impact, the efficiency of these sort of technology for building flexibility is comparatively low. A large amount of construction materials or products used in the construction phase caused higher environmental impact than an average, which might be used only once or twice in the entire building life cycle. Whether or not this is an environmentally friendly way of design or construction is the question that should be taken into consideration. By understanding this, it doesn't seem necessary to provide as much flexible technology as possible to the building at the beginning for a future possibility. It would be better to provide possibility of change throughout the entire lifecycle of the building according to the real needs of users, which, in other words, is to provide right components or equipment at the right time.

4.2.4. Summary

This section aims to identify the concept of usability and flexibility for the smart living lab through the literature review on the general idea and relevant practices of both terms. The review on the usability shows that it is a contextual concept while the evaluation of the building usability is strongly linked to the specific experience of final users. This suggests that the definition of usability for the project should be based on the understanding of the users' particular experiences including behavior and needs.

The review on the flexibility and related cases presents the general concept of building flexibility and the major approaches to realize flexibility. The research on the estimated lifespan of the current buildings and life-cycle performance suggests the necessity of introducing the idea of flexibility to the entire building lifecycle. The arguments on the drawback of the flexibility indicate that the definition of flexibility for the smart living lab is to provide right components and equipment at appropriate time according to the information. This definition is described as a way of making irreversible decision more reversible or postponing uncertain decisions until more information can be used to support the decision-making [16].

This definition leads to the method to achieve the flexibility as follows:

- Regarding the building lifecycle: What is the right time to fix the design of each component and how is it possible to postpone decision-making?
- Regarding the building component: What are the right components or equipment and facilities in the building?

4.3. Method for flexibility: Step-by-step procedure

This section is going to describe the method for realizing building flexibility, and to answer such questions as what is the right time to provide the right components or equipment.

4.3.1. Background on building lifecycle and lifespan of components

The above literature indicates the strong connections between users' needs and building performance during the entire lifecycle, which offers a hint that the decision-making on the design and installation of the components or equipment should respectively correspond to the availability of user knowledge. Therefore, the availability of information on users becomes the key of the above questions. In order to apply this parameter, it is necessary to take one step back to understand the importance of information and changes in the conventional building courses.

Cost-change-information relationship in building lifecycle

The importance of the concurrency of information and knowledge in design process has been recognized by practitioners and researchers from different design disciplines, which is considered as one of the fundamental conditions for developing better products [31].

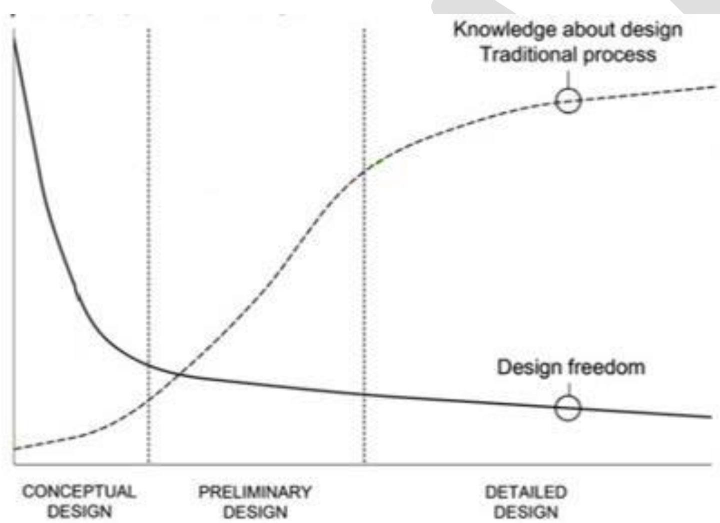


Figure 31: Knowledge-design relation in construction [31]

On the one hand, as it is illustrated by Figure 31and based on Fabrycky's lifecycle cost analysis [32], the information and knowledge about design is constantly increasing when the design is processing, while the freedom of design is decreasing. This suggests that: as more and more information and knowledge relevant to design is exposed, the design would be more and more specified and fixed.

On the other hand, Patrick Macleamy's effort curve for the building lifecycle Figure 32 demonstrates the conventional building courses. As it is shown by the figure, along with the development of building design going, the difficulty of making changes on the construction cost and final building performance would increase. In the meantime the costs for any changes in terms of money, time and human labor resource would also increase dramatically, especially in the construction and operation phases. However, most of the workload is concentrated in the phase of construction documentation, comparatively less efforts are distributed to the early design and later operation phases.

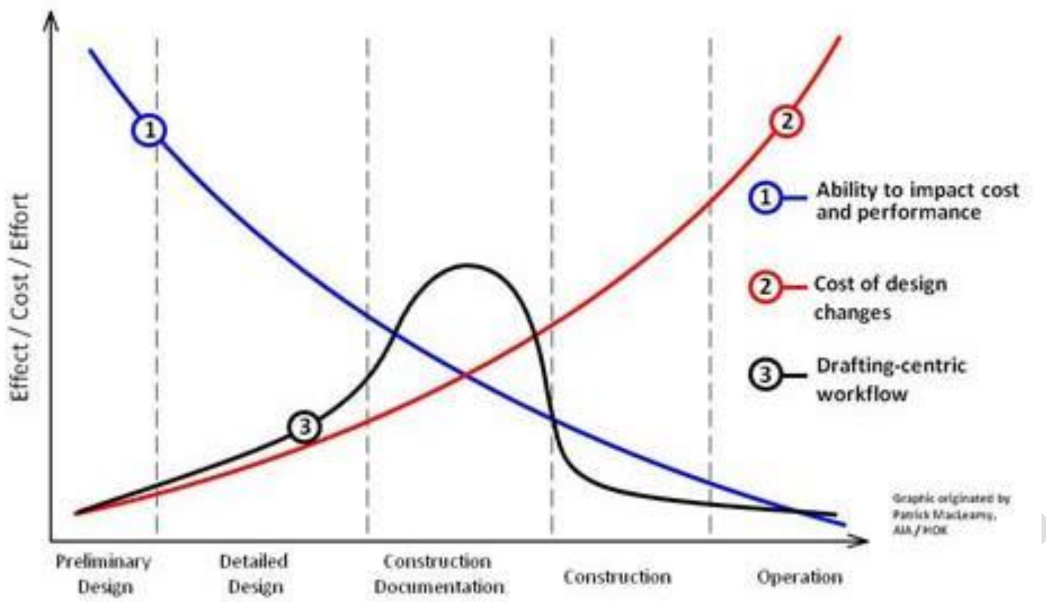


Figure 32. Patrick Macleamy's effort curve for the building lifecycle

Macleamy's theory has been proved by Dvir and Lechler [33] through a study on 448 real projects. This increase of change cost over time is widely accepted as a rule of thumb, and is a major challenge to project. Once a project has been decided upon and the planning or execution has begun, changes are likely to reduce the efficiency of the project [31]. However, confronting a changing world, it is known to all that changes cannot be avoided, but can be reduced in terms of extra costs and negative impacts on the building projects, which is considered as the key purpose of the flexibility strategy [16].

Combining the above two background theories, the correlation between information or knowledge, changes, and costs is clear in the construction courses. The more the information and knowledge flows into the project, the less the uncertainty the project would have to deal with, and the less changes the project would take. This suggests that the entire project of the smart living lab should be divided into several parts in accordance with the available information. The first part named as the Project A can be designed and built according to the fixed information of the contexts, and the second or even later parts named as the Project B or C, D would be decided and built step by step when more user information or knowledge is available. This step-by-step process is illustrated as Figure 33 below.However, considering the complication of a construction project and the risk of uncertainty in the future, the project would be divided into 2 parts preliminarily.

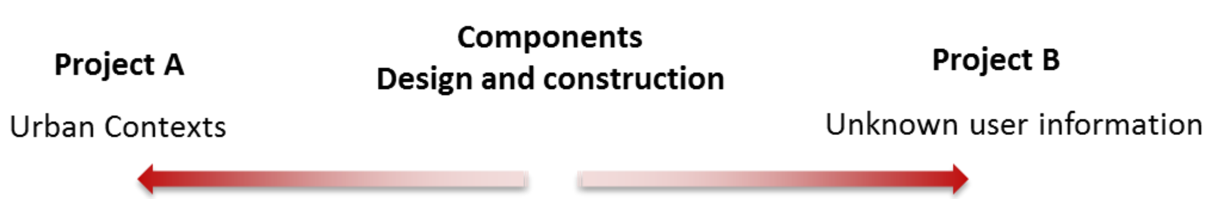


Figure 33: Concept of classification of project

Lifespan of construction components

Being composed by different materials and functioning differently, construction components' lifespan vary a lot. Figure 34 shows the variation of building components in dwelling buildings [34]. It demonstrates that there are big differences among the lifespan of construction components from 100 years to no more than 5 years. This indicates that during the lifecycle of a dwelling building, some components and equipment would be changed more frequently than others, and the components such as external wall structure, the structural framework and the slabs might be able to last without any changes within the entire life cycle of the building. The physical lifespan of components and equipment varies a lot according to the materials. Hereby, an average value is used in this figure representative of one component with various materials.

These data are taken from a study completed by the National Association of House Builders and Bank of America Home Equity in 2007 in the US. The research group took one year collecting information from users, component producers and dealers. The catalogue of the data covers the components and products from building structure elements to the daily appliances and necessities with different materials. The study also emphasized during the information collection that building component lifespan is highly impacted by a number of factors, including the quality of installation, levels of maintenance, climate and weather condition, and the intensity of use. Therefore, the physical lifespan of each component or equipment is used. Certain relevant or similar information were also presented in some European studies [35][36]. These studies deeply analyze the life-cycle environmental impact of certain construction components; however, they only focused on certain or particular components. The environmental impacts of certain materials are also listed in certain European norms, while there lack the relative data for the whole set of construction components. Therefore, the data from the National Association of House Builders is selected here, and with the completion of the information on the construction components in Europe, this figure may be revised.

This study refers that the lifespan of components or construction products should be considered in two aspects: the physical lifespan as the natural duration of components without any external influence which is determined completely by materials and manufacture; and the expected lifespan as the real duration of components in reality which is strongly impacted by the situation of users, environment, maintenance, etc. It suggests the hint that the expected lifespan of components would be linked to the information and knowledge of users. The study also demonstrates that, if we take account about renewal, upgrade or even functional changes of a building in the future, it would be wise to keep the components with longer expected lifespan independent from the ones with comparatively shorter expected lifespan. By doing so, the negative influence to the longer lifespan components would be reduced.

Being back to the smart living lab project, the above understanding on the project processes and construction components lead to two questions that closely related to the realization of the building flexibility, which are:

- How can we divide the construction process based on the availability of information?
- How can we group the construction components into Project A and Project B respectively?

These two questions are based on the hypothesis that:

- There is correlation between user and real lifespan of building components.
- There is correlation between lifespan of building components and their environmental impacts.

There is one more question that would interest the research project but benefit the environmental impact. It is that whether or not we are able to establish connection between user needs and excepted component lifespan in the entire building lifespan. Take an internal door as an example. The data of the physical lifespan of the components from the above US study show the average physical duration of internal doors can be as long as 50 years. However, as the internal doors would be changed in accordance with the shifts of space functions, e.g. doors for laboratories may probably different from the ones for normal office space, therewith, the real lifespan of these internal doors are determined by the users rather than their own materials. This kind of influence from the users to the components or construction products might exist in most components, and is assumed to be related to the interaction between users and the components.

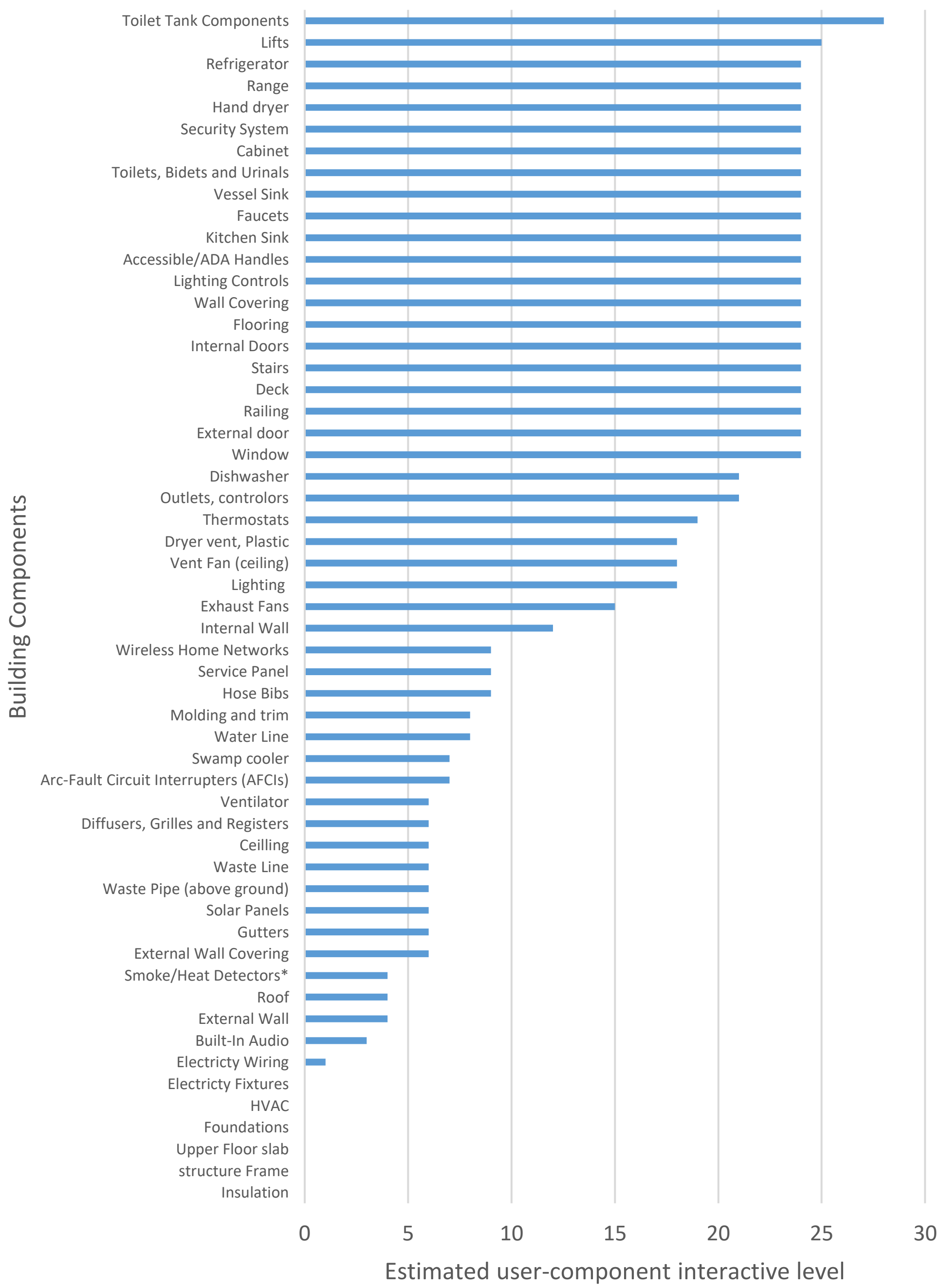


Figure 34:Estimated expected lifespan of housing components

Current application on construction separation process

The applications of the construction process separation can be found in the last half century, including certain practices on some modern architecture concept.

One concept was Archigram group and their Plug-in-City Figure 35 [37]. The “city” was structured based on a mega steel framework, and a series of detachable living and working units that could be plugged into the framework when necessary. Building obsolescence was considered in the design concept that each space unit had its own lifespan and could be replaced and moved.

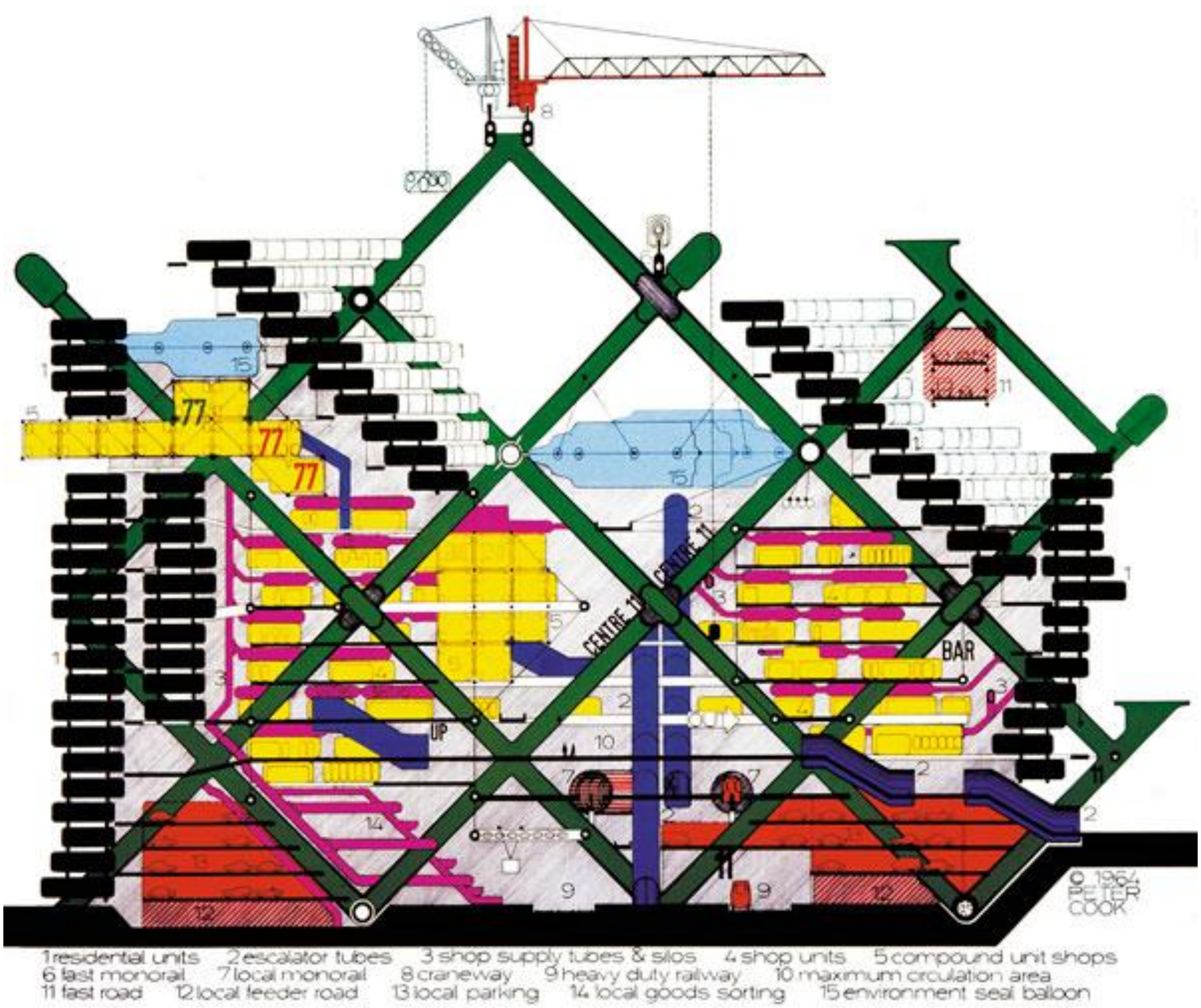


Figure 35: Archigram "Plug-in City" Source: https://va312ozgunkilic.wordpress.com/2010/12/07/archigram-plug-in-city/

Another concept was Japanese Metabolism Architecture [38]. The idea was, in general, to let the area or building “grow” along the designed infrastructure by adding, replacing and changing functional space units without major disturbance on the infrastructure [39]. Different from Archigram, certain practices were taken based on the concept of Metabolism, including the Richards Medical Research Laboratories in Philadelphia designed by Louis Kahn [40], Marina City in Chicago US, and Nakagin Capsule Tower in Japan [41] in Figure 36.

Figure 36: Richard Medical reseawrch Laboratories, Marina City and Nakagin Capsule Tower

The similarity between Archigram group and Metabolism is that the whole project was carried out in two steps: the completion of the main infrastructure including structural frame, vertical circulation space and shafts, as the first step, and the complementation of the specific functional space units onto the infrastructure as the second step. The functional space units were independent from each other and can be connected or detached from the infrastructure.

Another large group of practices on the construction separation process in the last 50 years around the world are based on the concept of "Support-Infill" proposed by John Habraken [27]. This theory separates the space form urban scale to the scale of rooms into a series of hierarchic levels by the parameter of who would and should control which space. Based on this control level, the lifespan of the construction components are suggested to be from more than 100 years to less than 20 years respectively. The theory believes that the lower the control level, the more the individual users can make decisions on it, and the more frequently the layer would be changed in the user phase. 67 practical projects were collected[27], and the collection has been growing by the cases such as NEXT 21 Residential Complex by Osaka Gas, Japan[42], Maya Rise Residential Building in China [43], E-Science Lab for ETH Zurich [44], and INO Hospital in Bern [45], etc. Those cases exhibit the designated hierarchy of components in the construction by either the control of final users or the lifespan of the components. With the progressing of the project and the involvement of the users, the construction evolved from an abstract profile to a completed building with specific functions serving particular groups of people.

The above practices process seem to suggest that:

- The separation in the construction process usually appears between buildings' infrastructure and specific functions, the former of which might be fixed, while the latter may be decided and built in later as it depends on the particular needs or requirements of specific users.
- There are two major ways to specify building usage and function following the particular needs of final uses, one is based on the space unit and the other on the hierarchy of the components.

4.3.2. Separation of construction process for the smart living lab

The drivers to divide construction process

The theoretical background of the construction process separation and its application indicated that the question of how to separate the construction process may be transformed to be based on the available information: which part of the building would be the "infrastructure", and which part would be with the specific functions? The key to the questions is the knowledge of users. This means whether or not the design of the components needs the information of users would be used to classify the component of the building.

Meanwhile, as the progress towards convergence observed in both natural and man-made system indicates the increase of stability of both form and function [28], the degree of universality of the functional space units would imply the potential and degree of changes occurring to the functional space units. Functional space units and their characteristics would be used to demonstrate their universality in different types of buildings, and would also be used to establish space family as well. This introduces two drivers as user-component closeness relations and the characteristics of the space units for splitting up the building components and space units respectively, which can lead to the following three aspects:

- The layers of building components to the users;
- The universality of the functional space units in different type of buildings;
- The family of functional space units.

Building layers and the interactive levels between construction components and users

The building component-user interaction level was firstly discussed by John Habraken as the control levels coordinating with the Support-Infill system. This theory has been implemented in many projects as a precondition or hypothesis within a number of projects, especially residential building Figure 37.

This figure shows that with the space levels going down from the urban scale to the particular detailed plan of room, the scale of parties involved in the levels varies from a group of people to an occupant household and finally to the individual occupant, and the individual capability of controlling the space increases. However, this controlling-controlled relationship and its connection to the lifespan building or space stayed at the theoretical phrase without scientific proof or practical verification, the linkage between users and buildings has actually never been clarified.

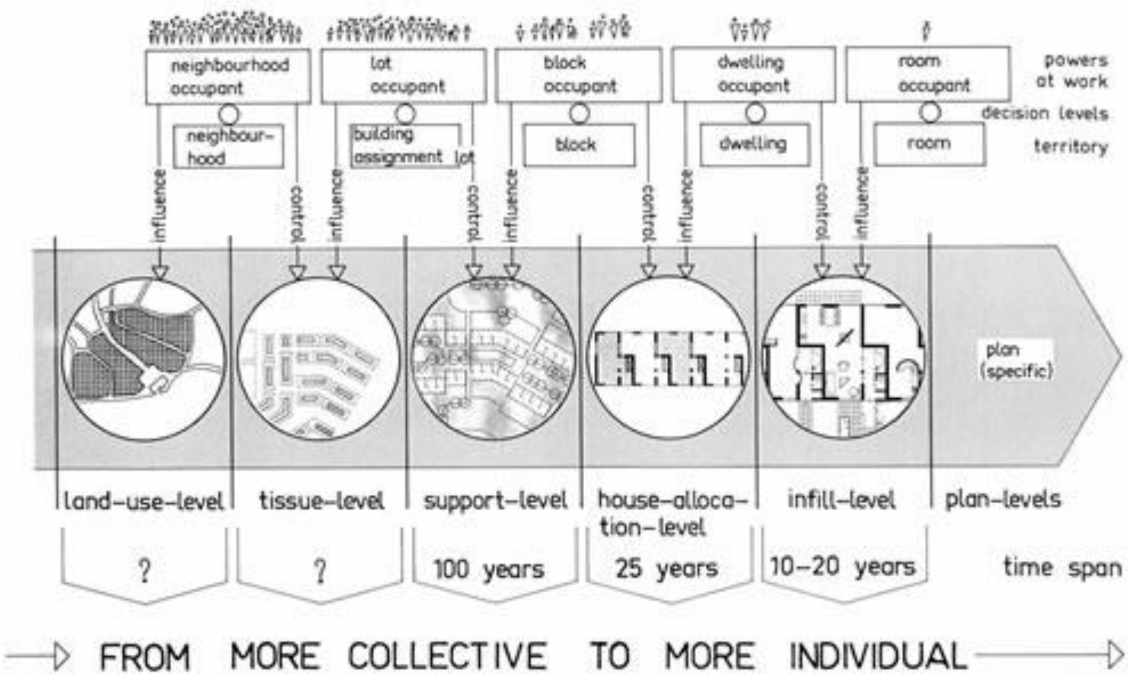


Figure 37. Control levels in Open Building theory [27]

This theory is then developed and specified by identifying the physical layers. Stewart Brand proposed in 1994 his shearing layers diagram which consisted of a hierarchical system of layers and components with different life cycle and speed of changes (Figure 38), which could be described with more details as permanent site, structure, skin, services, space plan and the stuff [46]. Brand's intuition came from his observation on the traditional buildings and their transformation process, and the parameter of his classification is the lifespan of each components or products. This idea split up the layers from building to room, and believed that the short lifespan layers, i.e. services, should not be obstructed by the ones with longer lifespan, i.e. structure [47]. Confusion has definitely brought forward some questions, for instance, can the lifespan of a component or product determine the layer that the component belongs to? Which kind of lifespan should be consider here? And by who is the lifespan of a component defined?

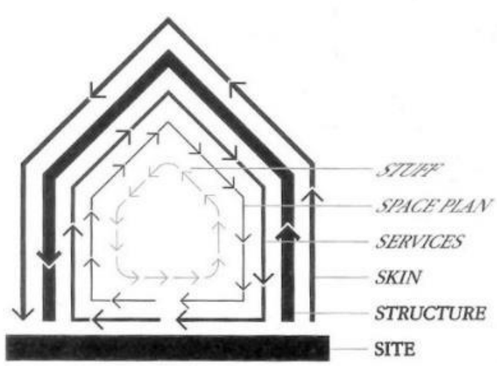


Figure 38. Shearing layers diagram by Stewart Brand, 1994

How to identify the interrelations between construction components and users is the question that needs to be answered here. These interrelations refer not only to the physical distances, but also to the interactive levels between the users and components, i.e. the mutual impacts between user and components, such as visual or physical touch, use or operation, and the ability of change and move, etc. A ranking system would need to measure all this mutual impact for identifying the real interactive levels between the components and users. A draft example is given as Table 7 below. The table considers both types of interactions between components and users, and the frequency of this interaction. Hierarchic weights are also given to each type of interactions to emphasize the differences among the interactions and their influence on the final closeness level. The frequency can also be presented as the times per period of time. This system would be developed in the next phase of the project, and appear as one part of survey in the social study to the target group of the smart living lab, i.e. researchers, professors, and students.

	Never 0	Seldom 1	Few 2	Many times 3	Frequent 4	Weight
See						1
Touch						2
Use or operation						3
Move or change						4
Total						

Table 7: Example of ranking system on the interactive levels between users and components

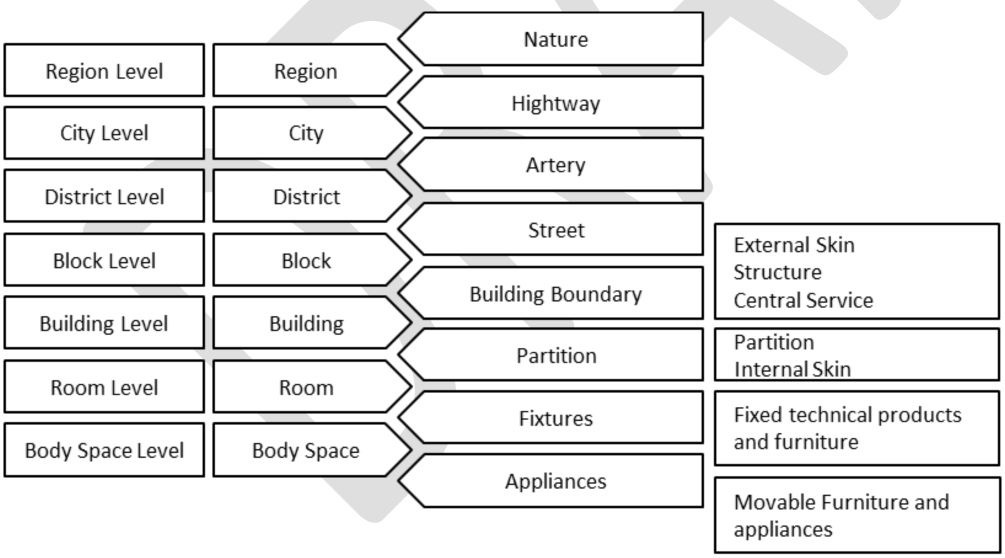


Figure 39. Building layers by Wang, 2000

However, for the moment, this interactive level can only be simplified to the building-user physical layers in terms of physical distance, which is developed based on the "Support-Infill" concept to the physical boundaries and the physical distance from building users to building components of the space levels by Wang [48] as shown in the Figure 39. This simplification is based on the assumption that the physical distance from components to users can positively affect the mutual impact between components and users; or in other words, the farther the component is physically away from the users, the less the mutual impact exists, and therefore the looser the connection between the components and users. Regarding this building layers by physical distance, it is suggested that the farthest layers belonging to the building boundary such as external skin, structure, central service should be grouped as the infrastructure which can be fixed by the knowledge of contexts, while the other four layers would be designed separately as the second step following the information of users and particular situations. On the other hand, a social survey is going to be conducted for this component-user interactive level ranking system as a part of the smart living lab research project. As soon as the information is collected, certain analysis will be implemented to discuss the difference between the real user components interaction levels and physical distance, so that the group of the construction components for both the primary building and the secondary building would be improved.

Universality of functional space units

The second aspect is the universality in different types of buildings. Regarding current use situation of the smart living lab, the building is designated as mixed-use, functioning as office, laboratory, residence and school. The future development of the building might take place by changing the proportion of the space occupancy among each function. Taking the extreme situation into the consideration, the foreseen transformation of the smart living lab in the future would become one building with the type among office building, educational building, laboratory building, residential building or dormitory building. The potential functional space units that might be involved in any of the five types of buildings are listed together based on the requirements on the ISO standards and certain practical projects. In order to figure out which are the most universal space units, a simply statistic method is conducted as presented in Table 8 below. The possible involvement of one functional space unit in one type of building is given 1 point, and the space units with the highest points crossing the five building types would probably be the most universal ones in the building. In other words, the space units with the biggest value are the ones that no matter how the building would be transformed from one type to another, i.e. from an educational building to an office building, or from an office building to a residential building, etc., they would be needed in the building and might be kept without changes.

	Office Space	Standard Study Place	Training Room or Classroom	Meeting Room	Storage Space, Entrepot	Residential Space	Laboratory Space	Library	IT-Laboratory	IT-Support Centre, server room	Reprography or Digital Space	Circulation Space	Entrance Hall, Reception	Auditoria Hall	Exhibition Space	Recreation and Communication	Lounge Area	Dining space	Cooking Space in Dwelling	Cuisine area in Restaurant	WC	WC, Showering, Bath Space	Laundry, dryer space	Garage
Office	1			1	1					1		1	1	1	1	1	1				1			1
Education	1	1	1	1	1		1	1	1	1		1	1	1							1			
Lab	1	1	1	1	1		1	1	1	1	1	1	1	1	1	1	1			1	1	1		1
Residency					1	1						1	1					1	1		1	1	1	
Dormitory						1						1	1				1		1		1	1	1	
Total	3	2	2	3	4	2	2	3	2	3	1	5	5	3	2	2	3	1	2	1	5	3	2	2

Table 8: Example of common functional space units in different types of buildings

By doing so, there are three functional space units, circulation space, entrance hall and WC, appear as the most universal ones. This indicates that within the future development of the smart living lab, these three units would be more stable than the others, and can be suggested to be designed earlier as a part of the Project A.

Nevertheless, with the particular requirements and needs on the functions of the smart living lab, the functional space units would probably vary as well as the ones with the maximum universality value. This might increase the number of the units that can be designed as a part of the primary building.

Families of functional space units

The last but not the least aspect is the families of functional space units, the space unit group with similar or even same characteristics. Within one family the space units can be transformed one another relatively easier than those between two different space families, as the intra-family space transformation might need certain technical assistance.

As the following table shows, the possible functional space units and their special design requirements are listed here to identify the space families among them. The information of design requirements for each space units currently can only be got from certain norms including ISO/TR 11219:2012, AC D40-005: 2008-03, SIA 382 / 1:2014, SIA 2024, ISO 2051. In the Figure 40, the special requirements related to the construction components, such as the height of story, the strength of floor slab, the needs of water pipes, the installation of particular equipment or appliances, etc. are listed; other than the requirements that can be achieved by mechanical adjustment, such as indoor temperature, humidity, illumination, and ventilation etc., the design requirements for office space are used as reference to compare the differences of the other space units. Three situations are marked:

	Office Space	Standard Study Space	Training Room or Classroom	Meeting Room	Storage Space, Entrepot	Residential Space	Laboratory	Library	IT-Laboratory	IT-Support Centre, server room	Reprography or Digital Space	Circulation Space	Entrance Hall, Reception	Auditoria Hall	Exhibition Space	Recreation and Communication Space	Lounge Area	Dining space	Cooking Space in Dwelling	Cuisine area in Restaurant	WC	WC, Showering, Bath Space	Lanuary, dryer space	Garage
Large difference on Storey height								?	?	?	?	?	X	X	X	?	?	?						?
Live load difference								X	?	?	?	?	X	X	X									?
Water suppliment																X	X	X	X	X	X	X	X	
Special lighting														X	X									
Special acoustic insulation									X	X	X	?	X	X	X	X	X	X	?	X	X	X	X	X
Special consideration on ventilation and pollutions									X	X	X													X
Special Fixture: sanitary																			X	X	X	X	X	
Special Fixture: cooking																			X	X				
Special Fixture: computer related equipment									X	X	X													
Special electrical needs									X	X	X								X	X				

Figure 40: Special design requirements of each functional space unit and the families of space

- The spaces without any symbol represent the same or similar design requirements with the office space;
- The spaces with “X” represent very different or special requirements in the space design; and

- The spaces with "?" represent the lack of information in space design.

As the highlighted information in the table, the functional space units as office space, standard study space, training room or classroom, meeting room in office, storage space, residential space including living room and bedroom, and laboratory space are almost the same. Another space family includes WC, WC and bathroom and laundry space. Because of the lack of the information, the rest functional space units have the potential to be grouped as 5 space families, which are marked by the blue boxes with dashed line. These space families would probably vary as the special requirements for the smart living lab would provide in the design and construction process.

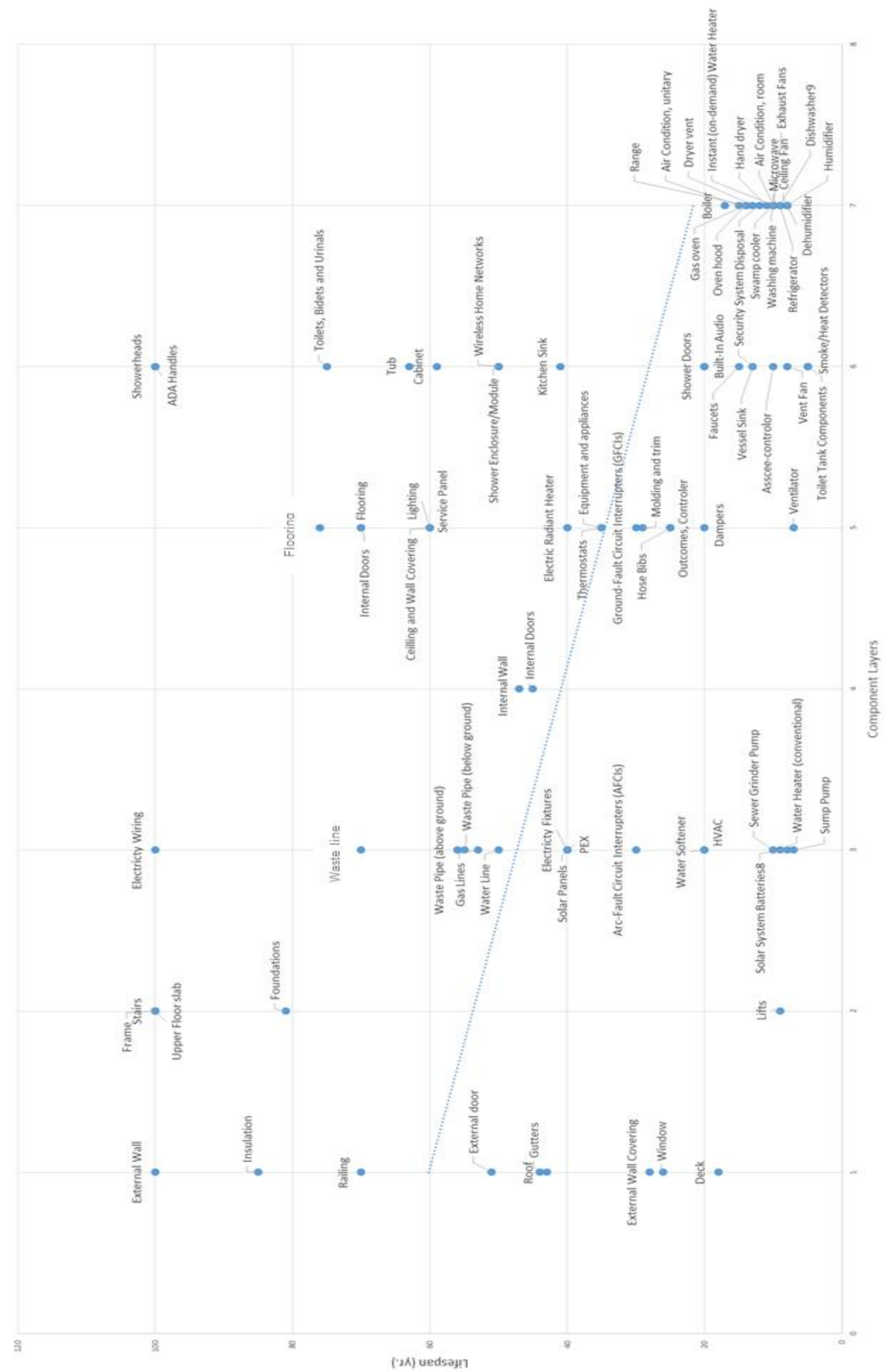
The existence of the space families suggests that at the early stage of design, with the uncertainties of the space occupancy proportion among functions, the building volume could be divided by space families horizontally or vertically. These space arrangement based on space families can to some extern reduce the complication of the space change in the future.

4.3.3. Implementation of component lifespan

The separation of construction process has also been implied based on the lifespan of construction components in certain practice, as it is understandable that the frequency of changes of the construction components are not the same or similar to one another. By splitting the components with longer lifespan from the ones with shorter lifespan and grouping the components with similar lifespan can to some externs reduce the negative influence when some changes of the components take place. This idea was used in the healthcare project INO Hospital of Bern, Switzerland, with the purpose of managing the cost of building within the entire lifecycle performance. The construction components were divided into 3 groups, namely as primary building, secondary building and tertiary building.

The question of whether or not there is a correlation between the lifespan and the building layers as it is mentioned above is going to be answered within the research project of the smart living lab. Figure 41 shows the combination of the information of physical lifespans of construction components and Component-user interactive levels. The component-user interactive levels are simplified to be the physical layers of building presented along the X axis from 1 to 7, standing for the 7 physical layers from buildings to the individual space, while the lifespan of each component is presented along the Y axis from 0 to 100 years. Each construction component is marked according to these two parameters. The tendency of the correlation between these two parameters is shown as the trend line in the figure. This indicates that the components with longer physical lifespan might be farther away from users than the ones with comparatively short lifespan in terms of physical distance. This correlations between physical lifespan of components and their interactive levels to users can be used to suggest the expected lifespan of the components finally used in the smart living lab, which can benefit the environmental impact and energy consumption of the smart living lab as a whole in the entire duration of life. The result of this implementation could be improved to reflect the real situation more precisely by the results from both, the interactive levels between users and construction components and the lifespan of the components, and installation technology in the region of Europe, both of which might be achieved in the scientific research part of the project.

Taking the lifecycle environmental impact of components and construction materials in to consideration, the answer to this question might be helpful in terms of component and technology selection in the smart living lab. The trend line of the correlation between component lifespan would be adjusted by the real user-component interactive levels and the component information in Europe. Based on the trend line, the materials of the components and the technique would be selected to be closer to the line so that the energy consumption on the construction would be optimized.



Lifespan (yr.)
Component Layers
External Wall
Insulation
Railing
External door
Roof
Gutters
External Wall Covering
Window
Deck
Frame
Stairs
Upper Floor slab
Foundations
Lifts
Electricty Wiring
Waste line
Waste Pipe (above ground)
Gas Lines
Waste Pipe (below ground)
Water Line
Electricty Fixtures
Solar Panels
PEX
Arc-Fault Circuit Interrupters (AFCIs)
Water Softener
HVAC
Solar System Batteries8
Sewer Grinder Pump
Water Heater (conventional)
Sump Pump
Internal Wall
Internal Doors
Flooring
Internal Doors
Ceilling and Wall Covering
Lighting
Service Panel
Electric Radiant Heater
Thermostats
Equipment and appliances
Ground-Fault Circuit Interrupters (GFCIs)
Hose Bibs
Molding and trim
Outcomes, Controler
Dampers
Ventilator
Showerheads
ADA Handles
Toilets, Bidets and Urinals
Tub
Cabinet
Shower Enclosure/Module
Wireless Home Networks
Kitchen Sink
Shower Doors
Faucets
Built-In Audio
Vessel Sink
Security System Disposal
Asscee-controlor
Vent Fan
Toilet Tank Components
Smoke/Heat Detectors
Gas oven
Boiler
Oven hood
Swamp cooler
Washing machine
Refrigerator
Dehumidifier
Range
Air Condition, unitary
Dryer vent
Instant (on-demand) Water Heater
Hand dryer
Air Condition, room
Microwave
Ceiling Fan
Exhaust Fans
Dishwasher9
Humidifier

Figure 41: Tendency between component lifespan and building layers

4.3.4. Summary: The separation of the primary building and the secondary building

This section demonstrates the methods to achieve flexibility in the smart living lab, to divide the construction process into two independent parts: Project A and Project B, according to the available information. The drivers for this division are the component-user interactive levels and the universality of the space units.

According to the current available information, the smart living lab can be preliminarily divided as follows:

- Project A would be suggested to the part which can be fixed by the contexts of urban and site.
- The functional space units as entrance hall, the circulation space and WC of the whole building can be designed first as a part of the primary building.
- The partition of the building volume might not follow the conventional matter by floors but by space families in either horizontal or vertical way.

Based on Project A, Project B would be design and construction strictly following the needs and requirements from the users. It could include the specific design of the floor plan and the arrangement of the internal partition walls, the layout of rooms, the technical services on the room levels, and some particular furniture and equipment as well.

4.4. General recommendation on building flexibility

The cases collected so far for the flexibility include more than 100 cases on the aspects of construction process separation [27], building flexibility [13], and some individual studies on particular cases. These cases coming from different parts of the world vary their strategies and methods based on their particular situation. These cases also cover certain types of buildings including residential building, education building, healthcare building, and mixed-use building as well. Certain general recommendation that can enhance building flexibility are summarized by the studies on the cases as it is shown in Table 9 below:

No.	Recommendation	Reference
1	Increasing the components belonging to the project B building	[49], [50], [15]
2	Increasing the independence among building layers	[51], [15]
3	Neutralizing the construction structure with simple and robust construction techniques	[51], [52], [15]
4	Increasing the usable building space or surface without columns	[51], [52]
5	Increasing the bearing capability of the structure components appropriately	[52], [15]
6	Increasing the independence of the internal walls	[49], [50], [52], [15]
7	Increasing the independence of the external skin from the building structure	[49], [50], [51], [15]
8	Increasing the independence of internal skin	[49], [50], [15]

9	Using equilateral and regular shape in building layout	[49], [50]
10	Increasing the possibility of independent use of the entrance by different user groups	[49], [50], [51], [52]
11	Using universal space dimension to layout or divide the surface of building floor	[49], [50], [51], [15]
12	Neutralizing space unit with multiple functions	[49], [50], [51]
13	Increasing the accessibility of the space unit from different directions	[49], [50]
14	Using smaller grid frame on the building facade	[49], [50]
15	Using more universal facility components rather than special ones	[49], [50]
16	Increasing the functions that the building can support	[49], [50], [51]
17	Increasing the possibility for measurement or control of the facilities on space unit level	[49], [50]
18	Increasing the ability to disconnect of facility components	[49], [50]
19	Increasing the accessibility of facility components	[49], [50]
20	Increasing the accessibility of the vertical service ducts	[51], [15]
21	Increasing story height appropriately for accommodation of service ducts	[52], [15]

Table 9: General recommendations on building felxibility design

4.5. Conclusion

The state of the art on the building flexibility is going to set up a methodology of design that can help the smart living lab project to realize the goals of high building performance in the entire life cycle and the best energy consumption solution in the lifecycle assessment point of view. .

First of all, according to the Kaya Equation, the main purpose of the flexibility part is to optimize the ratio between the building volume and user population, and this may be linked to the study on the future users in the aspects of their behavior, needs and requirements in the built environment such as office building, educational building, experimental hall and residential buildings. This information strongly contributes to the final value of the space usability in the smart living lab, and this information availability and accessibility determine the design and construction methods that smart living lab would apply.

Taking into account the current situation of the project, the lifecycle performance and the environmental impact of the entire building in the long-term run, the flexibility for the smart living lab is defined as providing necessary building components and products at the right time according to the requirements and changes from users. This definition would be reflected by the separation of the construction process into two major parts: Project A corresponding to the already fixed information from macro contexts and Project B responding to particular needs from building situations and users. The drivers for the separation include the component-user interactive levels, the universality of functional space units and space families. The preliminary separation of the construction process is proposed and would be further improved with exact information obtained from the research of the project. Regarding the construction components, the study suggests that the components and products should also be considered to keep independence in accordance with their own lifespan, which means the changes of the products with short lifespan should influence the ones with longer lifespan as little as possible.

Based on the collected cases on building flexibility and construction process separation, certain general recommendations are given at the end of the state of art.

4.6. Scientific Research Topics

The scientific research topics for the flexibility aspects are the study on the hypothesis proposed in the state of the art:

Is there any correlation between user and the lifespan of construction components?
This topic is trying to find the correlation between users and the construction components. In other words, is it true that the closer the component is to space users, the shorter the lifespan the component has, or vice-versa? This includes studies from two aspects, the understanding on the user-component interactive levels and the lifespan of construction components, the physical lifespan and expected lifespan. Both of these two aspects are the keys to both the usability of the built space andbuilding flexibility and the lifecycle analysis. The result of this research topic can benefit from the selection of the construction components

Can the physical building layers reflect the real interactive relations between users and construction components?
This research topic is to establish a building layer system based on real use knowledge. By the literature view and case study, it is clear that so far there is little serious research on this issue, and most of the statements or the development of ideas were only based on theory without an understanding of the real situation. This research topic will be conducted by three steps: the development of the ranking system to assess the interaction levels between users and components, the survey as a part of a social study among the target groups, and the analysis of the data. The result of this research would be used to verify the building physical layers that are currently used for building flexibility.

Can we integrate building flexibility criteria into the whole building lifecycle analysis by the design process?
This research topic will be the summary of the smart living lab project in the aspect of building flexibility in the entire life cycle of the building. This would generalize the determination process of the flexibility strategy, and its collaboration with building lifecycle assessment and technical application, such as active and passive systems. This generalization can be further developed to research on architectural design method, including the relevant case studies as well.

4.7. ANNEX: Adopted Cases

Cases from Schneider and Till on building flexibility [13], Stephen Kendall [27] and other references :

1. Rochdale, Britain, 2007 [13]
2. Donnybrook, Britain, 2006 [13]
3. Oakridge Village, Britain, 2006 [13]

4. St James Urban village, Britain, 2005 [13]
5. Domino.21, Spain, 2004 [13]
6. Optima House, Britain, 2004 [13]
7. Silvertown, Britain, 2004 [13]
8. Abode, Britain, 2003 [13]
9. Edificio Balmes, 2003, Spain [13]
10. Eichrain, Switzerland, 2003 [13]
11. Siedlung Hegianwandweg, Switzerland, 2003 [13]
12. Wenswonen, The Netherlands, 2002 [13]
13. Berlin Terrace, Germany, 2001 [13]
14. Flexible Housing in Almer, The Netherlands, 2001 [13]
15. Greenwich Millennium Village (II), Britain, 2001 [13]
16. Housing Terrace, Slovenia, 2001 [13]
17. Kettenhaus, Germany, 2001 [13]
18. Kraftwerk 1, Switzerland, 2001 [13]
19. Multiple Choice - Housing In Isla Margarita, The Netherlands, 2001 [13]
20. 495 West Street, USA, 2000 [13]
21. Affordable Rural Housing Demonstration Project, Britain, 2000 [13] [27]
22. Flexsus 22, Japan, 2000 [13] [27]
23. Weberhaus Option, Switzerland, 2000 [13]
24. Cala Domus, Britain, 2000 [13]
25. Modular construction system, Austria, 2000 [13]
26. Kölner Brett, Germany, 1999 [13]
27. Kronsberg Karrée, Germany, 1999 [13]
28. Wohnregal Koppstrasse, Austria, 1999 [13]
29. Westferry Studios, Britain, 1999 [13]
30. Atelierhaus Sigle, Germany, 1998 [13]
31. Housing blocks in Pamplona, Spain, 1998 [13]
32. Office and Residential Building, Austria, 1998 [13]
33. Regal, Germany, 1998 [13]
34. Pelgromhof, The Netherlands, 1998/2001 [13]
35. Apartment in Pavia, Italy, 1997 [13]
36. Casa a la Carta, Mexico, 1997 [13]
37. Gespleten Hendrik Noord, The Netherlands, 1996 [13] [27]
38. Apartment in Logroño, Spain, 1996 [13]
39. Estradenhaus, Germany, 1996 [13]
40. Grieshofgasse, Austria, 1996 [13] [27]
41. The Transformable Apartment, Britain, 1996 [13]
42. Wulzendorfstraße, Austria, 1996 [13]
43. Brandhöfchen, Germany, 1995 [13] [27]
44. Apartment in Vitoria-Gasteiz, Spain, 1994 [13]
45. Banner Building, USA, 1994 [13] [27]
46. Housing Graz-Straßgang, Austria, 1994 [13] [27]
47. NEXT 21 Complex, Japan, 1993 [13] [27]

48. YWCA Family Village, USA, 1993 [13]
49. Gulfgate Housing, USA, 1993 [13]
50. Überbauung Brahmshof, Switzerland, 1991 [13] [27]
51. Überbauung Hellmutstrasse, Switzerland, 1991 [13] [27]
52. Davidsboden, Switzerland, 1991 [13] [27]
53. Hinged space, Japan, 1991 [13]
54. The Dynamic House, Sweden, 1990 [13]
55. Habitat Industriel "La Faye", Switzerland, 1989 [13]
56. Dapperbuurt, The Netherlands, 1989 [13]
57. Ålekistevej, Deenmark, 1988 [13]
58. Honor Oak Park, Britain, 1987 [13]
59. Wohn- und Geschäftshaus, Germany, 1987 [13]
60. Wohnregal, Germany, 1986 [13]
61. Nemausus, France, 1985 [13]
62. Quartier Saint-Christophe, France, 1985 [13]
63. Wohnüberbauung Riehenring, Switzerland, 1985 [13]
64. Flexibele woningbouw, The Netherlands, 1984 [13]
65. Keyenburg, The Netherlands, 1984 [13]
66. Wohnhäuser im St. Alban Tal, Switzerland, 1982 [13]
67. Feßtgasse Housing, Austria, 1980 [13]
68. Adelaide Road Estate, Britain, 1979 [13]
69. Brockley Park Estate, Britain, 1978 [13]
70. Industrialized construction system, Italy, 1978 [13]
71. Lunetten, The Netherlands, 1978 [13]
72. Molenvliet, The Netherlands, 1977 [13]
73. Flexibo, Denmark, 1976 [13]
74. Purkersdorf, Austria, 1976 [13]
75. Wohnen Morgen, Austria, 1976 [13]
76. Housing Estate Olari, Finland, 1975 [13]
77. Les Anticonformes, France, 1975 [13]
78. Les Marelles, France, 1975 [13]
79. Metastadt, Germany, 1974 [13]
80. Asemwald, Germany, 1972 [13]
81. Wohnanlage Genter Strasse, Germany, 1972 [13]
82. Diagoon Houses, The Netherlands, 1971 [13]
83. Montereau, France, 1971 [13]
84. Norrliden, Sweden, 1971 [13]
85. Orminge, Sweden, 1971 [13]
86. Brahmshof, Switzerland, 1990 [27]
87. The Transformable Apartment, Britain, 1996 [13]
88. Tsukuba Two Step Housing, 1996- [53] [54] [55]
89. Yoshida Next Generation Housing Project, 1998-2000 [56]
90. HUDc KSI Demomstration Project, 1998 [27] [57]
91. Housing “Living in Lohbach”, 1998 [58] [59] [60]

92. Baumschlager & Eberle Eco-School, 1998 [61] [62]
93. Housing Sebastianstrasse, Austria, 2001 [63] [64]
94. Suitcase House, Hong Kong, 2001 [65]
95. Suitcase House, Beijing China, 2001 [66]
96. Sculpture ShowRoom of Naijing University, 2001 [27]
97. Jia's Flat, Hong Kong, 2002 [27]
98. Gifu Kitagata Housing, Japan, 2002 [67]
99. Urbanex Sanjo, Japan, 2002 [68]
100. INO Hospital, Switzerland, 2004 [69] [45]
101. Arabianranta Project, Finland, 2005 [70]
102. Catamaran Houses, Russia, 2005 [71]
103. Wohnanlage Eichgut, Switzerland, 2005 [63]
104. Maya Project, China, 2006 [72]
105. Multifunk Building, the Netherlands, 2006 [73]
106. Klippinki Housing, Finland, 2006-07 [74]
107. Solid Ijburg, 2008 [63] [75]
108. E-Science Lab, Switzerland, 2008 [63] [76]
109. vonRoll Library, University of Bern, Switzerland, 2013 [77]
110. Krankenhaus AZ Groeninge, Belgium, 2014 [78] [79]
111. Wohnhaus Kronsberger Straße, Germany, 1969 [13]
112. Wohnhaus Schärer, Switzerland, 1969 [13]
113. Alexandra Road, Britain, 1969 [13]
114. Eastfields, Britain, 1968 [13]
115. Sutton Dwellings, Britain, 1968 [13]
116. Neuwil, Switzerland, 1965 [13]

5. Energy Strategies

Authors: Arianna Brambilla, Stefano Cozza, Thomas Jusselme

5.1. List of abbreviations

C	Concentration CO2
CCP	Climatic cooling potential
CDD	Cooling degree days
Db	Internal system noise
De	External air noise
DGI	Daylight glare index
DhC	Number of discomfort hours weighted on the difference with the comfort upper limit
DHW	Domestic hot water
Di	Internal air noise
Dt	Temperature drift
E	Enlighten on visual task
EE	Embodied Energy
Fc	Free cooling
g	Solar energy transmittance of a windows
G	Irradiance
GHI	Global horizontal radiation
HDD	Heating degree days
HI	Heat index
IEA	International energy agency
IPCC	Intergovernmental Panel on Climate Change
L'	Noise by shock
LCA	Life cycle analysis
Mc	Mechanical cooling
Mo	Manually operated
n	Utilization factor
Nh(*N*)	Hours with Top above (if summer) or below (if winter) the threshold defined by *N*
OEn	Operating Energy
PV	Photovoltaic panels
Ra	Radiant asymmetry
SH	Space heating
So	Operated by the system
Tb	Building temperature
Tdp	Dew point temperature
Text	External temperature
Top	Operative temperature
Trm	Running mean temperature
Ts	Surface temperature of floor
Twb	Wet bulb temperature
U	Thermal transmittance
Uax	Absolute humidity
UGR	Unified glare rating

UNEP	United Nations Environment Programme
Uo	Uniformity of background
Ur	Relative humidity
V	Ventilation ratio
Vf	Wind velocity
Vr	Air flow velocity
WMO	World Meteorological Organization

Table 10: List of abbreviations in energy strategy

5.2. Introduction

The whole energy concept is related to reduce the Kaya factors $\frac{OEn}{EE}$ and $\frac{CO_2}{OEn}$, that are representative of the passive and active fields. As it is shown from the factors, the operative energy plays an important role in this poise, as it make the link between this two fields.

Optimizing them, means finding the balance between the energy consumption during the operation phase, the quality and the CO_2 content of this energy and of course the embodied energy used to implement materials and components into the building. Therefore, it is possible to make an observation: it is clear that the more the materials will be efficient from a life cycle point of view and the lower will be the CO_2 content of the energy, the easier it will be to reach the goal defined by the LCA field.

Passive and active strategies final goal is to achieve the indoor comfort desired, using an energy that is as "cleaner" as possible, balancing all the other requirements, such as embodied energy, environmental impacts and flexibility issue. The first step is to understand the starting point of the relationship embodied and operating energy to achieve the requirements desired. Then, thanks to a sensitivity analysis, it will be possible to understand where to focus the attention to improve the energy behavior. Second step is to understand which are the systems to provide this energy with the lower CO_2 content per kWh.

5.2.1. Methodology of the state of the art

The state of the art regarding the energy field aims to create a complete and clear picture of the requirements and the resources linked to the building design. The energy concept is defined as the way in which the building interact with the environment, providing the energy necessary to keep the indoor comfort conditions. It is composed by two different part: the active and passive strategies. Passive design is the filter between the indoor environment and the external context, and acts as mediation of these two different spaces. Active strategy, instead, is the other half of the energy concept, which try to develop the smartest way to answer to buildings requirements regarding the resources availability and the environmental impacts targets. As in Figure 42, it is clear that active and passive strategies cannot be separated from the context in which the building will works.

As it is shown in the Figure 42, the importance of the environmental context and of the internal requirements is essential to set up better the whole energy concept. Knowing the strength and the weaknesses of the specific case it is fundamental to understand in which direction lead the future analysis and on which points put more attention.

The definition of the internal environment and external context is therefore the first step to assess an energy concept that could be really effective for the smart living lab.

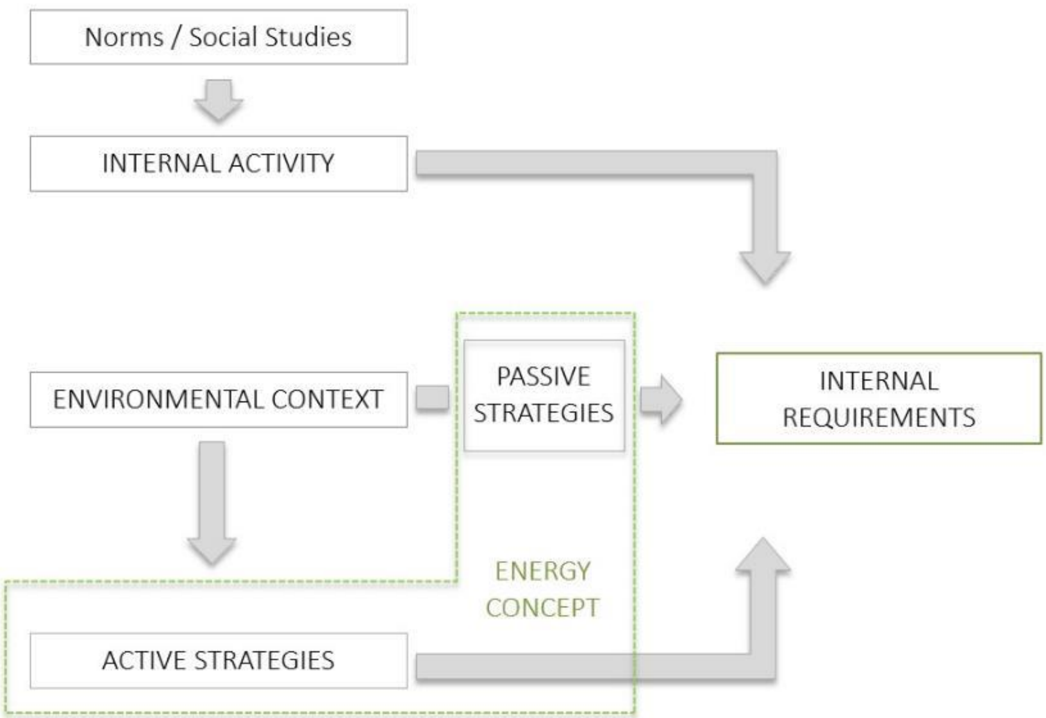


Figure 42: Energy concept

5.2.2. Passive strategies framework

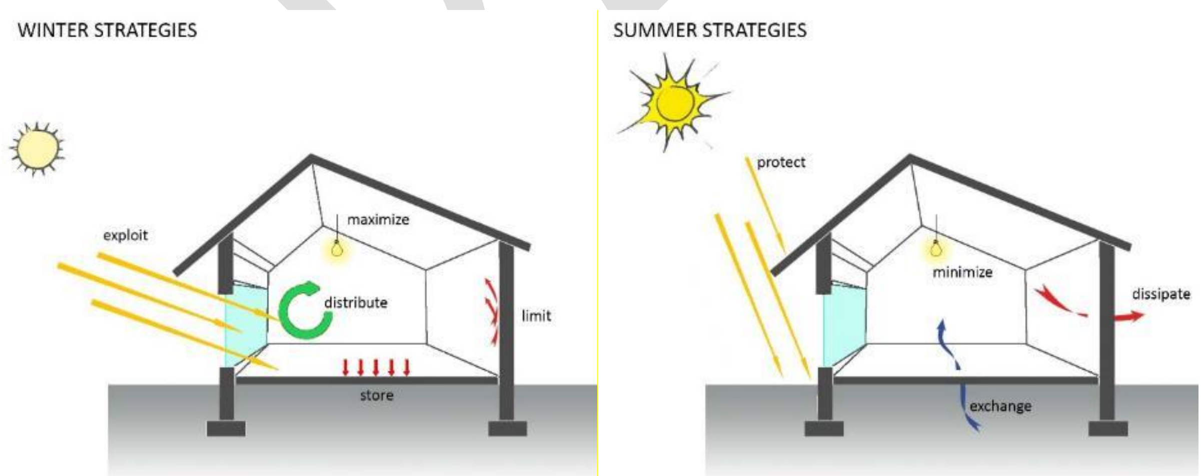


Figure 43: Passive strategies families for winter and summer period

Passive design is the combination of climatology, thermodynamics, fluid dynamics and human thermal comfort. In a building it is necessary to best use the resources available and achieve the comfort levels desired with the minimum demand of energy. Passive design is the process that support a good project; starting from the needs it set up an energy concept that will drive all the choices regarding architecture, technological system and technical installation.

In the last years, due to the economic crisis and fossil fuel scarcity, passive solar design has been developed and has progressed in knowledge and use from designers and the whole constructions world. However, a good design process starts from the availability on site and the goals of the building to achieve the right balance between each element of the passive design. The common knowledge divides the strategies into two big groups, depending on the season in which they act: winter and summer, as it is possible to see in Figure 43.

These families of passive strategies are, however, very wide and their application needs to be weighed in context; improving all of them without any criteria could lead to the opposite results and increase the hour of discomfort, due to an uncorrected prioritization. The goal of the state of the art is to define which category of passive strategy will be implemented in the design and which one may be left aside. In this way, a first energy concept will be given and the future step of the research program will aim to validate it or better calibrate it.

5.3. Internal requirements

Defining the internal requirements means understanding which is the building's indoor context. In order to have a clear picture of this, it is important to understand the target values the design will aim to, and which is the internal situation of the building, meaning the loads and the gains related to the energy consumption. The first ones are the conditions and the goals of the design process that must be fixed before starting the optimization in order to have a clear understanding of what we want to achieve and why we are designing and choosing solutions for the smart living lab. The second, instead, is representative of the internal situation that will occur in meeting, or not, the goals. Building's thermal balance is made on the losses (technical issue) and the heat gains (solar as architectural/climatic issue, internal as precondition). In order to understand how the balance will be affected by each component, it is important to see the importance of each factor.

In this chapter building's objectives are set and an analysis on design priorities in actual best practice in Swiss context is addressed.

5.3.1. Comfort criteria

The design target values are defined as comfort criteria and not energy consumption. This choice is driven by two different aspects: the final goal of the construction and the smart living lab purpose. The first one refers to the general aim of construction: providing comfort and creating a healthy space for users. As shown in the state of the art for flexibility field, the internal environment can influence users behavior and efficiency to achieve goals inside the space (for offices, for example, it affects the productivity); creating a mutual exchange between the perception of the quality of the spaces and the behavior inside it. For this reason it is important to create and guarantee a certain level of comfort, strictly related to the satisfaction and usability of the indoor environment. The second one is related to the optimization process of the smart living lab that will involve more than just operating energy, thus enlarging the building's dimension to the whole life cycle balance. Minimizing the life consumption of the building and, at the same time, minimizing the environmental impacts, could not coincide with the minimization of the operating energy consumption. For this reason the target value on the energy part will be led by the LCA analysis, while the final target value of the design during the operation phase will be defined by comfort criteria.

Indoor comfort is composed by four main fields: hygrothermal, air flow quality, lighting and acoustic environment. Temperature and humidity are the most variable and difficult to control, for this reason some studies have already been done on the field, often with conflicting results; normative try to summarize the knowledge on this field, but it is impossible to detail a set of target values referring to just one source. For the smart living lab, the sources used are

SIA, ISO EN and ASHRAE, but the values are then checked scientific studies about human preference and behavior in order to adapt the value as much as possible to the real situation of occupancy of each zone.

5.3.2. Comfort target values

Temperature

The design process will be focused on the achievement of the targets in a passive way, trying to not recur to mechanical treatment of the environment to meet the criteria. For this reason the thermal comfort model chosen is the adaptive one, described in ISO EN 15251[1]. In this model, the comfort is no more a static band around the optimum temperature, but a mesocomfort zone, described as the zone between the optimum comfort and the boundaries in which the physiological and psychological answers of users[2] are found. The larger width of the temperature range is representative of the adaptive opportunity[3],[4]: the possibilities of users to do actions that help in meeting comfort. This range is defined from the external running mean temperature. However, this is only valid for free running buildings, where the correlation between external/internal temperature is stronger; for this reason it is necessary to set up another target if the passive cooling alone is not enough to keep the desired conditions. Using the criteria described in SIA 380/1[5], we suppose that cooling is necessary if daily heat gains are above 120 Wh/s^2; in this case, the comfort model to be used is the static one, described in ISO 7730[6].

Starting from the norms the values are then adapted in order to create a more accurate set of values for each occupancy zone of the smart living lab.

The parameters considered are:

- Top: Operative temperature, linked to the thermal sensation of users
- Dt: Temperature drift, maximum difference of operative temperature per time unit
- Ts: Surface temperature of the pavement
- Ra: Radiant asymmetry for preventing local discomfort from surfaces temperature difference

Predicting the maximum temperatures acceptable in buildings is highly difficult, since they involve establishing the distribution of comfort levels about the optimum represented by the comfort temperature. They may also require a judgment of the frequency of discomfort which will be acceptable for occupants: for this reason a maximum deviation allowed is set up, weighting the distance to the comfort range for each hour of discomfort.

Humidity

Humidity has only a small effect on thermal sensation and perceived air quality in the rooms of sedentary occupancy. However, different effects are related to extreme values of these parameters. On one hand, very low levels of relative humidity - less than 20% - are associated to dryness and irritation of eyes and air ways, causing a sensation of high discomfort and body disease. On the other hand, very high humidity ratio can cause microbial growth. The formation of mildew and spore is not directly caused by the air humidity, but by moisture on the internal surface, that must be more than 80% for three consecutive days[7]. It is obvious that high internal relative humidity makes it easier to meet these conditions. The adaptive model of comfort, related to summer conditions, does not fix any threshold, even if the sensation of “warm” is mainly connected to the wittedness of the skin. Oppositely, the static model, representative of the winter condition where the sensation of “cold” is given mainly by the temperature, the risk of fungal growth limits the humidity to a certain level.

Given that in Switzerland, mildew is a problem for 1 apartment on 4.5[8], a maximum target value is introduced to limit these effects. The value is deducted from several studies about thermal comfort and humidity, for example it is known that dust mites, pathogens for different airways diseases, take water directly from air and the perfect environment for their growth has an average value of Ur between 70% and 80%[9]. At the same time formaldehyde is released into the air by materials as faster as higher is the temperature or humidity inside the spaces. For this reason, the threshold adopted is between 60% and 70%, depending on the type of use space.

The parameters considered are:

- Ur: Relative humidity
- Uax: Absolute humidity

The upper boundary is defined as the limit beyond which the human body can have problems in its thermal regulation due to the influence on the evaporative heat losses.

Regarding this issue, it will be important in the next research phase to investigate further the effects of humidity on thermal comfort; especially regarding the fluctuation between high values.

Air quality

No common standard index has been found in literature to define the indoor air quality. Following the normative values it is possible to set up a combination of criteria that can help in keeping the inside air healthy and comfortable. The health criteria are met by the requirements of ventilation for comfort.

The parameters are:

- Vr: Ventilation ratio
- V: Flow velocity
- C: Concentration of CO2 inside the space

Lighting

Lighting targets are set on the measurement of the illuminance on the task area. However, it is important to also set other parameters that control the visual environment to guarantee an adequate lighting comfort, which it is important to avoid eye strain, especially in the working space. If possible, enlighten requirements should be achieved with natural light.

> *The illuminance and its distribution on the task area and on the surrounding area have a great impact on how quickly, safely and comfortably a person perceives and carries out the visual task. Daylight can supply all or part of the lighting for visual tasks, and therefore offers potential energy savings. Additionally, it varies in level, direction and spectral composition with time and provides variable modelling and luminance patterns, which is perceived as being beneficial for people in indoor working environments. Windows are strongly favoured in work places for the daylight they deliver, and for the visual contact they provide with the outside environment.*[10]

Sedentary work is also sensitive to the glare problem. However, up until now, there is no accepted method or uniformity to define a parameter that can describe this phenomenon. For this reason, the unified glare rating is used for artificial appliances, and the daylight glare probability is used for natural light. On the other hand, it is important to say that the most important glare discomfort is due to the direct sunlight entering the space, but there is no standard methodology that can help in defining this value. In literature it is possible to find studies that use an utilization factor [11][12], as ratio between the total amount of useful solar energy and the maximum solar energy available. A factor of 1 corresponds to an optimum situation in which users do not influence the solar gains acting on the building, minor value, instead, is representative of a situation in which occupants use shading or blinds to prevent glare, excluding from outside the free solar energy. This parameter is, however, strictly dependent on the design and construction of the building, as well as the behavior and the possibility of interactions of users. For this reason, it is necessary to further investigate the issue, trying to understand how it will be possible to include this into the future assessment of the smart living lab behavior.

The parameters used are:

- E: Enlighten on the task area
- Uo: Uniformity of illuminance, take into consideration the lighting of the background area and the surrounding area
- UGR: Unified glare rating
- DGP: Daylight glare probability

Acoustic

Acoustic target values for comfort do not influence the energy consumption of a building directly, because they are related only to passive action such as insulation or orientation of the indoor spaces.

The acoustic comfort is driven by the position of the noise source, for this reason the parameter considered are related to the minimization of the inside noise and the defense against the one coming from outside or other functional spaces.

The parameters are:

- Db: indoor noise system
- Di: internal noise in building between different areas
- De: external noise
- L': shock noise

Comfort values

The comfort target values for the smart living lab, divided per use space, are summarized in the table in Annex 1. It is important to notice that the concept will be tested also with the assumption that the internal requirements from users will change in the future. The future population, in fact, may have different comfort preferences and the smart living lab should be able to answer or to adapt to this change. The laboratory LASUR is assessing a social study, based on surveys among the same typology of occupants as those of the smart living lab, which will help to define a new set of values for testing the sensibility to internal comfort requirements of the building.

It is possible to plot the hygrothermal comfort on the psychometric chart, as in Figure 44, to compare each use space and see which one requests higher (or lower in summer) temperature and, consequently, more energy, meant as life cycle, spent for achieving it.

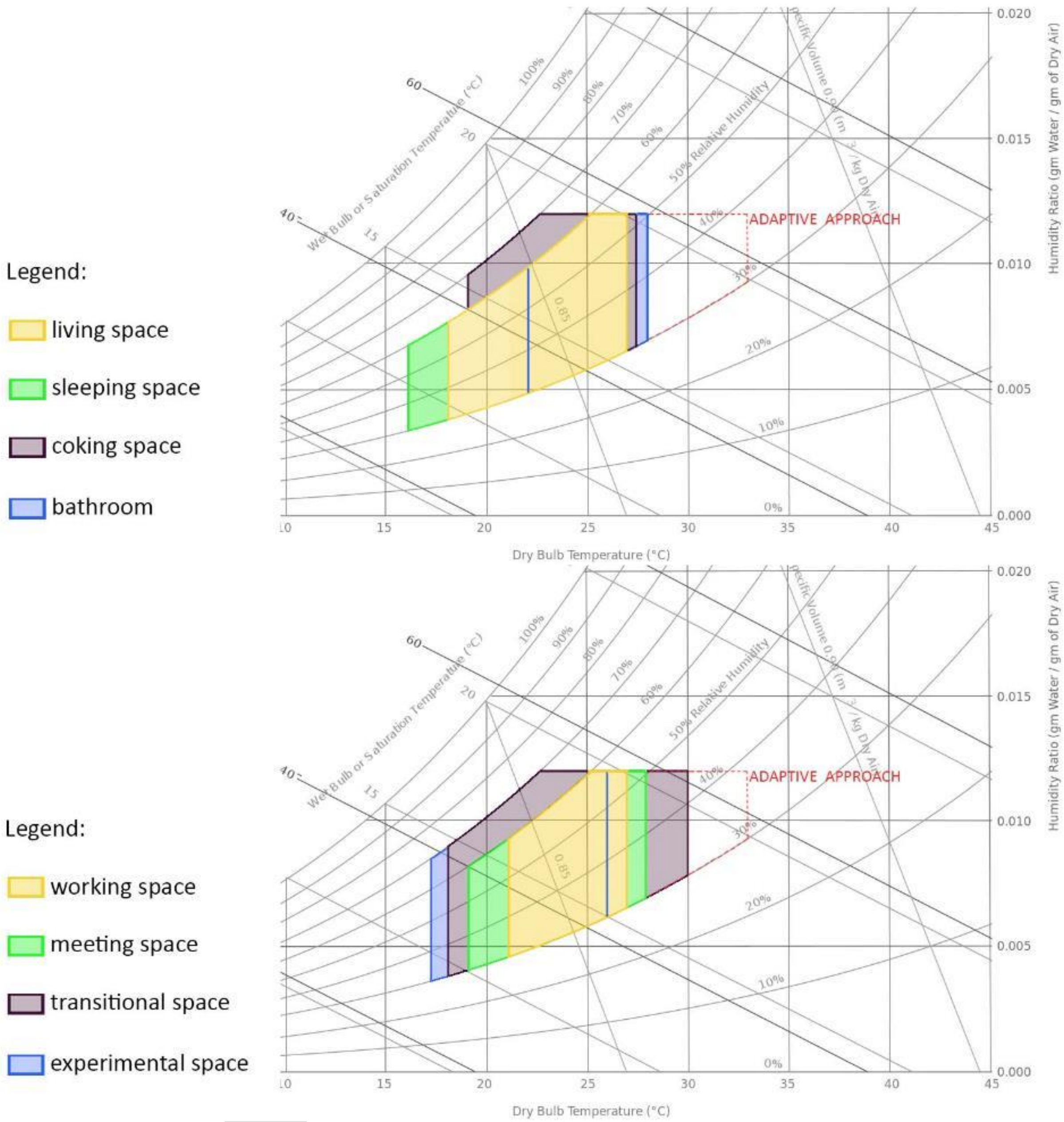


Figure 44: Hygrothermal comfort for dwelling (above) and office (below)

The spaces are plotted as sum of area, starting from the closer one. It is also possible to see the extension to higher value in case of adaptive approach as defined in the target values. The upper temperatures level is set up by the maximum Top allowed regarding to the maximum Text in Fribourg. The graphs are a useful tool to understand the correlation between each space and to relate it to the energy concept. The wider the zone, the easier to achieve the results. Spaces with less strict requirements can meet the comfort range with larger internal conditions. In this way it is possible to say that a bigger zone needs less adaptability of passive strategies to keep the indoor environment comfortable without spending energy for conditioning.

5.3.3. Case studies

For the realization of this state of art, a careful selection of case studies has been done. The criteria used for the selection of such cases were discussed and approved by all team members. Stringent criterion is the geographic positioning, case study building must be in Switzerland. This is to try to maintain the external condition the more homogeneous as possible and in this way better underline the real performance of the building. The decision to only choose buildings in Switzerland also allows greater accuracy in the DHW and electrical consumption, which may vary from country to country depending on people's habits. Second parameter is the "quality" of the building, in the sense of energy efficiency. So only buildings with the Minergie label or at least approved by the SIA 380/1 have been chosen. The third criterion is the intended use. The smart living lab will be a mixed-use building with a large area for housing and office, but also experimental space, which makes it very rare. Last parameter is the date of construction of the building, which could not be older than 2004. So all the case studies of the last 10 years have been gathered. Homes, offices, schools, light industries and mixed buildings, with particular attention to the first two types, have been selected. At the end 21 building for housing, 9 offices, 2 schools, 2 light industries and 2 mixed buildings were chosen. To collect all this data, PhD thesis [13][14], the database Minergie and the contact with the designers were used. As it can be seen on the Figure 45, despite the fact that all buildings are certified and in Switzerland, there is a big difference in consumption, because of the different technologies used.

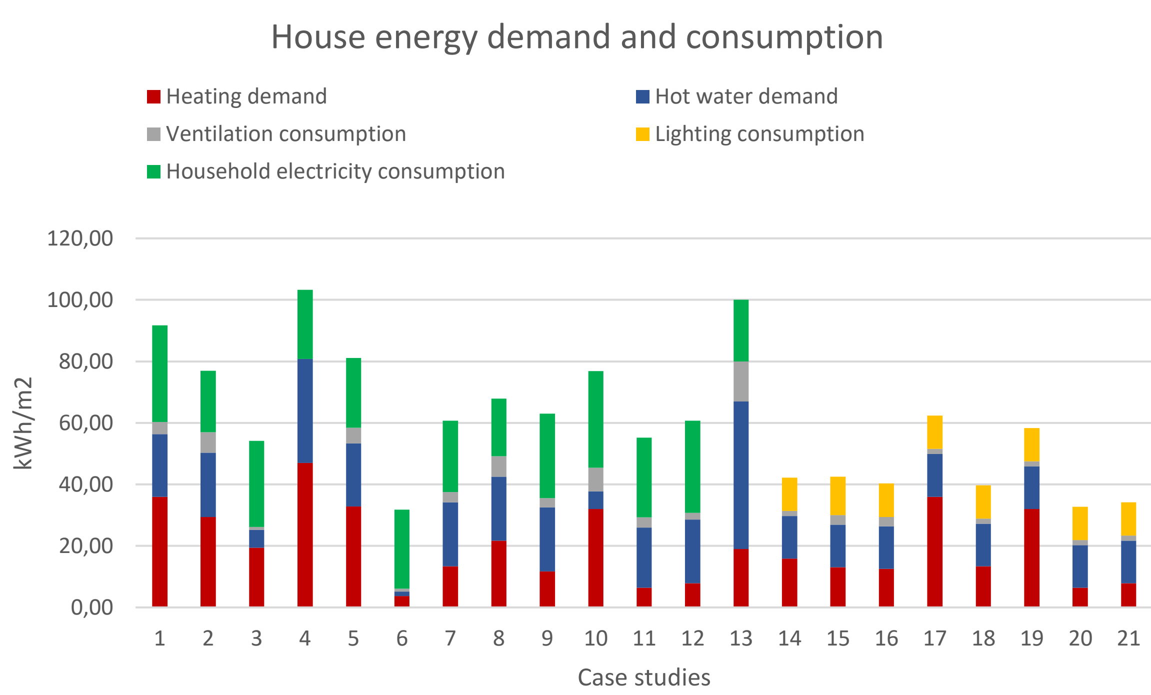


Figure 45: Case studies energy demand-consumption for dwellings

The Table 11 shows the results only for homes, but the same work has been done for all the other cases to better understand the differences for each field of consumption for each destination of use. Nevertheless, for some of the cases there is a lack of data, and some fields (ex. lighting) are evaluated using the SIA standards, and not making a real calculation for each case. This is something done directly by the architects, that assume this general values without taking in account the real properties (ex. exposition) of the building. So this value becomes interesting to better understand his importance in the total energy consumption.

Case study	Heating demand [kWh/m2]	Hot water demand [kWh/m2]	Ventilation consumption [kWh/m2]	Lighting consumption [kWh/m2] (with auxiliary)	Household electricity consumption [kWh/m2]
John-mfh01:	36.00	20.31	4.00	-	31.39
John-mfh02:	29.44	20.83	6.67	-	19.97
John-mfh03:	19.44	5.78	0.92	-	28.06
John-mfh04:	47.03	33.72	-	-	22.50
John-mfh05:	32.78	20.56	5.10	-	22.64
John-mfh06:	3.69	1.50	0.92	-	25.72
John-mfh07:	13.33	20.81	3.36	-	23.17
John-mfh08:	21.67	20.83	6.67	-	18.72
John-mfh09:	11.67	20.81	3.11	-	27.44
John-mfh10:	31.94	5.78	7.72	-	31.39
John-mfh11:	6.39	19.56	3.31	-	25.97
John-mfh12:	7.81	20.81	2.10	-	30.00
Solarcity	19.00	48.00	13.00	-	20.00
House A.15 Wyss	15.83	13.89	1.67	10.83	-
House A.17 Wyss	13.06	13.89	3.06	12.55	-
House A.18 Wyss	12.50	13.89	3.06	10.83	-
House A.19 Wyss	36.00	13.89	1.67	10.83	-
House A.24 Wyss	13.33	13.89	1.67	10.83	-
House A.27 Wyss	31.94	13.89	1.67	10.83	-
House A.28 Wyss	6.39	13.89	1.67	10.83	-

Table 11: House energy demand-consumption

In the Figure 46 instead are summarized the systems used to provide to this energy demand. It is clear that the most frequently used technology, both for the SH and the DHW, is the heat pump. Regarding only the DHW, solar thermal energy is a solution almost always used, also if it is often coupled to other systems, and it's very rarely used alone to fulfill the total requirements. To conclude, the active systems that will need more attention in the next research phase are the heat pump, the wood pellet boiler and the solar collector, all of them used with the technology of the PV. The latter does not look very used regarding this cases but this is only for an economic reason. In the last two years the production by PV has increased a lot and the cost is lowering. In the 2020 the PV energy is expected to have the same cost of wind or biogas energy [15]. It is a technology that will be therefore very important in the energy concept of the Smart Living Lab.

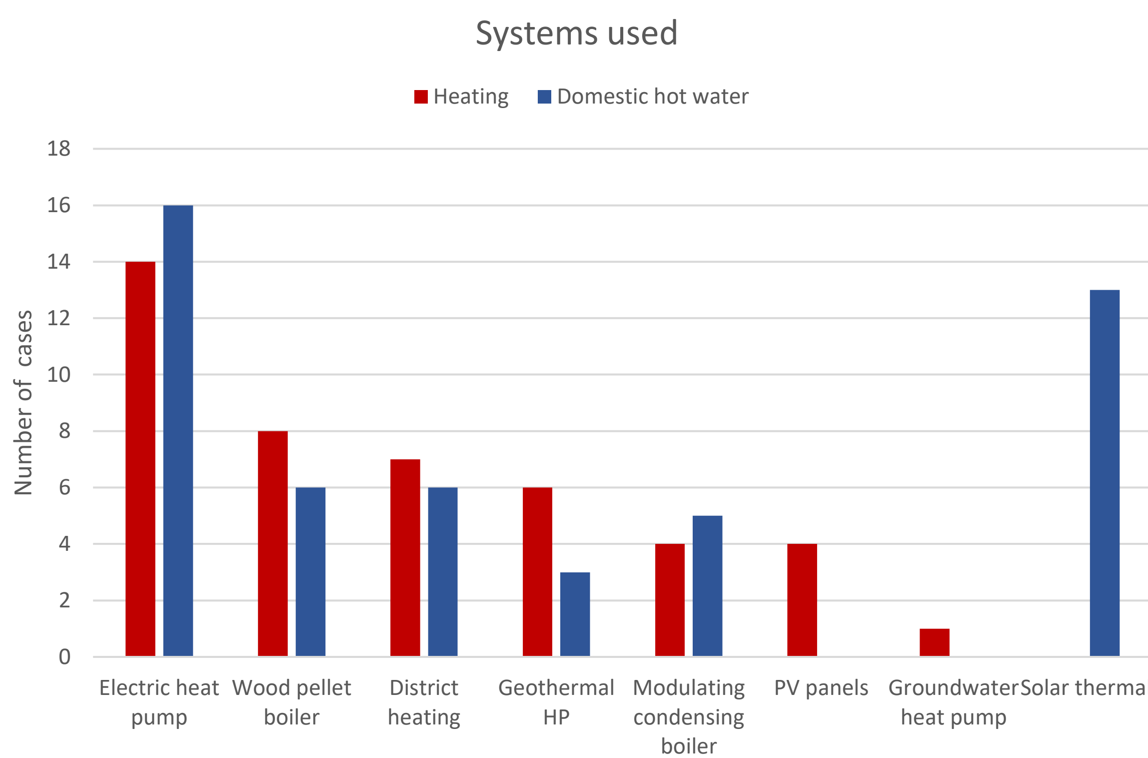


Figure 46: System used in the analyzed case studies

5.3.4. Building requirements

As shown in the previous section, the electricity consumption (for appliances and lighting) is very high in the final balance and, sometimes, for very well designed building, it is the highest value. This is confirmed in the Figure 47, where the average values of primary energy consumption are shown for different kind of buildings.

As represented in Figure 47, the higher the performance of the building (Minergie-P), the higher the weight of the electricity consumption. Therefore, it is clear that also in the smart living lab which will be a highly performant building, the consumption for lighting and appliances, must be taken seriously into account from the design phase. This consumption has been quantified using a first draft of destination of use (1000 m2 of housing, 950 m2 of offices, 600 m2 of experimental hall and 150 m2 of meeting room) and the SIA norm [17].Matching this information it is possible to have a first idea of what the requirements of the building will be, only with regards to appliances and lighting, and then how to provide to it. The results for a normal working day are shown in Figure 48, compared with the power available from the sun in two different months. The latter has been calculated by PVGIS [18], using a catchment area of 813 m2 (the surface of the roof in the smallest architectural draft), a tilt for the panels of 0° and an efficiency of 16%.

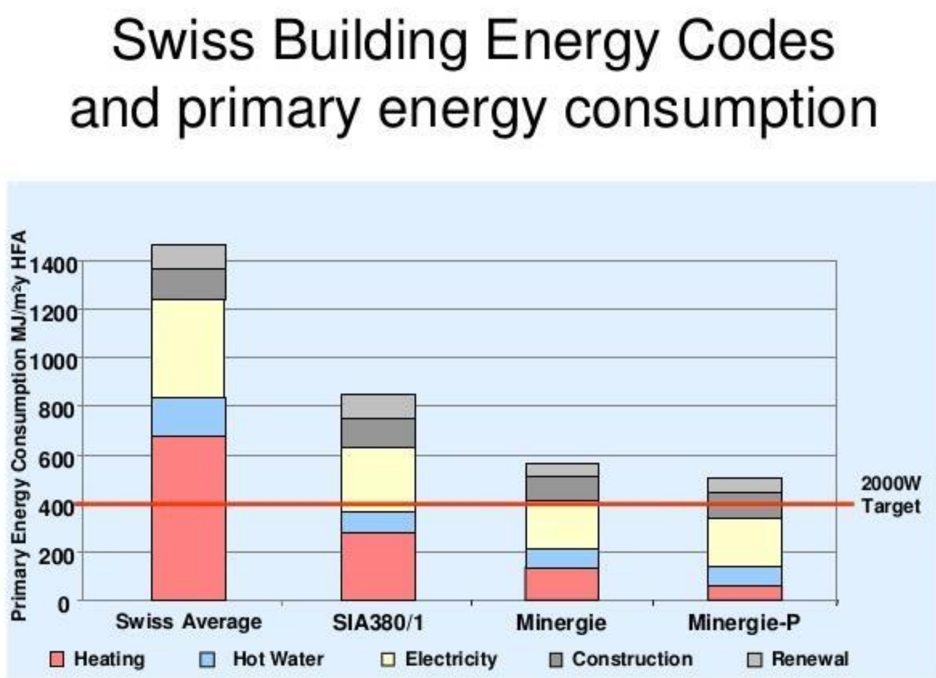


Figure 47: Primary energy consumption in Swiss buildings [16]

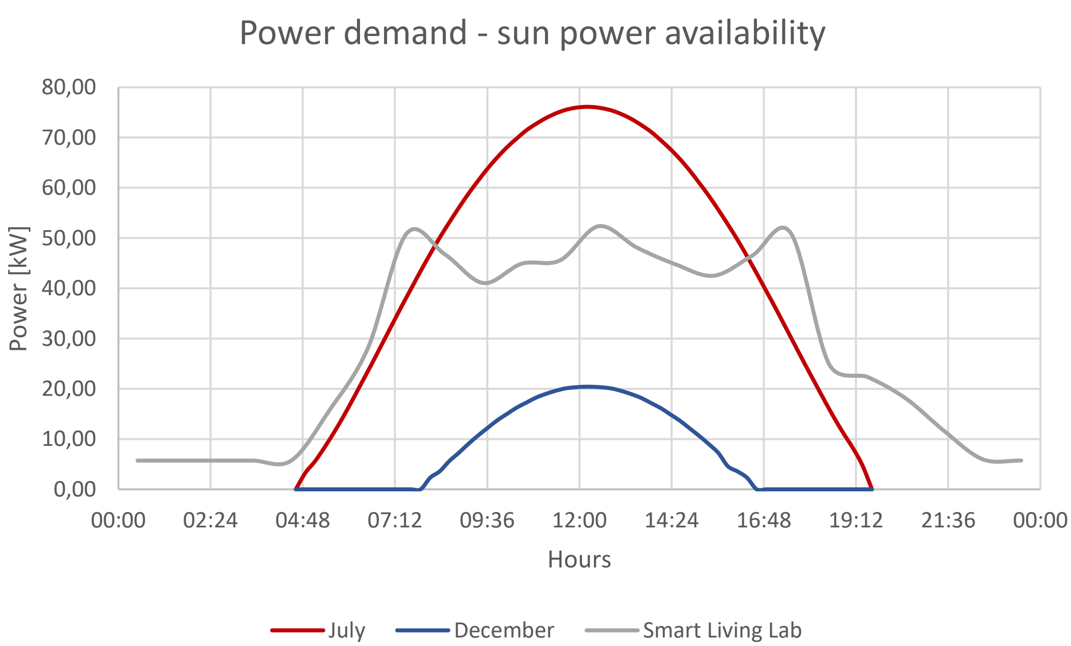


Figure 48: Smart Living Lab power demand - Power given by PV panels on the roof

Some important considerations can be done by looking at the Figure 48. During a normal working day there are not high variances of consumption. There is a clear difference between night and day, and within daily time there are 3 different peaks linked to eating time. But it is important to remember that this is a power requirement done using SIA norm, so it is representative of the current consumptions of Swiss buildings in that field. It is therefore possible that the Smart Living Lab will have different consumptions, for example using a different policy for the lighting. In some months (ex. July) it is possible to cover almost all the electricity demand by the photovoltaic system. In other months (ex. December) the radiation is insufficient to coverer the requirements. Given the big GHI difference between summer and winter, it is very important to think a way to store the energy that it is produced in excess. Also, the energy storage must work in a seasonal way (ex. hydrogen).

5.3.5. Design priorities

The case studies are helpful for a first analysis about the design priorities for the smart living lab. They are the expression of the best practice in the construction sector in Switzerland and they are built to meet the criteria of the Minergie standard, focusing the attention on the reduction of the operating energy. The first draft of the energy concept is set up on crossing the information about the resources available and the criticisms that the building will face. For this reason, it is possible to start with an estimation of the main issue similar constructions have, to understand the order of magnitude of each parameter in the energy consumption during the operation phase.

The energy-consuming factors in a buildings are: heating, cooling, domestic hot water, lighting and electrical appliances.

The case studies are analyzed through the energy demand and not the primary energy consumption. However, the information available was not always complete. For this reason, when there was a field not described, the mean value was used. The ranking criteria is based on the average weight of each factor on the total consumption.

The score starts from 4 to 1, where:

1. Not significant
2. Averagely important
3. Very important
4. Priority

Divided as follow:

- 1 : 0 – 5 %
- 1.5 : 5 – 10 %
- 2 : 10 – 15 %
- 2.5: 15 – 20 %
- 3 : 20 – 25 %
- 3.5 : 25 – 30 %
- 4: >30 %

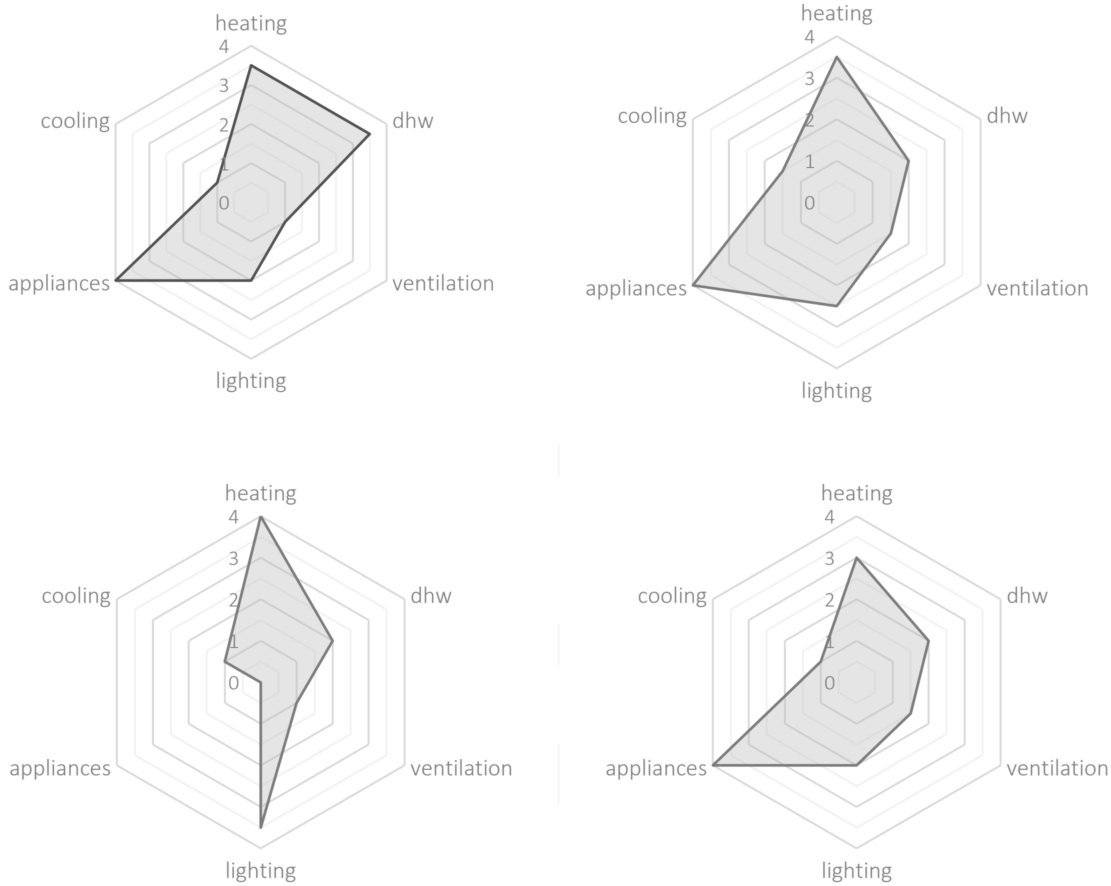


Figure 49: Research priorities given by the case studies for the different destination of use

The light industries do not have any weight on the appliances because, this parameter is strictly linked to the type of activity made inside, more than all the other use destinations. In order to not make any assumptions that could easily mislead to wrong results, the parameter is not considered for this category.

It is possible to understand from the analysis, that the main priority in Switzerland for all the functions, is represented by the thermal loads. Cooling, instead, seems to be not an issue in any typology, neither offices, where the internal gains due to the appliances are usually very high. It is clear that the design should be focused to solve the criticisms of the heating season. Appliances have a high importance within the case studies, this is due to the fact that the buildings used are representative of the best practice today, where the envelope is well insulated and the thermal losses minimized: in low energy buildings, the electricity demand from appliances is greater due to decrement of the thermal one. On the other hand, lighting weight is almost constant in all the typology, except from light industries. This result is aligned to the internal comfort objectives defined, where the lighting for the experimental hall is higher than in the other use spaces.

A criticism of the analysis is that the cases do not specifically concern the smart living lab, but they are necessary to give the direction of the design and to quantify the order of magnitude of each parameter. Results must, however, be validated with the future simulation.

5.4. External context

For external context is meant the whole set of parameters and conditions that can characterize the framework in which the building will work. Defining the context means, therefore, understanding the constraints and the strengths of the site. At the same time, it also means understanding if the criticisms can be solved or must be considered as fixed assumptions and how it is possible to deploy the opportunities that are present and inherent to the construction area. The analysis has been divided into two different macro-areas: one is related to the construction site and its relevant aspects, the other is represented by the climatic context of Fribourg. Both of them will affect the design and the operational energy use and so it is important to understand how they can interact with the smart living lab.

5.4.1. Environmental context

The environmental context is defined as the external conditions or surrounding, in which the building acts and which tend to influence its development and behavior. Defining it means understanding the condition of the site and the resources available in the nearby area. For this reason, two types of analysis are made to clarify the context and translate it into pragmatic indication useful for the design stage.

Site analysis

The site analysis aims to define the constraints and the weaknesses, as well as opportunities and strengths of the area. Since the Bluefactory area has been object of a public competition for the masterplan design, several studies about it are already available. Taking the documents available from the competition[19], it is possible then to complete and verify the information thanks to specific cantonal rules and more general tools available[20],[21],[22]. In particular, the last reference is a complete set of documents, provided by the Fribourg Commune, where it is possible to check on plans and official cartography the actual situation of the site interested. On the below table, the main issue analyzed, the value associated to each parameter and the reference are reported. In the following tables it is possible to see the main findings.

LOCATION	Blue Factory Site – Fribourg CH	
SURFACE	53 000 sm	Guichet Cartographique du Canton de Fribourg
ALTITUDES	Average: 630 m Maximum: 665 m Minimum: 617 m	Google Earth
REMARKS	24% of green spaces More than 1000 little species reported to be living in the Fribourg area	Guichet Cartographique du Canton de Fribourg

Table 12: Site context

SUN AVAILABILITY	Maximum: 1702 h in 2013- average 1750 h Minimum: 203 h in winter 2011 – average 250 h	Database prevsion-meteo.ch
TEMPERATURE	Maximum: 32.2 °C in 2013 Minimum: -18.9 °C in 2012	Database prevsion-meteo.ch
PRECIPITATION	Average: 683 mm Last year: 834 mm in 2014	Database prevsion-meteo.ch
WIND	No main direction	Database

	Average speed: 11.5 km/h Maximum speed: 113 km/h	prevsion-meteo.ch

Table 13: General climatic context

NOISE	Actual zone: 4, maximum 60/70 dB Future zone: 3, maximum 55/65 dB	SITECOF
UNDERGROUND WATER	Protection zone: uB	SYSIF
SURFACE WATER	Infiltration zone: low	PGEE
BIODIVERSITY	Zone of protection: low	Guichet Cartographique du Canton de Fribourg

Table 14: Site features

TRAFFIC	Plus 0.5% daily traffic (from 2014 to 2024) Equal to improvement of 10% of daily noises Equal to 5% of night noises	Route cantonale, Service de ponts et chaussèes, Route communales, cadastre du bruit de la ville de Fribourg
TRAFFIC NOISE	Increase limits to 1dB	OBP Art.9
INSTALLATION NOISE	Limits of emission value on facades: 65 dB per laboratories and 60 dB per housings	OBP Art.9
AIR QUALITY	The most pollutant factor is traffic, the project must limit the improvement of daily traffic and enhance the public transport	Sen, Annex 2
EXCAVATION	Digging waste are to be meant as contaminated waste, to be threaten	Osites Art.3
WATER MANAGMENT	Separation of clear and dark water Grid already prepared Drain water harvesting tank: min 316m3	PGEE Fribourg

Table 15: Project impacts

Resources analysis

Energy use in Switzerland produces the lowest CO2 emissions per unit of Gross Domestic Product in IEA member countries, matched only by Sweden. Switzerland had also one of the lowest CO2 emissions per capita in the IEA member countries in 2010, the carbon intensity of energy supply is so low because renewable and nuclear energy have a high share in total primary energy supply (TPES) [23]. But in the next few years the scenario is going to change due to the decision taken in 2011 to not build new nuclear power plants and to turn off gradually those that are working [24]. Consequently, to respond at the increase of the energy demand, the gas import and especially the use of renewable energy are going to increase[25]. This will bring about a change in the energy mix in Switzerland, with a decrease of CO2 content per kWh. In the Table 16 it is possible to see the actual production of electricity in Switzerland and in the Canton of Fribourg, with all the different sources.

	Switzerland		Fribourg		
	Production Elec. [GWh] [23]	Production Heat [GWh] [23]	Production [GWh] [25][26]	Cost of kWh [cts/kWh] [24][15]	Quantity of CO2 [g Co2/kWh] [27]
Oil	53	127	0	8	979.2
Gas	923	1044	0	8 - 12	468
Biofuels	527	437	1500 (potential)	16 - 24	178.2
Waste	2209	3079			7.3
Nuclear	25441	380	0	4 - 5	23.6
Hydro	40305	0	647.2	6 - 9	12.6
Geothermal	0	2481	205.8 (potential)	11 - 15	55.1
Solar PV	320	0	16.5	80 - 100	95.1
Solar thermal	0	515	-	16 - 24	41.8
Wind	88	0	0	25 - 29	26.4

Table 16: Sources of energy in Switzerland

Looking at the renewable energies at local level, as summarized on the Table 17, there is availability of solar energy, low depth geothermal power and the chance to use some waste heat, or urban wastes/biomass [28] in the BlueFactory site. The resources that are not available are wind-energy and hydro-energy. Regarding the wind, the analysis of the data shows that the average wind speed in Fribourg is less than 3.1 [m/s] [29] per year, too weak to implement a standard machine [30]. As for hydroelectric power, usually a strong resource in Switzerland, there is no chance to increase production and use energy from this source, because the 91% of the potential of hydraulic power in Fribourg is already being exploited [24].

Sun	High GHI values (average annual sum 1250 kWh/m2), but very various between summer and winter	SOLARGIS
Hydro	The 91% of the potential of hydraulic power in Fribourg is already being exploited	Etat de Fribourg
Future district heating	New grid development between Granges Paccot, Fribourg and Agy 1700 MWh/a	Solar Decathlon Energy Concept
Geothermic	8.6 GWh/y electrical, 23 GWh/y thermal of potential for the BlueFactory	The SwissTerraPower consortium
Wind	Low potential of wind speed and no main direction to be exploited	windfinder
Industrial waste	197 GWhel + 140 GWht in Swiss context Villars industrial site: heat availability	Concept energetique Blue Factory, Energie Concept, rapport 29/11/2013

Table 17: Resource at site

More at a building's level, despite the availability of solar power, the use of this resource can be elaborated. This because of the great difference of GHI during the year. As it is shown in the Figure 50, about the 50% of the radiation is concentrated in only three months [31]. It will be necessary to think about a seasonal storage for the exceeding energy.

Figure 50: Distribution of the solar radiation during the year 2014

Another resource with a big potential is renewable energy from biomass. Biomass is a viable solution because the site is located in proximity of the railway and therefore supplies of new biomass would be easy to obtain. Biomass is already quite used in the form of single boiler, but the energy production can be further increased by using this technology at bigger scale (to heat not only the Smart Living Lab) and consequently increasing its efficiency. In the Table 18 it is possible to see the potential production of the Smart Living Lab, referring to its geometric size.

Photovoltaic	152 MWh/y per horizontal 813 sm	PVGIS
Solar thermal	72 MWh/y per surface 160 sm	Appel A concept énergétique Blue Factory, Groupe e, rapport 2013
Geothermic	232 MWh/y per probe's length: 1500 m SH + 800 m DHW 63 MWh/y geocooling	Appel A concept énergétique Blue Factory, Groupe e, rapport 2013

Table 18: Resources at building's level

Observations

The main finding of this analysis is that there are no big constraints related to the site for the construction and the design. The soil has a very low draining capacity, and a rainwater harvesting tank should be implemented in the district planning, in order to store water for the extreme rain events. The closeness to the railway is a criticism for the noise protection that should be checked and verified during the design stage in order to see whether or not the activities inside the building can be affected, causing acoustic discomfort. On the contrary, the infrastructure is well developed around the area and this can be a strong opportunities for smart living lab, which will be a melting pot and a strategic point for the whole city. These three findings could influence the district design but no one can directly impact on the smart living design for the research program.

The resources analysis, instead, points out that the solar availability on the area has a great potential for active systems and, therefore, a deeper study about the correct balance between position, technology and needs should be carried out during the next phase. As from the Figure 51, another big resource for the smart living lab is represented by the great amount of industrial waste generated by the nearby productive area: Chocolate factory Villars for example, is estimated to waste every year a lot of heat used during the chocolate process. It should be advisable to try to reuse this free power at a district level, creating a sort of exchange between the different buildings of the Bluefactory. On the contrary, wind power will be not developed as main source of electricity and wind turbine implementation will be developed only if necessary, as a side technology of production. (Resume in Table 19)

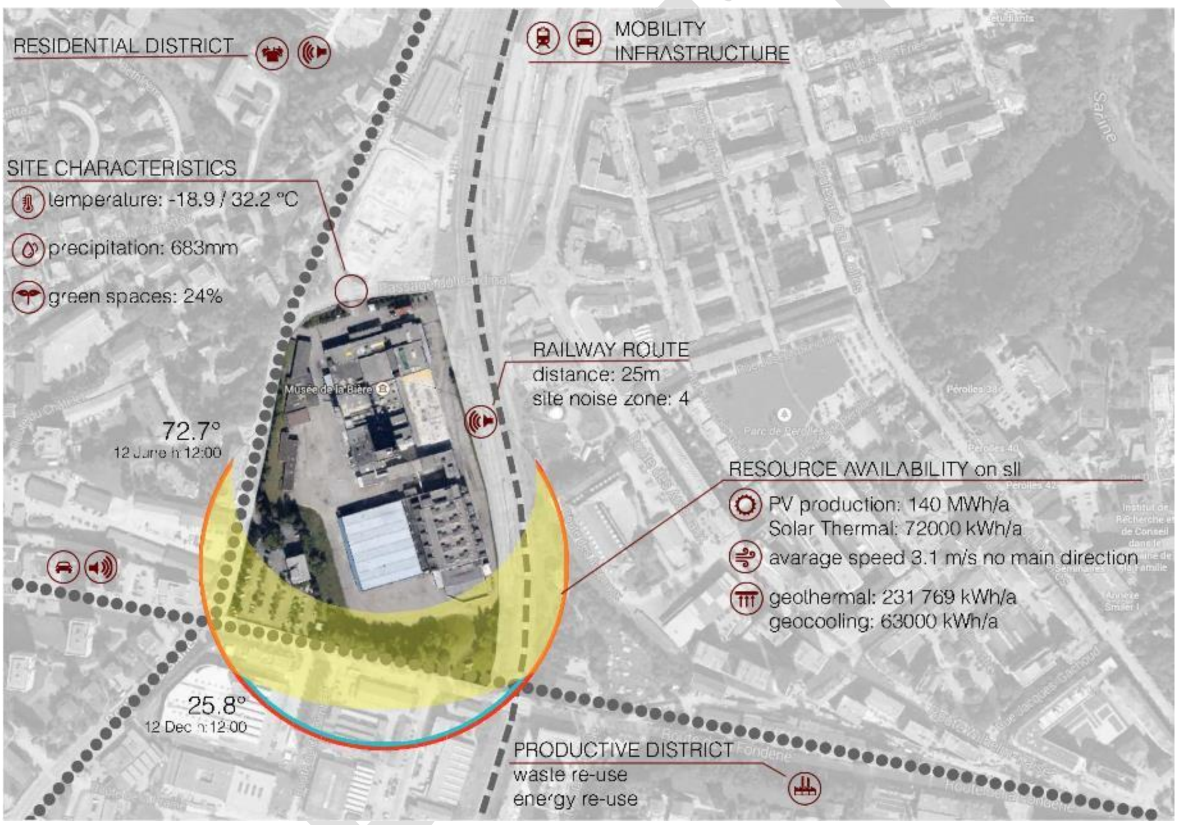


Figure 51: Image of the site with the main features deducted from the analysis of the context

STRENTGHS	WEAKNESS
Easy access to the site	Close to the railway route
Close to infrastructure facilities	Low wind usability (no main direction and low average speed)
High solar availability and high surface for installations	Low drain capacity of the soil

Industrial waste availability	No possibilities for electrical grid's renewable integration
High easiness of technical re integration during the construction	
Future improvement of the electrical grid	
Low risk for construction and low impacts on environment	

Table 19: Résumé of the main findings regarding the Bluefactory site

5.4.2. Climatic context 2015

The climatic context of 2015 aims to identify are the peculiarities of Fribourg weather which could directly influence and have an effect on the passive strategies energy concept. In this first chapter, the general situation is described to picture the possibilities for bioclimatic strategies and to dictate which should be the direction to develop, addressing new deeper analysis. The weather file used is taken from the software Meteonorm, the same used for the creation of the dataset for SIA verifications. The city is interpolated between the Payerne, Berm-Liebefeld, Neuchatel, Burgdorf, Interlaken and Pully stations. The software developer assures that the errors contained in the interpolation is robust and within the annual variation of each location [32]. The dataset used is the statistical average of 2000-2009 for temperature, humidity, wind and precipitation, and 1986-2005 for solar radiation.

The parameters analyzed are the most correlated to the passive strategies potential:

- Temperature gives the distance to the comfort zone, the main issue in terms of conditioning and the idea of the magnitude of the requests
- Humidity, related to comfort and health problems, regarding to the type of climate (arid or humid) it will be possible to choose which passive strategies should be develop
- Wind velocity and direction, gives the potential for active production but also the possibility to implement or not ventilation strategies
- Solar radiation, related to the active production, but also to the passive use of gains for winter or the need of protection in summer.

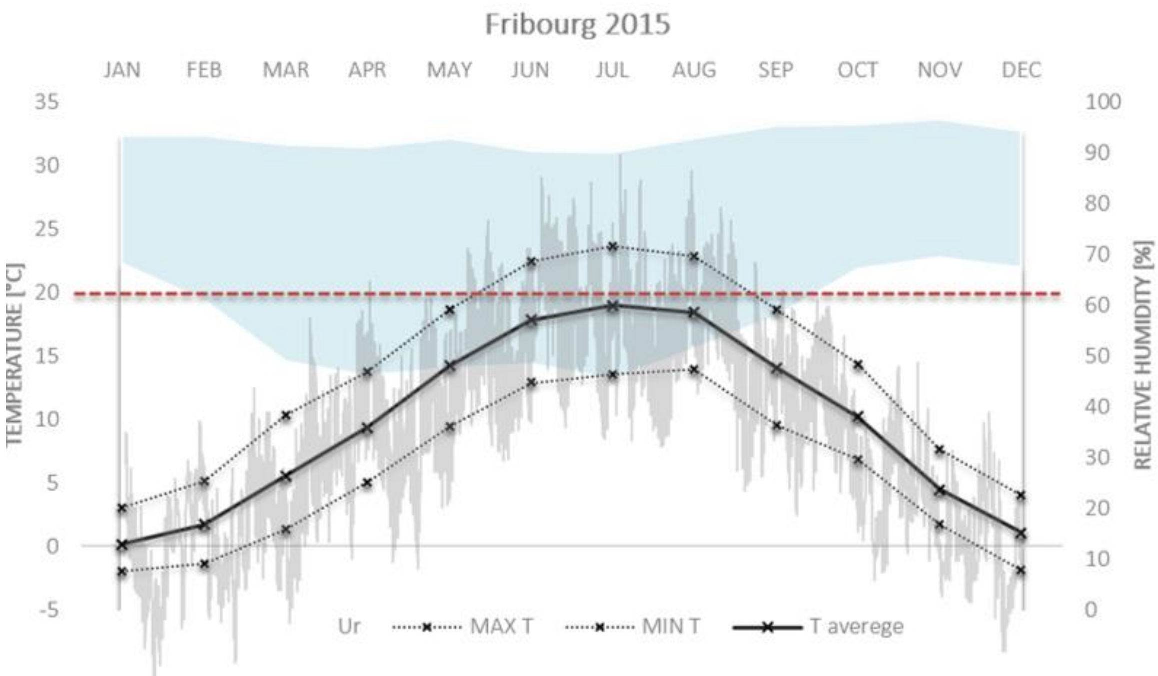


Figure 52: Fribourg Climate

From the data it is possible to notice that Fribourg has a very high relative humidity: the range of value is never below 50%, the data are generated with Meteonorm, but has been validated by SIA[33] and the 1961-1990 statistical value taken from the official meteo site[34]. Moreover, even when the minimum values are lower, the correspondent maximum ones are not following the same trend.

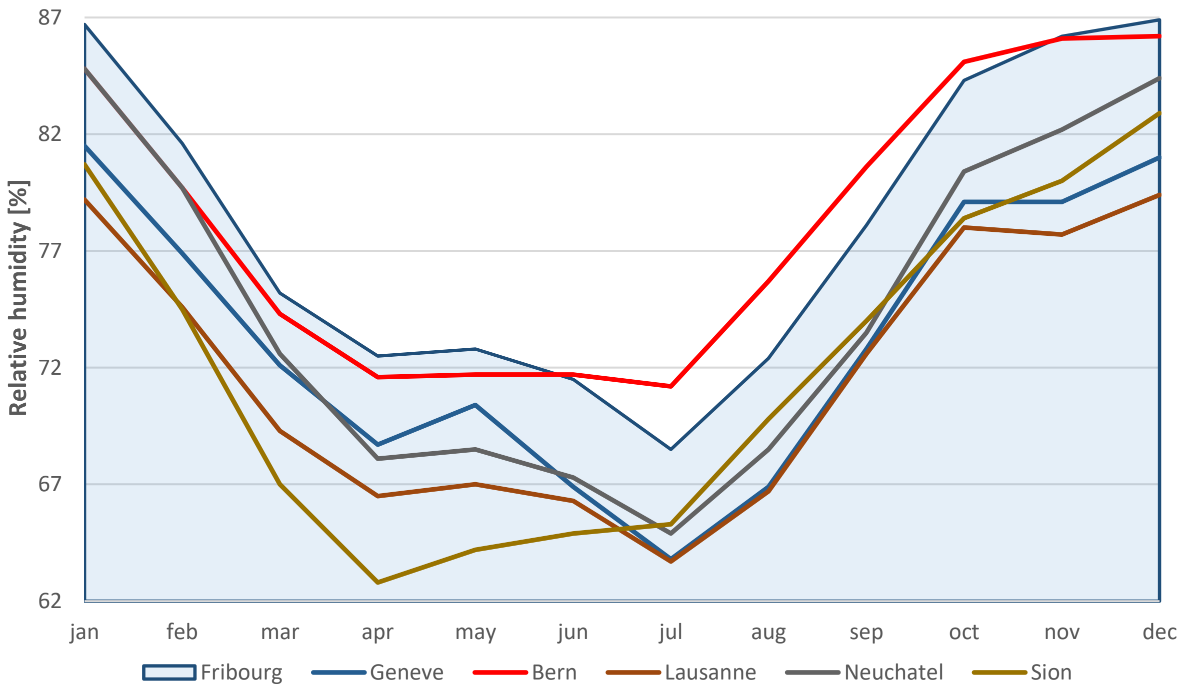


Figure 53: Average monthly humidity comparison for different Swiss locations

Comparing the data with other Swiss locations, as shown in Figure 53, it is possible to see that the geographical influence on the territory is relevant for this issue: the humidity of whole Fribourg-Bern zone is relatively higher than the rest of the country. The reason for this is found in the orography: Switzerland has a large number of lakes, whose evaporation increases the water content in the air. Moreover, the west region suffers from the influence of the Atlantic Ocean, which brings a temperate and humid wind inside. However, the effect of the "*foehn*", the hot and dry wind from the Alps, cannot reach the Fribourg area, and cannot therefore benefit from it, as Lausanne does[34].

High levels of humidity corresponds to comfort and health problems as well as easy degradation of materials and components. However, the humidity problem in Fribourg is not seen as a big issue, since there is no particular legislation that fixed the internal rate allowable, and the mechanical ventilation was introduced by the Minergie standard in the last years, focusing on this issue only recently. It will be important, therefore, to understand the reasons of this lag, the real effects of humidity in the region and the concrete repercussion on building's components and human life. An issue for the future development of the research program will be the assessment of humidity impacts and the necessary treatment.

On the other hand, temperatures indicate a rigid climate: the mean value is always below the limit of winter comfort, signed as 20°C. The monthly maximum, calculated as mean of the daily maximum, is less than 25°C, highlighting the results of the design priorities: heating is the main issue.

Wind analysis confirms the low potential for the active electricity production due to this resource. However, low value can be used for natural ventilation or be improved by district planning to change the site conditions, if needed. For this reason, further analysis will be done to understand deeper the favorable use of it.

Diffuse radiation is both scattered by the clouds and atmosphere, while the global one does not consider this phenomena. From the graph it is possible to notice that the difference between summer and winter of the two parameters is very different. Moreover, it is possible to see the high deviation of the value from the average during the cooling season: this is very important because it highlights that solar radiation is less but more constant on winter and, therefore, it is reasonable to implement solar gains catching measures inside the energy concept.

5.4.3. Climatic changes

The smart living lab will be tested for the 2015 Fribourg climate but also for future climates. Introducing a time shift will allow to understand the sensitivity of the design to climate change and validate the design or see where there is a necessity of implementation of the energy concept.

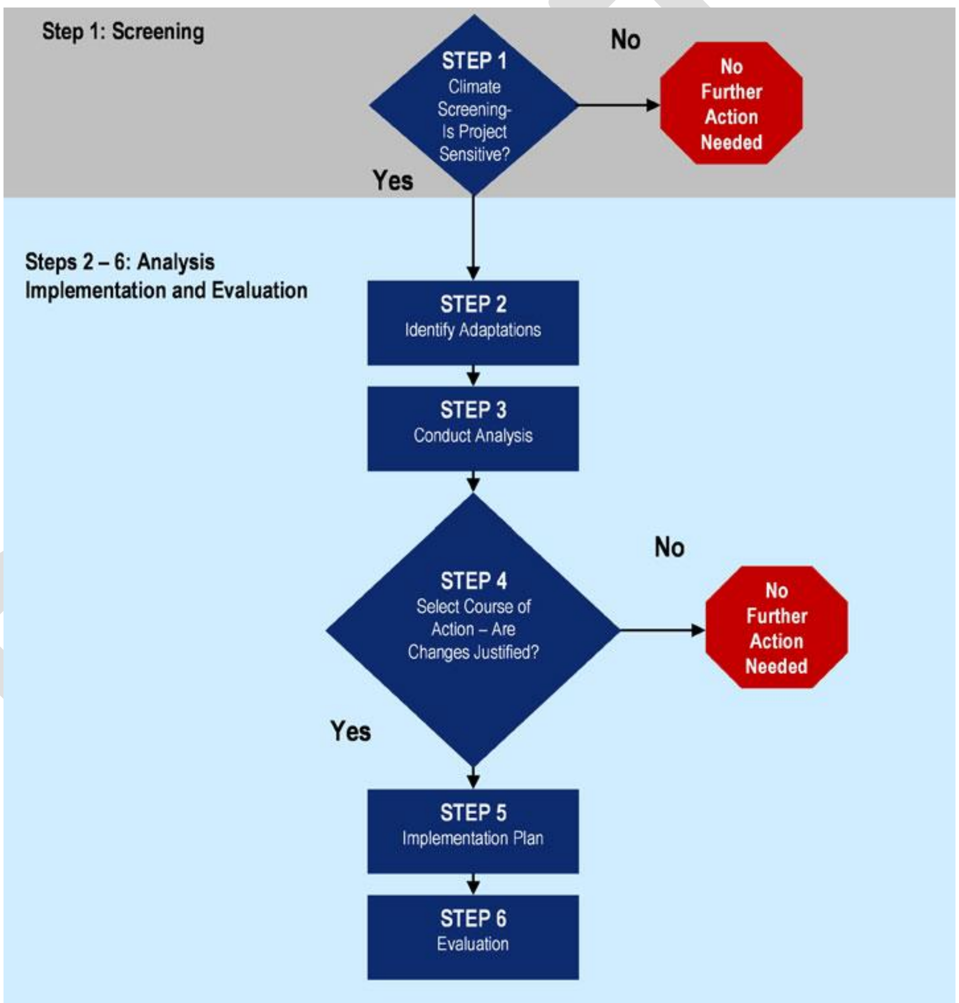


Figure 54: Methodology for testing the robustness of the design to climate change [17]

In order to perform the analysis under future climate it is necessary to refer to the already existing climate change scenarios, given by the Intergovernmental Panel on Climate Change (IPCC), an organization established by World meteorological Organization (WMO) and the United Nations Environment Programme (UNEP) to assess the scientific, technical and socio-economic information relevant for understanding the risk of the climate change. The so called SRES SCENARIOS are based on analysis of existing scenarios in literature and analysis of driving forces, relationships and characteristics of each of them. On these data there was the formulation of 4 storylines of future scenarios with the following quantification of each of them with modeling approaches coupled with an open review process[36]. There are different families of future scenarios, related to different trends of the driving factors; for the research program, three different are chosen, each of them representing a probable different situation. The METEONORM software is used to create the file. It works on a synthetic weather generator. Starting from known statistical relationship between observed climatic variables, projections are then used to stretch these links.

It is clear that future is unpredictable, and the scenarios are highly uncertain, however, based on the current state of climate science, the CH2011 studio offers this interpretation of the uncertainty range: the expected possibility that actual values will fall within the range of value given is two on three for temperatures and one on two for precipitation[37]. In the research program, the weather uncertainty is threatened in a simplified way: using the three different scenarios it is possible to create a range of value in which the smart living lab has to work. It is possible to have an interval of results in which the real performance will fall, by analyzing the behavior of the building according to all of them

Scenarios

The scenarios chosen are A1B, A2 and B1[36].

- A1B describes a very rapid economic growth, global population with a peak in mid-century and a decline after; rapid introduction of new and more efficient technologies in the energy system with a balance across the sources (fossil and renewable).
- A2 describes an uncontrolled continuous increment of global population; relying on fossil fuel and technological change is more fragmented and slower. This is the most uncertain scenario and represents the strongest warming potential.
- B1 describes a rapid change in economic structure, with reduction in materials intensity in favor of a service and information economy; introduction of clean and efficient technologies.

Differences

A deep and complete analysis on climate change in Switzerland is already available and gives a deep and complete vision of the problem[37][38]. In this paragraph the most important results for Fribourg are reported, confirming the trend of the whole Confederation.

For future scenarios the biggest uncertainty is related to the heating degree days and the cooling degree days[38],[39]. Defined as the difference between the temperature and the comfort zone, they are not just useful to estimate heating and cooling needs, but they are also useful parameters to set a fair comparison between different climate severity[40].The calculation is made based on the SIA method, considering a threshold of 12°C (normal construction), 10°C (efficient construction) and 8°C (very efficient construction) for heating, while for cooling the values considered are 18, 20 and 22°C.

SCENARIO	**HDD heating season**			**HDD year**			**CDD**		
	12°C	10°C	8°C	12°C	10°C	8°C	18°C	20°C	22°C
2015	3274	3057	2747	3282	3057	2747	133	63	19
2050 A1B	3068	2863	2500	3085	2863	2500	191	99	34
2050 A2	3098	2901	2572	3116	2901	2572	183	94	32

2050 B1	3223	3009	2664	3250	3009	2664	153	75	23

Table 20: Heating Degree Days and Cooling Degree Days for each scenarios calculated with different threshold of temperature

Results in Table 20 show that the city is aligned to the studies cited, in fact, also in Fribourg HDD will decrease and CDD will growth, signing the trend of moving towards a milder climate. The data show that energy spent for heating will be less than now, while theoretical energy spent for cooling will be more influent in the yearly balance. In fact, HDD will decrease of 10%, but CDD will increase up to 85%. However, even if this means that cooling will be more and more important in time, the difference in 2050 will be not enough to invert completely the design priorities. The critical season will be winter.

The scenario to which the analysis refers to is the 2050, and the changes are not yet so important and effective as the prevision for 2100 or later. However, the trend of the future is already visible, especially in the high variability scenarios.

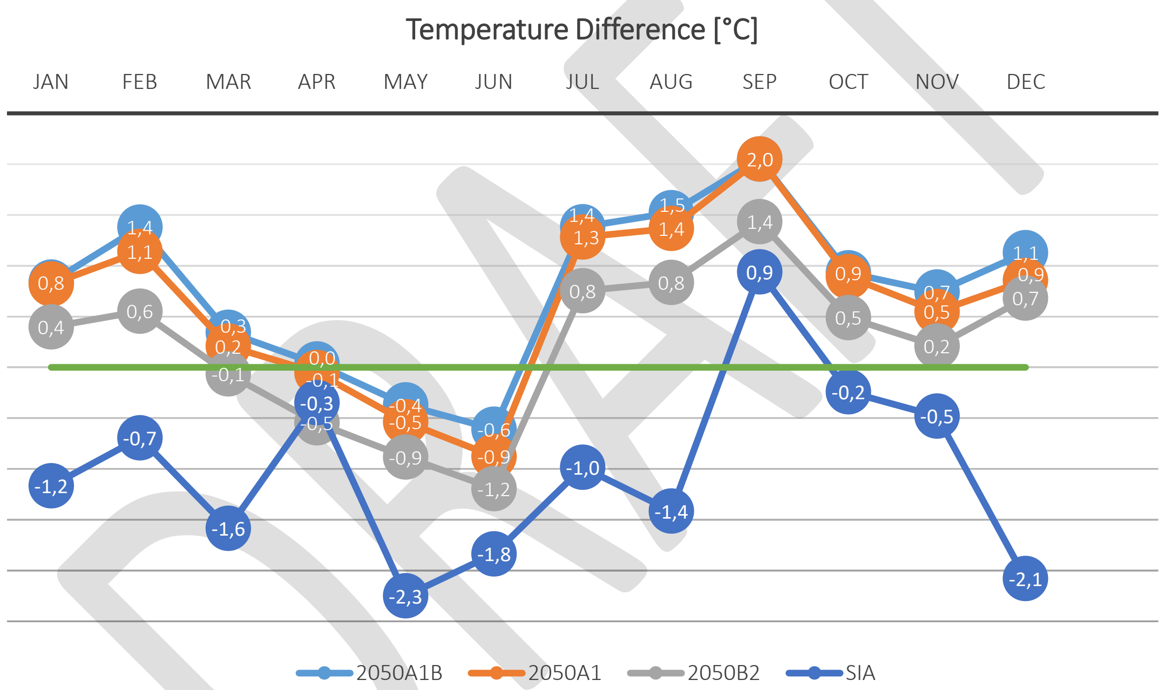


Figure 55: Temperature differences between 2014 (green line) and the other scenarios

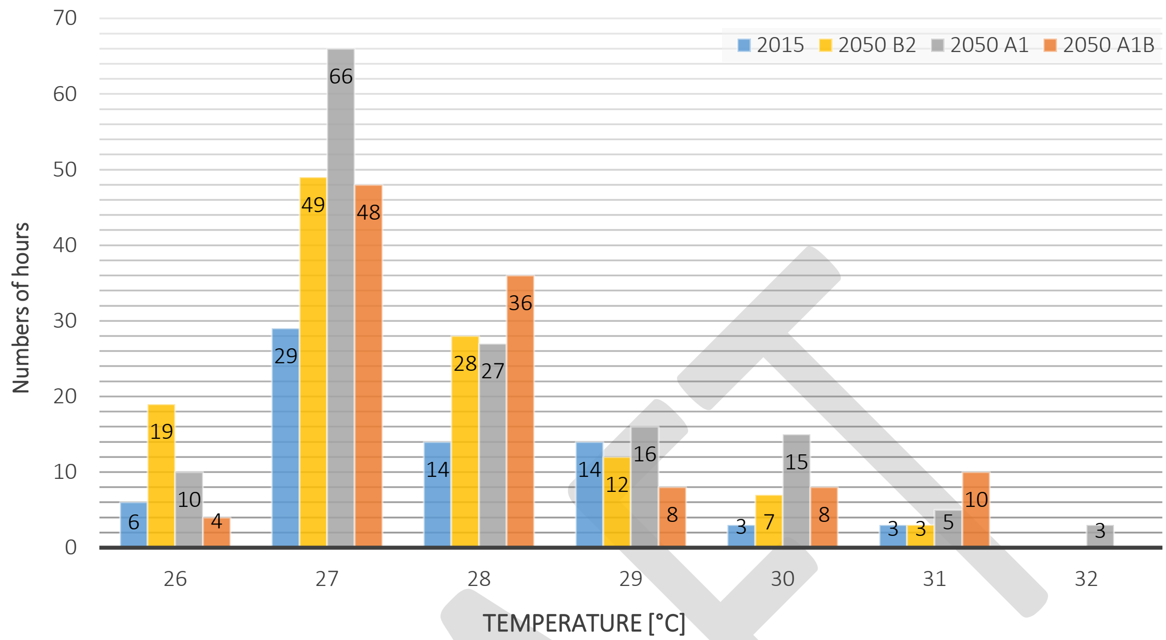


Figure 56: Distribution of hours above 26°C

In Figure 55 it is possible to see the difference between the actual weather file, the SIA indications and the future temperatures; in Figure 56, instead, it is reported the distribution of hours above each threshold. On average, the temperatures will rise up to 2°C. The maximum value will increase faster than the average, describing a more variable and standard deviation from the mean value in summer and balancing the temperature shift in winter. It is important to notice that, during the middle season, temperatures in all scenarios will decrease than the actual situation. This peculiarity can introduce, in the future, the implementation of new, different passive strategies. An interesting data is represented by the series of value given by SIA as the descriptive temperature for Fribourg: these are always lower than the actual one, showing a delate in updating the reference data in normative. This means that in Switzerland, buildings are designed on the basis of weather data that are already no more representative of the real climatic conditions, and, as consequence, constructions are dimensioned to answer to a more rigid climate. It is clear that the difference between normal buildings at the present time and the futures ones will be more important and more penalizing for the smart living lab.

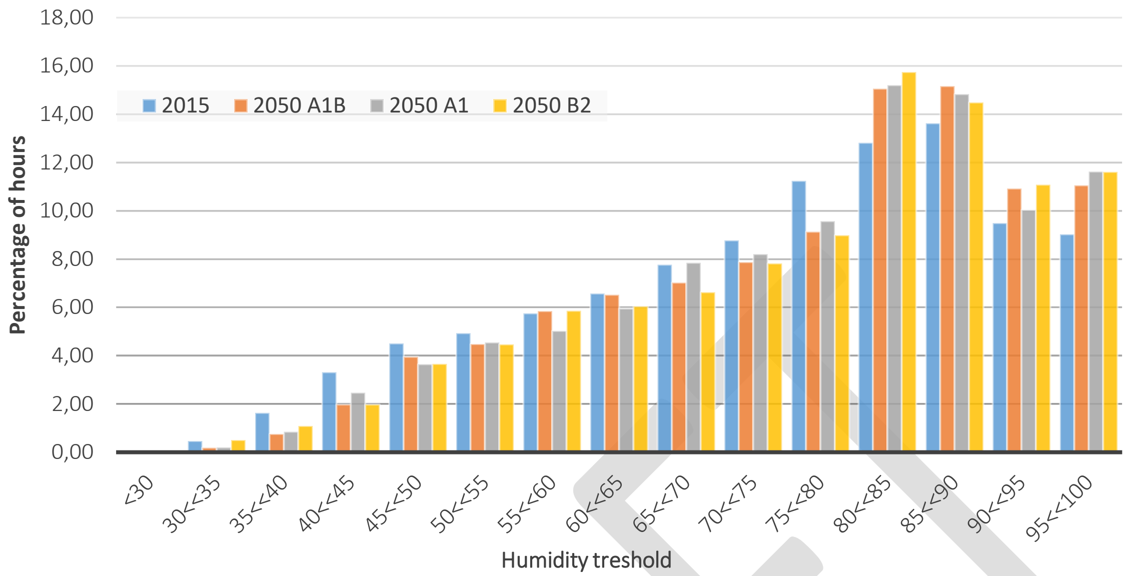


Figure 57: Percentage distribution of humidity value. The biggest number of hours have a humidity value bigger than 80%

Humidity, which is already the biggest issue in Fribourg weather regarding the target value fixed for the internal requirements, will continue to increase in future, as shown in Figure 57. The criticism is related also to the distribution of hours, which will, in all scenarios, increase in the upper band of values, between 90 and 100%. This means that the probability to fall in Ur value outside the comfort range is much higher and frequent, almost 50% of the hours in one year will have Ur more than 80%. In 2050, as now, the moisture problem is the main issue to face, both on the materials/components point of view and on the comfort/health side.

Heat wave analysis

The extremes of temperature show the future trend: mean summer value will rise, bringing also a higher frequency of hot spells. Coupled with a very high level of air humidity, it is possible that external conditions can easily bring to a condition of thermal stress and peaks. This phenomenon is called "heat wave" and it is highly unpredictable situation, catalogued as weather anomaly. The analysis of the heat wave is very important because extreme events can easily cause indoor overheating and situations of extreme discomfort[41]. The last exceptionally long canicule of the last years was registered in Europe in 2003. According to MetoSwiss, that summer was the warmest in the last 250 years. There were 975 deaths due to the extraordinary heat in Switzerland, where there were over 56 days with temperatures above 30°C and peaks of maximum daily value above 40°C, more than 5°C more than the averagely[42],[43]. The tendency is that heat waves are occurring more frequently: from one event every few decades to one every few years[37]. Since 2003, other events have been registered in 2006, 2010 and 2011. Unfortunately, there is no possibility to predict this situation in the long term; but an analysis on future trends can help to understand better the real danger related to canicule.

Actually, there is no unified and common definition, not only in the value that defines the boundaries, because strictly dependent to the climatic preconditions, but also in the methodology. The Swiss government, for example, refers to the definition of MeteoSwiss, which is based on the Heat Index defined by the National Oceanic and Atmospheric Administration[44]. However, there is still some confusion about it: the official Swiss definition does not report the units of the index and, moreover, on some documents other descriptions are given. For this reason, two different approaches were used: the American one and the one reported by the Service du Médecin Cantonal Fribourg[45].

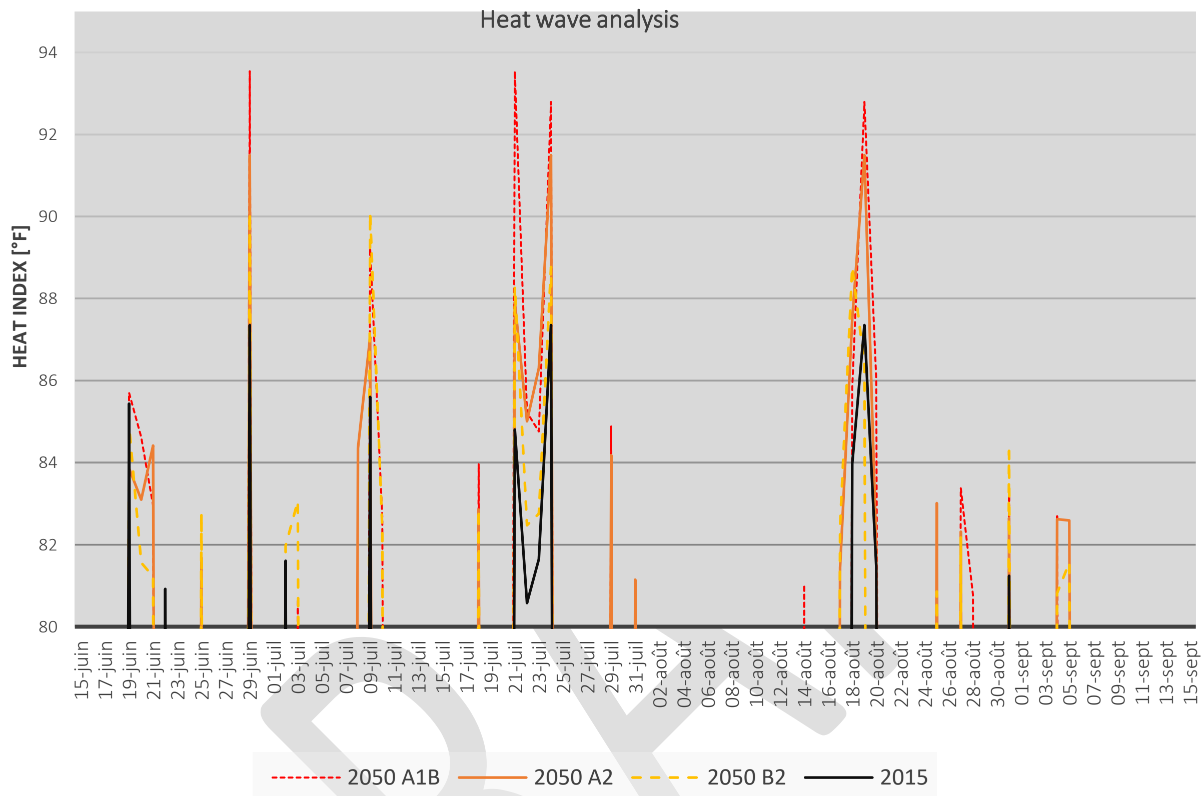


Figure 58: Heat index for each day of the heating season. 80°F is the limits for human body stress, 90°F is the limit for real danger

<u>*Method 1: METEOSWISS*</u>
The assessment of heat wave's risk is made through the evaluation of a parameter, called heat index (HI). This is calculated as a function of temperature and humidity with a complex algorithm, which is found to be valid only for the summer season. The boundaries of validity of this kind of analysis is given by the condition of temperature above 27°C and humidity more than 40%. Different values of HI are associated to a different level of health danger:

- 80°F < HI < 90°F: CAUTION Fatigue possible with prolonged exposure and/or physical activity
- 90°F < HI < 103°F: EXTREME CAUTION Heat stroke, heat cramps, or heat exhaustion possible with prolonged exposure and/or physical activity
- 103°F < HI < 124°F: DANGER Heat cramps or heat exhaustion likely, and heat stroke possible with prolonged exposure and/or physical activity
- HI > 124°F: EXTREME DANGER Heat stroke highly likely

If HI is above 90°F for more than 3 consecutive days, it's considered as a heat wave. However, all the value above 80°F in the analysis are considered and plotted on the graph.

Method 2: SERVICE DU MÉDECIN CANTONAL FRIBOURG

Given the high value of humidity of the region, the Health Office of the Canton states that it is possible to define a heat wave as the days in which the maximum daily temperature is above 32°C and the night one above 20°C. From Figure 58, it can be seen that there isn't any risk of heatwave according to the Heat Index definition, neither in 2015 nor in 2050. However, the value of the index is increasing fast, both in terms of value (more days with HI>90°F) and in terms of presence (more days with HI>80°F). According to the second definition, in 2015 there is no risk of heat wave and in 2050 just in one scenarios (A2) there is one day (21st July) in which maximum temperature could be 32.8°C and during the night 24.3°C. The weather file used for assessing the analysis, both for the actual situation and the future climates, are representative of the average set of values. Even if there is no clear clue of heat waves in the future, the higher values and the more frequent presence of peaks during the cooling season may bring the building to a situation of overheating. Simulation and analysis must be done to validate the design and to assess this risk.

5.5. Optmization of resources

Regarding the findings obtained during the previous analysis, it is important to assess the potential of the climate in relation to the possible bioclimatic strategies that could be implemented in the smart living lab. As said, passive strategies can be strictly related to the natural resources available on site or there can be architectural and technical solutions that respond to a determined need. The natural sources related to the different families considered are reported in Table 21. The following analysis tries to understand if the implementation of the main bioclimatic approaches is advisable with regards to the climatic conditions and the internal requirements.

Family	Aim	Solution's type		Parameters
Protect	protecting the interior boundaries from the external	architectural (technical)	SUN	global radiation, direct radiation
Dissipate	enhancing the thermal exchange between the indoor and the outdoor	architectural (technical)	AIR	ambient temperature, temperature swing, wind direction, wind pressure, relative humidity, specific humidity
Exchange	maximize the influence of the boundary surfaces within the thermal exchange	technical (architectural)	AIR	ambient temperature, sky clearness, sky temperature, relative humidity, specific humidity
Avoid	minimizing the internal sources of heat	technical and architectural	SUN	global radiation, direct radiation
Distribute	spreading the heat homogenously in the indoor spaces	technical and architectural	AIR	-
Store	enhancing the ability of the building to keep the heat	technical and architectural	AIR SUN	ambient temperature, temperature swing, direct solar radiation
Limit	minimizing the influence of the boundary surfaces within the thermal exchange	technical	AIR	ambient temperature
Exploit	maximizing the internal sources of heat	technical	AIR SUN	ambient temperature, direct radiation

Table 21:The passive strategies families and the natural source related

5.5.1. Heat gains

The design priorities identified by the case studies are the thermal loads, meant as heating demand and domestic hot water. For this reason the solar availability and the possibility to use the internal gains as a real resource must be analyzed. The common knowledge suggests that in cold climates windows should be designed, sized and orientated to maximize the heat gains; moreover, windows producers have introduced a coefficient of the elements, called Solar Heat gain Coefficient (SHGC). This parameter is defined as the fraction of incident solar radiation that enters indoor[46]. However, transparent surfaces are also the criticism of the envelope, with lower U value, surface temperature and thermal capacity. For this reason, it is important to understand if the positioning of a window and its relative thermal losses are compensated from the solar gains. A method to assess this analysis is to define a solar irradiation threshold, defined as the energy necessary to balance losses through the glazing during the heating season[47]. The parameters involved are:

- Glazing features as solar energy transmittance (g) and thermal transmittance (U)
- Climate, defined by the heating degree days (HDD)
- Utilization factor (n), to account the dynamic behavior of the buildings and its occupants

The formula is then defined by the literature as:

$$Glimit = \frac{24HDD\ U}{1000\ gn}$$

The analysis is made for two different type of glazing, one is the average common and the other a more efficient elements. The first set of value is characterized as:

- U: 1.3W/m^{2}K
- g: 0.75
- n: 0.6 [48]

The second, instead:

- U: 0.9W/m^{2}K, target value from SIA[5]
- g: 0.55, value for high thermal efficient glasses
- n: 0.8, improvement due to the higher awareness of users and better performance of buildings

Calculating the annual irradiation on a vertical surface with the main orientation the following results are found:

- irradiation on south façade: 725 kWh/m^2
- irradiation on west façade: 486 kWh/ m^2
- irradiation on east façade: 459 kWh/ m^2

Comparing with the threshold calculated, it is possible to see if the facades received enough solar energy to balance the hypothetical losses.

FACADE	AVERAGE WINDOWS	HIGH EFFICIENT WINDOWS
THRESHOLD	210 kWh/ m^2	180 kWh/ m^2
SOUTH	yes	yes
WEST	yes	yes
EAST	yes	yes

Table 22: Potential to balance the thermal losses due to windows on each facade

From the Table 22 it is possible to see that all the facades received enough solar irradiation to compensate the losses. However the research must be also validated with an urban assessment, in which the relationship between buildings and shades will confirm or change these conclusions. The first conclusion on the solar potential is that, in order to calibrate the losses, it is not so important to implement high thermal efficient glazing. On the other hand, it is possible to notice that losses with the average windows are much higher and, related to the uncertainty of the weather and the high clouds covering of Fribourg, the high efficient glazing should be implemented to consider this factors.

5.5.2. Evaporative cooling

Evaporative cooling is a strategy that relies on the physical principle of phase change of water into vapor in an adiabatic way. It is the addition of vapor into the air, which has the effect of lowering the temperature. The energy taken to evaporate the water, in fact, is taken from the air as sensible heat and converted in latent heat at a constant enthalpy value. The effect on the environment is to cause a drop in the air temperature and a proportional increase of humidity content of the air. When this process occurs without the assistance of a mechanical fan[49], it is called passive evaporative cooling. It is clear that high wet bulb temperature and humidity of the air decrease fast the potential of this technology[50]. Therefore, the criteria to understand the real applicability of this strategy are related to temperature and humidity of the external air[51]:

- external temperature > wet bulb temperature
- higher is the difference, higher is the potential (around 10°C is suggested)[51]
- wet bulb temperature must be within the comfort zone (indicatively between 9°C and 22°C)

The analysis is made on the whole cooling season. The critical months for passive evaporative cooling is September, because temperature is above the thermal neutrality, calculated as ISO EN 7730, but the minimum value of relative humidity is higher than in the hotter months.

As shown in Figure 59 the results indicate that the difference between the two temperatures is not enough, according to the definition, and constant to set up a real and effective cooling strategy. Moreover, to have a real effect on the internal temperature, the humidity rate used should be more than 90%, causing a higher probability of moisture and condensation inside. This strategy may have the opposite effect on the smart living lab, decreasing the level of comfort of users.

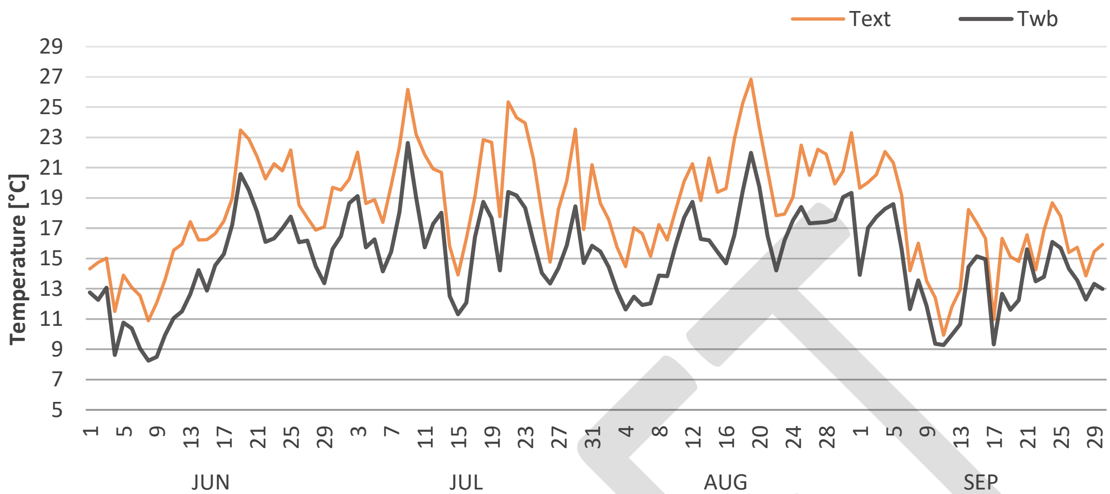


Figure 59: Evaporative cooling potential. The graph shows external and wet bulb temperature for the whole cooling season

5.5.3. Natural ventilation

The potential of natural ventilation is very difficult to assess and estimate, due to the variety of parameters from which it depends. However, it is possible to find how to simplify approaches that lead to a correct evaluation. For this study, the method reported by Givoni, refined by Watson and Labs and implemented in the software Climate Consultant is used[51],[52],[53].

Natural ventilation relies on pressure difference to move fresh air from outside to inside the buildings. This difference can be caused by wind or temperature swift. It is clear that the dependency on openings size, placement and orientation is predominant. However, it is important to analyze if the resources available can be used or not for this purpose, especially with regards to the comfort target value set. It is important, in fact, to remember that the air introduced with the windows opening is not treated and could be a cause of discomfort during the occupied hours.
The parameters involved are:

- Wet bub temperature (Twb), that should be below 22.8°C
- Velocity of air flow (Vf), that should be more than 2 m/s
- Relative humidity (Ur), indicated as lower than 90%, in this study the threshold of 70% is also assessed according to the target value
- External temperature (Text) that should have a difference between the internal (Tb) between 5°C and 20°C

The first three are related to the comfort requirements chosen, while the last one is the expression of the pressure difference needed to cause a movement of the air. The lower limits give the minimum difference necessary; the upper one, instead, is given for avoiding the risk of overcooling. The calculation is made on the daily average value.

[% DAYS ON COOLING SEASON]	2050 A1B
ALL THE REQUIREMENTS	16

ALL THE REQUIREMENTS (90)	43
WEB BULB TEMPERATURE > 22 °C	1
WIND SPEED < 2 m/s	57
RELATIVE HUMIDITY > 70%	66
RELATIVE HUMIDITY > 90 %	2
dT <5°C o dT>20°C	33

Table 23: Percentage of days during the cooling season that meet or not the requirements

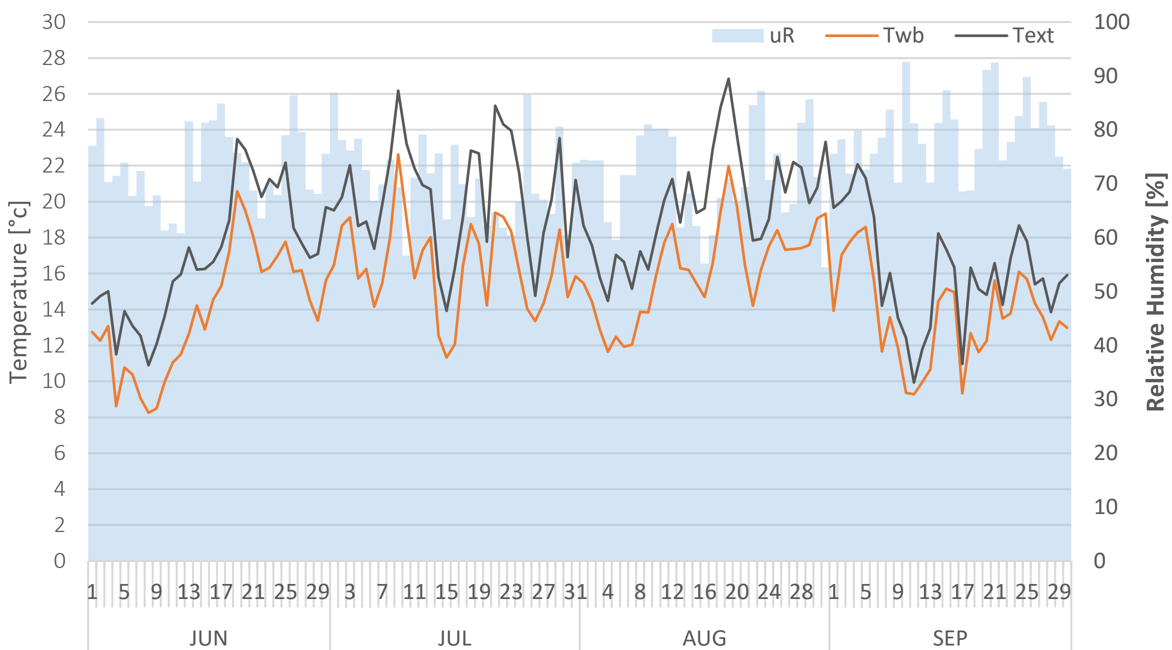


Figure 60: Natural ventilation potential. The graph shows the difference between external and wet bulb temperatures compared with levels of air humidity

It is possible to notice in Table 23 that only 16% of the days in the cooling season is inside the boundaries set, however the potential due to the temperature is quite high. The wind is not stable and the low velocity can make the ventilation ineffective due to the low pressure. However, the limiting factor is the humidity, and only 24% of the days have a value below 70%. If the threshold for it is increased to 90% of Ur, the possibility of using these strategies rise up to 43%. Considering that overheating is not the main issue inside, according to the case study analysis, it is possible to accept a maximum deviation allowed from the humidity target value for discrete periods of time. In this way, if cooling necessity occurs, for a shorter time during the day, it is possible to active natural cooling and accept Ur up to 90%. The research phase, with simulations and detailed design, will allow to quantify this limit due to the internal assessment.

5.5.4. Night ventilation

The high potential due to temperature shift during the day opens the possibilities for using exchange strategies during the night time. Low external night temperatures as reported in Fribourg, are a real resource for office building. During the night time, when the spaces are not occupied, it is in fact possible to discharge the heat stored during the working hours with lower strictness on internal comfort target values. The potential of this strategy is evaluated through a factor, called climatic cooling potential (CCD), which is the equivalent of the degree days but weighted on the night time. The criteria of evaluation is defined around a value of 80Kh, calculated as the minimum value for discharging a gain of 50W/m^2 in 8 hours with an air change rate of 6 ACH[54]. According to this, the potential is defined as:

- CCP<60Kh very low
- 60<CCP<120Kh promising potential
- CCP>120Kh high potential but risk of overcooling.

The principal parameters is the difference between the night temperature (Tn) and the inside temperature (Tb). In order to consider the dynamic and cyclical behavior of the building, Tb is calculated as a sinusoidal function on the night ventilation activation time, floating around the temperature that is set as internal requirement. The climatic cooling potential is then defined as the sum of all the hours, during the activation time (assumed from 20 pm to 07 am), in which the difference between Tn and Tb is higher than a value defined as threshold, suggested equal to 3°K[55].

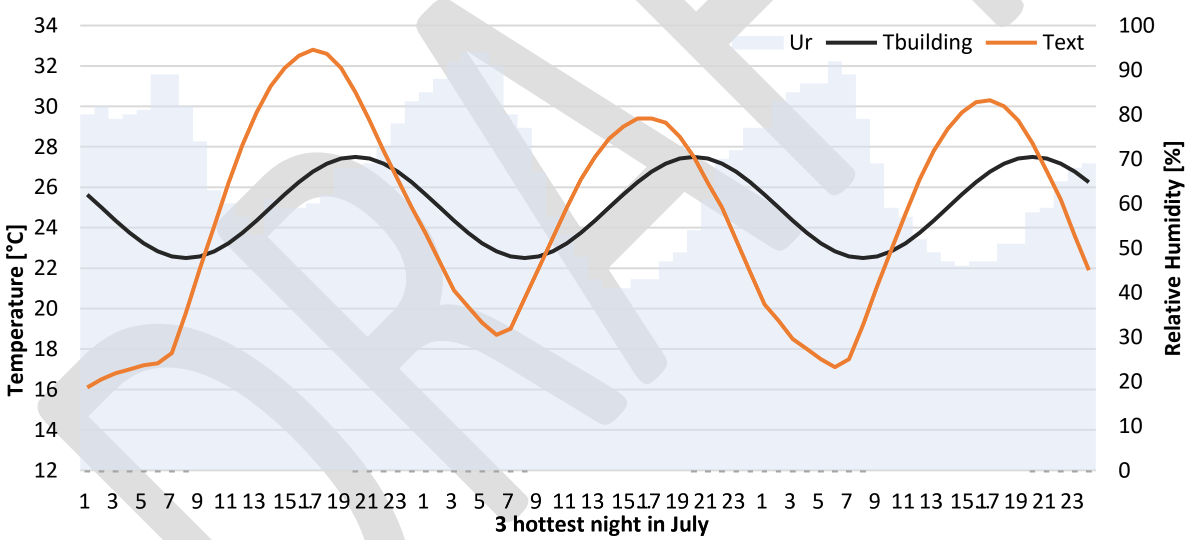


Figure 61: Night ventilation potential. The graph shows internal and external temperature for 21 -22-23 July, as well as relative humidity (critical parameter).

In Figure 61 are plotted the three worst night, defined as the ones with the lowest temperature potential, during the summer period. It is possible to notice that there is still a differential between the external temperature and the internal one, making the strategy a resource for natural cooling. However, the relative humidity nighttime is higher, due to the lower temperature, signing a limit that must be considered.

According to the definition, the lowest CCP possible for Fribourg is equal to 87Kh, signing a great potential of the night cooling and discharge of gains during the night. However, as it can be seen on the graph, relative humidity is still the main criticism. As for natural ventilation, it is possible to define a limit of acceptability from the deviation of the target value to implement night ventilation, should the need for cooling arise. In this case, the value of this threshold will be led only by the internal gains discharge issue and not comfort, because it takes place during the non-occupied hours. It is possible, therefore, that the use of this strategy will be more implementable in the design, in relation to the health and moisture requirements.

5.5.5. Passive energy draft

Understanding the potential of bioclimatic strategies is very difficult, because they are all strictly dependent on architecture, design and technological installation integrated in the building. Considering that the smart living lab will be highly innovative in terms of methodology of design, due to the life cycle driver, it is possible that the potential of each passive strategy will change consistently during the analysis. It is also possible that the requirements will change and, as a consequence, the way to treat resources. For example, as demonstrated, cooling may be an issue in the future and, therefore, since that the potential of exchange is low, working on the heat source inside the building will be necessary (removing internal gains). This analysis, however, is the first tool to define a draft of energy concept and indicate in which way the optimization process should go on.

Based on these assumptions, it is possible to define a radar of passive strategies that can show which one will be developed inside the building and which one does not have a great potential.

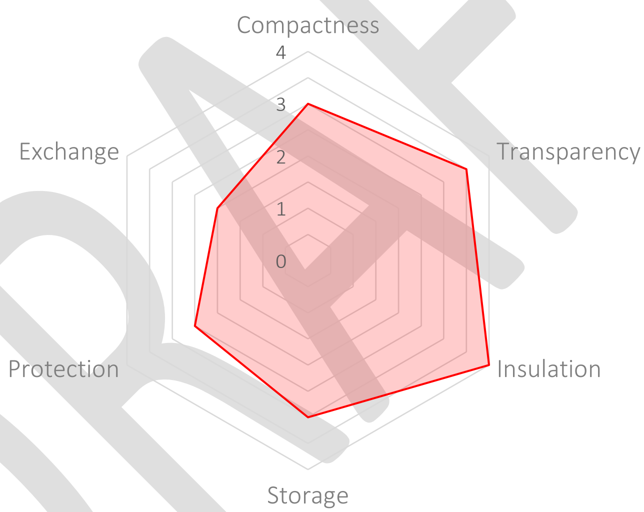


Figure 62: Radar of the future implementation and development of passive strategies inside the design optimization process

From Figure 62**Erreur ! Source du renvoi introuvable.**, it is possible to understand that the design will try, in the first place, to limit the thermal losses and maximize the heat gains. This solution is directly driven by the research priorities, defined by the case study analysis and the passive strategies potential, deducted by the external context and the internal target values. From the general strategy it is possible then to defined different families of spaces, according to the internal requirements defined for each zone. The procedure is the same that it is used in the flexibility field: grouping the functional spaces according to the similarity of requirements. The grouping, however, is different because for the energy concept it is important to look at comfort target values, while for flexibility it is based on a wider range of values, including construction and technological systems.

Based on the results of the case study, the clustering is made on the heating need, which are the most relevant and critical. In Figure 63 there are shown the spaces on a double axis: lighting requirement and heating need. Spaces have been ranked according to the internal requirements defined in Annex I.

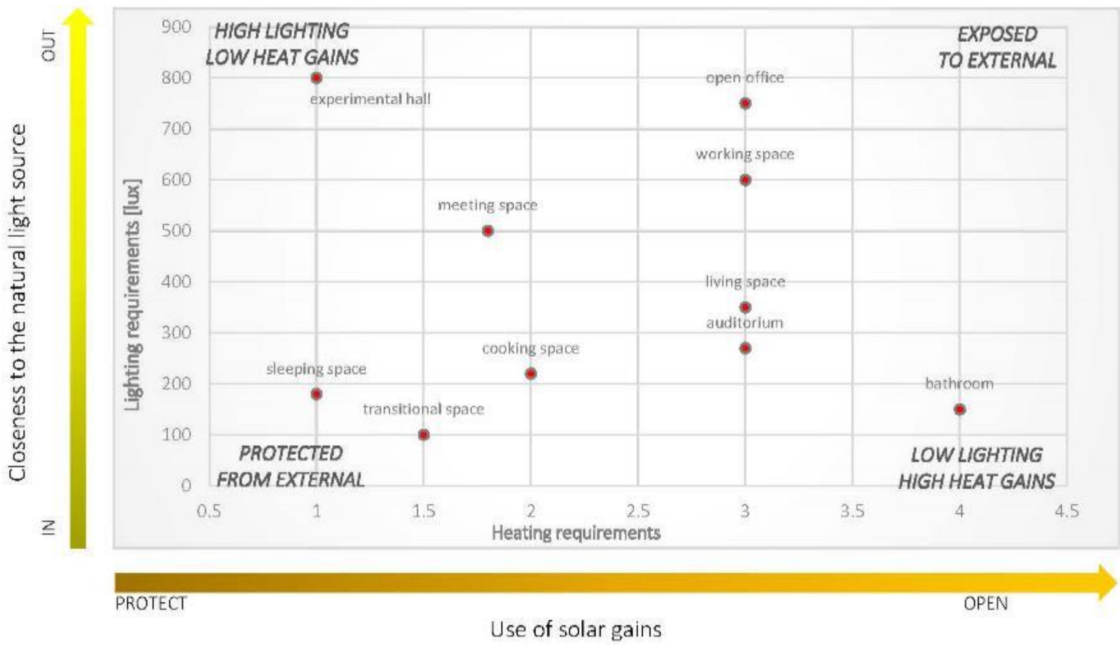


Figure 63: Disposition of the use spaces in the chart lighting/thermal requirements

It is possible then to clustering spaces on this basis:

- Group A, High lighting – low heating : experimental hall, meeting room
- Group B, Low lighting –high heating: bathroom, auditorium
- Group C, High lighting – high heating: open office, working spaces, living spaces
- Group D, Low lighting – low heating: sleeping spaces, transitional spaces, cooking spaces

Based on the group it is possible to define a set of criteria for the first draft of the energy concept related to the passive field.

PARAMETER	GROUP A	GROUP B	GROUP C	GROUP D
U value	SIA target value	SIA target value	SIA target value	SIA target value
Orientation	east – west - north	east - west	south	north
Porosity	high	normal	high	normal
Air exchange	controlled	controlled	controlled	controlled
Heat gains	avoid	exploit	exploit	avoid
Shading system	glare + gains	glare	glare	glare + gains

Table 24: Draft of the energy concept related to different space groups

Regarding the bioclimatic strategies related to the cooling season, the research will indicate if it is necessary to implement them inside the smart living lab concept or not. The application of each will be checked and cross regarding the requirements and the possibilities. For example, if natural ventilation is necessary to cool down the indoor spaces, but the external condition does not meet the comfort requirements (for humidity content of temperature) that it will be not used or it will be implemented during non-occupied hours and for limiting periods.

5.6. Conclusions

The state of the art highlights different important conclusions that will determine the direction of the future step in the research program. Starting from the Kaya factor optimization, the first step is to define the energy concept that could minimize the operational energy, to understand where, at the present time, is the current technology on the life cycle point of view. To define this, it is important to characterize the context beforehand.

In the first part, the internal comfort requirements are defined. It has been important to set limits for all the parameters that play an important role in the users' sensation and for the parameters that can cause health or technical problem. An example is the threshold for relative humidity, which has been fixed to 70% maximum, due to the moisture problems that can facilitate the fungal growth and the deterioration of materials.

The definition of the external context was the second step, in order to define an energy concept that can be specific to the smart living lab purpose. From the environmental point of view, there are no big constraints that can affect the design. However, the site presents several features that can be better exploited and investigated: industrial waste availability and easiness to implement geothermal probes on all. The analysis of the context focused then on the climatic conditions of Fribourg. The low temperature and relatively high humidity are the parameters that characterized the zone. The geological conformation of the land and the high rate of rainy days and cloud covering make the site critical on the moisture point of view. Analyzing the future trend, it is possible to see that this tendency will not be smoother in 2050. Climate is changing and going towards stronger summers, temperature will rise and, due to the greenhouse gas emission, sky coverings will be higher. Humidity, rainy days and direct radiation will, on the long term, change the relationship between resources availability and therefore, passive strategies potential. The energy concept must be validated on both time levels to assess the sensitivity of the smart living lab concept to climate change. On the other hand, regarding the renewable resources available in situ, there are some strengths and some weaknesses related also to the renewable energy production.

A strength is that the solar resource is present in a strong way in situ, even if it is not distributed evenly. Almost the 50% of the radiation is concentrated in three months (May-June-July). This is a problem for the matching of the requirements of the building (that are higher during the winter) with the solar radiation (lower in winter). Anyways, just generating electricity through photovoltaic system does not seem sufficient to cover the requirements of the Smart Living Lab during the whole year, or at least without using an energy storage for a seasonal time. The weakness is that other "traditional" renewable resources for the production of electrical energy cannot be used. The wind's average annual speed is too low, which does not allow the use of this source for energy purposes. However, considering that the electricity from the grid in Switzerland is one of the cleanest in the world, if it will be not possible to produce independently all the energy that the Smart Living Lab requires, it is more sustainable use the one from the grid. In this sense the heat pumps, with their small consumption of electricity, are an excellent solution for SH and DHW.

A deep analysis on case studies, to understand exactly the state of the art of the Minergie examples, has also been addressed. The investigation confirms that thermal loads are the main issue in Switzerland and, therefore, the passive strategies should focus on the heating season. These cases are, however, not specific to the smart living lab and a more accurate assessment will be done to see if, coupled with the future climate, cooling may become an issue. In general, looking at the renewable integration and smart energy production, they all suggest to not use particularly innovative or complicated technologies to provide energy for the building. They use wisely all the current technologies (like PV, Heat pump). Therefore, it will be useful to follow this path and possibly combine innovative systems for study or research, but do not base the whole energy concept of Smart Living Lab on that kind of systems. Always speaking of active systems, it is clear that some solutions are advantageous, from an efficiency point of view, and they must serve other buildings of the BlueFactory site and not only the Smart Living Lab (ex. biomass power plant with power generation and heat recovery).

Thanks to the analysis, it is possible to define the first energy concept, which will be developed and implemented due to the sensitivity analysis related to climate, use and requirements change. The design will be checked from an LCA point of view, trying to find the optimum to the Kaya factor. It is clear that optimum does not mean minimization, so it may be possible to re-design the energy concept that will not aim at minimizing the operation phase energy but will be validated on the balance with the embodied energy.

5.7. Research topics

How may short lifespan components have an influence on comfort regarding the passive strategies field?

Passive strategies are a filter between the internal and the external context, from the other point of view, it is possible to say that are the filter between weather and users, and act on the buildings level. However, it is still not clear if, related to the division into the primary and secondary project given by the state of the art in flexibility, they are influenced or not by the life span and the users interaction. It will be important during the research to understand which is the extent of the influence of lifespan of components to the passive field. Assuring passive strategies related to the secondary building, and so more close to users and more flexible to change, could be an important adding value to the customization of the internal environment according to users' preferences and assumptions' changes. However, deeper analysis must be taken to understand whether it is possible to implement the energy concept with in the shorter lifespan components or not and regarding the feasibility of this process.

How to implement inertia, if needed, into the smart living lab regarding to the life cycle target values?

The program is focused on the achievement of target value for the whole life cycle of the building, considering therefore the energy and the emissions used for processing materials. From the state of the art of the LCA field, it is possible to notice that concrete is one of the major contributors to the increase of the total embodied energy; for this reason the inertia issue must be considered carefully into the smart living lab. If it will be needed for assuring comfort, a deep analysis on the possibilities to implement it into the design must be assessed. From the state of the art it is possible to understand that inertia components are important into the Swiss climate to play into the building's system as thermal tank, however, there are not deep studies about the correlation of the role of concrete for comfort and not structural reason into the LCA. On the other hand all the studies are focusing on new materials, as phase change material, for addressing the comfort issue, even if it is not clear the relationship on the life cycle point of view. When it will be defined the total amount of inertia needed inside the smart living lab, it will be possible to understand in which way it is better to proceed:

- Implement traditional inertial material (concrete)
- Implement innovative artificial massive components (phase change materials)
- Implement low technological but high innovative materials (sand, soil, water..)

How to address the users interaction into the program? How to consider the influence of occupants inside the operating phase?

Users behavior can change operating energy of a factor of three, depending on the buildings characteristic and the users awareness to the theme of energy saving. In high efficiency building, the system is studied to work directly on external stimuli, bypassing the occupants; however, the most recent projects try to leave to users the possibility to adapt building's system according to their preferences. It is clear that if users interact with the equipment, then the performances of the building are far from the predicted ones, under the statically/statistical approach of simulations. Therefore, it is important to understand how it may be possible to guarantee change-efficient building, which could mean either a strong robustness of the design or a high capability to adapt and change according to needs. The research phase will also try to answer these questions, analyzing the sensitivity of the smart living lab to changes in assumption and understanding which should be the optimum way to achieve the target in every scenario.

5.8. ANNEX 1

	COMFORT		OPTIMUM	APCETTABLE	MAX DEVIATION ALLOWED	REFERENCES
Working space	thermal	**Top** [°C]	Winter: 22 Summer: Mc: 24.5 Fc: 0.33Trm+18.8	 21 / 24.5 Mc:23.5 / 27 Fc: Tn ± 4	 Nh20 <5% Mc: Nh25 <5% Nh28 <1% Fc: DhC <5%	SIA 180, EN 15251 ASHRAE 55
		Dt [°C/h]	0	2.2°C in 1h		SIA 180, EN 15251
		Ts [°C]	Top	19 / 29		SIA 180, EN 15251
		Ra [°C]	vertical: walls cool: wall warm: ceiling cool: ceiling warm:	3°C 10°C 20°C 15°C 5°C		SIA 180, EN 15251
	humidity	**Ur** [%]	30 / 60	80	Uax < 15.2 g/m^3 Out of limits for less than 5 consecutive days	EN 15251
	air quality	**Vr** [m/hper]	-	36		SIA 2024, SIA 380/1
		V [m/s]	-	Mo: 1.2 So: T<22.5: 0.15 T>22.5: 0.8		EN 15251
		C [ppm]	400 / 600	< 1000		EN 13779
	lighting	**E** [lux]	750	500		EN 12464-1
		Uo	0.7	0.6		EN 12464-1
		UGR	-	19		EN 12464-1
		DGP	0.35	0.45		CISBE code for lighting CIE 117
	acoustic	**Db** [DbA]	30	45		SIA 181, EN 12354
		Di [Db]	-	52		SIA 181
		De [Db]	-	27		SIA 181

		L’ [Db]	-	53	SIA 181

	COMFORT		OPTIMUM	APCETTABLE	MAX DEVIATION ALLOWED	REFERENCES
Meeting space	thermal	**Top** [°C]	Winter: 22 Summer: Mc: 24.5 Fc: 0.33Trm+18.8	 19 / 25 Mc:23 / 28 Fc: Tn ± 4	 Nh19 <5% Mc: Nh28 <5% Fc: DhC <5%	SIA 180, EN 15251 ASHRAE 55
		Dt [°C/h]	0	2.2°C in 1h		SIA 180, EN 15251
		Ts [°C]	Top	19 / 29		SIA 180, EN 15251
		Ra [°C]	vertical: walls cool: wall warm: ceiling cool: ceiling warm:	3°C 10°C 20°C 15°C 5°C		SIA 180, EN 15251
	humidity	**Ur** [%]	30 / 60	80	Uax < 15.2 g/m^3 Out of limits for less than 5 consecutive days	EN 15251
	air quality	**Vr** [m/hper]	-	36		SIA 2024, SIA 380/1
		V [m/s]	-	Mo: 1.2 So: T<22.5: 0.15 T>22.5: 0.8		EN 15251
		C [ppm]	400 / 600	< 1000		EN 13779
	lighting	**E** [lux]	-	500		EN 12464-1
		Uo	-	0.6		EN 12464-1
		UGR	-	19		EN 12464-1
		DGP	0.35	0.45		CISBE code for lighting CIE 117
	acoustic	**Db** [DbA]	30	45		SIA 181, EN 12354
		Di [Db]	-	52		SIA 181
		De [Db]	-	27		SIA 181
		L’ [Db]	-	53		SIA 181

	COMFORT		OPTIMUM	APCETTABLE	MAX DEVIATION ALLOWED	REFERENCES
Transitional space	thermal	**Top** [Db]	Winter: 22 Summer: Mc: 24.5 Fc: 0.33Trm+18.8	 18 / 26 Mc:22.5 / 30 Fc: Tn ± 4	 Nh18 <5% Mc: Nh30 <5% Fc: DhC <5%	SIA 180, EN 15251 ASHRAE 55
		Dt [°C/h]	0	2.2°C in 1h		SIA 180, EN 15251
		Ts [°C]	Top	19 / 29		SIA 180, EN 15251
		Ra [°C]	vertical: walls cool: wall warm: ceiling cool: ceiling warm:	3°C 10°C 20°C 15°C 5°C		SIA 180, EN 15251
	humidity	**Ur** [%]	30 / 70	80	Uax < 15.2 g/m^3 Out of limits for less than 5 consecutive days	EN 15251
	air quality	**Vr** [m/hper]		36		SIA 2024, SIA 380/1
		V [m/s]		Mo: 1.2 So: T<22.5: 0.15 T>22.5: 0.8		EN 15251
		C [ppm]	400 / 600	< 1000		EN 13779
	lighting	**E** [lux]	-	100 lift: 200		EN 12464-1
		Uo	-	0.4		EN 12464-1
		UGR	-	28 Stairs 25		EN 12464-1
		DGP	0.35	0.45		CISBE code for lighting CIE 117
	acoustic	**Db** [DbA]	30	45		SIA 181, EN 12354
		Di [Db]	-	47		SIA 181
		De [Db]	-	22		SIA 181
		L' [Db]	-	58		SIA 181

	COMFORT		OPTIMUM	APCETTABLE	MAX DEVIATION ALLOWED	REFERENCES
Auditoria	thermal	**Top** [°C]	Winter: 22 Summer: Mc: 24.5 Fc: 0.33Trm+18.8	 21 / 24.5 Mc:23.5 / 27 Fc: Tn ± 4	 Nh21 <5% Mc: Nh27 <5% Nh28 <1% Fc: DhC <5%	SIA 180, EN 15251 ASHRAE 55
		Dt [°C/h]	0	2.2°C in 1h		SIA 180, EN 15251
		Ts [°C]	Top	19 / 29		SIA 180, EN 15251
		Ra [°C]	vertical: walls cool: wall warm: ceiling cool: ceiling warm:	3°C 10°C 20°C 15°C 5°C		SIA 180, EN 15251
	humidity	**Ur** [%]	30 / 60	80	Uax < 15.2 g/m^3 Out of limits for less than 5 consecutive days	EN 15251
	air quality	**Vr** [m/hper]	-	36		SIA 2024, SIA 380/1
		V [m/s]	-	Mo: 1.2 So: T<22.5: 0.15 T>22.5: 0.8		EN 15251
		C [ppm]	400 / 600	< 1000		EN 13779
	lighting	**E** [lux]	300	200		EN 12464-1
		Uo	0.5	0.4		EN 12464-1
		UGR	-	22		EN 12464-1
		DGP	0.35	0.45		CISBE code for lighting CIE 117
	acoustic	**Db** [DbA]	30	35		SIA 181, EN 12354
		Di [Db]	-	57		SIA 181
		De [Db]	-	27		SIA 181
		L’ [Db]	-	53		SIA 181

smart living lab

	COMFORT		OPTIMUM	APCETTABLE	MAX DEVIATION ALLOWED	REFERENCES
Experimental hall	thermal	**Top** [°C]	Winter: 21 Summer: Mc: 24 Fc: 0.33Trm+18.8	 17.3 / 23 Mc:22 / 26 Fc: Tn ± 4	 Nh18 <5% Mc: Nh26 <5% Nh28 <1% Fc: DhC <5%	SIA 180, EN 15251 ASHRAE 55
		Dt [°C/h]	0	2.2°C in 1h		SIA 180, EN 15251
		Ts [°C]	Top	19 / 29		SIA 180, EN 15251
		Ra [°C]	vertical: walls cool: wall warm: ceiling cool: ceiling warm:	3°C 10°C 20°C 15°C 5°C		SIA 180, EN 15251
	humidity	**Ur** [%]	30 / 70	80	Uax < 15.2 g/m³ Out of limits for less than 5 consecutive days	EN 15251
	air quality	**Vr** [m/hper]	-	36		SIA 2024, SIA 380/1
		V [m/s]	-	Mo: 1.2 So: T<22.5: 0.15 T>22.5: 0.8		EN 15251
		C [ppm]	400 / 600	< 1000		EN 13779
	lighting	**E** [lux]	750	500		EN 12464-1
		Uo	-	0.6		EN 12464-1
		UGR	-	19		EN 12464-1
		DGP	0.35	0.45		CISBE code for lighting CIE 117
	acoustic	**Db** [DbA]	30	35		SIA 181, EN 12354
		Di [Db]	-	47		SIA 181
		De [Db]	-	22		SIA 181
		L’ [Db]	-	58		SIA 181

smart
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	COMFORT		OPTIMUM	APCETTABLE	MAX DEVIATION ALLOWED	REFERENCES
Living space	thermal	**Top** [°C]	Winter: 20.5 Summer: Mc: 25 Fc: 0.33Trm+18.8	18 / 24 Mc:23.5 / 26.5 Fc: Tn ± 4	Nh18 <5% Mc: Nh27 <5% Nh28 <1% Fc: DhC <5%	SIA 180, EN 15251 ASHRAE 55
		Dt [°C/h]	0	2.2°C in 1h		SIA 180, EN 15251
		Ts [°C]	Top	19 / 29		SIA 180, EN 15251
		Ra [°C]	vertical: walls cool: wall warm: ceiling cool: ceiling warm:	3°C 10°C 20°C 15°C 5°C		SIA 180, EN 15251
	humidity	**Ur** [%]	30 / 60	80	Uax < 15.2 g/m^3 Out of limits for less than 5 consecutive days	EN 15251
	air quality	**Vr** [m/hper]	-	36		SIA 2024, SIA 380/1
		V [m/s]	-	Mo: 1.2 So: T<22.5: 0.15 T>22.5: 0.8		EN 15251
		C [ppm]	400 / 600	< 1000		EN 13779
	lighting	**E** [lux]	-	200		EN 12464-1
		Uo	-	0.4		EN 12464-1
		UGR	-	22		EN 12464-1
		DGP	0.35	0.45		CISBE code for lighting CIE 117
	acoustic	**Db** [DbA]	30	45		SIA 181, EN 12354
		Di [Db]	-	52		SIA 181
		De [Db]	-	27		SIA 181
		L' [Db]	-	53		SIA 181

	COMFORT		OPTIMUM	APCETTABLE	MAX DEVIATION ALLOWED	REFERENCES
Sleeping space	thermal	**Top** [°C]	Winter: Summer: Mc: Fc: 0.33Trm+18.8	 16 / 25 Mc:26.5 Fc: Tn ± 4	 Nh169 <5% Mc: Nh28 <5% Fc: DhC <5%	SIA 180, EN 15251 ASHRAE 55
		Dt [°C/h]	0	2.2°C in 1h		SIA 180, EN 15251
		Ts [°C]	Top	19 / 29		SIA 180, EN 15251
		Ra [°C]	vertical: walls cool: wall warm: ceiling cool: ceiling warm:	3°C 10°C 20°C 15°C 5°C		SIA 180, EN 15251
	humidity	**Ur** [%]	30 / 60	80	Uax < 15.2 g/m^3 Out of limits for less than 5 consecutive days	EN 15251
	air quality	**Vr** [m/hper]	30	15		SIA 2024, SIA 380/1
		V [m/s]	-	Mo: 1.2 So: T<22.5: 0.15 T>22.5: 0.8		EN 15251
		C [ppm]	400 / 600	< 1000		EN 13779
	lighting	**E** [lux]	-	200		EN 12464-1
		Uo	-	0.4		EN 12464-1
		UGR	-	22		EN 12464-1
		DGP	0.35	0.45		CISBE code for lighting CIE 117
	acoustic	**Db** [DbA]	25	35		SIA 181, EN 12354
		Di [Db]	-	52		SIA 181
		De [Db]	-	27		SIA 181
		L' [Db]	-	53		SIA 181

	COMFORT		OPTIMUM	APCETTABLE	MAX DEVIATION ALLOWED	REFERENCES
Cooking space	thermal	**Top** [Db]	Winter: 20.5 Summer: Mc: 25 Fc: 0.33Trm+18.8	 19 / 25 Mc:23.5 / 27.5 Fc: Tn ± 4	 Nh19 <5% Mc: Nh28 <5% Fc: DhC <5%	SIA 180, EN 15251 ASHRAE 55
		Dt [°C/h]	0	2.2°C in 1h		SIA 180, EN 15251
		Ts [°C]	Top	19 / 29		SIA 180, EN 15251
		Ra [°C]	vertical: walls cool: wall warm: ceiling cool: ceiling warm:	3°C 10°C 20°C 15°C 5°C		SIA 180, EN 15251
	humidity	**Ur** [%]	30 / 70	80	Uax < 15.2 g/m^3 Out of limits for less than 5 consecutive days	EN 15251
	air quality	**Vr** [m/hper]	-	36		SIA 2024, SIA 380/1
		V [m/s]	-	Mo: 1.2 So: T<22.5: 0.15 T>22.5: 0.8		EN 15251
		C [ppm]	400 / 600	< 1000		EN 13779
	lighting	**E** [lux]	-	200		EN 12464-1
		Uo	-	0.4		EN 12464-1
		UGR	-	22		EN 12464-1
		DGP	0.35	0.45		CISBE code for lighting CIE 117
	acoustic	**Db** [DbA]	25	40		SIA 181, EN 12354
		Di [Db]	-	47		SIA 181
		De [Db]	-	22		SIA 181
		L’ [Db]	-	58		SIA 181

	COMFORT		OPTIMUM	APCETTABLE	MAX DEVIATION ALLOWED	REFERENCES
Bathing space	thermal	**Top** [°C]	Winter: 23.5 Summer: Mc: 27.5 Fc: 0.33Trm+18.8	 22 / 28 Mc:24 / 28 Fc: Tn ± 4	 Nh22 <5% Mc: Nh28 <5% Fc: DhC <5%	SIA 180, EN 15251 ASHRAE 55
		Dt [°C/h]	0	2.2°C in 1h		SIA 180, EN 15251
		Ts [°C]	Top	19 / 29		SIA 180, EN 15251
		Ra [°C]	vertical: walls cool: wall warm: ceiling cool: ceiling warm:	3°C 10°C 20°C 15°C 5°C		SIA 180, EN 15251
	humidity	**Ur** [%]	30 / 70	80	Uax < 15.2 g/m^3 Out of limits for less than 5 consecutive days	EN 15251
	air quality	**Vr** [m/hper]	30	15		SIA 2024, SIA 380/1
		V [m/s]	-	Mo: 1.2 So: T<22.5: 0.15 T>22.5: 0.8		EN 15251
		C [ppm]	400 / 600	< 1000		EN 13779
	lighting	**E** [lux]	-	200		EN 12464-1
		Uo	-	0.4		EN 12464-1
		UGR	-	22		EN 12464-1
		DGP	0.35	0.45		CISBE code for lighting CIE 117
	acoustic	**Db** [DbA]	40	50		SIA 181, EN 12354
		Di [Db]	-	47		SIA 181
		De [Db]	-	22		SIA 181
		L' [Db]	-	53		SIA 181

6. Conclusions

The state-of-the-art report is aimed at finding the current available scientific knowledge regarding the research fields within the smart living lab building 2050 program.

Concerning the 2050 goals, the first challenge was to define the targets. According to the literature, we have chosen to follow the 2,000-Watt Society model, which is a political and scientific way to outline a sustainable society that would tackle climate change. Three main impacts will be assessed: the cumulative energy demand, the non-renewable cumulative energy demand and the global warming potential indicator. Thanks to both top-down and bottom-up approaches, we were able to define objectives at the smart living lab building component level.

The LCA research field enabled us to understand the performance of current best practices. It shows that none of the three analyzed impacts (CED, CEDnr, GWP) reaches in the same time the 2,000-Watt Society model. Also, there is no correlation between operating impacts and embodied impacts. For example, a very efficient building for operating energy could have a high or low embodied impact. The only strong correlation that has been observed is between the CEDnr and GWP impacts. Analyses also demonstrate that it is harder to reach the GWP than the CEDnr goals. Thus, instead of always using the three analyzed impacts (CED, CEDnr, GWP), we will also be able to only consider two of them: GWP and CED. Regarding the research scope, we have noticed that the building field is well-covered by LCA studies, whereas there is comparatively very few scientific material about induced impacts of buildings' related mobility and food issues. As a last point, the literature enabled us to choose the database and tools that will be relevant for us in the next research phase.

As a second point, we have come up with a definition of the flexibility of the smart living lab building. Taking into account that it has to be a very efficient building, the flexibility cannot be achieved through a highly multifunctional building with a lot of implemented technologies resulting in a high-embodied energy content. Therefore, flexibility for the smart living lab means providing at the right time building components and products to the users' requirements and changes. This leads to separate the building components at every lifecycle steps, this according to two different parameters: the component lifetime and the interactive level between components and users.

Finally, the energetic strategies research field offers us a deep understanding of the Fribourg climate situation and its consequences on the smart living lab building design. This analysis takes into consideration the current climate, but also the 2050 predicted climate based on IPCC scenarios. For instance, it reveals that the relative humidity is very high during the whole year, reaching frequently 90% at night during the hot season, and that this phenomenon will increase till at least 2050. This situation will be specifically taken into account in the future design thanks to comfort and health assessments. Moreover, all the available renewable energies were evaluated in order to measure their potential within the future building. In the meantime, internal comfort requirements were defined according to each different functional spaces of the smart living lab building. This analysis of internal requirements and external climate context, coupled with a best practice analysis, enabled us to define the first energy strategies suitable for the smart living lab building and its environment.

7. References

7.1. LCA

[1] E. Jochem, G. Andersson, D. Favrat, H. Gutscher, K. Hungerbühler, P. R. von Roh, D. Spreng, A. Wokaun, et M. Zimmermann, « A white book for R&D of energy-efficient technologies », Novantlantis, Switzerland, 2004.
[2] SIA Documentation 2040, « La voie SIA vers l'efficacité énergétique », SIA, Switzerland, Norm, 2011.
[3] B. Bébié, P. Dietrich, A. Eckmanns, K. Egger, R. Frischknech, H. Gugerli, C. Hartmann, M. Lenzlinger, S. Schneider, R. Stulz, et U. Vogel, « Société à 2000 watts. Concept pour l'établissement d'un bilan », Office fédérale de l'énergie, Switzerland, 2012.
[4] R. Frischknecht, N. Jungbluth, H.-J. Althaus, C. Bauer, G. Doka, R. Dones, R. Hischier, S. Hellweg, S. Humbert, T. Köllner, Y. Loerincik, M. Margini, et T. Nemecek, « Implementation of Life Cycle Impact Assessment Methods Data v2.0 (2007) », Switzerland, 2007.
[5] D. Kellenberger, M. Ménard, S. Schneider, M. Org, K. Victor, et S. Lenel, « Réhabiliter des friches industrielles pour réaliser la société à 2000 watts. Guide et exemples », Projet conjoint de Stadt Zürich, Zürich ewz, Confédératioin Suisse, Switzerland, 2012.
[6] D. Leuthard, H.-P. Nützi, M. Beniston, R. Nordmann, J. Audemars, F. Schiesser, J.-F. Affolte, K. Baltensperger, K. Boulouchos, P. Dietrich, X. Edelmann, J. Hering, J. Kirchner, H.-B. Püttgen, J.-L. Scartezzini, A. Wokaun, C. Mauch, M.-T. Büsser, B. Bébié, H. Gugerli, R. Ott, S. Rigon, H. Hoffmann-Riem, B. Hohl, G. Morin, A. Binz, V. Yoyce, D. Keller, W. Müller, R. Camponovo, J. M. Duret, Y. Leuzinger, K. Egger, A. Braunwalder, M. Chenal, S. Borboën, B. Dufour-Fallot, R. Stulz, V. Sutter-Gmür, F. Frei, E. Schmausser, M. Bourquin, A. Fink, U. Richard, S. Lienin, S. Perret, et B. Kasemir, « Vivre plus légèrement. Vers un avenir énergétique durable : l'exemple de la société à 2000 watts », Projet conjoit de la SIA, suisse énergie and Novatlantis, Switzerland, 2011.
[7] D. Kellenberger, M. Ménard, S. Schneider, M. Hänger, M. Org, K. Victor, et S. Lenel, « Arealentwicklung für die 2000-Watt-Gesellschaft Beurteilungsmethode in Anlehnung an den SIA-Effizienzpfad Energie », Stadt Zürich, Zürich ewz, Confédératioin Suisse, Switzerland, 2012.
[8] F. Wyss, R. Frischknech, et V. John, « Zielwert Gesamtumweltbelastung Gebäude: Machbarkeitsstudie », Switzerland, 2014.
[9] SIA Documentation D0236, « La voie SIA vers l'efficacité énergétique-Compléments et exemples relatifs au cahier technique SIA 2040 Zurich », SIA, Switzerland, Norm, 2011.
[10] A. F. Donzel, U. Liman, G. Riera, et Y. Roulet, « Sméo Société à 2000 watts », Equipe SméO Bâtiment, Switzerland, 2014.
[11] N. Jungbluth, M. Stucki, et M. Leuenberger, « Environmental Impacts of Swiss Consumption and Production: A combination of input-output analysis with life cycle assessment. », Federal Office for the Environment FOEN, Switzerland, 2011.
[12] « BEDZESD PAVILION ». [En ligne]. Disponible sur: http://home2.btconnect.com/bedzedpavilion/.
[13] « Quartier Vauban », 2013. [En ligne]. Disponible sur: http://www.vauban.de/fr/. [Consulté le: 30-mars-2015].
[14] « Vesterbro ». [En ligne]. Disponible sur: http://www.visitdenmark.fr/fr/copenhagueencoreplus-vesterbro. [Consulté le: 30-mars-2015].
[15] ConsoGlobe, « Eco-Viikki : le quartier vert d'Helsinki ». [En ligne]. Disponible sur: http://www.consoglobe.com/eco-viikki-ecoquartier-dhelsinki-cg. [Consulté le: 30-mars-2015].
[16] « EVA-Lanxmeer ». [En ligne]. Disponible sur: http://www.eva-lanxmeer.nl/. [Consulté le: 30-mars-2015].
[17] Le Nouvelliste, « De l'écoquartier à la ville "durable" », 2014. [En ligne]. Disponible sur: http://www.lenouvelliste.ch/fr/en-continu/de-l-ecoquartier-a-la-ville-durable-479-1327397. [Consulté le: 30-mars-2015].

[18] G. Yepez-Salmon, « Construction d'un outil d'évaluation environnementale des éco quartiers : vers une méthode systémique de mise en œuvre de la ville durable », PhD, Université Bordeaux, France, 2011.
[19] L. Gustavsson, A. Joelsson, et R. Sathre, « Life cycle primary energy use and carbon emission of an eight-storey wood-framed apartment building », Energy Build., vol. 42, no 2, p. 230-242, févr. 2010.
[20] A. Lebert, S. Lasvaux, F. Grannec, S. Nibel, F. Achim, et N. Schiopu, « Capitalisation des résultats de l'expérimentation HQE Performance. Rapport intermédiaire », CSTB, France, DEE/ EICV - 14 . 027, oct. 2013.
[21] T. Ramesh, R. Prakash, et K. K. Shukla, « Life cycle energy analysis of buildings: An overview », Energy Build., vol. 42, no 10, p. 1592-1600, oct. 2010.
[22] CIRCE, « Energy Saving through Promotion of Life Cycle Assessment in Building », enslic Building, Europe, EIE/07/090/SI2.467609, 2010.
[23] J. Arfvidsson, E. De Angelis, A. Dodoo, F. Doleza, L. Gustavsso, A. Hafner, T. Häkkinen, M. Kuittinen, L. Linkosalmi, A. Ludvig, O. M. am Tinkhof, H. Mötzl, S. O. Mundt-Petersen, S. Ott, D. Peñaloza, F. Pittau, R. Sathre, C. Spitzbart, A. Takano, T. Toratti, T. Valtonen, S. Vares, G. Weiss, S. Winter, et G. Zanata, « Wood in carbon efficient construction: Tools, methods and applications », Aalto University, Finland, 2013.
[24] B. Berggren, M. Hall, et M. Wall, « LCE analysis of buildings – Taking the step towards Net Zero Energy Buildings », Energy Build., vol. 62, p. 381-391, juill. 2013.
[25] A. Passer, H. Kreiner, et P. Maydl, « Assessment of the environmental performance of buildings: A critical evaluation of the influence of technical building equipment on residential buildings », Int. J. Life Cycle Assess., vol. 17, no 9, p. 1116-1130, mai 2012.
[26] A. Passer, « Assessment of the environmental performance of building », PhD thesis, TU Graz, Austria, 2010.
[27] V. John, « Derivation of reliable simplification strategies for the comparative LCA of individual and "typical" newly built Swiss apartment buildings », PhD, ETH Zurich, Switzerland, 2012.
[28] U. Lehman, « Analyse du cycle de vie du "Green-Offices" », Minimémoire, Univérsité de Lausanne, Switzerland, 2011.
[29] PRé, various authors, « SimaPro Database Manual: Methods library », PRé - Sustainability, nov. 2014.
[30] Ecoinvent, « Ecoinvent V3 », Swiss Centre for Life Cycle Inventories, 2015-1998. [En ligne]. Disponible sur: http://www.ecoinvent.ch/. [Consulté le: 30-mars-2015].
[31] R. Itten, R. Frischknecht, et M. Stucki, « Life Cycle Inventories of Electricity Mixes and Grid », treeze Ltd., fair life cycle thinking Kanzleistr. 4, CH - 8610 Uster, Switzerland, 2014.
[32] W. Ott, R. Frischknecht, M. Kärcher, M. Grütter, A. Baumgartner, R. Itten, et N. Cerny, « Erfolgskontrollei 2000-Watt-Gebäude », Energieforschung Stadt Zürich, Switzerland, 2014.
[33] R. Bergman, M. Puettmann, et A. Taylor, « Carbon impacts of wood products », U.S.A.
[34] S. Tranchte et A. de Herde, « Chox des matériaux. Ecobilan de parois », Belgium, 2010.
[35] Association HQE, « INIES database », 2013. [En ligne]. Disponible sur: http://www.base-inies.fr/Inies/default.aspx. [Consulté le: 30-mars-2015].
[36] Timber Research and Development Association (TRADA°, « Reusable and adaptable wood structures », England.
[37] F. Werner, R. Taverna, P. Hofer, et K. Richter, « Carbon pool and substitution effects of an increased use of wood in buildings in Switzerland: first estimates », Ann. For. Sci., vol. 62, no 8, p. 14, 2005.
[38] C. M. T. Johnston et G. C. van Kooten, « Carbon Neutrality of Hardwood and Softwood Biomass: Issues of Temporal Preference », University of Victoria, Department of Economics, Resource Economics and Policy Analysis Research Group, Working Paper 2014-06, 2014.
[39] C. Thormark, « A low energy building in a life cycle—its embodied energy, energy need for operation and recycling potential », Build. Environ., vol. 37, no 4, p. 429-435, avr. 2002.
[40] J. Basbagill, F. Flager, M. Lepech, et M. Fischer, « Application of life-cycle assessment to early stage building design for reduced embodied environmental impacts », Build. Environ., vol. 60, p. 81-92, févr. 2013.

smart living lab

[41] C. Grasland, « Initiation aux méthodes statistiques en sciences sociales », Université Paris VII, 2000-1998. [En ligne]. Disponible sur: http://grasland.script.univ-paris-diderot.fr/STAT98/STAT98.htm. [Consulté le: 02-avr-2015].

[42] S. Lacroix, « Mathématiques du deuxième cycle au secondaire », 2013-2007. [En ligne]. Disponible sur: http://www.sylvainlacroix.ca/. [Consulté le: 30-mars-2015].

[43] ISO 14040, « ISO 14040:2006 - Environmental management -- Life cycle assessment -- Principles and framework », International Standards Organization, Belgium, 2006.

[44] European Committee for Standardization (CEN), « Sustainability of construction works — Environmental product declarations — Core rules for the product category of construction products », Belgium, European Standard EN 15804, 2012.

[45] European Committee for Standardization (CEN), « Sustainability of construction works. Assessment of environmental performance of buildings. Calculation method », Belgium, European Standard EN 15978, 2012.

[46] Gabi, « GaBi LCA Database », PE INTERNATIONAL. [En ligne]. Disponible sur: http://www.gabi-software.com/international/databases/. [Consulté le: 30-mars-2015].

[47] IVAM, « IVAM LCA DATA 4 », Greenhouse Gas Protocol, 2012. [En ligne]. Disponible sur: http://www.ghgprotocol.org/Third-Party-Databases/IVAM. [Consulté le: 30-mars-2015].

[48] National Renewable Energy Laboratory NREL, « U.S. Life Cycle Inventory Database », 2013. [En ligne]. Disponible sur: http://www.nrel.gov/lci/. [Consulté le: 30-mars-2015].

[49] European commission, « European life Cycle Database », EPLCA - European reference Life-Cycle Database. [En ligne]. Disponible sur: http://eplca.jrc.ec.europa.eu/ELCD3/. [Consulté le: 30-mars-2015].

[50] CHALMERS, « CPM LCA Database ». [En ligne]. Disponible sur: http://cpmdatabase.cpm.chalmers.se/. [Consulté le: 30-mars-2015].

[51] Japan Environmental Management Association for Industry (JEMAI), « JEAMI LCA Database », 2013. [En ligne]. Disponible sur: http://www.jemai.or.jp/#2. [Consulté le: 30-mars-2015].

[52] SimaPro UK Ltd, « SimaPro 8 », 2015. [En ligne]. Disponible sur: http://www.simapro.co.uk/. [Consulté le: 30-mars-2015].

[53] PE International, « GaBi software ». [En ligne]. Disponible sur: http://www.gabi-software.com/international/index/. [Consulté le: 30-mars-2015].

[54] Leiden University, « CMLCA Software ». [En ligne]. Disponible sur: http://www.cmlca.eu/. [Consulté le: 30-mars-2015].

[55] GreenDelta GmbH, « openLCA Nexus », 2015. [En ligne]. Disponible sur: https://nexus.openlca.org/. [Consulté le: 30-mars-2015].

[56] Quantis, « Quantis Sustainability Counts », 2015. [En ligne]. Disponible sur: http://www.quantis-intl.com/software5.php. [Consulté le: 30-mars-2015].

[57] JEMAI, « MiLCA Multiple Interface Life Cycle Assessment », 2010. [En ligne]. Disponible sur: http://www.milca-milca.net/english/. [Consulté le: 30-mars-2015].

[58] Earthshift, Inc, « EarthShift Building Pathways to Sustainability », 2014-2011. [En ligne]. Disponible sur: http://www.earthshift.com/. [Consulté le: 30-mars-2015].

[59] CleanMetrics Corp, « CleanMetricsTM », 2011-2007. [En ligne]. Disponible sur: http://www.cleanmetrics.com/. [Consulté le: 30-mars-2015].

[60] ifu Hamburg GmbH, « Umberto », 2015-1998. [En ligne]. Disponible sur: http://www.ifu.com/en/. [Consulté le: 30-mars-2015].

[61] M. Goedkoop, M. Oele, et S. Effting, « Simapro Database Manuel, Methods Library. Pre consultants BV », Netherlands, 2004.

[62] « Building Greenhouse Rating Software ». [En ligne]. Disponible sur: http://www.abgr.com.au. [Consulté le: 30-mars-2015].

[63] « Lisa Software ». [En ligne]. Disponible sur: http://www.lisa.au.com/. [Consulté le: 30-mars-2015].

[64] eTool, « eTool Software », 2014. [En ligne]. Disponible sur: http://etoolglobal.com/software/. [Consulté le: 30-mars-2015].
[65] RDC Environment, « InstatLCA ». [En ligne]. Disponible sur: http://www.instantlca-textile.com/index_en.html. [Consulté le: 30-mars-2015].
[66] Athena Institute, « Impact Estimator for Buildings | Life Cycle Assessment Software », 2014. [En ligne]. Disponible sur: http://calculatelca.com/software/impact-estimator/. [Consulté le: 05-avr-2015].
[67] Athena Sustainable Materials Institute, « Athena Database », 2015. [En ligne]. Disponible sur: http://www.athenasmi.org/our-software-data/lca-databases/. [Consulté le: 30-mars-2015].
[68] « LEGEP Sofwtare ». [En ligne]. Disponible sur: http://legep.de/. [Consulté le: 30-mars-2015].
[69] « ÖKOBAU Database ». [En ligne]. Disponible sur: http://www.nachhaltigesbauen.de/baustoff-und-gebaeudedaten/oekobaudat.html. [Consulté le: 30-mars-2015].
[70] « eco-bat Software ». [En ligne]. Disponible sur: http://www.eco-bat.ch/. [Consulté le: 30-mars-2015].
[71] treeze, « KBOB Database », 2014. [En ligne]. Disponible sur: http://treeze.ch/projects/case-studies/building-and-construction/kbob/. [Consulté le: 30-mars-2015].
[72] GmbH, « LTE OGIP Software », 2013. [En ligne]. Disponible sur: http://www.the-software.de/. [Consulté le: 30-mars-2015].
[73] « EIME Software ». [En ligne]. Disponible sur: https://demo.bveime.com/login. [Consulté le: 30-mars-2015].
[74] « EIME Database ». [En ligne]. Disponible sur: http://www.codde.fr/logiciel-acv.com/180_base-de-donnees.html. [Consulté le: 30-mars-2015].
[75] « mobi tool Software ». [En ligne]. Disponible sur: http://www.mobitool.ch/. [Consulté le: 30-mars-2015].
[76] Sméo, « Quartiers durables Software ». [En ligne]. Disponible sur: http://www.quartiersdurablesbysmeo.ch/. [Consulté le: 30-mars-2015].
[77] E4tech, « Lesosai Software », 2015-2008. [En ligne]. Disponible sur: http://www.lesosai.com/indexfr.cfm. [Consulté le: 30-mars-2015].
[78] NIST, « BEES Software », 2009. [En ligne]. Disponible sur: http://www.nist.gov/el/economics/BEESSoftware.cfm/. [Consulté le: 30-mars-2015].
[79] « Eco-QuantumSoftware ». [En ligne]. Disponible sur: http://www.ivam.uva.nl/. [Consulté le: 30-mars-2015].
[80] Selerant Corporation, « EcodEX Software », 2015. [En ligne]. Disponible sur: http://www.selerant.com/main/en-us/solutions/ecodex.aspx. [Consulté le: 30-mars-2015].
[81] University of Manchester, « CCaLC2 Software », 2015-2007. [En ligne]. Disponible sur: http://www.ccalc.org.uk/index.php. [Consulté le: 30-mars-2015].
[82] GreenDelta GmbH, « GREENDELTA Software », 2015. [En ligne]. Disponible sur: http://greendelta.com/. [Consulté le: 30-mars-2015].
[83] « EcoEffect Software », 2008. [En ligne]. Disponible sur: http://www.ecoeffect.se/. [Consulté le: 30-mars-2015].
[84] Cycleco, « FoodPrint Software ». [En ligne]. Disponible sur: https://foodprint.cycleco.eu/. [Consulté le: 30-mars-2015].
[85] « EcoTransIT World Software ». [En ligne]. Disponible sur: http://www.ecotransit.org/. [Consulté le: 30-mars-2015].
[86] « Carbonosti Software ». [En ligne]. Disponible sur: http://www.carbonostics.com/. [Consulté le: 30-mars-2015].
[87] CSTB, « ELODIE Software ». [En ligne]. Disponible sur: http://www.elodie2-cstb.fr/. [Consulté le: 30-mars-2015].
[88] International Institute for Sustainability Analysis and Strategy (IINAS), « GEMIS Software », 2015. [En ligne]. Disponible sur: http://www.iinas.org/gemis.html. [Consulté le: 30-mars-2015].
[89] Cycleco, « Spin'it Software », 2015. [En ligne]. Disponible sur: https://spinit.cycleco.eu/auth.php. [Consulté le: 30-mars-2015].

[90] Cycleco, « e-Licco Software », 2014. [En ligne]. Disponible sur: https://e-licco.cycleco.eu/. [Consulté le: 30-mars-2015].
[91] ARVALIS, « EGES Software ». [En ligne]. Disponible sur: http://www.eges.arvalisinstitutduvegetal.fr/. [Consulté le: 30-mars-2015].
[92] EcoMundo, « CORINE Software », 2015. [En ligne]. Disponible sur: https://www.ecomundo.eu/fr. [Consulté le: 30-mars-2015].
[93] IZUBA eénergies, « Equer Software ». [En ligne]. Disponible sur: http://www.izuba.fr/logiciel/equer. [Consulté le: 30-mars-2015].
[94] Green Design Institute, « eiolca Software ». [En ligne]. Disponible sur: http://www.eiolca.net/. [Consulté le: 30-mars-2015].
[95] « GreenCalc+ Sotware ». [En ligne]. Disponible sur: http://www.greencalc.com/. [Consulté le: 30-mars-2015].
[96] Médias Transcontinental S.E.N.C, « VoirVert Software », 2015. [En ligne]. Disponible sur: http://www.voirvert.ca/. [Consulté le: 30-mars-2015].
[97] Nobatek, « NEST - Neighborhood Evaluation for Sustainable Territories », 2014-2013. [En ligne]. Disponible sur: http://www.nobatek-nest.com/. [Consulté le: 30-mars-2015].
[98] « Tool for Rapid Assessment of City Energy (TRACE): Helping Cities Use Energy Efficiently | ESMAP », 2011. [En ligne]. Disponible sur: http://esmap.org/TRACE. [Consulté le: 30-mars-2015].
[99] « CityCAD Software », 2015-2005. [En ligne]. Disponible sur: https://www.holisticcity.co.uk/. [Consulté le: 30-mars-2015].
[100] « SMEO Software », 2014. [En ligne]. Disponible sur: http://www.smeo.ch/. [Consulté le: 30-mars-2015].

7.2. Flexibility

[1] G. Duca, "Usability requirements for buildings: a case study on primary schools," *Work J. Prev. Assess. Rehabil.*, vol. 41, pp. 1441–1448, 2012.
[2] K. Alexander, "Usability of Learning Environments," in *CIB W111 Research Report: Usability of Workplaces - phase 3*, 1st ed., International Council for Research and Innovation in Building and Construction, 2010, p. 84.
[3] J. A. Lackney, "Assessing School Facilities for Learning/Assessing the Impact of the Physical Environment on the Educational Process: Integrating Theoretical Issues with Practical Concerns.," 1999.
[4] J. Nielsen, *Usability engineering*. San Francisco, Calif.: Morgan Kaufmann Publishers, 1994.
[5] "ISO 9241-11:1998: Ergonomic requirements for office work with visual display terminals (VDTs) -Part 11: Guidance on usability." IOS, 1998.
[6] K. Alexander, "The application of usability concepts in the built environment," *J. Facil. Manag.*, vol. 4, no. 4, pp. 262–270, Oct. 2006.
[7] S. H. Blakstad, N. Olsson, G. K. Hansen, and W. Knudsen, "Usability Mapping Tool," in *CIB W111 Research Report: Usability of Workplaces - phase 3*, International Council for Research and Innovation in Building and Construction, 2010, p. 18.
[8] K. Alexander, "Usability of workplaces: phase two: philosophy and concepts," 2008.
[9] G. Lindahl and J.-A. Granath, "Culture and Usability," *Proc. Trondheim Int. Symp. Chang. User Demands Build. - Needs Lifecycle Plan. Manag. Trondheim 12-14 June 2006*, 2006.
[10] M. Fenker, "Towards a theoretical framework for usability of buildings," *CIB Rep.*, vol. 316, pp. 14–23, 2008.
[11] N. A. Behkami and D. A. Dorr, "User centered design in complex healthcare workflows: the case of care coordination and care management redesign," in *AMIA Annual Symposium Proceedings*, 2009, vol. 2009, p. 39.
[12] S. N. Haron and M. Y. Hamid, "Quality of Hospital In-use: Usability Evaluation Method as an Assessment," *J. Sustain. Dev.*, vol. 4, no. 2, Apr. 2011.
[13] T. Schneider, *Flexible housing*, 1st ed. Amsterdam ; Boston: Architectural Press, an imprint of Elsevier, 2007.

[14] N. Hamdi, *Housing without houses: participation, flexibility, enablement*. London: Intermediate Technology, 1995.
[15] S. Kendall, M. Cupello, T. Kurmel, and K. Dekker, “Healthcare facilities design for flexibility.” National Institute of Building Sciences, 30-Jul-2012.
[16] N. O. E. Olsson, “Management of flexibility in projects,” *Int. J. Proj. Manag.*, vol. 24, no. 1, pp. 66–74, Jan. 2006.
[17] W. Yang and N. Kohler, “Simulation of the evolution of the Chinese building and infrastructure stock,” *Build. Res. Inf.*, vol. 36, no. 1, pp. 1–19, Jan. 2008.
[18] C. B. Aktas and M. M. Bilec, “Impact of lifetime on US residential building LCA results,” *Int. J. Life Cycle Assess.*, vol. 17, no. 3, pp. 337–349, Mar. 2012.
[19] D. Pearce, “The Social and Economic Value of Construction: The Construction Indutry’s Contribution to Sustainable Development,” The Construction Industry Research and Innovation Strategy Panel, 2003.
[20] M. Kornmann, “La duree de vie des batiments en Suiwsse,” in *4eme Symposium sur las Energiew Renouvelables et l’Environnment dans de Batiment*, Yverdon-les-Bains, Suisse, 2009.
[21] M. Mequignon, L. Adolphe, F. Thellier, and H. Ait Haddou, “Impact of the lifespan of building external walls on greenhouse gas index,” *Build. Environ.*, vol. 59, pp. 654–661, Jan. 2013.
[22] M. Mequignon, L. Adolphe, F. Thellier, and H. Ait Haddou, “Impact of the lifespan of building external walls on greenhouse gas index,” *Build. Environ.*, vol. 59, pp. 654–661, Jan. 2013.
[23] “ISO 15686-7:2006: Buildings and constructed assets-Service life planning-Part 7: performance evaluation for feedback of service life data from practice.” ISO office, 2006.
[24] C. Rudbeck, *Methods for designing building envelope components prepared for repair and maintenance*. Lyngby: IBE, Institut for Bygninger og Energi, Danmarks Tekniske Universitet, 1999.
[25] B. Atkin, J. Borgbrant, and P.-E. Josephson, Eds., *Construction process improvement*. Oxford: Blackwell Science, 2003.
[26] B. JIA, “The Qualities of the Basics: Base Building Design,” in *Open and Sustainable Building*, 2010, pp. 96–104.
[27] S. Kendall and J. Teicher, *Residential open building*. London: E&FN Spon, 2000.
[28] W. Lidwell, K. Holden, J. Butler, and K. Elam, *Universal principles of design 125 ways to enhance usability, influence perception, increase appeal, make better design decisions, and teach through design*. Beverly, Mass.: Rockport Publishers, 2010.
[29] N. Olsson, “Project Flexibility in Large Engineering Projects,” Norwegian University of Science and Technology, 2006.
[30] “Jia House | Dr. JIA Beisi.” [Online]. Available: http://fac.arch.hku.hk/arch/jia-beisi/design/jia-house/. [Accessed: 18-May-2015].
[31] A. Cavieres, R. Gentry, and T. Al-Haddad, “Knowledge-based parametric tools for concrete masonry walls: Conceptual design and preliminary structural analysis,” *Autom. Constr.*, vol. 20, no. 6, pp. 716–728, 2011.
[32] W. J. Fabrycky and B. S. Blanchard, *Life-cycle cost and economic analysis*, 3. pr. Upper Sallde River, N.J: Prentice Hall, 1991.
[33] D. Dvir and T. Lechler, “Plans are nothing, changing plans is everything: the impact of changes on project success,” *Res. Policy*, vol. 33, no. 1, pp. 1–15, Jan. 2004.
[34] D. Seiders, G. Ahluwalia, S. Melman, R. Quint, A. Chaluvadi, M. Liang, A. Silverberg, and C. Bechler, “Study of Life Expectancy of Home Components,” National Association of Home Builders, Bank of America Home Equity, 2007.
[35] E. Hoxha, G. Habert, J. Chevalier, M. Bazzana, and R. Le Roy, “Method to analyse the contribution of material’s sensitivity in builidngs’environmental impact,” *Journal of Cleaner Production*, 66, pp. 54–64, 2014.
[36] N. Jungbluth, M. Tuchschmid, and M. de Wild-Scholten, “Life Cycle Assessment of Photovoltaics: update of ecoinvent data V2. 0,” *ESU-Serv. Ltd*, 2008.
[37] S. Sadler, *Archigram architecture without architecture*. Cambridge, Mass. [u.a.]: MIT Press, 2005.

[38] M. Schalk, “The Architecture of Metabolism. Inventing a Culture of Resilience,” *Arts*, vol. 3, no. 2, pp. 279–297, Jun. 2014.
[39] P. Crowther, “Design for buildability and the deconstruction consequences,” 2002.
[40] “National Historic Landmark Nomination: Richards and Goddard Buildings.” .
[41] Z. Lin, “nakagin Capsule Tower and the Metabolish Movement Revisited,” 2007.
[42] Osaka Gas Company, *Oksaka Gas Experimental Housing: NEXT 21*. NEXT 21 Planning & development Team, Residential Market Development Department, 2007.
[43] H. Li and R. Zhijie, “Control and Appearance of Architecture Design--Maya High-rise Residential Building Design,” *Urban and Architecture*, pp. 45–47, 2008.
[44] M. Pestalozzi, “Netz-Bau-Akademie,” *Atchitektur & Technik*, vol. 5, no. 8, pp. 10–14, 2007.
[45] S. Kendall, *Open Building: A New Paradigm for Health Care Architecture: the INO Hospital, Bern Switzerland*. College of Architecture and Planning, Ball State University, 2002.
[46] S. Brand, *How buildings learn: what happens after they're built*. New York: Penguin Books, 1995.
[47] N. Setien, “Towards an open and user driven housing architecture: layers principle, infrastructure types and technical devices,” in *Congreso Internacional de Vivienda Colectiva Sostenibl*, 2014, pp. 96–101.
[48] M. Wang, *Paper Collection on Open Building: Step towards to the Buildings with User Participation and User Friendliness*. Taibei: Architecture Association of Taiwan, 2000.
[49] R. P. Geraedts, “Upgrading the flexibility of buildings,” *CIB Rep.*, pp. 149–156, 2000.
[50] R. P. Geraedts and H. Remøy, “Building with Future Value: A method to Assess the Adaptive Capacity of Building,” *Open House Int.*, 2014.
[51] J. Till and T. Schneider, “Flexible housing: the means to the end,” *Arq Archit. Res. Q.*, vol. 9, no. 3/4, pp. 287–296, 2005.
[52] R. Blok, F. V. Herwijnen, A. Kozlowski, and S. Wolinski, “Service Life and Life Cycle of Bulding Structures.” .
[53] P. Tiwari and others, “Housing demand in Tokyo,” *Int. Real Estate Rev.*, vol. 3, no. 1, pp. 65–92, 2000.
[54] A. Yoshida and T. Shichijo, “Spatial clustering of housing construction in the Tokyo Metropolitan Area: an application of spatially clustered fixed-effects and spatially correlated random-effects models,” in *Econometric Society 2004 Australasian Meetings*, 2004.
[55] M. Kaneko, T. Ito, and Y. Osawa, “Duality in comparative statics in rental housing markets with indivisibilities,” *J. Urban Econ.*, vol. 59, no. 1, pp. 142–170, Jan. 2006.
[56] OPHS Corporation, *Corporation Next Generation Urban Complex Housing: Flex Court Yoshida*. Osaka: Osaka Prefecture Housing Supplying Corporation, 2000.
[57] Y. Cuperus, Ed., *Agile Architecture proceedings: Conference of CIB W104*. Delft, Netherlands, 2001.
[58] C. Baumschlager, “Resources and Architecture,” presented at the Wiener Kongress für zukenftsfähiges Bauen, Wiener, 2013.
[59] B. Coldham, “Good Green Multi-Family Housing in Europe,” presented at the Multi-family Building 2013, New York, 2003.
[60] Sustainable Building Conference, K. Höfler, P. Maydl, and A. Passer, Eds., *Proceedings of the Sustainable Building Conference 2013: 25-28 September 2013, Graz University of Technology, Austria : sustainable buildings - construction products & technologies : collection of abstracts*. Graz: Verlag der Technischen Universität Graz, 2013.
[61] D. Eberle, “Building by Baumschlager & Eberle.”
[62] D. Gauzin-Müller and N. Favet, *Sustainable architecture and urbanism: concepts, technologies, examples*. Basel ; Boston: Birkhauser, 2002.
[63] Baumschneider Eberle, W. Nerdinger, and Architekturmuseum, Eds., *Baumschlager-Eberle 2002 - 2007: Architektur, Menschen und Ressourcen = Baumschlager-Eberle 2002 - 2007, architecture, people and ressources*. Wien: Springer, 2007.
[64] N. Ventura, “Contemporary Housing,” School of Architecture La Salle.

[65] R. Yeung, Ed., *Creation 10 Hong Kong: A Product Design Story*. Hong Kong: Hong Kong Design Centre, 2008.
[66] “Asian Architecture in the New Millennium: A Postmodern Imagery,” in *Asian Ethical Urbanism*, WORLD SCIENTIFIC, 2005, pp. 63–90.
[67] K. Scheerlinck, “Shared Space in Depth Configurations.”
[68] *RIAS: Quarterly: the Journal of the Royal Incorporation of Architects in Scotland*. 2014.
[69] S. Kendall, “Managing Change: the application of Open Building in the INO Bern Hospital,” in *Design & Health World Congress*, 2005.
[70] Helsnki City Planning Department, “Walking in Arabianranta,” *Hels. Plans*, no. 7, pp. 1–16, 2009.
[71] S. Kendall and N. Kiseleva, “Report on Free Plan Apartments in Moscow,” 2013.
[72] Z. REN, H. LI, and B. JIA, “Implementation of the Open Building Theory in China’s Residential Market: a Case Study of the Maya Project.”
[73] “Multifunk.” [Online]. Available: http://mimoa.eu/projects/Netherlands/Amsterdam/Multifunk.
[74] U. Tiuri, “Muuntojousto Teoriassa Ja Kaytannossa,” Rakennusfoorumi, 2014.
[75] G. Wallagh, “De onbekende toekomst huisvesten.” Platform31, 2013.
[76] “Nachhaltiges und ökologisches Bauen – Gebäudetechnik für höchste Raumqualität,” *Lauber IWISA Plant Baut Erneuert*.
[77] C. Lüthi, “Two new library buildings for y g Bern University Library.”
[78] Baumschlager-Eberle, “Krankenhaus AZ Groeninge,” *Zement+beton*, pp. 40–43.
[79] M. Corrodi, “1.000-Betten-Krankenhaus, A.Z. Groeninge Kortrijk, Belgien,” in *Baumschlager-Eberle 2002–2007*, W. Nerdinger, Ed. Vienna: Springer Vienna, 2008, pp. 66–71.

7.3. Energy Strategy

[1] EN 15251 - Critères d’ambiance intérieure pour la conception et évaluation de la performance énergétique des bâtiments couvrant la qualité de l’air intérieur, la thermique, l’éclairage et l’acoustique. .
[2] A. G. Kwok e N. B. Rajkovich, «Addressing climate change in comfort standards», Build. Environ., vol. 45, n. 1, pagg. 18–22, gen. 2010.
[3] J. F. Nicol e M. A. Humphreys, «New standards for comfort and energy use in buildings», Build. Res. Inf., vol. 37, n. 1, pagg. 68–73, feb. 2009.
[4] R. J. Cole, J. Robinson, Z. Brown, e M. O’shea, «Re-contextualizing the notion of comfort», Build. Res. Inf., vol. 36, n. 4, pagg. 323–336, ago. 2008.
[5] SIA 380/1 - [aktueller Titel, gültig ab 01.01.2009] L’énergie thermique dans le bâtiment. .
[6] EN 7730 - Ergonomie des ambiances thermiques - Détermination analytique et interprétation du confort thermique par le calcul des indices PMV et PPD et par des critères de confort thermique local. .
[7] O. M. Koskinen, T. M. Husman, T. M. Meklin, e A. I. Nevalainen, «The relationship between moisture or mould observations in houses and the state of health of their occupants», Eur. Respir. J., vol. 14, n. 6, pagg. 1363–1367, 1999.
[8] World Health Organization 2007, «Large analysis and review of European housing and health status (LARES)». [In linea]. Available at: http://www.euro.who.int/__data/assets/pdf_file/0007/107476/lares_result.pdf. [Consultato: 13-apr-2015].
[9] C. Vergani, «Umidità relativa ed inquinanti indoor». [In linea]. Available at: http://www.dentalfix.com/files/test/files/Umidita_relativa_e_inquinamento_indoor.pdf. [Consultato: 16-apr-2015].
[10] «EN 12464-1 - Lumière et éclairage - Éclairage des lieux de travail - Partie 1 : lieux de travail intérieursaga Web». [In linea]. Available at: http://sagaweb.afnor.org/fr-FR/sw/Recherche/Resultat. [Consultato: 12-apr-2015].

[11] J.-L. Scartezzini, A. Faist, e J. B. Gay, «Experimental comparison of a sunspace and a water hybrid solar device using the LESO test facility». [In linea]. Available at: http://www.sciencedirect.com/science/article/pii/0038092X87900089#. [Consultato: 28-apr-2015].

[12] «Solar Thermal Technologies for Buildings: The State of the Art - M. Santamouris - Google Libri». [In linea]. Available at: https://books.google.ch/books?id=EyNpAwAAQBAJ&pg=PA4&lpg=PA4&dq=usability+factor+of+solar+gains&source=bl&ots=Hvtp0Axua4&sig=xRpzglgoRwEgs9QWspTakML04C0&hl=it&sa=X&ei=Q0c-VdqgCMb1at-agWA&ved=0CEUQ6AEwBA#v=onepage&q=usability%20factor%20of%20solar%20gains&f=false. [Consultato: 27-apr-2015].

[13] J. Viola, «DERIVATION OF RELIABLE SIMPLIFICATION STRATEGIES FOR THE COMPARATIVE LCA OF INDIVIDUAL AND “TYPICAL“ NEWLY BUILT SWISS APARTMENT BUILDINGS», 2012.

[14] F. Wyss, R. Frischknecht, K. Pfäffli, e J. Viola, «Zielwert Gesamtumweltbelastung Gebäude». 03-dic-2014.

[15] Prognos AG, «Die Energieperspektiven für die Schweiz bis 2050». 12-set-2012.

[16] «Multiscale Building Physics - EMPA», 01:20:10 UTC.

[17] «Cahiers techniques SIA 2024 - Conditions d’utilisation standard pour l’energie et les installations du batiment». .

[18] «PV potential estimation utility». [In linea]. Available at: http://re.jrc.ec.europa.eu/pvgis/apps4/pvest.php. [Consultato: 21-apr-2015].

[19] Basler + Partner, «Masterplab Bluefactory: notice d’impact sur l’environnement». .

[20] «GeoNetwork - Il portale dell’informazione territoriale». [In linea]. Available at: http://www.geocat.ch/geonetwork/srv/ita/geocat. [Consultato: 13-apr-2015].

[21] «Statistique Fribourg». [In linea]. Available at: http://appl.fr.ch/stat_statonline/standards/etape2.asp?Tableau=186&langue=fr. [Consultato: 13-apr-2015].

[22] «Ville de Fribourg - Site cartographique». [In linea]. Available at: http://www.sitecof.ch/frame.php?site=fr_internet&resol=2&lang=fr. [Consultato: 13-apr-2015].

[23] International Energy Agency report, Switzerland Energy Policy Review 2012. Organization for Economic, 2012.

[24] Etat de Fribourg, «Rapport N°160 du Conseil d’Etat au Grand Conseil relatif à la planification énergétique du canton de Fribourg (nouvelle stratégie énergétique)». 29-set-2009.

[25] Etat de Fribourg, «Annuaire statistique du canton de Fribourg 2014». 2014.

[26] F.-D. Vuataz, F. Bossy, B. Colliard, e J. Wilhelm, «Evaluation du potentiel géothermique du canton de Fribourg - Rapport final», 2005.

[27] «KBOB / eco-bau / IPB 2009/1:2014, Data from “Electricité du réseau”.» .

[28] J.-P. Bacher e S. Boschung, «Concepts énergétiques blueFACTORY - Recommandations du Groupe de Travail intégration énergétique». 04-apr-2014.

[29] «Windfinder.com - Wind and weather statistic Fribourg Nord», Windfinder.com. [In linea]. Available at: http://www.windfinder.com/windstats/windstatistic_fribourg-nord.htm. [Consultato: 21-apr-2015].

[30] Service des transportes et de l’énergie, Canton de Fribourg, «Concept éolien du canton de Fribourg Rapport final». 2008.

[31] Bousquet e Cotture, «SolarDecathlon: Energy and water management system analysis at a building scale», gen. 2015.

[32] «Meteonorm: Irradiation data for every place on Earth». [In linea]. Available at: http://meteonorm.com/. [Consultato: 28-apr-2015].

[33] SIA 2028 - Dati climatici per la fisica della costruzione, per l’energia e per l’impiantistica degli edifici. .

[34] «MeteoSwiss». [In linea]. Available at: http://www.meteosvizzera.admin.ch/home.html?tab=overview. [Consultato: 17-apr-2015].

[35] J. Furlow, J. B. Smith, G. Anderson, W. Breed, e J. Padgham, «Building resilience to climate change through development assistance: USAID's climate adaptation program», Clim. Change, vol. 108, n. 3, pagg. 411–421, ott. 2011.
[36] «IPCC - Intergovernmental Panel on Climate Change». [In linea]. Available at: http://www.ipcc.ch/ipccreports/tar/wg1/index.php?idp=474. [Consultato: 13-apr-2015].
[37] C. C. Raible e CH2014-Impacts Initiative, A c. di, CH2014-Impacts: toward quantitative scenarios of climate change impacts in Switzerland. Bern: Universität Bern, Oeschger Centre for Climate Change Research (OCCR), 2014.
[38] T. Frank, «Climate change impacts on building heating and cooling energy demand in Switzerland», Energy Build., vol. 37, n. 11, pagg. 1175–1185, nov. 2005.
[39] M. Christenson, H. Manz, e D. Gyalistras, «Climate warming impact on degree-days and building energy demand in Switzerland», Energy Convers. Manag., vol. 47, n. 6, pagg. 671–686, apr. 2006.
[40] «Temperature Analysis | Sustainability Workshop». [In linea]. Available at: http://sustainabilityworkshop.autodesk.com/buildings/temperature. [Consultato: 14-apr-2015].
[41] «Plan canicule 2013 FR - zotero://attachment/119/». [In linea]. Available at: zotero://attachment/119/. [Consultato: 14-apr-2015].
[42] E. Thalmann, C. Appenzeller, J.-J. Dätwyler, U. Neu, ProClim, e Kongress, Canicule de l'été 2003: rapport de synthèse : basé sur les exposés et contributions du forum du 7 juillet 2005 sur la canicule de l'été 2003 ainsi que sur d'autres travaux scientifiques et rapports à ce sujet. Berne: ProClim-, 2005.
[43] L. Grizea, A. Hussa, O. Thommena, C. Schindlera, e C. Braun-Fahrländera, «Heat wave 2003 and mortality in Switzerland», Swiss Med Wkly, vol. 135, pagg. 200–205, 2005.
[44] «NOAA - National Oceanic and Atmospheric Administration». [In linea]. Available at: http://www.noaa.gov/. [Consultato: 14-apr-2015].
[45] «SMC : Hitzewelle - Staat Freiburg». [In linea]. Available at: http://www.fr.ch/smc/de/pub/praev_gesundheitsfoerderung/gesundheit_umwelt/hitzewelle.htm. [Consultato: 14-apr-2015].
[46] «BFRC - the UK's national system for rating Energy Efficient Windows :: BFRC Homepage». [In linea]. Available at: http://www.bfrc.org/. [Consultato: 14-apr-2015].
[47] R. Compagnon, «Solar and daylight availability in the urban fabric», Energy Build., vol. 36, n. 4, pagg. 321–328, apr. 2004.
[48] R. Compagnon, «PRECis: Assessing the Potential for Renewable Energy in Cities», Annexe 3 Sol. Daylight Availab. Urban Areas, 2000.
[49] R. McDowall, Fundamentals of Hvac Systems. 2006.
[50] B. Givoni, «Options and applications of passive cooling», Energy Build., vol. 7, n. 4, pagg. 297–300, 1984.
[51] B. Givoni, «Passive Low Energy Cooling of Buildings», 1994. [In linea]. Available at: http://books.google.ch/books?hl=it&lr=&id=rJsVoRw1geoC&oi=fnd&pg=PA1&dq=Passive+and+Low-Energy+Cooling+of+Buildings&ots=IAkSpbVSQl&sig=mwEylzErNtAE_994Yz27crLlwQ8#v=onepage&q=Passive%20and%20Low-Energy%20Cooling%20of%20Buildings&f=false. [Consultato: 14-apr-2015].
[52] D. Watson e K. Labs, Climatic Building Design: Energy-Efficient Building Principles and Practices. Mcgraw-Hill, 1993.
[53] «Energy Design Tools». [In linea]. Available at: http://www.energy-design-tools.aud.ucla.edu/. [Consultato: 14-apr-2015].
[54] N. Artmann, D. Gyalistras, H. Manz, e P. Heiselberg, «Impact of climate warming on passive night cooling potential», Build. Res. Inf., vol. 36, n. 2, pagg. 111–128, mar. 2008.
[55] N. Artmann, H. Manz, e P. Heiselberg, «Climatic potential for passive cooling of buildings by night-time ventilation in Europe», Appl. Energy, vol. 84, n. 2, pagg. 187–201, feb. 2007.