Building 2050
Scientific concept
and transition to the experimental phase

V4 / January 2016

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Fribourg, Switzerland, November 2015

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1. Executive summary

The smart living lab is a national centre for technological innovation in the built environment, and is composed of members from the University of Fribourg (UNIFR), the School of Engineering and Architecture of Fribourg (HEIA-FR) and the Swiss Federal Institute of Technology in Lausanne (EPFL). One of the smart living lab's projects is the design and construction of its own building, which will be at the cutting edge of research and best practice on sustainability. Before construction starts on the smart living building, a preliminary research programme called **smart living building research programme** has been set up. Its objective is to define the scientific specifications to be used by the future designers and the way in which they will be integrated into the construction. Located in the blueFACTORY innovation quarter in Fribourg, the planned smart living building is a mixed-use building (residential, offices and experimental lab). The construction must correspond to the intermediate objectives of the vision of the 2000-Watt Society model by the middle of the 21st century (hereafter called the 2050 objectives). These objectives concern environmental impacts, as represented by three main indicators, namely the **cumulative energy demand** (CED), the **non-renewable** part of the CED (CED_{nr}), and the **global warming potential** (GWP). The first part of this report presents the scientific concept which will allow the smart living building to meet these objectives. The second part of the report relates to the transition of this concept to the experimental phase of the building design.

The general definition of environmental impact targets is presented and discussed, and in particular for the case of the smart living building. Two kinds of targets are analysed. Achievement of the overall building target is compulsory in order to satisfy the 2050 objectives. Sub-targets are set for the building's components or systems. A suitable balance of these sub-targets helps the construction and the use of the building to reach a global performance level.

Different populations of possible projects concerning the future smart living building are analysed from the perspective of environmental impacts. A first population of projects represents current best practice in building construction and operation. A second population consists of top-performing projects that anticipate possible future improvements, and a final population relates to projects that can achieve the 2050 objectives. An analysis of these three populations indicates how the balance of sub-impacts should evolve in the future in order to achieve the very challenging 2050 objectives. A recommendation of sub-targets for building components and systems is proposed. Present environmental impacts related to food and mobility and their 2050 targets are also set out.

A global synthetic vision made up of groups of construction elements which form the **vital organs** of a building is suggested. These macro components simplify our understanding of the different mechanisms that ensure overall performance. They also allow for the establishment of a strategy enabling highly efficient use of the available resources. The vital organs that represent the major performance contributors of the building are the envelope, the energy supply and its storage, the technical systems, the users and their mobility. The scientific concept analyses each of these organs and proposes specific measures that should be undertaken for an efficient improvement in overall building performance.

A **sensitivity analysis** based on the Morris method identifies the major contributors among the population representing current best practice in building construction and operation. It is noted that more than three quarters of the total energy required for the building, including both embodied energy and operational energy, was used for lighting, appliances and ventilation. Technical and architectural solutions to improve the global performance of the building among the vital organs have been proposed.

Concerning the building **envelope**, three main components present key performance issues. They are related to the climate (insulation and inertia), to natural light (transparent surfaces) and to air quality. An improvement to the impacts concerning the external walls, and especially the careful choice of low-carbon materials, allows us to keep thermal transmittance at the desired level. At the same time, this could drastically reduce the embodied energy. Windows are also subject to an analysis. Compared with the glazing, the frames constitute the main

source of environmental impact, and this should be minimised. The integration in the façade of prefabricated modules with incorporated light shelves, a shading system and special movable panels facilitates natural ventilation and an optimisation of the natural lighting.

Two types of **energy** are required for the planned smart living building: heat and electricity. Heat could be delivered by various methods, and their related specific carbon emissions have been analysed. Because of the recent significant improvements in heating technologies, environmentally efficient ways to provide heat now allow us to fulfil the 2050 objectives. Electricity supply in the context of the blueFACTORY comes from the Swiss electricity grid and electricity produced on site using photovoltaic (PV) panels. The specific carbon content of the electricity from the grid varies over time. At the present stage, only an annual average value is provided by the electricity supplier. The carbon emissions for the electricity provided by PV panels have been evaluated, which allows us to quantify the environmental benefits of producing electricity on site.

Some general aspects of **storing** heat and electricity are set out. Existing technologies, their specific characteristics and implementation parameters are summarised. In any case, the storage process mitigates the environmental impact of the energy used. The specific case of seasonal thermal storage for covering domestic hot water demand is taken as an example. The embodied energy related to the tank is of prior importance when demonstrating that the carbon benefits obtained during its period of use cover the amount of GHG emissions involved, as is required for its implementation. The potential thermal inertia in the walls also requires careful monitoring to achieve a positive balance. Concerning electricity storage, the main parameters of this choice should not just include the embodied impact; the round-trip efficiency and charge/discharge life cycle numbers must also be taken into account in order to make a proper evaluation.

Systems consider all the components that use operative energy to provide comfort to the users of the building. These systems are ventilation, heating and its distribution, as well as lighting and appliances. Appliances are currently a major contributor, but it is difficult to achieve a reduction in their intensity of use by using an architectural solution. There is significant potential to reduce consumption by artificial lighting. Measures such as specific visual comfort zones, where only the workspace areas are optimally lit during the required time, have been proposed. The implementation of natural ventilation in place of mechanical systems is viewed as an efficient way to substantially reduce environmental impact.

Buildings can influence the **mobility** of their users. For example, an evaluation has been made of the number of parking spaces provided to building users and their influence on both the environmental impacts of user mobility and the embodied impact of the building. The development of these impacts is analysed for different parking availability, for the present day and for a future case in 2050. The study demonstrate that the environmental weight of the direct and induced impact of parking places is in both time a key issue.

The usability of a building is strongly influenced by the building's **users**. A social survey enables us to identify the dwellers needs of the future smart living building and their related working schedules, workloads and work types. The attitude of the users towards their working environment and their willingness to control and share their workspace is discussed. It is proposed to allow for a denser population by improving the usability of the working space. A reduction in electricity consumption for users' appliances is suggested, through a systematic implementation of general switch-off systems in each office. The optimisation of functional space locations could contribute to a reduction in operational impact. For instance, the spaces needing higher brightness levels (e.g. workspaces) shall be located closer to the windows, and shall not be designed with large depth.

The particular nature of the smart living building and its goals require a new design tool or method that is able to integrate the considerations related to energy consumption, the environmental impacts and performance related to the entire building lifespan at an early phase of the design process. The proposed method consists of two parts: climate change design method and building flexibility design method. The factors that can influence the ability of the designers are identified as the quality of the design brief, the skills of the design team, the experience of the designers in dealing with similar projects, and the allocation of resources for the project. Other information has also been requested, such as the knowledge of users and the properties of building components in terms of energy consumption and carbon footprint. The acquisition of this information is described in the experiments chapter.

In the second part of the report, the **transition of the smart living lab design to the experimental phase** is discussed. Four research topics are planned for carrying out investigations on the smart living building research programme. The description, the research questions, the objectives and the necessary work packages are presented in detail for each of these four experiments.

The first topic consists of creating a building performance simulation prototype, enabling a variation of input parameters to explore their contribution to the overall edifice performance. The use of this tool shall demonstrate the potential of design efficiency by simplifying the inclusion of performance criteria in the design process.

The second experiment relates to the correlation of low-carbon electricity production and its consumption. A strategy based on low-carbon electricity supply and its storage, human behaviour and the electricity consumption of the smart living building will be studied and quantified.

The third subject is the optimisation of the relationships between building space and user density. The final outputs that are sought include a social database of user knowledge, a prototype of the user environment and a set of recommendations or guidelines that can help designers in the fields of both architecture and technical engineering to design the working spaces of the smart living building.

The last experiment aims to study the façade, its environmental impact and its influence on comfort. One virtual prototype is planned to provide a better understanding of the parameters involved in the LCA evaluation and to underline which aspects need to be highlighted in the design process. A second step will consist of constructing a real test chamber based on the results achieved with the virtual prototype.

Within the framework of the scientific concept, a round table was organised between the main local actors in the construction sector and the smart living lab researchers. Three different themes were selected, because of their potential impact on the scientific programme. The requirement specifications, the constraints on innovation and their identification, as well as building flexibility, were debated by the participants. The conclusions of these discussions have been summarised at the end of the report.

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 that is ahead of its time: both the building itself – housing an interdisciplinary, interinstitutional centre of excellence in the field of innovative concepts and technologies linked to the built environment – and the contents of the building.*[1]

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

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

The "State of the Art" report by Jusselme et al. (2015) was the first deliverable of the smart living building research programme.
This is the second deliverable: the scientific concept. As defined in the previous report, the next deliverables will be:

- the scientific programme (draft): translation of the scientific concept and the workshops into a brief for the future smart living lab designers;
- experimentation: construction of prototypes, performance monitoring and feedback;
- the scientific programme: the definitive programme that will be submitted to the smart living lab designers, to include technical and performance specifications and recommendations.

This report sets targets and suggests technical and architectural concepts to meet them.
As illustrated in the following figure, the scientific concept is the raw material that will be subsequently translated into a scientific programme. This translation seeks to propose a clear and understandable design brief for future designers, with a method that will allow them to integrate the constraints that are faced into the design process.

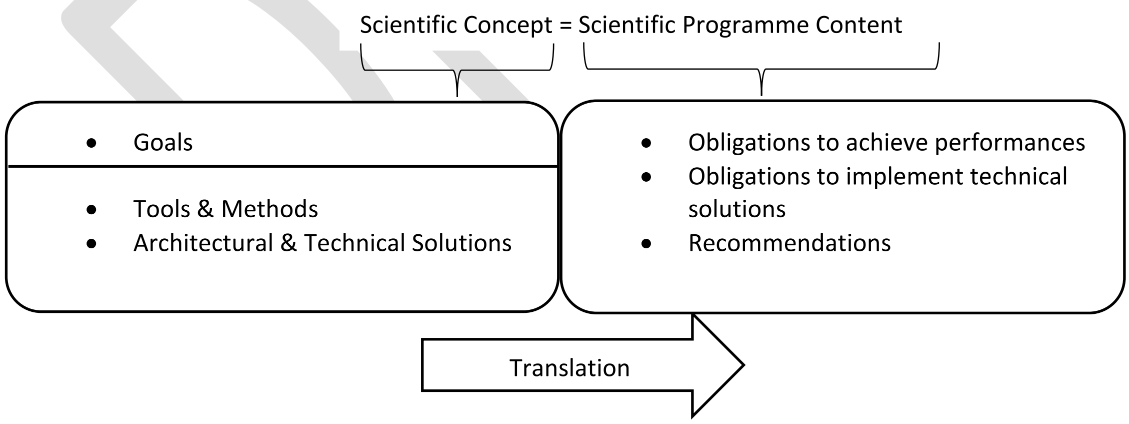


Figure 1: Scientific concept and scientific programme definition

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

3. Scientific concept structure

This chapter aims to justify the way chosen to describe the scientific concept. First, the utility of environmental targets is discussed. Secondly, the method which enable to fix these targets is described. Finally, a decomposition of the smart living lab building is proposed in order to attribute these targets to building macro components called vital organs.

3.1. Towards environmental impact targets

The optimisation of complex systems typically involves a large number of design variables and corresponding multidisciplinary analyses. Due to the large amount of information required for calculating the impacts, buildings are considered more complex than systems in other industrial sectors. A translation of objectives in terms of target values helps to optimise this complex system by reducing time and effort in the design process. The definition of target values has two purposes:

- To show the goods and services with biggest influence in an identification analysis;
- To guide the design process towards defining goals in complex and multidimensional systems.

Figure 2 has tabulated the comparison of targets with the environmental impacts of building components and systems, using two examples. In case 1, even though the impacts of some building components and systems are above the sub-targets, the overall impact of case 1 is below the target. Balancing the impacts of all the systems and components allows case 1 to achieve the goal.

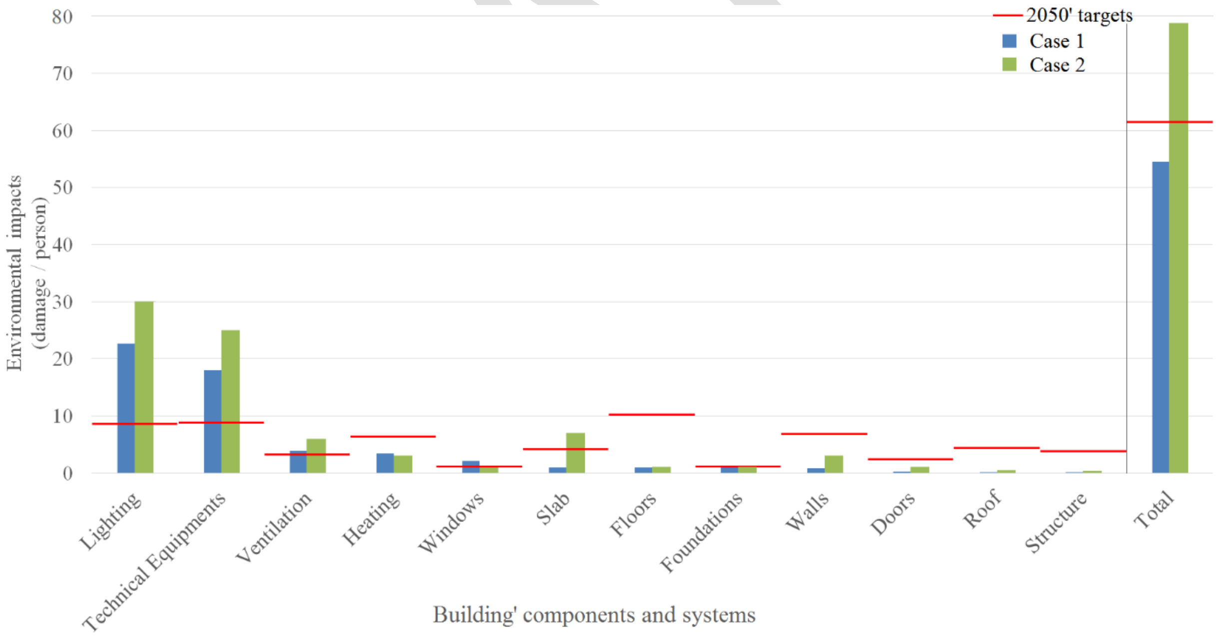


Figure 2 : Comparison of the impacts of building components and systems with their respective targets (red lines)

In case 2, the total impact is above the total target, so it does not achieve its goal. Some of the building components and systems present impacts that are below the target, while others have impacts that exceed the target, but the benefits of having some low impacts are not allowed to counterbalance the impacts that exceed the sub-targets. This is why additional improvement is required, especially for those components and systems whose impact exceeds the target. These comparisons of the targets against the impacts of the components and systems can guide the life-cycle assessment (LCA) practitioners in determining where to direct their efforts in order to improve building performance.

Figure 2 shows a second utility of the definition of target values. In case 2, only lighting, technical equipment, ventilation and slabs have not met their respective goals. The comparisons of the targets with the impacts of building components and systems identify that the impact of slabs, and the improvement of this, is less important than improving the impacts of lighting. A results analysis classifies lighting, technical equipment, slabs and ventilation according to the significance of the improvement of their impacts.

The purpose of improving the impacts with the help of targets is to meet the objectives defined for the project. In “State of the Art”, (Jusselme et al. 2015) have been presented the global target values of the 2000-Watt Society vision, which the buildings must meet by 2050. The definition of robust targets is a step-by-step process, using a bottom-up approach. In the next section we will present a calculation of the 2050 targets for the smart living building at the component and system scale. This aim of this process is to guide us in designing the smart living building so that it will achieve the 2050 goals according to the 2000-Watt Society vision, with an evaluation of targets that can be used by the architect, civil engineers, thermal engineers, etc.

3.2. 2050 targets – definition for the smart living lab

The purpose of this section is to define robust environmental impact targets for the smart living building at the components and systems level. The definition of impact targets for a building can be viewed as a step-by-steps process, combining top-down and bottom-up approaches in a population of case studies. In the first step, the desirable global-level impact targets for the buildings have been defined using a top-down breakdown of the 2050 objectives. These objectives have been inspired by the 2000-Watt Society vision, which is promoted by the Board of the Swiss Federal Institutes of Technology.

The component and system targets are then defined using a bottom-up decomposition of the building impacts. The values of the targets depend on the carbon weighting of components and systems and the embodied primary and non-renewable energy, which is directly influenced by building performance. To increase the robustness of the calculation of targets, a population of projects containing buildings with different performances should be created.

A database of projects can be generated using the Morris method. A Morris sensitivity analysis allows us to create a set of projects by changing the design parameters influencing the performance of a building one at a time. The sensitivity analysis identifies which key data or assumptions significantly influence the output of a model, in quantitative or/and qualitative ways. In the context of a smart living building, this sensitivity analysis helps us to better understand the design parameters and their influence on the global building performance. Other sensitivity methods such as the variance decomposition method, the Monte Carlo method, Sobol sensitivity indices, etc are proposed in the literature (see e.g. Iooss, 2009). In the context of the present study, the Morris method is considered to be the most suitable method, since the other methods are more complex, need a lot of information and parameters and are time consuming. The application of the Morris method needs a minimum number of runs, which is a function of the number of trajectories (successions of points starting from a random base vector in which two consecutive elements differ only in one component) and the number of inputs in a model.

The KBOB database (Friedli et al., 2014) and the lifetime of components proposed by PI-BAT (Meyer et al., 1995) have been used for assessing the environmental impacts of each case. Lesosai software (E4tech, 2008) has been used for the energy consumption assessment. The environmental impacts of a given population of projects form the basis for the calculation of the impact targets.

According to the 2000-Watt Society vision, the number of users of the smart living building is required in order to make an appropriate calculation of the targets. There are different approaches for evaluating the number of users of a building. The first approach used in this study was inspired by SIA 2039 (Hänger and Schneider, 2011), and involves a “standard” space allocation per person (60m² for residential use, 40m² for office use and 18m² for school). For the smart living building, the residential area, office area and experimental area are divided by these standard space allocations to calculate the numbers of users. The alternative approach is based on the 2000-Watt Society vision. According to this “effective” space allocation, each Swiss citizen has 60m² of residential space, 5m² of office area and 2.5m² for school. We have calculated the numbers of people in the smart living building using the average effective space allocation of three architectural feasibility studies carried out for the smart living building. The results obtained are presented in **Erreur ! Source du renvoi introuvable.**. More details about the three architectural feasibility studies of smart living lab, and the number of peoples associated to each space destination are presented in **Erreur ! Source du renvoi introuvable.**.

Table 1: Number of people in the smart living building according to standard and effective space allocations

	Residential	Office	School
no. of standard person[2]	21	45	58
no. of effective person[3]	21	333	507

The overall environmental impacts in the case studies are distributed among people based on their effective space. The literature proposed top-level impact targets only for a single-destination building (residential, office or school, etc), but the smart living building is a mixed-use building. The targets for this building are assessed with the help of the following equation:

$$T_{smart\ living\ lab} = \frac{21 \cdot T_{residential} + 333 \cdot T_{office} + 507 \cdot T_{school}}{861} \qquad \textit{(unity: Impacts / person}_{eff}\textit{)}$$

where *T* represents the impact targets. The impact targets are calculated using a simple linear regression of impacts to the 2050 objectives.

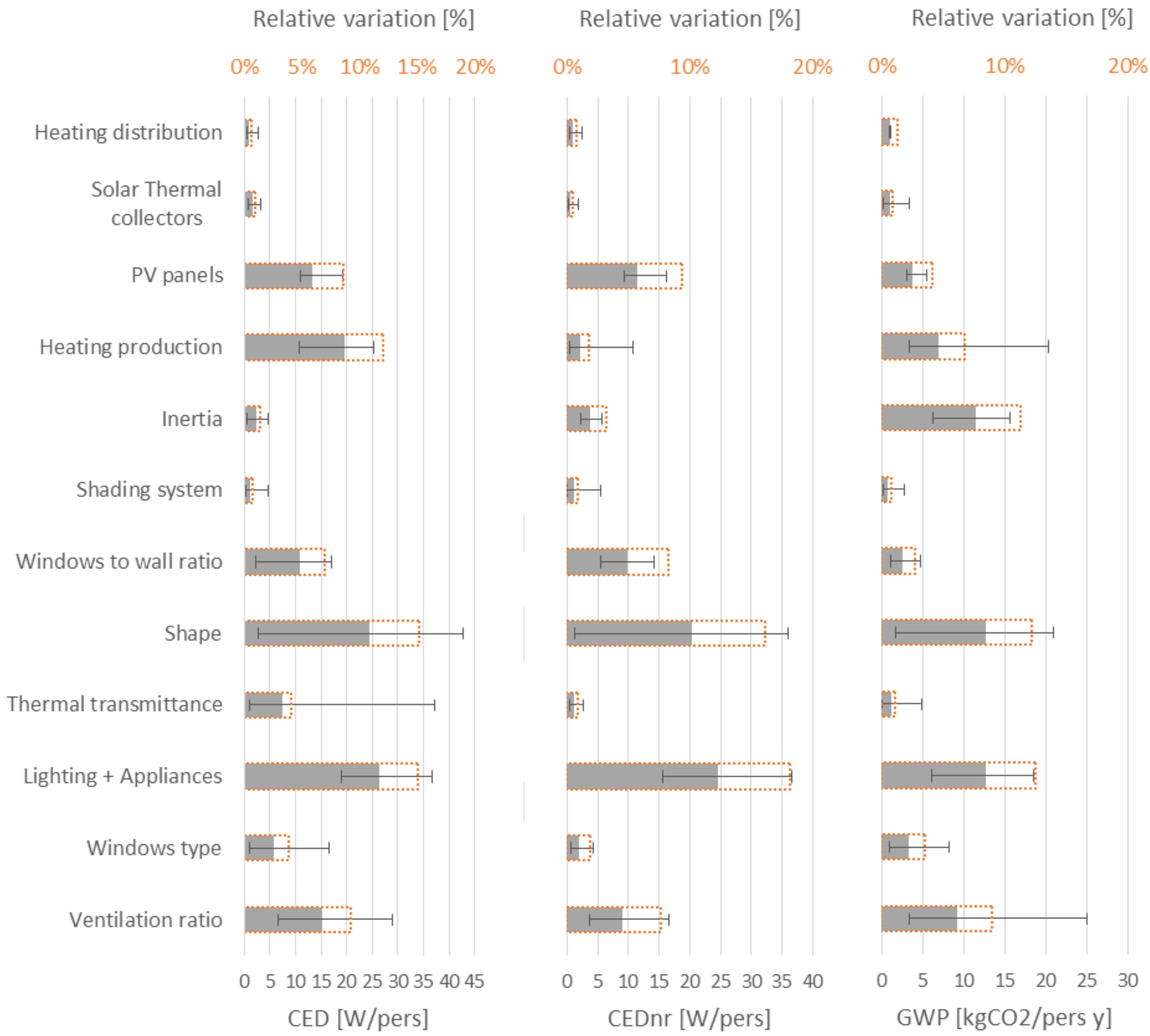
The calculations of impact targets in the smart living lab are based on three different populations of cases: projects representing current best construction practice in Switzerland (78 case studies, known as the first sensitivity analysis); projects representing very high-performance projects anticipating possible future improvements in building construction and operation (90 case studies – hereafter called the second sensitivity analysis); and projects capable of achieving the 2050 goals (42 case studies among the 90 cases in the second sensitivity analysis).

In the **first sensitivity analysis**, using the Morris method, 12 inputs are considered, with the number of trajectories equal to 6 (4, 6 or 8, as recommended by Saltelli et al (Saltelli et al., 2004)). The inputs of cases have been defined in accordance with the recommendations given by SIA 380/4 (SIA 380/4, 2006), as well as three architectural feasibility studies carried out for the smart living building. The environmental impacts are assessed for each project. Since the purpose of this analysis is to develop possible projects for the smart living building that are capable of achieving the 2050 goals, the impact assessment considers materials with low embodied impacts. Comparisons of the impacts of each of the 78 projects under consideration with the 2050 objectives show that only two cases come close to achieving the goals, but none of them simultaneously achieved the goals for the three indicators (CED, CEDnr and GWP). More details about the calculations involved in the first sensitivity analysis can be found in Erreur ! Source du renvoi introuvable.. According to Saltelli et al, (Saltelli et al., 2004) the Morris method is referenced as a qualitative method. To complete the analysis, successive steps are applied for identifying the quantitative influence of the input parameters on the environmental impacts. The absolute and relative influences of the inputs are shown in

[2] Number of standard person ($person_{st}$) are consider the number of users of smart living lab calculated in function of the “standard” space allocation (each Swiss citizen has 60m² of residential space, 40m² of office area and 18m² for school) proposed by SIA-2039.
[3] Number of effective person ($person_{eff}$) are consider the number of users of smart living lab calculated in function of the “effective” space allocation (each Swiss citizen has 60m² of residential space, 5m² of office area and 2.5m² for school) proposed by 2000 watt society vision.

■ Influence of the parameter in absolute value
□ Influence of the parameter in percentage
— Variance of the absolute value

Figure 3.



■ Influence of the parameter in absolute value
□ Influence of the parameter in percentage
— Variance of the absolute value

Figure 3 : Qualitative influence of input parameters on environmental impacts (78 cases of first sensitivity analysis)

The results obtained for CED, CEDnr and GWP, which are presented in

■ Influence of the parameter in absolute value
□ Influence of the parameter in percentage
— Variance of the absolute value

Figure 3, show that electricity is generally the most critical factor: impacts due to the energy used for ventilation and lighting always represent the biggest contributors to the totality of impacts. Thermal contributions, on the other hand, are much more variable, depending on the type of construction; however, their influence on the final results is not as great as that of electricity. At a deeper scale, the first analysis was carried out to understand the impacts of macro-components within the framework of the smart living building.

3.3. A second sensitivity analysis was performed in order to investigate more deeply the impacts of components and systems with greater influences on the impacts of the building. Applying the Morris method in this second sensitivity analysis, 14 inputs were considered, and the number of trajectories was 6. This meant creating a second population of 90 case studies. For this new population of projects, the inputs linked to electricity (ventilation, lighting, appliances) and windows (glazing, frames) were improved in order to reduce impacts, so as to develop projects that could meet the 2050 objectives. As with the first sensitivity analysis, the environmental impacts in the second analysis were assessed using Lesosai software (E4tech 2008) and the KBOB database (Friedli et al. 2014). For this second analysis, the embodied impacts of PV panels and solar thermal collectors was set to zero, but the reported impact was placed in the operating part. This method was adopted mainly in order to quantify the CO_2 content of the energy produced by the PV panels. The GHG emitted for the physical production of the panel is divided in relation to the energy produced by the panel itself during its entire lifespan. Hence, some values in terms of kg CO_2/MJ have been calculated for both technologies – PV panels and solar thermal collectors. The environmental impacts of the electricity demand of appliances, lighting and ventilation are assessed using the values of kg CO2/MJ of PV panels and Swiss electricity grid. It is no longer possible to see a target value for the embodied impacts of PV panels in this way. A comparison of the environmental impacts with the 2050 targets shows that around half are achieving the goals (42 out of 90), thanks to the different input values proposed. The details of the inputs, assumptions, calculations and environmental impacts of the second sensitivity analysis are presented in

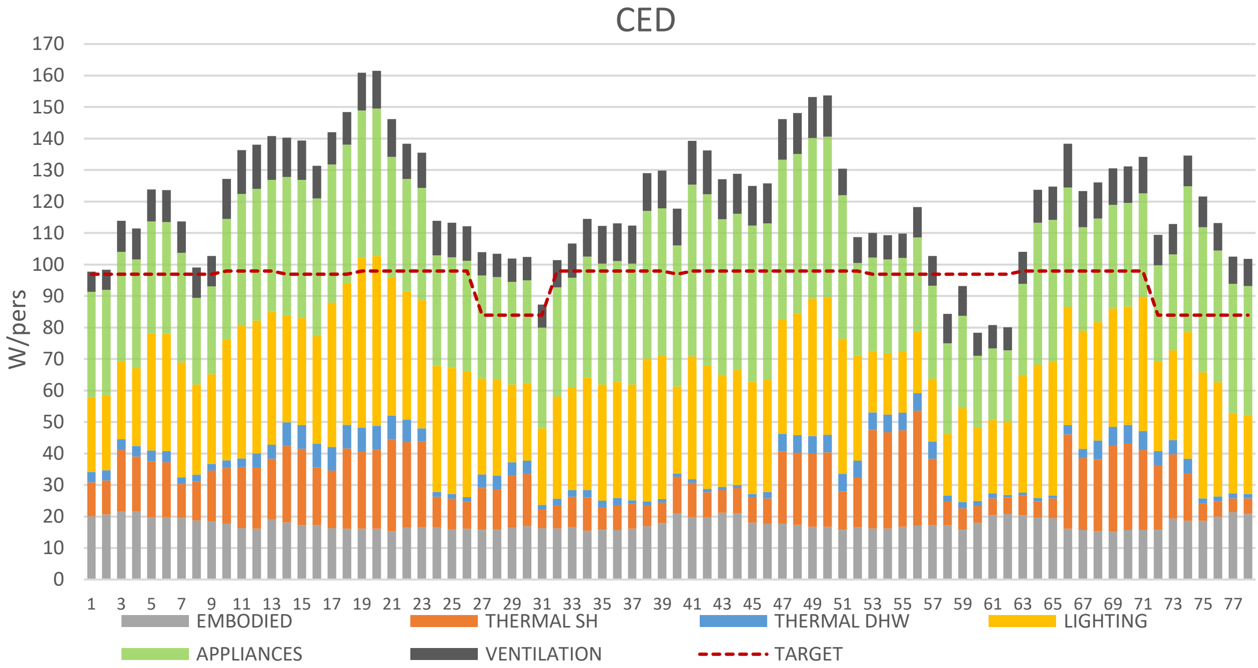


Figure A 1: CED Index for the 78 simulations of SA I

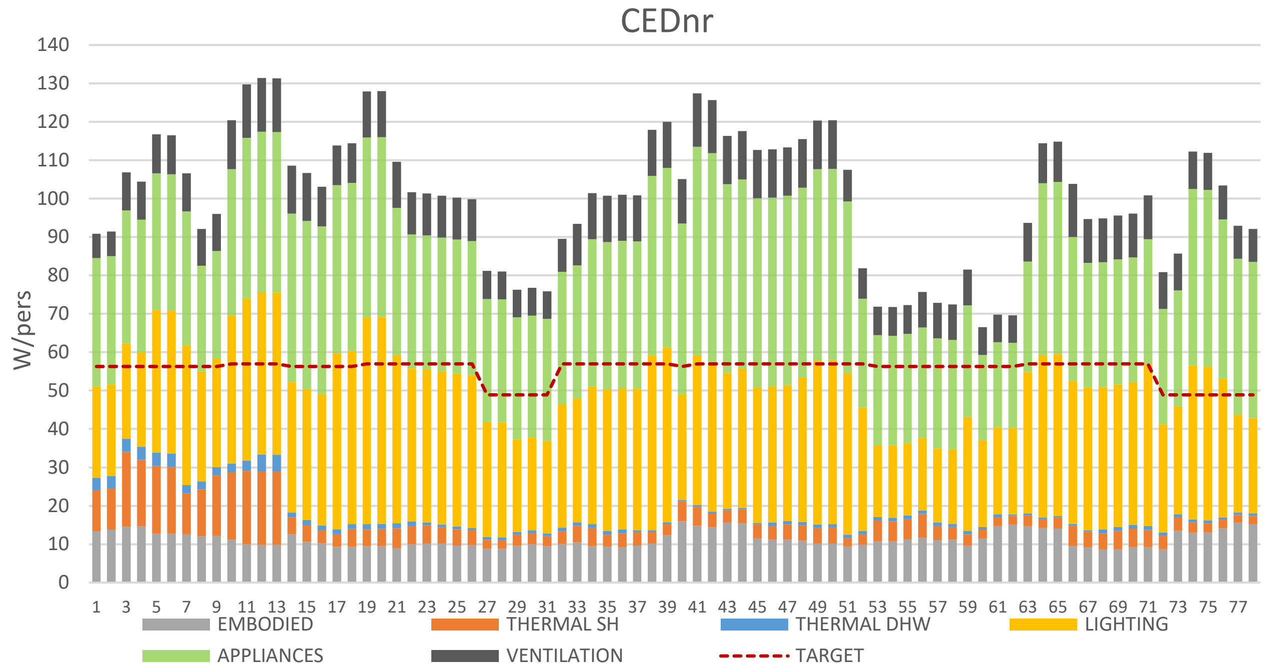


Figure A 2: CEDnr Index for the 78 simulations of SA I

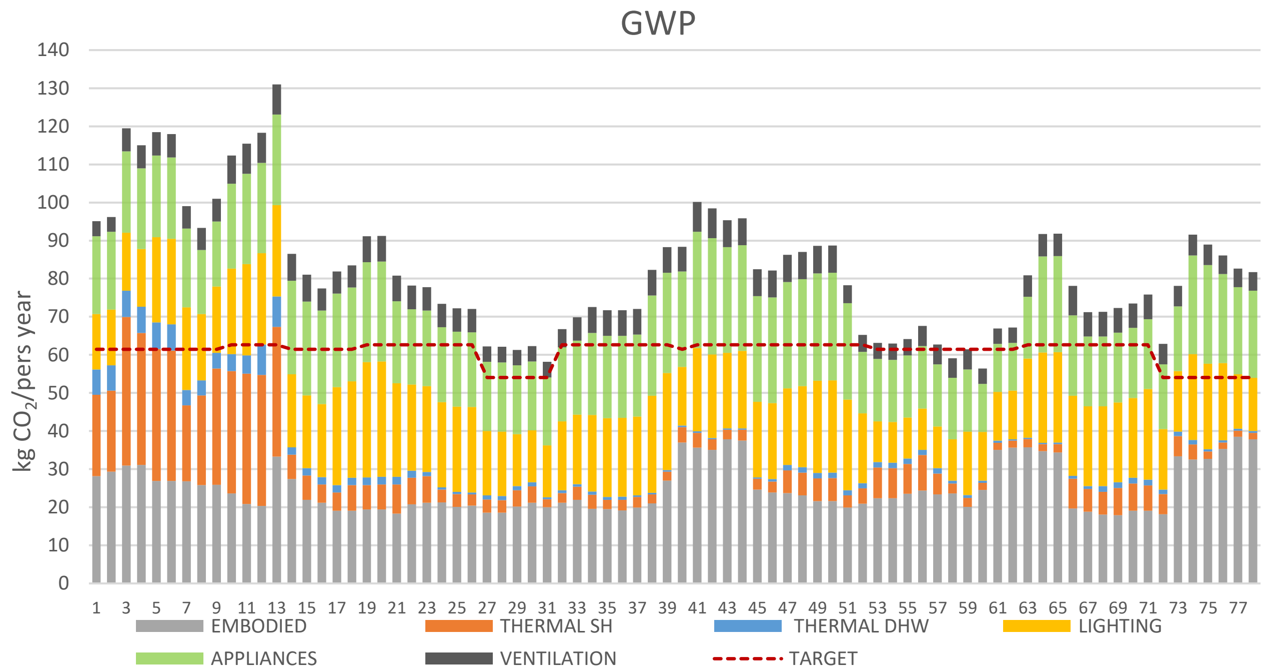


Figure A 3: GWP Index for the 78 simulations of SA I

3.4. Morris analysis results (SA I)

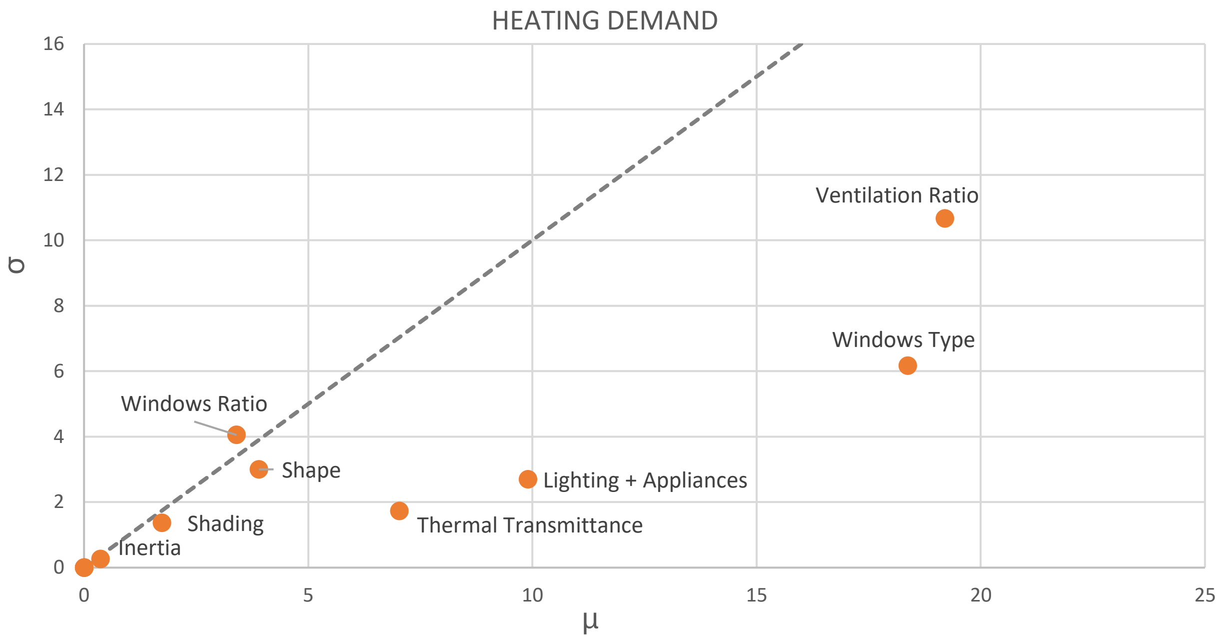


Figure A 4: Results of the Morris analysis regarding HEATING DEMAND output

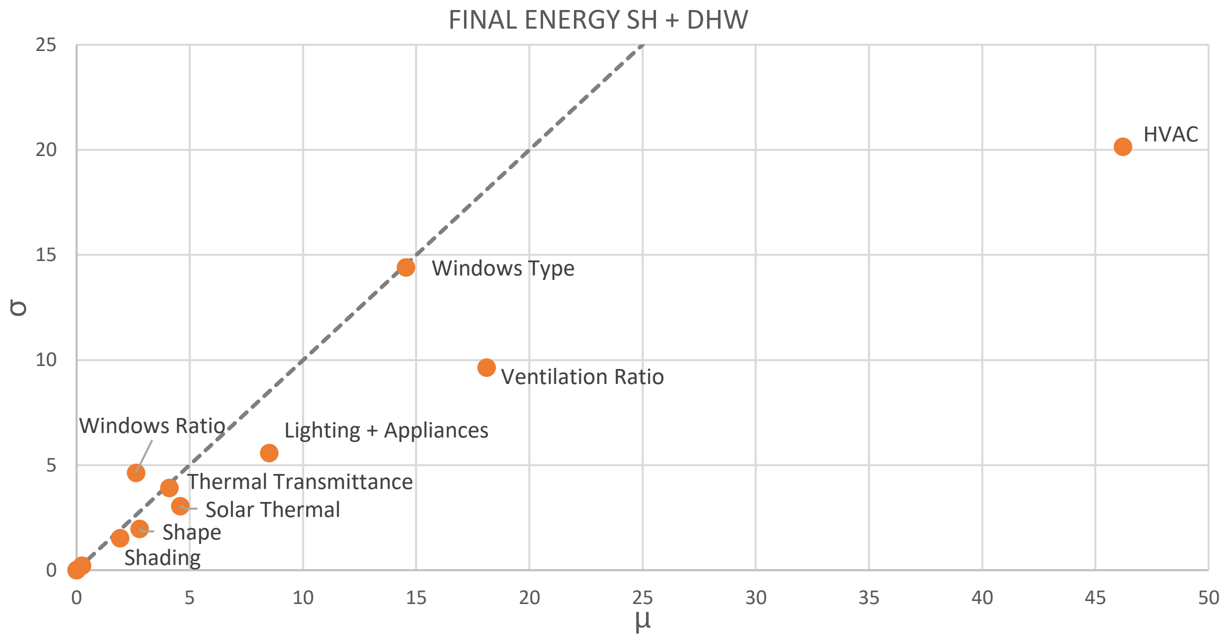


Figure A 5: Results of the Morris analysis regarding FINAL THERMAL ENERGY output

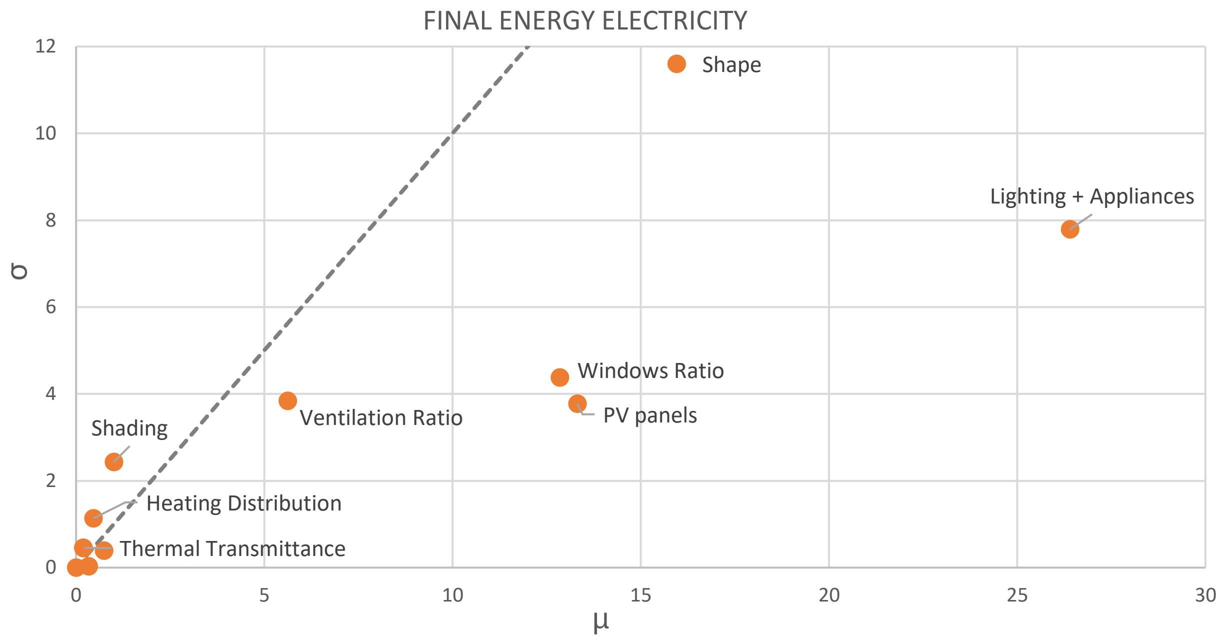


Figure A 6: Results of the Morris analysis regarding FINAL ELECTRICAL ENERGY output

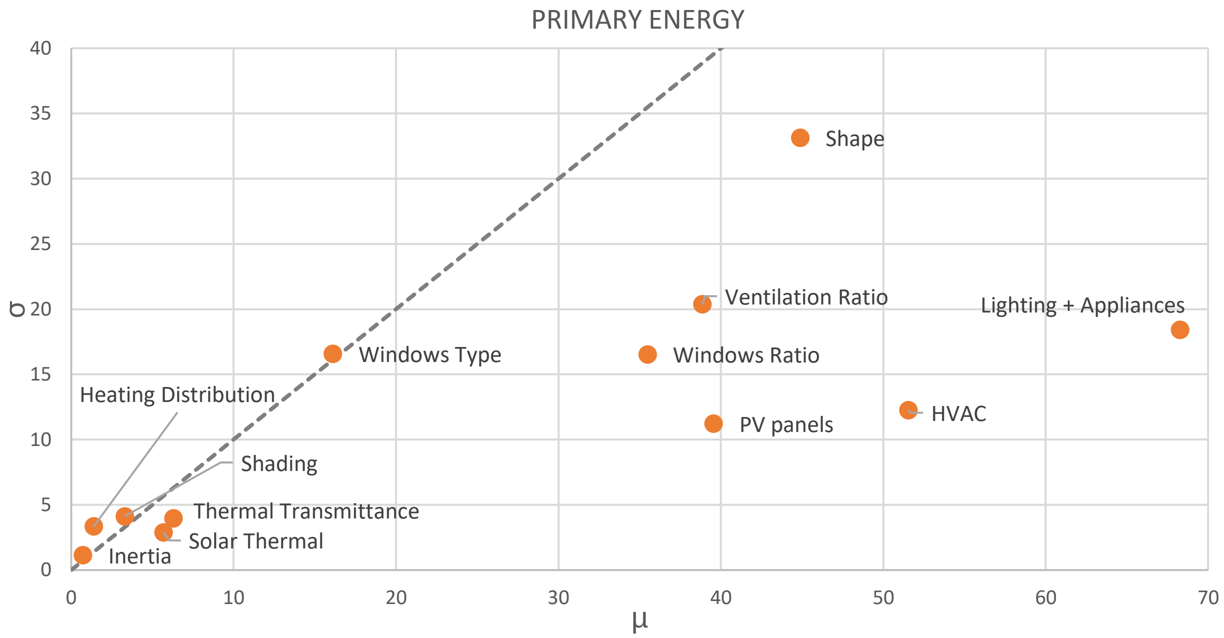


Figure A 7: Results of the Morris analysis regarding PRIMARY ENERGY output

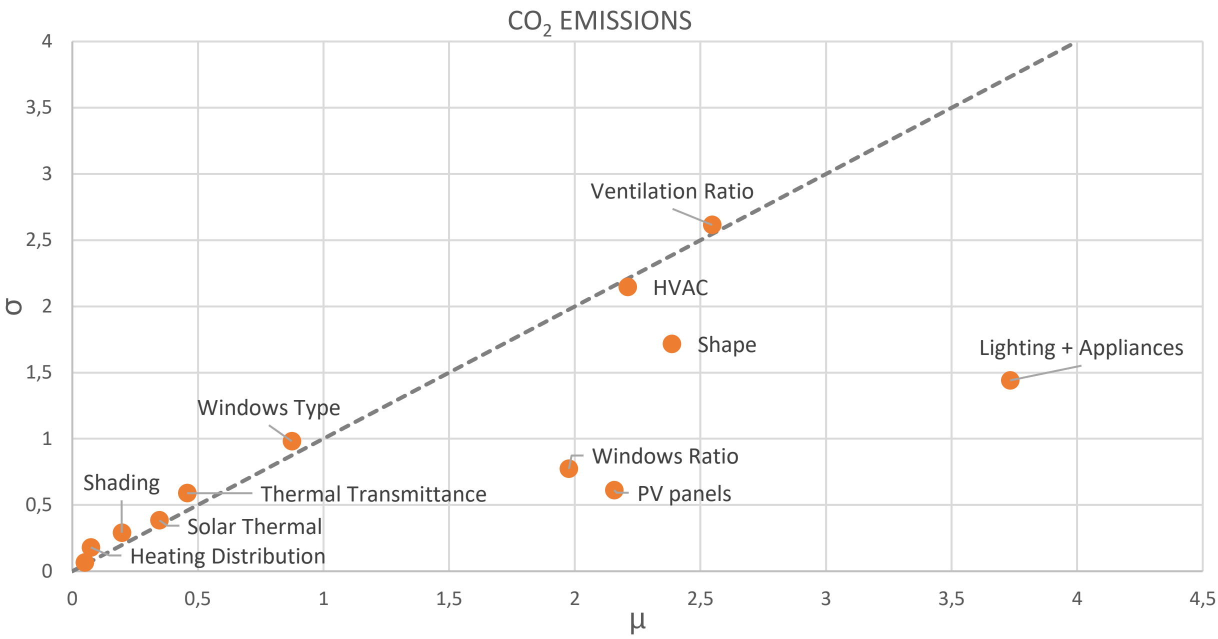
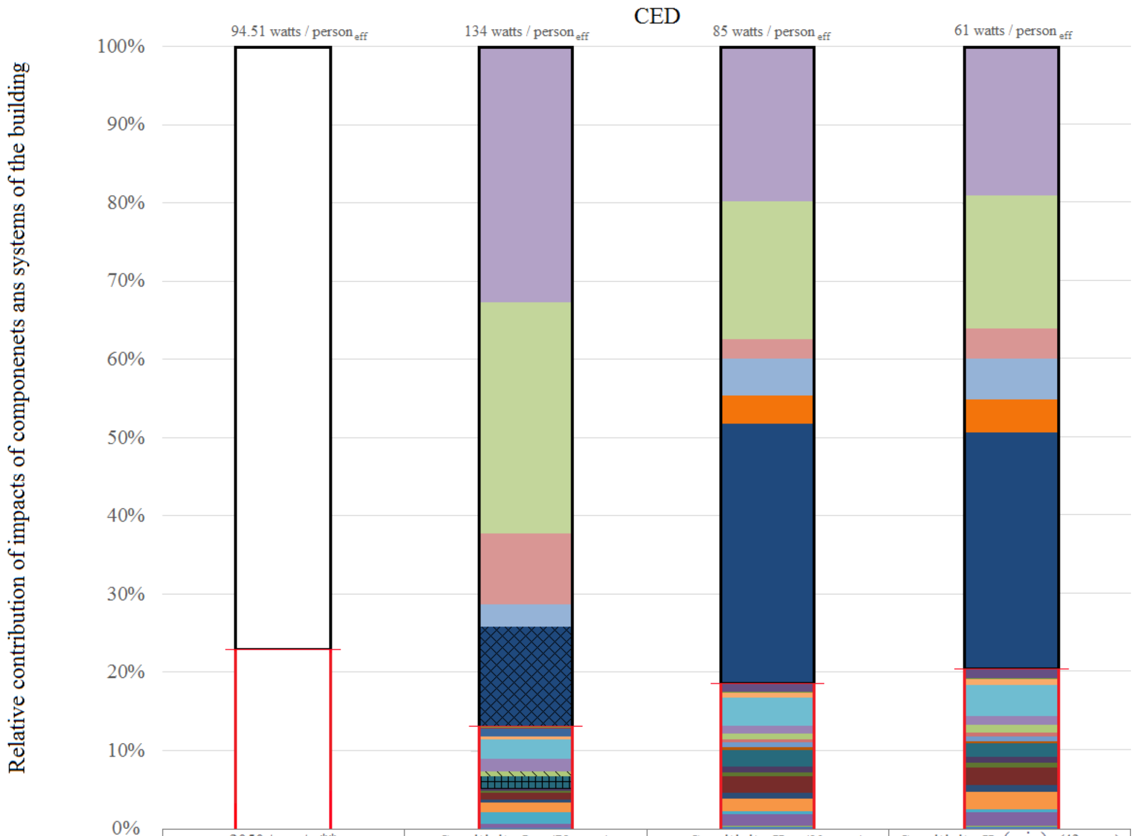


Figure A 8: Results of the Morris analysis regarding CO_2 EMISSIONS output

Annex 2: Sensitivity Analysis II**.**

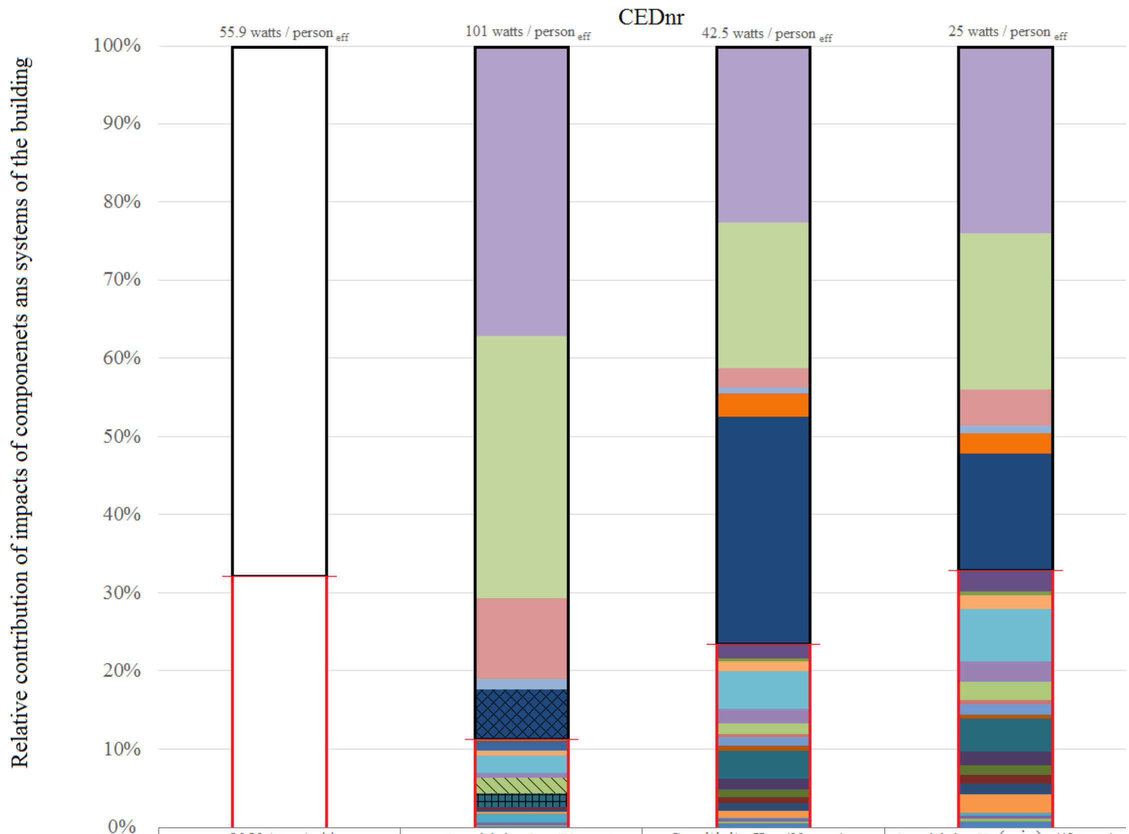
In the end, the impact targets shown in Figure 4, Figure 5, and Figure 6 were calculated based on these cases. The results obtained for the CED show that the impacts of the operation phase are more significant than the embodied impacts. For the GWP indicator, however, the increment of the performance of the building makes the embodied impacts more significant than the operation impacts. The results also show that the internal appliances, lighting and ventilation have the biggest impacts.

According to these indicators and going from the results of the first sensitivity analysis to the cases that achieve the 2050 objectives, the results show that the targets for the internal appliances, lighting and ventilation are reduced by a factor of 2. This is because, in the first case, the internal appliances are considered using the values given by SIA 380/4 (SIA 308/4 2006), whereas the values are considered to be lower in the second case. In the cases from the second sensitivity analysis, there was a shorter lighting period in the apartments, offices and experimental hall. The surface area of the building that will be lit has also been reduced. These hypotheses have brought about a reduction in the amount of electricity used, and consequently a minimisation of the CED, CEDnr and GWP results. The targets for the ventilation systems are lower when they are calculated using cases from the second sensitivity analysis than when they are calculated using cases from the first sensitivity analysis. The reason for this is that, in the cases in the first analysis, only mechanical ventilation was taken into account; in the 90 cases in the second analysis, both mechanical and natural ventilation were considered. Natural ventilation negatively influences heating, by increasing its impacts, hence the impact targets for heating are increased. The results show also that the targets of PV panels and solar thermal collectors are zero when 90 case studies and 42 case studies are used for making the calculation. The reason is that the embodied impacts of PV panels and solar thermal collectors are placed in the operating part.



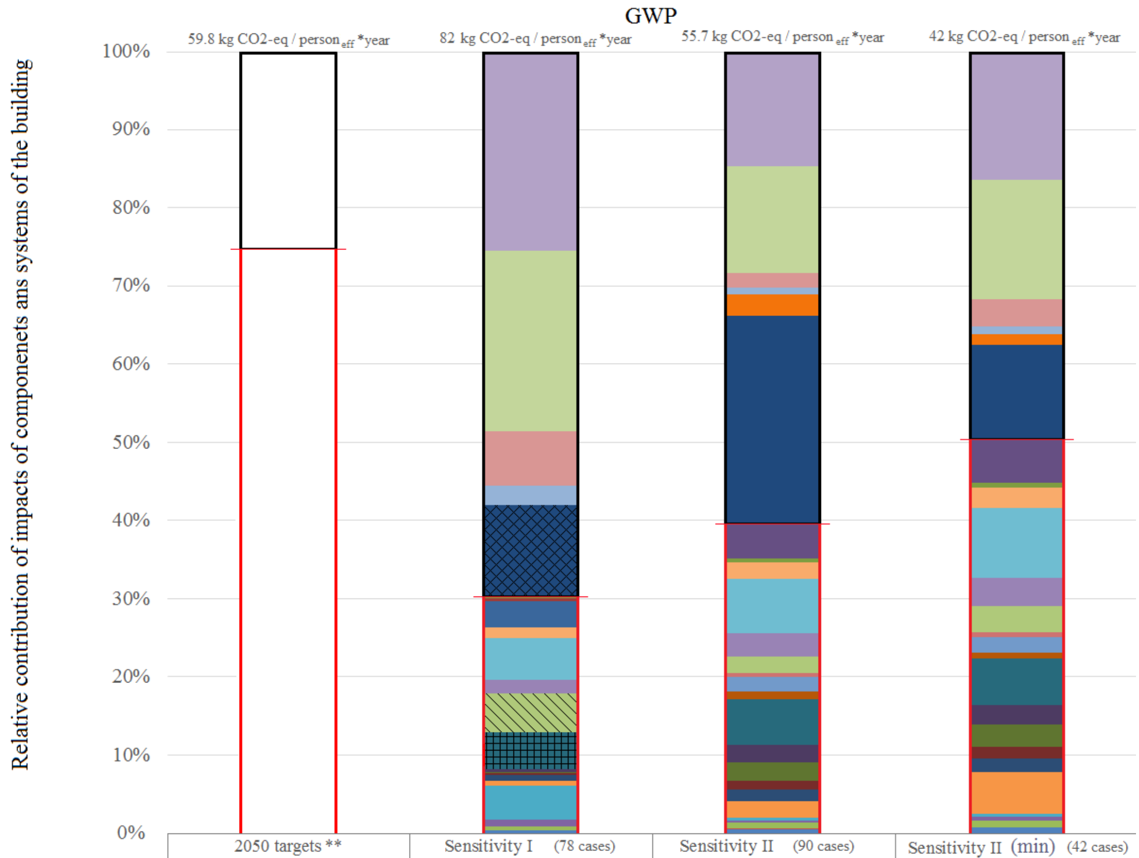
Group	Component	2050 targets **	Sensitivity I (78 cases)	Sensitivity II (90 cases)	Sensitivity II (min) (42 cases)
Operating (Watts / p)	Intenal app	72.69	30.88	18.68	17.91
	Lighting		27.93	16.64	16.1
	Ventilation		8.53	2.28	3.62
	Solar DHW		2.74	4.44	4.88
Heat	Heating DHW		12.01	3.45	4
	Space heating			31.36	28.56
Embodied (Watts / p) – Technical equipment	Parking	21.82	0	0.96	1.09
	HVAC		0.11	0.17	0.19
	Solar thermal		0.14	0	0
	PV panels		0.91	0	0
	Sanitary equipment		0.4	0.61	0.67
	Electrical equipment		2.34	3.36	3.77
	Heating distribution		1.54	0.92	1.01
	Ventilation		0.53	0.69	0.98
Windows	Internal windows		1.47	0.4	0.44
	Windows north			0.6	0.56
	Windows east/west			0.32	0.23
	Windows south			1.94	1.68
	Doors		0.27	0.75	0.73
	Roof		0.18	0.46	0.5
	Structure		0.86	1.95	2.21
	Internal walls		0.3	0.69	0.78
	External walls		1.25	1.62	2.14
	Floors		1.38	0.31	0.35
F+Sl	Slab		0.41	1.4	1.55
	Foundations		0.07	0.12	0.14
	Excavation		0.01	0.02	0.02
	Backfill		0.15	0.26	0.29
Total		94.51 watts / person			

*Figure 4 : 2050 targets of smart living building for the CED indicator (**from Pfäffli and Preisig, 2011)*



			2050 targets **	Sensitivity I (78 cases)	Sensitivity II (90 cases)	Sensitivity II (min) (42 cases)
Operating (Watts / p)		Intenal app	37.813	20.73	12.58	13.35
		Lighting		18.75	10.47	11.2
		Ventilation		5.72	1.36	2.57
		Solar DHW		0.76	0.39	0.54
	Heat	Heating DHW		3.62	1.7	1.43
		Space heating			16.2	8.31
Embodied (Watts / p)	Technical equipment	Parking	18.06	0	1.06	1.52
		HVAC		0.07	0.2	0.28
		Solar thermal		0.1	0	0
		PV panels		0.62	0	0
		Sanitary equipment		0.29	0.68	0.94
		Electrical equipment		1.25	2.7	3.8
		Heating distribution		0.38	1.01	1.4
		Ventilation		1.11	0.75	1.34
	Windows	Internal windows		0.97	0.19	0.25
		Windows north			0.64	0.76
		Windows east/west			0.33	0.32
		Windows south			2.04	2.3
		Doors		0.08	0.77	0.97
		Roof		0.04	0.51	0.69
		Structure		0.06	0.44	0.63
		Internal walls		0.1	0.53	0.74
		External walls		0.16	0.48	1.36
		Floors		0.61	0.12	0.17
	F+Sl	Slab		0.2	0.16	0.22
		Foundations		0.05	0.14	0.19
		Excavation		0.01	0.02	0.03
		Backfill		0.12	0.3	0.42
		Total	55.86 watts / person			

*Figure 5 : 2050 targets of smart living building for the CEDnr indicator (** from Pfäffli and Preisig 2011)*



			2050 targets **	Sensitivity I (78 cases)	Sensitivity II (90 cases)	Sensitivity II (min) (42 cases)
Operating (kg CO2-eq/p)		Intenal app	15	15.25	8.75	9.78
		Lighting		13.79	8.16	9.15
		Ventilation		4.21	1.15	2.05
		Solar DHW		1.49	0.49	0.61
	Heat	Heating DHW		6.99	1.62	0.85
		Space heating			15.94	7.17
Embodied (kg CO2-eq / p)	Technical equipment	Parking	44.78	0	2.65	3.38
		HVAC		0.12	0.31	0.39
		Solar thermal		0.27	0	0
		PV panels		1.95	0	0
		Sanitary equipment		0.86	1.23	1.52
		Electrical equipment		3.17	4.2	5.35
		Heating distribution		1.03	1.74	2.14
		Ventilation		3.01	1.28	2.04
	Windows	Internal windows		2.78	0.3	0.37
		Windows north			1.1	1.17
		Windows east/west			0.57	0.49
		Windows south			3.51	3.52
		Doors		0.21	1.34	1.51
		Roof		0.12	1.41	1.71
		Structure		0.13	0.68	0.86
		Internal walls		0.46	0.88	1.09
		External walls		0.38	1.27	3.17
		Floors		2.58	0.2	0.24
	F+Sl	Slab		0.54	0.2	0.25
		Foundations		0.26	0.42	0.52
		Excavation		0.02	0.04	0.05
		Backfill		0.25	0.39	0.48
Total			59.78 kg CO2-eq / person year			

*Figure 6 : 2050 targets of smart living building for the GWP indicator (**Pfäffli and Preisig 2011)*

These first results for the CED, CEDnr and GWP indicators presented in the Figure 4, Figure 5 and Figure 6 show the possibility and validate the methodology of definition of impact targets at component and system level. But to validate the robustness of these targets, it is recommend to enhance the project database.

For these reasons, increasing the number of case studies where other types of materials and systems are implemented is recommended for the future development of the impact targets. In addition, statistical methods should be used to evaluate the robustness of the target values. The objective of the statistical methods should be to form conclusions about the stability of the targets calculated from one population case to another.
These studies will be part of a scientific paper submitted in the SBE 2016 conference (section 12.5).

3.4.1. 2050 targets – definition for mobility

Mobility and food account for the consumption of renewable and non-renewable energy (See Figure 7: Repartition of the cumulative energy demand (CED) for given sector in Switzerland (Leuthard et al., 2011) and are emitters of CO_2-eq gases (Leuthard et al., 2011), (SimaPro UK Ltd, 2015). For this reason, the 2000-Watt Society vision has set intermediate targets for these impacts, which should be met by 2050. Table 2 summarises the present impacts of mobility and food and the targets that they must meet by 2050.

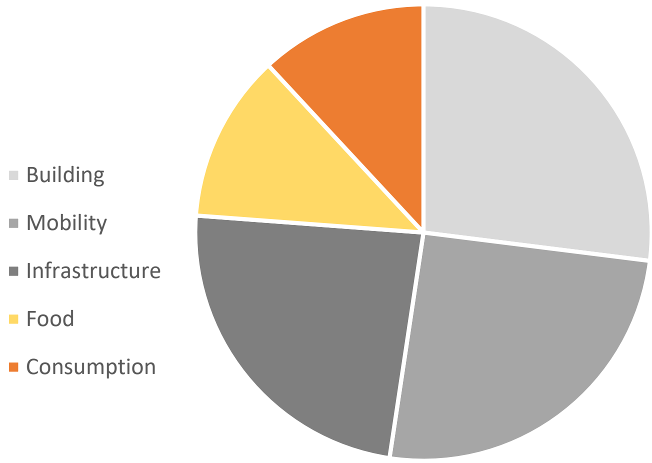


Figure 7: Repartition of the cumulative energy demand (CED) for given sector in Switzerland (Leuthard et al., 2011)

Table 2: 2005 impacts and 2050 targets for food and mobility

		CED [Watts / pers]	**CEDnr** [Watts / pers]	**GWP** [kg CO_2-eq / pers year]
2005 impacts	Mobility	1700	1150	2350
	Food	750	650	1150
2050 goals	Mobility	395	382	519
	Food	435	205	158

This section presents the 2050 targets that the smart living building has to meet in minimising the impacts of mobility more effectively. The definition of detailed target values concerning mobility is based on SIA 2039 (Hänger and Schneider, 2011) and the KBOB database (Friedli et al., 2014). The 2050 goals for daily mobility and occasional mobility are defined. Daily mobility includes holiday journeys, commuting and shopping. Occasional mobility includes trips made for attending conferences, meetings, training events, etc.

For these calculations, the following steps were followed:

- First, we calculated the environmental impacts of a Swiss citizen. These calculations were made using information about the number of kilometres travelled by different modes of transport by a Swiss citizen, (Hänger and Schneider, 2011) which was then translated into impacts (corresponding to the values given in Table 2).
- As a second step, we assessed the impacts of a Swiss citizen's mobility using the "Calculation method for buildings whose user mobility is unknown" proposed by SIA 2039 (Hänger and Schneider, 2011). This second evaluation allows us to distribute the impacts that a citizen has in relation to different purposes (house, office or education).
- The impacts on people in the smart living building (based on effective space) are calculated based on the results obtained in the previous step. These impacts have been distributed proportionally to different modes of transport.
- In the end, the impacts associated with different modes of transport have been minimised linearly to calculate the 2050 targets for occupants of the smart living building based on an effective space allocation.

The results obtained for the CED, CEDnr and GWP indicators are presented in Figure 8.

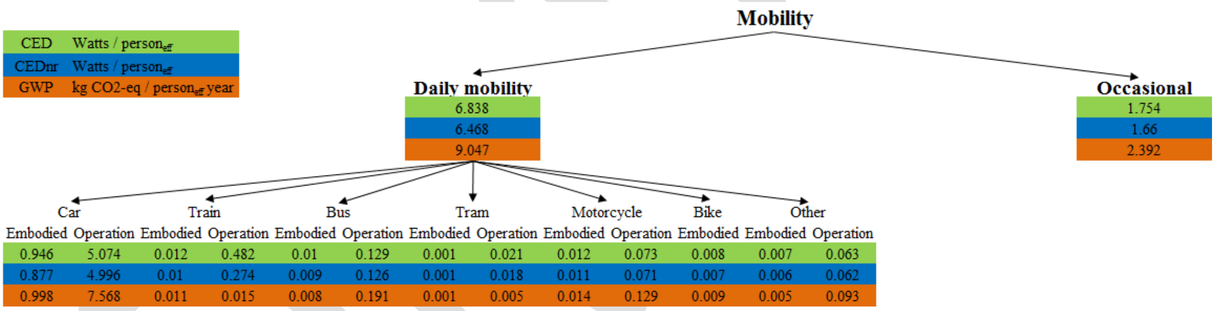


Figure 8 : 2050 smart living lab mobility targets

Much effort is required to achieve the mobility targets presented in Figure 8. To better understand the efforts that the users of smart living lab have to make, the target of occasional mobility is translated in number of kilometre that a person of smart living lab is recommended to travel in order to achieve 2050 goals.
Using the equation presented in the section 3.2, we have calculated the 2050 target of the occasional mobility for the all the users of smart living lab.

$$T_{smart\ living\ lab} = T_{Impacts\ /\ person_{eff}} * no\ person_{eff} = 2.392 * 861 = 2060\ \mathrm{kg\ CO_2 - eq}$$

According to the KBOB database, for each kilometre travelled by an intercontinental plane, 0.109kg CO_2-eq / km is emitted per person.
The target of occasional mobility is divided with the impact of one kilometre travelled by intercontinental plane for assessing the number of kilometres that the persons of smart living lab should travel in order to reach the 2050 goals.
This calculation, gives a recommended maximum of 18'800 kilometres to be travelled by all persons in the smart living building over one year. If this journey is made by one person in the smart living building, then it must be recommended that the rest do not undertake any other occasional trips. This is equivalent to a return journey between Switzerland and India.

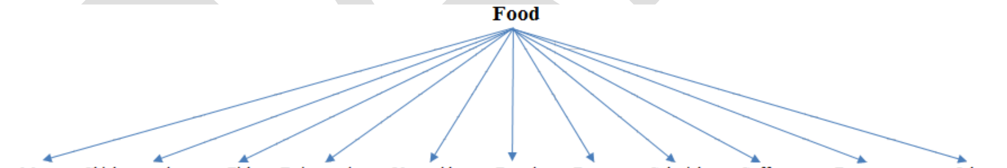
3.4.2. 2050 targets – definition for food

Targets relating to food are evaluated using the information given by Jungbluth et al. (Jungbluth et al., n.d.) and the results of a survey presented by a COOP study (COOP, 2009). According to the COOP results (COOP, 2009), the percentages of food consumed in the house or outside (restaurant, fast food, cafeteria, etc.) are presented in Table 3.

Table 3: Percentage of food consumed at home, outside the home, and the percentage who don't eat at certain times (COOP 2009)

	at home	outside	Don't eat at this time
Breakfast	69%	6%	26%
Lunch	43%	55%	5%
Between lunch and dinner	96%	4%	5%
Dinner	22%	45%	37%

The objective of the distribution in percentages presented in the Table 3 is to associate to smart living lab the corresponding impacts since it is a mix building. For the residential part of smart living lab are associated the 69% of breakfast, 43% of lunch, 96% of the food consumed between the lunch and dinner and 22% of the dinner. For the office part of smart living lab are associated only 55% of the lunch.
Using this information and in accordance to the information about the people in section 3.2, the target values for food have been calculated using the same methodology as that used for mobility. The results obtained according to this calculation are presented in Figure 9.



	Meat	Chichen products	Fish	Dairy products	Vegetables	Bread	Frozen	Colonials	Coffee	Beverages	Other
CED (watts / person$_{eff}$)	3.68	0.618	0.547654	5.456	0.709	0.372	0.583	1.032	0.344	0.513	0.190
CEDnr (watts / person$_{eff}$)	1.07	0.337	0.218384	2.198	0.711	0.206	0.539	0.503	0.162	0.557	0.120
GWP (kg CO2-eq / person$_{eff}$)	1.435	0.172	0.212689	1.696	0.375	0.140	0.156	0.368	0.250	0.217	0.079

Figure 9 : 2050 targets of a smart living lab user for food

Much effort is required to achieve the food targets presented in Figure 9. To better understand the efforts that the users of smart living lab have to make, the target of meat is translated in quantity of beef that a person of smart living lab is recommended to eat in order to achieve 2050 goals.
Using the equation presented in the section 3.2, we have calculated the 2050 target of the meat for the all the users of smart living lab.

$$T_{smart\ living\ lab} = T_{Impacts\ /\ person_{eff}} * no\ person_{eff} = 1.435 * 861 = 1235\ \mathrm{kg\ CO_2 - eq}$$

According the information presented in **Erreur ! Source du renvoi introuvable.**, the smart living lab is responsible for the impacts of 21 habitants, 45 employees and 58 students.
For assessing the target of one person, the total target of food (1235 kg CO_2-eq) is divided with the total number of persons (66), giving the value of 18.7 kg CO_2-eq.
One kilogram of beef accounts for emissions of around 15.7 kg CO_2-eq, according to the Ecoinvent database (SimaPro UK Ltd, 2015).

In the end the target of meat is divided with the impact of beef and per 12 months for assessing the quantity of beef that a person of smart living lab should eat in order to reach the 2050 goals.
After this calculation, an individual in the smart living building is recommended to eat no more than 100 g of beef per month (including both the lunch and the dinner), in order to achieve the 2050 goals.

3.5. Vital organs

The increasing number of necessary components and related techniques takes the complexity of the building to a very high level. Climate change challenges in the construction sector demand highly efficient buildings and require a full understanding of the performances and interactions between all constituents. It is necessary to identify them in order to optimise the major performance contributors (in terms of CED, CEDnr and GWP). A first sensitivity analysis based on actual building construction and operation allows for a global synthetic vision made up of groups of construction elements, which are the vital organs of a building.

These macro components simplify the understanding of the different mechanisms that ensure overall performance and allow for the establishment of a strategy enabling high-efficiency use of the available resources. The vital organs are necessary for the performance of a building and have their own specific performances. They are the envelope, the energy supply, the technical systems and mobility (See

Figure 10). Energy fluxes and dynamic relationships between these subsystems are made efficient through user behaviour and storage technologies. The global performance strategy is more accessible using a definition of vital organs, rather than speaking about all components. This vision is used for presenting the scientific concept and will be more deeply developed during the scientific programme. It is believed that splitting a building into "organs", as is proposed, has the advantage of probably being continued in the future, independently of the evolution of architecture, technological breakthroughs and changing user habits. A vital organ performs well when it achieves its function with a low CO_2 content.

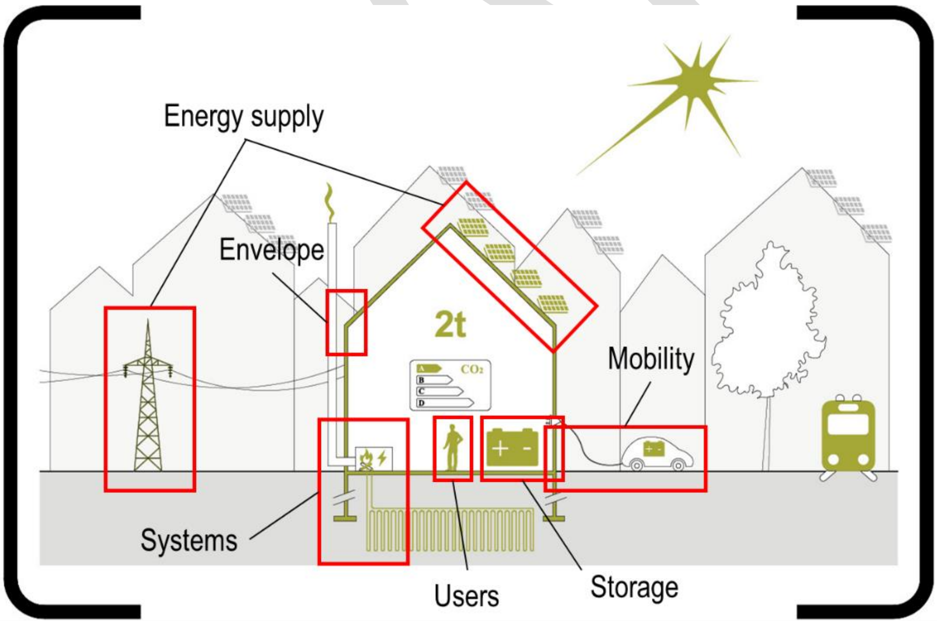


Figure 10: Overview of the vital organs of a building

Envelope

The envelope is the interface between the external environment and the user's protected space. It is the reason why we construct buildings: to protect ourselves from the environment. The envelope is mainly composed of external walls and windows, slabs, the roof and so forth.

Energy supply

Energy is necessary for all buildings, and its availability is determined by the external context. The energy demand of the smart living building mainly comes from the need to heat the living space and domestic hot water, and from other requirements for electricity. Other more complex buildings could require other kinds of energy.

Systems

The systems provide comfort to users by means of heating, ventilation, lighting and appliances. They are located inside the building and are powered by the energy supply.

Mobility

The mobility of building users has significant environmental impacts. The location of the building in the external environment is a major parameter of mobility, but architectural features such as parking space for personal transportation and energy supply for mobility also affect this performance.

Storage

Energy storage decouples the needs of energy and its production. This subsystem is seen as an efficient way to couple the vital organs. It could be heat storage, electricity storage, fuel storage, thermal inertia storage, etc. The aim of such storage is to better correlate energy needs and a low-carbon energy supply.

Users

Knowledge about user needs (in term of usage and comfort) is of prime importance in order to create a usable and efficient building. Usage intensity and its correlation with low-carbon energy is a key factor of this organ.

4. Scientific concept

4.1. Envelope

4.1.1. Introduction: envelope functions

The envelope's basic functions are related to the needs and the nature of exchanges, and they can be subdivided into four main groups:

- Protect from external agents,
- Control, related to energy of all types and to flows,
- Support, to resist and transfer mechanical loads,
- Finishing, to meet architectural and aesthetic goals.

The first two have the greatest impacts on the building's performance and guide the behaviour of the construction; in this study, attention is focused on the control function and its related meanings for the building due to the importance detected by the sensitivity analysis (see Annex 9.4 and Annex 10.4). Control covers all the sub-functions of the building which aim to manage the interaction of the construction itself with the surrounding physical environment.

Air flow control, for example, is crucial to ensure indoor air quality, to limit energy consumption, to avoid condensation and to improve comfort. Lighting control is necessary to ensure indoor visual comfort and, at the same time, to provide protection from unwanted glare. These two parameters very much influence the impacts of the building, and are related both to the envelope and to the energy system. In this chapter, the passive strategies to enhance natural daylighting and ventilation are described, while chapter 4.2 deals with aspects of the active strategy to reduce electricity consumption related to these factors. Thermal control is a big issue because of the opposite directions of flow in summer and winter. The enclosure should act as a shield to energy exchange (insulation) and, simultaneously, should provide energy storage (inertia).

It is clear that these functions need to be translated into functional components, which constitute the envelope and characterise the building's architecture, construction and performance. It is possible to distinguish four main components related to the key issues analysed previously: insulation, thermal inertia, transparent elements and ventilation elements. From the sensitivity analysis I (cf. Annex 9), it is clear that the most influential components are the windows. The ventilation system was computed in a simple way, not detailing all the components but just the major ones (like the ducts). Moreover a main assumption was done: the influence of higher ventilation rate will influence proportionally the size of the air-ducts. Based on this simplifications, ventilation is one of the major contributors in the CO_2 impacts. Thus, enhancing natural ventilation could improve overall environmental performances.

Insulation is provided by the layers and materials in the building's envelope that combine to create a thermal shield to attenuate or delete the thermal flux between the indoor and the outdoor, contributing to maintaining a comfortable temperature inside and saving energy for air conditioning. Thermal inertia is considered as an essential part of the passive strategies to maintain comfort. The functional components related to daylighting and ventilation control are usually identified in the glazing elements. Windows are essential to bring light into the interior spaces and to make sun gains during winter time; at the same time, they should prevent overheating and unwanted direct solar radiation (in summer) and should address glare issues.

The envelope plays an important role in all the standard regulations, as a fundamental element of buildings and as a major contributor to their real performance. Standards and national laws fix performance levels regarding the physical properties of the enclosure, especially related to the thermal part and thermal transmittance. However, despite the growing awareness of the importance of embodied energy and emissions related to the manufacturing and construction phase, studies are focusing only on one part at time of the building's life, with consideration given only to embodied or operating impacts. There has been no clear, in-depth analysis of the effects and benefits of pushing towards better operating performance (more insulation) or an improved embodied performance (fewer materials). One of the goals of the smart living building is precisely to couple these two major perspectives (embodied and operating phases) into one single big vision. Regarding the envelope, this means weighting the materials involved according to a life-cycle point of view, and understanding whether the operating savings are greater than the embodied impact.

4.1.2. Envelope's impacts by sensitivity analysis

A deeper inquiry has been made about the results of the sensitivity analysis related to the envelope's parameters, in order to understand better where criticisms of this vital organ may be. It is very important to clarify that all the results obtained are strictly dependent to the assumptions made during the evaluation. Especially, regarding the envelope, the materials implemented are the best one in terms of embodied energy, while the operating parameters (Annex 9.1 and Annex 10.1) are not optimized for the operating energy saving. Moreover, based on the State of the Art, the evaluation is made only on the winter energy behaviour, without considering the cooling needs and the comfort assessment. The assumption made is that the building will provide internal comfort during summertime with the integrated passive design strategies.
However, in order to optimise the whole project, it is important to dig into the components and understand better the meaning of the results obtained.

From an energy point of view, besides the electrical components, the most influential parameters are the windows ratio, followed by thermal transmittance and window type. The sensitivity analysis were made only on the heating consumption, without considering cooling needs and comfort assessment. Thus the shading system and the inertia effects are negligible, regarding the energy indicators. The effects of inertia become preponderant according to the GWP indicator, due to concrete being used as the material for the assessment. Regarding this last indicator, the glazing surface still has a medium to high importance, whereas thermal transmittance does not. Translated into the envelope's components, these results affect the insulation, the concrete for inertia and the windows.

Thermal transmittance and insulation

The thickness of the insulation influences energy consumption more than the carbon emissions, meaning that the impacts of heating due to poor insulation are greater than the embodied impact due to the production of the insulation material itself. The boundaries of these results are to be considered as part of the framework of the analysis, which has been carried out using cellulose fibre, an insulation material with a very low embodied impact.

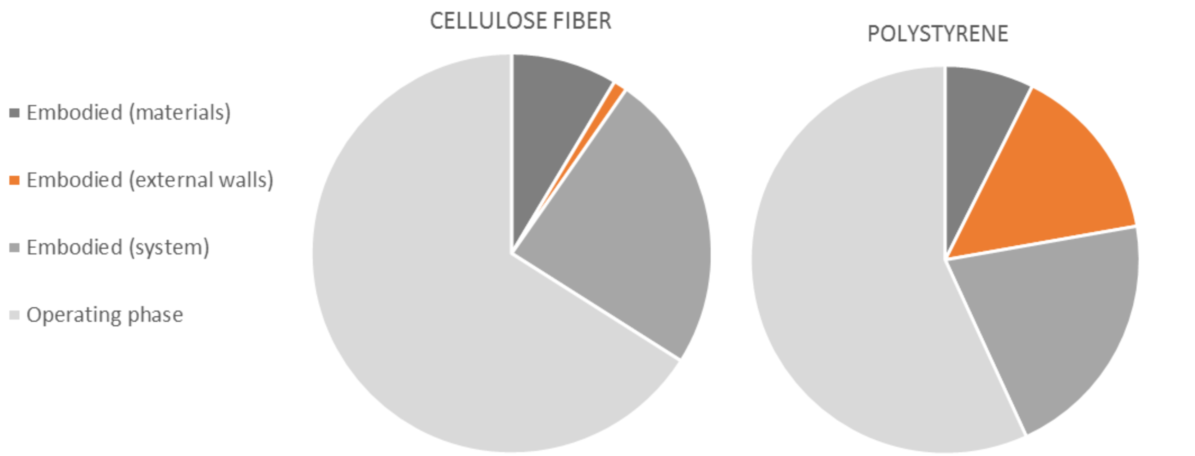


Figure 11: Percentage distribution of impacts on GWP indicators for macro-components. The analysis is made for case 60 in the first sensitivity analysis (identified as the best case), changing only the insulation materials: cellulose fibre and polystyrene

A comparison is made in order to understand the importance of the choice of materials to be used for the external walls. Keeping the thermal transmittance fixed but changing the material for insulation, the results may change consistently. As shown in Figure 11, comparing the emissions related to the fibre and the polystyrene, the results vary by a factor of 25 (from 0.3 to 7.5 $kgCO_2/kg$), indicating the importance of the materials. However, given the "State of the Art" results (Jusselme and al., 2015), it is possible to understand that chemical products need to be avoided due to their high GWP.

Inertia and thermal storage

Thermal inertia is directly affected by the quantity of concrete used in the construction. The results clearly show that the effects on the energy part are much less important than those on the carbon emissions indicator; this underlines the need to limit the quantity of material that can be used. These results refer to the actual situation, and it is clear that, in the future, a new manufacturing process may exist that could lead to better environmental results for concrete. Inertia is also part of the vital organ storage and it is further explored in chapter 4.3.

Windows ratio and frame features

Transparent elements affect energy and carbon emissions equally, hence the need for further inquiry about the correlation between saving energy and the related embodied impact, which was fulfilled in the second sensitivity analysis. Windows were decomposed according to orientation and according to the quality of the glass and the quality and size of the frames. On the operative part, the east and south façades, due to their large surface, greatly influence both heating demand and electricity consumption. This influence is direct in the first case, thanks to solar gains, and indirect in the second, thanks to the increased daylighting. A comparison of the CO_2 impacts of a case study with three different scenarios for the glazing part (simple, double and triple glazing) has been made in Figure 12 to evaluate the differences in the results.

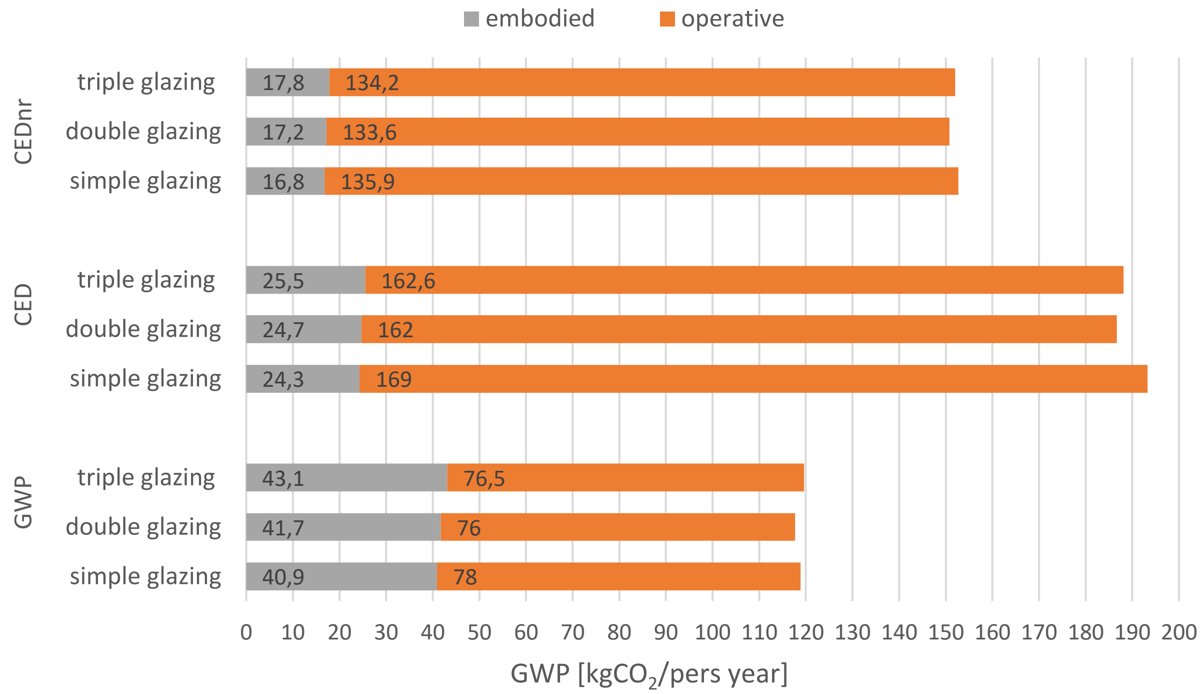


Figure 12: Operating and embodied impacts for carbon emissions in a case study with three different scenarios: single-glazed (U: 6W/m²K - g: 0.92 - t: 0.83), double-glazed (U: 1.1W/m²K - g: 0.62 - t: 0.8) and triple-glazed (U: 0.7W/m²K - g: 0.5 - t: 0.72) windows. Windows to wall ratio: 0.5 - Frame 25% wood

Figure 12 shows the results of the three types of glazing for both the operating and embodied sides. Simple glazing has the lowest embodied impacts among the solutions, however, the high energy requested to heating the indoor spaces due to the higher thermal losses makes this scenario the worst one. All the results obtained are strictly related to the case study utilised and to the assumptions made during the analysis. It is important to remind that the small embodied impacts are due to the utilization of very LCA performant materials during the calculation. As expected, the embodied impacts increase with the increase number of glass in the elements. The operating ones, instead, do not follow the same trend. Single glazing has the highest EI due to the low thermal resistance of the windows, and the consequent high heating demand. Double glazing is the one that can balance in a positive way the two quantity, achieving the best overall performance (OI+EI). It has to be noticed that the triple glazing has a higher operative part. In fact, even if the heating demand is lower, thanks to the lower thermal transmittance of the element, the lighting consumption is increase, due to the lower lighting transmittance of the glasses.
To achieve the 2050 target value more effectively, all the elements must be weighted towards this double-level perspective, and not just considered for the operation or embodied result.

Focusing on the material scale, it is possible to divide the whole windows element into two different sub-components: the frame and the glazing. The impacts of these elements are very different: in relation to the surface, the impacts of the frame are 4.5 times greater than those of the glass (32 and 144 $kgCO_2$ eq/m²). It is clearly necessary to investigate the major contributors identified with the first sensitivity analysis more effectively and thoroughly in order to understand how to achieve the 2050 goals.

Conclusions

The second sensitivity analysis, therefore, focuses on the criticisms detected by the previous one, regarding lighting, ventilation and windows. These three parameters are strictly correlated since, by improving the daylighting and the natural ventilation, it is possible to act directly on the related electricity consumption. The clear conclusion is, beyond the assumptions made at the beginning and dig into the real results, that the envelope and the glazing components play an essential role in achieving the 2050 goals, even if the direct impacts are not so significant.

4.1.3. Solutions for the major envelope contributors

Minimising the embodied energy related to the materials used in the envelope is the first step towards minimising the impacts of the envelope itself: during the design stage it will be important to pay attention to the quality of the materials used. The choice of natural, recyclable or recycled materials can have significant effects on final performance. Regarding the analysis conducted, it is possible to identify different criticisms related to the envelope, which must be thoroughly investigated in order to achieve the goals of the smart living building.

Component: EXTERNAL WALL
Target:

Table 4: Target values for the external walls in smart living building

	CED [W/pers]	**CEDnr** [W/pers]	**GWP** [kgCO$_2$/pers year]
External walls	2.05	1.47	3.37

Solution: LOW-CARBON WALL
As mentioned above, insulation seems not to be an issue as long as cellulose is considered. Changing the insulation material, to polystyrene for example, leads to a significant change in the results. For this reason, the impacts of the external walls vary greatly, and practical measures must be undertaken to limit the embodied energy due to them. The proposed solution is based on the idea of low-tech innovation, bringing back traditional materials into high-performance buildings. This consists of straw insulation and a self-supporting core (the so-called Nebraska technique (Minke and Friedmann, 2005). This represents a low-tech, low-carbon solution, which utilises natural and easily available materials. To evaluate the potential of the low-carbon wall, an emission impacts comparison is made between two different types of construction. The thermal transmittance is kept at the same level in order not to influence the operating performance, while the composition of the walls is changed so as to have an effect on the embodied performance. The straw wall is composed of earth mortar, straw balls, a panel of OSB and a layer of render (McCabe, 1993). The other option involves the wall used for the sensitivity analysis, comprising render, wood elements, cellulose insulation and wood cladding. The reduction can be up to three times less, highlighting the high performance of the proposed stratigraphy in comparison to one that is already optimal.

Recommendation:
The important key point is to use materials with very low impacts from an LCA point of view. Translated for the external walls, this means utilising locally available materials that are easy to obtain, with a low level of manufacturing required. Another approach is to use recycled and/or recyclable material, which decreases the total LCA impacts.

To do:
The solution requires questions to be resolved in order to understand whether or not it is really suitable for the construction of the smart living building. The first point is related to the external conditions of Fribourg: from “State of the Art” (Jusselme et al., 2015), it is clear that the city has a high level of humidity, which could represent a problem for construction. Straw is particularly sensitive to moisture (Lawrence et al., 2009) and, therefore, the behaviour of the enclosure must be tested and verified. Another criticism is the possible use of new technical components in the construction: the smart living building needs to be flexible and adaptable to future change, the proposed solution is massive and its suitability to the objectives needs to be better developed. Regarding the envelope functions, it will be very important to understand better how the comfort issue and evaluation could be integrated in this solution, especially regarding thermal storage and the inertial components needed to smooth temperature peaks and maintain thermal stability.

Component: WINDOWS

Target:

Table 5: Target values for the windows in the smart living building

	CED [W/pers]	**CEDnr** [W/pers]	**GWP** [kgCO_2/pers year]
Windows	2.35	3.15	4.8

Solution: MINIMISING FRAME

Windows are one of the major contributors to the embodied impacts in a building. The frame is almost 3 times heavier than the glass in surface's unit. To achieve the 2050 goal, it is important to minimise these impacts as much as possible and, for this reason, a more in-depth analysis on the frame has been done. Two different types of frame have been considered: wood and aluminium. The biggest difference is in the frame percentage on the whole windows, since metal allows thinner profiles. Referring to the real component on the market, the proportion of the frame size related to the window surface is evaluated taking into account the difference according to the necessity of double or triple glazing.

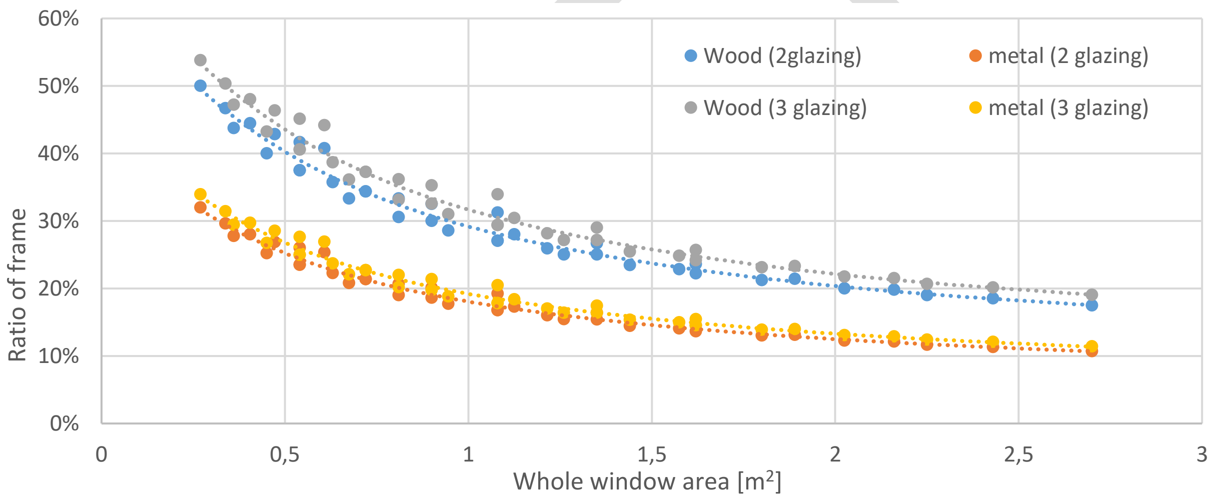


Figure 13: Relationship between the whole window area and the percentage of frame for two different profiles (wood and metal) and for different kinds of panes

It is clear from Figure 13 that the best solution for minimising the frame is to have a large window surface in order to achieve smaller frame proportions. However, a set of simulations has been evaluated on both operating and embodied impacts, in order to see which combination of glazing and profile achieves the best results from an LCA point of view. Taking into account the related frame proportions, different panes are tested: single, double and triple glazing with metal and wood profiles. Unexpectedly, the materials of the frame turn out to be more important than its dimensions. The combination that achieves the lowest results in terms of greenhouse gas emissions is a double glazed pane with a wood frame. This result indicates that it is unnecessary to use triple glazing, from an LCA point of view, and the window frame should be made of wood.

Recommendation:
The basic recommendation is to choose the profile based on the real needs of the construction, and not only for aesthetical reasons. Wood profiles are thicker but better performing than metal ones and, therefore, they should be preferred.

To do:
The analysis shows the best combination of windows and frame in the smart living building context; however, more generally, the windows, and especially the frame, still give rise to the biggest criticism for the façade performance against the target values. For this reason it would be beneficial to work on this part and to integrate a profile that could minimise the surface of the frame on the total transparent element.

Component: WINDOWS

Target:

Table 6: target values for ventilation, lighting and windows in the smart living building

	CED [W/pers]	**CEDnr** [W/pers]	**GWP** [kgCO_2/pers year]
Ventilation	3.99	2.75	2.25
Lighting	16.75	11.43	9.45
Windows	2.35	3.15	4.8

Solution: CLIMATE BOX
It is apparent from the sensitivity analysis that the major criticism of the smart living building is represented by electricity consumption due to ventilation and lighting. These factors are not directly included in the vital organ envelope, but the indirect connection between them is quite clear. The transparent elements influence the level of daylighting inside the room and, therefore, decrease (or increase) lighting consumption to maintain the desired visual comfort level. Other highlight of the sensitivity analysis is the positive effects of the natural ventilation. Its reduced embodied impacts combined with a low carbon heating generation decreases sensibly the GHG emissions thanks to a lower electricity demand. Windows, therefore, have a great potential to minimise the impacts of the smart living building and to help achieve the goals of the construction. For this reason, the solution proposed is to integrate the control of these two contributors into only one element, designed to respond to the issues with the lowest impacts possible.

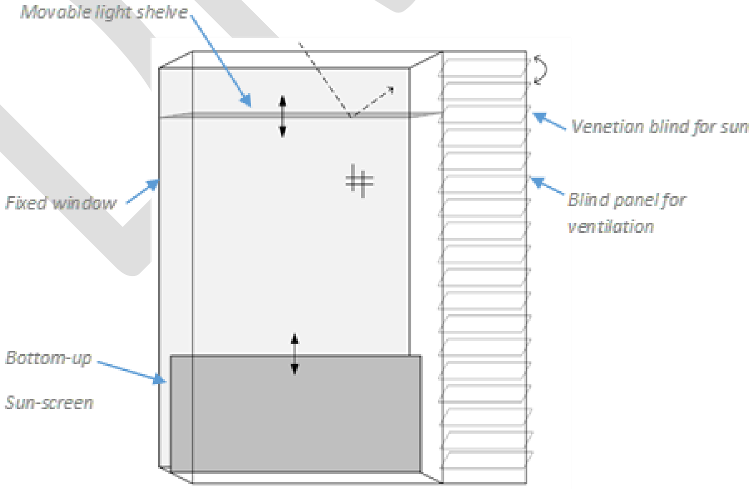


Figure 14: Sketch of the "climate box" element of the solution – transparent components with shading system, light shelves and a special panels for ventilation

The basic idea is to have a prefabricated element that could incorporate everything necessary for ventilation and lighting: as shown in Figure 14, the glazing part, a shading system to protect from unwanted solar radiation, light shelves to enhance the daylighting and a ventilation system. The main purpose of the solution is to manage all the issues and aspects related to the windows in only a single component. The climate box aims to incorporate all the functions mentioned above, but in a dis-associated way. Separating openings for lighting and ventilation makes possible to minimise the frame (due to the implications of openable glazing), at the same time the ventilation components could be opaque to reduce the glass impacts. The same is applied for the lighting and solar shading, incorporating two different kind of shading system.

Light Shelves

Light shelves reflect light deeper into the room, reducing the lighting requirements. Basically, they are flat or slightly sloped platforms covered with highly reflective materials that intercept the sunlight and bounce it up to a reflective ceiling, which bounces it back to the working surface.

Usually, they are placed within the structure, but some models can protrude outside. They can also function as fixed shading devices. For efficiency, the internal height of the room should be 3m; smaller rooms could reduce the positive effects of daylight reflection. The penetration of the light inside the room is estimated to be around 2.5 times the height of the windows if the light shelf hang is 1.5m (Kroelinger, 2011). This element is easy to integrate, and is formed by an independent plate structure (metal, polycarbonate or wood) and a reflective surface (metal or water). In order to minimise the environmental impacts related to this element, the material must be chosen according to the life cycle assessment. Operating savings and embodied impacts must be weighted to guide the implementation of this element. In order to amplify its effects, it must be designed together with a reflective ceiling (white, metal). Positioning is also very important as, on a north façade and in orientations that have different radiation profiles, the effects must be analysed better.

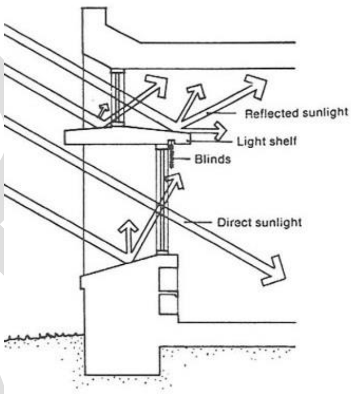


Figure 15: Scheme showing the functioning of the light shelves to bring light deeper inside the room

Bottom-Up Sun Screen

The bottom-up sun screen couples the sun protection and the psychological comfort related to the view out from the working spaces. The screen slides from the bottom part of the windows, excluding the direct solar gains entering through the lower part of the transparent element, protecting the working surface and the related activity area from glare. At the same time, it is still possible to keep a portion of the outside view if a fixed light shelve is also used as a sunscreen. The main characteristic of this element is the possibility to shade the work station from glare without shading the whole windows surface. In this way the upper part could continue to let the solar gains entering the indoor.
The criticisms of the solution are related to the waterproofing of the elements and to their integration into the architectural concept, since the frame of the screen is visible and requires larger elements than normal top-down curtains.

Ventilation column

The ventilation column is integrated in the modular windows, providing better comfort to each room. According to the sensitivity analysis results, the most efficient option is coupling natural ventilation and efficient heating supply system. For this reason the element will integrate natural ventilation and enhancing natural air exchanges. Some sensors can be placed to automatically open the element when needed. The opening flaps allow fresh air to be flushed through during the night, without interfering with the security of the premises. At the same time, they can be integrated with PV cells, in order to contribute to the production of electricity.

A similar set of components is provided by TEmotion, by Wicona.[4] This element regulates ventilation, sun protection and natural light at the same time, thanks to an adaptable control system. The module consists of a window with a normal solar screen and a ventilation column with automatic flaps covered by PV cells. The simulations shows that it is possible to save up to 40% of primary energy thanks to the mechanical control of all the variables described.

To do:
The existing solution shown incorporates windows and a hybrid ventilation system. Due to the nature of this element, one of the biggest criticisms is the maintenance of the fixed windows and all the components. Moreover, the technology required is highly visible from outside and takes up space on the inside, so it needs to be well integrated into the architectural process. On a larger scale, it is also necessary to investigate the suitability of the component for the smart living building programme, especially regarding the performance, the guaranteed flexibility and the users' environmental perception regarding thermal, visual and acoustic comfort. Another open question that must be faced is the integration of natural ventilation in the building: to cut the impacts of the electricity required for the ventilation system the best solution is in fact to use only natural ventilation. However, it is not clear yet if this strategy could be used in the smart living building context. Thermal and acoustic comfort must be assessed to evaluate this possibility.

4.2. Energy supply

4.2.1. Introduction

Providing energy to the smart living building in a sustainable way in order to guarantee the comfort of the users and to assure the usability of the building itself is fundamental to achieving the 2000-Watt Society targets. The energy needed to meet the building requirements is mainly of two types: heat and electricity. According to "State of the Art" (Jusselme et al., 2015), the cooling needs will be covered by appropriate passive strategies and design.

4.2.2. Heat

Heat is used principally for Space Heating (SH), but also for Domestic Hot Water (DHW). There are many ways to reach the target values related to the heating supply as shown in Figure 16, while finding the right balance between the energy demand of the building [kWh/m^2] (x-axis in the Figure 16) and the quality of the energy used [kg CO_2/kWh] (y-axis in Figure 16).

[4] http://www.wicona.com/en/int/Product/Facade/TEmotion-Intelligent-facade-concept/

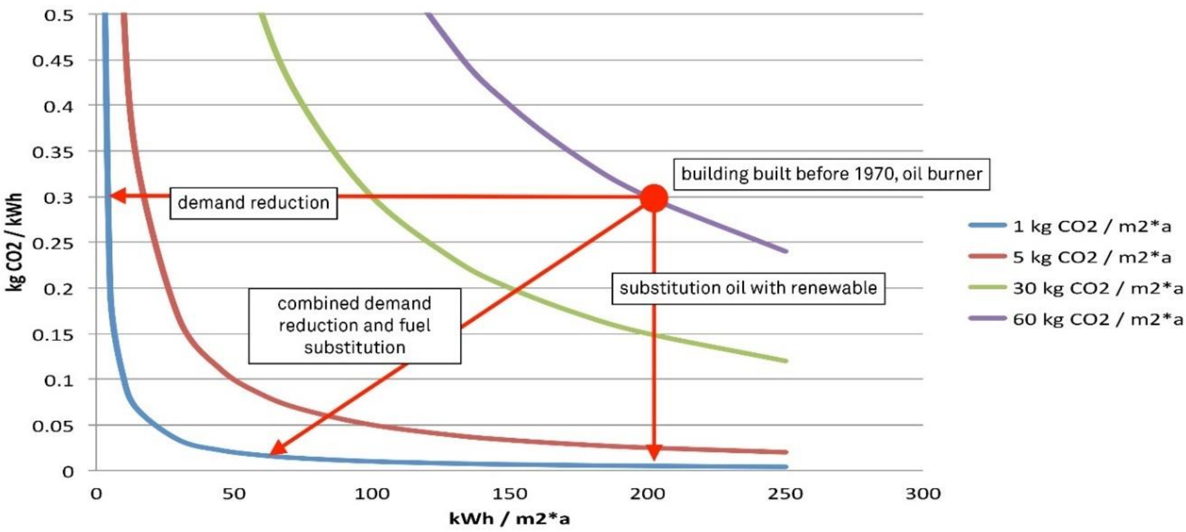


Figure 16: Current state and path to zero-emission buildings (Leibundgut, 2011)

The first sensitivity analysis has been used to understand which level it is possible to reach with the current practices. This is why all the energy resources available (renewable and otherwise), with their related systems, have been selected. Therefore, four possibilities have been proposed as regards the heating supply:

- **Natural gas:** this solution is the only one involving the use of fossil fuel.
- **Pellets:** it has been seen in "State of the Art" (Jusselme et al., 2015) that wood pellets are viewed as a high-performance method in Minergie houses and they are therefore often used.
- **Waste heat (district heating):** this solution has been selected to model the waste heat from the nearby industrial area.
- **Electricity (heat pump):** electricity and heat from the ground are two resources available in the area, so a heat pump with geothermal probes has been selected.

Table 7 summarises the CO_2 emissions of the different energy resources used in the analysis, for 1 MJ of Higher Heating Value (HHV).

Table 7: CO_2 emissions for different kinds of fuel, for 1 MJ of HHV (Friedli et al., 2014)

Resource	**Emission** [g CO_2/MJ]
Wood	3,2
Pellets	9,6
Electricity HP	13,8
Natural gas	63,3

As already stated, heat is also needed to cover the DHW demand. Solar thermal collectors are coupled with the chosen heat production system to provide hot water. Since solar collectors alone cannot feasibly supply the entire demand for DHW, it becomes important to understand how the integration of this system can influence the final energy (and thus the emissions) used to meet thermal needs. The value used to describe this parameter is the percentage of covering the hot water demand during the whole year (between 0 and 60%).

The results of the first simulations are presented in Figure A 1, Figure A 2 and Figure A 3 in the annex. From these figures, it may be understood that any of the proposed solutions, in these conditions of usage, is able to achieve the targets for the three indicators (CED, CED_{nr} and GWP). The first sensitivity analysis shows clearly, in Figure A 5, the importance of the solar thermal collectors for improving the performance of the smart living building regarding the final energy used for SH and DHW.

In the second sensitivity analysis, the parameter related to the heating supply technologies has not been defined as an existing solution, but only as a quantity of CO_2 per useful unit of heat that the heating supply produces. The idea is that some breakthrough in heat production systems must not be excluded. In this way, the only request for the heating supply is in terms of kg CO_2/MJ. As was learned from the first sensitivity analysis, the solar thermal collectors have been used in all the simulations to cover 60% of the DHW demand. In the second sensitivity analysis, the results (See Figure A 9, Figure A 10 and Figure A 11 in the annex) lead to the conclusion that it is possible to meet the 2000-Watt Society targets with several CO_2 levels, related to several heating supplies. More details regarding the heating systems may be found in the paragraph on Systems (4.4).

4.2.3. Electricity

The second kind of energy needed for the smart living building is electricity, which can be provided by the grid and by photovoltaic panels. As has been seen in "State of the Art" (Jusselme et al., 2015), other renewable sources (wind and hydro) are not feasible at the construction site location.

Using both of these methods, it is possible to meet the targets (see Table 8) as long as some precautions are followed.

Table 8: Target value for the electricity consumption in the smart living building

	CED [W/pers]	**CEDnr** [W/pers]	**GWP** [kg CO_2/pers year]
Electricity consumption	39.18	27.56	21.71

It is known that the CO_2 content of the grid is variable during the days, months and years, as shown in Figure 17 (representing the French case).

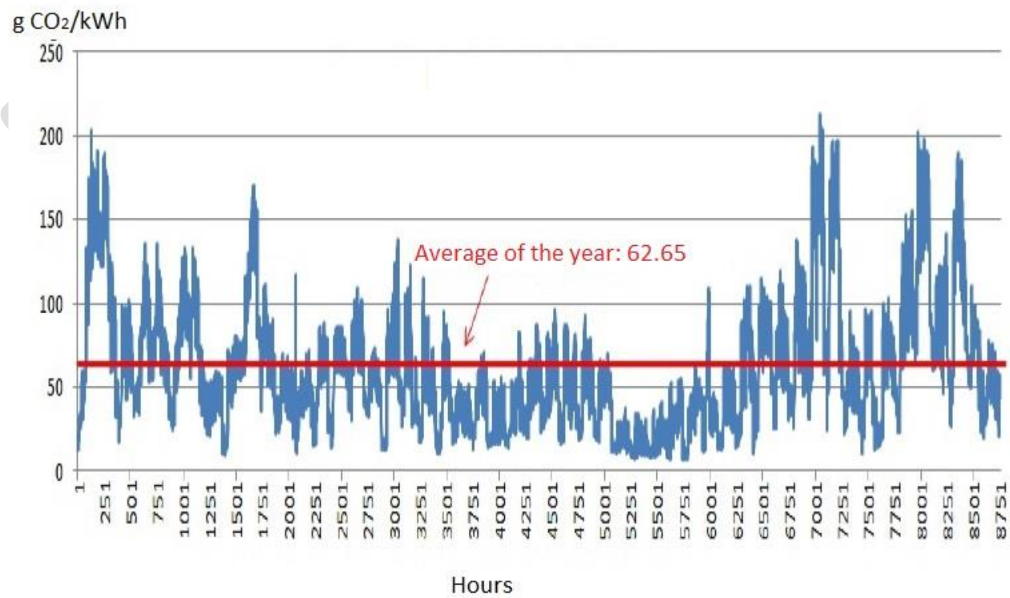


Figure 17: hourly variation of CO_2 content for 1 kWh from the grid in France (Thais, 2013)

The same variation is found in Switzerland, with the CO_2 content of the produced electricity that varies for instance from 6.01 to 11.23 g CO_2/MJ in a day. This significant fluctuation is due to the amount of a given technology used to produce the Swiss energy mix. The technologies are mainly nuclear, hydroelectric and pumped water storage. The CO_2 content of the electricity used by consumers (38.5 g CO_2/MJ) is still far from these values, due to the significant amount of imported electricity. More in-depth research on the hourly trend of the CO_2 content of grid electricity is absolutely necessary, in order to understand which is the right moment during the day to use the electricity from the grid and when it is better to use other sources. Evidently the objective is always to energy source which have the lowest CO_2 content at the time that the energy is requested. Side effects of this strategy on the global electricity network should also have some benefits, but must be further investigated.

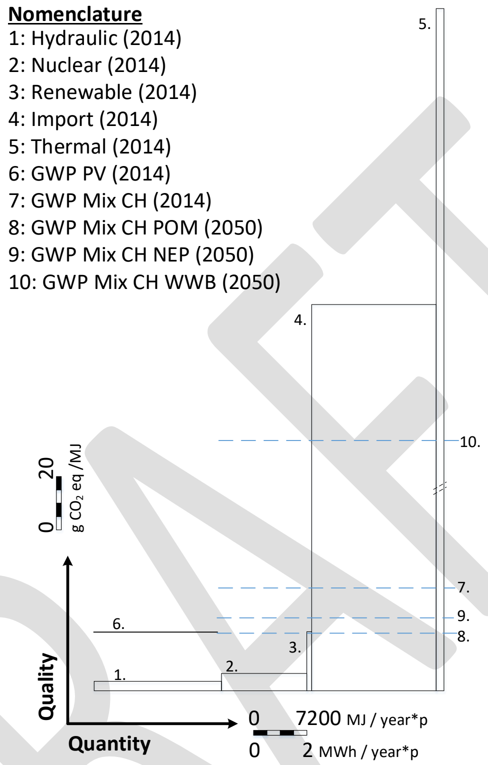


Figure 18: Representation of the actual composition of electricity in the Swiss mix, together with the tree scenario concerning the future electricity mix. From Wyss et al. (2013), OFS (2015), State of the Art Building 2050 (2015) and KBOB database (2014)

As shown in Figure 18, the CO_2 content of renewable resources (mainly PV) is always lower, or at most equal, in all the scenarios of the future electricity mix. This result is not trivial, because it allows us to define the minimum CO_2 content of the grid for guaranteeing a sustainable use of the PV panels (from the emissions point of view). As the lifespan of the panels is 25 years, this value has been defined as 19.25 g CO_2/MJ. Until the grid reaches this value, the use of PV with current performances will be suitable. The CO_2 emissions of a panel have been calculated with the GHG emitted to produce that panel spread against the quantity of energy that it can produce during its life. In this way, it is obvious that the same panel operating at a different location, or simply with a different orientation, will have a different quantity of CO_2 per energy unit. As is shown in Table 9, the case related to the north orientation is the only one with a CO_2 content higher than the grid. All other orientations provide a profitable result in relation to the Swiss grid. This statement remains correct until the grid becomes “cleaner” than the value given by PV for a given orientation.

Table 9: CO_2 content of the electricity produced by PV panels for different orientations

Source	**CO_2 content** [g CO_2/MJ]
PV north façade	84.5

Final users mix (CH)	38.5
PV west façade	33.4
PV east façade	32.6
PV south façade	23.6
PV roof at 35° south	15.7

To conclude regarding electricity, it may be affirmed that it is not possible to meet the 2000-Watt Society targets only using electricity from the grid. The coupling of electricity from the grid with electricity from PV panels in order to reduce the global CO_2 emissions of the building provides a means of achieving the targets.

However it is fundamental the way that the matching with the renewable sources is done, and how this benefits are counted, if in a static or dynamic way. Working in a static way, at the yearly scale for example, it is possible to say that covering the smart living building with PV panels (100% of the roof surface and 80% of the façades) to meet the demand for electricity (529.24 GJ per year) will lead to emissions of 13544 kg CO_2/year. To supply the same amount of electricity by using only the grid, approximately one third more carbon is emitted (20376 kg CO_2/y). But this statement is true only if it is assumed that all the electricity produced by the PV panels is directly used, and also that the CO_2 content of the grid during the whole year is the same. This procedure is literally following a static way, but changing the approach in a more dynamic one should lead to sensibly different results. This is the aim of the experimentation carbon content correlation (0)

4.3. Storage

Different forms of energy can be stored in various ways (e.g. mechanical, electromechanical, chemical, electrical and thermal), but the practical implementation of this in buildings is nowadays limited mainly to heat and electricity. The benefits of using energy storage are numerous, such as the displacement of the requirement for conventional generation capacity, a reduction of the grid losses security of supply, the reduction of operating cost and the absorption of renewable energy generation. Until now, the reasons given for using storage were mainly economic or energy-related. Three main parameters are taken into consideration when evaluating the necessity of energy storage:

- The embodied energy of the storage technology
- Matching the timing of energy production and consumption
- Differences in the carbon content between the energy at the time of production and at the time of consumption

This last aspect could allow for a reduction in the carbon footprint of the energy used. This is especially true when renewable energy is harvested, or when there is a change in the carbon content of the energy over time, as is the case for electricity from the grid (See Figure 19). In any case, the storage process enhances the environmental impact of the energy concerned. For reasons of sustainability, when storage technology is deployed, one may be convinced that the carbon benefits obtained during its period of use covers the amount of GHG necessary for its development.

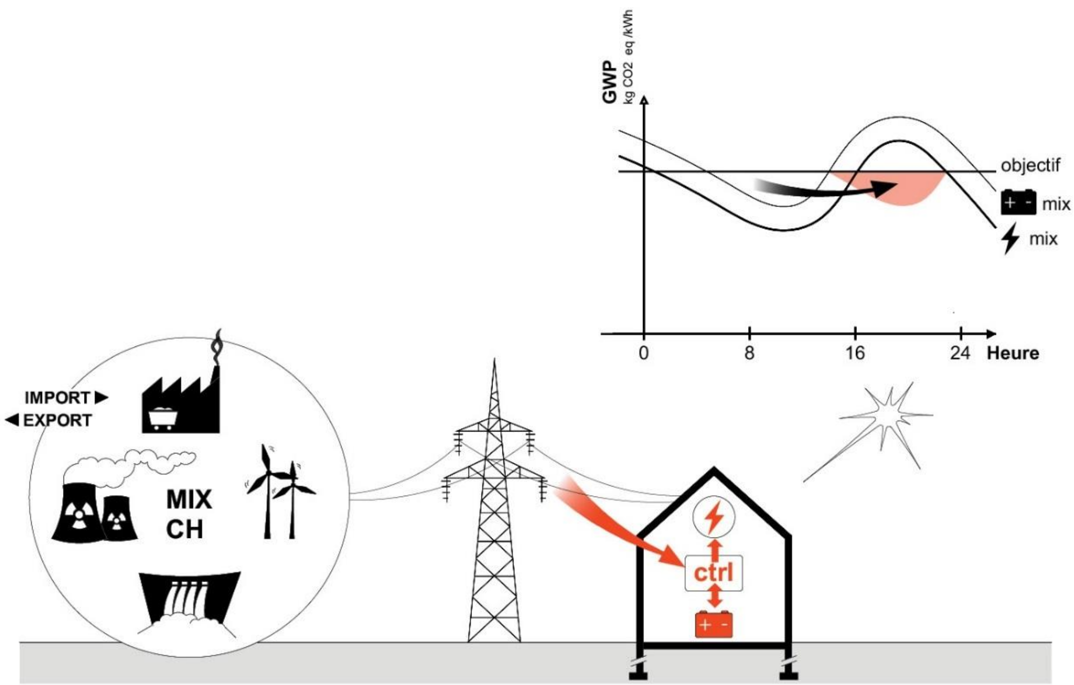


Figure 19: Temporal variation of the carbon content of the electricity mix and the possibility to integrate storage for a better correlation between low carbon electricity and its consumption

4.3.1 Solutions for thermal energy storage

Thermal energy storage could be envisaged over different time ranges (from hours to a seasonal scale), and using different means (passive or active system). The medium used and its related specific storage capacity has an important impact on the required storage volume (See Figure 20). The embodied environmental impact of the storage medium is of prime importance. The chemical and latent media have particularly high embodied impacts.

When considering phase change material, the number of charge-discharge cycles (from liquid to solid phase) is one of the key parameters for gaining benefits from the operational phase in relation to the manufacturing impact (de Gracia et al., 2010). The latent heat storage medium should be recommended, with a daily cycle. The material undergoing the phase change is also of prior importance. The manufacturing impact presented by salt hydrates is 75% lower than that of paraffin (de Gracia et al., 2010).

The passive system mainly consists of thermal inertia and is used in-building to store thermal energy and to smooth the temperature peaks, especially in summertime. This is considered an essential part of the passive strategies to maintain comfort, due to the system's capacity to delay heat release and absorb heat extremes.

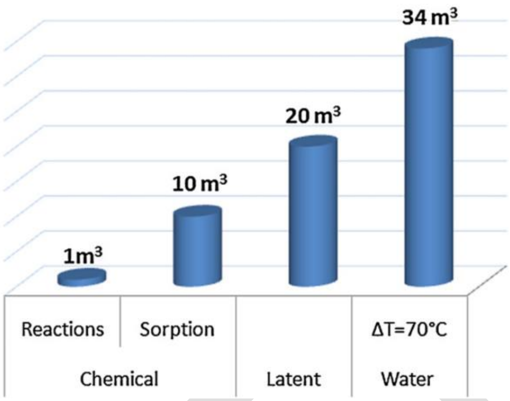


Figure 20: Volume required to store 6.7 MJ (Pinel, 2011)

Component: Domestic hot water
Targets:

Table 10: Target values for Domestic Hot Water in the smart living building

	CED [W/pers]	**CEDnr** [W/pers]	**GWP** [kg CO_2/pers year]
Domestic hot water	4.88	0.55	0.61

The use of seasonal sensible heat storage for covering the domestic hot water (DHW) demand of the smart living building has been analysed. The storage capacity, including the thermal losses, has been determined on the basis of the study by Simons and Firth (2011). Three alternative 100 m^3 storage vessels have been considered (PEHD, steel and concrete). These three storage options for heat harvested by a solar collector covering the full DHW demand are compared with two other traditional ways to provide this demand, namely a heat pump working with a geothermal borehole and a combined system comprising a solar collector connected to a daily storage of heat. An overview of the analysed cases is presented in Table 11.

Table 11: cases to meet demand in the smart living lab.

Case	Description of case	Solar collector area [m^2]	Volume storage [m^3]
1	DHW covered by heat pump (HP)	-	-
2	Combined system with solar fraction of 60%	26	1.5
3.1	Seasonal storage tank in concrete	70	100
3.2	Seasonal storage tank in PEHD	70	100
3.3	Seasonal storage tank in steel	70	100

The GWP of these solutions has been analysed (See Figure 21). The direct production of DHW by a heat pump represents the worst solution from a GHG point of view. More significant is the impact of the material used for the seasonal storage tank. When taking into account the space occupied by a seasonal storage tank, and knowing that no concrete support base for the tank has been evaluated in solution 3.2, it is revealed that long-term storage is not necessarily the best-case solution in terms of carbon emissions.

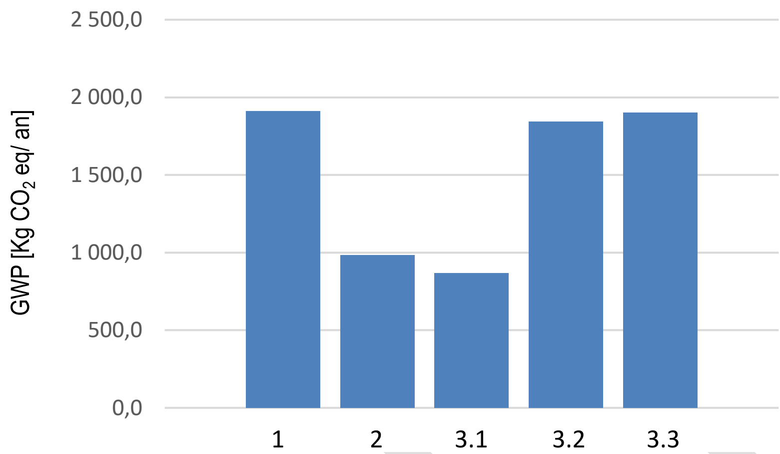


Figure 21: Yearly carbon content of different seasonal storage cases studied in Table 1

Recommendation:
An existing readily available storage reservoir such as an aquifer or natural surface water for a solar pond could be particularly advantageous for considerably reducing the amount of material needed for seasonal storage purposes. If a new storage tank is planned, its material should be carefully chosen with respect to its embodied impact.

To do:
A carbon balance must confirm the benefit of GWP reduction through the full lifecycle of the storage system.

Component: WALLS AND SLABS
Target:

Table 12: Target values for the walls and slabs in the smart living building

	CED [W/pers]	**CEDnr** [W/pers]	**GWP** [$kgCO_2$/pers year]
Walls and slabs	4.49	2.34	4.52

Solution: LOW-CARBON INERTIA
Concrete is one of the biggest contributors of carbon emissions during the construction phase. However, its benefits in the operating phase are not negligible: concrete is traditionally used for its thermal inertial properties. This feature makes it possible to store heat in the element and release it later, smoothing the temperature peaks and maintaining a certain level of comfort for the indoor space. Despite this positive effect, concrete must have a reduction in its GHG emissions to be usable in the construction (See Figure 22). At the same time, it is not possible to ignore the benefits of inertial behaviour on comfort. For this reason, another material with high inertial properties should be used to replace its effect from a comfort point of view. The solution proposed to avoid this problem is to use natural materials with high inertial behaviour, such as sand or earth. The effects of the inertial layer are directly linked to the surface of exposure and exchange between the material and the indoor air, therefore the key idea is to create a mortar made by raw earth that could be used as an inertial component.

The main purpose is to use this cladding on all the internal surfaces in order to increase the inertial behaviour of the building.

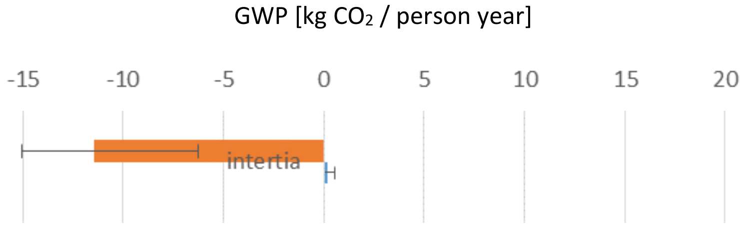


Figure 22: Effect of inertia by implementation of concrete in the walls on the embodied impact (orange) and operational impact (Blue) evaluated during the first sensitivity analysis)

Recommendation:
The LCA impacts of the internal walls are directly related to the materials that are used to build them. As for the external walls, it is important to verify and choose them carefully. In relation to the inertia issue, a calculation of its effects is necessary to understand whether or not it is essential to integrate it into the building in order to achieve the required comfort level. In this way, the losses on the embodied part will be totally or partially covered by the operation gains.

To do:
The influence of inertia on the smart living building is not still clear, therefore its effects on both comfort and impacts must be evaluated and quantified in order to understand the potential of this solution. Moreover, no studies on the position of the elements have been carried out to assess the best option for using the earth mortar and in what quantity. The answer provided by the system used in the environment of the smart living building should be investigated more to clarify the role of inertia in construction and to quantify the need for the material to achieve better results in terms of comfort and user satisfaction. This will be faced in the façade experimentation (See **Erreur ! Source du renvoi introuvable.**)

4.3.2 Solution for electric energy storage

One of the main reasons for installing electricity storage is to match a temporarily low-carbon energy supply with demand. Low-carbon electricity can be obtained from solar energy harvested by a photovoltaic system or from the grid when network demand and its related carbon content are low. The potential to substitute high-carbon electricity from the grid by a storage strategy is explained in Figure 23. This potential could be less attractive in the future, however, when electricity production will be more virtuous.

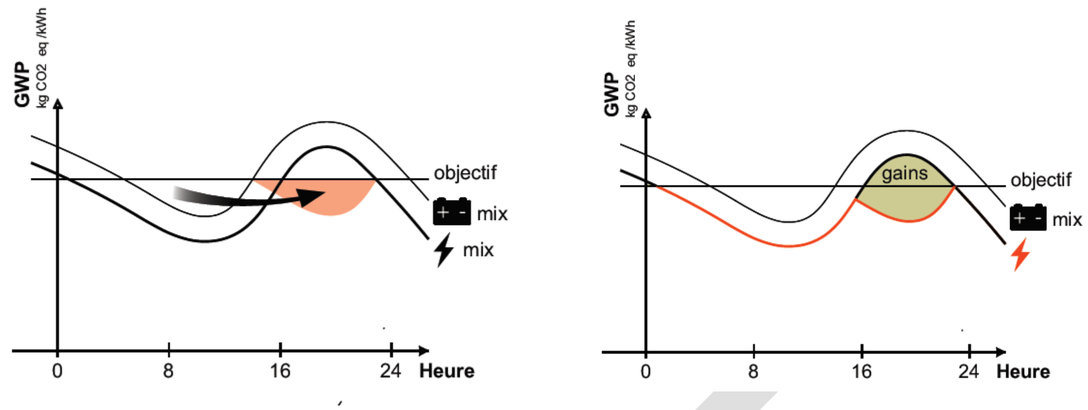


Figure 23: Concept of decarbonisation of electricity from the grid. In a first step, the low-carbon electricity is stored (left side) to be used when the carbon content of the electricity of the mix reaches a higher level than that of the stored electricity (right side).

Nowadays a variety of electricity storage devices are commercially available, but they are not equivalent in terms of environmental impact, specific storage capacity, price, efficiency, etc. *Table 13: Range of performance and cost characteristics of various battery technologies (Kinter–Meyer et al. 2010)*Table 13 gives an overview of the different electric batteries available on the market. In order to choose the best environmental battery type, one significant comparison is the ratio of the total energy stored over the lifetime of a storage technology to its embodied primary energy (Barnhart and Benson, 2013). Mass or storage capacity are less important parameters than round-trip efficiencies, because the use stage of batteries dominates their life-cycle impacts significantly. According to Hiremath (Hiremath et al., 2015) and based on these considerations, Li-ion technologies seem particularly well adapted for electricity storage.

Table 13: Range of performance and cost characteristics of various battery technologies (Kinter–Meyer et al. 2010)

		Li ion	Ni metal Hydride	Nickel Cadmium	Lead Acid	Sodium Sulfur	Zinc Bromine Flow	Vanadium oxide flow
Performance Data	Energy density (kWh/m^3)	225-375	175-275	100-175	60-125	145-150	60	15-25
	Specific energy (Wh/kg)	90-190	60-120	40-80	25-50	90	70	5-25
	Specific power (W/kg)	80-2000	200-1500	200-500	80-300	150	100	
	Response time	Instant	Instant	Instant	Instant	Millisecond	Millisecond	Millisecond
	Charge time[1] (best)	3hrs	1hr	1hr	8-36hrs		n/a	n/a
	Discharge rate[2] (best/peak)	1C / 30C+	0.5C / 5C	1C / 20C	0.2C / 5C		n/a	n/a
	Round trip efficiency (%)	85-95%	70%	70-90%	75%	85%	70-75%	65-75%
	Self-discharge[3] (% per month)	5-10%	30%	20-25%	5%	None	Insignificant	Insignificant
	Life Cycle Number of charges/discharges cycled to 80%, depth of discharge	300-1000+	300-500	1500-2,000	200-500	3,000-5,000	10,000+	Up to 10,000
Cost	Capital cost ($/kWh)	$600-$1200	$500-$700	$500-$600	$175-$250	$350-$500	$150-$250	$350-$500
	O & M cost (exclusive of power)							
	O & M service intervals	None	60-90 days	30-60 days	3-6 months			

Component: ELECTRICITY DEMAND
Target:

Table 14: Target values for electricity demand (appliances and lighting only) in the smart living building

	CED [W/pers]	**CEDnr** [W/pers]	**GWP** [$kgCO_2$/pers year]

Electricity demand (appliances & lighting)	34.02	24.73	18.93

Solution: SYNCHRONISATION AND STORAGE OF LOW ELECTRICITY PRODUCTION AND CONSUMPTION
The demand for electricity in the smart living building will be highly linked to its users. Therefore, electricity demand could be adapted for users' frequentation of the building and their habits. On the other hand, the production of electricity and its related carbon content will vary depending on its source, e.g. photovoltaics or the grid. The electricity storage could be stationary, but automotive batteries could also play a part in the storage capacity of the building (See Figure 24).

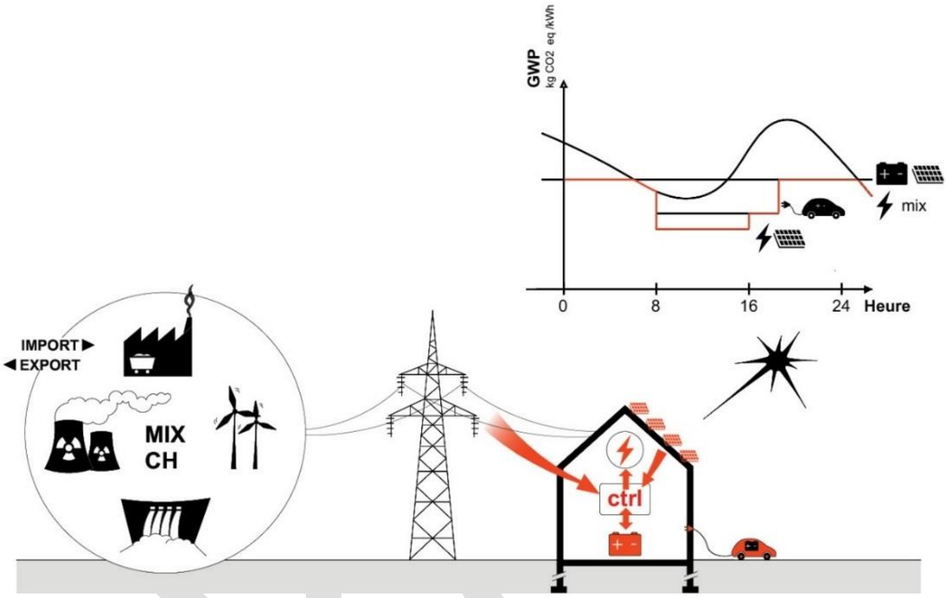


Figure 24: One possible storage strategy proposed for the smart living lab.

We propose to study a strategy for a better synchronisation between low-carbon electricity (direct use or stored electricity) and the demand from the smart living building.

Recommendation:
The best electric storage technology must be carefully chosen regarding its embodied impact, round-trip efficiencies and life-cycle level of charge/discharge.

To do:
Develop a full strategy for low-carbon electricity production, storage and consumption for the smart living building. A quantitative evaluation of the carbon content of the electricity from the grid must be performed. Users' needs and the possible shifts in electricity demand because of changes in user frequentation and habits should be evaluated. Based on these elements, a quantitative evaluation of GWP reduction through the full lifecycle of the building and its installations could be carried out in the carbon correlation experimentation (See 0).

4.4. Systems

4.4.1. Introduction

All the components that use operative energy to provide comfort to the users of the building have been considered in this group. These systems are ventilation, heating and its distribution, but also lighting and appliances. All of these are operated by the energy supply vital organ.

The first sensitivity analysis (Figure A 7, Figure A 8), which was based on the current best practice of the construction and operation of buildings, has shown the weighting of the lighting and appliances as part of electricity consumption. It has been decided to devote them special attention in the design of the smart living building. Due to the high importance of electricity on the three environmental indicators (CED, CED_{nr} and GWP), both its embodied and operative energies have been analysed.

For the ventilation system, it is known that small changes in air flow greatly impact on the thermal performance of the building. This tendency has been confirmed by the results obtained from the first sensitivity analysis (Figure A 4) Trends in using mechanical ventilation in new buildings (for example, mechanical ventilation systems are mandatory in all new buildings in order for them to be granted the Minergie P label in Switzerland) require us to understand the extent of its influence on energy consumption. Moreover, ventilation can be used for different purposes beyond air quality. For example, a higher ventilation ratio helps to dissipate extra internal gains when necessary.

The importance of the kind of energy used by the heating system in order to achieve the 2000-Watt Society targets has already been demonstrated in the energy supply subchapter (4.2). For each kind of energy, a specific technology is used to transform it into useful heat. For this reason, the system itself has been analysed in order to understand the efficiency level and the requirements that it has to fulfil to meet the targets. The heat distribution system and its specific impact on whole-building performance has been also investigated. The choice of heat distribution system impacts on the final thermal energy in a highly variable way.

4.4.2. Evaluation of systems-related impacts by sensitivity analysis

In order to understand how the systems influence whole-building performance, all the systems mentioned above were integrated in the first sensitivity analysis. The final values that it is important to control are always the main impact indicators: CED, CED_{nr} and GWP. Inputs parameters were chosen to describe the systems that could be integrated in the building. In this way, it is possible to quantify the effect of the choice of systems on both the embodied and operative impacts.

An input parameter has been created to assess the relevance of electricity consumption for lighting and appliances on the primary energy used. The quantification of this value has been made through four possible scenarios obtained using different SIA norms. The upper limits represent values given using SIA 2024 (2006), whereas the lowest level is weighted in accordance with the technical improvements given by new technologies available in the future. These values are given using SIA 380/4 (2006).

The ventilation system has always been defined as a mechanical system, in which the ventilation ratio changes in each simulation. Accordingly to the SIA 382/1 (2014) norm, a different ventilation ratio is defined for each distinct zone of the building. Values from the SIA provide the reference, and different percentages of change have been proposed.

The heating systems chosen for this analysis depend on the resources available in situ. Four possibilities have been identified, with the aim of including all the technologies seen in “State of the Art” (Jusselme et al. 2015):

- Pellet boiler
- Natural gas boiler
- District heating system
- Heat pump with geothermal probes

A parameter describing the heat distribution system has been also established. Different options have been considered, having come from the case studies analysed in “State of the Art” (Jusselme et al. 2015). Four solutions are envisaged:

- Radiators
- Floor heating
- Ceiling heating
- Air heating

The importance of all these systems is summarised in Figure 25, which represents the distribution of the main contributors in the operational phase for the GWP indicator.

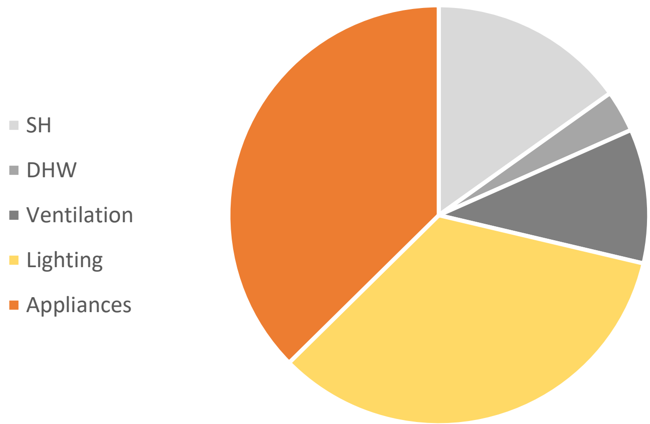


Figure 25: GWP distribution for operative energy in the first sensitivity analysis

Looking at the Figure 25, it is clear that the GWP impacts of lighting and appliances are the most important in the sub-group of systems.

Regarding the *final electric energy* (Figure A 6) from the first sensitivity analysis, the “lighting and appliances” parameter is the most important one. This is mainly due to the high electrical requirements of the working spaces. Varying the input value from the item with the highest consumption to the best-performing one generates a reduction of almost 35% for the energy used, without any link to the other parameters.

When looking at the *primary energy* (Figure A 7), it is also clear that the largest share of electricity use is by appliances and lighting. It may be noted that the absolute value of the main parameters is very high. This is due to the great influence that the lighting and appliances have on primary energy. There is great potential in each of them to improve final consumption. Ventilation also accounts for a significant share.

Regarding *CO_2 emissions* (Figure A 8), “lighting and appliances” is the parameter with the biggest influence. This parameter is not strongly related to the others, but it does have a linear correlation with emissions. The ventilation ratio is also a very important factor in relation to potential emissions reduction. In this case, however, it is very much related to all the other energy supply parameters, which must be balanced between them if we are to achieve the most suitable solution.

Concerning the sensitivity analysis on the *final thermal energy* (Figure A 5), an important conclusion can be made: the “heating systems” parameter has an influence whose absolute value is almost 2.5 times bigger than that of all the other parameters. It is clear that the efficiency of the adopted system is the most significant factor for the final energy. Providing energy in a clean way is much more important than saving it.

4.4.3. Solutions for the major system contributors

In the systems framework, minimising operative energy is more important than reducing embodied energy. During the design stage, it is fundamental to work mainly on this topic in order to meet the 2000-Watt Society targets. Some innovative ideas have been proposed under this objective and, in order to investigate their potential, they have been investigated in the second sensitivity analysis.

Component: LIGHTING
Targets:

Table 15: Target values for lighting in the smart living building

	CED [W/pers]	**CEDnr** [W/pers]	**GWP** [kg CO_2/pers year]
Lighting	18.55	13.23	11.96

Solution: SPECIFIC COMFORT ZONE
This proposed solution is based on reducing the amount of energy used for lighting by limiting the lit zone to a surface very close to the user and his visual comfort. It consists of using different light spots mainly to illuminate the area where light is most required. A sketch of the idea is shown in Figure 26. An input parameter called “Lighting surface” was used in the second sensitivity analysis (see Table A 2) and has been used to change the surface of the rooms that must be illuminated in each of the different simulations. To evaluate the potential of this solution more thoroughly, a second input, called “Lighting time” was also adopted. This parameter is used to reduce the lighting time prescribed by norm SIA 380/4 (2006). According to this norm, an office requires 11 hours of artificial light per day during the week. For each destination of use, during a given time of use and for a given lit area, the same power as the one prescribed by norm SIA 380/4 (2006) is applied.

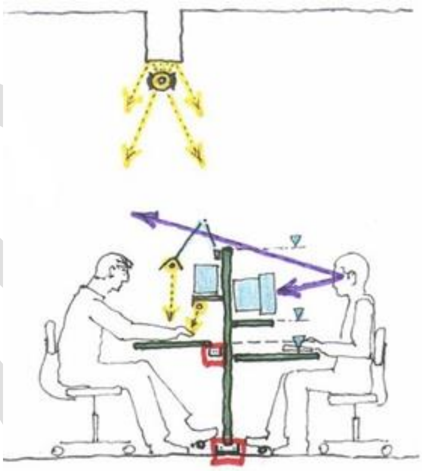


Figure 26: Sketch of the enlightened comfort zone

Recommendation: Not to follow SIA norms strictly when estimating the electricity demand for artificial light. The concept of “specific comfort zone” is a powerful measure for electrical energy reduction and must be integrated in the design of the building.

Component: VENTILATION
Targets:

Table 16: Target values for ventilation in the smart living building

	CED [W/pers]	**CEDnr** [W/pers]	**GWP** [kg CO_2/pers year]
Ventilation	4.98	4.08	4.26

Solution: NATURAL VENTILATION
This solution relies on the assumption that mechanical ventilation consumes high levels of both embodied energy (ducts and pipes) and operative energy (electricity for fans), whereas a proper ventilation ratio guarantees comfortable conditions for the inhabitants and the building. If well-managed, natural ventilation can replace mechanical ventilation, then one proposition could be to create a central atrium to which the offices are exposed (see Figure 27). In this way, the appropriate ventilation ratio could be provided by the control of given openings, but with no operating energy expense linked to the ventilation system. However, it is technically difficult to integrate a heat recovery system. For this reason, heating demand will be higher in a system using natural ventilation than in one using a mechanical one.
This solution was implemented in the second sensitivity analysis (see Table A 2). The same ventilation ratio given by norm SIA 382/1 (2014) is always guaranteed, but this is supplied in different ways. As an alternative to choosing between mechanical ventilation and natural ventilation, there are two other mixed solutions, with the air flow coming partly from natural ventilation and party from mechanical ventilation.

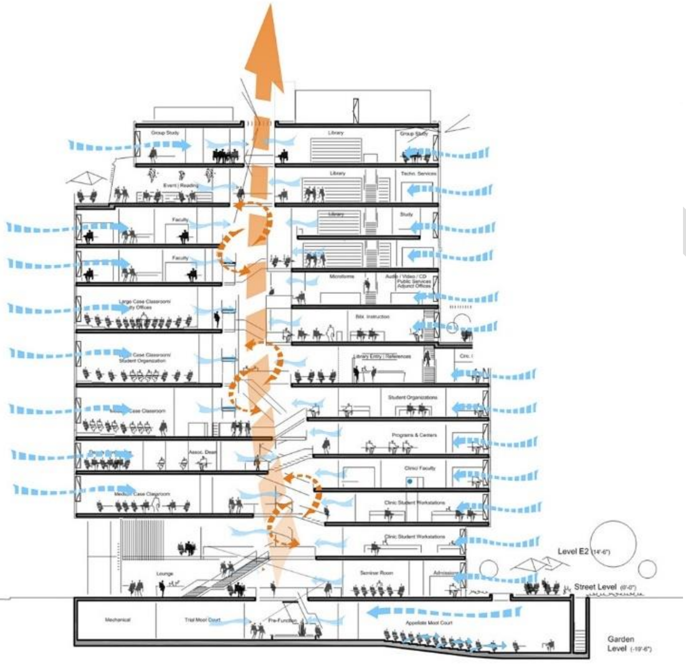


Figure 27: The John and Frances Angelos Law Center at the University of Baltimore, Behnisch Architekten 2013

Recommendation: It is fundamental to define global energy performance rather than prescribing a specific strategy. Because heating systems and ventilation technology are continuously evolving, it is not possible to prescribe one given solution without taking into account the energy demand implications on both ventilation and the heating system.

To do: The main disadvantage of natural ventilation is the difficulty of controlling it. Natural ventilation introduces variables such as acoustic and thermal discomfort. Moreover, it is difficult for the users to have full control over it. These problems should be solved in the next development stage, once the feasibility and potential of the natural ventilation concept has been proved. The preheating of external air before it is blown inside the building by heat recovery is a very big challenge. To understand how to resolve these criticisms a deep investigation will be done on natural ventilation benefits and influences on the indoor environment and on the façade design. In the façade experimentation (see chapter 0) in fact, a working group will be in charge only of this task, addressing all the issues detected and understanding how to reduce energy consumption due to ventilation need thanks to the integration natural ventilation.

Component: HEATING

Targets:

Table 17: Target values for the heating system in the smart living building

	CED [W/pers]	**CEDnr** [W/pers]	**GWP** [kg CO_2/pers year]
SH	27.29	8.32	7.40
DHW	9.23	2.12	1.49

Solution: HEATING SYSTEMS – DEVELOPMENT TRENDS
Improvements are continually being made in primary energy and in the efficiency of heat production systems. This trend is reflected in the different CO_2 content that the energy used for heating can have. In order to anticipate these changes, we would not define a specific technology for the heating system, but only a quantity of kg CO_2/MJ for the thermal energy used inside the building. In this way, all the possible combinations for reaching the proposed values are left open, although some suggestions are given. To be able to provide this suggestions, some CO_2 content for the final heat are given, see Table 18, using existing database (Friedli et al., 2014) and future prediction (SIA 308/4, 2006). The requested CO_2 content has been coupled with an already existing technology to lead to a minimum global efficiency for the heating system. This efficiency is representing the global conversion of the GHG of the fuel (wood, electricity…) into the one of the useful heat delivered to the building. From the Table 18 can be deduced that some solutions are feasible to attain the targets of the **Erreur ! Source du renvoi introuvable.**, as the wood boiler or the HP (the efficiency is not the COP of the HP but again is representing the quality with which the primary energy is treated), some are very difficult to reach, as the pellet boiler, and others are simply impossible, as the gas boiler.

Table 18: Different efficiencies for several heating system

System	**CO_2 content** [g CO_2/MJ]	**Efficiency** [%]
Wood boiler	5	63.8
Pellet boiler	10	95.9
HP air-water	20	68.75
Gas boiler	50	126.6

Recommendation: As was stated for the ventilation case, a global energy strategy must be established instead of prescribing a specific solution. The natural ventilation seems to be the most interesting to achieve the targets, due to the big saving in embodied and operative energy. On the other hand the high SH demand and the lack of a heat recovery system, often associated with this solution, make necessary to implement a heating technology with a maximum CO_2 content of 10 g CO_2/MJ (as for example a pellet boiler). Vice versa as long as mechanical ventilation is installed in the building (with heat recovery and a low SH demand), it is possible to use a less "green" energy system with a maximum CO_2 content of 50 g CO_2/MJ. Nevertheless with this second solution will be much more difficult to attain the targets of **Erreur ! Source du renvoi introuvable.**, due to many other design constrains that must be respected.

To do: Investigate which are the design constrains mentioned above, and how these are related with the chosen heating system. The main purpose of the experimentation CO_2 expert tool (0) is exactly that, to better understand the relation between all the technical and architectural energy solution for the smart living building, in order to discover the consequence of each choice taken in the design phase.

4.4.4. Conclusion

Active systems providing comfort represent the vital organ with the highest impact on the final results. Carefully choosing the systems which must be integrated in the building is the only way to achieve the 2000-Watt Society targets. As shown in the results of the simulations (Figure A 9, Figure A 10 and Figure A 11), there is no way to reach the goals if all these systems are set up as the SIA norms prescribe. In the case of the electrical systems, it is not possible for the given amount of energy to supply the building based on current performance, even if all of this energy is provided by PV panels. Therefore, at least one of the solutions for reducing the energy used for lighting, appliances and ventilation must be employed. The importance of these systems is underlined by the results of the second sensitivity analysis (Figure A 12, Figure A 13 and Figure A 14), which make it clear how these parameters affect the operative impact of the building. Regarding the ventilation system, the natural solution seems to be the most suitable to attain the targets.

4.5. Mobility

In section 3.4.1, we showed the renewable and non-renewable energy consumed and the CO_2-eq emitted by people's mobility in Switzerland. There are many possibilities for reducing the impacts of mobility and for responding to the 2050 targets, such as the capacity to provide low-carbon electricity through building-integrated photovoltaics **Erreur ! Source du renvoi introuvable.**, or a decrease in the number of parking spaces.

In this section we will present the incremental influence of parking spaces in terms of impacts. The presence of parking in the building has direct and indirect influences. It has an indirect influence, because it motivates people to use their car for mobility. It also has a direct influence on the embodied impacts. These influences are different if we consider a present-day scenario or a 2050 scenario. The "Calculation method for buildings whose mobility of users is unknown", presented in SIA 2039 (Hänger and Schneider, 2011), has been used for calculating the influence of parking spaces through their mobility impact.

To evaluate the embodied impacts, we have calculated the quantity of materials needed for the construction of underground parking spaces, translated into impacts with the help of the KBOB database (Friedli et al., 2014).

Different scenarios are tested to evaluate the influence of parking spaces on the final impacts. In the best scenario, no parking spaces are available for the smart living building user. In the worst scenario, the site of the building will contain 40 parking spaces. These spaces are situated in an underground level and will be used for the employees and occupants of the smart living building.

These two cases have been evaluated for present-day and 2050 scenarios. The impacts that the smart living building will have if it is built in the same way as the projects presented in "State of the Art" (Jusselme et al. 2015) represent the present-day scenario. The impacts that the smart living building will have if it is built in 2050 and achieves the intermediate goals defined in section 3.2 represent the 2050 scenario. The results obtained after calculation are presented in Figure 28.

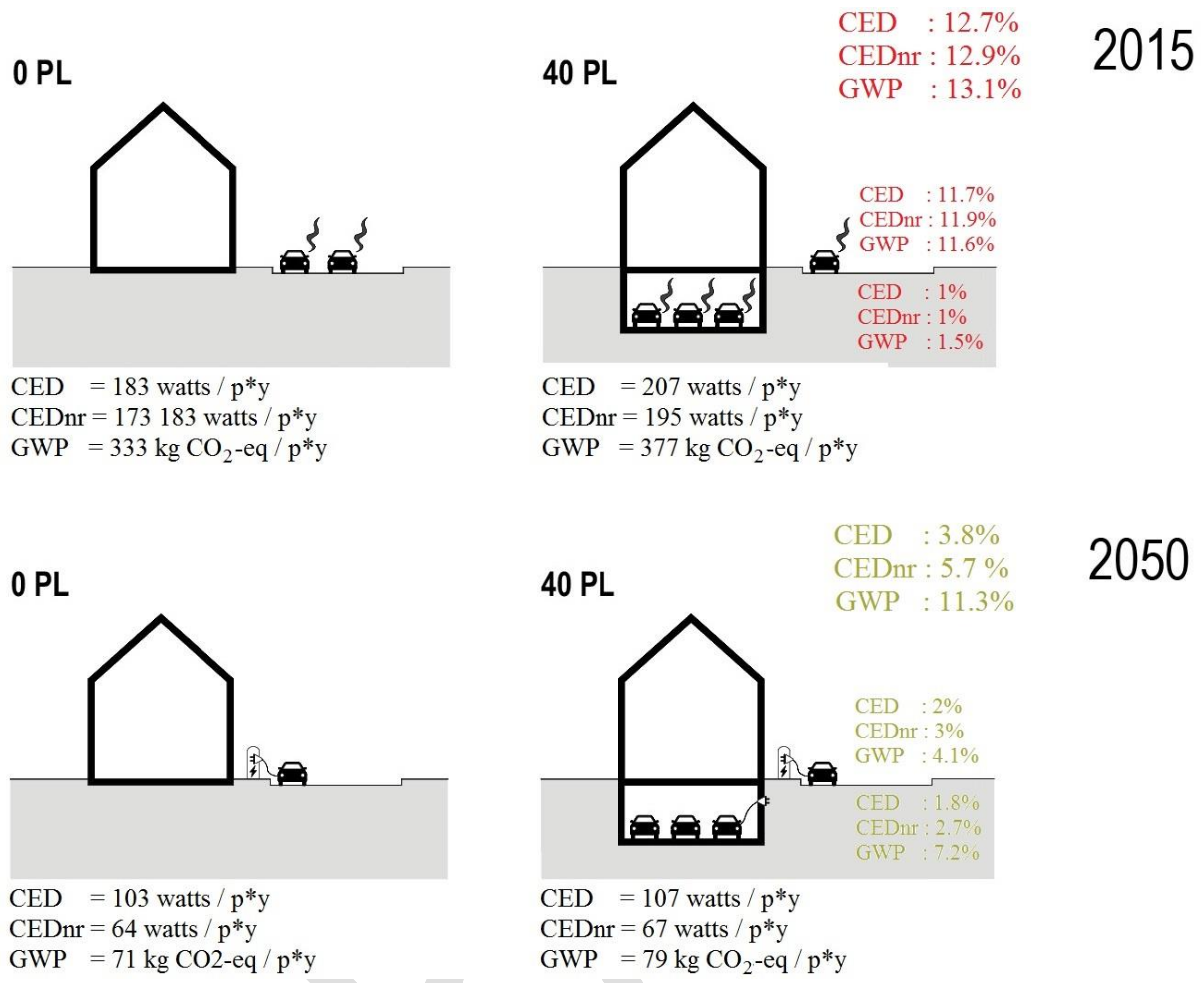


Figure 28 : Influence of parking spaces in increment of environmental impacts in a present-day scenario and a 2050 scenario

The results presented in Figure 28 show a significant environmental weight of parking to the overall impacts. The results remark also that the weight of parking place change over time.

In the present-day scenario, the increment of impacts due to the presence of parking spaces is around 13%, whereas around 12% is due to mobility and only 1% is due to the materials used for the parking spaces.
For the 2050 scenario the increment of the impacts due to the presence of parking spaces is around 4% for CED, 6% for CEDnr and 12% for GWP. The results show that the embodied impacts are most responsible for the increment of this percentage of the impacts. In the case of the GWP indicator, mobility is responsible for 4%, and the embodied impacts for 7.2%.

Based on these results, we can conclude that the presence of garages in a building has significant influence to the overall impacts for today and 2050. In any case, parking spaces should be reduces to the minimum, if other low carbon transportation means are on-site available.

4.6. Users

4.6.1. Introduction

The vital organs demonstrate the importance of users in the design strategies of the smart living building. The understanding of the users help to optimise the design of the building and to improve the performance of the building in its future use. User knowledge can be obtained in two ways: top-down methods and bottom-up methods.

The top-down methods are used to identify the objectives or targets that shall be achieved in the smart living building in accordance with the global goals of climate change and energy consumption. The bottom-up methods are used to identify needs and preferences of the users that shall be considered and referred to in the design. These two aspects compose the entire picture of the user environment in the smart living building. This environment includes not only the physical conditions within which the users act, but also the influence of user behaviours on those physical conditions. These behaviours include operations and activities, personal control on the environment and spatial dimensional changes in various circumstances.

The phrase "user environment" is mentioned and discussed mostly in the field of computer science. It is used to describe a provided workplace that grants each single user access to certain operational systems and appliances required by their roles. This workplace includes the physical environment composed of necessary appliances, access to different hierarchic levels within the framework of the organisation, and possible interactions between users, appliances and the system that allow users to work more efficiently through a certain level of personalisation.

Based on this concept from computer science, the user environment in a building shall include:

- The physical environment with the required comfort, i.e. visual, acoustic and thermal comfort, ventilation, etc.,
- The support environment required for work, i.e. appliances, furniture, electricity, communication systems, etc., and
- Interaction between users and the environment among users.

4.6.2. Targets for building flexibility and usability

The targets of the usability are strongly linked to the performance and users' satisfaction on the building. This states that whether or not users' requirements to the building could be considered and presented in the design is the vital parameter for the building usability. The requirements of the users of the smart living building will be studied and investigated through the social survey by the EPFL-LaSUR research group, and will be used as the targets for the building.

According to the definition in "State of the Art" (Jusselme et al., 2015), the final goal of building flexibility for the smart living building is to maintain the building performance at an acceptable high level in the entire life span through certain required adjustment or adaptation from time to time. Hereby, the target of building flexibility is whether or not it is easy to adjust the building to meet the variation of users' requirement in different situation. This is a challenge of design method. The evaluation system for flexibility design is still under development; however, a group of design guidelines were generalized and listed in "State of the Art".

4.6.3. The importance of the user environment and key issues

One objective of the smart living building is a high level of usability. The better the usability of a building, the more the building will be used. The usability of a building includes users' feelings of satisfaction towards the building and their working performance (i.e. working efficiency and effectiveness) within the provided environment. Both of these aspects relate to the achievement of spatial comfort and working requirements, which involve ventilation, heating or cooling systems, acoustic insulation, lighting and working appliances.

The lifecycle assessment of the environmental impacts of the smart living building, based on the two sensitivity analyses, demonstrates that more than three quarters of the total energy required for the building, including both embodied energy and operation energy, was consumed by space heating, ventilation, lighting and all the appliances used in the building (Figure 4, Figure 5, Figure 6). This indicates that, as our target is to reduce the energy used in the building, these four elements have comparatively more potential for improvement than the others. In other words, a proper design, organisation, use and management of the user environment would be helpful for reducing energy consumption and the carbon footprint of the building. However, as the target value for the smart living building is identified by the number of users, the optimisation of the population in the building can also benefit energy use.

Hence, the key issues for the user environment are:

- Ventilation
- Heating or cooling system
- Lighting
- Electricity for appliances
- User population

4.6.4. Boundary of the research

It is understandable that there are strong connections between users and the required user environment. Different users need different user environments. This study considers the users of the building as a whole and takes the general situation or condition in account of the solution, rather than focusing on a particular user group (e.g. professors or students) or their special needs.

4.6.5. The target users in the smart living lab building

According to "State of the Art" (Jusselme et al., 2015), the usability of a building is strongly influenced by the building users. Different requirements of users leads to different usability results. Regarding the functions of the smart living building, the target users are mainly scholars such as professors, researchers at various levels and students with research backgrounds working at EPFL or partner institutions. In order to understand the target users, a social survey was distributed online, and a certain amount of information has been collected.

This information is also helpful regarding energy production. The working schedule and patterns are useful for optimising the relationships between energy use and production. For instance, if the peaks of energy consumption in the office can be associated with energy production by PV panels or other low-carbon means, the use of this energy can be maximised, and thus the need for energy from other sources can be reduced.

A glance at the feedback from the survey demonstrates the preliminary characteristics of the target users. This information will be delivered separately by the social survey report completed by the EPFL-LaSUR research group.

4.6.6. Solutions for the user environment

The overall goal of optimising the user environment includes reducing the CO_2 emissions and energy consumption of the smart living building, as well as improving the usability of the building. Several solutions are proposed.

Topic: POPULATION DENSIFICATION
Target: TO IMPROVE THE USABILITY OF THE WORKING SPACE AND TO OPTIMISE THE POPULATION IN THE BUILDING

Solution: CHOOSABLE SHARED SPACE
People have various requirements with respect to their working environment and atmosphere, and these requirements themselves change as the working situation changes from time to time. Users may be provided with a diversity of space or a workplace environment with specified standards. Instead of being settled in a normal large open space, with a fixed physical environment and personal working place, users are encouraged to share their working space and relevant appliances with others at various scales, and to choose their working environment according to their daily requirements, moods, activities and needs. This concept includes:

- No fixed personal working space;
- Movable equipment or appliances, and supporting facilities for working, e.g. electricity sockets, data servers accessible from everywhere, etc.

- Various working environments with different physical comforts, functions and scales, etc.
- Possibilities for users to choose their working space.

The advantages of this solution are:

- It can increase space use flexibility by providing users with work space options.
- It can reduce operational energy and environmental impacts by only providing what is necessary for each space individually rather than doing so throughout the entire building.
- It can optimise the building population by increasing the efficiency of space use at different times.
- It can enhance communication and information exchanges among users.

There are also some disadvantages that should be taken into consideration:

- This solution might raise classification issues among the user population, as people usually have their own preference for space use.
- The robustness of the solution relies on the real situation of post-occupancy in the building.

Recommendation:

- The storage of personal and shared items shall be taken into account in the sharing of space.
- The balance of use in each shared space shall also be considered.

To do:

- An investigation into the relationships between space function, physical comfort, user working requirements, etc.
- An investigation into the acceptance of sharing working space rather than having open or common space

These two items will be done in the experiment of the user environment (section 0).

Topic: OPERATING ENERGY FOR APPLIANCES

Targets:

Table 19: Target values for the appliance operating energy in the smart living building

	CED [W/pers]	**CEDnr** [W/pers]	**GWP** [kgCO_2/pers year]
Appliance operating energy	20.24	15.18	12.52

Solution: SWITCH-OFF SYSTEM

Among the normal operational needs for electrical energy, around 10% of the full energy demand in a house is attributed to appliances in stand-by mode. This mode exists in many electricity appliances, e.g. computers, televisions, data servers, printers, projectors, etc., and in many cases it is not appropriately used with respect to the rational use of energy. The solution is to establish a switch-off system for all electrical appliances and machines in the building and to manage the system more wisely. This system should include:

- A hierarchical control system that links various levels, i.e. the entire building and each floor, space zone, single room, and workstation / work space.
- A management and instruction process so that the population in the building may understand and follow the strategy.

The advantage of this solution is that energy consumption in the building can be considerably reduced by just a simple daily action by the users. This solution can easily be adapted to any building with any function with few extra construction or installation.

Recommendation:

- Some attractive signs or symbols shall be displayed to remind users to switch off appliances when they leave their work place.
- The appliances shall be switched off automatically when they are not in use for a certain period of time.
- The lighting in working spaces shall be turned off automatically when there are no users in the office.

To do:

- An investigation of electricity demand reduction in real situations, and the efficiency of the solution.

The information of users' work habits will be investigated through the social survey by EPFL-LaSUR and onsite investigation in the Blue Hall. It will be used to estimate the demands on electricity in the experiment of CO_2 correlation (0).

Topic: OPTIMISATION OF THE LOCATION OF FUNCTIONAL SPACE
Target: TO REDUCE ENERGY CONSUMPTION FOR VENTILATION AND LIGHTING, ETC.

Solution: LOCATING FUNCTIONAL SPACES BASED ON DEMANDS IN THE BUILDING
Based on the analysis of energy demands and CO_2 emissions attributed to different items in the building, ventilation and lighting account for a high proportion. However, certain functional spaces have higher demands on lighting and ventilation than other spaces. For instance, office or study space usually needs higher brightness levels than residential space (Figure 29); kitchen and dining spaces require more ventilation than other spaces. These facts remind us that, if these functional spaces can be located appropriately, the use of natural ventilation and lighting can be optimised, and energy use and CO_2 emissions for ventilation and lighting can therefore be reduced. This solution includes:

- Locating the canteen, cafeteria or some common cooking or eating area for the residents on the roof of the building, and using natural ventilation for this space, rather than just mechanical ventilation.
- Locating working, study and some other spaces requiring high brightness levels to areas with good natural lighting.

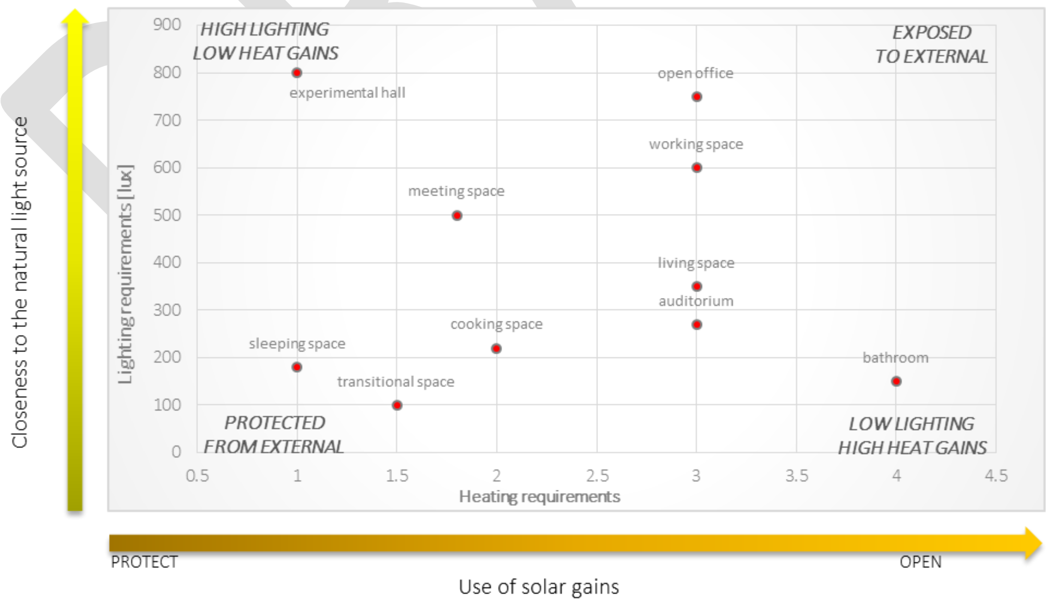


Figure 29: Layout of user spaces in relation to lighting/thermal requirements

The advantage of this solution lies in energy reduction—reducing not only the operation energy for lighting or ventilation, but also the embodied energy derived from construction components used for soundproofing, thermal insulation, etc.

Recommendation:

- The working space needing higher brightness levels shall be located closer to the windows, and these spaces shall not be designed with a large depth.

To do:

- An investigation of space requirements and the establishment of functional space families. The spaces in one family have the same or almost the same physical comfort requirements.

This will be done for the scientific programme phase.

Topic: FOOD
Targets:

Table 20: Target values for food in the smart living building

	CED [W/pers]	**CEDnr** [W/pers]	**GWP** [$kgCO_2$/pers year**]**
Food	14.04	6.62	5.1

Solution: LOCAL FOOD AND IMPROVEMENT OF USER AWARENESS ON FOOD
Consuming food is one of major user behaviours in the built environment, and food creates a large carbon footprint. The heavy environmental impacts of food and related activities have inevitably attracted our attention. The research conducted by Jungbluth (2010) shows that the environmental impacts of different types of food vary significantly. The foods with the biggest impacts are meat and dairy products (see Figure 30).

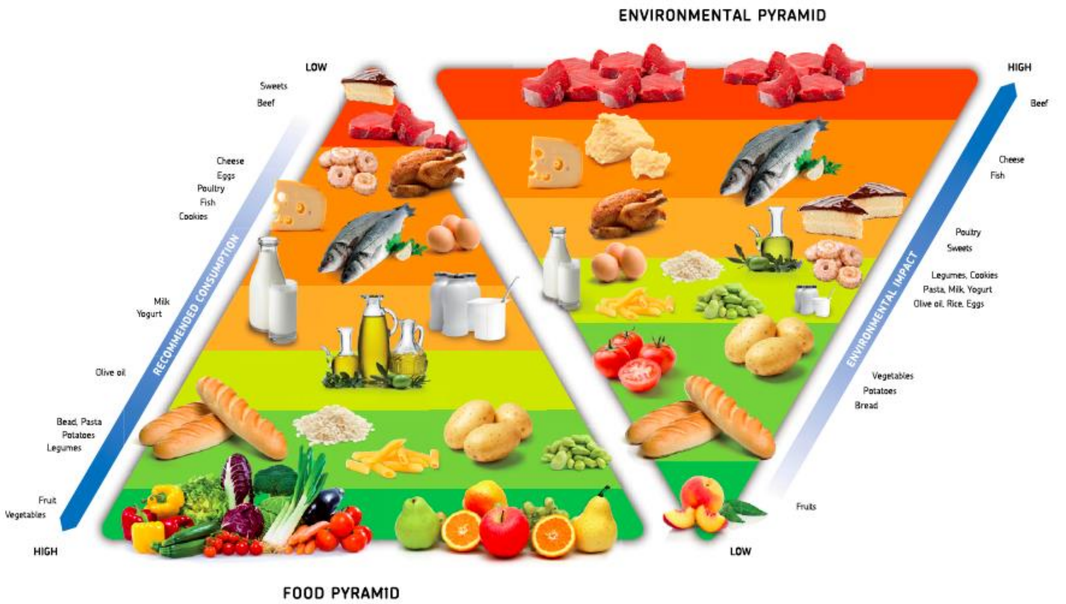


Figure 30: Environmental pyramid showing environmental impacts of food and food that should be consumed https://sites.google.com/a/cornell.edu/childhood-obesity_bee/history.

The direct solution to this issue is to reduce the carbon footprint of food and related activities. For instance, replacing meat with vegetables and encouraging people in the smart living building to consume more local food and fewer dairy products can obviously shrink the total environmental impacts. Accompanying these ideas is the possibility of sensibilizing users on these concepts of food consumption and its relationship to environmental impacts, and establishing close connections with local communities for food supply.

However, food supply as a solution to the smart living building energy strategies has its own problems. A study on Swiss local food indicates that the limitations of the country's natural resources make it impossible to produce enough local food for the whole Swiss population. On the other hand, food solutions are always related to issues of management or maintaining the behaviours of the population in the building, rather than there being a direct solution for the building design itself.

Recommendation

- The consumption of meat and dairy products could be limited in the building.

To do:

- An investigation into the real situation concerning food needs in the building.

This should be considered and implemented by the operational committee of the smart living building.

5. Methods

With the Swiss 2050 energy strategy, the building environment will have to be highly efficient in order to divide current CO_2 emissions. This will have to be done according to a lifecycle point of view. That is to say by also investing less energy in the construction phase. Thus, the question of how to face this challenge is mainly a methodological issue, as means are limited. This will complicate the design process by adding more constraints to the design brief.

As shown in Figure 31, the earlier we have knowledge about the design, the easier it is to integrate performance criteria into it. A key issue is therefore to correlate knowledge and design through the following questions:

- What do we need to know?
- How do we integrate this into the design process at an early stage?

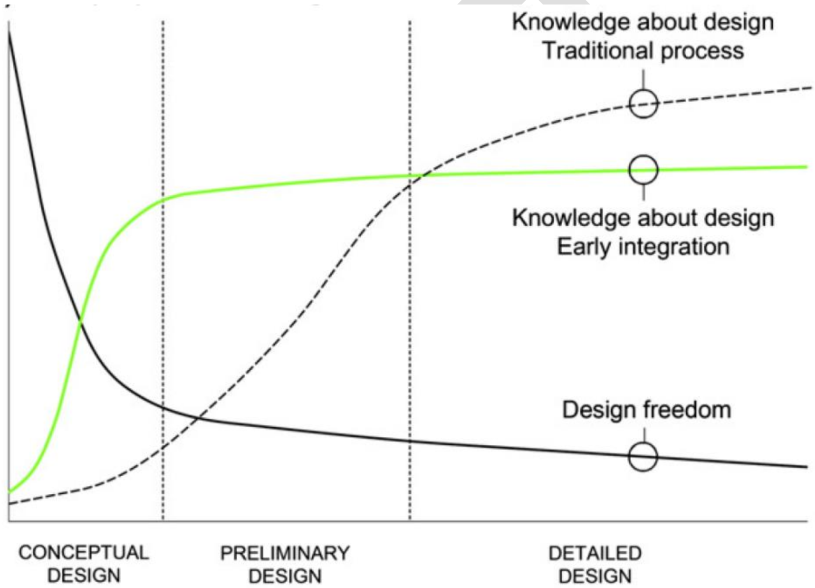


Figure 31: Knowledge-design relationship in construction (Fabrycky, 1991)

The challenges begin at the design brief phase, when the project starts to be defined. The "Architectural Quality" work package aims to describe a design process that will allow the designer to build a high-architectural-quality project for the smart living building. Thus, specific work and deliverables will be carried out within this framework. We will now develop some suitable methods for integrating climate change objectives and flexibility issues into the design process.

5.1. Climate change design method

As we cannot replicate buildings from one context to another, the design process is unique and each building is a prototype. The appropriate method therefore needs to be flexible, as the key issues that arise in projects vary.

The parameters that influence the ability of designers to integrate climate change objectives in the design process may be listed as below:

1. The quality of the design brief: clear objectives, design freedom, etc.
2. The appropriate skills of the design team to tackle the design brief (holistic skills, method, shared language, etc.)

3. A lack of experience because of the singularity of the project (unique programme, state-of-the-art performance, unique environment)
4. The resources allocated for design: time and fees.

Parameters 2 and 4 are more related to the human resources management strategy. Parameter 1 is based on an appropriate translation of the future user's needs and clear political objectives.

Parameter 3 is much more difficult to deal with, as experience allows us to integrate climate change objectives more easily if we have already frequently worked with the same performance level, building programme and construction site. The problem is that this situation rarely arises, even for the smart living building, as it is a very specific programme with unfulfilled objectives at the forefront.

At this point, we have a challenge: how to enhance the designer's experience with contextualised key issues and potential architectural strategies in a highly constrained framework? This can be only done using a virtual experience with a tool that informs us of the physical consequences of architectural strategies, because the physical experience is not compatible with the schedule of a design project.

This tool should allow us to:

- provide immediate feedback about an architectural strategy,
- determine the consequences of this strategy on the physical characteristics of the building components,
- determine the key parameters that have to be set in order to increase the robustness of the design performance,

Efforts will be made to meet this challenge through the experimentation described in section 0.

5.2. Flexibility design method

The vernacular design and construction process is linear in terms of time and procedure, and most determination of design and construction is based only on particular situations at one point in time without any consideration about the whole lifespan of a building.

As we know, neither the context nor the users of a building are immune from change over its entire lifespan. The continuous changes and the intention to maintain building performance at a high or at least acceptable level indicate that the smart living building should be dynamic and changeable from time to time. This is the definition of flexibility for the project.

According to "State of the Art" (Jusselme et al., 2015), a process separation system can be applied in the smart living building project. The idea of this system is to provide or adapt users' working spaces with the necessary environment and equipment, rather than supplying superfluous components. Therefore, the key issues of the system are usability and energy consumption.
The parameters that influence the flexibility design process are listed below:

1. The satisfaction of users, including working preferences and requirements, and personal influence on the working environment, etc.
2. The interaction levels of building components in the separation system, and
3. The environmental impacts of building components, including embodied energy, CO_2 emissions, interaction level with users, etc.

The first and the second parameters are based on an understanding of the future users. The working requirements and preferences will differ according to various working styles. It has been demonstrated in "State of the Art" (Jusselme et al., 2015) that, the more a component is influenced by users, the more frequently that component will be changed. The third parameter is used to evaluate components from a material perspective. From an environmental impact perspective, the components with a greater value should be designed to be used for longer than those with a lower value. Thus, this parameter would impact on the selection of each single building component when combined with the second parameter, and would influence design strategies and the decision-making process for the smart living building.

These parameters also indicate the information that would be useful for the smart living building design process:

- Information about the users: working behaviours, patterns, etc.
- The coherence between user-component interaction levels and the environmental impacts of each component respectively.

By understanding these parameters, the main challenges of this aspect appear to be as follows:

- The preciseness of user knowledge:
  The importance of user information has been indicated both in "State of the Art" (Jusselme et al., 2015) and above. It is clear that the accuracy of user information can positively influence design. However, it is difficult to forecast the behaviours of future users exactly. In order to address this, three levels of information shall be collected, involving norms that provide a global pictures of users, a social survey based on the target user group, and an on-site observation and interview based on a population very close to the future users of the smart living building. The all level of information collection will be integrated into the experimentation carried out in relation to the user environment.

- The evaluation of user-component interaction levels:
  There are few existing studies on user-component interaction levels in the fields of either architecture or construction. The only reference comes from research on the human-computer interaction. The translation of this knowledge needs testing and correction through experimentation. For architectural designers, this might create constraints on the selection of building components on the basis of material environmental impacts, interaction levels and real lifespan as identified by the previous two factors. However, these constraints can optimise the use of materials in the smart living building.

  This will be integrated into the conference paper for SBE 2016 Zürich (cf. abstract in section 12.3).

- The integration of the flexibility method at the early stage of design:
  This includes integrating the consideration of both users and the entire lifespan of the building at the beginning of the project. Unlike a normal building project, this concept may challenge the whole organisation and management of the project. However, this approach is worthy of a building such as the smart living building, which is more concerned with the sustainable development of the environment and society.

6. Transition to the experimental phase

6.1. Framework of the experimentations

The smart building research programme will produce the six following deliverables:

1. The state-of-the-art report defines current best practices and 2050 environmental and flexibility objectives
2. Scientific concept report: proposes technical solutions and methodologies usable for the smart living lab building
3. Workshops report: scientific concept proofing by building professionals and scientists
4. Scientific programme (draft): translation of the scientific concept and the workshops into a brief for the future smart living lab designers
5. Experimentations report: prototypes construction, performance monitoring and feedback
6. Scientific programme: the definitive programme that will be submitted to the smart living lab designers and that will include technical and performance specifications and recommendations.

The scope of research includes four research fields and four experimentations, which are presented in Figure 32**Erreur ! Source du renvoi introuvable.**.

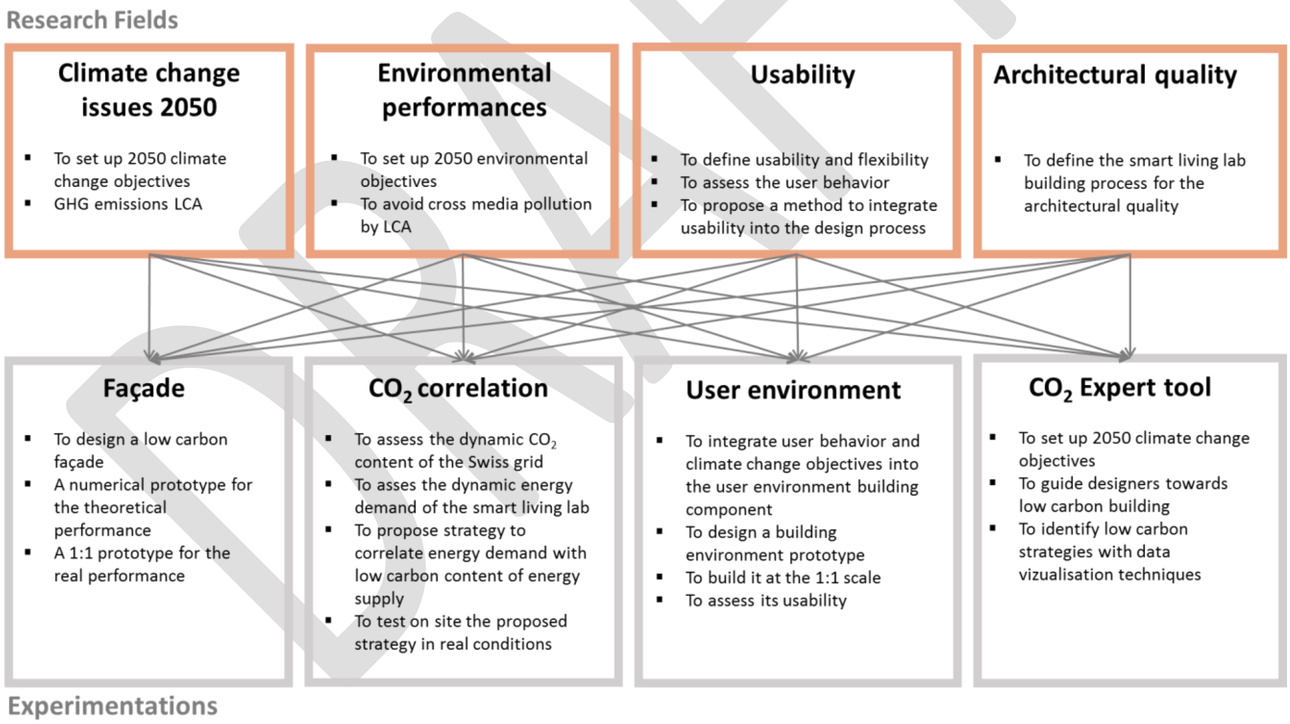


Figure 32: Research fields and experimentations

The experimentation phase will allows researcher to test innovative solution in real environment. The smart living building research group has defined the main research questions of these experimentations thanks to the scientific concept and invite other partners with complementary skills and experiences to face them.

6.2. Experimentation 1: Carbon content correlation

6.2.1. Objectives of the experiment

Electricity production is achieved by different processes (e.g. nuclear plants, fossil fuels, and renewables) with different environmental impacts and different production capacities. To provide the necessary amount of electrical energy, different sources of different qualities are combined together. As a result, the carbon content of the electricity mix varies with time over the course of each day and in the course of each year. The intensity of usage and the design of a building induce variations in energy consumption at the same time. In its 2050 energy strategy, Switzerland has proposed new policies to tackle climate change and decrease greenhouse gas (GHG) emissions. The scope of synchronising a low-environmental-impact electricity supply and the building's electricity consumption is addressed in this experiment. The scope of the study is limited to the smart living building.

Four different aspects make up this experiment, namely:

1. The carbon content of the electricity supply
2. Electricity consumption in the building
3. The matching between 1 and 2.
4. The possible approaches enabling a better environmental match between 1 and 2.

Based on these four aspects, a low-carbon energy strategy coupling electricity production and its consumption will be studied. An assessment of this strategy will allow us to quantify the annual benefits which could be realised by the proposed strategy compared with the sole use of the Swiss electricity grid.

Many environmental indicators exist, but three are mainly used in the 2050 energy strategy: the cumulative energy demand (CED), the non-renewable cumulative energy demand (CEDnr) and the global warming potential (GWP). Cross-media environmental impacts should be monitored. There is also a need to include other environmental indicators (such as the quantity of nuclear waste).

6.2.2. Organisation chart

A steering committee composed of the six WP leaders will meet once a month. The committee will invite the other stakeholders if required.
The experiment to establish a correlation between a low-environmental-impact energy supply and the building's energy consumption is composed of six work packages (WPs), which are described in **Erreur ! Source du renvoi introuvable.**:

- WP1 aims to evaluate the dynamic environmental impact of the electricity supply
- WP2 aims to evaluate the dynamic electricity consumption of the smart living building.
- WP3 aims to evaluate the matching potential between electricity consumption and supply.
- WP4 aims to study possible approaches affecting human behaviour in order to reduce the carbon footprint from electricity.
- WP5 aims to evaluate the possible integration and benefits of electricity storage.
- WP6 proposes a strategy and a quantification of its environmental benefit.

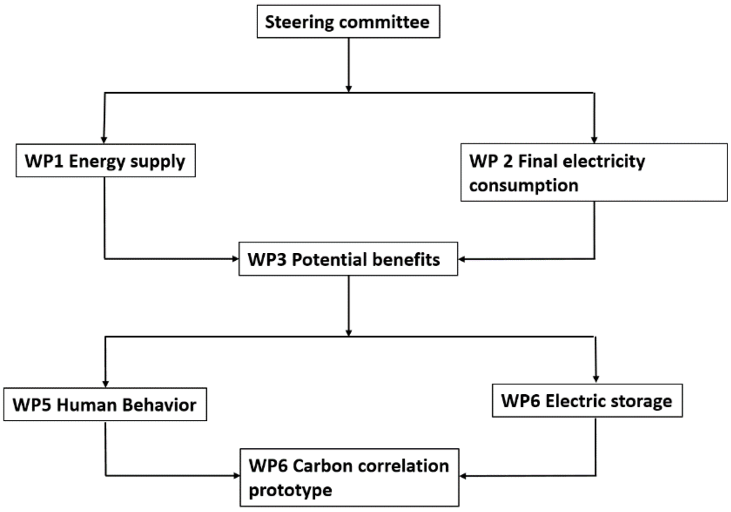


Figure 33: Experiment organisation chart

6.2.3. Work Package content

WP1 Energy supply

WP1 aims to analyse the environmental impact of the energy supplied on-site. This includes the Swiss electricity grid and the local electricity production. It is sought to make building-integrated photovoltaics (BIPV) the main on-site solution for producing electricity to the smart living building.

Task 1.1 Evaluation of the dynamic carbon content of the Swiss electrical mix

The hourly carbon content of the Swiss electricity grid will be evaluated on the basis of the statistical data accessible from energy producers in Switzerland for a one-year period in 2015.

Task 1.2 Quantitative & qualitative evaluation of the energy harvested by BIPV

BIPV will be investigated for implementation and use in the smart living building. Depending on possible technologies, photovoltaics have different characteristics and should be evaluated. The necessary tasks are as follows:

- To make an overview of current PV technology, related performances and environmental impacts.
- To select PV technologies that fit with GHG emissions and energy objectives, especially as defined in task 2.4.
- To evaluate the local production of electricity for the future smart living building.
- To asses GHG emissions per unit of electrical energy, depending on orientation.

WP2 smart living lab final electricity consumption

This WP addresses the problem of electricity consumption in the smart living building. Electricity is mainly used for appliances, lighting and operating HVAC systems. An hourly assessment of the electricity consumption of the building is sought under this work package. The robustness of this work package depends directly on the energy usage of building dwellers, which will be better known thanks to on-site observation (social studies) and measurements (post-occupancy assessment). The main output of this work package is the definition of potential electricity consumption based on a realistic smart living building configuration that could satisfy the environmental objectives given by the 2050 strategy vision.

Task 2.1 Choice of software

- To select the appropriate software for generating hourly electricity consumption for each consumption sector on the basis of usage intensity.

Task 2.2 Dweller usage

This task defines assumptions regarding dweller usage to facilitate the energy simulations.

- To measure the usage of electricity by building dwellers in the smart living lab offices in the Blue Hall.
- To evaluate the variation in electricity consumption in the smart living building based on the literature (e.g. LaSUR survey) and on actual usage by building dwellers.
- Translation of the previous variation in an intelligible language for the software selected in task 2.1.

Task 2.3 Definition of an architectural project

- Selection of an architectural feasibility project, from the possible case proposed in the scientific concept of the smart living building, (Jusselme and al., 2015: chap. 10.5).
- Selection of physical parameters that satisfy the objectives according to the CO2 tool experiment (cf chap. 0).

Task 2.4 Assessment of the hourly electricity consumption of the smart living building

- To model and simulate the hourly electricity consumption of the smart living building.
- To analyse results from the dynamic simulations; possible re-adaptation to satisfy the 2050 objectives given by the 2000-Watt Society vision (especially the renewable part of the CED).

WP3 Potential benefits

A comparison between the potential of dynamic consumption (WP2 and the hourly content of the energy supply correlation (Grid and BIPV, WP1)), and also between the dynamic consumption and the static carbon content of the energy supply.

Task 3.1 Evaluation of the potential of the experiment

- To define the methodology making it possible to demonstrate the potential benefit of a correlation between the hourly carbon content of the energy supply and the hourly energy consumption.
- To assess this theoretical potential.

WP4 Human behaviour

The behaviour of the smart building users has an impact on electricity consumption. This work package proposes to study how to influence this behaviour to achieve a better carbon correlation.

Task 4.1 Identification of usage related to high-carbon-content electricity

- Hourly decomposition of overall electricity consumption in different usage sectors.
- Statistical correlation between each usage sector and related carbon content.
- Identification of high-carbon electricity usage by usage sector.

Task 4.2 Remodelling the electricity consumption

- To propose measures for shifting and remodelling the electricity consumption of the smart living building (such as reflecting technologies, rescheduling, etc.).
- To evaluate the potential of these measures in the context of the Blue Hall with the model developed in 2.4.
- To select efficient measures for numerical evaluation as inputs of the human interface (task 6.2)

WP5 Electricity storage

Electricity storage is a powerful technology for matching low-carbon electricity and its consumption. Storage increases the environmental impact of the electricity, and therefore must be carefully analysed before its implementation. This WP aims to evaluate the various potentials for implementing electricity storage in the smart living building.

Task 5.1 Evaluation of storage characteristics according to the carbon benefits
Storage scenarios should be developed according to the carbon benefits, in order to define the following features:

- Energy storage capacity
- Time shifting

Task 5.2 stationary storage
An overview of the different electricity storage technologies and their performances should be made. The required tasks are as follows:

- To set out an overview of current storage technology and related performances.
- To define inputs for smart control (task 6.1)
- To assess GHG emissions per unit of electrical energy stored.
- To select the most suitable stationary electrical storage technology, according to 5.1, for the smart living building.

Task 5.3 Automotive storage
Automotive storage should be evaluated to increase the storage capacity of the smart living building. The present and future characteristics of automotive storage technologies should be evaluated. The required tasks of the work package are as follows:

- To set out an overview of current automotive storage technology and related performances.
- To define inputs for smart control (task 6.1)
- To assess GHG emissions per unit of electrical energy stored.
- To select the most timeously available and suitable automotive electrical storage technology, according to 5.1, for the smart living building.

WP6 Carbon correlation prototype

WP 4 deals with the possible human behaviour actions on electricity consumption in the building, and WP 5 enables a time shift between low-carbon electricity production and its use. WP6 has the objective of drawing up a prototype to manage the actions of WP4 and WP5 regarding overall strategic performance in the framework of the smart living building.

Task 6.1 Smart control
Smart control consists of an electrical energy strategy implemented using a computer interface, driving the different energy fluxes between all the components of the system. The requirements for setting up smart control are:

- To create a computer interface linking the different actors (electrical grid, BIPV, storage, users and electricity consumption).
- To organise the different criteria of choice between the direct energy supply and the stored energy for the delivery of electricity.
- Using the computer interface to integrate anticipated electricity consumption and its correlation with supply.
- To coordinate possible actions with the human interface (task 6.2).
- To write an algorithm for electricity management in the smart living building, covering energy supply, storage and the possible remodelling of energy consumption by human action (the electrical energy strategy).

Task 6.2 Human interface
Linked to smart control, a human interface at the disposal of the smart living lab users should suggest human actions for remodelling and optimising electricity consumption as a function of the energy strategy. The elaboration of the human interface consists of:

- Proposing a human/machine interface for suggesting actions to the users.
- Creating a connection between smart control (task 6.1) and the human interface.

Task 6.3 Experimentation

- A quantitative evaluation of the benefits achieved by the electrical energy strategy is performed on the basis of tasks 6.1 and 6.2

Task 6.4 Cross-media environmental impacts

The relatively low number of indicators (CED, CED_{NR} and GWP) used in this experiment makes it necessary to study cross-media environmental impacts. There is a need to confirm that the proposed electrical energy strategy is sustainable and environmentally friendly. This work package includes:

- Studying other possible indicators that are necessary for the strategy.
- To propose new indicators and their method of evaluation.
- To confirm that no transfer of pollution results from the proposed low-carbon electrical energy strategy.

Task 6.5 Reporting and deliverables

Intermediate progress and final achievements will be reported in several documents. They are:

- A conference paper relating to work packages 1, 2 and 3
- A journal paper setting out the global achievement of the experiment
- A final report

6.3. Experimentation 2: CO2 Expert Tool

6.3.1. Objectives of the experimentation

To tackle climate change and decrease greenhouse gas (GHG) emissions, Switzerland has proposed new policies for the 2050 energy strategy. Designers will have to create better-performing buildings with fewer resources: this is a methodological issue.

The parameters that influence the ability of designers to integrate climate change objectives in the design process may be listed as follows:

1. The quality of the design brief: clear objectives, design freedom, etc.;
2. The appropriate skills of the design team to tackle the design brief (holistic skills, method, shared language, etc.);
3. The level of experience linked to the project (uniqueness of programme, knowledge and data related to the environment, etc.)
4. The resources allocated for the design: time, fees and resources.

Parameter 1 is based on an appropriate translation of regulations and of the future users' needs on clear political objectives. Parameters 2 and 4 are more related to the human resources management strategy. Parameter 3 is much more difficult to deal with, as experience allows us to integrate climate change objectives more easily if we have already frequently worked with the same performance level, building programme and construction site. The problem is that this situation rarely arises, especially in the case of the smart living building as it is a very specific programme with unfulfilled objectives at the forefront.

It is well known that there is a relationship between the efficiency of the design and the early integration of design knowledge (*Figure 34*). On the other hand, to face the foremost climate change objectives means working in an unknown environment. It is therefore crucial to enhance the knowledge of the designers at the early design stage with a deep understanding of these constraints on the architectural strategies.

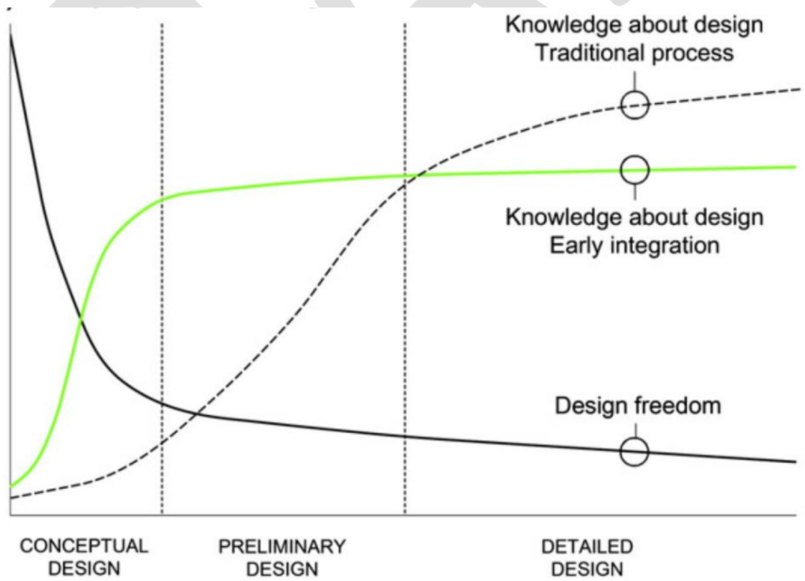


Figure 34: Knowledge-design relation in construction (Fabrycky, 1991)

At this point, we have a challenge: how to enhance the designers' experience with contextualized key issues and potential architectural strategies in a highly constrained framework? This can only be done using a virtual experience with a tool that informs designers of the physical consequences of architectural strategies, because the physical experience is not compatible with the schedule of a design project.

This experiment will focus on the development of an expert tool prototype that will try to enhance the designers' knowledge in order to tackle the 2050 climate change objectives, by answering the following research question: "Is it possible for the designers to feel the 2050 climate change framework at the pre-design phase?"

By using building performance simulation tools, it is possible to vary the input parameters in order to explore the contribution of each parameter to the overall performance. By systematically covering this parameter space within realistic bounds, the implications of certain parameter choices on the rest of the parameters that have been set to meet the 2000-Watt Society vision can be computed. Given the potentially very large amount of parameters in a real architectural project, the way to present such results in an exploitable manner remains an open challenge.

The aim of this experiment is firstly to create a CO_2 expert tool prototype, and secondly to demonstrate the potential of design efficiency by simplifying the inclusion of performance criteria in the design process. The prototype should be able to demonstrate the following features:

- Fixing 2050 climate change targets at the component level. This gives designers scope to choose components that will fit with the objectives.
- Ranking the components according to their CO_2 weighting. This allows designers to consider heavy components at the early stage of the design in order to increase the robustness of the building's performance,
- Offering a set of component combinations that achieves the objectives. This allows designers to draw up a range of components that are usable for meeting the objectives,
- Providing immediate feedback about the consequences of the architectural strategy on the physical characteristics of the building components,
- Developing suitable data visualization techniques to set up technical strategies,
- Developing suitable visual language techniques to set up architectural strategies.

6.3.2. Organizational chart

A steering committee composed of the three WP leaders will meet once a month. The committee will invite the other stakeholders if required.
The CO_2 expert tool experiment is composed of four work packages (WPs), which are described in Figure 35:

- WP1 aims to translate the 2050 climate change objectives into technical descriptions at the building component and energy system level.
- WP2 aims to translate these technical descriptions into carbon strategies through data mining and interactive visualization.
- WP3 aims to translate these carbon strategies into architectural strategies through a visual interaction language and interaction principles.
- WP4 aims to compile WP1, WP2 and WP3 into a prototype for the smart living building design.

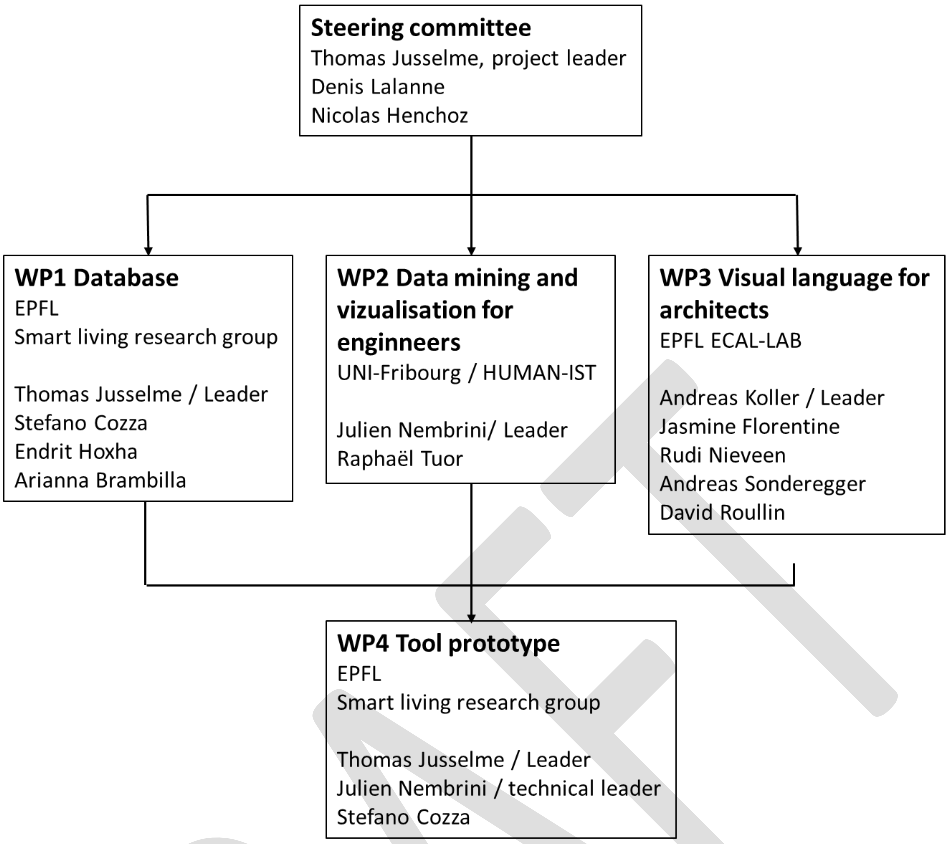


Figure 35: Experiment organization chart

6.3.3. Work Package content

WP1 Database

WP1 aims to create a robust database, which will provide the scientific material to establish technical and architectural strategies and achieve the 2050 climate change objectives. The higher the number, the more representative and diverse will be the set of parameters that fulfil these objectives in the database; likewise, the higher the number, the more useable for designers.

Task 1.1 Choice of physical parameters

The physical parameters that contribute the most to GHG emissions are selected based on a literature review and on the two sensitivity analyses from the climate change research field. These parameters should be useful for and understood by the engineers and architects. Task 3.1 will help to select these parameters, and task 3.5 will confirm that they are correct.

Task 1.2 Overview of LCA and energy simulations tools

The selected physical parameters will have to be applied to the architectural feasibility studies. Then, the influence of this parameter on primary energy consumption and GHG emissions must be analyzed. To that end, a lifecycle analysis and an energy simulation will have to be carried out. An overview of the suitable software is required, with the following specifications:

- To assess GHG emissions, cumulative energy demand and non-renewable energy demand,
- To use the selected parameters as inputs for the simulation.
- To be able to use easily the set of parameters that will be generated with the statistical methods chosen in task 1.3.

Task 1.3 Statistical method and tool review
The choice of the statistical method used to generate the set of physical parameters and to analyze the results is crucial for the robustness of the tool. This method should address the following challenges:

- To generate a high diversity of solutions,
- To be able to assess the performance of each parameter selected in task 1.1 individually,
- To rank the environmental weighting of these parameters according to the results of task 1.6,
- To enhance the data-visualization possibilities of tasks 2.3 and 2.4.

The tool that will allow the selected statistical method to be applied must also be chosen or created.

Task 1.4 Coupling statistical method and assessment tools
In order to create a consistent database, it is necessary to run the LCA and energy analysis tools automatically based on the set of physical parameters generated by the statistical method. This link must be created.
The practices of the designers (task 3.1) will influence tasks 1.2, 1.3 and 1.4 by specifying the maximum time allowed to process the whole tool prototype procedure.

Task 1.5 Generating set of physical parameters
After the selection of physical parameters and the tools to assess their relative influence, the first step will be to generate a set of physical parameters according to previous tasks.

Task 1.6 LCA and energy analysis
The set of physical parameters in task 1.5 are applied to the architectural feasibility studies of the smart living lab building. The link created in task 1.4 between the statistical tool and the assessment tools is used to evaluate the GHG emissions, the cumulative energy demand and the non-renewable energy demand of each set of parameters.

Task 1.7 Creating the database
This task is to compile the results of the environmental assessment and the statistical method in a way that may be used for data visualization techniques (WP2) and architectural language development (WP3). This task will be carried out three times:

- At the very beginning of the project, based on the climate change research field outputs, to provide initial scientific material for WP2 and WP3,
- At a middle stage of the project, to integrate feedback from WP2 and WP3,
- As a final output to be integrated in WP4.

WP2 Data mining and vizualisation for technical strategies
This WP aims to develop interactive visualizations of building performance data to help designers to explore the physical parameters. The data will be produced using simulations performed in the context of the smart living lab project, which take into account the building's embodied impacts as well as building operation impacts. These interactive visualizations will support an understanding of the underlying rules and models, as well as using parametric building simulation results to help to design buildings that are compatible with the requirements of the 2000-Watt Society.

Task 2.1 User requirements
Using the smart living lab team as users, we will ascertain early user requirements. This is not redundant with task 3.1, which is more systematic and addresses a larger population towards usage scenarios. In this early task, we will propose several prototypes for understanding the client's needs and will obtain valuable feedback.

Task 2.2 Data format and storage
The data provided by the smart living lab team will be processed and stored in a simple database to enable further fast interactions with the interactive visualizations produced.

Task 2.3 Interactive visualizations

Several interactive visualizations will be developed using a web-based library for easy access. Well-known visualizations will first be implemented and evaluated in task 3.5. Link and brush mechanisms will allow for the connection of several interactive visualizations to allow filtering and navigation in the dataset. Further on in the project, new interactive visualizations will be designed to suit the project needs.

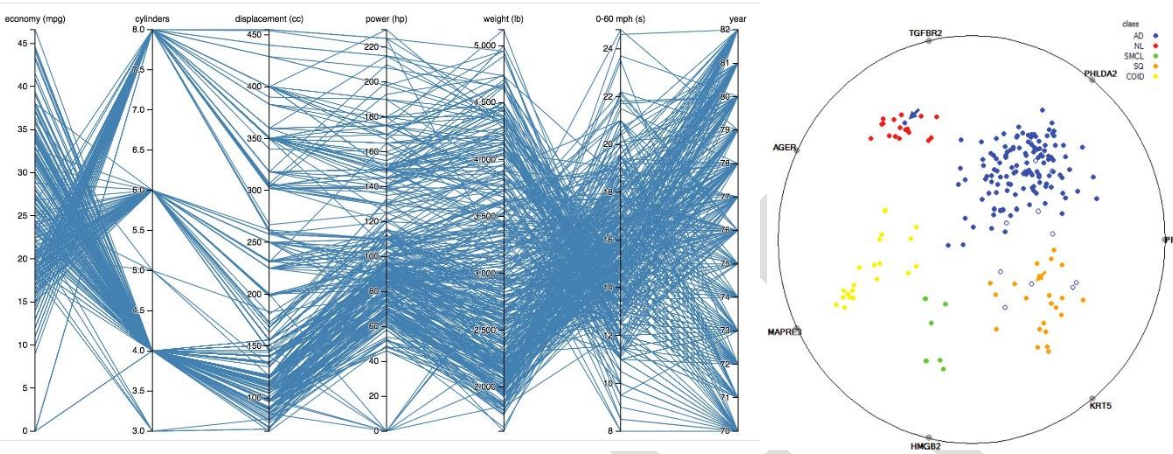


Figure 36: Examples of information visualization techniques. A parallel coordinates on the left and a RadViz on the right.

Task 2.4 Data mining

Simple data mining techniques will be implemented as a complementary approach, mainly to highlight interesting patterns in the visualizations such as clusters, correlations and outliers.

Task 2.5 User evaluations

User evaluations with end-users of the visual tools developed in tasks 2.3 and 2.4 will be organized every three months, in collaboration with task 3.5. The evaluations will target several aspects such as usability (how easy it is to interact), efficiency (how much information they can discover with it), and adoption (how interesting they find the tool).

WP3 Visual language for architectural strategies

This WP will address the challenge of translating the technical description of the carbon strategies into architectural visual language.

Task 3.1 Needs and perception

Based on the knowledge already established by the Smart Living Lab on current practices in architectural firms for integrating energy concepts, the authors study—using an interactive design approach—the relation that architects have with current tools and their partners. The work focuses on, in particular, the use of case studies and the impact on their visual expression in order to target a representation goal for the project. Included in the WP is an analysis of the diversity of practices and an inventory of the invariables.

Task 3.2 Data organization

In close collaboration with Human-IST, the EPFL+ECAL Lab shares the results from WP1 in order to determine the right data for the interface together, taking user perception into account. The results emerging from the work of the Smart Living Lab and the Human-IST will be studied in order to take the data into account and maximize the impact of the project on architectural concepts. A further goal is to better understand modalities of collaboration with these two partners in order to establish a clear definition of the available data during the different phases of the project. The database is the responsibility of the Smart Living Lab.

Task 3.3 Functional mock up exploration

Based on the first information garnered from users as well as the first available data, the EPFL+ECAL Lab proposes interactive scenarios, including functional approaches as well as visual languages—and tests these proposals with the target public. It defines the method for evaluating the potential impact on architectural composition itself. This work constitutes the heart of the process lead by the EPFL+ECAL Lab and is in the form several successive iterations.

Task 3.4 Prototyping

The most convincing results from the functional models will be integrated into an advanced interface—sufficiently robust to allow for autonomous functionality and longitudinal tests (over time) with architects and the project's external partners, as well as with potential users from other professions (such as designers). The final prototype cannot, however, be compared to a finished project ready for distribution since the industrialization phase depends on skill-sets typically found in the private sector (reliability, compatibility, maintenance, etc.).

Task 3.5 Users studies

This task aims to study the proposition's impact on users. With its design-oriented approach, the EPFL+ECAL Lab does not aim to undertake only a traditional study (functionality and ergonomics), but more importantly study the way in which the interfaces line up with the cultural and emotional daily lives of its users and their relationship with partners. These tests are typically punctual in nature, but also generate new knowledge in the perception of interaction and visual language in connection to this specific context.

WP4 Tool prototype

This WP aims to gather into one prototype the relevant output of the previous WP.

Task 4.1 Identification of the relevant features of the prototype

Task 2.5 and 3.5 will be used to identify the techniques developed in the frame of this experimentation that seems to be relevant to be integrated in the prototype.

Task 4.2 Gathering of all the relevant technologies into one tool prototype

Relevant technologies of task 4.1 are assembled into one prototype tool. A specific issue will be to ensure that the final output of the different WP will be able to communicate together, in order to provide a unique and usable prototype tool. This will be handle by the Human-IST team.

6.4. Experimentation 3: envelope

6.4.1. Objectives of the experimentation

Increasing efficiency in the whole life cycle of buildings is the only efficient measure to react to and mitigate climate change and global warming. Efficiency applies both to energy consumption and to greenhouse gas emissions. In a lifecycle assessment (LCA), these are evaluated using the indicators of primary energy consumption (CED), non-renewable primary energy consumption (CEDnr) and carbon emissions (GWP). Switzerland has already introduced a new vision for a sustainable way of living in order to decrease per capita emissions: the so called 2000-Watt Society. This concept has been translated into target values (see Chapter 3.2**Erreur ! Source du renvoi introuvable.**) for environmental impacts in the construction sector, which set a l imit for the main indicators of an LCA. Environmental targets are set at the scale of the building, and soft targets are set for its components. As part of the preliminary phase of the smart living building research programme, a set of 168 case studies has been generated using the Morris method. Thanks to Lesosai software, it has been possible to assess the energy behaviour in these cases. The lifecycle analysis was carried out using the KBOB database. A sensitivity analysis was used to understand which part of the construction most affected the potential of achieving the 2050 goals. In this way, it has been possible to focus the design on the main contributors, making for significant saving measures on a larger scale.

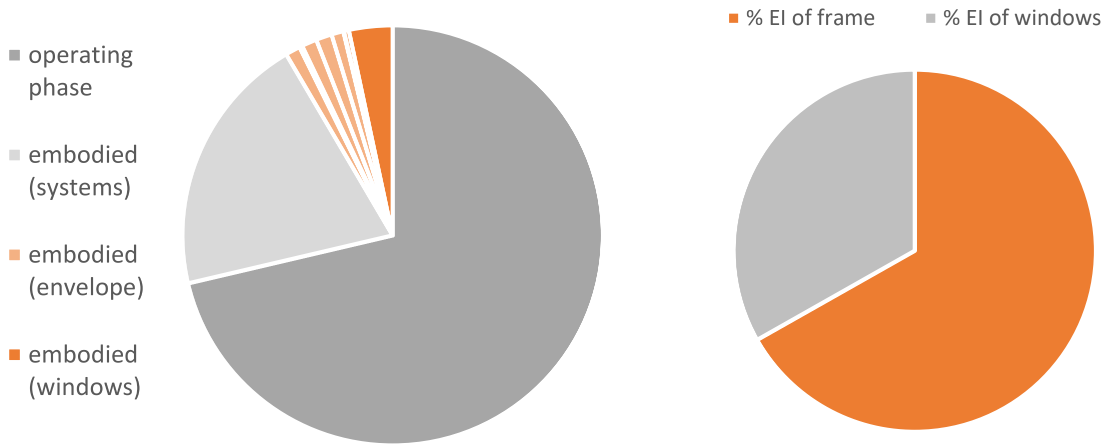


Figure 37: Right: GWP impacts for the best case of SA I. Highlight on the windows. Left: GWP embodied impacts for windows components: frame and glass

The sensitivity analysis detected a major issue related to the windows with regard to the envelope's components. They have a major influence on the building's impact. The materials involved are the biggest contributor to the embodied impacts related to the envelope constructions. In particular, the carbon content of the frame is 3 times greater than that of the glass. Windows' role as filters with the outside makes them important with regard to the operating impacts, too. They are responsible for controlling solar gains (which can reduce heating and increase cooling demands) and they are also important for decreasing consumption related to ventilation (thanks to the possibility of using them for natural ventilation) and lighting (enhancing the natural daylighting inside a room).

Moreover, the analyses made up to this point have been focused on the environmental indicators, but without including the user environment and flexibility: comfort, user interactions with building components and user preferences regarding space and equipment. These are clearly linked to the envelope, and in particular to the windows components. For example, glazing is important for thermal sensation due to the lower surface temperature of the element, and the shading or reflection of sunlight through the windows is important with regard to visual comfort and glare.

Usually, environmental impacts and comfort influence each other in an opposite sense, obliging designers to find a balance between these two different aspects of the construction. For this reason, the façade experiment will help designers in the decision-making phase, giving a range of performances and recommendations as the results of a process of optimisation.

The experimentation will consist of two stages. Firstly, a virtual prototype will be set up to understand the optimum of the parameters involved in the calculation in terms of LCA. In this phase, the investigation will focus on the parameters highlighted by the sensitivity analysis, therefore some assumptions on the other ones (such as the internal environment) will be made to simplify the model. Secondly, a real test chamber will be constructed to test these assumptions and to analyse the effects of the solutions proposed in the first step more deeply. In this second phase, it will be also possible to add the dimension of the user environment, thus understanding the correlation between the façade and the occupants of the space and how this can change the final results.

The aim will be to provide guidelines and recommendations to the smart living building designers. The final output should be a list of parameters/components that help the construction to achieve the performance levels that have been set and their optimum range of validity.

Briefly, it is possible to say that the experimentation will:

- Translate performance requirements into physical values
- Provide an understanding of how to implement thermal inertia regarding summer comfort with respect to the defined impact targets
- Provide an understanding of the effects of implementing natural ventilation on environmental impacts and the user environment
- Balance lighting consumption and windows-embodied impacts
- Test the robustness of the results according to construction and management
- Provide feedback on acceptance of the solutions in the user environment

6.4.2. Organisation chart

Due to the complexity of the experimentation, the whole process is divided into four work packages (WPs). These are related to the issues that must be resolved in the experimentations in order to achieve the two defined milestones.

A steering committee composed of the WP leaders will meet once a month. The committee will invite the other stakeholders if required.

The organisation scheme is the following:

- WP1 aims to describe the performance required for the façade
- WP2 aims to translate the performances into physical parameters which will constitute an environmental strategy for the façade and to choose the solutions that must be included in a more accurate analysis
- WP3 aims to translate the results into consistent architectural and technical specifications
- WP4 aims to monitor and control the results in the test chamber

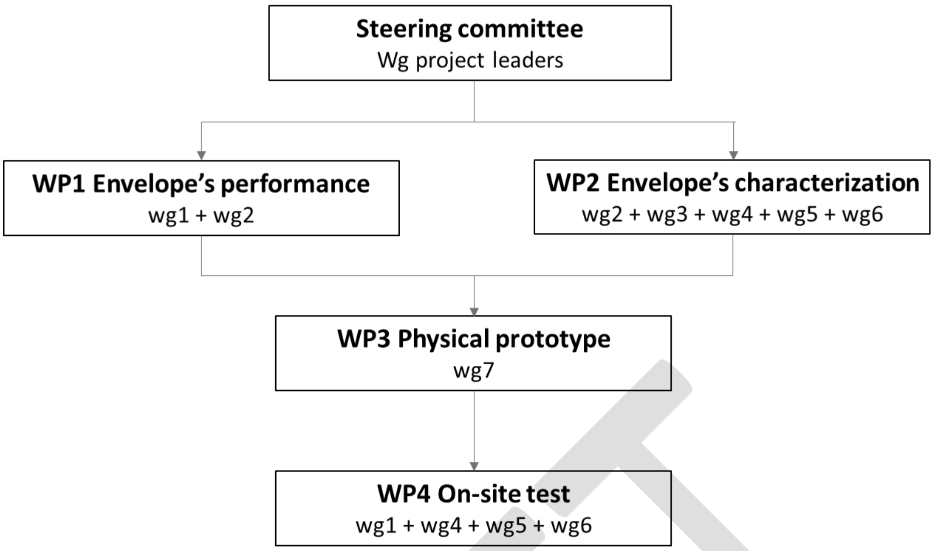


Figure 38: Experiment organisation chart

Each work package has to complete different tasks and requires different expertise and competences. On the basis of the knowledge required, it is possible to identify seven working groups (wg) that will each address a different thematic area:

- wg1: user environment
- wg2: environmental impacts
- wg3: energy production
- wg4: opaque envelope
- wg5: transparent envelope (lighting)
- wg6: envelope's ventilation
- wg7: design and construction

6.4.3. Work Package content

WP1 Envelope performance

The first work package is focused on the definition of the performances that are required of the façade. These can be given by measureable quantity as well as according to qualitative aspects. The requirements will be linked to the envelope's physical characteristics both directly (thermal, acoustic, air tightness, etc.) and indirectly (indoor comfort, usability, etc.). This phase will also define the boundaries of the experimentation, fixing the assumptions that will be used during the operative phase.

Task 1.1 Definition of environmental performances (wg2)

Based on the decomposition of the 2050 environmental targets and on the calibration of the sub-targets for components and systems, a set of performance levels will be created. This set should include all the performance levels required for the façade, its components and the related internal effects. The indicators used are the CED, CEdnr and GWP.

Task 1.2 Definition of user environment performances (wg1)

At the same time, a set of performances related to the user environment must be created. These can be quantitative parameters, related in particular to measurable comfort indoors, or qualitative parameters, related to the users' interaction with the façade itself. The source of this task should be standards and legislation, as well as the results of a social survey conducted on a specific representative sample of the future smart living building population.

Task 1.3 Assumptions and boundaries (wg1 + wg2)

The assumptions of the experiment will be defined based on the set of performances defined in the previous tasks, the sensitivity analysis and the social survey indications (Jusselme et al., 2015). In fixing the boundaries of this study, consideration must be given to the wide range of interactions between the façade and the whole building system. In this task, the working groups will decide which are the most sensitive and interesting performances to be evaluated.

WP2 Envelope characterisation

The second step is the characterisation of the envelope through physical parameters or real building components. This WP aims to define a set of values for the envelope's features which could represent the optimum in terms of balancing the performances established in WP1. Direct and indirect requirements, in fact, can have opposite consequences for the envelope design. For this reason, it is important to understand how it is possible to find a balance. The anticipated results are a range of values or physical properties that could optimise the multi-criteria problem presented by the different requirements that must be considered.

In this phase, a virtual prototype of the smart living building will be created and used for the dynamic simulations that are needed to address this issue.

Task 2.1 Transparent envelope (wg5 + wg6 + wg2)

This task will transform the performance related to the glazing part of the envelope into real physical parameters. Studies involving the thermal part will be coupled with a lighting analysis, ventilation assessment and comfort evaluations. It is anticipated that the results will present a set of choices regarding the physical elements that could meet the requirements and fulfil the environmental targets. The required delivery involves a component which could integrate the issues of increasing daylighting, integrating summer shading, avoiding glare and implementing natural ventilation. At the same time, a clear idea is required about what needs to be better investigated and how.

This task is divided into sub-tasks:

- Translation of the performances required into criticisms regarding the windows and identification of the weak points on which improvement is necessary. This phase must consider the sensitivity analysis carried out.
- Overview of the possible solutions (daylighting / ventilation) that already exist or evaluation of a new technology that could be used to minimise the impacts.
- Evaluation of the balance of operative / comfort / embodied performances and ranking of them on the basis of the environmental impacts. This phase will use specific virtual prototypes and software to evaluate the best performance level achievable.
- Definition of a catalogue of solutions that could help to achieve the results
- Choice of the best solutions that must be evaluated more accurately, according to the real performances in the smart living building context and the user environment interactions (usability).

Task 2.2 Opaque envelope (wg4 + wg2)

This task is the equivalent of the previous one, but is focused on the opaque parts of the envelope. The aim is to translate the performances required as specified in WP1 into tangible values and parameters for the envelope's constitution. The virtual prototype will help with performance evaluation and with choosing the optimal solution(s). This should be evaluated according to an LCA point of view, considering also the embodied impacts involved. The final delivery should involve the design of the envelope with its thermal properties and with the implementation of dynamic behaviour.

The sub-tasks are:

- Overview of the criticisms related to the envelope considering the performances required and the sensitivity analysis conducted
- Identification of possible solutions
- Evaluation of the LCA impacts and ranking of these solutions according to interest for the research
- Definition of all the physical characteristics of the envelope and of a catalogue of solutions

- Choice of the solutions that must be validated also according to usability and the real conditions of the smart living building.

Task 2.3 Integrated energy production (wg3 + wg2)

According to the sensitivity analysis results, as mentioned in the scientific concept report, it is important to integrate electricity production on the façades in order to minimise the environmental impacts. This requirement influences façade design, since having different technologies to produce electricity implies not only various technological and constructional changes, but also differences in the behaviour of the envelope. Delivery should involve a clear picture of the best technologies, their implications for the envelope's design and the reason for conducting a deeper assessment (if any).

The sub-tasks can be organised as:

- Overview of the most interesting technologies used to produce electricity;
- Calculation of the electricity that needs to be produced on the smart living building façade;
- Ranking of the technologies based on the balance between their production potential and their embodied impacts;
- Selection of the most interesting technologies to be analysed;
- Identification of the possible influence that they can have on envelope performances and façade construction.

WP3 Physical prototype

WP2 aims to find solutions for delivering the multi-criterial performances that are required for the envelope. Among these, some will be highlighted as critical and of particular interest. Therefore, a more accurate analysis will be carried out regarding the real smart living building context, usability and interactions with all the other parameters. In order to test all of these features and the mutual interactions between all the parameters of the study, a real test chamber will be constructed and monitored. Moreover, in order to calibrate the design and the results, it will be important to understand the robustness of this analysis and to quantify the gap between the simulations and the reality. The test chamber will allow us to understand the construction feasibility of the proposed solutions, to quantify the uncertainty related to the virtual simulations, and to better investigate the performances and feasibility of the solutions.

Task 3.1 Design (wg7)

The first task should be the translation of the technical solutions and the parameters into an architectural project with detailed technical specifications. The design should follow the directions given by each WG for WP2 and should include the assumptions made for WP1. The result is a complete and reliable design of a test chamber at the level of executive drawings, complete with technical details, which will be submitted as tender documents to construction companies. The economic assessment of the prototype is also part of this task. If the budget is exceeded, wg7 will have to develop an iterative design process with WP2 working groups in order to meet the economic objective.

Task 3.2 Validation of the design (all)

All the working groups will participate in the design phase to ensure that the prototype will reflect the solutions that have been arrived at and will be able to carry out the exact tests required. Prior to construction, a meeting is scheduled with all the working group leaders in order to validate the design and continue with the process.

Task 3.3 Construction (wg7)

Once the test chamber is designed, it will be constructed near the Blue Hall. The results of the task will be the real prototype itself, equipped with the sensors required for the monitoring phase and ready to be tested.

This task includes:

- Submission of tender document to building companies,
- Assessment of building company proposal,
- Administration of building contract,
- Building construction management, including regular site inspections and progress reviews,

- Building construction invoices,
- Building construction commissioning.

WP4 on-site test

The aim of this work package will be to conduct the test planned by each working group in WP2 and to translate this into recommendations, requirements and solutions to be integrated into the scientific programme. This work package is not fixed, as the required tests will be agreed by the WP1 and WP2 working groups when the solution is determined and the related criticisms are identified. It is clearly the aim to carry out the required monitoring test in this phase, analysing the results and translating them directly into clear outputs for the scientific report. The following tasks are outlined as examples:

Task 4.1 Enhancing daylighting (wg5 + wg1)
Task 4.2 Integration of natural ventilation (wg6 + wg1)
Task 4.3 Envelope's dynamic behaviour (wg4 + wg1)
Task 4.4 Electricity production and integration on façade (wg3 + wg1)

All these tasks have the same purpose: applying the monitoring test scheduled for the real chamber, monitoring the behaviour of the prototype according to the test performed, understanding the results and translating them into a proper format. The final outputs are the recommendations, requirements and solutions for each working group that can be implemented directly into the scientific report.
The task can be characterised as follows. Each wg must:

- Prepare the details of the planned on-site test;
- Monitor the test chamber according to the schedule delivered by WG2 and WG3;
- Collect the data and interpret the results;
- Translate the results into clear outputs for the scientific report (recommendations, solutions and requirements).

6.5. Experiment 4: User environment

6.5.1. Objectives of the experiment

In order to tackle climate change and decrease greenhouse gas (GHG) emissions, the smart living building aims to achieve the 2050 goals of the 2000-Watt Society. When translated into the field of construction, the design strategy aims to increase the population density and the flexibility of the building. Theoretically, this requires the designers to create more efficient, high-performance buildings.

In accordance with the earlier study, the parameters that will influence the ability of designers to improve the performance of the building in the course of the design process may be listed as below:

1. The clear objectives and criteria for building performance;
2. Obtaining user information, including their requirements and preferences regarding space use;
3. The ability to translate strategies and guidelines into particular designs;
4. A lack of experience because of the singularity of the project (unique programme, state-of-the-art performance, unique environment);
5. The resources allocated for design: time and fees.

Parameters 1 and 2 are based on an appropriate translation of the political objectives and user requirements. Parameters 3 and 5 are related to the human resources management strategy. Parameter 4 is much more difficult to deal with, as experience allows us more easily to integrate user requirements into the design on different scales. The problem is that this situation rarely arises, especially in the case of the smart living building, as it is a very specific programme with unfulfilled objectives at the forefront.

A significant improvement to performance is required with regard to the 2050 goals of the 2000-Watt Society. The challenge is to improve the energy use of the building, mitigate the carbon footprint and fulfil the user requirements at the same time. An appropriate balance between energy use and user requirements can only be struck based on an understanding of the interrelations between user behaviours, building component design and the environmental impacts of the building.

The aim of the entire user environment experiment is to integrate and balance user knowledge and the climate change targets through an appropriate design. The final outputs of this experiment will include a social database of user knowledge, a prototype of the user environment and a set of recommendations or guidelines that can help designers in the fields of architecture and technical engineering to design the working spaces in the smart living building.

6.5.2. Experiment hypothesis and questions

The main questions that would be answered by the experiment are:

- What are the physical comfort thresholds for users in various working environments and locations?
- Can users control their working environment in terms of physical comfort and building components, and what are the limits to this control?
- Can the sharing of working space optimise the population density and reduce environmental impacts in the workplace, and what are the limits to this sharing?

The hypotheses of the experiment in the user environment are:

- The physical comfort of the working space can vary within an acceptable range, where users can still feel comfortable without any negative impact on their working performance while energy consumption can still be reduced.
- When users have more ability to control or adjust their working environment, including physical comfort and components, they will be more satisfied with their working space. This will increase the utility of working spaces and of the entire building.
- Users' willingness to share may allow increased mobility among users within their working environment. This mobility is achieved by users changing workstations, depending on their different needs. This will break down a uniform working space into several space zones, with various conditions.

This can avoid an over-design of the environment and can reduce both embodied and operation energy and lower the environmental impacts of the building.

6.5.3. Organisation chart

A steering committee composed of the three WP leaders will meet once a month. The committee will invite the other stakeholders if required.

The user environment experiment is composed of six work packages (WPs), which are described in Figure 39:

- WP1 aims to identify the target values / objectives that will be used to evaluate the user environment for the smart living building objectives, translating them into technical descriptions regarding energy consumption and the GHG emissions threshold.
- WP2 aims to establish a knowledge database and user profiles. This database will be used to summarise strategies and recommendations regarding sociological aspects, and to define the flexibility requirements.
- WP3 proposes strategies for product design based on both user knowledge (WP2) and targets / objectives (WP1), which will form the framework to design specific products.
- WP4 aims to translate the strategies into product design and the user environment.
- WP5 aims to set up the user environment prototype for testing in a real-use situation.
- WP6 aims to assess the performance of the prototype in a real situation, to deliver feedback on user knowledge for correction, and finally to validate the robustness of the prototype.

The working groups that will be involved in this experiment are:

- WG1: The research group that will focus on the study at a theoretical level, i.e. the smart living lab research team;
- WG2: The research group that will focus on the target population and user profiles, i.e. EPFL-LaSUR;
- WG3: The research group that will focus on small particular samples of the user population on site, i.e. Human-IST at the University of Fribourg;
- WG4: The design group that will focus on the design of the product and the user environment, and that will also take the charge of building the user environment prototype, i.e. Atelier-OÏ

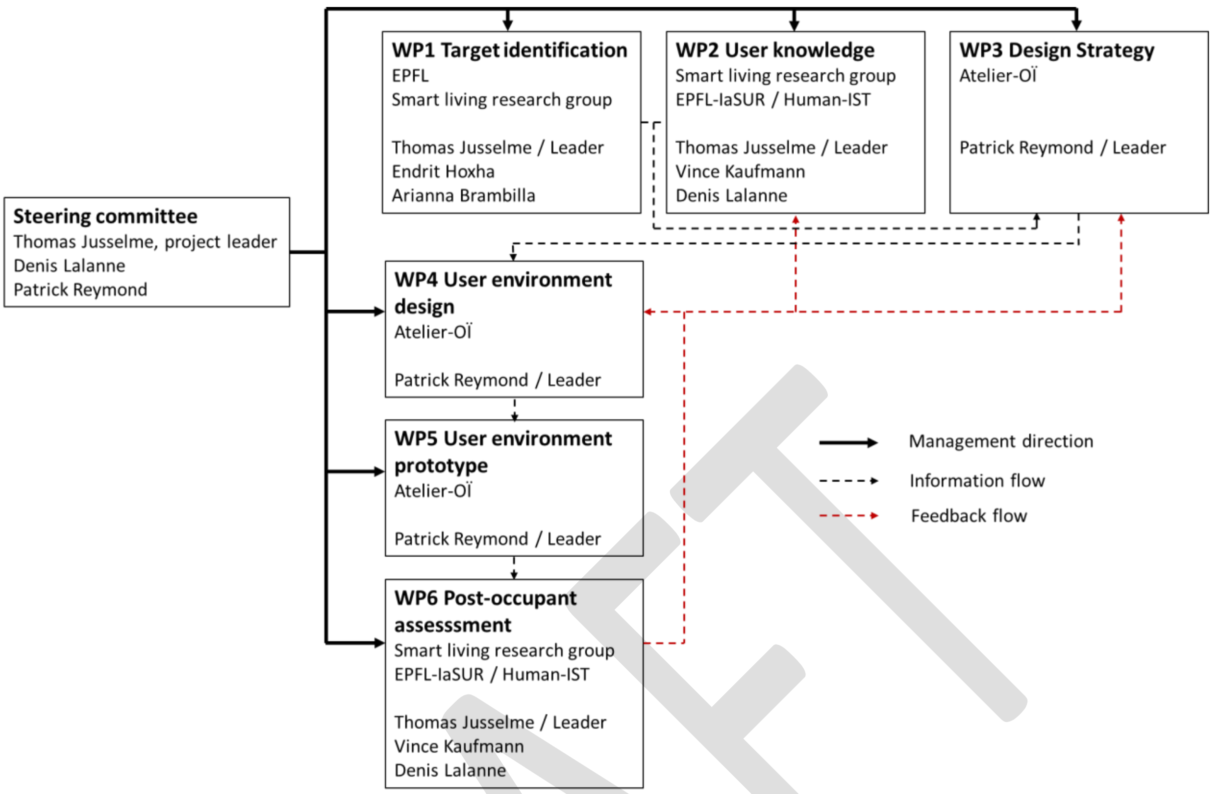


Figure 39: User environment experiment organisation chart

6.5.4. Work Package content

WP1 Target/Objective identification

The targets / objectives of the building will be identified through a top-down approach based on the 2050 goals of the 2000-Watt Society on the level of building consumption, i.e. appliances, equipment and furniture, and indoor physical comfort, i.e. ventilation, temperature, lighting, noise and humidity.

Task 1.1 Building component identification

The multiplicity of components in a building means that we cannot put equal effort into every single component; we must select those with greater impacts on the project. By understanding this, WG1 will identify the building components that require further attention through study and design. These building components can be appliances, furniture and other items that will be involved in the user environment, according to the initial project study.

Task 1.2 Target value identification

Based on "State of the Art", WG1 will identify the target values for the building components in the user environment in terms of environmental impacts using life cycle assessment (LCA) methods. The environmental impacts that apply to this aspect of the project include:

- CED: cumulative energy demands,
- CED_{nr}: cumulative energy demands for non-renewable fuels, and
- GWP: global warming potential.

WP2 User knowledge

User understanding, as a parameter that can influence the quality of the project, is a further challenge, as the building users are unpredictable. In order to obtain user information and to build up as precise a user database as possible, three scales of information will be collected in this work package:

- General requirements under Swiss Society of Engineers and Architects (SIA) standards and regulations,
- Information from a large population with similar characteristics to those of the real users, who may also be involved in the building, and
- A study on a specific population that will be involved in the on-site experiment.

The purpose of this three-scale investigation is to understand the basic requirements of working space, the particular characteristics of the target user population in terms of working space use, and the real, practical situation in relation to the specific conditions.

The outputs of this work package include a user information database, user profiles with various characteristics, and a set of social strategies for the design phase in the future.

Task 2.1 General requirements

Climate change brings forward the necessity of understanding the physical comfort requirements in different situations. WG1 will first identify the parameters and criteria that can be used to evaluate indoor physical comfort theoretically, through the literature reviews regarding the basic SIA physical standards and regulations. These parameters can be accepted in most situations and will reflect the general requirements.

Through scientific studies on the correlations between the parameters for the second step, WG1 will establish a prioritisation in order to build up a framework of parameters.

Task 2.2 Information on target population

This task relates to the target users and specifies their requirements for working spaces. WG2 will implement this task via both top-down and bottom-up approaches to understanding the different users and their working habits and working preferences. With the intention of answering the research questions of the experiment, the survey is designed to focus on the main issues, i.e. daily behaviour patterns, preferences and acceptance of space control and sharing. This information will be worked out specifically in the following aspects:

- The establishment of an original database on user behaviours and preferences among the particular population in the academic institutions involved
- The establishment of user profiles on behaviours and workplace preferences in the academic institutions involved
- The priorities and the framework of user requirements for working spaces
- Recommendations or suggestions

Task 2.3 On-site small-scale investigation

The user knowledge will be refined further on a comparatively small scale by WG3 based on the findings of task 2.2. According to the research questions and hypotheses, a specific on-site investigation will be conducted, including

- Observing and recording daily activities in different real situations
- Interviewing typical building occupants to understand the reasons behind their behaviour patterns and their real feelings of comfort and satisfaction regarding various aspects of the real work environment

This information will be obtained following certain steps:

Step 1: The protocol of on-site observation, including

- The method of observation
- The scale and location of observation
- The introduction of the observation equipment, such as the interaction machines, sensors, etc.
- The designation of the observation equipment
- The data processing methods

Step 2: Approval of the observation on site by the smart living lab operation committee
Step 3: The on-site observation
Step 4: The interview protocol, including

- The method of interview
- The design of the interview questions
- The selection of the interviewees
- The data processing methods
- References to the observations or other research findings

Step 5: Implementation of the interviews
Step 6: Data collection
Step 7: Data processing and analysis

The outputs of this task will include:

- A precise behaviour picture of users in real working situations
- A possible extension of the findings to the general situation
- A proposal of social strategies.

Task 2.4 Interaction measurement

The literature reviews on users controlling built environments and the earlier studies refer to the relationship between users, building components and component lifespan. A simplified simulation of this relationship suggested that, the more the building component interacts with users, the shorter its lifespan is. Combining with the environmental impacts of building components, this correlation will be considered as a possible parameter for designing or selecting building components. In order to apply this in the next phase of the project, two sets of information are required:

- The lifespan of building components in the user environment, and
- The interaction level of each single building component to users in the user environment.

The first set of information can be adapted from the existing products on the market, while the second set needs a measurement to be made. Combining the current studies on the interaction between users and machines in the fields of computer science and social studies in relation to the cognitive processes, WG1 will establish a method that can measure the interaction levels between users and building components, including:

- Identification of the interactions between users and components
- Priority among the interactions
- Parameters that can be used to measure the interactions, and
- Method that can numerically translate the interactions.

With the information acquired in tasks 2.2 and 2.3, the interrelationships between users, components and component lifespans can be identified and implemented in the next phase.

Task 2.5 Social strategy formulation

WG3 will integrate the information and findings of tasks 2.1, 2.2, 2.3 and 2.4. The social strategies and recommendations will be generalised following the steps below:
Step 1: Classification of the information and findings according to their interrelationships:

- Confirming or verifying one another;
- Existing gaps or differences between one another; and
- Other supplementary / extra information

Step 2: Integration of the information
Step 3: Correction of the framework of user requirements in the working environment
Step 4: Proposal for the social strategies

WP3 Design strategy / vision

Based on the social strategies proposed in the previous work package, the appointed design partner will, as for WG4, draft design strategies for the building and products.

Task 3.1 Strategy formulation

The findings of WP1 and WP2 will be assimilated and translated into design strategies for the task. This will allow us to clearly identify the scope of the experiment, and which products or components will be integrated into the user environment prototype. The following will be specified:

- The scale / dimension of the prototype model;
- The arrangement or allocation of the space and schedule in the prototype for each representative situation and population group;
- The connections to the other experiments in the Blue Hall, e.g., the façade technology and the energy experiment;
- The location of the prototype model in the Blue Hall according to the interrelationships with other experiments.

Task 3.2 Product specifications

The output of task 3.2 is translated into specifications that will be developed in WP4. The specifications should at least include the following descriptions at the product level:

- The environmental targets
- The comfort targets
- The user requirements
- The role of the product in the whole design vision.

Task 3.3 Product classification

The building components and products involved in the user environment prototype are classified into two types: the products that can be selected directly from the market, and the products that need to be designed particularly for the smart living building.

WP4 User environment design

According to the design strategy, WG4 will design the user environment prototype for the smart living building.

Task 4.1 Product design based on the design strategy

This task will concentrate on designing the building components and products that cannot be selected from the existing market. The specification described in Task 3.2 will have to be fulfilled.

An iterative design process with the other partners involved in the definition of environmental targets, comfort targets and user requirements will be carried out to ensure that the final product will fulfil these specifications. The outputs of this task will be a series of detailed designs.

Task 4.2 Product selection from existing market

The other components or products will be selected from the market. Information for each product will be collected and compared according to the design strategy. The final selected products and suppliers will be listed.

Task 4.3 Integration of user environment design

This task will address the challenges of integrating both the designed and selected products together, as well as the design of the indoor working environment which will accommodate all the products and components.

WP5 User environment prototype

In this work package, WG4 will transform the design completed in WP4 into a 1:1 prototype model in the Blue Hall.

Task 5.1 Design

The first task should be the translation of the technical solutions and the parameters into an architectural project with detailed technical specifications. The design should follow the directions given by each WP. The result is a complete and reliable design of a working environment at the level of executive drawings, complete with technical details, which will be submitted as tender documents to building or manufacturing companies. The economic assessment of the prototype is also part of this task. If the budget is exceeded, an iterative design process will have to be carried out with the other WPs in order to meet the economic objective.

Task 5.2 Design validation

All the working groups will participate in the design phase to ensure that the prototype will reflect the solutions that have been arrived at and will be able to carry out the exact tests required. Prior to construction, a meeting is scheduled with all the working group leaders in order to validate the design and continue with the process.

Task 5.3 Construction and manufacturing

Once the working environment is designed, it will be built within the Blue Hall. The results of the task will be the real prototype itself, equipped and ready to be tested.
This task includes:

- Submission of tender document to building companies,
- Assessment of building company proposal,
- Administration of building contract,
- Building construction management, including regular site inspections and progress reviews,
- Building construction invoices,
- Building construction commissioning.

WP6 Post-occupancy assessment

In this work package, the performance of the prototype will be evaluated according to the parameters that were set up in the previous work packages by each working group.

Task 6.1 Test on prototype model

In order to understand the user environment performance in a real situation, task 2.3 will be repeated on the prototype.

Task 6.2 Feedback

The data and information from the test / assessment of the prototype model will be generalised and compared with the user knowledge and social strategies produced in WP2, with the following purpose:

- Provide answers to the research questions and hypotheses of the experiment;
- Confirm the feasibility of the design strategy;
- Confirm or propose suggestions about the design of particular building components and products;
- Estimate the energy consumption and environmental impacts of the final prototype.

Task 6.3 Final design guideline

By integrating the feedback achieved in task 6.2, the entire process of the experiment on the user environment will be summarised in a written report. The final outcome of the task is the user environment design guideline for the smart living building. This guideline will be integrated into the scientific programme.

6.6. Round Table

6.6.1. Objectives and programme of the roundtable

A round table between the main local actors in the construction sector and the smart living building project researchers was organised for 2 October. More than 100 professionals attended, representing architecture and engineering offices, energy suppliers, building construction companies, building owners and public authorities. The event was held at the NH hotel in Fribourg.

The aim of the event was to:

-present the smart living lab
-present the smart living building project and the first results of the research
-validate the scientific concept
-open up discussion and share opinions on three specific themes

The specific discussions were announced and, for each of them, four external experts were asked to stimulate the debate during the first part of each round table. In a second step, the audience was invited to comment or ask questions concerning the subject of discussion. The three specific themes were:

1) Requirement specification: How must be the design brief, rigid or flexible in order to guarantee quality and performances?

With : Stephan Wüthrich (CSD INGENIEURS SA), Yves Roulet (Ville de la Tour-de-Peilz), Philippe von Bergen (Geninasca et Delefortrie Architectes), Pascal Mirallie (Losinger Marazzi SA)

2) From theory to practice: Builders point of view regarding the constraints of innovations

With Patrick Clément (Sottas SA), Florentzou Florentzos (ESTIA, physique du bâtiment et développement durable), Emmanuel Rey (EPFL), Jean-Baptiste Zufferey et Arnold Rusch (Université de Fribourg)

3) Building flexibility: between will and results, feedback of pas experience

With: Cyril Baumann (ERNE AG Holzbau), Hugo Fuhrer (Canton de Berne), Hanspeter Oester (Pfenninger Architekten AG), Barbara Tirone (EPFL)

6.6.2. Outputs from the round tables for the research programme

Some of the discussions that took place during the round tables could have an impact on the scientific programme. These aspects are the following:

Requirement specifications: Should client orders be rigid or flexible in order to guarantee quality and performance?

The impact of efficiency on the specifications was discussed by the experts, and everybody agreed that an increasing number of factors needed to be taken into account in the construction area, e.g. economy, society, environment, energy and standards. This is why more and more constraints need to be taken into account nowadays. Based on these increasing constraints, there is a risk that buildings will look like each other in the future, and these constraints could become barriers to the requirements. Too often, however, requirement specifications have been limited to the specifications of an area for a given programme. It has also been emphasised that a common confusion exists between the concept of efficiency for achieving a given goal and that of effectiveness in doing something with the minimum of resources.

More and more actors have become involved in the construction process, and there is a need for a common language. It has been pointed out that the specification process needs to evolve, especially regarding unconventional building. A new three-step specification process has been proposed. It would include, first, a light specification, secondly, the selection of a construction team based on a pre-project carried out by the subcontractors, and then a final specification worked out with the collaboration of all parties.

From theory to practice: Builders' points of view regarding the constraints on innovation

Technological measures often require investors to be convinced. Decision makers seem to have a fear of risks, but also about loss of value linked to time-limited technologies and their obsolescence. Innovation does not necessarily mean the use of high technologies, and smart low tech could be the answer. Automation in the building sector is not so well accepted, mainly because of its high price, its lack of robustness and the fact that it does not meet user needs.

Standards often do not allow for innovation, and they prevent creativity. In the present situation, regulations and contracts are not well adapted for innovation. A clear example has been provided by a problem linked to the warranty. Consideration of risk management versus earnings generates a conservative approach on the part of a general contractor. Another barrier to innovation, and especially to the integration of renewables in buildings, is that spatial planning is not carried out as a function of the available types of energy.

Building flexibility: between will and results, feedback on past experience

Long-term anticipation of future building usage is an impossible task, involving a need for adaptability more than flexibility. Extending flexibility to every part of a building was judged unreasonable by the experts and the other participants, especially for cost reasons. Providing the correct function at the right parts of the building must be the target to achieve. Raising awareness among future users is a primary requirement when designing a building. Around 50 to 60% extra costs have been incurred when projects have been started too early and without the knowledge of users.

Pre-investment in technologies for providing flexibility has been reported to be a failure in many cases, such as for housing or for EPFL buildings. It is better to invest in the heavy structure (by providing enough space in height and width) than in technologies that may quickly become obsolete. Flexibility criteria could be set, for example for the charge load of the slabs. Technology should not be integrated in the concrete structures.

The notion of separating the building design into two separate projects (project A and project B) seems difficult to apply in practice. The definition of the interface between the two projects, as well as the defect responsibility, are the major drawbacks of the concept.

7. Conclusion

This “Scientific concept and transition to the experimentation phase” report is a key deliverable in the smart living building research programme. It is the first step towards the scientific programme that will be submitted to the future designers. Its goal is to specify the targets that will be integrated into the design brief for climate change, environmental quality, usability and flexibility. In order to face them, the first technical and architectural solutions are proposed. Suitable tools and methods to implement them are also suggested.

First, the method to define **targets for climate change** has been established (cf. chap. 3.2). The method consist in generating a set of projects that fulfil the objectives by varying the design parameters with a statistical approach. LCA results allowed us to define average impacts at the component and system scale which will constitute soft targets for designers. The usability of the method has been validated through a first proposal of targets. To enhance the robustness of these targets, a wider database with a higher diversity and number of projects should be developed. This work will be handled within the frame of the scientific programme and linked to the “CO_2 expert tool” experiment.
It is fundamental to establish **flexibility and usability targets** (cf. chap. 4.6.2), to better understand the needs of future dwellers. The current social survey and further investigation will propose a clear picture about their behaviour. However, this understanding is not enough to establish clear objectives for future designers. Translating these needs, requirements and behaviours into objectives for the design brief remains a great challenge. This is more related to a methodological issue that will be tackled within the architectural quality research field.

Secondly, **technical and architectural solutions** were proposed. As a building is composed by systems and subsystems, we propose to highlight “vital organs” (cf. chap. 3.5) that represent a group of building components and systems which contribute the most to the building performance. They are namely the architectural envelope, the energy supply, the technical systems and mobility. Energy fluxes and dynamic relationships between these subsystems are made efficient through user behaviour and storage technologies. Sensitivity analysis (cf. Annex 9 and 9.3) enables us to characterize the efficiency of different technical and architectural solutions (cf. chap. 0) that could make these vital organs efficient.

Finally, all the studies carried out during the scientific concept highlight very interesting, specific **research questions** that will be developed in six conference papers (cf. chap. 12) and the four following experiments (cf. chap 6).

This scientific concept deliverable reveals that in order to define usable guidelines for designers, it is necessary to deeply investigate the architectural and technical consequences of the proposed targets. The question here is not to start designing the project, but to investigate the consequences through experiments. We believe that a better understanding of these consequences at an earlier design stage is a key issue to integrate performance into the design process. The **“CO2 expert tool” experiment** will focus specifically on this issue (cf. chap. 0).

Usability and flexibility issues could be resumed as a simple question: “How can a high population density be kept within the smart living lab?” A high population density means a usable space. The flexibility challenge is to keep this density over time. Social and anthropological surveys should enable us to understand which the willingness of sharing of future dwellers is. With the **“user environment” experiment** (cf. chap. 0), we will understand how far ahead is possible to apply the integration of the density issue into the prototyping process of new working spaces.

This report also allows to understand the fact that producing a building with no GHG emissions is not possible, even if fully supplied by renewable energies. The infrastructure for these renewable technologies, and the building itself will still produce GHG during construction, even with the implementation of low carbon materials (cf. chap. 4.2.3). Regarding the energy supply, the right balance between energy production and its relative embodied impact have to be found. The energy surplus that will not be consumed by the building will be stored or injected into the grid. In this case, if the electricity CO_2 content injected from the building to the grid is lower than the one of the grid, the induced benefits should be attributed to the building. As the electricity mix is changing over the time, the induced benefits attributed to the building will therefore sensibly vary. The correlation between energy consumption and the availability of low carbon electricity is then a key issue to achieve the GHG emissions targets. The **"CO2 correlation" experiment** (cf. chap. 0) will specifically focus on this challenge through a better understanding of the hourly GHG emissions of the grid and the building.

Finally, we have demonstrated that the facade will play a key role by minimizing the major operating impacts, namely the lighting and the ventilation (cf. chap. 9.3). Significant new tendencies were pointed out by this deliverable. For the past 40 years, energy strategies have focused on increasing insulation, air tightness and ventilation heat recovery. A low carbon energy supply will challenge these practices. For instance, the embodied impacts benefits due to the implementation of a natural ventilation in comparison with a mechanical heat recovery ventilation starts to occur more savings than the induced operating energy consumption (cf. chap. 4.4). The **"low carbon facade" experiment** (cf. chap. 0) will specifically focus on this challenge through a lifecycle approach of the design.

All these challenges will be further investigated in the next phase of the smart building research programme.

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Building 2050
Scientific Concept – Annexes

9. Annex 1: Sensitivity Analysis I

9.1. List of parameters (SA I)

Shape: The first parameter necessary to describe the building's geometry is represented by its shape. It is therefore a central point to understanding how much change in the geometry can influence the thermal behaviour of the building.

- Shape 1
- Shape 2
- Shape 3

Windows to wall ratio: This parameter represents the porosity of the envelope, referring to the area of transparent surfaces used. An assessment of this feature is essential in order to take into consideration the variation in the balance between solar gains and thermal losses through the windows.

- Window surface as the 25% of the façade
- Window surface as the 50% of the façade
- Window surface as the 75% of the façade

Thermal transmittance: The importance of this parameter is related to the ability of the building's envelope to improve its heating efficiency. The thermal shield, in this case, refers to the total transmittance of the shell to the external air, signifying an overall building performance that is greater than the local performances of each component.

- U value: 0.1 W/m^{2}K
- U value: 0.15 W/m^{2}K
- U value: 0.20 W/m^{2}K
- U value: 0.25 W/m^{2}K

Window type: This input represents the transparent components used in the construction. Three different types of window have been used to show the different typologies that are applied in a continental climate such as that of Switzerland.

- Type 1: standard double glazing (U: 2.7 W/m^{2}K, g: 0.77)
- Type 2: low-E double glazing (U: 1.3 W/m^{2}K, g: 0.64)
- Type 3: low-E triple glazing (U: 0.7 W/m^{2}K, g: 0.5)

Inertia: Inertia is a key driver for comfort, acting as a heat reservoir to store gains, thus influencing the energy consumption of the building. In this study, since it is a preliminary analysis, it has been chosen to simulate it in a very simple way: considering three different types of construction associated with three different levels of inertia.

- Inertia 1: Average; massive walls, light concrete
- Inertia 2: Low; light walls, no concrete
- Inertia 3: High; very massive walls, concrete

Shading system: This parameter represents the shading factor of the transparent elements. To assess this calculation, percentages of shading of the glazing components have been chosen.

- Shading 1: 20%
- Shading 2: 50%
- Shading 3: 70%
- Shading 4: 90%

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Ventilation ratio: Since a different ventilation ratio (Vr) has been defined for each zone of the building, this study has used the SIA value as a reference for all values, and the relative percentage difference has then been used to change the Vr coherently for all ambient areas.

- Profile 1: Vr in m^3/h as SIA
- Profile 2: Vr in m^3/h as 120% of SIA
- Profile 3: Vr in m^3/h as 80% of SIA

Lighting + Appliances: To assess the importance of the internal gains on the final thermal performance, the parameter of internal load has been defined as the profile of appliances and lighting consumption. The quantification of this value has been made through a set of four possible scenarios: starting from the value given by SIA, a discrete percentage variation is ascertained.

- Profile 1: SIA 380/4 normal lighting, appliances SIA
- Profile 2: SIA 380/4 target lighting, appliances 73% of SIA
- Profile 3: Minergie lighting, appliances 82% of SIA
- Profile 4: SIA 2024 lighting, appliances 56% of SIA

Heat production: The HVAC system is counted as a variation of the chosen system. It allows a different CO_2 content to be used in the energy for each supply system. At the same time, the variation in efficiency shows the primary energy related to each solution.

- Heat production 1: Natural gas
- Heat production 2: Pellet
- Heat production 3: District heating
- Heat production 4: Heat pump

PV panels: Due to the importance of understanding the relative sensitivity of the relationship between the use of photovoltaic panels and the CO_2 content of the energy supply system, efficiency, orientation and inclination will stay constant in each scenario. The PV system aims to cover only the demand for lighting and appliances, and its use is meant to be integrated with the use of the electricity grid.

- PV 1: none
- PV 2: 30% of the roof surface
- PV 3: 60% of the roof surface
- PV 4: 100% of the roof surface

Solar thermal collectors: The collectors are used only for domestic hot water (DHW) demand. In fact, this is an implementation of the HVAC system, which is already providing heating and hot water. The value used to describe these parameter is the percentage of coverage of DHW demand.

- Solar 1: zero
- Solar 2: solar collector to cover 20% of DHW demand
- Solar 3: solar collector to cover 40% of DHW demand
- Solar 4: solar collector to cover 60% of DHW demand

Heat distribution: Different ways of providing heat in the ambient areas are chosen, with each solution having a different impact on both the embodied energy and the operative energy.

- Distribution 1: Radiators
- Distribution 2: Floor heating
- Distribution 3: Ceiling heating
- Distribution 4: Air heating

Table A 1: Summary of the parameters used in SA I

PARAMETER	INPUT			
SHAPE	1	2	3	-
WINDOWS TO WALL RATIO	25%	50%	75%	-
THERMAL TRANSMITTANCE	0.1 W/m^2K	0.15 W/m^2K	0.20 W/m^2K	0.25 W/m^2K
WINDOW TYPE	U:2.7 W/m^2K g: 0.77	U:1.3 W/m^2K g: 0.64	U:0.7 W/m^2K g: 0.5	-
INERTIA	Light wall	Average	Massive wall	-
SHADING RATIO	20%	50%	70%	90%
VENTILATION RATIO	SIA	120% SIA	85% SIA	70% SIA
LIGHTING + APPLIANCES	SIA Light SIA App	SIA target Light 73% SIA App	Minergie Light 82% SIA App	SIA 2024 Light 110% SIA App
HEAT PRODUCTION	Pellets	Natural gas	District heating	Heat pump
PHOTOVOLTAIC PANELS	none	30%	60%	100%
SOLAR COLLECTORS	none	20%	40%	60%
HEAT DISTRIBUTION	Radiators	Floor H.	Ceiling H.	Air H.

9.2. Simulation Matrix (SA I)

No.	Shape	Windows ratio	Thermal transmittance	Window Type	Inertia	Shading	Ventilation ratio	Light + Appl.	Heat Production	PV panels	Solar Thermal	Heat Distribution
1	1	75	0.25	3	Low	50	80	1	Natural gas	100	40	Air heating
2	1	75	0.25	3	Low	50	80	1	Natural gas	100	40	Floor Heating
3	1	75	0.25	3	Low	50	120	1	Natural gas	100	40	Floor heating
4	1	75	0.15	3	Low	50	120	1	Natural gas	100	40	Floor heating
5	1	25	0.15	3	Low	50	120	1	Natural gas	100	40	Floor heating
6	1	25	0.15	3	Low	90	120	1	Natural gas	100	40	Floor heating
7	1	25	0.15	3	Low	90	120	1	District heating	100	40	Floor heating
8	1	25	0.15	3	Low	90	120	3	District heating	100	40	Floor heating
9	1	25	0.15	1	Low	90	120	3	District heating	100	40	Floor heating
10	3	25	0.15	1	Low	90	120	3	District heating	100	40	Floor heating
11	3	25	0.15	1	Low	90	120	3	District heating	30	40	Floor heating
12	3	25	0.15	1	Low	90	120	3	District heating	30	0	Floor heating
13	3	25	0.15	1	High	90	120	3	District heating	30	0	Floor heating
14	1	50	0.2	3	Average	70	120	1	Pellets	0	0	Floor heating
15	1	50	0.2	3	Low	70	120	1	Pellets	0	0	Floor heating
16	1	50	0.2	3	Low	70	100	1	Pellets	0	0	Floor heating
17	1	25	0.2	3	Low	70	100	1	Pellets	0	0	Floor heating
18	1	25	0.2	1	Low	70	100	1	Pellets	0	0	Floor heating
19	3	25	0.2	1	Low	70	100	1	Pellets	0	0	Floor heating
20	3	25	0.2	1	Low	20	100	1	Pellets	0	0	Floor heating
21	3	25	0.2	1	Low	20	100	3	Pellets	0	0	Floor heating
22	3	25	0.2	1	Low	20	100	3	Pellets	60	0	Floor heating
23	3	25	0.2	1	Low	20	100	3	Pellets	60	40	Floor heating
24	3	25	0.2	1	Low	20	100	3	Heat pump	60	40	Floor heating
25	3	25	0.2	1	Low	20	100	3	Heat pump	60	40	Air heating
26	3	25	0.1	1	Low	20	100	3	Heat pump	60	40	Air heating
27	2	25	0.1	1	Low	50	80	3	Pellets	60	20	Air heating

No.	Shape	Windows ratio	Thermal transmittance	Window Type	Inertia	Shading	Ventilation ratio	Light + Appl.	Heat Production	PV panels	Solar Thermal	Heat Distribution
28	2	25	0.1	1	Low	90	80	3	Pellets	60	20	Air heating
29	2	50	0.1	1	Low	90	80	3	Pellets	60	20	Air heating
30	2	50	0.1	1	Low	90	80	3	Pellets	60	20	Floor heating
31	2	50	0.1	1	Low	90	80	3	Heat pump	60	20	Floor heating
32	3	50	0.1	1	Low	90	80	3	Heat pump	60	20	Floor heating
33	3	50	0.1	1	Low	90	100	3	Heat pump	60	20	Floor heating
34	3	50	0.1	1	Low	90	100	3	Heat pump	0	20	Floor heating
35	3	50	0.1	3	Low	90	100	3	Heat pump	0	20	Floor heating
36	3	50	0.2	3	Low	90	100	3	Heat pump	0	20	Floor heating
37	3	50	0.2	3	Low	90	100	3	Heat pump	0	60	Floor heating
38	3	50	0.2	3	Low	90	100	1	Heat pump	0	60	Floor heating
39	3	50	0.2	3	Average	90	100	1	Heat pump	0	60	Floor heating
40	1	50	0.1	1	High	90	120	4	Heat pump	30	60	Ceiling heating
41	3	50	0.1	1	High	90	120	4	Heat pump	30	60	Ceiling heating
42	3	50	0.1	2	High	90	120	4	Heat pump	30	60	Ceiling heating
43	3	50	0.1	2	High	90	120	4	Heat pump	100	60	Ceiling heating
44	3	50	0.2	2	High	90	120	4	Heat pump	100	60	Ceiling heating
45	3	50	0.2	2	Low	90	120	4	Heat pump	100	60	Ceiling heating
46	3	50	0.2	2	Low	90	120	4	Heat pump	100	20	Ceiling heating
47	3	50	0.2	2	Low	90	120	4	Pellets	100	20	Ceiling heating
48	3	50	0.2	2	Low	90	120	4	Pellets	100	20	Radiators
49	3	25	0.2	2	Low	90	120	4	Pellets	100	20	Radiators
50	3	25	0.2	2	Low	50	120	4	Pellets	100	20	Radiators
51	3	25	0.2	2	Low	50	80	4	Pellets	100	20	Radiators
52	3	25	0.2	2	Low	50	80	2	Pellets	100	20	Radiators
53	1	75	0.1	1	Low	20	80	2	Pellets	30	20	Air heating
54	1	75	0.1	1	Low	70	80	2	Pellets	30	20	Air heating

No.	Shape	Windows ratio	Thermal transmittance	Window Type	Inertia	Shading	Ventilation ratio	Light + Appl.	Heat Production	PV panels	Solar Thermal	Heat Distribution
55	1	75	0.1	1	Low	70	80	2	Pellets	30	20	Floor heating
56	1	75	0.1	1	Low	70	100	2	Pellets	30	20	Floor heating
57	1	75	0.1	2	Low	70	100	2	Pellets	30	20	Floor heating
58	1	75	0.1	2	Low	70	100	2	Heat pump	30	20	Floor heating
59	1	25	0.1	2	Low	70	100	2	Heat pump	30	20	Floor heating
60	1	25	0.1	2	Low	70	100	2	Heat pump	100	20	Floor heating
61	1	25	0.1	2	High	70	100	2	Heat pump	100	20	Floor heating
62	1	25	0.1	2	High	70	100	2	Heat pump	100	60	Floor heating
63	3	25	0.1	2	High	70	100	2	Heat pump	100	60	Floor heating
64	3	25	0.1	2	High	70	100	4	Heat pump	100	60	Floor heating
65	3	25	0.2	2	High	70	100	4	Heat pump	100	60	Floor heating
66	3	25	0.15	3	Low	20	120	2	Pellets	30	60	Air heating
67	3	25	0.15	3	Low	20	100	2	Pellets	30	60	Air heating
68	3	25	0.15	3	Low	20	100	2	Pellets	30	20	Air heating
69	3	25	0.25	3	Low	20	100	2	Pellets	30	20	Air heating
70	3	25	0.25	3	Low	20	100	2	Pellets	30	20	Floor heating
71	3	25	0.25	3	Low	70	100	2	Pellets	30	20	Floor heating
72	2	25	0.25	3	Low	70	100	2	Pellets	30	20	Floor heating
73	2	25	0.25	3	High	70	100	2	Pellets	30	20	Floor heating
74	2	25	0.25	3	High	70	100	4	Pellets	30	20	Floor heating
75	2	25	0.25	3	High	70	100	4	Heat pump	30	20	Floor heating
76	2	25	0.25	3	High	70	100	4	Heat pump	100	20	Floor heating
77	2	75	0.25	3	High	70	100	4	Heat pump	100	20	Floor heating
78	2	75	0.25	2	High	70	100	4	Heat pump	100	20	Floor heating

Matrix generated for SA I. Total number of simulations for Morris analysis: N = r x (k + 1) = 6 x (12 + 1) = 78, where r is the number of trajectories (successions of points starting from a random base vector in which two consecutive elements differ only for one component) and k the number of model input factors.

9.3. Simulation results (SA I)

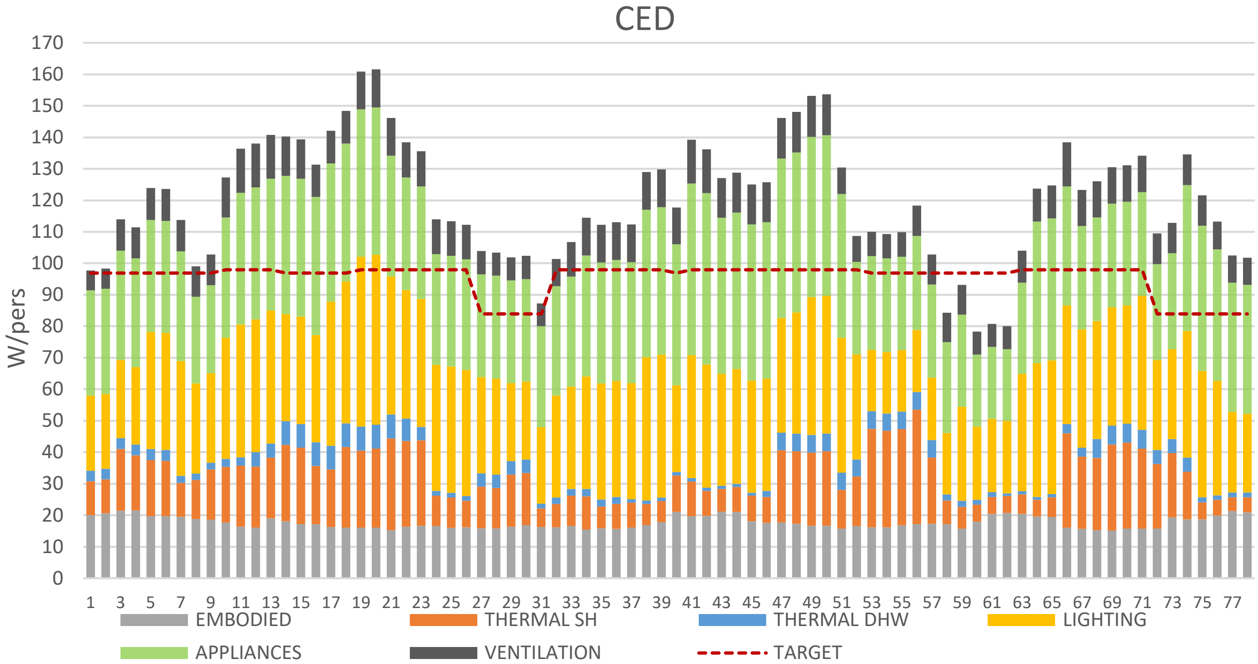

Figure A 1: CED Index for the 78 simulations of SA I

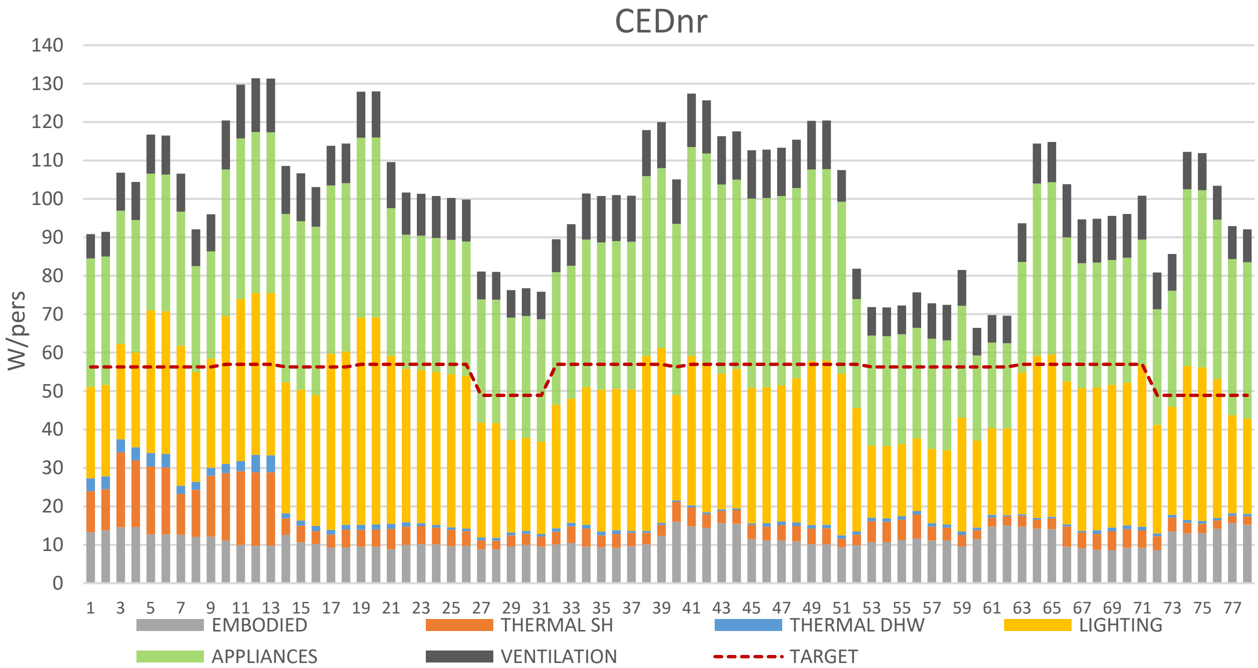

Figure A 2: CEDnr Index for the 78 simulations of SA I

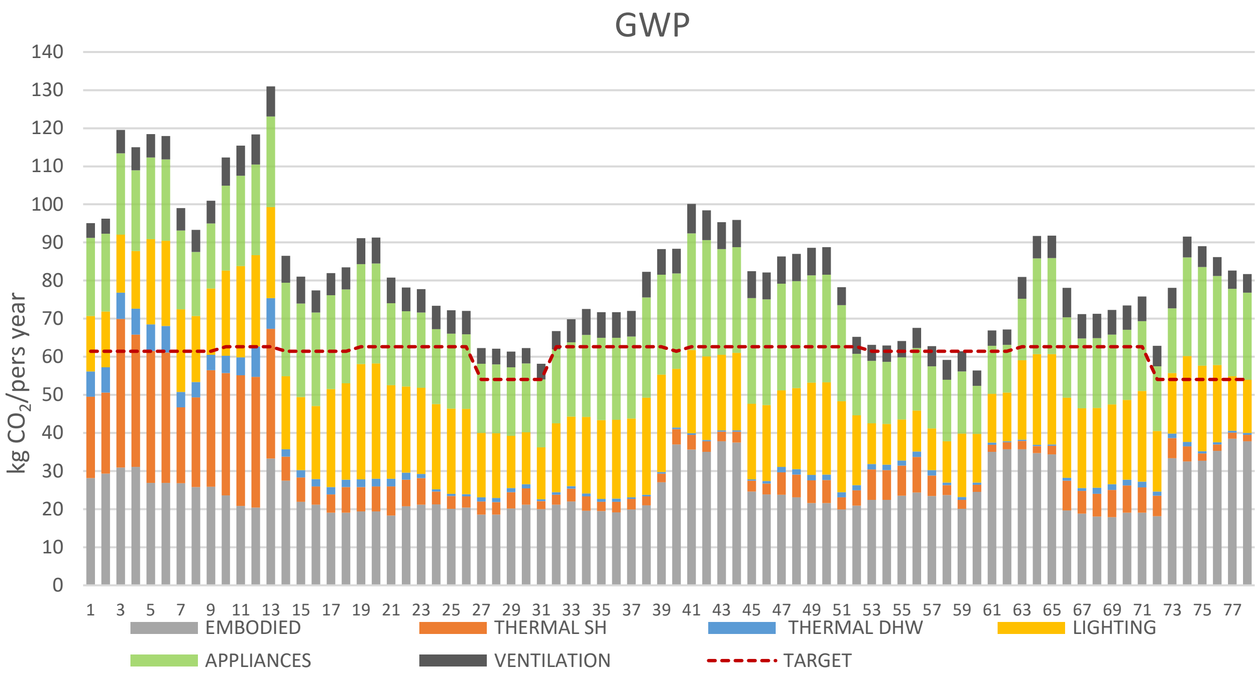

Figure A 3: GWP Index for the 78 simulations of SA I

9.4. Morris analysis results (SA I)

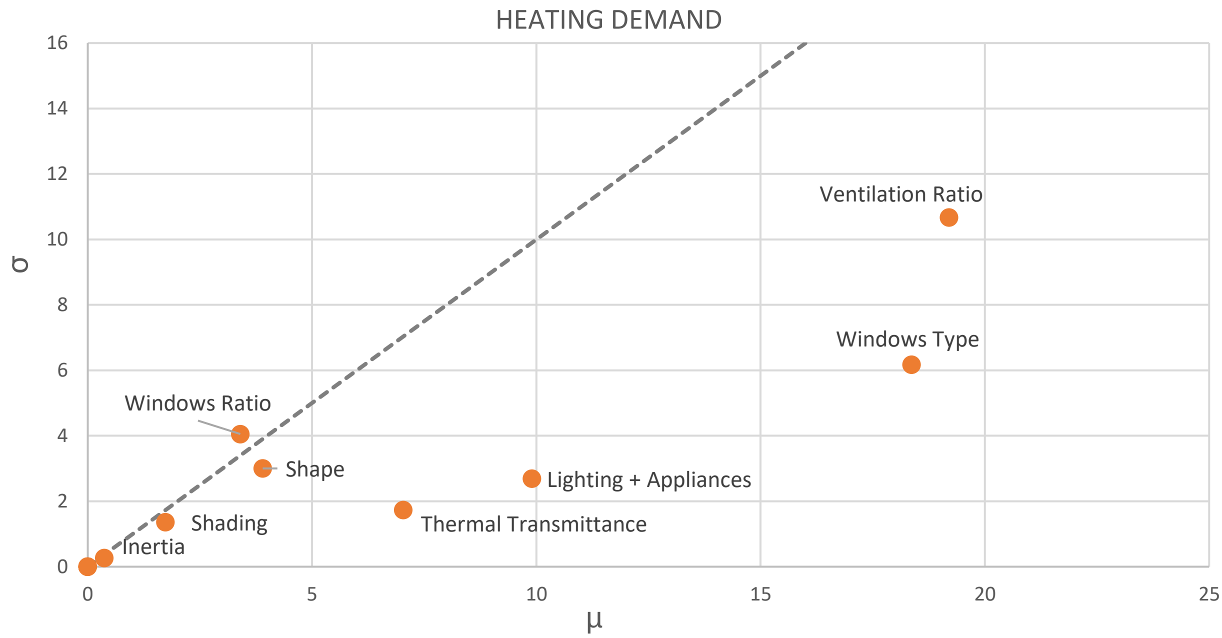

Figure A 4: Results of the Morris analysis regarding HEATING DEMAND output

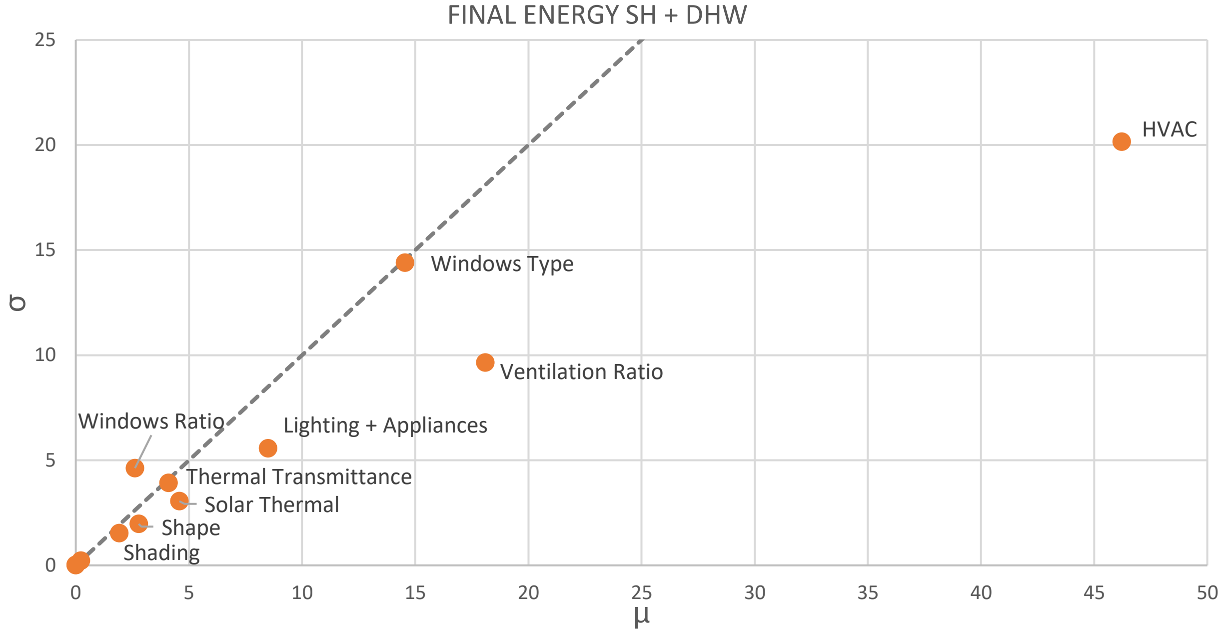

Figure A 5: Results of the Morris analysis regarding FINAL THERMAL ENERGY output

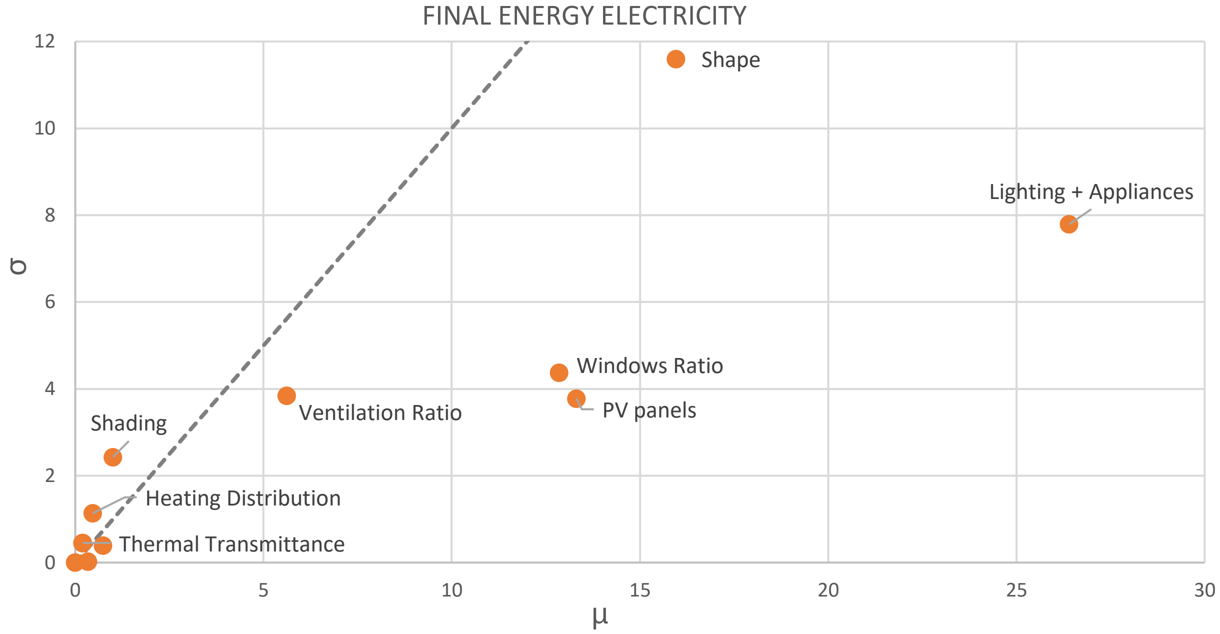

Figure A 6: Results of the Morris analysis regarding FINAL ELECTRICAL ENERGY output

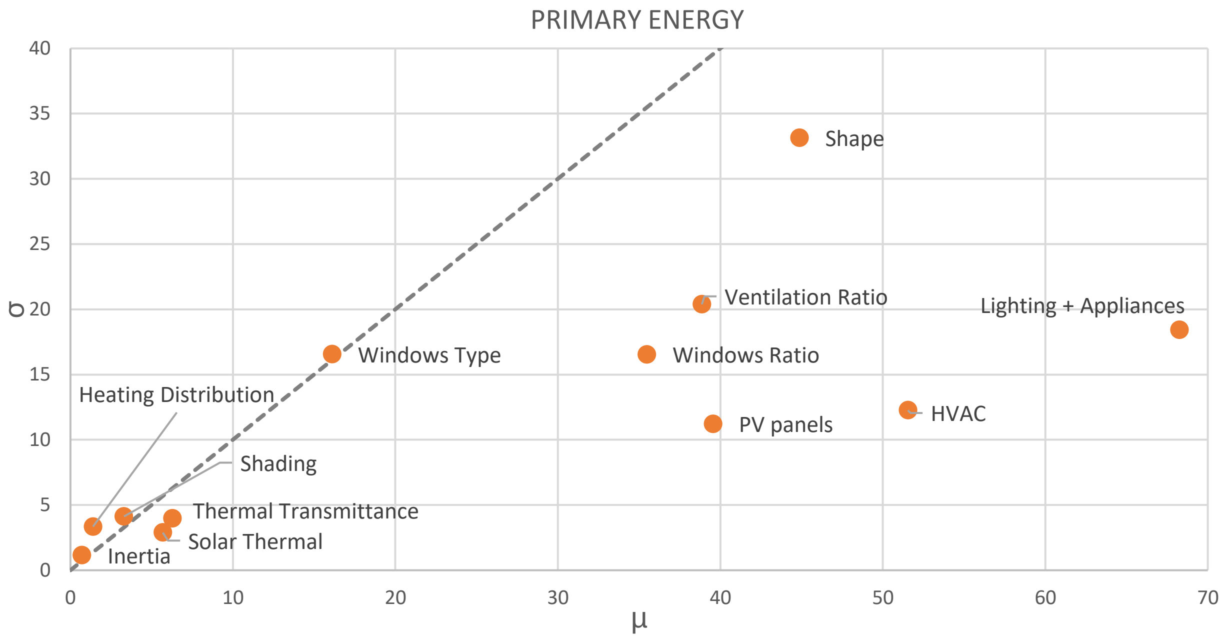

Figure A 7: Results of the Morris analysis regarding PRIMARY ENERGY output

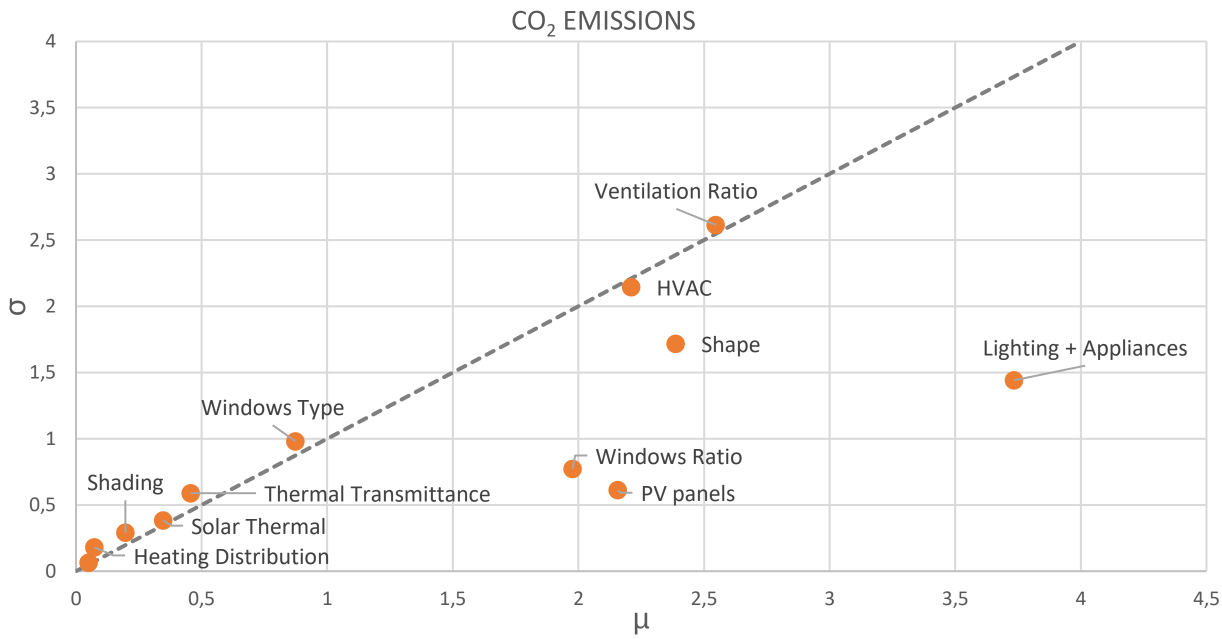

Figure A 8: Results of the Morris analysis regarding CO_2 EMISSIONS output

10. Annex 2: Sensitivity Analysis II

10.1. List of parameters (SA II)

Shape: again, three shapes are used in order to ascertain whether, with an improvement in the efficiency of all the systems, it is possible to decrease or totally delete the scale effect.

- Shape 1
- Shape 2
- Shape 3

South Windows-PV: different combinations of percentages between windows and PV panels on the façade.

- 100% windows – 0% PV
- 75% windows – 25% PV
- 50% windows – 50% PV

West/East Windows-PV: different combinations of percentages between windows and PV panels on the façade.

- 100% windows – 0% PV
- 75% windows – 25% PV
- 50% windows – 50% PV
- 25% windows – 75% PV

North Windows: different percentages of windows on the façade.

- 80% windows
- 60% windows
- 40% windows
- 20% windows

Window type: two different window qualities, with the frame as the independent variable, in order to understand the real benefit of better insulation.

- Double glazing - U value: 1.1; Lt: 0.8; g: 0.62
- Triple glazing - U value: 0.7; Lt: 0.72; g: 0.5

Frame quality: independent input used to investigate the different relationships between the % of the frame and its thermal properties.

- Metal (U: 1.34 W/m^2K)
- PVC-XL (U: 1 W/m^2K)
- Wood + PUR (U: 0.73 W/m^2K)

Frame quantity: different percentages of frame area in proportion with the glazing part.

- 5%
- 10%
- 15%
- 20%
- 25%

PV Roof: different percentages of PV panels on the roof, always with the same inclination (35°) and orientation (south).

- 25%
- 50%

- 75%
- 100%

Heating system: four different systems, all with the same efficiency, but with a different CO_2 content of the useful heat delivered to the users. This parameter is used to investigate the maximum quantity of kg CO_2/MJ allowed in order to meet the targets.

- 100% efficiency and 0.005 kg CO_2/MJ
- 100% efficiency and 0.01 kg CO_2/MJ
- 100% efficiency and 0.02 kg CO_2/MJ
- 100% efficiency and 0.05 kg CO_2/MJ

Natural ventilation: this parameter simulates different conditions of ventilation, ranging from using only mechanical ventilation to using only natural ventilation. The ventilation ratio is always the same, as given by SIA.

- As SIA 382/1, but with 0% of natural ventilation (only mechanical)
- As SIA 382/1, but with 30% of natural ventilation (and 70% mechanical)
- As SIA 382/1, but with 60% of natural ventilation (and 40% mechanical)
- As SIA 382/1, but with 100% of natural ventilation

Lighting time: this represents the variation of the time for which the lights are switched on. The same level of W/m^2 is used, but always with a different timing (and therefore a different energy consumption).

- Lighting as SIA 380/4 target, with SIA schedule
- Lighting as SIA 380/4 target, with 80% of SIA schedule
- Lighting as SIA 380/4 target, with 65% of SIA schedule
- Lighting as SIA 380/4 target, with 50% of SIA schedule

Lighting surface: some "light spots" are created, to change the surface of the rooms that must be illuminated in each simulation. The different surfaces are always lit under the same conditions (given by SIA).

- Lighting 25% of the surface according to the SIA standard
- Lighting 50% of the surface according to the SIA standard
- Lighting 75% of the surface according to the SIA standard
- Lighting 100% of the surface according to the SIA standard

Appliances: here, the power defined by SIA 380/4 is reduced to find the maximum amount of energy that can be used to meet the objectives.

- Appliances as SIA 380/4
- Appliances as 80% of SIA 380/4
- Appliances as 60% of SIA 380/4
- Appliances as 40% of SIA 380/4

Parking: number of parking spaces available for users, which represent an increase of embodied energy for the concrete and a decrease of operative energy used for mobility.

- No parking
- 0.5 each employee + 1 each household
- 1 each employee + 2 each household

Table A 2: Summary of the parameters used in SA II

PARAMETER	INPUT			
SHAPE	1	2	3	-
WINDOW - PV SOUTH	100% windows 0% PV	75% windows 25% PV	50% windows 50% PV	-
WINDOW - PV EAST/WEST	100% windows 0% PV	75% windows 25% PV	50% windows 50% PV	25% windows 75% PV
WINDOWS - NORTH	80% windows	60% windows	40% windows	20% windows
WINDOW TYPE	Double glazing	Triple glazing	-	-
FRAME QUANTITY	5%	10%	15%	20%
FRAME QUALITY	Metal	PVC-XL	Wood	-
PV - ROOF	25%	50%	75%	100%
HEATING SYSTEM	0.005	0.01	0.02	0.05
NATURAL VENTILATION	0%	30%	60%	100%
LIGHTING TIMING	SIA schedule	80% SIA schedule	65% SIA schedule	50% SIA schedule
LIGHTING DEAD ZONE	25% surface	50% surface	75% surface	100% surface
APPLIANCES	SIA 380/4	80% SIA 380/4	60% SIA 380/4	40% SIA 380/4
PARKING	0 per employee	0.5 per employee	1 per employee	-

10.2. Simulation matrix (SA II)

No.	Shape	Appliances	Light Surface	Lighting Time	Natural Ventilation	PV - roof	Frame Quality	Frame Quantity	Window Type	North Window	East/West Window	South Window	Heating System	Parking
1	3	40	50	80	100	50	1	25	2	80	50	50	0.05	1
2	3	80	50	80	100	50	1	25	2	80	50	50	0.05	1
3	3	80	50	80	100	50	1	25	2	80	50	50	0.05	0
4	3	80	50	80	100	50	1	25	1	80	50	50	0.05	0
5	3	80	50	80	100	50	1	25	1	80	100	50	0.05	0
6	3	80	50	80	100	50	2	25	1	80	100	50	0.05	0
7	3	80	50	50	100	50	2	25	1	80	100	50	0.05	0
8	3	80	50	50	100	100	2	25	1	80	100	50	0.05	0
9	3	80	50	50	100	100	2	25	1	80	100	50	0.01	0
10	3	80	50	50	100	100	2	25	1	40	100	50	0.01	0
11	3	80	50	50	30	100	2	25	1	40	100	50	0.01	0
12	1	80	50	50	30	100	2	25	1	40	100	50	0.01	0
13	1	80	100	50	30	100	2	25	1	40	100	50	0.01	0
14	1	80	100	50	30	100	2	25	1	40	100	100	0.01	0
15	1	80	100	50	30	100	2	15	1	40	100	100	0.01	0
16	1	80	50	80	100	25	2	20	1	60	75	50	0.01	0
17	1	80	50	80	100	25	2	20	1	20	75	50	0.01	0
18	1	80	50	80	100	75	2	20	1	20	75	50	0.01	0
19	1	80	50	80	100	75	3	20	1	20	75	50	0.01	0
20	1	80	50	80	100	75	3	20	1	20	75	100	0.01	0
21	1	80	50	80	100	75	3	20	2	20	75	100	0.01	0
22	1	80	100	80	100	75	3	20	2	20	75	100	0.01	0
23	1	80	100	80	100	75	3	20	2	20	25	100	0.01	0
24	1	40	100	80	100	75	3	20	2	20	25	100	0.01	0
25	1	40	100	80	100	75	3	10	2	20	25	100	0.01	0
26	1	40	100	80	30	75	3	10	2	20	25	100	0.01	0
27	1	40	100	80	30	75	3	10	2	20	25	100	0.01	1
28	2	40	100	80	30	75	3	10	2	20	25	100	0.01	1

No.	Shape	Appliances	Light Surface	Lighting Time	Natural Ventilation	PV - roof	Frame Quality	Frame Quantity	Window Type	North Window	East/West Window	South Window	Heating System	Parking
29	2	40	100	50	30	75	3	10	2	20	25	100	0.01	1
30	2	40	100	50	30	75	3	10	2	20	25	100	0.05	1
31	3	80	75	50	30	75	2	15	1	60	25	75	0.01	0.5
32	3	80	25	50	30	75	2	15	1	60	25	75	0.01	0.5
33	3	80	25	80	30	75	2	15	1	60	25	75	0.01	0.5
34	3	80	25	80	30	75	2	15	1	60	25	75	0.01	1
35	3	80	25	80	30	75	2	15	1	20	25	75	0.01	1
36	3	80	25	80	30	75	2	15	2	20	25	75	0.01	1
37	3	80	25	80	30	75	1	15	2	20	25	75	0.01	1
38	3	80	25	80	30	75	1	25	2	20	25	75	0.01	1
39	3	80	25	80	100	75	1	25	2	20	25	75	0.01	1
40	2	80	25	80	100	75	1	25	2	20	25	75	0.01	1
41	2	40	25	80	100	75	1	25	2	20	25	75	0.01	1
42	2	40	25	80	100	75	1	25	2	20	25	75	0.05	1
43	2	40	25	80	100	25	1	25	2	20	25	75	0.05	1
44	2	40	25	80	100	25	1	25	2	20	75	75	0.05	1
45	2	40	25	80	100	25	1	25	2	20	75	100	0.05	1
46	2	40	100	65	100	50	2	20	1	20	75	75	0.005	0
47	2	40	100	65	100	100	2	20	1	20	75	75	0.005	0
48	2	40	100	65	100	100	2	20	1	20	75	75	0.005	0.5
49	2	80	100	65	100	100	2	20	1	20	75	75	0.005	0.5
50	2	80	100	65	30	100	2	20	1	20	75	75	0.005	0.5
51	2	80	100	65	30	100	2	20	1	20	75	100	0.005	0.5
52	2	80	100	65	30	100	2	20	1	20	75	100	0.02	0.5
53	2	80	100	65	30	100	2	20	1	20	25	100	0.02	0.5
54	3	80	100	65	30	100	2	20	1	20	25	100	0.02	0.5
55	3	80	100	100	30	100	2	20	1	20	25	100	0.02	0.5
56	3	80	100	100	30	100	2	20	2	20	25	100	0.02	0.5

No.	Shape	Appliances	Light Surface	Lighting Time	Natural Ventilation	PV - roof	Frame Quality	Frame Quantity	Window Type	North Window	East/West Window	South Window	Heating System	Parking
57	3	80	100	100	30	100	1	20	2	20	25	100	0.02	0.5
58	3	80	50	100	30	100	1	20	2	20	25	100	0.02	0.5
59	3	80	50	100	30	100	1	10	2	20	25	100	0.02	0.5
60	3	80	50	100	30	100	1	10	2	60	25	100	0.02	0.5
61	2	100	100	100	60	75	1	20	2	60	75	100	0.02	1
62	2	100	100	100	60	25	1	20	2	60	75	100	0.02	1
63	2	100	100	100	60	25	1	20	1	60	75	100	0.02	1
64	2	100	100	100	60	25	1	20	1	20	75	100	0.02	1
65	2	100	100	100	60	25	1	20	1	20	25	100	0.02	1
66	2	60	100	100	60	25	1	20	1	20	25	100	0.02	1
67	2	60	100	100	60	25	1	10	1	20	25	100	0.02	1
68	2	60	100	100	60	25	1	10	1	20	25	100	0.005	1
69	2	60	50	100	60	25	1	10	1	20	25	100	0.005	1
70	1	60	50	100	60	25	1	10	1	20	25	100	0.005	1
71	1	60	50	100	0	25	1	10	1	20	25	100	0.005	1
72	1	60	50	100	0	25	1	10	1	20	25	100	0.005	0
73	1	60	50	100	0	25	3	10	1	20	25	100	0.005	0
74	1	60	50	65	0	25	3	10	1	20	25	100	0.005	0
75	1	60	50	65	0	25	3	10	1	20	25	50	0.005	0
76	1	40	100	65	60	25	3	15	2	60	75	100	0.05	0
77	1	40	100	65	60	25	3	15	2	60	25	100	0.05	0
78	1	40	100	65	60	25	3	15	2	60	25	50	0.05	0
79	1	40	100	65	60	25	3	15	1	60	25	50	0.05	0
80	1	40	100	65	60	25	3	15	1	20	25	50	0.05	0
81	1	40	100	100	60	25	3	15	1	20	25	50	0.05	0
82	1	40	100	100	60	25	2	15	1	20	25	50	0.05	0
83	1	40	100	100	60	25	2	5	1	20	25	50	0.05	0
84	1	40	100	100	0	25	2	5	1	20	25	50	0.05	0

No.	Shape	Appliances	Light Surface	Lighting Time	Natural Ventilation	PV - roof	Frame Quality	Frame Quantity	Window Type	North Window	East/West Window	South Window	Heating System	Parking
85	**1**	**40**	**100**	**100**	**0**	**25**	**2**	**5**	**1**	**20**	**25**	**50**	**0.05**	**1**
86	**1**	**40**	**100**	**100**	**0**	**75**	**2**	**5**	**1**	**20**	**25**	**50**	**0.05**	**1**
87	**3**	**40**	**100**	**100**	**0**	**75**	**2**	**5**	**1**	**20**	**25**	**50**	**0.05**	**1**
88	3	80	100	100	0	75	2	5	1	20	25	50	0.05	1
89	**3**	**80**	**100**	**100**	**0**	**75**	**2**	**5**	**1**	**20**	**25**	**50**	**0.01**	**1**
90	**3**	**80**	**50**	**100**	**0**	**75**	**2**	**5**	**1**	**20**	**25**	**50**	**0.01**	**1**

Matrix generated for SA II. Total number of simulations for Morris analysis: $N = r \times (k + 1) = 6 \times (14 + 1) = 90$, where r is the number of trajectories (successions of points starting from a random base vector in which two consecutive elements differ only for one component) and k the number of model input factors.
In red the cases that are reaching the 2000 Watt-society targets for the three main indicators; CED, CEDnr, GWP.

10.3. Simulation results (SA II)

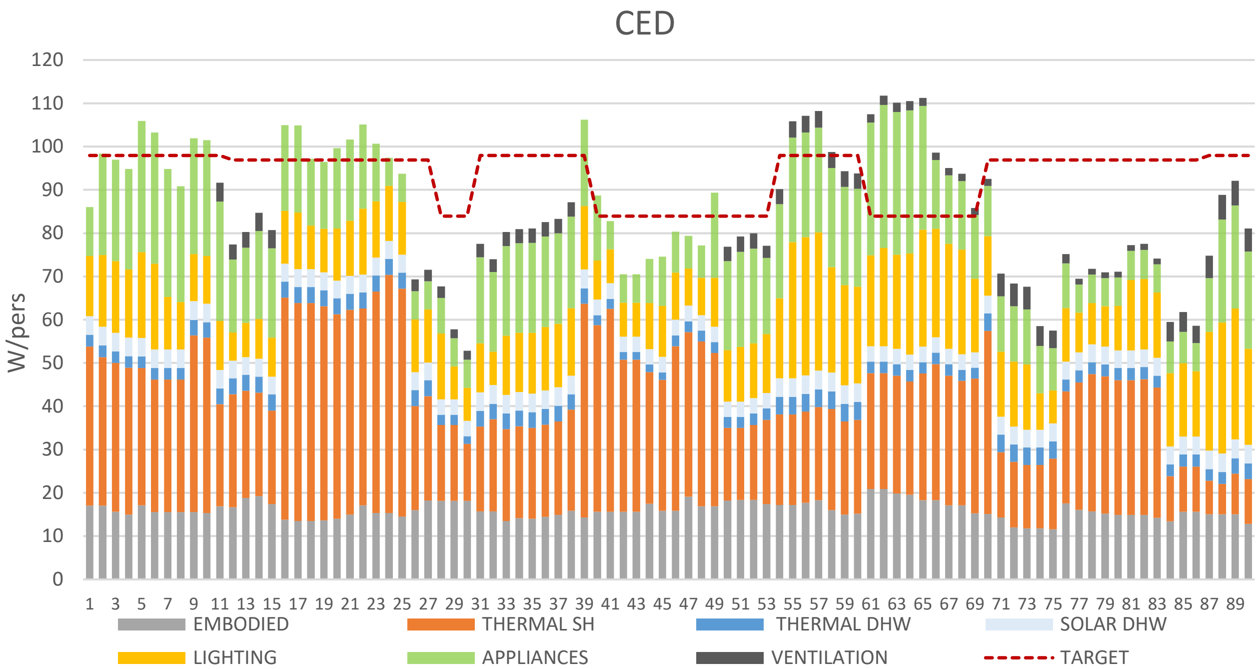

Figure A 9: CED Index for the 90 simulations of SA II

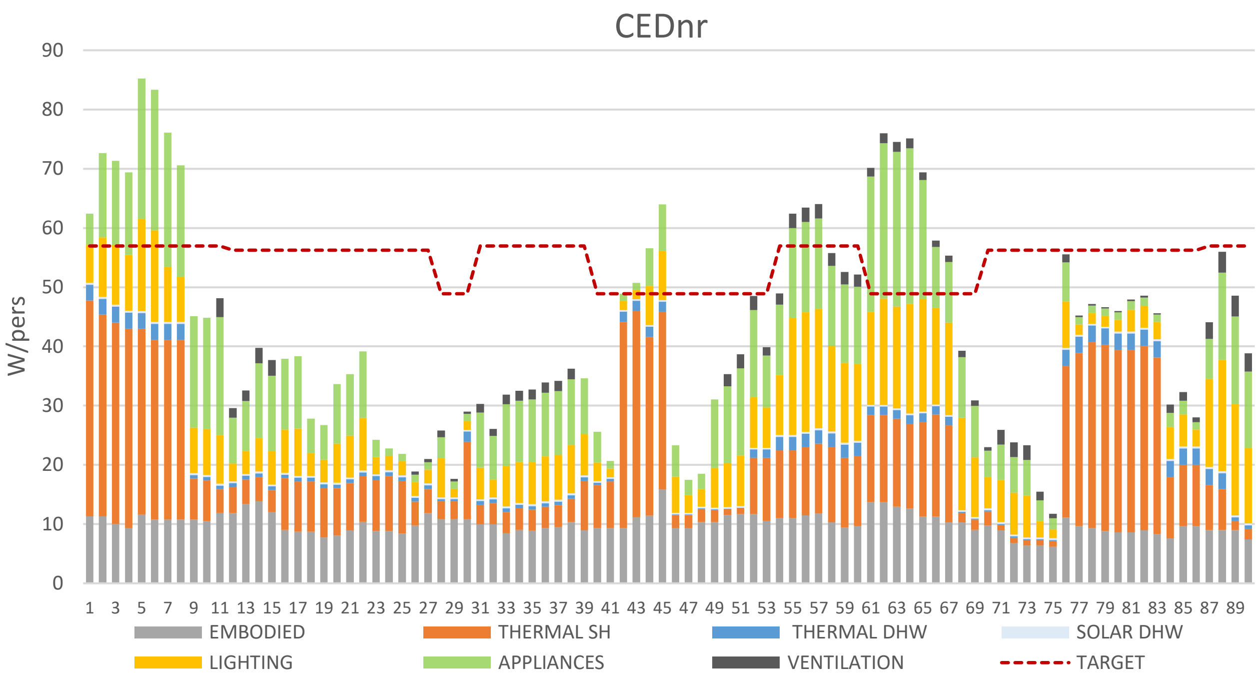

Figure A 10: CEDnr Index for the 90 simulations of SA II

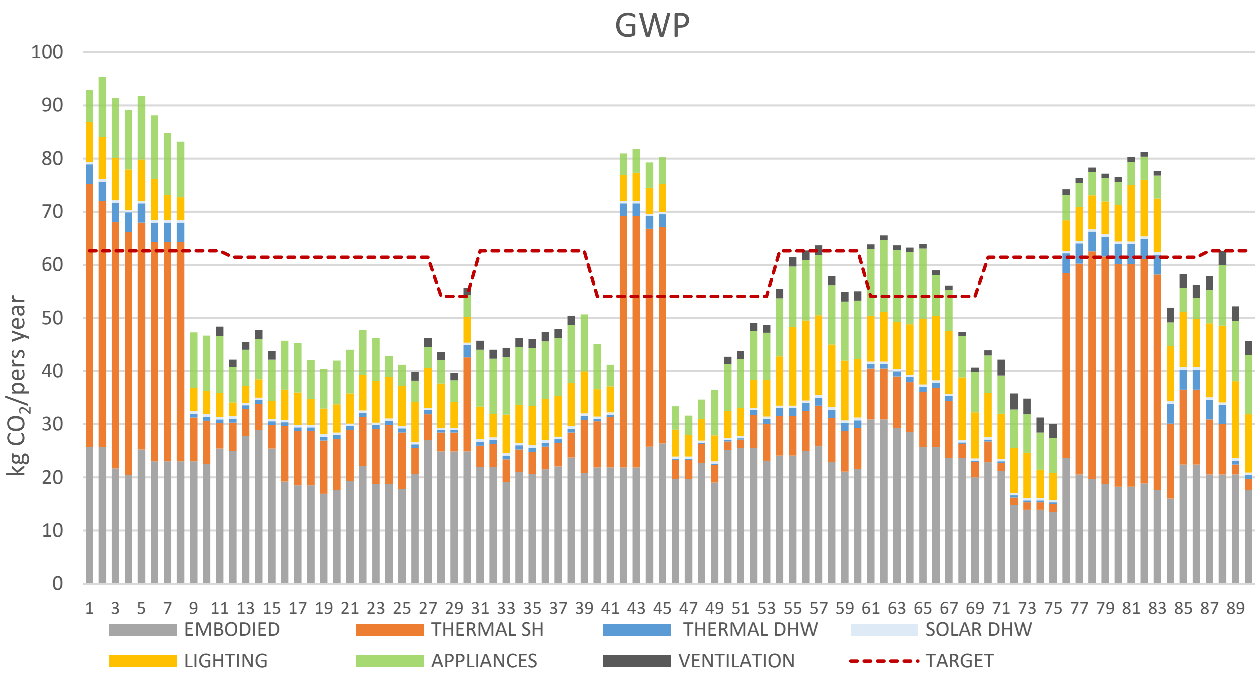

Figure A 11: GWP Index for the 90 simulations of SA II

10.4. Morris analysis results (SA II)

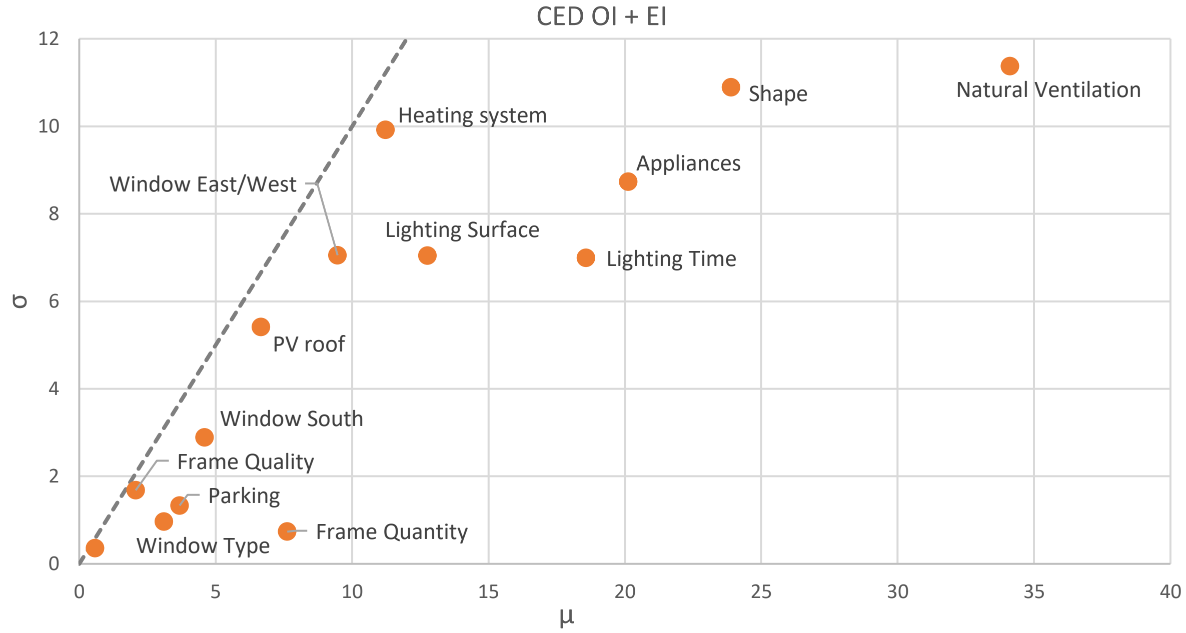

Figure A 12: Results of the Morris analysis regarding the PRIMARY ENERGY INDICATOR (CED), considering both the operative and embodied impacts

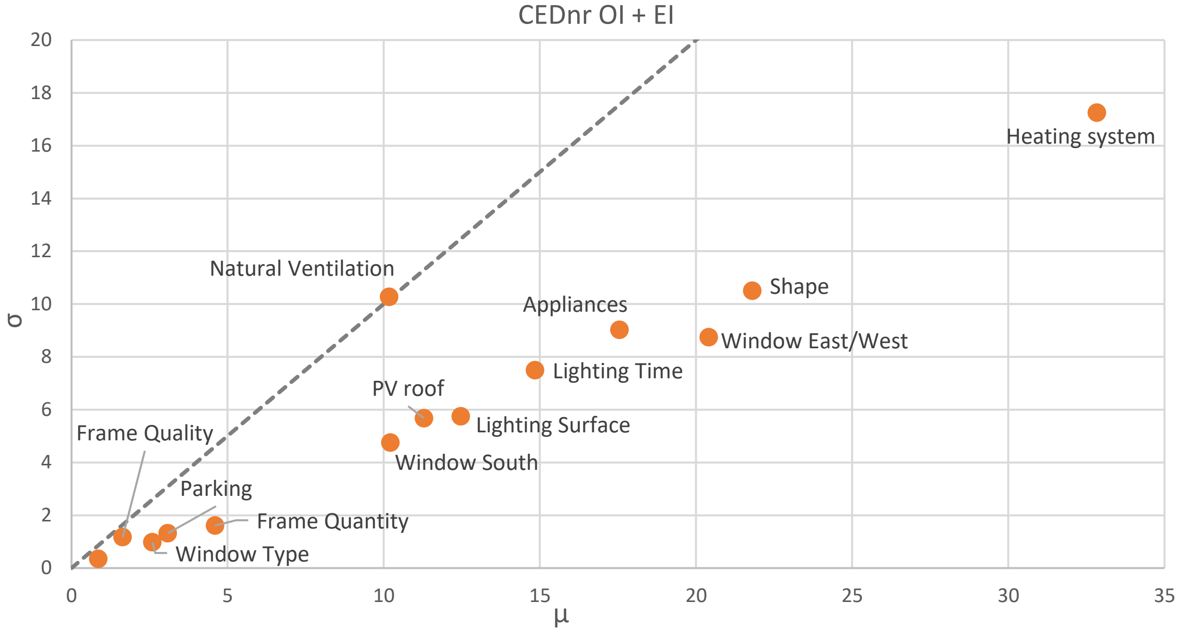

Figure A 13: Results of the Morris analysis regarding the NON-RENEWABLE PRIMARY ENERGY INDICATOR (CEDnr), considering both the operative and embodied impacts

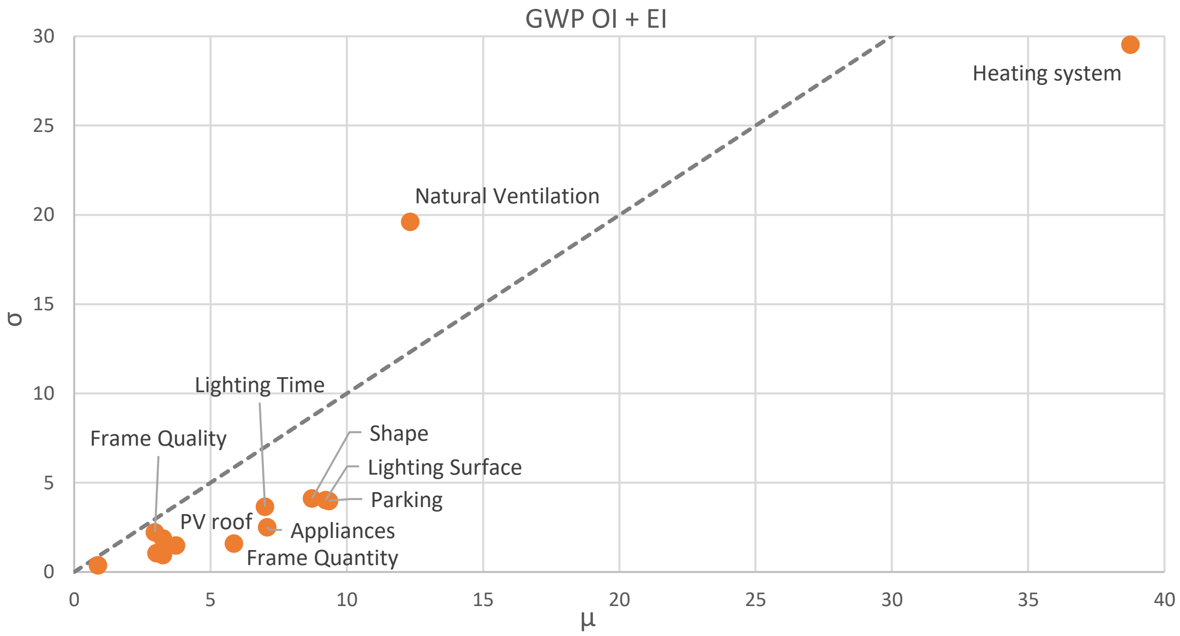

Figure A 14: Results of the Morris analysis regarding the CO_2 EMISSIONS INDICATOR (GWP), considering both the operative and embodied impacts

10.5. The three shapes

Figure A 15: The three different geometrical solutions proposed for the smart living lab

Table A 3: Table of surface areas and occupants considered for each zone within each shape

DESTINATION OF USE	**Shape 1**		**Shape 2**		**Shape 3**	
	Surface [m^2]	People	Surface [m^2]	People	Surface [m^2]	People
Dwellings	957.60	15.96	837.40	13.96	1903.90	31.73
Offices	1529.10	305.82	1290.70	258.14	2179.90	435.98
Meetings	145.10	58.60	155.10	62.64	310.40	125.35
Experimental	775.40	313.14	1074.10	433.77	1306.80	527.75
Others	553.10	0.00	409.20	0.00	941.10	0.00
Non-heated zone	193.50	0.00	233.80	0.00	329.90	0.00
Total heated [m^2]	3960.30		3766.50		6642.10	
Total non-heated [m^2]	4153.80		4000.30		6972.00	
Total equivalent occupants	693.52		768.50		1120.81	

11. Annex 4: Comfort requirement for each functional space

	COMFORT		OPTIMUM	ACCEPTABLE	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/m³ Beyond 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
	acoustics	**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	ACCEPTABLE	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 Beyond 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
	acoustics	**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	ACCEPTABLE	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 Beyond 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
	acoustics	**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	ACCEPTABLE	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 Beyond 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
	acoustics	**Db** [DbA]	30	35		SIA 181, EN 12354
		Di [Db]	-	57		SIA 181
		De [Db]	-	27		SIA 181
		L' [Db]	-	53		SIA 181

	COMFORT		OPTIMUM	ACCEPTABLE	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/m^3 Beyond 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
	acoustics	**Db** [DbA]	30	35		SIA 181, EN 12354
		Di [Db]	-	47		SIA 181
		De [Db]	-	22		SIA 181
		L’ [Db]	-	58		SIA 181

	COMFORT		OPTIMUM	ACCEPTABLE	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 Beyond 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
	acoustics	**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	ACCEPTABLE	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 Beyond 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
	acoustics	**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	ACCEPTABLE	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 Beyond 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
	acoustics	**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	ACCEPTABLE	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/m³ Beyond 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
	acoustics	**Db** [DbA]	40	50		SIA 181, EN 12354
		Di [Db]	-	47		SIA 181
		De [Db]	-	22		SIA 181
		L' [Db]	-	53		SIA 181

12. Annex 5: Contributions to international conferences

12.1. Introduction of a dynamic interpretation of building LCA results: the case of the smart living (lab) building in Fribourg, Switzerland

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(Accepted for the Sustainable Built Environment (SBE) regional conference, Zurich, June 13-17, 2016)

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Abstract
The building sector is one of the largest contributors to climate change. The life cycle assessment (LCA) is a method developed for the calculation of greenhouse gas (GHG) emissions. Although a building lifetime is not predictable, it is an essential data in the yearly impact calculation. Yet, the LCA is currently used as a static method, because it only considers one or a few buildings' lifetime.

The purpose of this study is to introduce a new dynamic interpretation of LCA results, which aims at improving the building assessment robustness.

To that end, two different methods of calculation are compared:
- a static approach that assesses the impacts on the 50th, then 70th and then 100th year of the buildings;
- a dynamic approach that assesses the impact anytime during the first 100 years of building lifetime.

Since the building impacts depends also on the chosen components and their quantity, in this study two scenarios have been applied: one compares two building projects that differ from each other only on the shape; the other compares two projects that differ only on the chosen components.
The smart living lab building has been chosen as a case study. This building aims at reaching the goals of the 2000-watt society vision and will be achieved in 2020 in Fribourg, Switzerland. As the lifetime is a key parameter of the performance, it is particularly interesting to conduct such a study in the frame of a very efficient building. KBOB database and lifetime of components proposed by PI-BAT were used for assessing the GHG emissions.

The dynamic interpretation shows that the results of the static method could vary up to 100% according to the chosen building lifespan and thus, completely change the conclusion of the impact comparison. This becomes more significant when the projects differ on their shape and even more obvious when they are compared on their chosen components. To conclude, a dynamic approach leads to more robust results and should therefore be chosen.

12.2. LCA as key factor for implementation of inertia in a low carbon performance driven design: the case of the smart living building in Fribourg, Switzerland

A. Brambilla[1,a], E. Hoxha[1,a], T. Jusselme[1,a], M. Andersen[1,b], E. Rey[1,c]
(Accepted for the Sustainable Built Environment (SBE) regional conference, Zurich, June 13-17, 2016)

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Abstract
The building sector is known for its major effect on climate change. The method used to calculate the greenhouse gas (GHG) emissions is the life cycle assessment (LCA). LCA considers two major aspects: the operating impacts (OI) occurred during the service life of buildings, and the embodied impacts (EI) occurred during the other lifecycle steps. However, some materials -like the ones that participate to the building thermal inertia- have positive and negative effects on OI and EI. This makes it difficult to understand the role of such materials in low carbon strategies.

The aim of this study is to understand how to weight the overall benefits of using thermal inertia in low carbon strategies.

This balance has been investigated on the smart living lab in Fribourg (CH), which aims at achieving the 2050 goals according to 2000Watt-Society vision. Three different models are used for the assessment with low, medium and high level of inertia, according to the French regulation “RT2012”.
These levels are reached while using materials characterized by different embodied impacts. The difference with the low inertia case, taken as the base case, is evaluated for each model regarding OI and EI. The comparison between the two factors determines whether a material is relevant or not for the LCA approach. To evaluate how the results are influenced by the climate change, the analysis is made twice, with two different scenarios: one with the typical meteorological year (TMY, Meteonorm) and the other with the weather file for 2050 (based on IPCC).

This study shows a method to define if a specific low carbon strategy is reliable regarding the balance between the operating benefits and the embodied impacts. The conclusions of this paper strictly depend to the specificity of the case analyzed, but they indicate that thermal inertia is not always a positive strategy, but must be weighted on an enlarged analysis. The results highlight the necessity of introducing a multi-criteria approach to evaluate the benefits of a low carbon strategy, which includes OI and EI.

12.3. Component-user interaction assessment: a conceptual application to the smart living building case study in Fribourg, Switzerland

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(Accepted for the Sustainable Built Environment (SBE) regional conference, Zurich, June 13-17, 2016)

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Abstract
The expected average life span of buildings is around 100 years (Kornmann, 2009). This forces us to take the future changes of users into consideration at the early stage of design. Indeed building flexibility can be achieved by changing components of the building to maintain or even enhance its usability. As it is impossible to predict all users' needs during the whole lifespan of the building, it is necessary to identify the building components that are impacted by users' behaviour modification and should be easily changeable. However, the interactivities between users and building components have not been clearly studied so far. Only the concept of building physical layers (Brand, 1994) can be used, but its reliability is still open to question.

The aim of this study is to propose a ranking system to assess the interactive levels between building components and users, and to compare it with the building physical layer concept.

The study introduced the egocentric concept (Pederson, Janlert & Surie, 2010) from intelligent computing field to identify the interactions between users and building components. The frequency of these interactions are being recorded. The smart living lab in Fribourg, Switzerland aims at reaching a high usability and has been used as a pilot case study. A small-scale specific population has been observed on site. Firstly, the interactions were scored according to the ranking system. Secondly, some interviews were conducted with the aim to compare the ranking results with the real feelings of users. This comparison further proved the reliability of the building physical layer concept in the frame of the smart living (lab) building design.

The ranking system proposed in this study demonstrated a way to assess the interactivities between users and building components with its tested reliability. This benefits the field of building flexibility by integrating this concept in the design process.

12.4. Towards a pre-design method low carbon architectural strategies

T. Jusselme[1,a], D. Lalanne[2], E. Hoxha[1,a], A. Brambilla[1,a], S. Cozza[1,a], M. Andersen[1,b], E. Rey[1,c]
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Abstract

To face climate change, Switzerland proposes the 2050 energy strategy by fixing greenhouse gas (GHG) emission targets for the built environment. Designers will then have to increase operating performances while minimizing embodied impacts. This represents an issue for the building design process. In addition, there is a relationship between the design efficiency and the early integration of the knowledge about design.

The purpose of this paper is to highlight the potential of a pre-design method to identify the building design parameters that reach the 2050 climate change objectives.

To that end, four major steps are developed in this project. First, design parameters (e.g. wall thermal transmittance) which influence the building GHG emissions the most, are identified thanks to a literature review. Morris method (Saltelli et al, 2004) is used to create combinations of design parameters changing their values one by one. Secondly, these combinations are attributed to architectural feasibility studies (Sinclair, 2013) developed in the brief design phase to perform lifecycle analysis. Thirdly, KBOB database (KBOB et al., 2014) and lifetime of components proposed by PI-BAT were used for assessing GHG emissions. Lesosai software was used for primary energy assessment. Lastly, the combinations of design parameters and their relative GHG emissions are interpreted with data mining and visualization techniques.
The smart living lab building has been chosen as a case study: this building aims at achieving the 2050 goals of the 2000-watt society vision and will be built by 2020 in Fribourg, Switzerland.

Thanks to the preliminary results it is possible to rank the design parameters according to their GHG contribution, in order to highlight them during the early building design stage. The method offers combinations of design parameters allowing to reach the 2050 climate change objectives. Data mining and visualization enable designers to easily find the values of these parameters to fit into the architectural strategy. In order to offer a wider range of design parameter values, techniques to enhance the database should be further investigated.

smart living lab

12.5. Impact target as guidelines towards low carbon buildings: preliminary concept

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Abstract
Buildings are responsible for approximately 40% of annual energy consumption and 30% of global greenhouse gas (GHG) emissions. Therefore, the minimization of a building's environmental impact is an urgent necessity. This minimization requests a well-coordinated improvement of environmental impacts of the whole components and systems of a building, which makes the design process complex. The targets leading to low-carbon buildings have the potential to simplify this complexity by separately analysing the environmental impacts of components and systems.

The purpose of this study is the definition of GHG emissions impact targets on building components and systems.

The definition of impact targets for buildings can be viewed as a two-step process combining the top-down and bottom-up approaches. In the first step, the desired global level of impact targets for buildings is defined by a top-down decomposition of the so-called 2050 objectives: these objectives are inspired by the "2000-watt society vision", promoted by the Board of the Swiss Federal Institute of Technology (Jochem et al, 2004). In the second step, the targets for components and systems are defined by a bottom-up decomposition of the buildings GHG emissions. The target values depend on the carbon weight of components and systems, which could be directly influenced by the building performance itself. In order to ensure the robustness of the target calculation, three groups of projects with different performance levels were therefore generated with the Morris' method (Iooss et al, 2014): 78 projects presenting today's impacts, 90 presenting intermediate impacts and 42 presenting 2050 impacts. Morris' method allows to create projects by changing one by one the design parameters influencing the GHG emissions of the smart living lab building. This building aims to achieve the intermediate 2050 goals of the 2000-watt society vision and is expected to be built in 2020 in Fribourg, Switzerland. Three sets of targets were then calculated based on these three groups by a simple linear regression of GHG impacts to reach the 2050 objectives. To validate the targets' robustness, the Student's t-test (Montgomery, 2010) is used to determine that the results of the sets of values are not significantly different.

Finally, we successfully demonstrated the possibility to set up robust impact targets on the components and systems for building GHG emissions. Impact targets can be used as guidelines for buildings to reduce time consumption in the design process and the minimization of iterations. However, further work is needed to better investigate the robustness of target values by increasing the number database projects.

12.6. Studying the dynamic relationship between energy supply carbon content and building energy demand

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(Proposed for the Passive and Low Energy Architecture (PLEA) conference, Los Angeles, July 11-13, 2016)

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Abstract

Electricity production is achieved by different processes (e.g. nuclear plants, fossil fuels sources, renewables, etc.) with different environmental impacts and capacities of production. To provide the necessary amount of electric energy demand, different sources of different quality are combined together and as a result, the carbon content of the electricity mix varies with time over the day and over the year. Likewise, the usage intensity and the design of a building induce variation of the energy demand at the same time. On the other hand, Switzerland proposes the 2050 energy strategy by fixing new policies to face climate change and decrease the greenhouse gas (GHG) emissions.

Therefore, the purpose of this study is to point out the potential of a more dynamic relationship between low carbon content energy supply and building energy demand.

To that end, three major steps are necessary and will be presented in this paper. The case study chosen to apply the proposed method is the building of the smart living lab, currently being designed and expected to be built by 2020 in Fribourg Switzerland, as it explicitly aims to achieve the intermediate 2050 goals of the 2000-watt society vision. Firstly, the hourly carbon content of the on-site available energies are evaluated. The Swiss electrical grid is assessed based on the accessible statistical data from the energy producers in Switzerland. The amount of renewable energy harvested by building integrated photovoltaics (BIPV) and its related environmental impact are evaluated with the solar tool PVGIS and the KBOB database. Secondly, the hourly energy demand is assessed thanks to dynamic simulation and to expected dweller usage of the building. Thirdly, the GHG emissions are assessed with the carbon hourly content of the energy supply that is used. The dynamic result is compared to a static approach that would use a yearly average carbon content of the energy supply. Also, the dynamic relationship between low carbon energy supply and building energy demand is analysed.

The results of this study point out significant differences between a yearly static and an hourly dynamic GHG emissions assessment. Moreover, the important variation of the carbon content energy supply and of the energy demand demonstrate that a better correlation between these two is a powerful element to increase the performance of a building. In future studies, strategies such as electricity storage, BIPV orientation and tilt, and dweller usage variation should be further investigated.