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

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Abstract

The building sector is known as a major contributor to greenhouse gas (GHG) emissions and energy consumption. These impacts are commonly evaluated by life cycle assessment (LCA), which assess the potential impacts of a building from the construction to the end of life. LCA considers: the operating impacts (OI) occurring during the service life of buildings, and the embodied impacts (EI) occurring during the other lifecycle. Materials usually increase EI, but some of them, such the ones used for thermal inertia (TI), concur to energy efficiency and can reduce OI. This makes it difficult to understand the role of such materials in low carbon building strategies. The aim of this study is to understand how to weigh the overall environmental benefits of TI.

Four building models were used to assess LCA with either low, medium, high or very high levels of TI. These are reached using materials characterized by different embodied impacts, such as concrete and earth. The difference with the low inertia case, taken as the base case, is evaluated for each model regarding OI and EI. The comparison between OI and EI determines which scenario brings the lowest impacts on LCA. To evaluate how the results are influenced by climate change, the analysis is made with two different scenarios: one with the typical meteorological year (TMY, Meteonorm) and the other with the weather conditions for 2050 (IPCC, International Panel on Climate Change).

The paper shows a methodology to evaluate the effects of a design strategy on the LCA, applied to the case of TI. It demonstrates that TI is not very relevant in the frame of this case study because the EI related to the added materials is higher than the induced operating savings. Furthermore, it has been demonstrate that in the future when the carbon content of the energy may be lower, TI can change its effects and influence negatively the lifecycle environmental impacts.

Keywords:
building thermal inertia; LCA; environmental performances; sustainability; natural-based materials

1 INTRODUCTION

The last decade witnessed an increasing awareness about environmental sustainability. Global warming and resource scarcity are amongst the biggest challenges to face nowadays, especially in the construction sector which is responsible for 40% of the total energy consumption in the European Union [1]. The main cause of energy use in buildings is heating, though the production phase of buildings materials and components can significantly participate to the total energy consumption and environmental impacts [2]. Life cycle assessment (LCA) evaluates the impacts produced in the exploitation period of the building, called operative impacts (OI), and the ones involved in the materials production, transportation, manufacturing, building's construction and demolition phase (EI) [3]. The LCA has been applied to buildings materials and components in several applications [2, 4]. High efficient buildings have low energy consumption and, therefore, their associated OI are lower. In contrast, usually added materials, such as insulation, are used to improve the energy efficiency and, consequently, the EI increase. Even if the EI are becoming relevant on the buildings life cycle perspective, façades and materials choice usually aim to reduce the buildings impacts on the environment during the exploitation period. A first step towards reducing the effects of buildings on the environment should be the introduction of an integrated design approach which includes OI as well as EI. Despite this fact, there are only a few studies aiming to the optimization of buildings envelope considering both environmental and energy performances [5].

In this paper we propose a multi-criteria approach for the envelope's design, considering the effects on both embodied and operative phases of the building's whole lifecycle.

The effects of a given design solution must be balanced between EI and OI. Some strategies used to decrease one of these two contributions, could have negative effects on the other, reducing or nullifying the benefits on LCA. An example is the thermal inertia (TI), which could have positive effects on operating impacts [7], but could also have heavy impacts on the embodied part. In fact, it is usually achieved thanks to massive materials, such as concrete-based materials or bricks. However, it is proven that traditional concrete buildings have higher EI tha~~e~~n ones with other construction technique [8]. Therefore, it is important to understand the potential of thermal inertia on LCA, considering both the savings regarding OI and the EI induced by the materials used to provide thermal mass.

2 METHODOLOGY

This paper aims to apply a methodology to evaluate the effects on LCA of TI employment as strategy to reduce heating consumption. Both operative and construction phase are taken in account: the reduction of OI due to a higher thermal inertial behaviour is compared to the increment of EI induced by the materials used to implement mass in the envelope. This methodology implies the comparison of different scenarios for a building, each one with a different influence on operative or embodied results. F Two groups of materials with different EI impacts are used: traditional (concrete and bricks) and natural (earthen materials). To vary the effects on OI, four levels of TI of the building are introduced according to the French thermal regulation [13]: *light*, *medium*, *heavy* and *very heavy*.

The analysis is made within the framework of the smart living building research programme. It aims to understand how it is possible to achieve in 2020, the 2050 goals according to the 2000 watt-society [9]. The smart living building will be designed and constructed in Fribourg, Switzerland, according to these principles and will be an innovative low-carbon building [10].

2.1 Case study

The smart living building will host:

- Services and experimental facilities on the ground floor
- Offices, on the 2nd, 3rd floors
- Housing, on the 4th and 5th floors

The case study is representative of a double office room, situated in the middle of the 3rd floor, orientated to south-east (Fig. 1). The dimensions and the internal loads are designed accordingly to the Swiss regulation [11]. Heat recovery is not used. The heating system adopted is an electrical heat pump, with a COP of 3.8 in all scenarios. Cooling loads and summer thermal comfort are considered not to be an issue. Therefore the attention is focused only on the heating part and the benefits of TI on energy consumption.

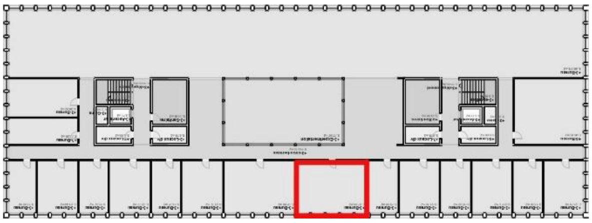

Fig. 1: Smart living building, office floor. In red the room considered: 6x6m.

2.2 Thermal inertia

TI in buildings help to lowering temperature peaks and store heat from solar radiation and internal loads, decreasing energy requirements [7, 12]. It is strictly dependent to the thermal mass of the components, which is function of materials properties, such as heat capacity, density and conductivity. TI effectiveness derives from the interactions among different parameters, both related to the mass of the building's components and building's design features, as climatic conditions, windows area, insulation, ventilation, internal loads, occupancy and active systems [5]. Due to these correlations, several way to consider and estimate inertial behaviour in constructions are recognized and used in different studies and standardisations [12]. In this paper the French thermal regulation is used as reference [13] because it allows to consider transitorily phenomena. In fact, the heat capacity of materials is weighted on their mass and surface of application. In this analysis four different levels are considered: *light*, *average*, *heavy* and *very heavy*. Assuming that in each scenarios the TI level is the only variable, heating demand is expected to decrease with higher TI levels and the consequent effect is a reduction of the OI. To affect also the EI, these levels are reached through two different group of materials: traditional (cement matrix or bricks) and natural (earth). The composition of walls, ceilings and floors changes in each scenarios, in order to achieve the TI levels desired with reliable components. It is necessary to change all of them to have a variation on the final inertial level, since the mass is weighted on the overall surface of exposure. Each scenario is composed by different components, which are design varying only the layers that really affect the inertial behaviour. The principal layer of the components are described in the following table.

name	LAYERS	THICKNESS [cm]	DENSITY [kg/m^3]	CONDUCTIVITY [W/m°K]	CAPACITY [kJ/kg°K]
Horizontal enclosure (floor and ceiling)					
fixed part	cork panel	0.5	175	0.046	1.5
	reinforced concrete	20	2300	2.3	1
	cellulose insulation	10	80	0.048	1.6
tr-h1 traditional light	ceramic tiles	1	1900	1	1
	light cement screed	5	1000	0.3	1
	fixed part				
	plasterboard	1.25	850	0.21	0.79
tr-h2 traditional medium	ceramic tiles	1	1900	1	1
	light cement screed	5	1000	0.3	1
	fixed part				
	mineral plaster	1.5	1200	0.7	2.8
tr-h3 traditional heavy	ceramic tiles	1	1900	1	1
	light cement screed	6	1000	0.3	1
	fixed part				
	mineral plaster	2.5	1200	0.7	2.8
nat-h1 natural light	rammed earth	5	1900	1	1
	fixed part				
	earth plaster low den	2.5	1400	0.59	1
nat-h2 natural medium	rammed earth	5	1900	1	1
	fixed part				
	earth plaster high den	2.5	1800	0.91	1
nat-h3 natural heavy	rammed earth	6	1900	1	1
	fixed part				
	earth plaster high den	3	1800	0.91	1
EXTERNAL WALLS fixed part					
fixed part	cellulose insulation	30	80	0.048	1.6
	wooden panel, type OSB	2.5	1200	0.7	2.8
	cement plaster	0.5	1500	1	1
tr-e1 traditional light	cement plaster	2	1500	1	1
	wooden panel, type OSB	1	1200	0.7	2.8
	fixed part				
tr-e2 traditional medium	mineral plaster	2	1200	0.7	2.8
	wooden panel, type OSB	1	1200	0.7	2.8
	fixed part				
tr-e3 traditional heavy	mineral plaster	2.5	1200	0.7	2.8
	mansory bricks	6	1100	0.44	0.9
	fixed part				
nat-e1 natural light	earth panel low den	2.5	650	0.2	1.3
	fixed part				
nat-e2 natural medium	earth panel high den	2.5	1700	0.8	1
	fixed part				
nat-e3 natural heavy	earth plaster high den	2.5	1700	0.8	1
	compressed earth block	6	1900	1.1	1
	fixed part				
INTERNAL WALLS fixed part					
fixed part	cellulose insulation	30	80	0.048	1.6
	wooden panel, type OSB	0.5	1200	0.7	2.8
	mineral plaster	0.5	1200	0.7	2.8
tr-i1 traditional light	mineral plaster	0.5	1200	0.7	2.8
	plasterboard	2.5	850	0.21	0.79
	fixed part				
tr-i2 traditional medium	cement plaster	1	1500	1	1
	plasterboard	2.5	850	0.21	0.79
	fixed part				
tr-i3 traditional heavy	mineral plaster	1	1200	0.7	2.8
	cement board	1	2400	1.48	1.1
	fixed part				
tr-i4 traditional heavy +	mineral plaster	2.5	1200	0.7	2.8
	masonry bricks	10	1100	0.44	0.9
	fixed part				
nat-i1 natural light	earth panel low den	2.5	650	0.2	1.3
	fixed part				
nat-i2 natural medium	earth plaster high den	2.5	1800	0.91	1
	wooden panel, type OSB	1	1200	0.7	2.8
	fixed part				
nat-i3 natural heavy	earth plaster high den	3.5	1800	0.91	1
	wooden panel, type OSB	1	1200	0.7	2.8
	fixed part				
nat-i4 natural heavy +	earth plaster high den	2.5	1800	0.91	1
	compressed earth block	10	1900	1.1	1
	fixed part				

Tab. 1: Description of the main layers of the components. Layers described from the inner side to the outside.

It is assumed that thermal mass is not affecting any other aspect of the construction except for TI.

The structures, for example, are kept fixed even if heavier components are used in order to achieve higher level of TI.

2.3 Embodied evaluation

Life cycle environmental impacts are evaluated with the KBOB database [14]. The results are expressed for the three main indicators of LCA: global warming potential (GWP), cumulative energy demand (CED) and cumulative non-renewable energy demand (CEDnr). The analysis of 2050 scenarios are made only on climate change (GWP). According to the study [15], three different carbon content for the electrical grid are considered (WWB, NEP and POM). The evaluations include all the life cycle phases, including the saving potential introduced by TI.

2.4 Operative simulations

Buildings have usually a long life span [16]. On the other hand, global warming and climate change are changing the entire environment and ecosystem. Therefore, buildings built today will face tomorrow a different external context. For this reason, their thermal behaviour will be different in future. Thence TI may change its potential as strategy to reduce heating consumption, according to the time of evaluation. Aiming to a life cycle performant building, the potential of TI must be estimated both for the current climate and the future context to assure that the efficiency will not decrease either become a criticism, increasing the overall environmental impacts. Therefore the heating consumption during the operative phase is evaluated both for actual and future climate.

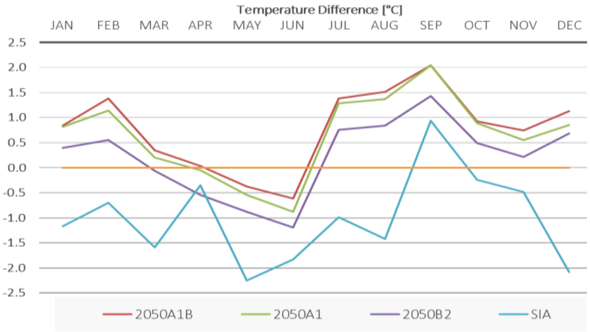

Fig. 2: Temperature variation: 2015 climate file (orange lines) and scenarios of IPCC for 2050

All the weather file are generated by the software METEONORM [17]. The future weather files are created from the different possible scenarios studied by the Intergovernmental Panel on Climate Change (IPCC). Temperature could arise in 30 years up to 2 degrees more. Thus, it is clear that this variation can influence the role of inertia in comfort and energy saving strategies. Dynamic operative impacts are simulated using the software TRNSYS [18].

3 SCENARIOS

The scenarios are identified combining all the parameters described: level of inertia (light, average, heavy and very heavy), type of materials (traditional and earthen), and future scenarios with climatic file (2015, 2050 A2, 2050 B1 and 2050 A1B) and 2050 carbon content projections (WWB, NEP and POM). The table shows the basic scenarios, obtained from the first two parameters.

SCENARIO	*external walls*	*floor*	*internal walls*
1: LIGHT TRAD.	tr-e1	tr-h1	tr-i1
2: MEDIUM TRAD.	tr-e1	tr-h2	tr-i2
3: HEAVY TRAD.	tr-e2	tr-h3	tr-i3
4: HEAVY+ TRAD.	tr-e3	tr-h3	tr-i4
5: LIGHT NAT.	nat-e1	nat-h1	nat-i1
6: MEDIUM NAT.	nat-e1	nat-h2	nat-i2
7: HEAVY NAT.	nat-e2	nat-h3	nat-i3
8: HEAVY+ NAT.	nat-e3	nat-h3	nat-i4

Tab. 2: Table of the scenarios with the different components to achieve the TI level both for natural and traditional materials. The components used are described in Tab. 1

4 CONCLUSIONS

The results are analyzed in comparison with the light level of TI for each group of materials: for earthen scenarios the reference is case 5, for traditional scenarios, it is case 1. The increment percentage of EI of each scenario compared to the base-case is analyzed regarding to the OI related savings, in order to evaluate if a scenario brings benefits on the LCA. The following graphs report the results of the 2015 scenarios on the three main indicators, and 2050 scenarios on GWP. The line represents the cases in which the OI savings are equal to the EI increments. If a point is above the line, it means that operating benefits are bigger than embodied increment for the considered scenario, inducing a total decrement of environmental impacts comparing to the light TI level. At the opposite, if a point is below the line, OI reduction doesn't balance the higher EI of the related scenario. In this case, on LCA the environmental impacts are higher than the base case. From Fig. 3 it is possible to observe that natural materials have always positive effects on LCA, while traditional materials influence negatively GWP for all the thermal inertia scenarios. The very heavy scenarios are the most influent on LCA for both materials groups, but the effects are interesting only on the energy part (CED and CEDnr). For this indicators the operative savings can reach 6% on the total value, in the case of traditional materials, but only 3% for natural ones. It is clear that the very heavy TI level is the most promising. On the other hand GWP is the limiting indicator, nullifying the benefits on CED and CEDnr for traditional materials.

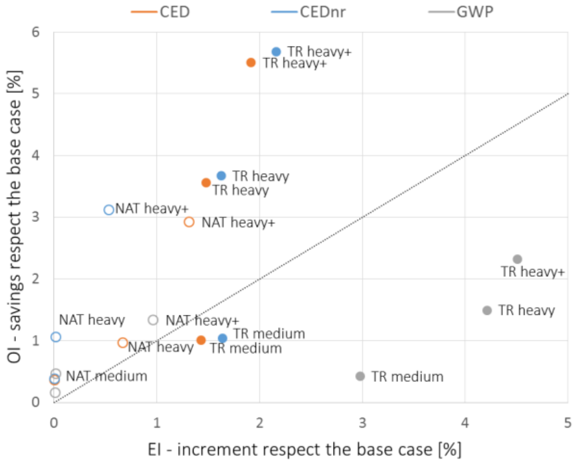

Fig. 3: Results of the analysis for 2015 and the three main LCA indicators (NAT: natural materials, TR: traditional materials)

Therefore we can conclude that thermal inertia is not an interesting strategy to reduce environmental impacts when traditional materials are used. While, if natural materials are implemented, TI have always benefits on LCA, but these improvement are not relevant in the framework of this study.

Fig. 4 and Fig. 5 show the results for 2050. These are expressed only for GWP and very heavy TI level, since that climate change is the most critical indicator and this TI level is the most promising. Fig. 4 is referred to traditional materials and Fig. 5 to natural ones. Based on Fig. 4 and Fig. 5, it is interesting to notice that the electrical carbon content scenarios are more influent than the climate scenarios.

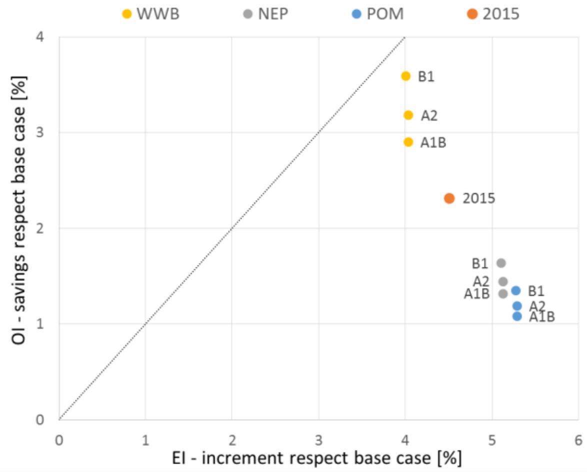

Fig. 4: GWP indicators results for the very heavy TI scenario, with traditional materials. Three scenarios for carbon content of the electrical grid (WWB, NEP and POM) and three scenarios for 2050 climate (A2, B1 and A1B) are considered

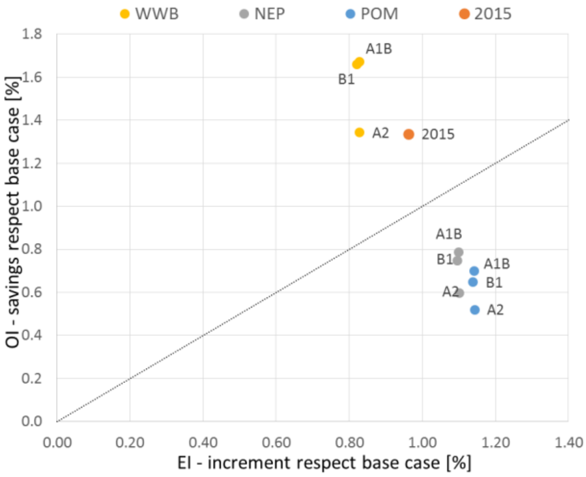

Fig. 5: GWP indicators results for the very heavy TI scenario, with natural materials. Three scenarios for carbon content of the electrical grid (WWB, NEP and POM) and three scenarios for 2050 climate (A2, B1 and A1B) are considered

For traditional materials the higher level of TI correspond always to an overall increase of environmental impacts. Results for natural materials change completely comparing to the 2015 scenario. According to the carbon content scenario that is considered, in fact, the overall impacts can be reduced or increased, in comparison to the light case. Among all the scenarios analyzed for 2015, the very heavy TI level achieved with natural materials was the most promising. Considering lower carbon content of the grid (NEP and POM), instead, TI loses its potential to decrease building's environmental impacts, while the increment of embodied impacts remains the same. Form Fig. 4 and Fig.5 it is clear that to lower CO2 content of the electrical energy correspond lower influence of TI on operating savings. Therefore, it is possible to conclude that TI is not an interesting strategy to reduce environmental impacts in the future. On the contrary, if the energy source is cleaner, then TI can become a criticism for the overall building's impacts.

5 DISCUSSION

This paper analysed the influence of TI on buildings life cycle performances. It underlines the importance of an integrated approach which could consider both OI and EI. The results show that TI is an interesting passive strategy to save energy for heating and to reduce environmental impacts over the whole life cycle only under certain conditions. The relevance of this solution is linked to the materials that is used to implement inertial levels in the construction and to the carbon content of the energy source.

It is important to contextualize the results to the reference case, situated in Switzerland. All the conclusions must be considered in the framework of this study. Moreover all the results obtained are strictly dependant to the assumptions made during the analysis, and the validity is confined inside the defined boundaries.

Although design guidelines in Switzerland suggest to focus on heating, also the assumption of no cooling loads can be limiting in understanding the real effects of TI on buildings. Summer comfort is an issue that should be investigated. TI can varies its potential in buildings application if this issue is taken in account. TI effects are not purely passive but the emission process of the stored heat depends also on building's features and the active systems of indoor environment control. For example, indoor temperature set point has great influence on determining the heat exchange within the internal elements heated and the surrounding.

All these assumptions open the question for deeper studies. Future works will try to understand the role of inertia in relation to buildings features, such as windows to wall ratio, active systems, internal gains and thermal behaviour. It will be important to understand which is the correlation between all these parameters and the inertial behaviour of the construction with a LCA approach.

6 ACKNOWLEDGMENT

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