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Impact Targets as Guidelines towards Low Carbon Buildings: A preliminary concept

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ABSTRACT: Developing building projects with low environmental impacts is a real challenge, yet a problem faced every day by designers. To that end, in the design process, iteration between propositions and objectives have been used that are complex and time consumption. The impact targets leading to low-carbon buildings have the potential to simplify this complexity and saving time in the building design process. This study introduces a methodology for the definition of impact targets for components and systems of buildings. The definition of impact targets has been envisaged as a two-step process combining top-down and bottom-up approaches. The desired impact target of building is defined by a top-down approach and the targets for components and systems by a bottom-up approach. Impact targets for the Swiss context are defined applying the methodology to the smart living building that aim at reaching the 2050 goals of the 2000-watt society vision. Through this approach, we were able to set up impact targets on the components and systems level for global warming potential indicator. Impact targets can be used as guidelines in the design process for developing component or system one by one without analysing the whole building, which is guided toward low carbon objectives.

Keywords: Life cycle assessment (LCA) of building, impact targets

INTRODUCTION

The necessity of minimizing of the environmental impacts of buildings is widely acknowledged (UNEP SBCI, 2009). This minimization requests a well-coordinated improvement of all the environmental impacts related to components and systems of building. In general in the design process, the minimization of the environmental impacts of building has been guide toward optimal objectives by iterative process. During this process the most appropriate combination of components and systems has been found by testing different proposition and solutions. This is both, time- and effort- consuming, due to a large number of variables that combine multidisciplinary analysis in order that building must respond to the needs of accessibility, safety, well-being, durability, energy efficiency, and being environmental friendly by emitting as less greenhouse gases as possible (Peuportier, 2013; Hens, 2010). Existing studies presented in the literature aim the simplification of the building's LCA (Bonnet et al, 2014) or aim to guide the design process towards optimal targets (Rivallain, 2013). The targets translate the objectives that a product or system has to reach. To reduce the time of calculation of the environmental impacts, Bonnet et al. (2014) proposed a simplification in a building's LCA based on the Pareto principle according to which roughly 80% of the effects come from 20% of the causes. They proposed to assess the impacts of 20% of the major causes and the rest to be considered in the form of a ratio. This study present as limit the fact that the results of the simplified LCAs have substantial uncertainty. In the other hand, Rivallain (2013) has proposed a methodology based on genetic algorithms for guiding the design process towards optimal targets in the rehabilitation of existing buildings. This methodology doesn't reduce the time of calculation and is complex. Studies presented in the literature have either tried to reduce the time of calculation or to guide the design process towards optimal targets, but none of them has tried to simplify the building's LCA by reducing the complexity and time consumption of design process.

In other fields, such as mechanics, the simplification of a complex system by guiding the process of development towards optimal targets has been solved by decomposing the system into subsystems and then in components (Kim et al., 2003).

To that end, the global target that the systems have to reach is decomposed in sub-targets. During this process, it is necessary the identification of the possible links that components can share with each other. In the case of strong intersection of components, it should be noticed and considered in the correspondent sub-level. From the design viewpoint, the main benefits of targets are saving time during the system design cycle and avoiding of the design iterations. In addition, decomposing the system into subsystems and components reduces the complexity of the overall design problem, especially when applied to large scale multidisciplinary design problems where it is more beneficial (Liu et al., 2006). The components will be less complex than the system, because the decomposition dissolves the complexity and reduce the connection of disciplines.

Concerning the definition of targets in the field of a building's LCA, only a few works (SIA 2040, 2011; Kellenberger et al., 2014; Frischknecht et al., 2014) have been published. They focus on the definition of the objectives that the buildings will have to reach in the future, but none of them has tried to define targets for components and systems of buildings. Moreover, none of them has treated the definition of the targets as a way to simplify the design process of the building and guiding the project towards demanding objectives. The targets help to save time in the design process by making the calculation more easy and understandable.

In this paper, we introduce a methodology for the definition of impact targets for components and systems of a building. This methodology will be used to define impact targets for global warming potential (GWP) indicator at a component and system scale for buildings that must achieve the 2050 energy strategy objectives in Switzerland.

METHODOLOGY

Being able to define impact targets of a building's components and systems can be viewed as a step-by-step process, combining top-down and bottom-up approach.

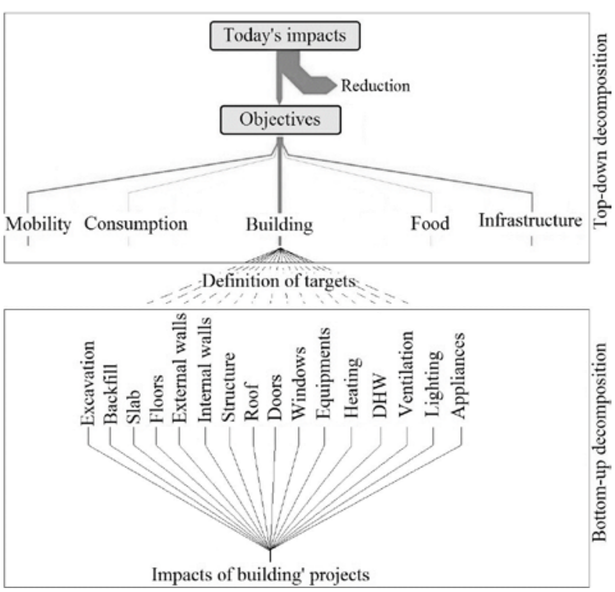

Figure 1: Top-down and bottom-up approach in the definition of impact targets

The aim of a top-down approaches is to cascade the global-level impact targets into sub-levels. The bottom-up approach aims at determining the environmental impacts of the building's components and systems. The impact targets of the building's components and systems are then linearly rebalanced upwards to the targets of a sub-level.

This balance is made in such a way that the sum of impacts of components and systems shall respond to the target the building has to reach. Fig. 1 summarizes the concept of the methodology used in this study for the definition of the impact targets.

Top-down approach

The building impact target is derived by cascading the global targets defined in the "2000-Watt Society vision" (Jochem et al., 2004). According to this vision, the 2013 impact of 7200 kg CO_2-eq/year emitted per each Swiss capita must be reduced to 2000 kg CO_2-eq/year by 2050, that is to say, by a factor of 3.6 (Kemmler et al., 2015).

Using the information about the quantity of CO_2-eq emitted per each sector and by each type of building (Weidema et al., 2013), the impact targets that each sector has to reach by 2050 are defined by a proportional decomposition of 2013 impacts and reduced by the same factor.

The conversion of the impact targets to the unit of kg CO_2-eq/year of energetic reference area (ERA) is applied then through the following equation:

$$T = T^* \cdot \frac{Swiss\ population}{Built\ ERA} \tag{1}$$

T [kg CO_2-eq/m² ERA year] and T*[kg CO_2-eq/person year].

The information about the Swiss population and the built area for each type of building can be found in (STATPOP, 2016).

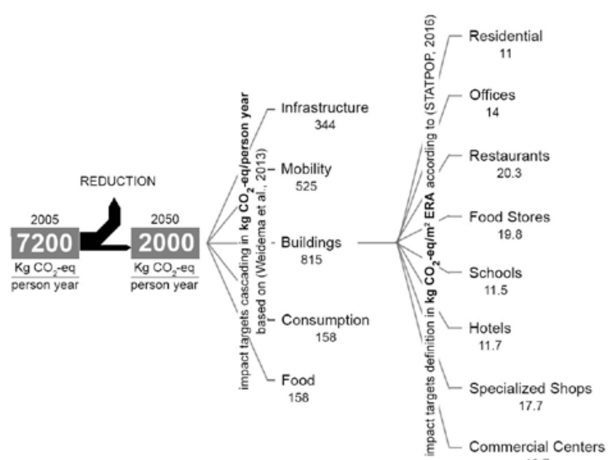

Figure 2: Top-down approach of impact targets

The results obtained from the top – down approach of impact targets are presented in Fig. 2. The values of the targets correspond to those defined by Kellenberger et al. (2013).

Bottom-up approach

For the assessment of the environmental impacts of components and systems, the analysis is based on materials and energy flows over the life cycle of a building. Since the type of materials and energy flows can vary from one case to another, in order to better understand their impacts, it is necessary to develop different project scenarios for a building.

Moreover, each material and energy flow can have several possible values, and various combinations flows can lead to different scenarios. In order to develop these scenarios, different type and quantities of materials and energy flows are combined by using the Morris approach (Morris, 1991). This approach allows us to create a set of scenarios by randomly changing the design parameters of the building one at a time while keeping all other design parameters constant. The minimal significant number of scenarios generated by the Morris approach is a function of the number of trajectories *r* (according Saltelli et al. (2004) it is generally considered four, six or eight), the number of design parameters *k* and can be calculated by the following equation:

$$N = r \times (k + 1) \qquad (2)$$

To prevent a definition of biased impact targets, the development of different independent groups of scenarios is necessary. This allows to consider in the calculation a large variety of buildings types with different performances. They will be used in the next steps to indicate the possibility of targets definition for all possible buildings performances or for each specific performance of building.

The environmental impacts can be then calculated with the help of the equation:

$$I_f = \sum_{i=1}^{n} \mathrm{m}_i \cdot \mathrm{k}_{f,i} \cdot \left(\left\lfloor \frac{LB}{LM_i} \right\rfloor + 1 \right) + \sum_{k=1}^{p} \mathrm{C}_t \cdot \mathrm{k}_{f,t} \qquad (3)$$

where: I_f is the environmental impact *f* of building; *n* is the number of components and systems the building is decomposed into; *p* is the number of different types of energy demand; m_i is the mass or quantity of component or system *i*; $k_{f,i}$ is the environmental impact *f* associated with the life cycle of one unit mass or quantity *i*; $\lfloor LB/LM_i \rfloor$ is the largest integer not greater than LB/LM_i; LB is the lifetime of the building; LM_i is the lifetime of the component or system *i*; C_t is the consumption of the energy in the exploitation phase of the building. $k_{f,t}$ is the environmental impact *f* for the unit energy *t* (EN 15978, 2011; Hoxha, 2015).

Calculation the environmental impacts of components and systems with equation (3) and then of the whole building responds to the needs of definition for impact targets.

To define targets of components and systems, the impacts of each scenario are rebalanced upwards. This step allows to define interval of targets for each group of scenarios. To indicate the possibility of a definition of targets for all buildings type and performances we have to know if the targets calculated from different groups are significantly different. To answer to this question the intervals of values are compared with the help of the Bhattacharyya distance, which measures the similarity of two intervals presented by probability distributions (Bhattacharyya, 1943). For two distributions with a probability density of *p* and *q*, the Bhattacharyya distance is calculated as follows:

$$BC(p,q) = \int p(x)q(x) \qquad (4)$$

where: $0 \leq BC \leq 1$. In the case of $BC \cong 0$ the intervals are different. In this case, it is impossible to choose one group of targets for components or systems. Different groups should be proposed, according to the different conditions of employment of the components or systems. In the case of $BC \cong 1$, intervals are similar, and one interval of targets can be chosen.

The last step of the methodology is the calculation of the variability of impact targets. This can be made with the help of the coefficient of variation which is a standardized measure of dispersion of values [ratio of mean value and standard deviation]. This coefficient is calculated based on the targets of a single group of scenarios. Coupled with the mean values of the impact targets they make it possible to classify the building's components and systems into different groups: the ones having a low mean value and a low value of coefficient of variation, the ones having a high mean value and a low value of coefficient of variation, the ones having a low mean value and a high value of coefficient of variation, and the ones having a high mean value and a high value of coefficient of variation. This last step allows to highlight the components and systems to focus on during the development process.

RESULTS

The methodology described in the previous paragraph has been applied to the smart living building for the definition of impact targets for the Swiss context. Once built, this building will be made up of a combination of apartments, offices and laboratories (smart living lab, 2015) with the aim to achieve the 2050 goals, according to the 2000-watt society vision and it is expected to be built by 2020 in Fribourg, Switzerland.

For creation of scenarios, we considered only the main design parameters of the building that have a significant influence on the environmental impacts. The parameters are those influencing the specific impacts of construction, exploitation (energy consumed for heating, ventilation, domestic hot water, lighting and appliances) and end-of-life of the building. However in the definition of the design parameters we did not consider or define the possible interconnection that the parameters can have with each other.

In the frame of this study, we developed two independent groups of scenarios by using the Morris approach.

For the development of the first group (SEN I), 12 design parameters are considered (shape, thermal inertia, thermal transmittance, shading system, window type, window to wall ratio, ratio of mechanical ventilation, heating distribution, lighting & appliances, solar thermal collectors, PV_{panels} on roof, HVAC). These parameters have been defined in accordance with the recommendations given by SIA 380/4 (SIA 380/4, 2006; SIA 382/1, 2014). A second group (SEN II) was developed by considering 14 design parameters (shape, appliances, unlighted surface, lighting time, ratio of mechanical and natural ventilation, PV_{panels} on the roof and facades, windows' frame quantity, windows' frame quality, glazing type, window to wall on the north facade, window to wall on the south facade, window to wall on the east/west facade, heating system, presence of parking). A group of 78 scenarios in SEN I and 90 scenarios in the SEN II were created according to equation (2) and for a number of trajectories six. Details about design parameters considered for each scenario can be found in (Jusselme et al, 2015). For each scenario, the energy consumed in the exploitation phase of the building for heating, ventilation, domestic hot water, lighting and appliances were simulated in a dynamic regime using the Lesosai software (Lesosai, 2015). In the end, the environmental impacts of scenarios are assessed with the help of KBOB database (Friedli et al., 2014) by considering a building's lifetime of 60 years. The results for 168 scenarios of the SEN I and SEN II for the GWP indicator are presented in Fig. 3.

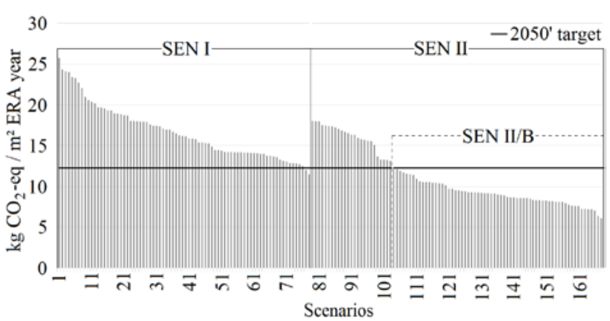

Figure 3: Carbon dioxide equivalent of the projects compared to the 2050 targets for global warming potential indicator

The CO_2-eq emission of scenarios is compared to the target impact, which is of around 12,3 kg CO_2-eq /m² year for the planned smart living building. These comparisons shows that for the group SEN I only two cases are able to reach the goal, but in the group SEN II, 65 scenarios are able to reach the goal. These scenarios are classified in a third group (SEN II/B).

To highlight which component or system has the biggest influence on the overall environmental impact the results are expressed as percentages. The results obtained are presented in Fig. 4. Based on these results, the building's components and systems can be classified according to the influence on the total building's impacts and to the variations of this influence from one scenario to the other.

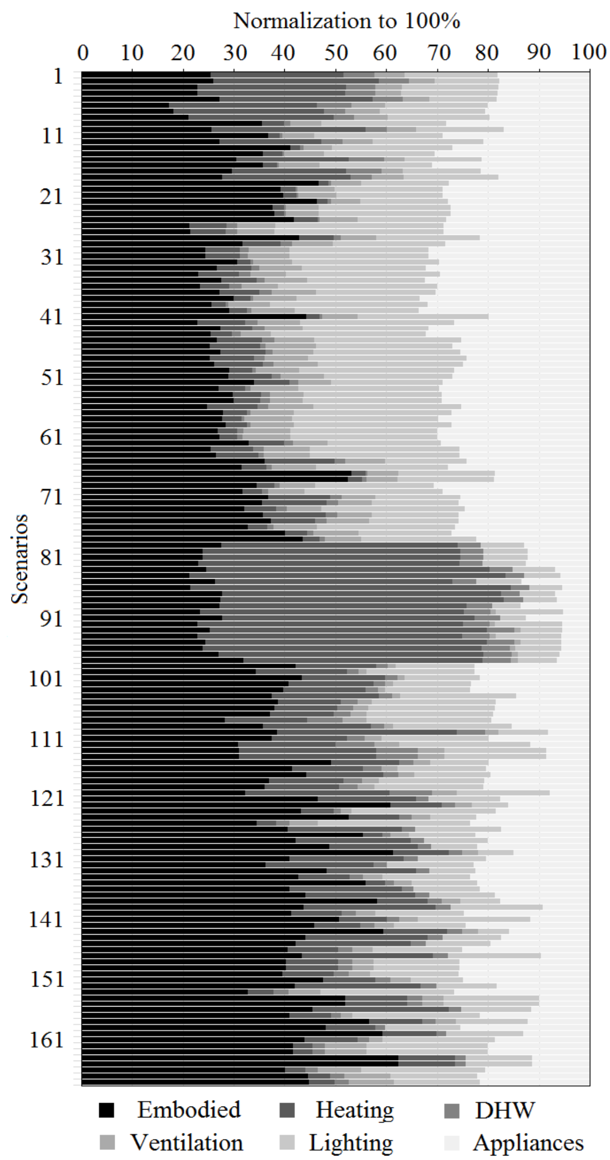

Figure 4: Influence of impacts of components and systems to carbon dioxide equivalent emission of scenarios

The results show that the impact of DHW and ventilation are lower compared to the impact of the other components and systems. The embodied impacts and the impacts of lighting and appliances can varies significantly between projects, but from the results we can conclude that they influence greatly the buildings impacts. The impacts of heating are those varying the most from one scenario to another. In order to define impact targets of components and systems, their environmental impacts were rebalanced so that the scenarios of building reach the 2050 goals. For the scenarios that haven't been able to reach the goals, the impacts of components and systems were proportionally decreased and for the scenarios that have been able to reach the goals the impacts of components and systems are proportionally increased. The results for the three groups of scenarios SEN I, SEN II and SEN II/B are presented in Fig. 5.

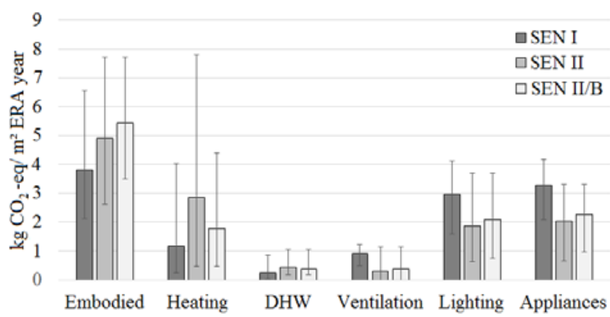

Figure 5: Environmental impact targets for the global warming potential indicator

The values of Bhattacharyya distance presented in Table 1 show a probability up to 50% that the targets defined form three set of scenarios are similar. The lower probability values obtained are 47% and 60% respectively for ventilation and lighting. For the rest of components and systems the probability of similarity is up to 70%. With such probability values we can conclude that the impact targets of three groups are not significantly different. Nevertheless, the targets of ventilation and lighting should be improved for better identifying the possibility to define one group of targets or different for specific performances of building. Because the three sets of impact targets are similar and because in that group of scenarios SEN II/B represent those reaching the 2050 goals, we have chosen their values as the most appropriate. Finally, the target values defined are presented in Fig. 6.
The mean, intervals of variation and the coefficients of variation are presented for the targets.

Table 1: Bhattacharyya distance calculated for the comparisons of SEN I, SEN II and SEN II/B

		Bhattacharyya Distance (%)
Embodied	SEN I - SEN II	89
	SEN II - SEN II/B	93
	SEN I - SEN II/B	68
Heating	SEN I - SEN II	83
	SEN II - SEN II/B	95
	SEN I - SEN II/B	88
DHW	SEN I - SEN II	72
	SEN II - SEN II/B	99
	SEN I-SEN II/B	73
Ventilation	SEN I - SEN II	47
	SEN II - SEN II/B	94
	SEN I - SEN II/B	53
Lighting	SEN I - SEN II	69
	SEN II - SEN II/B	98
	SEN I - SEN II/B	79
Appliances	SEN I - SEN II	60
	SEN II - SEN II/B	95
	SEN I - SEN II/B	70

For most buildings' components and systems the coefficient of variation has taken the values of 30%. Based on the mean values of the impact targets and coefficient of variation, we classified components and systems into two groups: those having a large mean value of target and a large coefficient of variation and those having a low mean value and a low coefficient of impacts. For this classification, the Pareto principle is applied. According to this principle, windows, electrical equipment, heating, lighting and appliances were found out to be the components and systems of the building with a high mean and a high coefficient of variation. For these components and systems, a particular attention should be paid during the development process. The impacts of components and systems should be very close to the mean value of the targets. If the values are significantly higher than the targets, then a lot of effort must be focused on decreasing their impacts.
But in case of other components with lower mean values and low coefficient of variation, to develop components and systems with impacts slightly higher than the mean value of targets, do not have significant influence. An interesting and unexpected result is that the impact targets can be used as a sensitivity method by indicating the most important components and systems in the sense of their influence to the impacts of building.

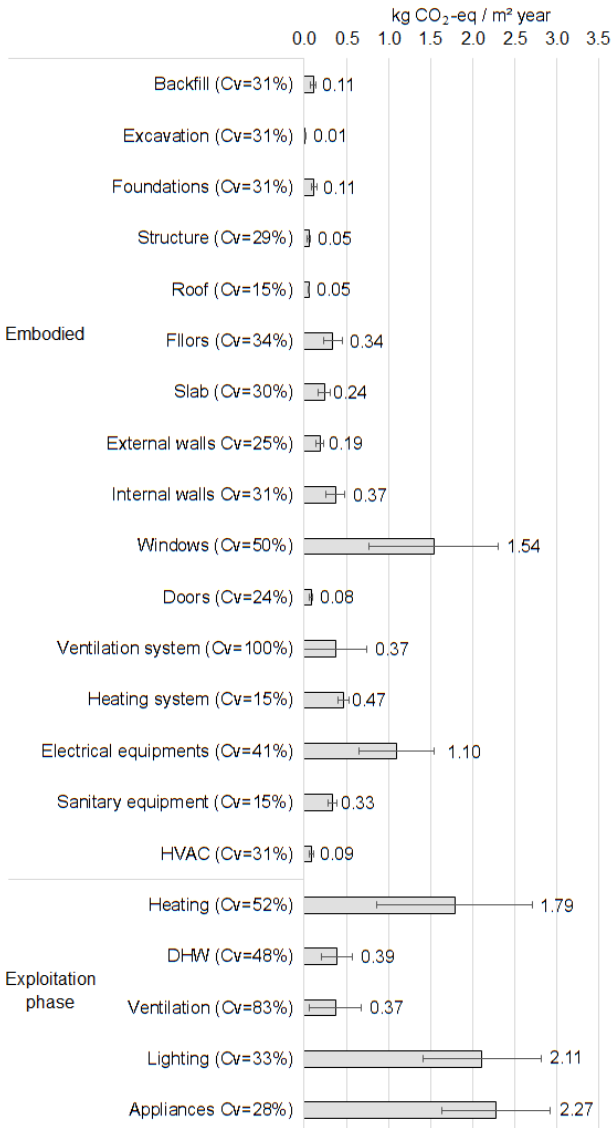

Figure 6: Impact targets of building's components and systems

Based on Fig. 6 we can classify the components according to their environmental impacts. With these results, the components and systems should be developed hierarchically during the building's design process. Firstly, components and systems with highest impact targets (appliances, lighting, heating, windows and so on) should be developed and after the others.

CONCLUSION

This paper introduces a new methodology for the definition of impact targets for components and systems of a building. The methodology has been applied to the smart living building to define impact targets at the components and systems level for the Swiss context. The decomposition of the global target of building in sub-targets for its components and systems simplifies the design process which is guided by the targets towards low carbon objectives. It should be noted that the targets can be used also as sensitivity analysis to show the components having the biggest influence on the environmental impacts of building.

For developing projects able to reach 2050 goals, the targets allow scientists, architects, civil engineers and all LCA-practitioners to develop the components or systems one by one without analysing the whole building.

Further work is needed to better investigate a possible generalisation of this method and definition of impact targets for the context of other countries.

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NOMENCLATURE

LCA	Life cycle assessment
GWP	Global warming potential
CO_2-eq	Carbon dioxide equivalent
HVAC	Heating, Ventilation and Air-Conditioning
DHW	Domestic hot water
LB	Lifetime of the building
LM	Lifetime of the component or system
BC	Bhattacharyya distance
I_f	Environmental impact *f*
$k_{f,i}$	Environmental impact *f* associated with the life cycle of one unit mass or quantity *i*
C_t	Consumption of the energy in the exploitation phase of the building

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