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€COFFICE-LCC AND LCA AS PART OF THE INTEGRATED DESIGN APPROACH FOR A HIGH PERFORMANCE-LOW COST OFFICE BUILDING

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Abstract
The main objective of the BTP1000 project was to design (and build) an office building (€coffice) that would comply to the PassivHauss principles, offer a very high comfort and integrate different sustainability features, but cost no more than a traditional building. In order to achieve those objectives, an integrated iterative design approach was followed. From the beginning of the project, all stakeholders and various building specialists contributed to the decision making process, and design alternatives were evaluated from various perspectives (e.g. energy performance, comfort, life cycle cost and impact, etc.).
The present paper focuses on how life cycle analysis (LCA) and life cycle costing (LCC) were used to integrate environmental and economic dimensions in the design process of the building envelope and how the results influenced final design options. LCA and LCC studies first compared different types of façades. The best compromise between LCC and LCA results, practical implementation, and thermal comfort were then selected for implementation. Subsequently, parametric energetic simulation results (combining heating, cooling, lighting, and ventilation) were used as input for LCA and LCC studies in order to optimise the insulation level of the building fabric elements (outer walls, roof, ground floor, glazing). In conclusion, LCC and LCA were very useful in the integrated design process and results showed the importance of taking into account not only the energy use for heating and cooling, but also for lighting into the building fabric optimisation.

Keywords:
Integrated design, Life cycle costing, Life cycle analysis, sustainability, optimisation, building envelope

1 INTRODUCTION

The €coffice building, which was completed in 2013, is the result of the BTP1000 research project. BTP1000 had as main objective to design (and build) an office building (€coffice) that would comply to the Passive House standard, offer a very high level of visual and thermal comfort and integrate different aspects of sustainable building design (e.g. low water use, biodiversity on site, reduced environmental impact, etc.), but cost no more than a traditional office building. Moreover, the design had to be reproducible, flexible and polyvalent.
To achieve those objectives, all stakeholders and various building experts were involved from the beginning of the project in the iterative design process, trying to find the best compromises between functional constraints, energetic performance, sustainability aspects, and financial considerations.
Subjects for optimisation were for example the implementation on the building site, building shape, window openings, materials and building installations [1], insulation level, etc.
Life cycle analysis (LCA) and Life cycle costing (LCC) were used all along the project to integrate environmental and financial considerations into the decision making process and to evaluate at the end of the project the as-built performance of the building [2]. The present paper; however, focuses on how LCC and LCA influenced the

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materials selection and insulation level of the building fabric elements.

Fig. 1: €coffice (http://www.€coffice-building.be/).

2 DATA AND METHODS

2.1 Life Cycle Analysis

From an environmental point of view, as the building owner was seeking a BREEAM certification, the *"Green guide to specification"* was partly used for material selection. However, for the optimisation of the envelope (composition and insulation level) and the as-built evaluation of the building a detailed LCA study was done, using the SimaPro software with Life cycle inventory data from the ecoinvent database v2.2 and gate-to-grave scenarios (e.g. transport and end-of-life of building materials) which are representative for Belgium [3]. Allocation principles and system boundaries were set according to EN 15978 [4]. However, during the design phase, as results needed to be usable for decision making, the ReCiPe life cycle impact assessment method [5] was used instead of the 7 impact indicators from the EN 15978. Indeed, the 18 midpoint ReCiPe indicators can be aggregated into a single score, which greatly facilitates interpretation. A disadvantage of the single score is that it is less robust (uncertainty related to the use of endpoint indicators) and more subjective (value-based weighing factors).

2.2 Life Cycle Costing

The LCC analyses followed the general principles of the ISO 15686-5 standard.

Data for building component service lives, frequencies and costs of maintenance activities were based on national and international sources [6], [7] and databases [8], [9].

The Net Present Value (NPV) was used as main LCC-indicator. NPV is the summation of all the discounted costs during the **reference study period (RSP)**, and provides a one-figure indicator that facilitates the comparison between different alternatives. A nominal discount rate of 3.5% and an inflation rate of 2.5% were assumed.

3 COMPOSITION OF THE OUTER WALLS

In order to optimise the material selection for the outer walls, different wall compositions with similar U-values (see Table 1, LF=light façade, MF=massive façade) were proposed by the architect (A2M). Those alternatives were then analysed using LCA and LCC, for a RSP of both 30 and 60 years.

For the 30-years analysis, no replacements of materials were considered. For the 60-year LCA assessment 2 alternative scenarios were analysed. The minimum replacement scenario supposed that when the rendering (alternatives LF2, LF3, MF2) or exterior panels (LF1, MF1) are replaced the underlying insulation can be preserved, while the maximum replacement scenario considered that the underlying insulation is replaced as well.

3.1 Results

Fig. 2 presents the LCC results for the RSP period of 30 years (from an investors point of view the most relevant RSP of both). *Fig. 3* presents the LCA results (expressed in ReCiPe single score points) for different RSP and replacement scenarios.

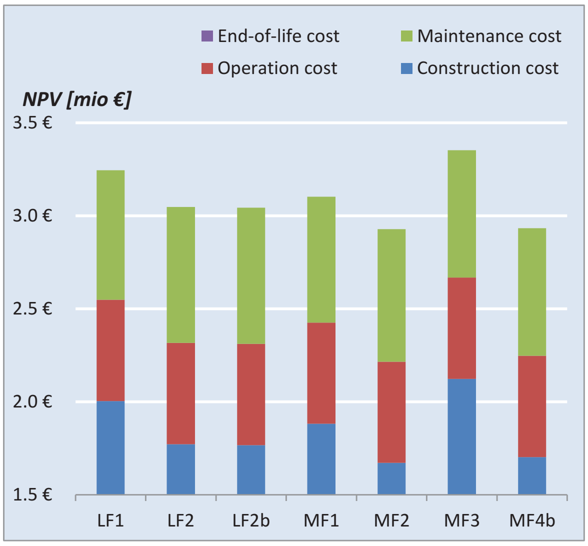

Fig. 2: LCC results for different façade variants.

3.2 Discussion

The LCA (and LCC) results show that independently of the RSP and replacement scenario considered, the light façades (LF) do not systematically have a better score than the massive façades (MF). Also, both from an environmental and financial point of view MF2 and MF4b are relatively interesting. MF4b is particularly interesting when considering a 60 year RSP and the maximum replacement scenario. Indeed, unlike the alternatives with rendering or fibre cement panels, the brick façade does not need to be replaced within the considered RSP. Note that the alternative MF4b was not part of the initial proposition made by the architect, but composed following the discussion

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of the preliminary LCA results (which showed the interest of using bricks as outer façade but also the high impact of a massif concrete wall compared to hollow concrete blocks). As the LCC study was completed following the LCA study, it did not consider FM4.

Considering the relatively good environmental performance of MF2 and MF4b, the fact that the contractor was more familiar with massive constructions, and the positive influence of the massive walls on summer comfort and the energy use for cooling (based on dynamic energy simulations), those alternatives were finally implemented (MF2 on the North and South and MF4b on the East and West oriented walls).

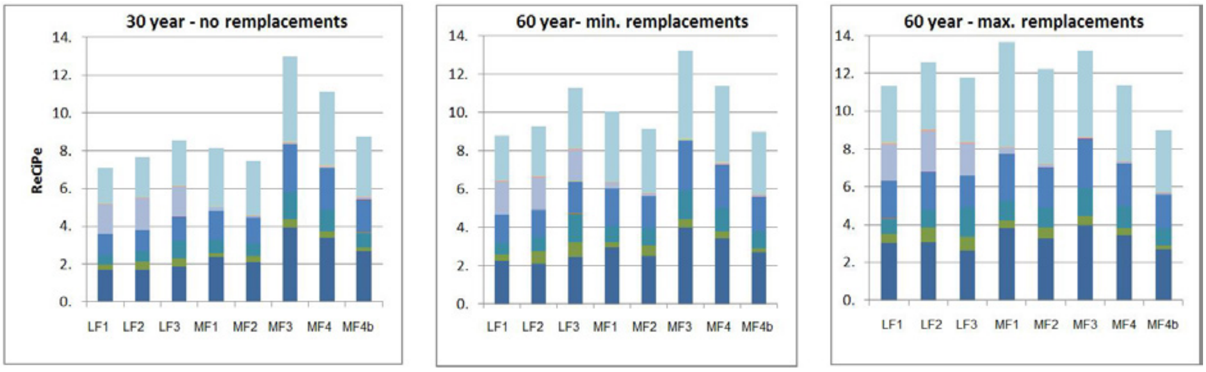


Fig. 3: LCA results (ReCiPe score) for different façade variants, RSP and replacement scenarios.

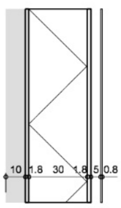
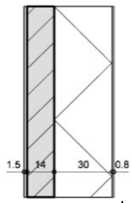
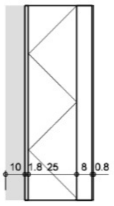
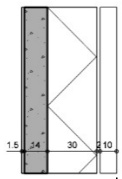
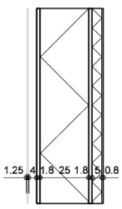
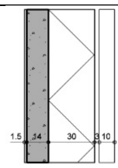
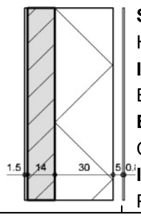
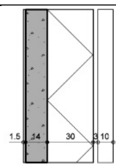
Light façade 1 (LF1)		**Structure** Wooden I-joists **Insulation** Cellulose (30cm) **External finish** Fibre cement panels **Internal finish** Gypsum blocks (10cm)	**Massive façade 2** (MF2		**Structure** Hollow concrete blocks **Insulation** EPS (30cm) **External finish** Rendering **Internal finish** Plaster
Light façade 2 (LF2)		**Structure** Wooden I-joists **Insulation** Cellulose (25cm) + woodfibre panels (8cm) **External finish** Plaster **Internal finish** Gypsum blocks (10cm)	**Massive façade 3** (MF3)		**Structure** Concrete curtainwall **Insulation** EPS (30cm) **External finish** Architectural concrete panels **Internal finish** Plaster
Light façade 3 (LF3)		**Structure** Wooden I-joists **Insulation** Cellulose (25cm) + woodfibre panels (8cm **External finish** Plaster **Internal finish** Gypsum blocks (10cm)	**Massive façade 4** (MF4)		**Structure** Concrete curtainwall **Insulation** EPS (30cm) **External finish** Concrete masonry **Internal finish** Plaster
Massive façade 1 (MF1)		**Structure** Hollow concrete blocks (14cm) **Insulation** EPS (30cm) **External finish** Cement fibre boards **Internal finish** Plaster	**Massive façade 4b** (MF4b)		**Structure** Hollow concrete blocks **Insulation** EPS (30cm) **External finish** Concrete masonry **Internal finish** Plaster

Table 1: Alternative wall compositions.

4 INSULATION LEVEL OF THE BUILDING FABRIC

Parametric energetic simulations (TRNsys 17 software [10]) showed that insulating the €coffice building (given layout, orientation, etc.) *beyond* the Passive House criteria of 15kWh/m^2 net energy consumption for heating would have a positive effect on the total energy consumption (sum of heating and cooling) of the building. However, considering that passive cooling strategies were in place (e.g. possibility to open windows during night time) no optimum (maximum) insulation level could be observed (within practically implementable thicknesses). Moreover, given the high compactness of the building (C=2.9) and its relatively high internal gains resulting from its use as office space, results also indicated that the 15kWh/m^2 requirement could be met with double glazed windows and insulation levels for the building fabric elements close to the Energy performance of buildings directive (EPBD) requirements that were in place in the Walloon region at that time (U-value of the ground floor and wall≤0.4W/m^{2}K and U-value of the roof≤0.3 W/m^{2}K).

4.1 Global insulation level

As optimal insulation levels and the choice of glazing could not be derived solely based on energetic considerations, LCA and LCC studies were executed to compare different global levels of insulation of the building fabric (U-value of outer walls, roofs and ground floor) in the case double glazing (U=1.1 W/m^{2}K, g=0.609) or triple glazing (U=0.59W/m^{2}K, g=0.584) would be used, and passive cooling would (not) be allowed. Those studies considered the life cycle impact (cost) of the relevant materials, and the energy use for heating (gas) and cooling (electricity) for a RSP of 30 years.

The following insulation materials were considered (selected based on environmental, financial and practical considerations):

- EPS (expanded polystyrene) for the walls: λ=0.032W/mK
- In-situ blown PUR (polyurethane) for the ground floor (λ=0.028W/mK)
- PUR plates for the (flat) roof (λ=0.026W/mK)

The results from those studies (which are not presented in detail here) showed that, unlike the energetic simulations results, LCC and LCA results enabled to identify an optimal global insulation level, even when passive cooling was allowed. However, the optimum U-value was lower with double glazing and natural ventilation. Also the optimum U-value based on LCA was systematically lower than the LCC optimum (see figure x considering the possibility to open windows at night, the LCA and LCC optimum when using double glazing were respectively 0.15 and 0.2 W/m^{2}K).

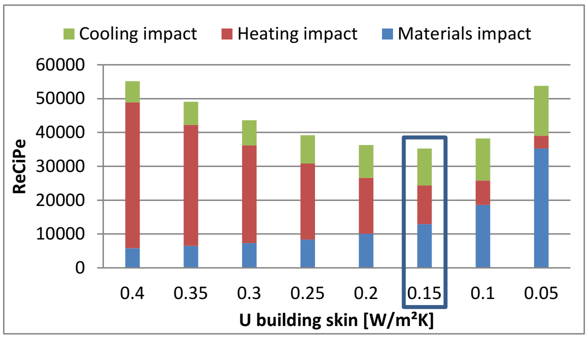


Fig. 4: Optimum insulation level based on LCA results (with passive cooling and double glazing).

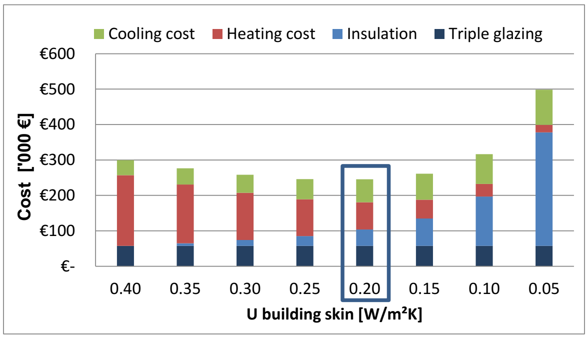


Fig. 5: Optimum insulation level based on LCC results (with passive cooling and double glazing).

4.2 Double or triple glazing

In order to enable a well-founded choice, the double and triple glazing alternatives were further analysed but this time also considering the energy use for lighting (see *Table 2*). Also, as from above studies the optimum insulation level seemed to be higher when using double glazing compared to triple glazing, both alternatives were defined such as to achieve a similar net energy use for heating (+-10kWh/m^2 based on PHPP calculation), resulting in a higher global insulation level (U_{fabric}=0.12W/m²K) for the double glazing alternative compared to the triple glazing alternative (U_{fabric}=0.25W/m^{2}K).

Again a reference study period (RSP) of 30 years was used for both analyses as the glazing would probably be replaced after 30 years and some insulation possibly too. In addition, a sensitivity analysis was performed for the LCA analysis based on a 60 year RSP and different replacement scenarios for the insulation (cfr. outer wall study)

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	Net Energy use (kWh/m^2) for		
	Heating	cooling	Lighting
Triple glazing U_{fabric}=0.25W/m^{2}K	13.16	1.17	21.05
Double glazing U_{fabric}=0.12W/m^{2}K	12.27	1.26	19.55

Table 2: Net energy use (calculated with Transys) for different compositions of glazing and insulation.

Results

Fig. 6 shows the results from the LCA (ReCiPe score) and LCC analysis for a RSP of 30 years.

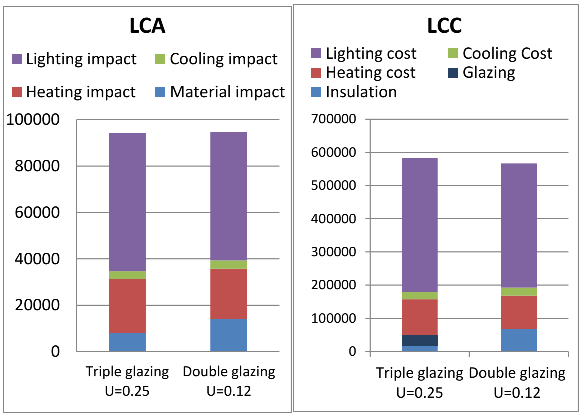

Fig. 6: LCA and LCC results for the triple vs. double glazing analysis for a RSP of 30 years.

Discussion

From an environmental point of view there is no significant difference between the life cycle impact of the option "double glazing with higher insulation levels (Double glazing + U=0.12)" or "triple glazing with lower insulation levels (Triple glazing + U=0.25)". Indeed, the first option has a slightly higher material impact (life cycle impact of glazing + insulation) but this is compensated by the resulting gains in energy use for lighting (better light transmission of double glazing). For a RSP of 60 years and considering that, unlike the glazing, the insulation does not need to be replaced within the considered timeframe, the alternative with double glazing becomes slightly more interesting (3%) than the alternative with triple glazing as the additional impact from insulation can be amortized over a longer time period, but the difference is still insignificant.

Concerning the LCC results, the additional investment cost for getting from an insulation level of U=0.25W/m²K to U=0.12W/m²K exceeds the difference in cost between triple and double glazing. However, the double glazing alternative achieved a lower heating energy consumption and a far lower lighting energy consumption. Consequently, even with a slightly higher energy consumption for cooling, this scenario obtained a lower overall NPV.

Finally, as results from thermal comfort simulations (according to NEN 15251 and ISO7730) showed that the alternative with triple glazing resulted in 10% more time in comfort 1 zone on the north side, it is a combination of glazing that was selected for the final design, namely triple glazing on the north side and double glazing on the south side. A post-construction LCC analysis considering the individually optimised insulation levels determined in next section supported this decision.

4.3 Optimisation of the insulation level of the individual building elements.

The next step consisted in the individual optimisation of the U-value of the various building elements. Therefore, parametric energy simulations calculated the energy use for heating of the building for varying U-values of each element (from EPBD requirements to realistically high insulation levels), supposing that the other elements were insulated to the applicable EPBD requirements. Those results were then used as input for LCA and LCC.

For each element, the LCA considered a RSP of 60 years. In cases where the service life of the insulation was possibly shorter, alternative RSP were also considered (e.g. for the flat roof insulation the calculations were done for a RSP of 30 and 60 years). On the other hand, the LCC study was also carried out for different RSP's, but a RSP of 30 years was finally considered to be the most relevant for decision making (investors preference). So only those results are presented here.

Results

Fig. 7 and *Fig. 8* show the detailed results from the LCA and LCC study of the roof insulation for a RSP of 30 years. *Table 3* summarises the optimum insulation levels, identified based on LCA and LCC results, for the various building fabric elements (and RSP's). Insulation thicknesses selected for implementation are also mentioned in that table.

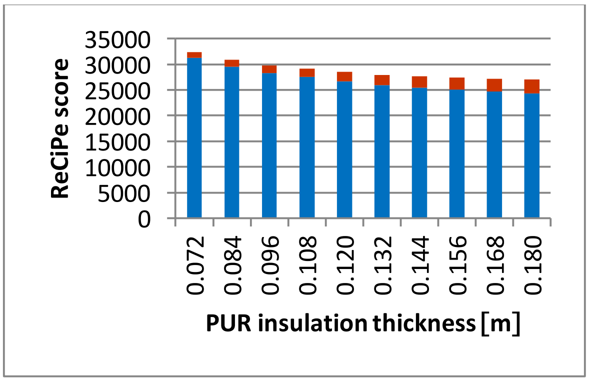

Fig. 7: LCA results for varying roof insulation thicknesses.

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Discussion

Fig. 7 shows that from an environmental point of view no optimum insulation level was reached for the flat roof within the analysed insulation thicknesses (max. 18cm PUR). However, as was the case for the other elements where LCA results did not lead to an absolute optimum, the marginal environmental gains between the higher insulation thicknesses are relatively small (see *Fig. 7* the curve is almost horizontal at the end). On the other hand, the LCC results presented in *Fig. 8* indicate that, the optimum insulation thickness for a return on investment of 30 years is 13cm for the flat roof. Finally, seen the relatively low environmental benefit from insulating beyond the LCC optima, 15cm insulation was placed on the flat roof.

For the same reasons, the LCC optima for a return on investment period of 30 years were finally also selected for various other elements as final design option. One exception was the ground floor, where the absolute economic optimum was chosen (return on investment of 60 years) instead of the 30 year return period. The reasons therefore were the fact that an LCA optimum was reached (17cm), the investment cost of extra insulation was relatively low, and the expected life time of the insulation would most probably be higher than 30 years.

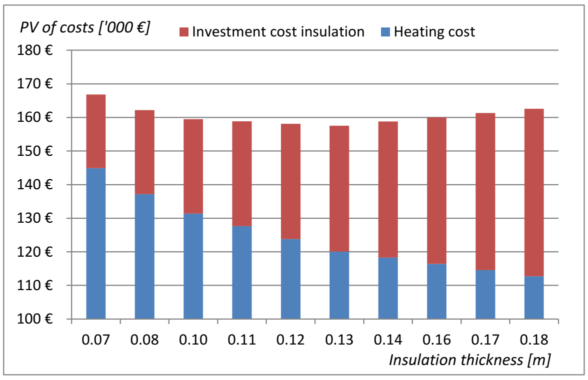

Fig. 8: LCC results for varying roof insulation thicknesses.

Element	**Insulation**	**LCA**		**LCC**	**Final design**
		RSP (years)	Optimum thickness	Practical economic optimum (30 years)	
Wall (N)	EPS	40 60	≥30 cm	17.6cm	18cm
Wall (S)	EPS	40 60	≥30 cm	17.6cm	18cm
Wall (E)	EPS	40 60	≥30 cm	17.6cm	18cm
Wall (W)	EPS	40 60	26 cm	17.6cm	18cm
Wall in ground	EPS	60		12.9cm	18cm
Roof	PUR	60 30	≥18 cm ≥18 cm	13.2cm	15cm
Floor	In-situ PUR	60	16.5 cm	<9cm	15cm

Table 3: Optimum insulation levels of building fabric elements, based on LCA and LCC results.

5 GENERAL CONCLUSIONS

The €coffice case study showed that performing LCA and LCC studies at various moments within the project development effectively enables to integrate life cycle environmental and financial considerations into the decision making process and to influence final design options. However, LCA and LCC do not always lead to the same results and are only truly useful for decision making when interpreted in combination with other considerations (e.g. budget, practical implementation, comfort, etc.).

6 ACKNOWLEDGMENTS

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7 REFERENCES

1. Van Moeseke, G. ; Dartevelle, O. ; Deltour, "€coffice–HVAC solutions for passive offices.," *Passive. House Symposium. 2011*, 2011.

2. Delem, L., Wastiels, L. and Van Dessel, J."Assessing the construction phase in building life cycle assessment," *Proceedings of LCA Conference 2013, avniR, Lille, November 4-5*, 2013, no. 1.

3. Delem, L., Van Dessel, J., et al., "Environmental Profile of Building elements," 2013.

4. European Committee for Standardisation, *EN 15978:2011 - Sustainability of construction works - Assessment of environmental performance of buildings - Calculation method*. 2012.

5. Goedkoop, M.; Heijungs, R., et al., "ReCiPe 2008," 2009.

6. Albano, J.-R., *La Maintenance des Bâtiments en 250 Fiches Pratiques*, 2nd ed. Paris: Le Moniteur, 2005.

7. WTCB, *Onderhoudsgids voor duurzame gebouwen*, WTCB, 2011.

8. BIM Media, "Beheer- en onderhoudkosten." Doetinchem.

9. RICS, "Building Running Costs Online." RICS, London.

10. M. University of Wisconsin, "Solar Energy Laboratory, TRNSYS: A Transient Simulation Program." 2013.

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