



## Sustainable building optimization – A systemic approach

Helmuth KREINER<sup>1\*)</sup>, Alexander PASSER<sup>1,2</sup>, Peter MAYDL<sup>1</sup>, Holger WALLBAUM<sup>3</sup>

<sup>1</sup>Institute of Technology and Testing of Building Materials-Working Group Sustainability Assessment, Graz University of Technology, Austria

<sup>2</sup>Institute of Construction and Infrastructure Management, ETH Zurich, Switzerland

<sup>3</sup>Chalmers University of Technology, Gothenburg, Sweden

### **Abstract:**

*Objective: During the last two decades various building sustainability certification systems have been developed and established. These assessment systems are considered to be appropriate tools for the evaluation of sustainability performance on buildings. Current building design optimisations mostly focus on single sustainability aspects like environmental quality or economic performance, disregarding a holistic approach. Investors strive to achieve a maximum of the assessment score on the one hand and optimized initial costs on the other. Project stakeholders usually have different points of view regarding project requirements and goals. Sustainable buildings – according to the upcoming CEN/TC 350 standards - should include environmental, social and economic aspects as well as functional and technical issues. In order to achieve a high performance concerning sustainability-assessment due to the choice of the right optimisation measures, early planning stages show the high potential (integral planning).*

*Methods: Based on the Austrian building certification system (ÖGNI/DGNB), we applied a systemic approach for building sustainability-improvement, using a case study of a public office building in Graz, Austria.*

*Results: The main part of our study describes six important steps required for systemic sustainability optimization. The applied method allows the quantification of the relative influence and the individual optimization potential of design options on each single assessment criterion.*

*Conclusion: Building certification combined with a systemic approach regarding the interdependency between single criteria is an appropriate method for the improvement of building sustainability.*

**Key-words:** Building sustainability assessment, design optimization, systemic approach, LCA, LCC

### **1. Introduction**

Stakeholders from politics and legislators at all different levels as well as in the private sector are now aware about the importance to promote measures for the environmental protection and social justice while pursuing economic growth and economic stability, and endeavour to implement such actions. Transferring the principles of sustainable development (WECD 1987) into the construction sector and the construction industry means introducing a change of paradigm with the challenge that there is no universally accepted definition and no unique solution for sustainable buildings. The perception of



what is a sustainable building is changing over time and depending on the location. During the last two decades various building sustainability certification systems have been developed and established (Cole et al. 2005; Wallhagen & Glaumann 2011; Haapio & Viitaniemi 2008). These assessment systems are considered to be appropriate tools for the evaluation of sustainability performance on buildings (Passer, Mach, et al. 2012; Passer et al. 2010). According to the forthcoming CEN/TC 350 standard (CEN 2010; CEN 2011; CEN 2012) sustainable buildings should fulfill environmental, social and economic as well as functional and technical aspects. Different users and investors' project-preferences, often lead to trade-offs during the design phase of a project. These trade-offs are caused by the optimization measures and their system interdependencies. A systemic approach to model and quantify the system effects caused by different design options are generally not considered yet (Kreiner & Passer 2012). At current no commercial tools for analyzing these interdependencies do exist. Decisions of design options are mainly reduced on the instantaneous assessed criterion in the assessment of buildings - this is caused by the current linear assessment approach for building certification of singular technical measures. The interdependency of other criteria and their influence in overall building performance is thereby often neglected, especially in early planning stages.

In contrast systemic thinking is gaining more and more interest in the last years (Hunkeler et al. 2008; Vester 2008; Cole 2011). Different systemic approaches are described in (Dzien 2011), (Thomas & Köhler 2011), (Girmscheid & Lunze 2010) and (Schneider 2011). In order to fulfill stakeholder interests on the one hand and a high certification result on the other, it is very important to identify appropriate measures, which improve the sustainability performance of buildings. Therefore good knowledge of system effects triggered by design optimizations – according to certification systems – is indispensable. A review of current literature does not show appropriate approaches considering both, stakeholder interests and system effects of several measures. First steps towards a systemic improvement are described in (Wittstock 2012), (Hafner 2011). With regard to systems thinking therefore a new approach leading to the integration of system theory in the field of building assessments is needed.

## **2. Method**

The identification of the system interdependencies of different optimization measures is based on the ÖGNI/DGNB building certification system (ÖGNI 2009). The system consists of 49 single criteria with individual weighting. Single criteria are allocated to assessment areas that are also weighted and finally combined to an overall ÖGNI target achievement. In complex systems – as in multicriteria analyses – single criteria often interact with each other (Schalcher 2008). By neglecting these interactions in building optimization process, single parameters are improved while effects on the overall assessment remain unknown.

In the last decades many methods for improvement of building sustainability have been developed. In this case study the sensitivity model of Vester (Vester 2008; Kreiner & Passer 2012) was applied in a new approach towards systemic building optimization. Systemic improvement of building sustainability should include the following steps:

1. Identification of assessment criteria role (S1)
2. Semi-quantitative building assessment (S2)
3. Matrix with possible measurements (S3)
4. Identification of system influence by several design measures (S4)
5. Systemic improvement (S5)
6. Scenario analyses (S6)

The identification of ÖGNI assessment criteria role is conducted with the sensitivity model of Vester (step S1), identifying the different roles of the assessment criteria. The most influencing construction measures of the case study were identified by prior semi-quantitative building assessment (step S2). Based on step S1 as well as on step S2 appropriate design measures can be identified (S3) in general for the subsequent systemic evaluation (step S4 and S5). Understanding criteria interactions does not necessarily lead to an appropriate building improvement process. Rather, attending to the systemic influence of single measures and/or system-parts of the building is quite important for the planning process (step S4). The environment's influence that often leads to project trade-offs must be analysed throughout scenario analyses (step S6). This is caused by the fact that summarizing the achievement in assessment target of single measures must not be similar with the assessment results after combining several design options. Rather, the system of a part can be only be understood by understanding the whole (Cole 2011), taking their interdependencies into account.

### 3 Case study analysed

The new approach was applied on an office building in Graz (Styria, Austria). Building owner and operator is the *Landesimmobiliengesellschaft mbH* (Landesimmobilien-Gesellschaft mbH 2010). The new office building is part of the *Karmeliterhof* project and was built during the renovation of the whole complex. Tab. 1 gives an overview about the key parameters of the building.

Table 1. Key parameters of investigated office building

Size	2.300 m <sup>2</sup> (gross floor area)
Floors	5+1
Walls	Concrete, bricks
Energy certificate	B (39 kWh/m <sup>2</sup> *a)
S/V ratio	0,21 (m <sup>-1</sup> )
Heating system	District heating
LEK	33[-]
Mean U-value	0,565 [W/(m <sup>2</sup> *K)]

In total 12 measures (M1-M12) and 25 different variants were analysed. For the comparison of single variants a reference scenario was modeled which represents minimum-requirements in energy efficiency and minimum initial costs in context to the investigated building. In this paper measure M-1 “Thermal insulation“ is discussed in detail. For each measure a reference measure on the one hand as well as different optimization options (ref-opt) on the other hand were investigated. Tab. 2 shows the variations of measure M-1:

Table 2. Variation of measure M-1

Measure		Reference	Built	Optimization		
		[ref]	[built]	[opt]	[opt1]	[opt2]
M1	Thermal insulation	10 cm EPS	16 cm EPS	22 cm EPS	30 cm EPS	20 cm mineral-wool

Several parameters were chosen for a subsequent scenario analyses (Fig. 4). Parameter “LCA” is thereby defined as the sum of ÖGNI-criteria 1-5 and 10-11. “LCCA” represents criterion 16 (life cycle cost) in ÖGNI certification system. By summarizing ÖGNI target achievement of LCCA and measure related criteria parameter “Use” is defined. Finally the scale of sustainability improvement is described by parameter “Sum target achievement” for each measure.

#### 4. Results

##### 4.1 Single measure influence on several criteria

The evaluation of each measure was realized by separate investigation of each parameter. Quantitative influence on parameters like energy or heating demand as well as initial or life cycle costs were analysed. Semi-quantitative optimization potential in ÖGNI building certification system has additionally been carried out. Each measure has an individual optimization potential allocated to the previously defined parameters. Fig. 4 shows the relative influence of the investigated measure “Thermal insulation”. The abscissa represents the ÖGNI-criteria (C1-C35) and resulting parameters (“Use”, “LCCA & LCA”, etc.) which were identified as having a possible influence when installing optimization measure M-1 (Thermal insulation). The ordinate describes the absolute variation of target achievement caused by different optimization measures (pictured in different colors in figure 4) in context of the reference measure.

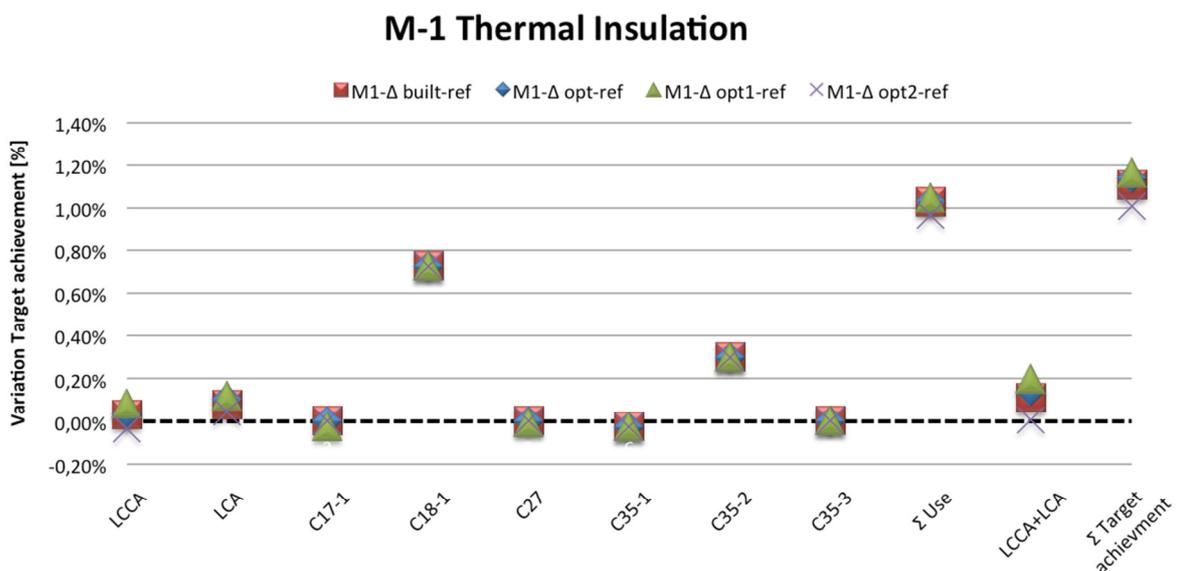


Figure 4. Influence of single measure M-1 on target achievement

As the thickness of the thermal insulation is increasing, the heating demand decreases. A lower heating demand has interdependency with criterion 18 (Thermal comfort in winter). At least 0,7 % of absolute target achievement in criterion 18-1 (Operative temperature) are influenced. Further there is a low influence on LCCA and LCA by installing measure M-1. Due to increasing gross floor area, space-efficiency changes slightly. Because of the system interdependency between criterion 17 (value stability) and 27 (space efficiency) the target achievement of criterion 27 also increases slightly and criterion 35-2 (Quality of the building shell) is influenced. A 0,3% increasing of target achievement can be reached by improving the U-Value of the facade. Influence on other concerned criteria did not cause relevant variation of target achievement in the investigated case. Finally, system trade-offs have to be analysed. The range between the investigated variants concerning measure M-1 can be neglected.

To summarize, by applying measure M-1 “Thermal insulation”, an improvement of ÖGNI target achievement between 1,0% and 1,2% can be reached. Final energy demand (ÖN\_H\_5055 2011) can be reduced by 2,6 to 5,4%, depending on the measure-variation which was chosen and the quantitative impact of the relevant parameter.

#### 4.2 System influence due to different design options

The previous investigation was carried out for several design options that were chosen based on the results of the quantitative analysis of the case study. Fig. 5 shows the ÖGNI target achievement of the investigated design options (M1-M12), including the system interdependencies.

The European Union strives for energy standard nearly zero for office and administration buildings by 2020 (EU 2010). So far, the focus of building design optimization is mainly laid on the reduction of the energy demand in the operation phase of buildings, e.g. through increased insulation. Fig. 5 gives an overview of the investigated measures regarding their influence on the end energy demand in comparison to the relevant reference measures.

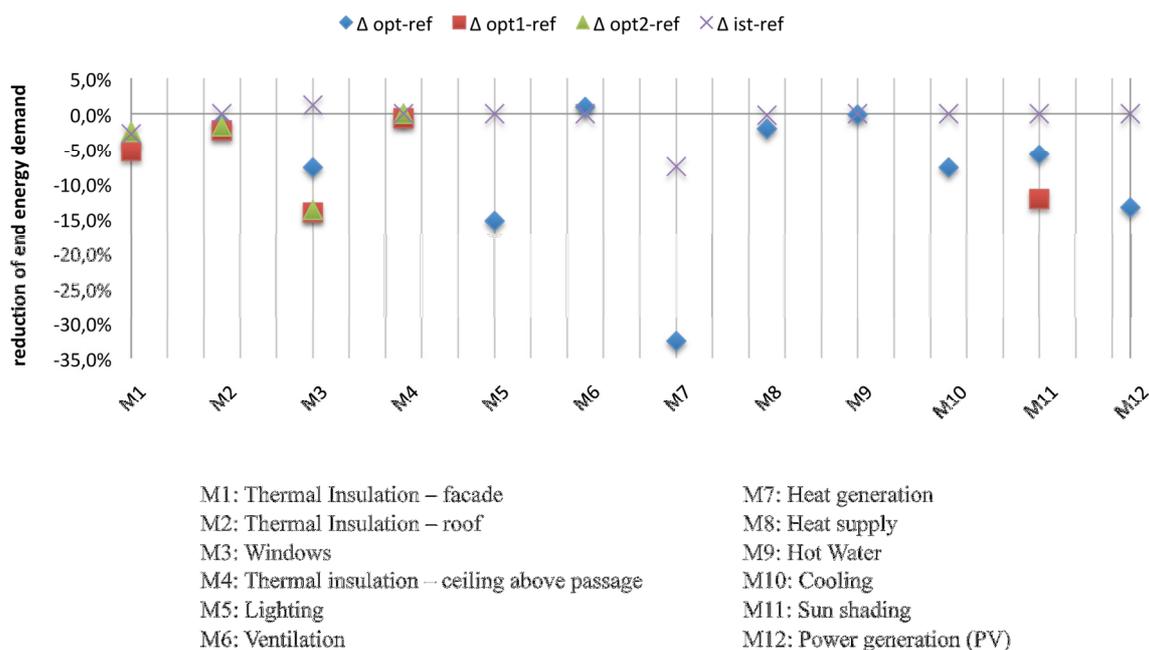


Figure 5. Influence of different measures on final energy demand

The results show that in this case, improvements of the building envelope (M1+M3) as well as the optimization of lighting (M5) and heat generation (M7) are most suitable measures to reduce the final energy demand.

A different picture occurs if a simultaneous and equivalent assessment of all sustainability aspects is applied what is required according to the assessment concept of CEN/TC 350,. Figure 6 shows the suitability of the investigated measures for the improvement of ÖGNI overall target achievement. Focusing sustainability based on the ÖGNI convention measures M5 and M7, follows the same trend as focusing on final energy reduction. Although measure M3 clearly shows a reduction potential in final energy demand, the optimization of ÖGNI overall target achievement by this measure depends on the selected alternative of the measure. Measure M2 acts similarly. While the measures M6 and M8 are not suitable for optimizations of ÖGNI target achievement at all.

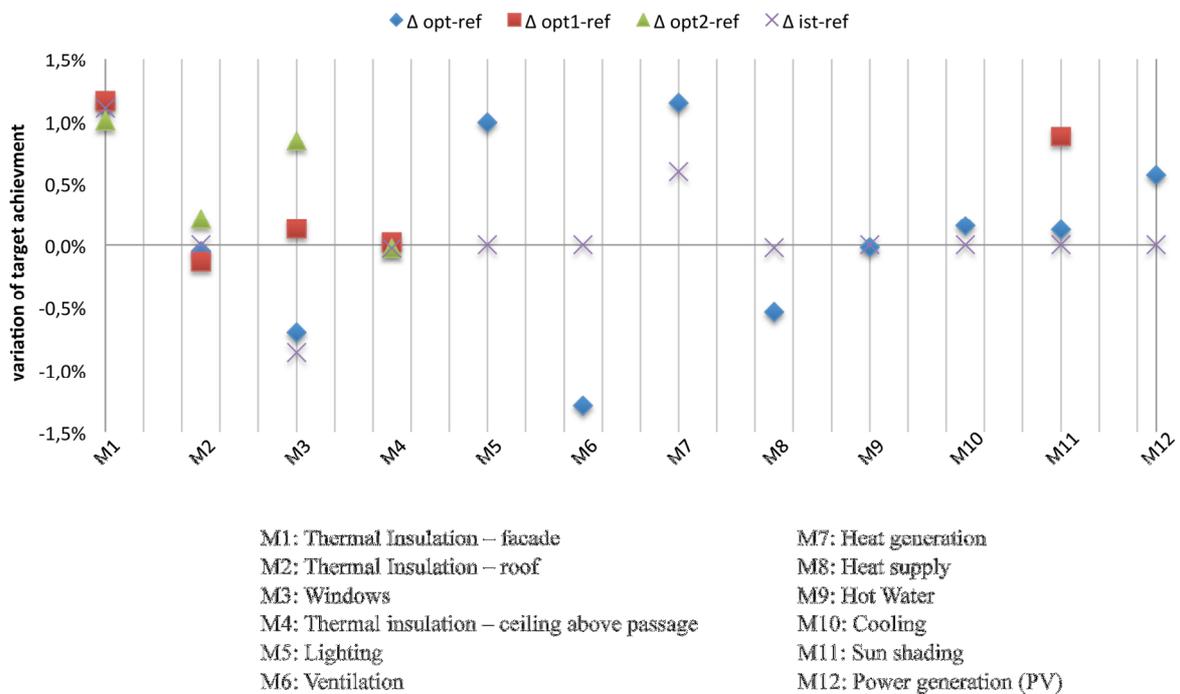


Figure 6. Influence of different measures on ÖGNI target achievement

## 5. Discussion

The evaluation of several design options and related measures is still connected with a rather high workload in early planning stages. Investigations using a systemic approach reveal the important role of the methods LCCA and LCA in the improvement of the sustainability performance of buildings (Kreiner & Passer 2012) and the related measures. To picture the evaluated measures and to allow a quick estimation of the optimisation-suitability of these measures the variation in LCA and LCCA are summed up in one figure (Fig. 7). Depending on which parameter – in particular LCCA or LCA – needs to be improved, various measures have to be applied. Fig. 7 describes the variation between reference measure and optimization measure as well as their correlation in LCA (abscissa) and LCCA (ordinate). The five areas shown can be described as follows:

- Area I: defines measures that are suitable to optimize LCCA and LCA respectively
- Area II: defines measures that are suitable to optimize majorly LCCA
- Area III: defines measures that are suitable to optimize majorly LCA
- Area IV: defines measures that cause a trade-off between LCCA and LCA by optimizing LCCA and LCA. The sum of LCCA and LCA results however shows optimization potential of the measure
- Area V: defines measures that are not suitable for LCCA and LCA optimization

Prior assessment goals have to be optimized to ensure the fulfillment of stakeholder requirements on the one hand while improving of LCCA or LCA in early planning stages on the other (e.g. reduction of end energy or heating demand, minimum of construction costs or highest ÖGNI target achievement). For example measure M7-opt (air to water heat pump) is suitable to reduce the building's final energy demand and to increase LCA as well as ÖGNI overall performance. In contrast M7-opt is not suitable to improve neither LCCA, nor use-performance. Possible trade-offs between stakeholder goals and their influence on ÖGNI overall assessment need to be taken into account, when choosing one measure.

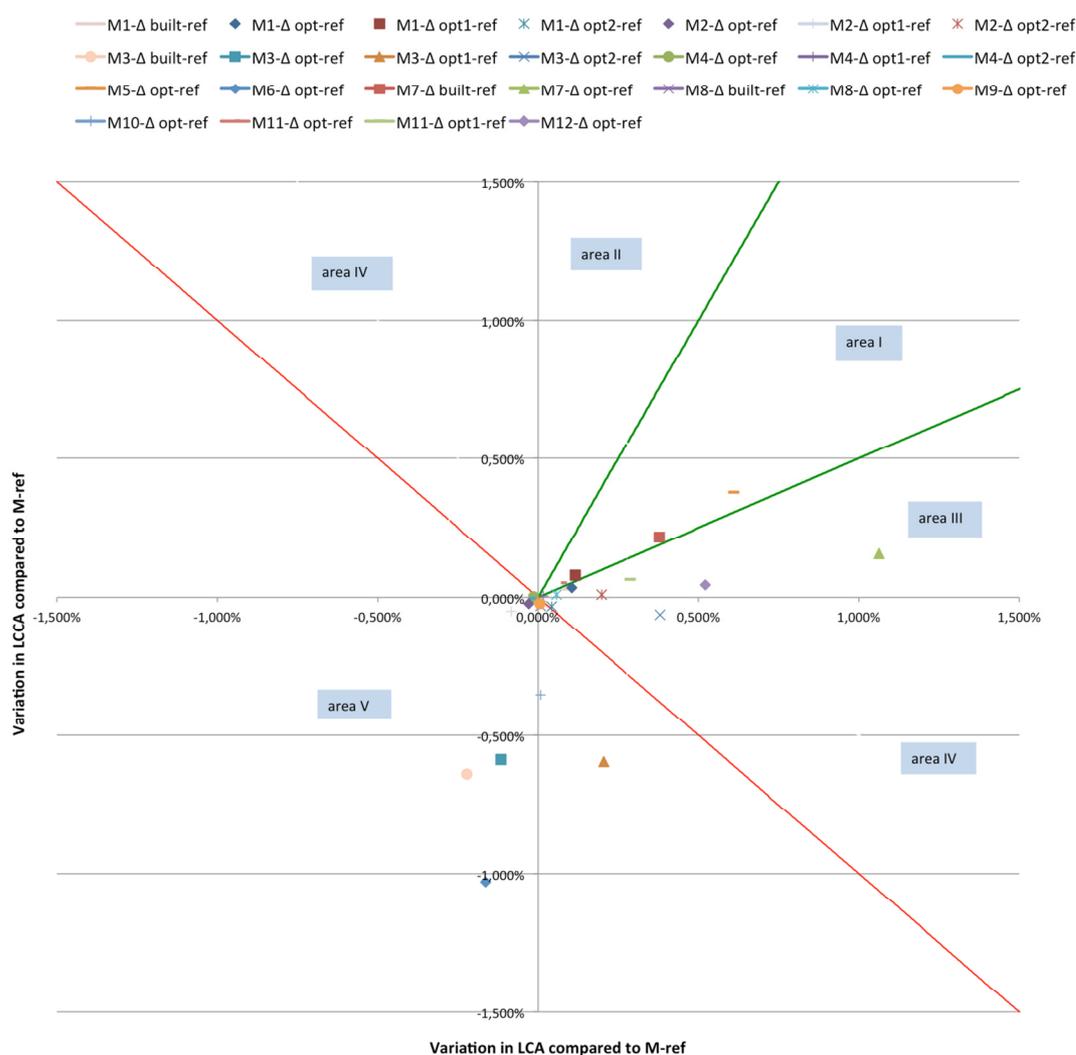


Figure 7. LCCA and LCA improvement-suitability of each measure



Further the results show the important role of technical equipment in both assessment methods – LCCA and LCA. Due to a current lack of LCA-data the environmental impact of technical equipment in this case study is based on a simplified assessment. However, based on the findings in Passer (Passer, Kreiner, et al. 2012) a more detailed consideration of technical equipment is strongly recommended for future investigations.

## 6. Conclusions

This paper presents a new approach to improve the sustainability performance of buildings. The results indicate that the presented model is suitable to identify the pros and cons of several measures for the improvement of building sustainability. Using a systemic approach also allows the highlighting of the trade-offs between different parameters.

In order to decrease the high workload in the context with systemic building improvements, there is a need to operationalize the presented optimization process by an appropriate IT-Tool.

Integrating a systemic approach in BIM (Building Information Modeling) could be one future way for the improvement of the sustainability performance of buildings. Translation of existing methods – depending on stakeholders – in a manageable form during early planning process, is an important requirement for operationalizing the approach presented in this paper.

## References

- CEN, 2010. *ÖNORM EN 15643-1 Sustainability of construction works - Assessment of buildings, Part 1: General Framework.*
- CEN, 2011. *ÖNORM EN 15643-2 Sustainability of construction works - Assessment of buildings, Part 2: Framework for the assessment of the environmental performance,*
- CEN, 2012. *ÖNORM EN 15643-4 Sustainability of construction works - Assessment of buildings, Part 4: Framework for the assessment of economic performance,*
- Cole, R.J. et al., 2005. Building Environmental Assessment Tools: Current and Future Roles. In *World Sustainable Building Conference 2005.*
- Cole, R.J., 2011. Environmental Issues Past, Present & Future: Changing Priorities & Responsibilities for Building Design. In *SB11 Helsinki.*
- Dzien, A., 2011. *Sensitivitätsanalyse des ÖGNI Nachhaltigkeitszertifizierungssystems unter Berücksichtigung der internen Zusammenhänge der Bewertungskriterien.* Available at: [http://sowibib.uibk.ac.at/cgi-bin/xhs\\_voll.pl?UID=&ID=94770](http://sowibib.uibk.ac.at/cgi-bin/xhs_voll.pl?UID=&ID=94770).
- EU, 2010. *RICHTLINIE 2010/31/EU DES EUROPÄISCHEN PARLAMENTS UND DES RATES vom 19. Mai 2010 über die Gesamtenergieeffizienz von Gebäuden,*
- Girmscheid, G. & Lunze, D., 2010. *Nachhaltig Optimierte Gebäude: Energetischer Baukasten, Leistungsbündel Und Life-Cycle-Leistungsangebote,*



- Haapio, A. & Viitaniemi, P., 2008. A critical review of building environmental assessment tools. *Environmental Impact Assessment Review*, 28(7), pp.469–482. Available at: <http://linkinghub.elsevier.com/retrieve/pii/S0195925508000048> [Accessed March 20, 2014].
- Hafner, A., 2011. *Wechselwirkung Nachhaltigkeit und ( Bau- ) Qualität – Systemische Betrachtung des Zusammenspiels von Nachhaltigkeitsaspekten und Kriterien der ( Bau- ) Qualität im Sensitivitätsmodell und in der Analyse von beispielhaften Gebäuden Dissertation : Annette H.* TU München.
- Hunkeler, D.J. et al., 2008. *Environmental life cycle costing*,
- Kreiner, H. & Passer, A., 2012. Interdependency of LCCA and LCA in the assessment of buildings. In *Third International Symposium on Life-Cycle Civil Engineering*. TAYLOR and FRANCIS GROUP, pp. 1794–1801.
- Landesimmobilien-Gesellschaft\_mbH, 2010. *Bau- und Ausstattungsbeschreibung Karmeliterhof*,
- ÖGNI, 2009. *Kriteriensteckbriefe NBV09 AUT 01*,
- ÖN\_H\_5055, 2011. *Energy performance of buildings - Documents relating to the energy certificate - Findings, expertise, advice and recommendations*,
- Passer, A. et al., 2010. Genormte Nachhaltigkeit. In *envoa 2010*. p. 10.
- Passer, A., Mach, T., et al., 2012. Predictable Sustainability ? The role of building certification in the design of innovative façades. In *Advanced Building Skins*. p. 14. Available at: [https://online.tugraz.at/tug\\_online/voe\\_main2.showMask?pPersonNr=1035&pCurrPk=65235&pVtKbz=BKT&pStatus=A&pSiteNr=1004600](https://online.tugraz.at/tug_online/voe_main2.showMask?pPersonNr=1035&pCurrPk=65235&pVtKbz=BKT&pStatus=A&pSiteNr=1004600).
- Passer, A., Kreiner, H. & Maydl, P., 2012. Assessment of the environmental performance of buildings: A critical evaluation of the influence of technical building equipment on residential buildings. *The International Journal of Life Cycle Assessment*, 17(9), pp.1116–1130. Available at: <http://link.springer.com/10.1007/s11367-012-0435-6> [Accessed August 3, 2013].
- Schalcher, H.R., 2008. *Systems Engineering*, Institut für Bauplanung und Baubetrieb, ETHZ.
- Schneider, C., 2011. *Steuerung der Nachhaltigkeit im Planungs- und Realisierungsprozess von Büro- und Verwaltungsgebäuden*. PhD, TU Darmstadt.
- Thomas, E. & Köhler, A., 2011. Strategien zur Prävalenz von Kriteriensteckbriefen. Richtig investieren: Maßnahmen für eine DGNB Zertifizierung. *Greenbuilding*, 10, pp.25–27.
- Vester, F., 2008. *Die Kunst vernetzt zu denken: Ideen und Werkzeuge für einen neuen Umgang mit Komplexität*,
- Wallhagen, M. & Glaumann, M., 2011. Design consequences of differences in building assessment tools: a case study. *Building Research & Information*, 39, pp.16–33. Available at: <http://dx.doi.org/10.1080/09613218.2010.513210>.
- Wittstock, B., 2012. *Methode zur Analyse und Beurteilung des Einflusses von Bauprodukteigenschaften auf die Nachhaltigkeitsbewertung im Rahmen der Zertifizierung von Gebäuden*. Stuttgart: Fraunhofer Verlag.
- World Commission for Environment and Development (WECD) (1987) Our common future. United Nations, New York