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Integration of Energy and Material Performance of Buildings: I=E+M

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ABSTRACT

A new methodology is proposed to asses integral performance of building with respect to energy and materials requirement over the building life cycle. Because the method builds on existing methods for Energy Performance and Materials Performance of Buildings, as defined by Dutch National Building Code, it provides an easily applicable method that allows optimized building design with respect to environmental impacts. Two case studies, one for building renovation and one for new Near Zero Energy Building show the advantages of integral assessment. Extending this approach for building assessment to other countries seems a logical step as it gives designers a better insight in total building performance.

Keywords: *green rating tool, design process, policy and regulation*

1. INTRODUCTION

The introduction of an energy performance requirement in the building regulations in Europe has resulted in major improvements in the energy efficiency of new buildings. Governed by the framework of the Energy Performance of Buildings Directive (EPBD Recast) each EU member state has formulated a methodology for energy performance evaluation for different building types. These calculation methods and performance standards, have been implemented in the national building regulations in each country. This legislation has been very successful in reducing the energy demand of buildings and in stimulating technological development for energy-efficient energy systems, building insulation and renewable energy. As a result the energy demand of new buildings has been reduced by a factor 10-100 since the 1970's. Moreover, from the year 2020 onwards all new buildings in the EU will have to conform to a "near-zero energy" (NZE) standard.

Now that NZE becomes the new standard, the role of building materials and embodied energy or related CO2-emission is becoming more and more important. It is recognized that a focus on energy efficiency only, entails a clear risk of having buildings not necessarily performing very well with respect to other environmental criteria.

However, a broader assessment of the environmental impact of buildings, including materials, is not done regularly yet. Already for a long time there exists within the building community a great demand for methods to support the selection of environmentally benign materials for buildings. Formerly, lists of "preferred materials" or "materials to be avoided" were used. Although such lists are easy to use, the draw-back is that they do not allow for performance-based building design and optimization of the design with respect to materials choice.

In the research community Life Cycle Assessment (LCA) is a broadly accepted methodology to assess the environmental impacts of products . This LCA method has been applied to buildings as well (see, for example, ref. However, among architects, technical consultants and construction companies the use of Life Cycle Assessment for building design and building maintenance is no common practice yet, mainly due to the relative complexity of LCA tools.

In order to fill this gap a process was started 20 years ago in the Netherlands to develop an LCA-based calculation method which was specifically focused on buildings and relatively easy to use. Moreover, this calculation method was meant to become part of the National Building Code, just like the energy performance method. Next to a calculation method, a national LCA database for building materials was set up, providing the necessary data for the assessments. As a result the so-called "material performance assessment of buildings" became obligatory for new buildings in 2014. Important is that the new method is restricted to only the materials used in the construction

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and maintenance of the building. This restriction was applied because the operational energy consumption of buildings is already governed by the existing Energy Performance standard.

So effectively there are now in the Netherlands two different performance indicators: one for the energy consumption during building use and one for the environmental impacts from materials. This raises the problem, that for designers it is difficult to determine the optimal solutions with respect to energy systems and the selection of materials with an impact on energy efficiency. For example the installation of solar panels or the addition of extra insulation to a building will result in a negative effect on the material performance due to additional materials, while on the other hand they improve the energy performance of the building. As the two indicators have an entirely different way of "impact assessment" and of normalization they cannot be compared or balanced against each other.

From a scientific point of view it would be quite logical to consider all environmental impacts from the building life cycle in one assessment system, and not divide it in two separate, incomparable assessments. On the other hand the building sector is very much accustomed to the use of energy performance methods and standards and a change towards an entirely new methodology would be problematic. In order to tackle this problem, we have developed a new framework to integrate the existing assessment methods for energy and materials performance , in such a way that their respective results are aggregated into a single indicator. In this method the LCA impacts of operational energy consumption are calculated and combined with the LCA results of the building materials, into a single impact score: I = E +M.

Below we will first outline the setup of the two existing assessment methods and describe how they were combined into a single, aggregated indicator. Then we will discuss some practical examples assessed with the new methodology and draw some conclusions.

2. EXISTING METHODS FOR ASSESSMENT OF BUILDING PERFORMANCE

2.1 Energy performance of buildings (EPG)

The method for calculation of the energy performance of buildings has been set up differently in each European country. In the Netherlands the method called "Energie Prestatie van Gebouwen" (EPG) is based on a quite detailed energy balance for the building, together with a typical meteorological year and a standardized building use . Local energy conversion systems (e.g.PV systems) are modelled with either standardized or customized conversion efficiencies.

As result from these model calculations the yearly energy consumption is determined in terms of the quantities of final energy carriers entering the building (i.e. electricity, natural gas, heat from district heating, biomass). The final energy consumption values are converted into equivalent primary energy requirements and normalized to a standardized primary consumption for the considered building type, thus resulting in a dimensionless Energy Performance Coefficient (EPC).

According to the present building standards a new residential building must have an EPC of 0.4, which corresponds to a primary energy demand of 60 kWh/m2 for a typical row house.

2.2 Material performance of buildings (MPG)

The evaluation method called "MilieuPrestatie van Gebouwen"(MPG) is a relatively new, standardized method to assess the environmental impacts of the materials used during the life cycle of a building. This life cycle includes resource winning and production of building materials as well as the construction, maintenance and decommissioning of the building. Also energy requirements during construction and decommissioning are included. The assessment is based on LCA methodology and all data about the building materials are derived from a national database of environmental impact data (Nationale Milieu Database, NMD) which has producer-specific and more generic data for building materials and products. This database is managed by an independent organization which also safeguards the quality of LCA data submitted by producers.

Note that energy requirements for production of materials ("embodied energy"), as well as GHG emissions from material production ("embodied CO2") are all included in the MPG evaluation. So all effects caused by building construction, maintenance and demolishment, except for operational energy consumption, are in principle covered

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by this method. Within the MPG method, standard values are predefined, for example with respect to the expected service life of buildings: 75 years for residential buildings and 50 years for non-residential buildings. More importantly the MPG definition document prescribes the impact assessment method that needs to be used. It was decided to perform the impact assessment in the first step on the basis of the CML method for Life Cycle Impact Assessment which discerns 10 impact categories. Because the assessment method has to be useful for building designers, a second step is applied in which all impacts are aggregated into one single impact score, with weighting factors based on the so-called "shadow price" for each impact category. The shadow price (in €) was set equal to the virtual cost to avoid or prevent the damage of an environmental impact. No normalization is performed.

With this method the environmental impact is expressed into one final score, using the functional unit prescribed by the MPG, as "€ per m2 per year".

3. NEW METHOD: INTEGRAL PERFORMANCE OF BUILDINGS

It is not always convenient to have two different assessment systems and performance indicators when actually it is the environmental life cycle performance of the building that one would like to consider. For an integral performance indicator we therefore take the life cycle methodology as starting point. The material performance indicator (MPG) is already evaluated according LCA methodology, so we need to assess the impacts of operational energy consumption (i.e. energy consumption during the utilization of the building) with the same impact assessment method. The amounts of energy consumed may then be derived from the energy performance calculation (EPG).

This sounds fairly simple, but it should be done very carefully in order to avoid double counting or not accounting some material or energy flows. For that we have to take a close look at the system boundaries defined in the two respective assessment methods.

We discern 5 different boundaries which are relevant for our considerations:

- the building boundary, where also energy flows entering the building are being measured (energy metering);
- the project boundary (i.e. a group of buildings with collective energy services);
- the system boundary for Energy Performance of Buildings calculation (EPG);
- the system boundary for energy distribution within the Netherlands;
- the system boundary for assessment of Material Performance of Buildings (MPG).

Whereas the Material Performance evaluation considers in principle a global system boundary, in line with general LCA methodology, the method for Energy performance considers a national or even subnational system boundary. Winning and distribution of natural gas, biomass and waste is not accounted explicitly in the EPG method, and production of electricity is only accounted with a standard conversion factor for primary energy and for CO_2 emission. Also notice that environmental impacts from the energy distribution system are outside the scope of both the EPG and the MPG methods.

For all energy conversion processes it should be considered carefully whether or not their material and energy flows are accounted in one of the methods. For example if we look at the conversion of natural gas in a gas boiler within the building we can notice that the inflow of gas into the building is well accounted for by the EPG method because it carefully models the efficiency of the heating system. But the emissions from the combustion process to the atmosphere (i.e. CO_2, NO_x) and to the water (acids) are not accounted for anywhere.

So, in order to obtain a complete assessment of environmental impacts, on the basis of EPG and MPG, we consider for each energy flow entering the building:

- Are all upstream impacts from the energy winning, conversion and distribution activities taken into account?
- Are all emissions and material inflows for the energy conversion processes within the building taken into account?

In practical terms this means that for each final energy carrier that may be consumed during utilization of the building we have to establish an impact factor (or a set of impact factors) which allows us to assess all

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environmental impacts of the energy consumption using this carrier. For energy carrier inflow into the building (Ei) we have defined the corresponding environmental impact EPGi* as:

$$EPG_i^* = IF_i \times E_i,$$

Equation 1

where

E_i = final energy consumption for energy carrier "i" (in MJ), as derived from EPG

IF_i = environmental impact factor for energy carrier "i" (impact unit per MJ)

E_i^* = environmental impact for energy carrier "i" (in impact units)

We determined impact factors for a number of major energy carriers, all for the context of the Dutch energy supply system [see ref. [16] for details].

If we add up the EPG*-results over all relevant energy carriers flowing into the building (e.g. gas and electricity) a total environmental impact score for the operational energy consumption of the building EPG* is obtained:

$$EPG^* = \sum_i EPGi^*,$$

Equation 2

Finally the integral environmental impact of the building is defined as:

$$IPG = MPG + EPG^*$$

Equation 3

The IPG score gives the desired score assessing the environmental impacts for operational energy consumption and the impacts related to materials use. As mentioned, impacts of embodied energy for materials are included in the MPG score.

Now for LCA practitioners and scientists in general the described method might sound as a cumbersome way to obtain results that can also be found by way of a standard LCA approach. The important difference, however, is that in our approach we make use of the results that are obtained from standardized calculation methods that are implemented in the Dutch Building Code and which are therefore familiar to the building community. In other words, without setting existing methods aside, we are able to derive integral impact scores for the building performance by applying just a few simple additional calculations. Moreover, the extra calculation step can easily be included in existing software tools for energy and material performance evaluation, like GPR Building and in that case requires almost no extra efforts from building designers.

In the next section we will explain what new insights can be gained from this new assessment tool for a case study on the construction of new houses. Elsewhere we have also discussed a case study for building renovation.

4. CASE STUDY: NEW NET ZERO ENERGY BUILDINGS (NZEB)

The IPG methodology should also be very useful for optimized design of new buildings especially as these have to meet the Net Zero Energy Building (NZEB) standard.

As a reference we start with a row house, which is built to comply with the draft NZEB standard. This house has a usable floor area of 124 m2, R-values for the building envelope of 6-7 (m2.K/W), triple glass windows (U=1.1 W/m2.K) and a high-efficiency gas boiler for heating and DHW supply. In order to make it NZEB it is also equipped with about 20 m2 of PV panels (3 kWp) and a Solar Hot Water system (2.5 m2).

First the effects of increased insulation thicknesses in the façade and roof was investigated. A feeling among designers may be that increasing insulation is not good for the environment because of the higher environmental load of the required materials. From our analysis we can observe that the contribution from the insulation material is never more than 3,5% of the total building's impact, even if we would go to an unrealistically high R-value of 20 m^2.K/W (see also ref.[16]).

But what is also clear is that the energetic effects of insulation beyond R=5, are very small. Partly this is due to type of house (row house) with only 98 m2 of exterior surface area. For a free-standing house the energy saving effects would have been larger. So there is no immediate reason to save on insulation thickness, because of concerns about the materials impact. The optimal thickness can be determined for each building type and climate, by using an analysis as shown above.

More significant effects can be seen in the next set of calculations were we look at solar energy installations. In Figure 1 we depict our NZEB house in 3 variants: 1) without solar energy installations, 2) with only photovoltaic panels (20 m^2, 3kW_p) and 3) a solar hot water installation of 2,5 m^2 and a slightly smaller PV panel area (17,5 m^2, where part of the PV panel area is replaced by solar hot water collectors. Figure 1 is a bit complicated because the PV panels generate more electricity than is used by the building (excluding domestic appliances!), which results in a negative impact from the PV generation. For this reason we show in a separate bar in Figure 1 the IPG-value, which is the sum of all impacts: IPG = MPG-building + MPG-solar + EPG*-gas + EPG*-electricity.

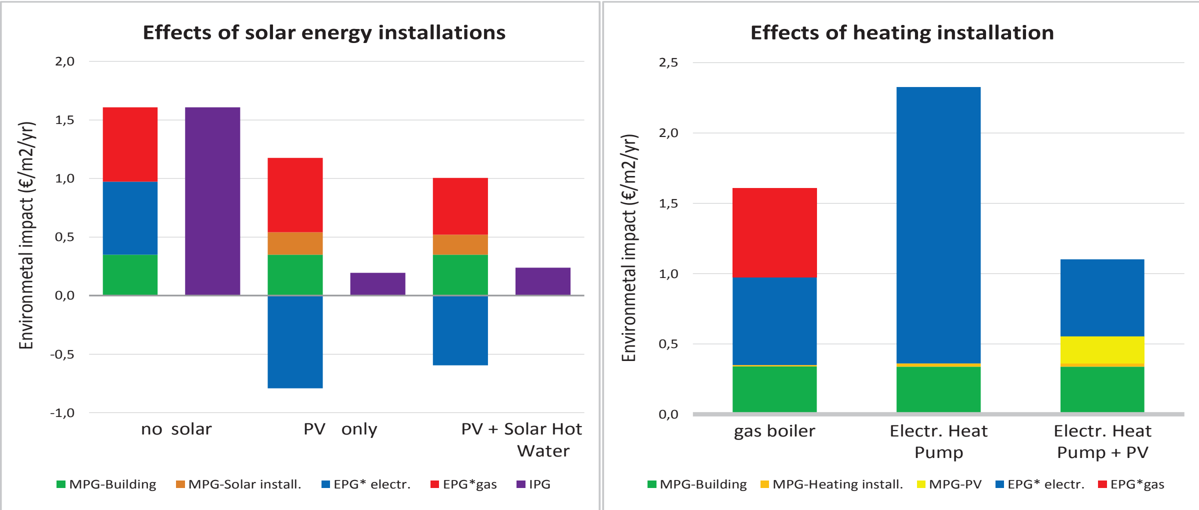

Figure 43 and 2: Effects on total environmental impact of building in relation to choice of solar energy installations and choice of the heating installation

Although the MPG-value from the PV installation is quite significant, about 50% increase in total MPG, the overall effect of the PV is very positive: the IPG-value is reduced from 1,61 to 0,19 €/m^2/yr. The replacement of 2,5 m^2 of PV panels by a solar hot water collector results in a slightly worse overall impact (0.24 €/m^2/yr). In this case the choice for a solar hot water system gives no improvement in environmental terms.

Figure 2 shows the effects of choosing a different type of heating installation, either a gas boiler or an electrical heat pump (ground water as source). Because the heat pump uses a substantial amount of electricity (from the grid) this has a significant negative effect. However if we add a PV installation (20 m^2) the total impact is about 30% better than with only a gas boiler (and no PV). Nonetheless, the situation with gas boiler and PV (Figure 1) if found to be most environmentally friendly choice for this building. To make the all-electric variant of this building the most environmentally friendly we need to install an additional area of PV panels.

One conclusion is that the choice of installation for heating or for renewable energy generation has more effect on the total environmental impact than the level of insulation, beyond a certain adequate insulation level.

5. DISCUSSION

It is clear that many assumptions affect the precise outcome of our calculations. Therefore the reader should be quite careful to extend the results beyond the scope and background data of our study. On the other hand the more general conclusions with regard to energy-related versus material-related impacts of façade and roof insulation should be fairly robust. Also our conclusion about the large effects of the choice of energy conversion equipment for heating and the effectiveness of PV systems should be reasonably robust as long as the background energy supply system is not entirely different from the Dutch system (for instance 100% hydro-electricity).

6. CONCLUSIONS

A methodology has been developed that makes it possible for building designers in The Netherlands to make an integral assessment of the environmental impacts of a new building or for building renovation projects. The new aspect is that our method is built on two existing building assessment methods that are already in use in the building community and which are part of the Dutch National Building Code. Because it builds on existing methods it is very easy for the building designer to determine the integrated environmental impact indicator for his plans, without necessity to learn complicated LCA tools.

In a number of typical examples we have shown the added value of the integrated assessment when designing a new construction at NZEB level. All-in-all the impact from materials choice and material amounts increases if we go towards near zero energy levels. For photovoltaic panels the material-related impact is fairly high (in comparison with other building components) but overall PV systems show a very large beneficial effect on the life cycle performance of the building.

Our general conclusion is that the proposed methodology to determine integrated environmental impacts provides valuable new insights for building designers. The new methodology and the related tools, will assist designers in making the right choices for specific buildings in specific circumstances. In our opinion it would be fruitful to develop and apply comparable methodologies in other countries. Our approach has the advantage that it provides a relatively easy assessment system for building designers without the need to learn new LCA tools which are not specific for buildings.

In view of the EU policy objectives to reduce the broader environmental impacts of buildings it would be advisable to develop further convenient methods and tools for life cycle impact assessment *at the building level*, such as described in this paper. Moreover, such tools should be easily applicable, so that they will be used in practice by building designers that wish to optimize their design with respect to integral environmental quality.

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