Identifying environmental improvement potentials of residential buildings

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ABSTRACT

Within the context of the Integrated Product Policy (IPP) [1], the research project "Environmental Improvement Potentials for Residential Buildings" (IMPRO-Building) was initiated by the European Commission's Joint Research Centre, Institute of Prospective Technological Studies (IPTS), with the aim to reduce the environmental impacts from residential dwellings throughout their entire life cycle. The main objective of the project is to outline the current situation of residential buildings in the EU-25, to assess environmental improvement options for new and existing buildings and to evaluate the improvement potentials from a European perspective.

The project divides into three major tasks. In the first step, an overview of residential buildings in the EU-25 is assembled and the residential buildings are grouped and aggregated into building types within geographical zones.

The second step is based on a generic life cycle building model, from which life cycle models for existing, as well as for newly constructed buildings of above mentioned types are derived. Using these life cycle models, environmental profiles for all building types are generated and environmental hotspots are identified.

These environmental hotspots provide a sound basis for the identification of improvement options and for the quantification of environmental improvement potentials from the European perspective.

Residential buildings in the EU-25

A synopsis of residential buildings throughout Europe provides the adequate basis to investigate the impacts of residential dwellings and to identify environmental improvement options. This synopsis has to be laid out in a way that it can be directly adopted to model the life cycles of residential buildings.

Building types in geographical zones throughout Europe

The residential buildings of the Eu-25 member-countries are aggregated into 73 individual building types. 54 of these types represent existing buildings, while another 19 building types represent currently planned buildings. These residential building types are defined, based on their architectural design on constructional and construction material criteria.

For each of three geographical zones, namely north-, middle- and south- European countries, the relevant building types are identified separately and clustered into 'single-, two-family and terrace houses', 'multi-family houses' and 'high-rise buildings'. The geographical zones are assembled from EU-25 member-countries on the basis of average heating degree days per year. For each geographical zone, are identified.

This overview of European residential buildings is based on comprehensive databases containing technical information of buildings for an extensive building stock throughout Europe. These databases have originally been set up to analyze the technical state of the European building stock.

Analysis of life cycle-based environmental hotspots of residential buildings

The extensive basis of 73 residential building types to perform life cycle assessments, addressing the impacts of residential buildings as well as the challenging task of identifying environmental improvement options from a European perspective, demands for consistency and mechanisms to automate certain procedures when modeling the life cycle of buildings.

Using a generic model for consistent life cycle analyses of buildings

To meet these challenges, a generic building model, providing a common structure for all individual building types has been developed. Within its common building structure, this generic model contains all relevant construction materials that are found in either of the building types to be modeled. Parameters are extensively used to define the actual life cycle model and to efficiently adjust the generic model to fit to the respective building type.

The life cycle model divides into two distinct model versions. One represents the life cycle of an existing building, where the construction phase is not considered, but the use phase and the end of life (see Figure 1). The second version represents new buildings, where the construction phase is also incorporated into the building's life cycle (see Figure 2). This distinction into two model versions supports the identification of the decisions that can be made today. Promoting retrofit measures with existing buildings, for instance, presents a feasible decision to be made, while past construction actions do not provide space for any improvement today. Consequently, the construction phase is not considered for existing buildings. It is, however, important to consider the structure and the materials used for construction, in order to be able to give statements considering retrofit options and to be able to account for the building's demolition.

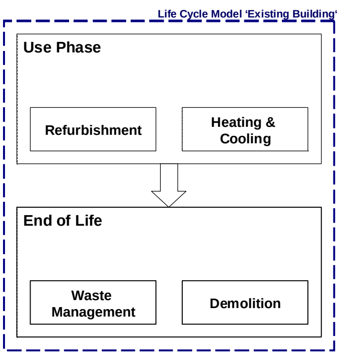

Figure 1. System boundaries and considered life cycle phases for existing buildings.

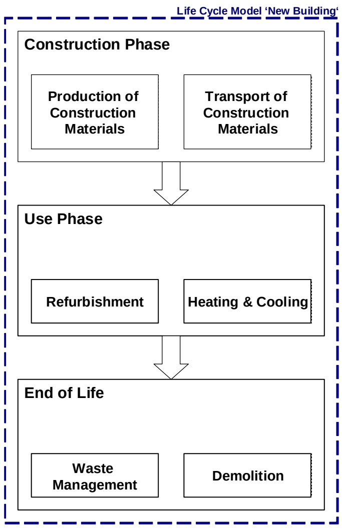

Figure 2. System boundaries and considered life cycle phases for new buildings.

Building model layout and boundary conditions

The generic model, and consequently the individual building type models bear a common structure of construction elements that assemble the required building materials of the respective part of the building. These construction elements are the roof, the exterior walls, the interior walls, the floors and ceilings, the windows and finally the basement. The life cycle phase of the construction of new buildings considers the construction materials used, as well as the transportation of the materials on the level of the construction elements of the building.

Following the objective of the study, of investigating improvement options for residential buildings that are based on decisions considering the selection of constructional alternatives or constructional practices to be encouraged, the construction materials represent European average datasets. The use of such European datasets that describe average technology data for the manufacturing of construction materials and European boundary conditions, assures that derivations in background data do not bias the basis for the decisions to be made within the scope of the study.

Considered life cycle phases and their specific aspects

Within the use phase, two major aspects of the utilization of a residential building in Europe are considered. These are, on the one hand, refurbishment actions that are conducted to maintain the function of the building, in general without changing the energy performance of the building. While retrofit measures describe actions that are taken with the aim to improve the performance of the building, it is known that some retrofit actions are taken in conjunction with refurbishment actions that have to be conducted in order to maintain the buildings' function. An example of such retrofit actions that go in line with refurbishment actions are the regular exchange of windows, where the existing windows are replaced with 'modern' windows that reduced heat transmission values. Another example is the insulation of the roof at a point, when the battening and the tiles have to be replaced. These measures are handled as refurbishment, in order not to overestimate certain retrofit actions as improvement options.

On the other hand, the heating energy demand, as well as the cooling energy demand, which is believed to gain significance in the future, is considered. Within the model, the heating energy demand is calculated from the energy balance that is based on heat transmission coefficients for the individual construction elements of the building type. The cooling energy demand, on the other hand, is provided as average values for each geographical zone, thus incorporating the fact that most indoor cooling devices within residential buildings work on a per-room basis. This means that the use of indoor cooling equipment in different building types does not generally differ.

The end-of-life phase of the models considers both, wastes from the demolition of the entire building, as well as wastes from the exchange of materials due to refurbishment actions. Recycling rates, shares for the deposition onto inert materials landfills, as well as incineration and other end of life routes are considered on the basis of average data for the construction sector throughout Europe.

One objective of the study is to provide information upon which recommendations for favorable actions, related to the improvement of the overall environmental performance of residential buildings may be given. Therefore, a maximum timeframe for the life cycle assessment of 40 years has been chosen. While this does not implicate that all buildings are expected to be demolished no later than 40 years from now, it is believed that no statement upon the development of the residential building sector beyond these 40 years can be made.

Methodology of the Life Cycle Impact Assessment

For both, existing, as well as new buildings, the impact assessment of the life cycle models is conducted and environmental hotspots within each building type need to be identified. The impact assessment is conducted using the CML 2001 characterization model [2] and the considered environmental indicators are the use of fossil primary energy, the use of renewable primary energy, as well as the impact categories 'global warming potential' (GWP_{100}), 'acidification potential' (AP), 'eutrophication potential' (EP), 'photochemical oxidant formation potential' (POCP) and 'ozone layer depletion potential' (ODP). These environmental indicators describe environmental effects that are, among others, generally considered as relevant within the current environmental discussions [3].

Life cycle impact assessment of three exemplary building types

The life cycle impact assessment (LCIA) of three building types is displayed in order to demonstrate the outcome of the analysis of the current situation of residential buildings in Europe. Those examples are:

- A ten-storey high-rise building type (concrete-based structure) from the south of Europe that has been built in the 1970s and is expected to be in use for another 20 years,
- A single-family building type with a brick masonry structure from central Europe that has typically been built between the 1940s and 1980s and that is expected to used for at least another 40 years, and
- A four-storey multi-family building type with an insulated brick masonry structure from the north of Europe that is planned to be built in the near future and on the basis of the current construction practice.

For the comparison of different building types, as well as of different construction elements within one building type, the results of the LCIA are presented on a per-square-metre-and-year-basis.

Comparison of the life cycles of three residential building types

Figure 3 illustrates the contribution from different life cycle phases to the global warming potential of the described building types. As described above, neither the high-rise building (left), nor the single family building (centre) contain a construction phase, as they represent existing buildings. The multi-family building (right), on the other hand, includes a construction phase. From Figure 3, it is clear that the heating and cooling energy consumption has the by far greatest impact on the building's life cycle. The construction phase, as well as the refurbishment measures taken and the end-of-life, on the contrary have rather minor impacts on the GWP_{100}. The 'incorporated GWP', having negative values, is in part due to wood, which is, in some sections of residential buildings, extensively used as a construction material. Another source for incorporated GWP is the use of renewable materials as fuel in residential heating. Consequently, the net value for the GWP_{100} is clearly below the currently displayed values.

From this graph (Figure 3), it can be stated that these building types, especially the single-family building type and the multi-family building type do not represent current best practice in construction, where the energy consumption for heating were significantly lower. For existing buildings, taking refurbishment measures usually reduces heat losses significantly. The reductions in heating energy losses due to refurbishment actions are considered in the displayed figure.

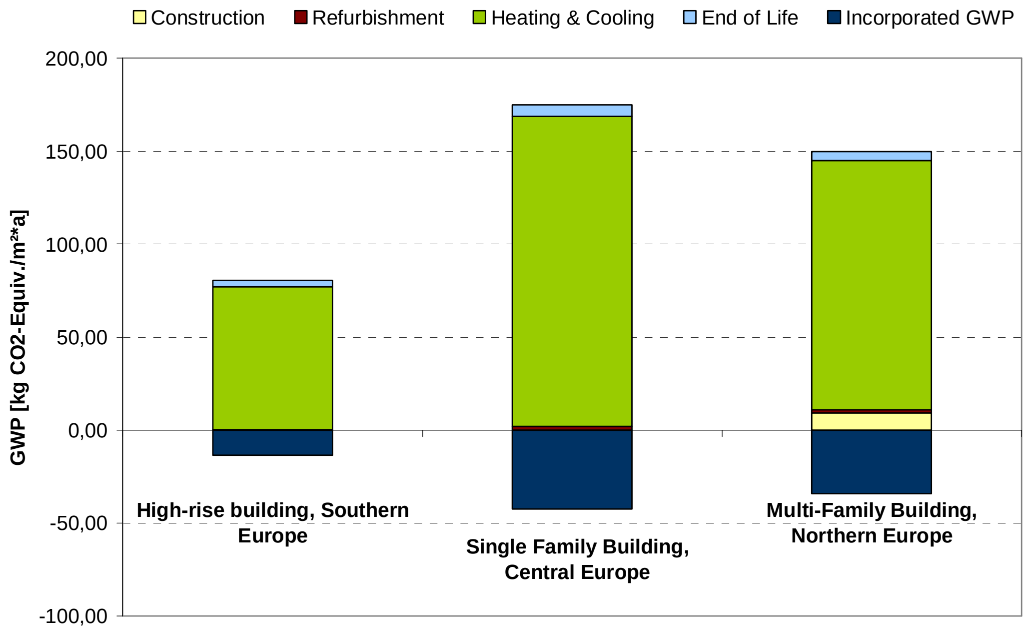

Figure 3. LCIA results for the global warming potential from the life cycles from three residential building types throughout Europe. Displayed: contribution from different life cycle phases in kg CO_2-Equivalent/(m²*a).

Analysis of the contribution to the life cycle impact from individual construction elements

Following the objective of the study to identify environmental improvement options, the individual building types are evaluated in a way that identifies the life cycle impacts from individual construction elements. Figure 4 displays the contributions from all construction elements to the global warming potential for the above described multi-family house from northern Europe. Some types of energy losses may not be allocated to individual construction elements within the context of an entire building and are presented separately.

From the graph in Figure 4, the impact from the manufacturing and demolition of construction elements, especially of those with high masses can be identified. The major impacts, however originate in ventilation, which stands for energy losses due to leaking window- and doorframes and other structural weak points. While the effects of ventilation may not be directly allocated to the windows, the heating losses of ventilation may be reduced by choosing adequate window types. Other highly significant impacts originate in losses from the heating system. These losses are directly related to the overall energy consumption of the building.

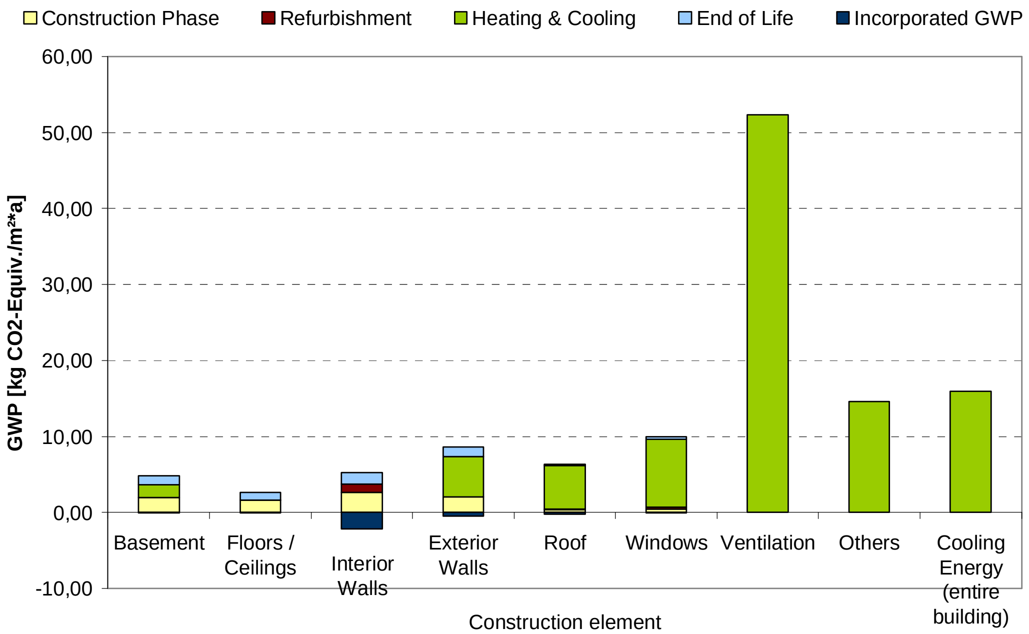

Figure 4. Contributions from construction elements and energy consumption to the global warming potential of the above described multi-family building type (North Europe). Note that the energy consumption from 'ventilation', 'others' and 'cooling energy' may not be allocated to individual construction elements and are therefore presented separately. Displayed: contribution to GWP in kg CO_2-Equiv./(m^2*a).

Conclusions

Using a generic building model that has been designed to incorporate all relevant aspects of residential building practice in Europe proved to be a viable way to approach the task of addressing the environmental impacts of residential buildings. Aiming at evaluating residential buildings throughout 25 European countries, the clustering into 73 building types and a consistent set of background data is an essential precondition for the approach chosen.

The results of the life cycle impact assessment of three exemplary building types show clearly that the use phase is the predominant life cycle phase for residential buildings and that special attention needs to be directed to the reduction of losses of heating and cooling energy. Especially the high environmental impacts from the consumption of cooling energy highlights an issue that is believed to gain significance in the future, as indoor cooling devices will become more available and will be more often used. As the protection from heat can not be accomplished with the same means as protection from cold, strategies and materials specifically designed for serving as summerly heat protection may provide feasible means for improving the environmental performance of the building.

At least for some building types, heating energy losses through ventilation appear to be a major aspect to be addressed for both, the refurbishment of existing buildings, as well as for newly planned buildings. In general, the study shows clearly that options to improve the environmental situation of residential dwellings in Europe exist and that adequate measures can be and have to be taken.

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