

Model analysis for existing buildings' efficient environmental evaluation

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ABSTRACT

Within the framework of EPBD and as a part of a wider initiative to reduce energy consumption a holistic and more complete approach is required for buildings' evaluation. The methodology discussed below is based on the development of an integrated analysis model, which implies, apart of the energy aspect, the environmental and economic evaluation of buildings. The analysis model presented is based on the synergy of different environmental tools such as LCA and ISO 14031 and economic ones such as LCCA towards buildings' compliance with the new regulations and standards. The environmental evaluation of buildings targets on energy consumption and environmental impact by identifying potential improvement options at a life cycle perspective. A data base is constructed containing certain parameters defined by the ENVEST software's requirements which adopts Life Cycle Analysis' methodology for buildings' evaluation and uses "ecopoints" for measuring environmental impact.

1. INTRODUCTION – GENERAL FRAMEWORK

Sustainability is an issue of great importance for the building sector and society. Environmental concern related to building as a topic is rising. At the same time the scope of environmental issues is widening from a single issue discussion, like the energy performance of buildings, into a full integration of all aspects during the whole lifetime of a building and its components. In Europe about 70% of the buildings are residential ones. There are more than 150 million

dwelling and on a European average 50-60% are single-family houses (with significant variations from country to country). The residential and the tertiary sectors together consume more than 40% of the total energy in Europe. The energy in a residential building is used at about 57% for space heating, 25% for hot water and the other 18% for appliances' use and cooking. Over 50% of national waste production comes from the building sector. Moreover buildings use: 40% of total energy, 40% of raw stone, gravel, sand and comparable share of other processed materials such as steel, 25% of wood for construction processes and 16% of total water withdrawals.

In addition, waste amounts produced are comparable in industrial countries to municipal solid waste generation, adding to landfill problems, such as leaching of heavy metals and water pollution. Finally, poor air quality in 30% of new and renovated buildings, having effect to higher incidence of sickness - lost productivity in tens of billions annually.

At the same time there is a growing legal activity on member states related to building sector. Directives cover: products labeling, energy efficient standards, boilers' efficiency, measures to limit carbon dioxide emissions by improving the energy efficiency and the recent directive 2002/91/EC for energy performance of buildings.

Energy Performance (EP) standardisation and legislation is in many European countries considered to be an attractive strategy for increasing the energy efficiency of new and existing buildings. Several countries have already implemented an Energy Performance Regulation (EPR), for instance the Netherlands,

France, Spain, Sweden, e.t.c. or are preparing a new regulation as in Belgium, Denmark, France, Germany, Greece, etc.

Within this legal framework, based on statistical data and adopting the idea of Sustainability, a model analysis is presented below, aiming at becoming an attractive strategy for increasing the energy efficiency and accomplishing a comprehensive evaluation of existing residential buildings.

2. METHODOLOGY ADJUSTED FOR BUILDING'S MANAGEMENT

Sustainable Building is a multicriteria subject relevant to three basic interlinked elements: economic parameters (behind a building an entire industry is based from materials' production, to builders and real estate enterprises), environmental parameters (direct and indirect, for instance direct impacts are those caused by land use, construction processes, demolition and waste management issues and indirect or discreet impacts result from mining, materials' supply including materials' transportation) and social criteria based on human's need for comfort and good living.

The basic concept adopted for building's integrate evaluation is Life Cycle Thinking Concept and the main tool used to support this concept is Life Cycle Analysis (LCA) methodology. The importance of environment-related product information by means of LCA is in that sense broadly recognised and LCA is considered to be one of the tools to help achieving sustainable building practices. LCA as such offers a comprehensive analysis which links actions with environmental impacts. At the same time it provides quantitative and qualitative results and taking into consideration the link between system's functions and environmental impacts it is easy to identify the issues that need improvement.

LCA is a tool for assessing the environmental impact of a product, process or service during its entire life cycle form "cradle to grave". LCA can be used as a decision making tool, for strategic planning and marketing. It is commonly used for identifying the hot spots in the life cycle of the system studied and make the necessary improvement options. It is also used to compare the environmental load from different

systems, products or services. The LCA methodology has been standardised in ISO 14040 to ISO 14043.

LCA implementation to buildings

The main tool used for the model analysis development is LCA and the system studied and analysed in our case is the building. More specific and according to LCA rules the methodology's implementation steps for building's analysis are the following:

- Goal and scope definition: the scope is to achieve a comprehensive environmental evaluation extending over the building's life cycle. At this phase the system's boundaries are defined. More specific the phases included to the system analysed are the following:
 - Construction phase, including mainly materials' consumption, structural and auxiliary materials' production and transportation, electromechanical systems' construction and installation and construction waste management.
 - Maintenance, including: renovation and modification.
 - Use phase, including operations concerning mainly energy consumption: heating, cooling, hot water production, lighting, electromechanical installations and operation (e.g. lifts, pumps), appliances' and office equipment operation.
 - End of life, including: selective sorting out of materials and their possible reuse, building's demolition, materials' recycling and reuse, materials' transport to deposition areas.

It is obvious that for the integrated LCA implementation in the building sector the data required concern life cycle assessment from many different materials and processes. Consequently precise estimations should be taken into account in order to approach the integrated analysis for the buildings' environmental and energy profile. Moreover, the important parameter of energy consumption calculated for the building's life cycle phases is related to the thermal protection. Continuing with the analysis of the framework for the LCA implementation, the following phases are examined:

- Inventory analysis: this stage deals with the input and output flows of all the procedures concerning the building's life cycle. The input flow contains data for materials (type, quantities), energy and water consumption. The output flow contains data for solid and liquid waste and air emissions.

More specific, a database is constructed including input data such as:

- initial building's data: location, operational life, building's type, orientation,
- building's architectural details: number of stories, building's width, length, storey's height, building's perimeter, height, gross floor area, ground floor area, upper floor area, external wall's surface, windows' surface, roof's data, internal wall's surface,
- structural building's elements: materials' consumption, building frame, foundation and soil type, external walls, internal walls, insulation data, upper floor's structure, floors, ground floor's structure, openings (doors, windows), ceiling, other data (glazing ratio, rooflight ratio, internal door ratio, cellular spaces, building's shape, internal decoration),
- building's operations: heating, lighting, water consumption, ventilation, air conditioning, lifts.

In correspondence all the output flows (solid and liquid waste, air emissions) which are considered to have an environmental impact, are also registered per building evaluated (separately for each structural element and operation). The output flows analysis is defined at the phase of impact assessment which follows.

- Impact assessment: at this phase the output flows defined from the inventory analysis is transformed to environmental impacts. The environmental impact categories examined include: climate change, acidification, fossil fuel depletion, ozone depletion, human toxicity to air and to water, waste disposal, water extraction, minerals extraction, ecotoxicity, eutrofication, land use and summer smog. The data for this phase are based on the inventory analysis phase. The impact assessment results will show the contribution of different structural elements and operations to the environmental impact from building's

life cycle. After the impact assessment phase implementation it would be easy to define which structural elements and consequently types and quantities of materials used and which operations cause significant environmental impact.

- Use and application of results – interpretation step: at this phase and after the system's analysis, crucial points are identified in order to focus on the procedures which need to be improved. All potential improvement options are proposed based on the materials and energy flows (inventory analysis phase) and the environmental impacts (impact assessment phase) deriving from the system's comprehensive analysis.

3. SUPPORTIVE METHODOLOGIES, STANDARDS AND TECHNICAL TOOLS IMPLEMENTED TO THE MODEL ANALYSIS

ISO 14031 is a non certified standard which provides adequate instructions and guidelines for efficient indicators' setting. The type of indicators proposed for the efficient results' and data's presentation and communication to third parties are environmental condition indicators (ECI) and operating performance indicators (OPI). The OPIs organize the large amount of primary data needed for LCA and LCCA, while the ECIs are used mainly to express the environmental impacts deriving from LCA implementation. The model's analysis results will be presented per m^2 as well as per inhabitant. Besides, the majority of studies presenting data related to building sector use, as functional unit, the m^2 . As far as the ECIs indicators setting, the environmental indicators are kg equivalents per chemical combination characteristic for the impact category (for instance kg CO_2 equivalents for greenhouse effect, SO_4 equivalents for acidification, CFC-11 equivalents for ozone depletion, etc.).

In order to insert economic criteria and evaluate the improvement options' scenario feasibility the Life Cycle Costing Analysis (LCCA) is adopted. LCCA shares common features and aims compared to LCA, that is seek to assess impacts over the whole life of a building or structure and present the information in a manner which supports decision-making processes.

The purpose of a life cycle costing exercise is usually to aggregate the total capital and operating costs of building systems and components over extended periods of time and then present the figures as relative values, which can be easily compared and assessed against alternatives. LCCA does not explicitly deal with environmental impacts, although it can frequently be used to support environmentally sensitive construction solutions, especially in cases where operating and/or maintenance costs are significant. The most typical approaches to LCCA are those of net present values (NPV) and payback periods. Basically the LCCA's role to the methodology presented is to strengthen the economic criteria and ensure feasibility of improvement scenarios suggested. The LCCA implementation can be technically supported by ENVEST® software.

The software tool suggested for the methodologies' support and implementation is ENVEST® which simplifies the otherwise very complex process of managing buildings with low and controlled environmental impact and whole life costs' estimation (LCCA). The ENVEST® suggests the ecopoints unit for measuring the environmental load. This methodology has been widely accepted over the last years, enabling a Europe-wide LCA of building (BRE, Centre for Sustainable Construction). ENVEST® is the first UK software for estimating lifecycle environmental impacts of buildings at the early design stage. This software considers to estimate the environmental impacts of both the materials used during construction and the energy and resources consumed over the building's life. Using minimal data entered through simple input screens, ENVEST® allows designers instantly to identify those aspects of the building which have the greatest influence on its overall impact. All environmental impacts are measured using a single points scale called Ecopoints, allowing designers to make direct comparisons between different designs and specifications. One hundred Ecopoints are equivalent to the environmental impact of the average UK citizen in one year. This BRE tool is informed by over four years of research into the environmental impacts of different materials in association with the UK building materials industry. The ENVEST® gives also the opportunity to implement LCCA methodology for the building

life cycle.

4. THE CASE STUDY IN AN INSTITUTIONAL BUILDING

The building studied is a 9 storeyed institutional building, with a unique architectural structure, as it comprises a cylindrical shape, glazed facades and partially aluminum cladding on its walls, over a life span of 20 years. The building is located in the campus of the Aristotle University of Thessaloniki, in the city center of Thessaloniki, Greece. The building was commissioned in 1999, it features 9 floors and a ground floor, and houses a number of offices, auditoriums and assembly halls. The total volume of the conditioned spaces is approximately 11,000 m³ whilst the volume of conditioned space of a typical floor is 1,050 m³. The height of the building is 35 metres. The environmental impact is measured with ecopoints separately for each element and operation. The ecopoints are divided to embodied and operational ecopoints. The embodied ecopoints express the environmental impact caused mainly from materials' consumption and the operational ones from operations and energy use.

The embodied ecopoints are influenced basically from two parameters: the type of materials used at the construction stage or at the operation or maintenance phase and the materials' consumption quantity. The total embodied ecopoints from building's life cycle are 31.909. For the environmental load caused by these ecopoints mostly responsible is building's frame construction at about 25%, the upper floor's construction at about 32%, windows at 25% and the other structural building's elements at about 18%. For the environmental load caused by these ecopoints mostly responsible is building's frame construction at about 25%. The term "others" is referring to data concerning foundation, external and internal walls, insulation materials, ceilings, roofs etc. In correspondence the operational ecopoints focus on the building's services. The total operational ecopoints' quantity is 298.253. Before analysing the total operational ecopoints to building's services it is important to notice that operational ecopoints and consequently services are about 90% more responsible for the building's environmental load during its life cycle in comparison to embodied

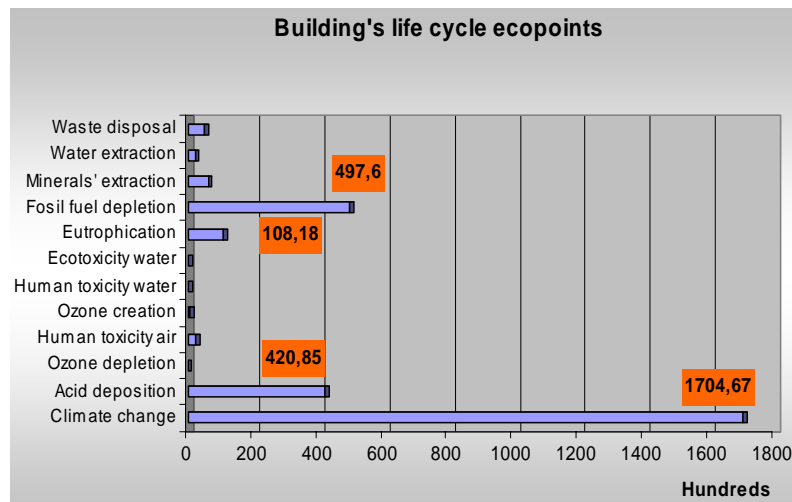


Figure 1: Building's environmental impacts measured with ecopoints.

ecopoints. In detail, the services analysed at the LCA procedure were: heating, ventilation, water consumption operations, ventilation, cooling, lifts' and office equipment's operation. As it was already analysed for the embodied ecopoints the total operational ecopoints from building's life cycle are 298.253.

For the environmental load caused by these ecopoints mostly responsible is the office equipment's operation at about 55%. It is essential to mention that the air conditioning operation is also included in the office equipment and that is the main reason for the operational ecopoints' increase. Moreover cooling operation contributes at about 12% while heating contributes at about 15%. Finally lighting is responsible at 11% to the total operational ecopoints amount. At this point it is important to translate the ecopoints into environmental impacts in order to detect the most significant environmental impact caused by building's life cycle. The above diagram depicts that the most crucial environmental impacts are climate change, fossil fuel depletion, acid deposition and eutrophication. The environmental impacts derived as a result of adding the entire amount of total operational ecopoints to total embodied. It was expected that climate change would be one of the most aggravated environmental impacts because the operational ecopoints are increased comparing to embodied ecopoints and as operational ecopoints are more related to energy consumption it was quite easy to predict that fossil fuel depletion and climate change would be rather increased comparing to other environmental impacts.

5. POTENTIAL ENVIRONMENTAL IMPROVEMENT OPTIONS

The environmental improvement options deriving from the LCA analysis would be examined at a multicriteria base, because of the issue's complexity (for instance adding insulation means energy saving while at the same time extra material is used for insulation) taking into consideration technical efficiency, environmental impacts, socio-economic criteria and inhabitants' comfort. The environmental options would refer to:

1. building design process, for instance,
 - heating: installing high efficiency boiler, changing fuel type, add operating controls and automations, combine space heating with domestic hot water production, use of RES systems etc.
 - cooling: allowing natural ventilation, installing ceiling fans and high efficiency HVAC systems, insulate pipes, install thermostat, use of RES systems etc.
 - insulating: add insulation to the building's envelope.
 - openings: installing double glazing windows, opaque shutters, sun-protection devices etc.
2. buildings' material management, for instance: materials environmental management (e.g. ISO 14001 implementation to construction materials' production process, environmental friendly materials' use (ecolabel)), etc.
3. building's operations, for instance,
 - domestic hot water: installing solar collec-

tors, suggesting water saving measures, installing central hot water production and storage, etc.

- lighting: install low consumption lights or presence detectors,
 - appliances: reduction of stand by time, use new low energy systems, improve maintenance etc.
4. construction and demolition waste management, for instance, selective sorting out of materials and their possible reuse, recycling or external management by certified institutions.

6. INSULATION CONTRIBUTION TO ENVIRONMENTAL IMPACT - THE CASE STUDY IN RESIDENTIAL BUILDING

Buildings constructed in the time span 1970-80 share common features and follow more or less the same construction typology. Till now 15 buildings are evaluated with the analysis suggested and some brief results per structural element and operation for the buildings examined till 1980 are:

- Walls are not insulated or are partially insulated. Moreover for insulation extruded polystyrene is used at about 63,6% and expanded at about 33,9%.
- Roofs are not insulated or are partially insulated.
- Windows, till 1980 were single glazed but after 1980 double glazing is the standard.
- Space heating: have central space heating system using oil-boiler.
- Domestic hot water: independent water heaters are used.
- Ventilation: no mechanical ventilation is used, buildings are naturally ventilated.
- Cooling: before 1980 only the 0,5% were air-conditioned.

Improvement Option Scenario: insulation

The insulation application to buildings examined showed a significant decrease of total ecopoints. Moreover the decrease was about 6% - 16%. The percentage varies and depends on the buildings' size, the number of building's windows and doors and the existence of partial insulation. For instance, buildings in which the percentage of external wall's insulation comes

up to 57% come up with decrease of total ecopoints at about 8%. For the total ecopoints decrease responsible is the reduction of the operation ecopoints caused from energy consumption. The operation ecopoints decrease is about 10 - 20%. Meanwhile the embodied ecopoints increase at about 6% because of extra materials' use for insulation. Moreover alternative scenarios proved that different insulation materials don't actually change the total ecopoints number and therefore the environmental impacts caused from building's life cycle. It is though interesting to examine what happens if we don't evaluate building's life cycle but applicate LCA methodology to insulation materials' life cycle. So by examing the insulation materials' system production individually it is self evident that the environmental impacts would differ. More specific, by choosing stone wool for insulation, the energy consumption is about 0,6 kWh/m². The condition indicator set for the greenhouse effect evaluates the environmental impact for insulating 1m². More specific, the environmental impact from 1 m² insulated by stone wool is 0,8 kg eq. CO₂ while the environmental impact when extruded polystyrene is used for insulation is 1,79 kg eq. CO₂ based on coefficients deriving from Greek data. If, instead, we estimate the greenhouse effect taking into consideration the data given from GEMIS's software the greenhouse effect caused by the energy consumption for producing 1 kg of stone wool is 0,39 kg eq. CO₂/kg (while the correspondence indicator based on Greek data is 0,4 kg eq. CO₂/kg stone wool) and for producing 1 kg of extruded polystyrene is 1,18 kg eq. CO₂/kg (based on Greek data 1,15 kg eq. CO₂/kg respectively). The difference observed between the two databases are due to primary mixture's prescription used for electric energy production.

7. CONCLUSIONS

Summarising the main concept of the methodology presented is to evaluate comprehensively existing buildings in the general framework of energy labeling and certification and taking into account the complexity of the issue. The model suggested is based on the synergy of different tools, methodologies and software. The point is to estimate the buildings' environmental impact at a lifetime perspective and suggest, based on

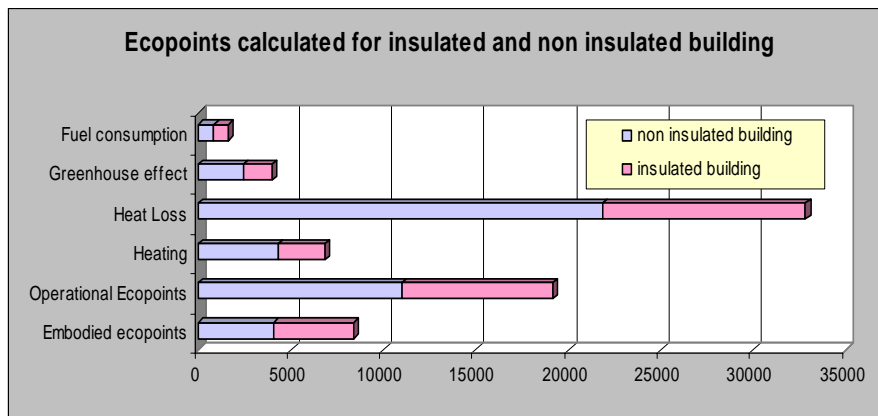


Figure 2: Environmental evaluation of residential buildings with and without insulation.

the analysis' results, efficient improvement options. Till now, the results of the analysis have pointed out that operational ecopoints and consequently services are without doubt more responsible for the building's environmental impact during its life cycle in comparison to embodied ecopoints. The operations are related to energy consumption therefore the improvement actions focus on the energy consumption's reduction.

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