The SYNERGY project: a holistic approach for assessing the energy, hygrothermal, fire and environmental performance of building elements.

Dimitrios Bikas, Dimitris Aravantinos, Christina Giarma, Karolos-Nikolaos Kontoleon, Theodoros Theodosiou, Katerina Tsikaloudaki
Laboratory of Building Construction and building Physics, Aristotle University of Thessaloniki, Thessaloniki, Greece

Abstract: The paper presents the content and part of the results produced under the context of the SYNERGY research project, which focuses on the holistic study and development of building elements with advanced performance in the fields of energy, hygrothermal, fire and environmental performance. Although the above aspects may have been studied individually in the past, there is a lack of information on their combined assessment both at a national and an international basis. The analytical information that is derived through the detailed analyses of each stage is going to be exploited by the industrial project partners for the improvement of their products and services, and at the same time it will be communicated to the engineering world through the development of computational tools and catalogues, leading ultimately to numerous benefits for the national economy and the environment.

Key words, energy efficiency, linear thermal transmittance, hygrothermal performance

Introduction
This paper presents steps of SYNERGY project that focuses on the research and the development of high energy-efficient building elements, assessed under integrated protection criteria and life cycle design aspects. More specifically, it concerns a holistic approach in designing and evaluating the building elements of new and existing constructions in Greece, with regard to their energy, hygrothermal, fire and environmental performances. It is elaborated by two academic units of the Aristotle University of Thessaloniki (the Laboratory of Building Construction and Physics and the Laboratory of Metal Structures) and two SMEs, FIBRAN, which plays a leading role as a producer of insulation materials both in Greece and in Europe, and TESSERA MULTIMEDIA, an ICT company that is active on the development of software and applications as well as on web design. During the project duration, a detailed analysis of all building elements met in the majority of constructions in Greece is conducted with reference to their energy, fire, hygrothermal, and environmental performances, as well as catalogues and computational tools for their properties’ estimation are developed. Although the above aspects may have been studied individually in the past, there is still a lack of information regarding their combination at a national and international basis, which has led to the vulnerability of their proper practical implementation.

Such an approach is crucial for the development of efficient buildings in the view of the implementation of the forthcoming EPBD recast, which aims at the promotion of nearly zero
energy buildings and the enhancement of their sustainability characteristics during their entire life cycle. Apart from the knowledge and the theoretical results that will derive during the project, there are also more practical products, such as the catalogues and the computational tools with numerous constructional details and information regarding their thermophysical, hygrothermal, fire resistance and environmental properties. These tools are very useful for all engineers, especially during the design and the decision-making phases of a new building or a renovation project. In fact, their importance will come to light in a few years, when the design and the construction of a building will take into account several energy related criteria due to the near zero-energy building requirements.

The SYNERGY current and future outcomes
Within the context of the SYNERGY project all the common construction element configurations that can be found in the building envelope of typical Greek buildings (load bearing elements, walls, roofs, floors) have been recorded, designed and systematically classified. The study refers to new, well-thermally insulated building as well as to existing buildings with poor or no insulation protection. Beyond the 180 construction details that have been produced for the individual building elements, details of their junctions have been elaborated, giving all necessary information for the appropriate layers’ succession, the associated materials and the finishes. An example of the produced details is presented in Figure 1, representing the individual building component, i.e. a flat roof, and Figure 2, portraying the junction between a vertical and a horizontal building element, i.e. between the wall and the flat roof. The examined parameters and the methodologies that are used for the analysis are described below for each individual issue.

1. Lime-cement mortar, 2. Reinforced concrete
3. Vapour barrier, 4. Thermal insulation
5. Polyethylene membrane
6. Lightweight concrete for slopes
7. Cement based leveling compound
8. Water proofing membrane
9. Geotextile
10. Cement mortar
11. Cement tiles

Figure 1. Construction detail of a conventional flat roof.
The energy performance of a building element is mainly represented by the value of its thermal transmittance (U-value). The U-value of each building element, that has been identified and included in the analysis, was calculated for different widths and thermophysical characteristics of the thermal insulation layer. For the remaining layers, the conventional widths and materials used in Greek constructions were taken into account. Given that among the objectives of the current project is to deliver catalogues and tools for engineers, a practical table was formulated for each building element, presenting the building element assembly along with the layers’ configuration and a matrix presenting the thermal transmittance values that are derived for the different widths and thermal conductivity values of thermal insulation (Figure 3). The width of thermal insulation varies from 0.0m, to 0.14m with a step of 0.01m. For the thermal conductivity, typical values of the insulation materials that are available in the Greek market were taken into account. The combinations of d and \( \lambda \) that result in U-values lower than the maximum allowed values per climatic zone are indicated in the matrix with different color. The practical merit of this matrix is that the engineer can make a quick estimate of the required thermal insulation, while at the same time the accurate and comprehensive construction detail is at hand.

Figure 2. Construction detail of the junction between the vertical wall elements and the flat roof.
Beyond the thermal transmittance, another significant parameter for the evaluation of the overall thermal behaviour of the building envelope is the estimation of the linear thermal transmittance coefficient $\Psi$ of the thermal bridges located in composite building elements and at the intersection between the construction elements. Values of $\Psi$ included in the national atlas published by the Technical Chamber of Greece or ISO 14863, neglect the influence of the material thickness and thermal properties on $\Psi$. This information is of great importance in cases where, beyond the fulfillment of regulation requirements, a more accurate estimation of the building’s actual heating and cooling needs is required.

Within the context of the SYNERGY project, $\Psi$ values have been calculated, resulting in a prolonged atlas for thermal bridges which present for different widths of thermal insulation, all possible positions of the thermal insulation layers and different finishes of the vertical building elements. For every examined case, apart from the calculation $\Psi$, the temperature profile within the construction element is calculated and presented on the elements’ cross-section. This representation has a twofold merit: it assists non-specialists to understand the thermal bridging effect and it constitutes valuable information when estimating the probability of vapour condensation. The calculations were conducted with the help of a 2-D finite element software and in line with ISO 10211. The presentation of the results for each building element follows the example of Figure 4.
The hygrothermal performance of the building elements

The study of the hygrothermal behaviour of the building elements reflects their performance against the presence, accumulation and variation of moisture in their mass or on their surface, as these phenomena are induced by various factors. More specifically, two main axes can be discerned: first the estimation of vapour condensation risk inside and on the surface of the building elements, as well as their performance against rain and driving rain.

For the estimation of vapor condensation risk a calculation tool has been developed. It can be used for the determination of the temperature and the vapour pressure profiles prevailing across the building element, as well as the risk of interstitial condensation. If the latter occurs, the amount of the condensation is calculated, along with the amount of evaporation. The comparison between the condensation and evaporation rates follows, which indicates whether moisture is accumulated in the building element on an annual basis. The algorithm employed by the tool is in line with the international standards [2-3]. The basic steps are summarized as follows:

- Selection of the boundary conditions for the building element analysis (i.e. city, for the climatic data, and usage density, for the vapour production).
- Determination of the building element’s position and composing layers, as well as the materials of each layer. The tool is equipped with a database containing the common building elements and materials, which can be enriched with new assemblies.
- Calculation of the saturation vapour pressure and the water vapour pressure for the assessment of the interstitial condensation phenomenon on a monthly basis.

If interstitial condensation occurs, the first month of the condensation is determined. The accumulated condensate is calculated till the rate of condensation becomes negative, i.e. till evaporation occurs.

The fire resistance performance of the building elements

The study concerns the fire dynamics of building enclosures, i.e. the detailed analysis of the fire performance of common building elements adopted in the majority of constructions in the Greek district. It is critical to point out that the propagation and spread of fire from one space to another is a highly complicated and multifaceted phenomenon. Evidently, the prediction
processes to quantify the behavior of fire and to extort the means to reduce the impact of fire on people, property, and the environment is extremely valuable. In order to undertake the above study FDS is applied; Fire Dynamics Simulator (FDS) is a computational fluid dynamics (CFD) model of fire-driven fluid flow developed by the National Institute of Standards and Technology (NIST). The above software solves numerically a form of the Navier-Stokes equations appropriate for low-speed, thermally-driven flow, with an emphasis on smoke and heat transport from fires. The exploitation of CFD and FEM research models is important in order to predict precisely the actual fire scenario, determine accurately the time-history temperatures at each discrete point (evolution of temperature profiles $T(t)$) and override the need of large-scale fire experiments.

The present study concerns a typical building volume which consists of two adjoined and similar indoor spaces (Figure 5). The investigated indoor spaces are separated by an interior wall and a corridor permits their connection by means of the inside doors facing the corridor. The other two walls of both interior spaces split the indoor environment from the outdoor environment. The structure of the involved opaque surfaces that form the building enclosure vary within a wide range of possible solutions that take into account the category of structural members, the type of the insulation material, the thickness and position of insulation, and the type and thickness of the assumed coatings. Aiming to acquire a broad range of outcomes the transient problem is carried out for three typical fire scenarios, which cover a representative width of possible fire incidents. The extracted outcomes are important in order to reduce the fire risk of buildings that describe the construction practices in Greece. In conclusion, recommendations for the determination of the efficient use of fire insulation materials and the benefits that can be obtained in comparison to non-insulated structural elements will be specified.

![Figure 5](image-url)

*Figure 5. (left) Plan view of the investigated building enclosure; (right) transient analysis of an assumed fire scenario via FDS.*

**The environmental performance of the building elements**

Under this task the aim is to study and estimate the environmental impact in the different levels of building materials, elements and whole buildings, according to life cycle principles, with the use of LCA tools. The intention is to show clear results and provide useful practical information of the environmental performance of the building materials, elements and whole buildings to engineers and to construction industry professionals.
In accordance with the principles of sustainable construction, the minimization and reduction of the impacts on nature and environment depends on the performance of the building during all the phases of its life. It is well known that the life-cycle of a building is a process, which starts with the formulation of a need to build and the preliminary planning. The phase of construction itself covers a rather short period, in contrast to the use and reuse of various building elements and buildings as wholes, eventually ending in the demolition of the building and waste management, or deconstruction and reuse of building elements. During every phase of the life cycle, decisions are made concerning the performance of the building, with or without consideration of the full potential impacts of these decisions. The LCA is a technique that evaluates the inputs and outputs of raw material and emissions in each step of the material life, adding the resource extraction impact and the emission of pollutants. Its origin is the immediate products industry and it was adapted to the environmental evaluations of building. The application, assembly form and use of equipment in the building system modify its environmental performance. It is worth noting that the absence of database of materials of the Greek market makes the use of LCA software, created in other countries, difficult because these are supplied by local databases or similar. Considering this difficulty, it is very important to transform the results of an LCA in data understandable to architects and engineers responsible for the selection of building materials, elements and systems. At the beginning of any decision, before setting their own priorities, architects and engineers need to be aware of the great variety of issues that should be re-evaluated from the perspectives of life-cycle and environmental sustainability. LCA is very important to compare possible alternative solutions, which can bring about the same required performance. The facility of using the system and understanding of the results are considered crucial in the use of the life-cycle principles for selecting building systems.

Conclusions

The need for energy conservation in buildings is an urgent priority both for Europe and at a national level. The requirements of current regulations and the more stringent requirements specified in the foreseeable future (EPBD recast, EUROCODES 2 and 3, EPD-Environmental Product Declarations) necessitate the thorough analysis and development of reliable component solutions that will ensure high energy and hygrothermal performance, fire safety and minimized environmental impacts in the lifecycle of the building components and buildings. The project not only focuses on the development and organization of theoretical knowledge, but also aims at the wide dissemination of its results, mainly through the development of user-friendly databases and calculation tools for the basic axes of the study. The unified tool that incorporates all the results obtained from the estimation of thermophysical, hygrothermal, fire and environmental performance of building elements with respect to their constructional configuration and the climatic conditions is web-based in order to facilitate its distribution and use by multiple users.

It is important to highlight that the expected products of the SYNERGY project will not only act as a guideline for the technical community, but it will promote the use of building
materials, which are efficient from every aspect of view. Subsequently, the private companies that participate in the project will not only benefit from the transfer of knowledge, but will also support their products, as well as gain important information for their further development. Within this context, the SYNERGY project can lead to significant energy savings and reductions in greenhouse gas emissions through the implementation of its results.

References


