CONFERENCE PROCEEDINGS

3RD INTERNATIONAL ACADEMIC CONFERENCE ON PLACES AND TECHNOLOGIES

EDITORS
EVA VANIŠTA LAZAREVIĆ
MILENA VUKMIROVIĆ
ALEKSANDRA KRSTIĆ-FURUNDŽIĆ
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PLACES AND TECHNOLOGIES 2016

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CONCEPTUAL STRUCTURAL DESIGN STRATEGIES FOR REDUCING ENERGY CONSUMPTION IN BUILDINGS

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ABSTRACT

Raising the level of sustainability in construction refers to reduction of negative environmental impact and resource consumption throughout the life-cycle of built facilities, with a simultaneous increase in life quality. The aim is to optimize the performances of buildings, in accordance with the indicators of ecological quality. The load-bearing structure, together with other elements of architectural space, determines the performances of the building. The load-bearing structure should be designed and evaluated as a sub-system of the building, whose behaviour is directed towards the aim of system-building – ecological quality. This paper analyses the conceptual structural design according to the criteria of environmental protection, with the aim of reducing the requirement for total primary energy. The subject of analysis is design interventions at the level of structural form and applied structural materials, which reduce total energy consumption, including embodied and operational energy, throughout the lifecycle of the building. The present analysis pointed to the necessity of applying a complex and systemic approach to the structural design, in function of achieving the ecological quality of buildings.

Keywords: Sustainable building, ecological quality of buildings, conceptual structural design, reducing energy consumption

INTRODUCTION

Raising the level of sustainability of building refers to the "reduction of negative environmental impact and resource consumption due to construction, use and dismantling of constructed facilities, with a simultaneous increase in life quality of and health and safety in the built environment" (Working Group for Sustainable Construction, 2001). The aim is the optimisation of building performances in the context of sustainability, in accordance with the indicators of ecological quality[2]. The building structure, along with other elements of architectural space, determines the performances of the building. The building structure should be designed and evaluated as a sub-system of the building, whose behaviour is directed towards the aim of

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[2] The indicators for integrated assessment of ecological quality of building are classified by the interrelated and conditioned sustainability criteria into three groups: indicators within the environmental criteria, indicators within the criteria of social well-being, and indicators within the criteria of economic well-being (Nenadović, 2014).

system-building – ecological quality (Nenadović, 2014), which within the criteria of environmental protection refers to the reduction of harmful emissions in the air, water and land, and to the increase of resource use efficiency, i.e., to the reduction in intensity of their use. This paper analyses the conceptual structural design according to the criteria of environmental protection, on the basis of following indicator: total primary energy requirement. The aim is to reduce the demand for total primary energy, i.e. more efficient energy use, through the reduction of embodied and operational energy throughout the life cycle of the building.

CONCEPTUAL STRUCTURAL DESIGN STRATEGIES FOR REDUCING ENERGY CONSUMPTION IN BUILDINGS

Energy consumption during the life cycle of the building includes energy consumption in phases of production of materials and products, of the building construction, of building use and of the end of life of the building. The goal is to achieve minimum energy consumption, consisting of embodied and operational energy, throughout the life cycle of the building.

Conceptual structural design strategies for reducing the initial embodied energy

Reduction of the initial embodied energy of the building, when it comes to the load-bearing structure, can be achieved: through reduction of total material consumption, via structural design characterized by a higher possibility of building reuse, by higher space efficiency, by higher level of functional integration of spatial elements and by higher structural efficiency; through greater share of materials obtained from less energy-intensive processes of raw material extraction; through the use of less processed materials and structural elements, i.e. materials which imply less energy-intensive production; through the use of materials and elements obtained from secondary raw materials, i.e. through the use of reclaimed structural elements, the use of already used products from other industries without prior processing, the use of materials obtained through recycling processes and the use of by-products; through the use of materials and elements obtained from local raw material sources and local production; through the use of materials and elements of lower transport weight; through the use of materials and elements which imply less energy-intensive form of transport; through the use of materials and elements whose installation is not based on the use of heavy machinery. Reduction of the embodied energy during the use phase of the building, which refers to materials and elements needed for maintenance, repair, renovation, adaptation or reconstruction, can be achieved by ensuring the durability of load-bearing structure, with a minimum of maintenance, as well as via structural design which ensures space adaptability without the need for radical intervention at the level of building structure.

Conceptual structural design strategies for reducing the operational energy

The energy needed for heating, cooling and ventilation of buildings, which account for a large percentage of total operational energy[3], can be significantly reduced by design interventions. In order to realize the above, during the design of the building, it is necessary to analyse the building as a whole, that is, as a thermal system that interacts with the environment through a process of heat transfer and fluid flow. Interventions at the level of structural form and applied materials, in order to optimize the heat transfer and fluid flow, and to minimize temperature fluctuations in the indoor environment, refer to the combination of reduction of heat conduction and convection, and adequate thermal mass.

Evaluation of the energy performances of structural assemblies is primarily based on the analysis of their thermal resistance. Thermal resistance of the entire surface of the structure can be

[3] HVAC systems are responsible for 50% of the total energy consumption in buildings (Pérez-Lombard, Ortiz and Pout, 2008).

significantly reduced in the case of assemblies with high framing factor, i.e. with high share of surface of structural members in the entire surface area of the wall (Sustainability Guidelines for the Structural Engineer, 2010), particularly when the structural members are made of material of high thermal conductivity, such as steel.[4] Besides heat losses, an additional issue related to thermal bridges is the occurrence of moisture, which can reduce the thermal insulating properties of insulating materials, lead to the development of mould and accelerate the deterioration of the load-bearing structure.

The new standards related to energy efficiency of buildings insist on a greater airtightness of buildings with the aim of reducing the heat losses that occur as a result of air leakage. Air leakage most commonly occur in the area of connection between individual elements of the structural assembly. In that sense, when it comes to the air leakage, non-monolithic load-bearing structures are more sensitive, especially one that are made of materials which are sensitive to the effects of wetting and drying in terms of dimensional stability, such as wood.

In addition to the reduction of heat conduction and convection, one of the strategies for saving energy needed for heating and cooling of buildings, as well as for minimization of temperature fluctuations in the indoor environment, is the formation of load-bearing structure with adequate thermal mass. The building structure made of material with high heat storage potential (concrete and clay-based materials), can, if properly thermally insulated from the external space and exposed to internal space[5] and if adequately dimensioned and positioned, effectively regulate a daily heat flow. In the case of moderate continental climate, in winter, within the strategy for heating, the building structure accumulates heat during the day and radiates it to the inner space during the night. In summer, within the strategy for cooling, the building structure accumulates excessive heat during the day. During the night, the building structure is cooled by contact with the outside cold air, which is achieved either by natural or by forced ventilation. Inadequate use of thermal mass of the load-bearing structure of the building can impede the realisation of desired thermal comfort and increase the operational energy consumption of the building, especially in conditions of prolonged high temperatures, i.e. in conditions that do not allow efficient cooling of the building structure. In addition, thermal mass of the load-bearing structure can increase the energy requirement in winter mode, in the case where there is not enough solar gain. In that sense, in order to adequately use the thermal mass, it is necessary to consider a number of parameters during the design of the building, including: local climate conditions, orientation and geometry of the building, level and method of building insulation, windows location and size, type of shading devices, position, size and purpose of spaces, mechanisms of ventilation, types of lighting, colour of surfaces[6] (The AIA Sustainability Discussion Group, 2007).

One of many examples in which the load-bearing structure of the building is integrally conceived with the aim of optimisation of heat and air flow, in addition to the aim of achieving a higher structural efficiency and better natural light distribution throughout the interior space, is Council House 2, an office building in the City of Melbourne, officially opened in 2006 (Architects: DesignInc). The design team used the mass of the exposed pre-cast load-bearing concrete shells (Error! Reference source not found.), in conjunction with active and passive strategies for heating and cooling, in order to control the temperature changes in the indoor environment and to reduce the operational energy consumption of the building. Thermal mass capacity is increased by means of 'wavy' profile of the concrete shells (Figure 2), which have increased the structural efficiency and led to the lower material consumption, i.e. reduction of the initial embodied energy.

[4] Given the above, the regulations of certain countries define the maximum allowable values for thermal bridges, due to the fact that they can significantly increase the energy requirements for heating and cooling in building (Europe's buildings under the microscope, 2011).

[5] The exposure of load-bearing structure to the interior space implies non-existence of layers which thermally isolate the structure, such as suspended ceilings, gypsum coverings, polystyrene interjoists, etc.

[6] Colour of structural elements affects the degree of solar energy reflection, i.e. the level of heat absorption, and thus the thermal performance of the structure. In this sense, the colour of exposed structural elements is an important factor in optimisation of building thermal performances (Bansal et al.,1992).

In summer, the concrete load-bearing shells absorb excess heat during the day and release it at night by natural ventilation. This lowers the office's daily temperature and is responsible for energy savings for cooling. In winter, the concrete shells accumulate heat during the day and radiate it to the inner space during the night, which saves the energy needed for space heating.

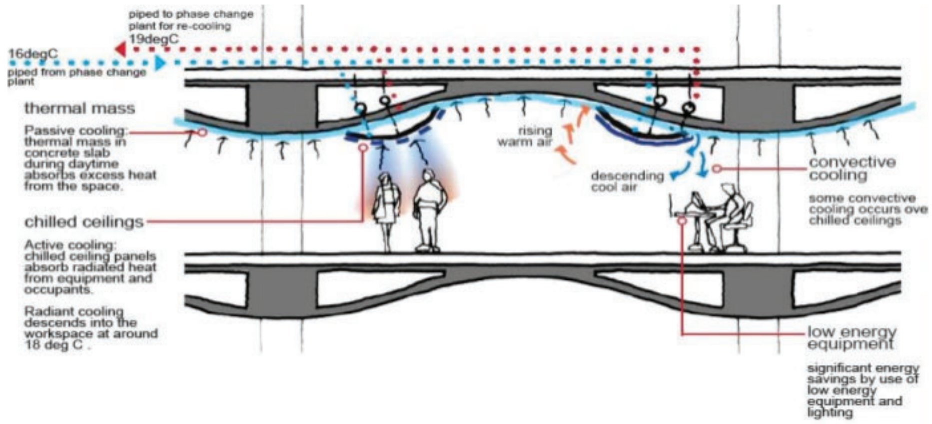

Figure 1: DesignInc, Council House 2, Melbourne, Australia, 2006, strategy for reducing the operational energy needed for cooling of the building based on the adequate shaping and materialisation of the exposed load-bearing concrete structure, illustrated in cross-section.
[Source: http://www.slideshare.net/vaisalik/biomimetic-architecture]

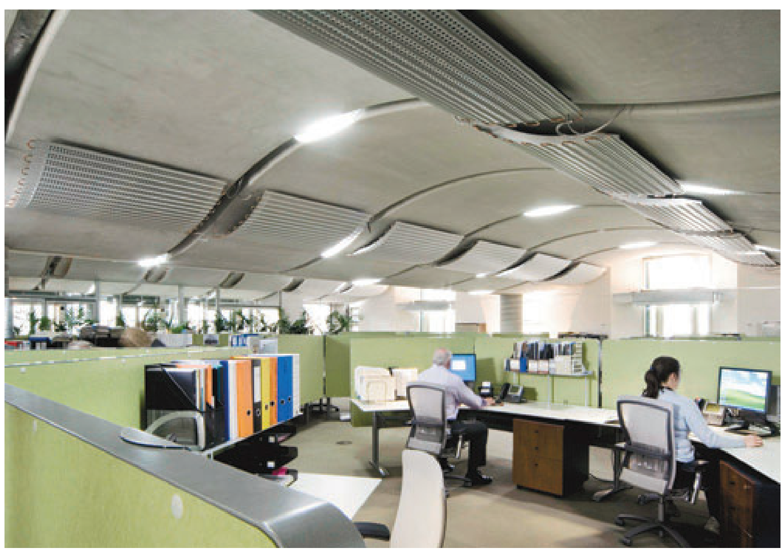

Figure 2: DesignInc, Council House 2, Melbourne, Australia, 2006, shaping and materialisation of the load-bearing concrete structure in function of reduction of the energy consumption of the building, illustrated in interior.
[Source: http://www.metrohippie.com/council-house-2-council-house-1/]

Bearing in mind the above factors, the new Directive on energy performance of buildings (Directive 2010/31/EU - on the energy performance of buildings, 2010), as well as the new Rulebook on energy efficiency of buildings ("RS Official Gazette" no. 61/2011) change the approach to evaluation of building energy performances. The importance of applying passive techniques is accented. The greater importance is given to the internal elements of the building, including the load-bearing structure. When it comes to the annual energy consumption, priority should be given to strategies which enhance the thermal performances of buildings during the summer period. The focus should be, among other strategies, on sufficient thermal capacity of the load-bearing structure of the building and on passive cooling techniques, primarily those that improve indoor climatic conditions and the micro-climate around buildings, with simultaneous reduction of energy consumption throughout the life cycle of the building.

CONCLUSIONS

The paper analysed the conceptual structural design according to the criteria of environmental protection, with the aim of reducing the intensity of energy-resources use, i.e. of reducing the total energy consumption, including embodied and operational energy, throughout the lifecycle of the building. The load-bearing structure is analyzed as subsystem of the building, whose behaviour is directed towards the aim of system -building – ecological quality. The present analysis pointed to the necessity of applying a complex and systemic approach to the structural design, in function of improving the ecological quality of buildings. In this context, it is necessary to improve the education of designers involved in the design of buildings, in order to prepare them for multidisciplinary optimization of design solutions based on multiple analysis of many aspects of ecological quality.

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