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Multi-criterion optimization of building envelope in the function of indoor illumination quality towards overall energy performance improvement

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ABSTRACT

This paper elaborates the formulation and application of an integral methodology for overall energy performance improvement of office buildings and demonstrates its application. The developed multi-objective methodology is demonstrated on a reference office building located in a temperate climate zone with high annual temperature variations. The idea is to formulate a research based proposition in building science with a formulation of a general/integral methodology which could be applied widely in energy performance refurbishment of existing office buildings and help architects and engineers in the early-design stages of new projects. The goal was to formulate an optimized building envelope model using multi-criterion optimization methodology in order to determine efficient window to wall ratio (WWR) and window geometry (WG) in the function of indoor illumination quality, followed by the assessment of glazing parameters influence on the annual energy demand. The integral methodology for overall energy performance improvement of office buildings utilizes multi-criterion optimization method and highly detailed Building Information Modeling (BIM) programs and dynamic energy simulation engines. The developed coupled-integral methodology links together both building envelope construction optimization and user comfort. The methodology is both flexible and adaptable for application in various climatic conditions and for different construction types.

1. Introduction

According to the International Energy Agency (IEA), buildings exceed 40% of world energy demand and emit close to 1/3 of CO_2 worldwide [1]. The need to optimize building energy performance was elaborated in numerous researches using various analysis methods, energy simulations and techniques in order to design sustainable, energy efficient and cost-effective buildings [2–7]. Authors Eui-Jong et al. developed a simplified model of building envelope design using physically simplified city simulation tools [8]. Rahman elaborated the energy and environmental life cycle assessment of office building envelopes [9]. Authors Attia et al. have summarized potential challenges and opportunities for integrating simulation-based building performance optimization tools in net zero energy buildings design [10].

Illumination performance analysis has been a widespread topic investigated in numerous papers via simplified models, daylight coefficient concept, daylighting schemes, window properties, building design and climate conditions [11–15]. Building simulation for energy strategy formulation in façade retrofitting different climatic conditions of EU was investigated by authors Capeulo and Ochoa [16]. A detailed multi-level optimization principle was demonstrated by Evins in a process on a straight-forward test case, applied to a case study simplified office building [17].

Thermal and lighting simulations applying energy modeling, glazing's transmittance dependence and envelope thickness and economic aspects were investigated in previous researches [18–21].

A recently published investigation from authors Ma et al. [22] investigated window to wall ratio as a function of two parameters; U-value and ambient temperature amplitude. Authors stated that factors which are heat gain related such as solar heat gain coefficient (SHGC), shading, sky cloudiness and building

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orientation do have a great impact on window to wall ratio (WWR) determination; however it was impossible to consider. Thus the authors propose the assumption of these factors. However, the multi-criterion optimization methodology applied in our research elaborates building envelope, window to wall ratio and window geometry selection further, by implementing various factors in the optimization process which influence indoor illumination quality, electricity reduction for lighting and exterior glazing properties in the aim of overall energy performance improvement of existing or newly designed office buildings.

This paper elaborates the formulation and application of an integral methodology for overall energy performance improvement of office buildings and demonstrates its application on an existing reference building. The idea is to formulate a general/integral methodology which could be applied widely in energy performance refurbishment of existing buildings and help architects and engineers in the early-design stages of new projects.

The developed coupled-integral methodology links together both building envelope construction optimization and user comfort. It is flexible and adaptable for application in various climatic conditions and for different building energy efficiency directives and regulations. The development process of the multi-objective methodology consisted of four major phases, which can be seen in the flowchart, Fig. 1. The first three phases refer to data analysis and construction of the reference building's computational model. In the first phase technical data, construction and building material data, HVAC data, and monthly energy expenses where gathered. Building's district heating energy utilization was monitored respectively. The second phase referred to the detailed processing, analysis and evaluation of the gathered data packages. Building performance was evaluated and critical building operation errors were determined. Finally in the third phase a computational CAD model was created using Building Information Modeling (BIM) technology where building geometry, function, construction and material data were integrated. Following the computational model's construction the multi-criterion optimization in the fourth phase referred to the determination of adequate window to wall ratio (WWR) and window geometry (WG) in the function of visual comfort and predefined parameters. Afterwards the optimized Best Case Energy Performance Scenario was determined according to glazing parameters and climate data using dynamic energy performance simulation.

The integral methodology will be demonstrated on a reference office building model located in a temperate climate zone with high annual temperature variations.

In order to formulate an efficient solution for building envelope improvement according to the European Standards, EN 15251 [23], the building was investigated as a dynamic multi-zone thermal system using multi-criterion research methodology. Building envelope performance is investigated both from glazing performance and thermal performance (heating and cooling demand) aspects by using multi-criterion optimization. Efficient WWR and WG was determined in the function of three criteria:

- Advanced spatial daylight dispersion analysis,
- Average daylight factor determination,
- Electric lighting reduction using automatic sensor system.

Authors Gvozdenac et al. elaborated the energy policy situation in Serbia and in the European Union [24–26], where authors determined that Serbia lags behind in the process of improving energy efficiency due to inadequate and slow institutional organization and application of state instruments in order to implement strategies.

The research was conducted on a typical not refurbished existing reference multi-level office building (total area 3430 m^2)

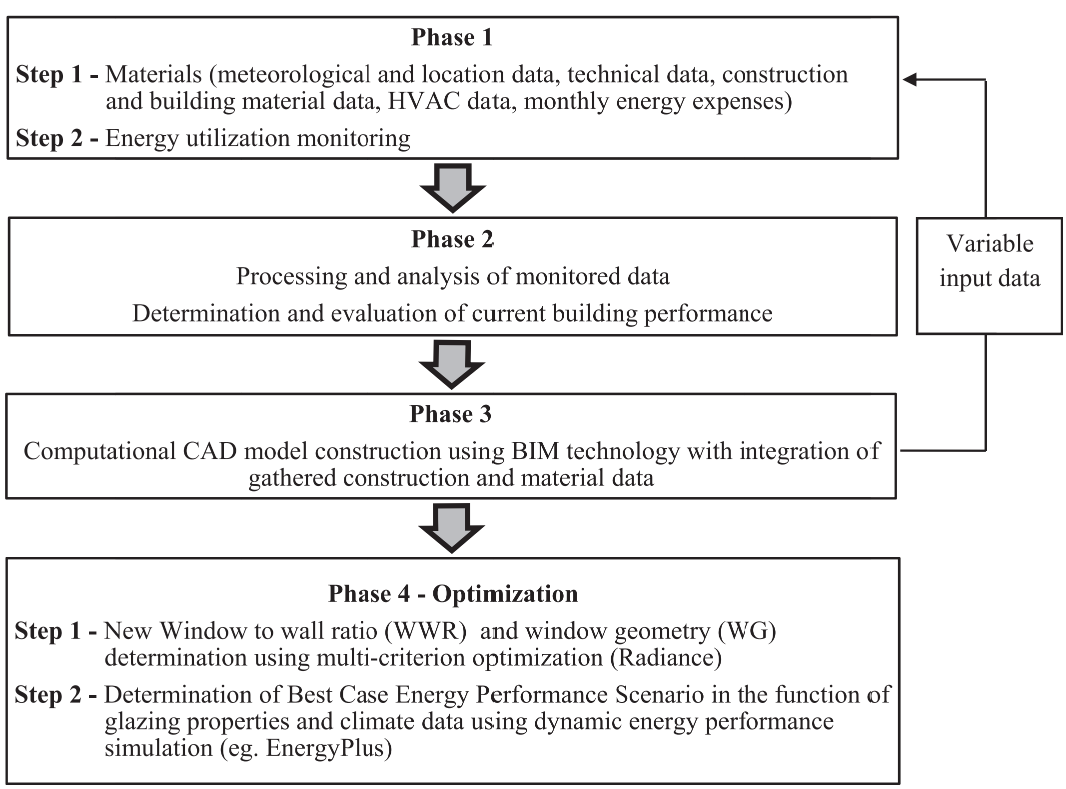

Fig. 1. Integral methodology flowchart.