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Energy renovation of an office building using a holistic design approach

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A B S T R A C T

This paper presents a holistic approach to perform energy renovations of office buildings. A real case study is used to demonstrate how different software can be used to facilitate the work of architects and engineers during different design stages. Initially, the moisture safety of the building is coupled to its energy performance to define the optimum insulation level. The new interior layout is based on an initial daylight study, rather than on architectural intuition. On a second stage, shading and natural ventilation are studied to eradicate any cooling demand, while the interdependence between heating energy and daylight is assessed for the use of light-wells. To demonstrate the trade-offs between visual control and electrical lighting, different shading systems are examined for a cellular office. Finally, two alternate HVAC systems are analyzed to investigate whether passive standards can be achieved with an all-air system and/or a hydronic system.

1. Introduction

The necessity to design sustainable buildings has long driven the scientific community towards modelling methodologies and building simulation tools [1,7,18]. The typical approach undertaken in energy renovation studies is to select the most suitable measures, based on the enhancement they can induce on the building performance (e.g. [20,27]). Design choices are then made based on a unidimensional approach, where one variable is optimized while retaining the other parameters constant. In some cases, the term "holistic" has been used to define the approach of monitoring the combined effect of multiple renovation measures on a single building performance aspect [32,33]. A hand full of studies (e.g. [23]) have simulated a combination of measures for a building and have calculated its resulting overall energy intensity.

In certain cases, significant focus is given on the early-design stage. For such cases a conceptual design layout is used as an initial study object, which is later optimized to achieve specific performance benchmarks (e.g. [21,26]). Similar to the holistic approach, other studies have considered the side-effect of energy measures on different objectives. For example, Zagorskas et al. [37] studied brick wall refurbishments and the resulting moisture issues.

In this paper improvements in energy renovation studies are suggested by considering the interdependence of different objectives and by suggesting a methodology from the early to the final design stage. Layout design, energy use, moisture safety, daylight utilization and HVAC design are investigated as mutually dependent design aspects. A renovation study approach is described and a set of tools for its implementation is demonstrated in the context of a case study.

The study object considered in this paper is the Maria Park building, which was designed in 1917 and was put in operation in 1927. Today it functions as a school, but is to be renovated into an office building. The energy required for heating today, based on the energy declaration, is 165 kW h/m^{2}yr, while the present national building code requires 65 kW h/m^{2}yr [3] and the passive house criteria for Sweden require 45 kW h/m^{2}yr [16] for new constructions. These requirements are set in terms of specific energy use, which is the energy required for heating, comfort cooling, domestic hot water and property electricity. The goal of this study is to achieve the passive standard. The building envelope has no insulation as it comprises of only three layers of brick and a layer of interior plaster. Meeting the passive building criteria would require insulation, which if added on the wrong side of the wall, could simultaneously deteriorate the moisture performance of the construction. The renovation also requires a ventilation system with a specific fan power (SFP) lower than 1 kW/m^3/s.

The new office building should also utilize daylight to meet the BREEAM criteria [5] and to minimize the electricity use for

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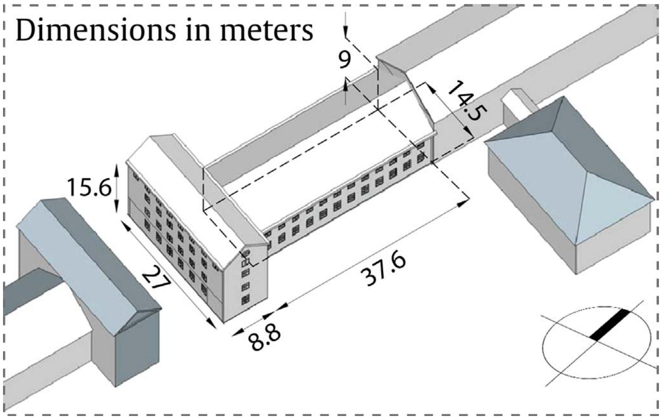

Fig. 1. Overall building geometry.

lighting. Statistics for Sweden show that the total end-use energy of office buildings was 211 kW h/m^{2}yr in 2005 [14], and 51% of that (108 kW h/m^{2}yr) was electricity. Lighting electricity was 23 kW h/m^{2}yr on average, ranging from 7 to 53 kW h/m^{2}yr according to the same survey. In this study, we have focused on the use of skylights and light-wells to increase the average daylight factor (DF) by 33%, while retaining the heating energy intensity low. The facades fenestration design is not altered, as an architectural limitation. Furthermore, we have shown that by using optimum shading, the electricity used for lighting can be decreased significantly while maintaining the visual comfort for users.

The studied building is shown in Fig. 1. It is exposed mostly on the east and west orientations. The northern wall is adjacent to a conditioned structure, and towards south there is an opposite building of equal height (15.6 m) at a distance of 13.4, which decreases the risk of overheating in summer.

2. Methodology

The study was developed in two stages, as shown in Fig. 2. The first stage (initial design stage) considered mainly the insulation and moisture issues for the exterior opaque building wall, as these are determinant parameters of the energy use. This stage also defined the new interior layout of each floor, based on a solar irradiation analysis and a daylight availability analysis. The second stage (optimization stage) consisted of optimizing the newly designed building in terms of its energy intensity, daylight utilization and the selection of an energy-efficient heating and ventilation system.

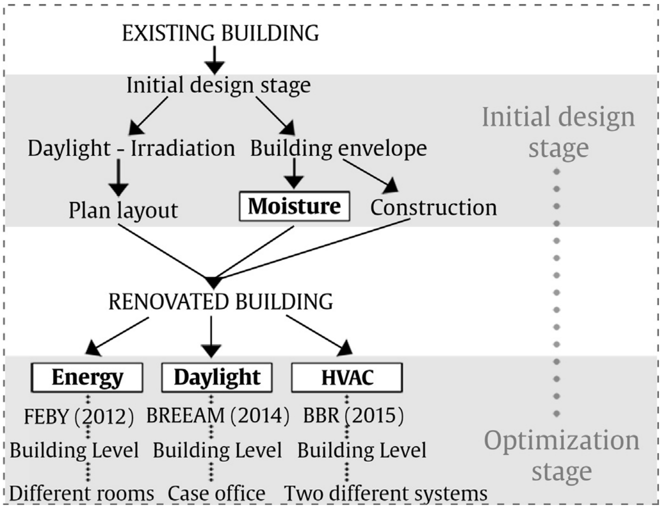

Fig. 2. Scheme of the study process.

2.1. Initial design stage

2.1.1. Moisture safety and envelope construction

A typical limitation for renovations of heritage buildings is that the façade should have the same architectural result after the improvements. This dictated that the new brick layer should retain the finish of the existing external wall in this case. The envelope construction and windows were selected in order to achieve an overall Heat Loss Rate that would be lower than 17 W/m^2, as per the requirements of the passive house criteria [16]. The moisture study was performed to investigate the application of the corresponding extra insulation without deteriorating the moisture performance of the external walls.

Fig. 3 shows the four different wall profiles that were simulated using the WUFI [36] software. *Case (i)* corresponds to the existing wall, in *Case (ii)* insulation was added only to the interior side, in *Case (iii)* insulation was added only to the exterior side and in *Case (iv)* insulation was added to both sides. The three latter cases had an equal U-value of 0.22 W/m^{2}K. Points A, B and C are positions of the camera in WUFI, meaning that temperature, water content and relative humidity values were extracted for these points in the wall profiles. The thermal properties of the materials can be found in the Fraunhofer-IBP Holzkirchen [36] catalog, which is the database used by the software.

An initial simulation for a 15 year timespan was conducted to define the moisture content of the existing wall (point B in *Case i*) and thus its existing condition. The water content stabilized after 7 years to a value of 45.8 kg/m^3, which was used as an input for the rest of the simulations (Cases *ii*, *iii* and *iv*) for a more realistic study. Three simulations were performed to define the good practice for adding insulation. The first simulation was used to check the risk of frost damage on the brick layer (point A in *Cases ii, iii, iv*). This point was assumed to be 2 cm inside the brick wall. The second simulation was used to estimate the possibility of using wood studs to support insulation on the inner side of the brick wall (point C in all cases). The third simulation was used to define the optimum amount of air changes in the air gap for the finally selected case to dry out faster (point B in *Case iv*), and to compare it with the existing wall (point B in *Case i*).

The old wooden construction of the roof was showing marks of rot on the wood boards as seen from the interior, due to condensation of the vapor on their surface. The existing attic space is unconditioned and is only used for the air handling units (AHU), leading to a cold roof overall. For the purpose of this study, the roof construction was assumed to be replaced by a new one with a small amount of insulation, only to avoid undercooling due to the long-wave radiation. Undercooling means that on a clear night, the roof becomes colder than the outside air, due to nocturnal heat exchange with the sky. If the roof temperature gets lower than the dew point of the outside air, then this air will act as a source of moisture.

The building envelope was insulated on the floor underneath the roof, so the space below the roof would remain as an attic to function as a thermal buffer space throughout the year.

Fig. 4 shows the roof construction and the position of the camera (point D) for the WUFI simulations. The diamond hatch below the battens shown in the section corresponds to the ventilated air gap. A simulation was performed (point D) to determine the optimal position for an addition of 2 cm of insulation. Since it is a cold roof, the insulation could be added either on the exterior or the interior side of the air gap, based on the moisture risk of each case.