Energy Performance versus Indoor Environment Quality—Non-traditional Form of Elementary Schools Renovation in Terms of Slovak Republic

Martin Kovac and Katarina Knizova
Civil Engineering Faculty, Technical University of Kosice, Kosice 040 00, Slovak Republic

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Abstract: The content of contribution is to analyse suggested renovation of school building in term of energy performance and indoor environment quality. There were three selected variants of possible renovation of school building. At first, it was installation of equipment for heat recovery into existing mechanical ventilation system. There were further evaluated possibilities how to use glass atrium or ground air-heat exchanger in mechanical ventilation system. These suggested variants were analysed in field of energy performance, namely in term of impacts on heat demand for space heating in order to keep required parameters of indoor environment quality according to standard STN EN 15251 (operative temperature, relative air humidity, air change rate). The analysis was elaborated by using energy simulation tool Design Builder in order to evaluate yearlong operation of buildings.

Key words: Energy consumption, indoor environment, school buildings, energy performance of building.

1. Introduction

During academic year 2011/2012, there was in operation globally 6,661 schools (nursery, primary, secondary schools and universities) in Slovakia, of which 2,741 are primary schools that manage large number of buildings built in different time periods [1]. Different thermal and constructional requirements for envelope constructions were valid during these time periods, which have large impact on energy performance of school buildings [2]. Renovation of elementary school buildings in terms of Slovak Republic is nowadays aimed to reducing of energy consumption only (application of thermal insulation on external constructions, exchange of window constructions, hydraulic regulation of heat system and change of heat source). In many cases, this form of elementary schools renovation leads to another decreasing of indoor environment quality in these objects. The aim of non-traditional form of elementary schools renovation is to solve together the energy consumption and environment quality by application of architectural elements in interaction with technical equipment and using of energy renewable sources. The case study for selected building was elaborated by using energy simulation tool Design Builder in order to demonstrate energy savings by application of non-traditional approach to school buildings renovation.

2. Case Study

The object of contribution is to analyse heat demand for space heating of school building which was already made a particular renovation (Fig. 1). It is common type of school buildings that were built in the 70 s and 80 s, and are located in bigger cities in Slovakia. The traditional form of building renovation, which was made on the most of these objects, was aimed at application of thermal insulation of external walls, roof,
at exchange of window constructions in order to reduce heat demand for space heating. This renovation form has brought shining reduction of operation costs, lifetime extension of building constructions and new appearance of object. But exchange of old windows for new and tight causes reduced air exchange in classrooms which can lead to deterioration of internal environment parameters. The aim was to suggest and analyse some variants of ventilation system in order to achieve energy savings in heat demand for space heating and to provide for required thermal state conditions of internal environment (operative temperature, air exchange, relative humidity) according to standard STN EN 15251. There are workable variants of proposal.

3. Geometric Model

With regard to complexity of energy flows in building, the energy simulation tool Design Builder was used for problem solution. The model geometric of analysed school building was created in tool environment (Fig. 2) with parameters of building constructions by Tables 1 and 2. There was selected reference year 2002, location Kosice that is defined by following parameters of outdoor environment: the outside air temperature, wind speed and direction, atmospheric pressure, direct and diffuse solar radiation. For the next analysis, the section by Fig. 2 was selected in order to shorten physical time for calculation of energy simulation. The analysed building section was divided into individual zones that have defined different parameters of internal environment (occupancy, required illumination, and minimum fresh air per person or minimal ventilation intensity). Operation of the heating system is in two modes with different requests in order to assure operative temperature in internal spaces. The operative temperature 20 °C [3] in value was considered in classrooms during teaching from 6:00 till 17:00, the operative temperature 17 °C in value [3] was considered out of school time, during weekends and holidays. The other rooms (corridors and toilets) are heated at operative temperature 15 °C [3].

4. The Sugested Variants of Ventilation Systems and Their Analysis

Nowadays, the simple system of mechanical ventilation without heat recovery provides for required air exchange in classrooms. This ventilation system is in service during work days from 6:00 till 17:00 with total fresh air flow about 12,000 m³/h (fresh air rate 7.0 L(s · person) [4]). Out of service there was considered with ventilation intensity 0.5 L/h. So defined existing system of mechanical ventilation represents default state that is marked as variant V0 in following analysis.

The following three variants were analysed in order to reduce energy requirements for operation of listed above defined ventilation system:

- **V1**—mechanical ventilation system with heat recovery (heat exchanger efficiency 65%);
- **V2**—mechanical ventilation system with heat recovery (heat exchanger efficiency 65%), utilization of supply fresh air preheating in space of glass atrium (glass system $U = 1.4 \text{ W/(m}^2\cdot\text{K)}, g = 0.72$), see Fig. 3;
- **V3**—mechanical ventilation system with heat recovery (heat exchanger efficiency 65%), utilization...
Table 1 Parameters of analysed school building.

| Parameters                 | Units            |
|----------------------------|------------------|
| Building floor area        | 2,982.00 m²      |
| Built-up volume of the building | 9,840.60 m³   |
| Windows area               | 744.48 m²       |

Table 2 Parameters of building constructions after renovation.

| Constructions            | U-values         |
|--------------------------|------------------|
| External wall            | U = 0.31 W/(m²·K) |
| Flat roof                | U = 0.19 W/(m²·K) |
| Ground floor             | U = 1.40 W/(m²·K) |
| Internal partitions      | U = 0.81 W/(m²·K) |
| Openings (windows)       | U = 1.4 W/(m²·K), g = 0.72, τ = 0.64 |

U-values of building constructions meet requirements by the standard STN 730540.

of supply fresh air preheating in ground air heat-exchanger (Fig. 4). The design parameters of ground air heat-exchanger by Blümel [5]: PVC tube, DN 200, number of tubes 24, length of one tube 50.0 m, foundation depth 2.0 m, wet soil (λ = 2.5 W/(m·K)), correction factor of soil 0.7, heat power of exchanger is seen in Fig. 5.

5. The Results from Analysis

Results that represent possible energy savings for variants under consideration were gained from energy simulation tool [6]. The gained results are shown on the following graphs (Figs. 6 and 7).

The application of heat recovery in mechanical ventilation system with required parameters (air flow, air rate per person, heat exchanger efficiency) represents energy savings about 30% in global balance during heating period (October-April) as compared with default variant V0 (Fig. 7). The most marked energy savings were achieved during winter months November-February (Fig. 6), when the outside air temperature is markedly lower than that at the beginning or at the end of heating period (October, April). The supply fresh air preheating in space of glass atrium (V2) or in ground air-heat exchanger (V3) reduces energy demands of heating system in order to assure operative temperature in classrooms. From the analytical results energy impacts of glass atrium (V2) and ground air-heat exchanger are very similar (Figs. 6 and 7).

All variants were suggested and analysed in order to reduce energy performance of heating system and to provide for required thermal state conditions of internal environment (operative temperature, air exchange, relative humidity) according to standard STN EN 15251. Data about monitored parameters of internal environment during two weeks in selected classroom are shown on the graph below (Fig. 8).

The proposed glass atrium (Fig. 9) represents active exploited energy space in which it is possible to achieve the increase of supply fresh air temperature at average about 4.0-7.0 K during day depending on solar radiation and outside air temperature (Fig. 10). During
Fig. 3  The functional scheme of mechanical ventilation with glass atrium.

Fig. 4  The functional scheme of mechanical ventilation with ground air heat-exchanger.

Fig. 5  Heat power nomogram for ground air heat-exchanger [5].

Fig. 6  The heat demand for space heating—monthly balance.
Fig. 7 The heat demand for space heating—heating period from October to April.

Fig. 8 Monitored parameters of internal environment for a period of two weeks in selected classroom.

Fig. 9 The visualisation of proposed glass atrium in school building.

In case of ground air heat-exchangers, it is possible to think over their realisation on land of school building namely under playing area of school playground (Fig. 11). On the base of detailed analysis of ground air...
heat-exchanger worked in Ref. [5], it is recommended to choose the relative distance between individual tubes in value 1.0 m in order to achieve maximum heat gain. Analogous to atrium, the ground air heat-exchangers will be in operation only during teaching time (workdays from 6:00 till 17:00). In the other times the heat-exchangers and surrounding soil will be in progress of regeneration [7].

### 6. Conclusions

As noted in introduction, the aim of contribution was to design and analyse variants that are realizable on objects after so called traditional form renovation (application of thermal insulation on external walls, roof, and exchange of window constructions) too. The results of analysed variants V1-V3 have shown their positive impact on final heat demand for space heating and on parameters of internal environment in compare with default state V0. The main reason for suggestion of equipment for heat recovery in ventilation system (variant V1) was existing state of building and its ventilation system (mechanical ventilation without heat recovery). Variant V3, application of ground air-heat exchanger in mechanical ventilation system, was analysed by reason of planned reclamation of playing-field. It would be possible to install underground tubes during this reclamation. Variant V2, which was analysed too and compared with variant V3, offers except for energy potential the possibility to use present atrium space actively (green, free time activities...). Variants V2 and V3 have shown almost the same energy impacts on heat demand for space heating, and selection one of them will be direct depending on financial charges for their realisation.

The object of evaluation was only heat demand for space heating, and the next energy savings in heating systems of school building is able to achieve by application of renewable energy sources in heating system (for example heat pump, solar collectors, biomass etc.) [8].

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