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Analysis of thermal energy demand and saving in industrial buildings: A case study in Slovakia

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ABSTRACT

Energy saving through incorporation of automation techniques in buildings is usually too complicated and costly and it is necessary to protect environment. Presently, there is no single directive and standard method to estimate and validate the energy consumption process in industrial buildings for heating to maintain a comfortable environment for working. The purpose of this study was to find and develop a practical method for analysis and calculation of thermal energy consumptions and saving in buildings. The energy required for heating in an industrial building in Kosice, Slovakia was studied using measurements, calculations and dynamic simulations. The energy needed for heating was determined according to the Slovakian and Austrian national standard methods using the simplified calculation method that is applied for non-residential buildings and the ESP-r and BuilOpt-VIE simulation programs. The repeatability of the experimental data and possibility of rapid assessments in an optimized process using these methods were studied. It was found that the clear definitions of the heat consumers inside the building, including all machinery and occupants, are very important for evaluation of energy needed for heating. Using dynamic simulation, it is not possible to reproduce actual temperatures at various heights without prior knowledge of the exact functionality of the heating and cooling systems. The simulations results also indicated that integration of lighting, heat recovery and door opening automation can significantly reduce the heating energy consumption.

1. Introduction

The world energy demand and consumption is rapidly growing that requires further energy supply to meet the larger future demands. Moreover, other issues, such as shortage of energy from natural resources and some environmental concerns, make the large energy consumption more serious. The International Energy Agency (IEA) has published alarming data on energy consumption trends. While the total primary energy supply (TPES) was doubled from 1973 to 2010 (from 6107 to 12,717 million tons of oil equivalent, MTOE) and crude oil production increased almost 40% (from 2869 to 4011 million tons), the total final energy consumption showed 31% increase (from 2815 to 3691 MTOE). Interestingly, in the last two decades the oil price has increased nearly five times. In the same period of 1973–2010, the CO_2 emission was also doubled (from 15,637 to 30,326 million tons CO_2) [1]. On the other hand, buildings consume more than 40% of energy, 25% of water, and 40% of resources, and emit nearly one third of the greenhouse gas emission [2]. Moreover, the buildings provide the greatest potential for reducing emission at relatively low cost. The consumed energy for heating the interior of buildings involves a major part of the total energy usage; therefore, energy efficiency in buildings, and the energy system at large, mainly depends on several physical, climatic, and human variables [3].

There have been a significant number of attempts to analyze the energy consumptions in buildings and to find methods for saving

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energy through various ways in different climate conditions and different kinds of buildings [4–53]. The thermal energy demands have been studied in: cold climates, such as in Finland and Turkey [6,19,46,48]; hot and humid climate, such as in Persian Gulf region, south Asian and African countries [16,17,24,31,40,41,48]; home and residential [15,18,22,32–34], high-rise [47,48] and low-rise apartment buildings [49]; non-residential and commercial [5,20,38,39,42], and industrial [13,53] buildings; and special buildings, for instance museum [35] and university [37]. The review of these papers highlights the fact that the results strongly depend on the types of climate and buildings. In most of these studies, the focus has been on thermal energy consumption analysis in the residential and commercial buildings and there are insufficient investigations on the industrial buildings, particularly in cold climate conditions that heating is very critical.

Building designers attempt to apply innovative technologies and methods to achieve low energy consuming building designs. For decades, advancing the manufacturing performance has been the ultimate goal of industries. Increase of demand, public pressure for minimizing the greenhouse gas emission to protect environment and increase of energy costs have made energy efficiency a critical issue in industrial sector. Greenhouse gas emission is mainly produced from burning of fossil fuels and significantly influences the climate and environment. Energy-efficient optimization has become the aim in industrial buildings designs for the establishment of manufacturing facilities and halls with optimum performance.

Chung has recently reviewed various mathematical methods to evaluate the energy performance in buildings [3]. The methods included simple normalization, ordinary least square (simple regression analysis), data envelopment analysis, stochastic frontier analysis, model-based method, and artificial neural network. Based on the rating models, two types of systems (public and internal) were categorized and the mathematical models were compared according to these categories for various types of buildings (school, residential, hotel). The thermal energy consumed in buildings for heating based on the kind of the building has also been reviewed [43]. Greenhouse gas emission directly relates to the amount of energy consumed in the buildings; therefore, reduction of energy usage significantly decreases the emission from the buildings. Taylor et al. recently studied the decrease of greenhouse gas emission from UK hotel buildings and found that 50% reduction in greenhouse gas emission from hotels is technically possible using mainly passive and practiced technologies [54].

The effects of buildings designs, materials and some other factors on their environment, internal climate and energy consumption have been studied [8,9,13,55]. The performances of buildings for energy consumption were investigated, leading to the conclusion that the required information about the energy can be collected at three stages with a special approach [14].

Many industries have recently reformed their energy consumption plans and policies to a more efficient use of electricity and heat to reduce costs and thus to improve their competitiveness in the present tough global economical conditions. For this reason, using automation in a new building is now possible via modeling and simulation in the serial production systems [56,57]. In spite of increasingly rigorous energy use reduction necessities in all other sectors, new industrial units are only needed to meet the minimum pre-registered thermal conductance and U-values of the building envelope in Slovakia and Austria. Presently, there is no formal program in practice for certification of energy in industrial buildings. Moreover, certificates for energy consumption are not legally necessary for these kinds of buildings, which may change in future.

The energy system in Slovakia mainly depends on the imported fossil fuels via an extensive natural gas distribution system with 29% share of energy. Industries are the major energy consumers, constitute 42% of the final energy and 50% of the electricity consumptions. Compared with the EU-average, the energy intensity in Slovakia is relatively high, primarily because of the significant role of energy intensive industries, such as steel, paper and chemicals. The government places high priority on improving energy efficiency, given the significant reliance on imported fossil fuels. As for the energy savings, it is expected that industry and transportation make 50% contribution, while other measures are estimated to make 30% of the savings by 2016 [58].

According to the rules for workplaces, internal climate conditions are required to satisfy the regulations. Because of the cold climate, spaces in most industrial halls of Slovakia need intensive heating, particularly in winter. The aim of the present joint project between the Technical University of Kosice and the Vienna University of Technology was to evaluate the thermal energy use through measurements, calculations and simulations applied to an industrial building. The objective was to investigate if the thermal energy can be determined through implementing various methods. The results will reveal if the thermal energy needed can be determined easily for all new industrial units and those under restoration, and if the buildings envelopes could rapidly be optimized.

The motivation behind this project was to decrease the relatively large amounts of energy consumption for the heating of manufacturing halls in factories, especially in cold regions like Kosice. In Slovakia, there are no clear heating energy measurements or calculation standards for industrial buildings. Because of the large energy demand for heating factories and the policy and public pressure to reduce energy consumption, many companies are looking for a verification method to purposefully optimize the energy consumption in their manufacturing buildings.

The performance of EN ISO 13790 standard method for calculation of the thermal energy consumption in cold climate conditions has been studied [6]. The authors found that this method provides as much as 46% larger or 59% smaller heat demand by buildings compared with the simulation tool in local conditions—depending on the building style and thermal inertia. It was concluded that the results can be calibrated for the residential buildings with the correct selection of the numerical variables for local climate conditions. The thermal energy consumptions in the selected factories were evaluated via measurements, simplified calculations and dynamics simulations. The first part of the analysis was related to in-situ examinations in a case study of manufacturing hall in a factory, applying Slovakian national standard of energy consumption evaluations for residential buildings [59–61]. The objective of this work was to find a mathematical model connecting the measured values in real conditions. In the second part, the energy demand values for heating of the industrial building were calculated according to the Austrian simplified method of EN ISO 13790 for non-residential buildings using the simulations programs [62]. The thermal energy consumptions were measured in-situ in winter in a selected industrial building. Various calculation methods are available for determining the heating energy use in the residential buildings. It is also possible to perform on-site measurements of the thermal energy use by the residential buildings. In this study, the applicability of the calculation method for thermal energy consumed for heating recommended by the standard methods was investigated and new numerical factors of the utilization suitable for the case study in Slovakia climate conditions were determined.

2. In-situ monitoring thermal energy consumption

The selected manufacturing hall in this case study was monitored according to the Slovakian national standard method of STN