ARTICLE IN PRESS

Renewable and Sustainable Energy Reviews xx (xxxx) xxxx–xxxx

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

journal homepage: www.elsevier.com/locate/rser

Impact of external insulation and internal thermal density upon energy consumption of buildings in a temperate climate with four distinct seasons

Junghun Lee[a], Jeonggook Kim[a], Doosam Song[a,*], Jonghun Kim[b], Cheolyong Jang[b]

[a] Department of Architectural Engineering, Sungkyunkwan University, 2066 Sebu-ro, Suwon 16419 Gyunggi-do, Republic of Korea
[b] Energy Saving Laboratory, Energy Efficiency Research Division, Korea Institute of Energy Research,152 Gajeong-ro, Daejeon 34129, Republic of Korea

ARTICLE INFO

Keywords:
Envelope design standards
Insulation level
Internal heat gain level
Energy savings

ABSTRACT

Most of the building codes for energy saving are focused on strengthening the insulation and airtightness of the building envelope. Insulation and air tightness of the building envelope reduces heat loss during the heating season, but can lead to overheating in the cooling season according to the building types owing to the internal heat gain levels.

This study reviewed the effect of strengthening the external insulation level on energy consumption for heating and cooling in buildings with various internal heat gain levels. The reference building was located in a temperature climate with four distinct seasons in Seoul, South Korea. The variation of annual heating and cooling energy consumption was analyzed in regard to diverse internal heat gain levels and envelope properties using parametric simulation methods. Less total energy was required for heating and cooling by enforcing the insulation level in buildings with low internal heat gain levels, while more energy was required in large office buildings with high internal heat gain levels. The present prescriptive envelope design standards of Korea are ineffective in high internal heat gain buildings. Actually, the current U-value envelope standard may increase the annual energy consumption in commercial buildings in Korea. The standard for external thermal insulation should depend on whether the building is envelope-dominated or internally dominated to reduce the building heating and cooling energy demands.

1. Introduction

Buildings represent 32% of the total final energy consumption and 40% of the primary energy consumption in the world [1–3]. In addition, the building sector is often cited as one of the most cost-effective areas to reduce energy use [4,5]. The building envelope, the interface between the interior of the building and the outdoor environment, serves as a thermal barrier and plays an important role in determining the energy demand to maintain a comfortable indoor environment [6–10]. Most countries began issuing building standards on insulation in the 1970s, and these standards have been updated over the years with prescriptive or compulsory code and a performance-based index [11–20]. A performance-based index allows designers greater flexibility than prescriptive code when selecting variables and tends to encourage more innovative building designs [21–24]. However, many countries are still adopting prescriptive codes rather than a performance-based index. Prescriptive codes are often considered easier to follow than performance-based indices because they clearly describes what is acceptable and require little analysis by the building designer. Inspectors and code officials also prefer prescriptive codes because they can easily confirm compliance with the codes during the design review phase and site inspections [25–30]. Prescriptive codes, however, have several shortcomings [31–33]. First, the process of selecting items from the list does not ensure maximum energy savings for the whole building. Second, prescriptive codes cannot ensure that the performance has not degraded with time.

The typical performance-based indices include the 2010 Energy Performance of Buildings Directive, the 2012 Energy Efficiency Directive, the Energy Cost Budget Method, the Total Building Performance Method, the Overall Thermal Transfer Value (OTTV), Perimeter Annual Load (PLA), and so on. The 2010 Energy Performance of Buildings Directive and the 2012 Energy Efficiency Directive are EU's main legislation when it comes to reducing the energy consumption of newly constructed and existing buildings [11]. The Energy Cost Budget Method was introduced in ASHRAE 90.1–2013 [14]) and the Total Building Performance Method was presented in the IECC 2012 [15], which are both used in the United States (US) as whole building performance methods. The Overall Thermal Transfer Value (OTTV) is a measure of the average heat gain into a building through the building envelope and was introduced in ASHRAE 90A-1980 [34,35]. Singapore was the first country to develop an OTTV standard [36] in Asia. The standard for energy conservation in buildings and building services in Singapore was based on ASHRAE Standards 90-75 and 90-80 A with

* Corresponding author.
E-mail address: dssong@skku.edu (D. Song).

http://dx.doi.org/10.1016/j.rser.2016.11.087

Available online xxxx

some refinements to suit the local climate and construction practices. In the 1980s and early 1990s some countries in the Association of Southeast Asian Nations (ASEAN), including Indonesia, Malaysia, Philippines and Thailand, used Singapore's development as a reference model to develop their building energy standards [37–39]. PLA, proposed by the Japanese government, is the total annual cooling and heating load in the perimeter of a building per unit floor area [40]. It includes heat conduction through an envelope and is caused by indoor and outdoor temperature differences, solar radiation heat gain, fresh air load and indoor heat gain. The performance-based method is the most time consuming, and various manufacturer representatives and governmental agencies have developed software packages to determine compliance due to the complexity of the performance-based method analysis. The appropriate use of a dynamic energy simulation tool requires a considerable degree of qualification and training. Therefore, they require the incorporation of additional resources to control the regulation and certification schemes, both for the building design team as well as for the administration [41]. However, these additional resources will most likely not be incorporated, resulting in the simulator not being qualified. Thus, any energy analyses cannot be trusted; this is the biggest issue with performance-based method analysis.

In South Korea, the building envelope requirements in the Building Design Criteria for Energy Saving (BDCES) are mandatory for all new buildings, and this standard is specified as a prescriptive building code. It states that the building envelope should be designed with predefined thermal insulation and heat resistance levels, and either the U-value of the building envelope component or the specific thicknesses of insulation materials are specified [20]. Here, the U-factor or U-value is the overall heat transfer coefficient that describes how well a building element conducts heat or the transfer rate of heat (in watts) through one square meter of a structure divided by the difference in temperature across the structure. The BDCES categorizes the U-factor values based on three geographical zones in South Korea, including central, south and Jeju Island. The Korean government has increased the thermal resistance level of the building envelope to reduce the building energy consumption, and therefore the U-value of the building envelope continues to drop in Korea.

Previous research has shown that a high thermal insulation in envelopes with high internal thermal loads exhibits low heat dissipation through the envelope, thus increasing the energy consumption required for cooling the building [42–44]. Likewise, inappropriate envelope design standards could increase the energy consumption of a building rather than reduce it [45]. To design the optimum envelope thermal insulation level, the indoor thermal environment, including the internal heat gain level, should be considered; this is because heat transfer of the envelope occurs when there is a temperature difference between the inside and outside of the building [46–52]. When designing an energy efficient building, both the internal heat gain level and the strength of the envelope thermal insulation should be considered. However, the prescriptive building codes for building envelopes in South Korea do not take into account the dependency of internal heat gain when deciding the optimum thermal insulation level according to building type.

The aims of this study are to review the prescriptive building codes for envelopes and determine if they can effectively improve energy saving according to the internal heat gain levels in a building. A high-rise building in a temperate climate with four distinct seasons in Seoul, Korea was also reviewed. The scope of this study includes investigating the energy consumption of alternative envelope properties, such as the U-value of building envelope and the Solar Heat Gain Coefficient (SHGC) of fenestration, by using various different internal heat gain conditions. Finally, the limitations of prescriptive building codes will be discussed.

2. Case study

2.1. Reference building

The reference building used in our analyses was a large-scale office building that is located in Seoul, South Korea. Other specifications of the building are shown in Table 1. For the simulation modeling, the interior zone and perimeter zone were divided by virtual partitions; the adjacent zones with the same thermal environment were merged into a single zone [53,54]. The reference building equipped with Building Energy Management System (BEMS) to assist the energy audits and identify the energy conservation opportunities [55]. The density of lighting, equipment and schedules were obtained from the BEMS, described in Appendices (a) to (c). The infiltration rate was set at 0.1 ACH [56,57]. The occupancy density and schedules were obtained via field measurement from 22 July to 26 July in 2014, and a metabolic rate of 130 W was applied for people referenced by ASHRAE Handbook 2013 [58]. Historic Seoul weather data (IWEC) published by the Korean Solar Energy Society [59] were used for the energy simulation. Seoul corresponds to the 4 A climate region in the US [60]. The system operation hours are described in Appendices (d) and (e).

Table 1
Analyzed building information and simulation conditions.

Building information	Location	Seoul, Korea
	Building type	Large-scale office building
	The number of floors	32 floors above ground and 6 floors underground
	Building height	About 150 m
	Floor area of a typical plan and floor height	About 1200 m^2, 2.8 m
	Construction and materials	-Wall: 0.25 W/(m^2·K) -Window: 1.6 W/(m^2·K), 0.4 (SHGC), 0.744 (VT) -Interior wall: 2.761 W/(m^2·K) -Roof: 0.18 W/(m^2·K) -Floor: 0.8 W/(m^2·K)
	Window to wall ratio	70.8%
	Infiltration	0.1 ACH
Simulation conditions	Indoor set-point temp. and RH	Cooling: 26 °C, 50% RH, Heating: 20 °C, 40% RH
	Weather data	Seoul, South Korea (EPW)
	Internal thermal loads	-People: 0.2 person/m^2 with a metabolic rate of 130 W -Lighting: 25 W/m^2 -Equipment: 25 W/m^2 -Schedules: See Appendix
	Minimum fresh air	25 CMH
System	Cooling system	Type: Steam turbine Inlet and outlet temp. of chilled water: 13.4/5.6 °C Inlet and outlet temp. of condenser: 30/35 °C Refrigerating capacity: 1000 USRT COP: 4.5
	Heating system	Type: Gas-fired Capacity: 8 t/h Max pressure: 16 kg/cm^3 Efficiency: 92%

2.2. Simulation method

The simulation modeling for analysis was based on the M & $2V guidelines of ASHRAE Guideline 14 [61]. There are four options in the M & $2V guidelines; option D was selected to calibrate the simulation. The actual energy consumption data of the reference building was obtained by the BEMS to conduct the calibrated simulation [62–65]. The mean bias error (MBE) and the coefficient of variation of the root mean square error [Cv(RMSE)] were used as an error index to determine the accuracy of the calibrated simulation results. This value represents the overall uncertainty of the simulation when predicting whole-building energy usage. The lower