Energy and Buildings 76 (2014) 513–523

Contents lists available at ScienceDirect

Energy and Buildings

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

Expanding Inter-Building Effect modeling to examine primary energy for lighting

Anna Laura Pisello [a,*], Veronica Lucia Castaldo [a], John E. Taylor [b], Franco Cotana [a]

[a] CIRIAF – University of Perugia, Via G. Duranti 67, 06125 Perugia, Italy
[b] Charles E. Via, Jr. Department of Civil and Environmental Engineering, Virginia Tech, 113B Patton Hall, Blacksburg, VA 24061, USA

ARTICLE INFO

Article history:
Received 30 November 2013
Received in revised form 21 February 2014
Accepted 26 February 2014
Available online 13 March 2014

Keywords:
Dynamic simulation
Energy efficiency
Inter-Building Effect
Model calibration
Primary energy
Lighting

ABSTRACT

Building modeling and energy performance assessment models have become fundamental tools for both designers and researchers. Spanning the boundary of single building analysis, the purpose of this paper is to investigate how buildings energy performance is influenced by Inter-Building Effects (IBE). Previous research has examined IBE impact on cooling and heating energy performance predictions across buildings, however, the impact of IBE on lighting, which may be substantial, has not been examined. We investigated this impact through coupled numerical and experimental analysis. We built upon and further validated the Inter-Building Effect approach through modeling the contribution of lighting energy use on IBE and through the use of empirical data for model calibration. We demonstrated that the energy use performance prediction deviations resulting from lighting IBE are greater than those from heating or cooling in a case study building and we described this expanded IBE calculation and assessment as IBE^{II}. To further confirm the reliability of the findings, we replicated the analysis for four different building orientations and observed non-negligible primary energy requirement modeling errors irrespective of orientation. This demonstrates the critical need to include lighting in IBE calculations to more accurately model primary energy requirement for buildings in urban contexts.

1. Background and research objectives

In the past few years, the important role of building energy models in the field of dynamic simulation [1,2] and prediction of buildings' year-round energy performance has been investigated by many researchers [3]. This is driven by the fact that buildings globally account for nearly 24% of total energy consumption, and up to 40% in developed countries [4], but still they are widely reported to operate inefficiently [5,6]. Dynamic calibrated thermal-energy modeling and simulation represent a useful tool to describe buildings' actual behavior [7], together with the collection of experimental data about building physics [8,9] and the analysis of occupants' real attitudes and energy consumption patterns in buildings [10,11]. Additionally, a key role is played by the non-negligible effect produced by a building's surroundings affecting the thermal-energy performance of the building and microclimate conditions [12]. This phenomenon has been modeled as the Inter-Building Effect (IBE) [13,14]. The IBE index represents a parameter aimed at quantifying the effect of the mutual influence and interaction of adjacent buildings in terms of year-round energy performance. The goal is to quantify the error in the primary energy requirement prediction that may derive from considering the building as a non-realistic stand-alone object, rather than the same building in its real urban neighborhood context, even if the analysis is carried out, in both cases, by sophisticated dynamic simulation tools [15]. Earlier works by Pisello et al. [13] demonstrated that effects attributable to the mutual interaction among buildings can become significant in terms of energy dynamics of buildings' heating and cooling requirement. In particular, the IBE proposed analysis revealed inaccuracies in energy requirement prediction of up to 42% in summer in Miami, FL, and up to 22% in winter in Minneapolis, MN. Therefore, inter-building phenomena cannot be neglected while accurately predicting buildings' energy use in urban context. These works [13] show that heating and cooling effects occur across buildings in terms of IBE, but it is reasonable to expect that other effects could also be important influences of primary energy use at the inter-building level, e.g. lighting.

A substantial literature has investigated the impact of lighting on buildings' energy consumption (e.g., [16,17]). Day-lighting analysis and the relative energy implications due to the shading effects from nearby buildings have been investigated by Li et al. [18]. They found that the shading effect due to nearby obstructions strongly

* Corresponding author. Tel.: +39 075 585 3796.
E-mail address: pisello@crbnet.it (A.L. Pisello).

http://dx.doi.org/10.1016/j.enbuild.2014.02.081
0378-7788/

affects buildings' energy budget, as the detected electricity-energy reductions were up to 25–28 kWh/m^2. Therefore, building designers should critically consider the external environment in order to achieve energy-efficient buildings, given that natural light could help reduce the electrical demand and the sensible cooling load due to artificial lighting. Lam [19] assessed that total annual building energy use would be slightly overestimated (i.e. 2% of the total building cooling load) if shading effects due to neighboring buildings were neglected. Day-lighting is an important and useful strategy in terms of visual comfort and energy-efficient building design. In fact, energy savings resulting from day-lighting leads to lower lighting electricity demand, reduced electricity peaks' intensity, as well as reducing internal cooling loads and modifying air-conditioning (HVAC) equipment performance in general. In this scenario, Capeluto [20] investigated the influence of different obstruction patterns on the daylighting performance of a typical office building in Israel, and demonstrated that the availability of daylighting is approximately proportional to the sky solid angle subtended from the center of the window.

Lately, there has been increasing interest in integrating daylight with electric-lighting to reduce building energy consumption [21]. As such, the conditions when day-lighting reduces net annual energy use, as well as those conditions under which energy use may increase, have been examined by means of an hour-by-hour energy analysis program (DOE-2.1B) as the primary simulation tool [22]. Moreover, a mathematical model linking the energy demand for lighting of a single room (kWh/m^2 per year) and several architectural features affecting the indoor daylight availability, i.e. orientation, window size, and glazing visible transmittance properties, was developed by Aghemo et al. [23].

In the present paper, the IBE [13] is extended to include an analysis of the lighting contribution to building energy performance analysis. The new IBE considering lighting, heating and cooling is reported as IBE^{II}, while the first version of the IBE [13], which only took into account heating and cooling, will be described in this paper as IBE^{I}. The purpose of this research is the development and calibration of reliable building energy models through the collection of experimental data, monitored by outdoor weather stations and indoor temperature sensors, in order to evaluate how the primary energy of buildings is influenced by the Inter-Building Effect and how such IBE is able to affect building lighting requirement, in addition to building cooling and heating requirement (IBE^{II}).

To develop a detailed and reliable predictive model, we conducted calibration and uncertainty analyses in order to estimate its accuracy [24], because significant discrepancies could exist between simulation results and actual monitored thermal-energy behavior of real buildings [25], even when sophisticated simulation tools are used [26]. The calibration process consisted of the minimization of the discrepancy between the simulation model and the actual physical system, with the purpose being to calibrate uncertain input parameters in order to ensure that the model is able to reproduce the thermal-energy performance of the real building. Pernetti et al. [27] investigated the extent to which several different variables such as infiltrations, climate boundary conditions and envelope properties could affect the calibration process and, furthermore, the reliability of the simulation results. Moreover, they defined a calibration procedure using temperature as control variable and using some validation indices such as the "Mean Bias Error" (MBE) and the "Root Mean Square Error" (RMSE) in order to quantify the gap between actual and predicted values, and their correlation. After the calibration of the model, a sensitivity analysis [28] was carried out with the purpose of investigating the extent to which several parameters affect the energy model. Raftery et al. [29] proposed a systematic and evidence-based methodology for calibrating building energy models where parameters were modified in the calibrated model according to the monitored energy consumptions. Soebarto [30] presented a calibration methodology using two to four weeks of hourly monitored data and monthly utility records. The procedure included data collection about building features, HVAC systems, weather conditions and monthly energy consumption. Clarke et al. [31] developed a validation methodology which emphasized the use of empirical data in the model proving process. The procedure consisted of the use of simulation to obtain model predictions and parameter sensitivities' analysis, and of the use of high quality datasets. The authors also prescribed techniques to evaluate residuals and determine their cause.

In this paper, the research objective is to propose an expanded methodology for energy performance assessment of buildings. This method accounts for experimentally calibrated and validated energy simulation models that implement a refined Inter-Building Effect approach which includes the lighting contribution to the primary energy requirement, together with heating and cooling requirement, to assess primary energy performance deviations caused by surrounding buildings.

2. Methodology

The study consists of the analysis of the Inter-Building Effect existing among the buildings situated inside the campus of the University of Perugia, Italy, in order to quantify how the IBE affects buildings' energy performance in terms of heating, cooling and lighting year-round requirement. The main steps of the research are described below:

- Continuous indoor thermal monitoring of two offices of the "control building" chosen for the overall study;
- Development of the thermal-energy model and dynamic simulation of the year-round thermal-energy behavior of the whole building;
- Calibration and validation of the model through collected experimental data;
- Inter-Building Effect (IBE^{II}) assessment through numerical analysis.

2.1. Case study: description of the building and modeling procedure

In order to quantify the mutual impact of buildings situated within close proximity of other buildings, a case study university campus was selected. First, architectural and technical analysis of energy equipment and envelope materials was carried out, in order to collect the input data for the development of a realistic building model using the Energy Plus simulation tool. We selected a case study building located inside the campus of the University of Perugia (latitude: 43°07′04″N; longitude: 12°.21′03″E) which houses the Department of Civil Engineering. The whole university complex contains a group of seven buildings located at different levels (Fig. 1). After modeling all the buildings, a "control building" was chosen for the analysis of the Inter-Building Effect in terms of primary energy requirement for heating, cooling and lighting.

The "control building" is a rectangular two story building. It hosts professors' offices, laboratories and lectures rooms. The two monitored offices are located on the first floor of the building. The structural system consists of reinforced concrete columns and beams. The opaque envelope consists of external brickwork (0.10 m), rock wool insulation panel (0.10 m), an air gap (0.10 m) and internal gypsum plasterboard (0.020 m), with a global thermal transmittance of 0.34 W/m^{2}K. The internal partitions are made of two layers of gypsum plasterboard (0.03 m) with an internal air gap (0.10 m). The roof contains an internal layer of plasterboard (0.013 m), an air gap (0.20 m), glass wool insulation (0.14 m)