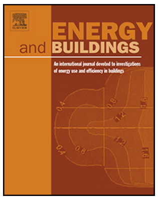
Energy and Buildings 127 (2016) 870–883

Contents lists available at ScienceDirect

Energy and Buildings

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



The impact of natural ventilation on building energy requirement at inter-building scale

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

[a] CIRIAF—Interuniversity Research Center on Pollution and Environment "M. Felli", University of Perugia, via G. Duranti 63, 06125 Perugia, Italy
[b] Department of engineering, University of Perugia, via G. Duranti 93, 06125 Perugia, Italy
[c] Charles E. Via, Jr. Department of Civil and Environmental Engineering, Virginia Tech, 114 Patton Hall, Blacksburg, VA 24061, USA

ARTICLE INFO

Article history:
Received 3 August 2015
Received in revised form 1 May 2016
Accepted 6 June 2016
Available online 17 June 2016

Keywords:
Inter-Building Effect
Natural ventilation
Dynamic thermal-energy simulation
Sensitivity analysis
Building energy performance
Energy efficiency in buildings

ABSTRACT

Inter-building effect is responsible for affecting buildings' primary energy requirement for heating, cooling, and lighting. Nevertheless, the impact of natural ventilation should also be considered while predicting building energy demand, since it is documented to substantially affect indoor environmental quality and thermal comfort. This paper investigates the impact of natural ventilation on building primary energy requirement prediction. The Inter-Building Effect (IBE) approach is applied in a typical residential block in Italy. A sensitivity analysis is performed to determine the key input parameter among (i) climate boundary, (ii) infiltration rate, (iii) opening percentage, and (iv) wind strength. Two scenarios, i.e. the stand-alone building and the same building surrounded by its neighborhood, are compared. The thermal-energy dynamic simulation of the different scenarios is carried out to investigate the impact of outdoor airflows on building primary energy requirement for heating and cooling and on indoor thermal comfort, investigated by means of the Thermal Deviation Index method. Inaccuracies in energy need prediction imputable to natural ventilation without taking into account the IBE are detected. The findings show that IBE is much more affected by buildings' opening percentage, infiltration rate, and local wind compared to the weather context since IBE is a local microscale phenomenon.

1. Introduction and research background

Climate change and global warming phenomena represent a mounting threat to peoples' health and life, since they lead to increased air temperatures and consequently higher CO_2 emissions in the atmosphere [1–3]. It is largely acknowledged that almost 60% of the global energy consumption in developed countries is attributable to buildings, and that cities are responsible for up to 80% of the global CO_2 emissions [5,6]. Therefore, the necessity to implement innovative low-cost and sustainable technologies for the design of more efficient and comfortable buildings is now undeniable, since local climate change will lead to even higher building energy consumption and greenhouse gas emissions [7–9]. In response to these trends, during the last decade a substantial research effort has been dedicated to the development of strategies to reduce building energy consumption. The same strategies were frequently investigated for being able to mitigate localized overheating. For instance, the use of high albedo materials for urban surfaces [10] was demonstrated to be one of the most effective solutions to decrease cooling energy consumption in summer and to reduce urban overheating, together with the increase of vegetated urban surface [11,12], able to reduce urban heat island at the inter-building level and energy needs in both summer and winter conditions.

Along the same lines, the optimized design and exploitation of natural ventilation among buildings located in close proximity in dense urban environments has been demonstrated to play a key role for (i) improving indoor thermal comfort, (ii) reducing energy requirements, and (iii) mitigating urban heat islands [13]. In fact, it was demonstrated that the lack of control of natural ventilation in buildings leads to the reduction of occupants' thermal comfort [4].

A good understanding and prediction of natural ventilation phenomena and infiltration rates in buildings and its relationship with the outdoor local microclimate can help to resolve many issues related to indoor environmental quality [14]. In particular, night cooling as a combination of natural and mechanical night ventilation was found to be effective in the reduction of cooling load [15]. Artmann et al. [16], for instance, managed to map regions

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[*] Corresponding author at: CIRIAF—Interuniversity Research Center on Pollution and Environment "M. Felli", University of Perugia, via G. Duranti 63, 06125 Perugia, Italy.

E-mail addresses: pisello@crbnet.it, anna.pisello@unipg.it (A.L. Pisello).

http://dx.doi.org/10.1016/j.enbuild.2016.06.023
0378-7788/

Nomenclature

SA	Stand alone configuration of the case study building i.e. 1° case scenario
N	Network configuration of the case study building i.e. 2° case scenario
IBE	First version of Inter-Building Effect accounting for primary energy for heating and cooling
IBE_{II}	Second version of Inter-Building Effect accounting for primary energy for heating and cooling, and lighting
IP	Input parameter
OP	Output parameter
SC	Sensitivity coefficient
TDI	Thermal deviation index
TDI_{b-s}	Building thermal deviation index referred to the building performance for each season “s” (−)
TDI_{BC-S}	Base case thermal deviation index for each season “s” (°C h)
$TDI_{b,site-s}$	Thermal deviation index referred to the building performance freely from the climate (−)
TDI_{site-s}	Thermal deviation index for each season s referred to the building in relation to the climate (°C h)
$TDI_{max,i}$	Maximum value of the OP for each i-th IP
$TDI_{min,i}$	Minimum value of the OP for each i-th IP
T_{a-s}	Location sol-air temperature calculated on a reference horizontal surface (°C)
T_{O-in}	Indoor thermal zone operative temperature (°C)
$T_{O,M-s}$, $T_{O,m-s}$	Seasonal target range limits of T_{O-in} (°C)
t_s	Seasonal analysis period (h)
t_{T-s}, $t_{T-s,site}$	Periods during which T_{O-in} and $T_{a-s,site}$ respectively are within the thermal seasonal target (h)
$T_{M-s,site}$, $T_{m-s,site}$	Sol-air temperature range limits (°C)
P_h, P_c	Periods during which T_{O-in} is out of the seasonal thermal target (h)
$P_{h,site}$, $P_{c,site}$	Periods during which T_{a-s} is out of the site seasonal thermal target (h)
IP_i	Generic input parameter
$IP_{max,i}$	Maximum value of the i-th IP
$IP_{min,i}$	Minimum values of the i-th IP
IC_i	Influence coefficient for each IP
w	Number of months during which IBE_{III} is calculated
$PE_{n,i}$	Primary energy requirement for cooling and heating of the control building within the surrounding building network for the i-month
$PE_{s,i}$	Primary energy requirement for cooling and heating of the stand-alone control building for the i-month
q	Volumetric flow through the opening
δP	Pressure difference across the opening
n	Flow exponent varying between 0.5 for fully turbulent flow and 1.0 for fully laminar flow
C	Flow coefficient, related to the size of the opening
P_w	Surface pressure due to wind
P	Density of air
C_p	Wind pressure coefficient at a given position on the surface
v_z	Mean wind velocity at height z
A_min	Stand-alone configuration characterized by the lowest IP
A_max	Stand-alone configuration characterized by the highest IP
N_min	Network of buildings configuration characterized by the lowest IP
N_max	Network of buildings configuration characterized by the highest IP

with sufficient night cooling potential to define a sort of climate cooling potential index based on the indoor-outdoor temperature gap. Moreover, many numerical tools for wind-driven ventilation design have been proposed, in order to effectively predict external pressure coefficients and airflow rate (e.g., [17]). Furthermore, the possibility to apply controlled natural ventilation as a natural cooling ventilation technique was studied by Chiesa and Grosso [18] with reference to the Mediterranean area. In this study, the complex relationship between local climate phenomena, building characteristics, and ventilative cooling was assessed. Natural ventilation has been therefore demonstrated to be one of the key design parameters affecting the buildings' indoor thermal behavior [19], since a correct airflow rate from the outside can be used to maximize the annual thermal comfort level within occupied spaces. A detailed analysis of the transmission losses and gains for investigating the potential of natural ventilation was performed by Andelkovic et al. [20]. It was demonstrated that optimized night-time natural ventilation regimes and airflow rates can help reduce the overall energy consumption by preventing overheating in summer in the case of a multi-story building located in Belgrad (Serbia), with a naturally ventilated double-skin facade. In this same scenario, full-scale experiments to determine the airflow rate in naturally ventilated rooms of a building located in Corsica (France), were carried out in cross ventilation configurations in order to develop different airflow modeling approaches [21]. The coupling between thermal models was found out to be suitable for model based natural ventilation control.

In particular, the effectiveness of such ventilative cooling action is strongly affected by buildings' thermal characteristics and climate boundary conditions in terms of wind speed, wind direction, and outdoor air temperature [22,23]. In fact, a non-negligible effect on building energy requirements is produced by a building's surroundings affecting the thermal-energy performance of the building and microclimate conditions [24]. This phenomenon has been defined as the Inter-Building Effect (IBE) [25]. The IBE is an index aimed at quantifying the effect of the mutual interaction of adjacent buildings in terms of year-round energy performance. The purpose of the IBE is to determine the inaccuracy in energy predictions deriving from considering the building as a non-realistic stand-alone entity rather than surrounded by its real urban context [26]. In fact, non-negligible impact on buildings' heating and cooling requirement was previously detected [24,25] due to the mutual interaction among buildings. In particular, inaccuracies in energy requirement estimation up to 42% were found in summer in Miami (FL) through the application of IBE method. Therefore, the presence of surrounding buildings cannot be neglected while simulating buildings' energy need in urban environment by means of dynamic simulation tools. Moreover, significant inaccuracies in the primary energy requirement prediction were detected when lighting is not taken into account [27]. This results in the necessity to include lighting in energy simulations as it has a significant influence on building primary energy requirement at the inter-building scale. Lastly, recent studies have examined the impact of IBE on localized heating of building surfaces with implications for Urban Heat Island effects [28].

Although Inter-Building Effect research has examined from many perspectives as described in the previous paragraphs, research is lacking that would consider the significant impact on building energy behavior at urban scale that could be created by natural ventilation [29,30]. In fact, both the airflow and flow regime in an urban environment can be significantly modified and affected by the presence of buildings located in mutually close proximity, acting as obstacles and “shields” to the air flow. Therefore, the lack of consideration of the urban surrounding might generate errors and inaccuracies in the primary energy prediction also due to the