Energy & Buildings 173 (2018) 315–325

Contents lists available at ScienceDirect

Energy & Buildings

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

Indexes for passive building design in urban context – indoor and outdoor cooling potentials

Madi Kaboré[a,b,c], Emmanuel Bozonnet[a,c,*], Patrick Salagnac[a], Marc Abadie[a]

[a] LaSIE (UMR CNRS 7356), University of La Rochelle, Av. M. Crépeau, 17042 La Rochelle, France
[b] SOPREMA, 14 Rue de St Nazaire, 67025 Strasbourg Cedex, France
[c] IRSTV (FR CNRS 2488), Nantes, France

ARTICLE INFO

Article history:
Received 8 October 2017
Revised 25 April 2018
Accepted 26 May 2018

Keywords:
Passive cooling
Passive building Key Performance Index
Summer thermal comfort
Urban Heat Island

ABSTRACT

In this paper, we propose a practical approach for decision-making regarding passive cooling design for buildings in dense urban contexts. For non-cooled buildings under temperate climates, assessment of summer thermal discomfort determines the usual passive cooling design together with fossil energy and GHG savings at earth scale. However, passive cooling techniques for indoor climate can be also valuable for local environment impacts, especially urban heat islands' mitigation. Lack of simple representative criteria and complexity of simulation outputs constitute a barrier for the development of passive cooling. Based on a study of a generic commercial building, we analyzed several designs with Sankey diagram and we developed two performance indexes. This chart synthesis of complex output data allows a direct comparison of design solutions. This analysis gives hints for better designer understanding of urban climate and building interactions for the studied passive cooling solutions: cool roofing, nocturnal natural ventilation and rooftop PV system as shading device. Our results show that nocturnal natural ventilation is efficient to moderate indoor overheating compared to the "cool roof". In addition, cool roofs reduce anthropogenic heat transferred to urban environment. PV panels as shading device mitigate summer discomfort and produce energy that increase building energy efficiency through the year. We defined two Key Performance Indexes (KPIs) to define cooling potential of both indoor and urban environment. These KPIs obtained for different temperate climates highlight new prospects for the design of efficient urban designs with controlled environmental impacts and decision process of stakeholders.

1. Introduction

According to the IPCC [1], global warming could increase from 1.1 to 6.4°C by the end of the 21st century. The consequences will be particularly significant in urban areas where the building and their immediate surroundings are the source of multiple microclimate disruptions. The perceptible manifestation of these disruptions is the well-known phenomenon of Urban Heat Island (UHI), which is characterized by increased temperatures compared to the surrounding countryside. UHI is a mutual response of several factors related to climate and specificities of the sites, building design and urban construction materials and urban population activities (anthropogenic heat).

Critical heatwaves are observed during summer periods, with consequences on thermal comfort (indoor and outdoor environments overheating), energy consumption, pollution and more dramatic heat-related health problems [2–5] particularly in middle and high latitude countries. Sensible populations to extreme heat are vulnerable [6], and summer thermal comfort is an emergent criterion in building and urban design. Heatwaves due to combined effects of UHI and climate change would contribute to a widespread use of air conditioning [7,8], whereas most buildings in Europe are currently naturally ventilated in summer. Air-conditioning systems contribute to anthropogenic heat rejections, and local urban microclimate, which in turn increases air-conditioning capacities and associated waste heat. Existing buildings' energy demand could increase together with future climate change [9]. In this context, cooling demand would intensify while performant passive buildings regarding heating would have low winter energy needs. New buildings have to be designed considering this climatic context and a variety of Key Performance Indicators (KPIs) such as thermal comfort, global cost and environmental impact. Improving energy efficiency of buildings and quality of urban environments requires a holistic approach that integrates UHI interactions. Usually, main target of building design aims at improving energy performance; yet, early decision stages affect other

---

* Corresponding author at: LaSIE (UMR CNRS 7356), University of La Rochelle, Av. M. Crépeau, 17042 La Rochelle, France
E-mail address: emmanuel.bozonnet@univ-lr.fr (E. Bozonnet).

https://doi.org/10.1016/j.enbuild.2018.05.043

environmental KPIs and result in trade-offs that requires clear understanding to be quantified in an integrated design process [10].

Reduction of urban and buildings vulnerability requires new urban and building policies for heatwaves [11]. Mitigation and adaptation strategies are well known [9,12–15], based on passive cooling techniques at building scale and restoration of natural cooling at district and city scale. The control of the outdoor thermal comfort is also a challenge for cities and an emergent research topic to develop innovative techniques, such as proposed by Rossi et al. [16]. Increased albedo of urban surfaces is a passive cooling technique used by Doya et al. [17] who measured and compared cool and standard paints for façades and various street canyon configurations. They observed cooling effects in the street canyons with an average temperatures reduction of 0.5°C. At a larger scale, Morini et al. [18] modeled the potential UHI mitigation with a Weather Research and Forecasting (WRF) model. They showed that urban temperature peaks could decrease by 1°C at daytime and 2°C at nighttime, due to the increased albedo of building envelopes and roads. Green roofs and façades is also efficient for UHI mitigation in street canyons as highlighted by Djedjig et al. [19]. Comparative experimental results highlighted a reduction up to 4°C for the mean radiant temperature in the street canyons.

Taking into account UHI mitigation is not yet clearly defined and quantified in urban policies and building efficiency standards. On one hand, regarding construction process for single buildings, specificities of UHI are not directly addressed. On the other hand, urban microclimate is mainly due to the addition of impacts of each building designs. New building design would then focus both on indoor environment quality and environmental issues such as UHI and climate change. These new environmental factors increase the design process complexity [13]. The development of new Building Performance Simulation (BPS) tools is valuable for building design process. However, detailed output data are complex to integrate in the decision process and meaningful information mainly resides only in expert hands [10,20], without holistic approach. Finally, main decision processes are driven by simplified performance evaluations of heating and cooling demands. Regarding the building envelope, requirements usually include thermal insulation without dynamic behavior (U-values) and overall energy consumption. Transient thermal behavior of buildings results of more complex interactions with parameters such as ambient environment or thermal capacity [21]. Then, an appropriate wall design for an air-conditioned room may be inappropriate in free-running conditions [22]. Various studies proposed methodologies to evaluate and compare building component performances of free-running buildings. Kabre proposed the new thermal performance index (*TPI), in which the rating 100 (the higher the better) is assigned for the decrease of ceiling temperature of an optimal roof solution with respect to the ceiling temperature achieved in the worst case of a galvanized iron roof [23]. In [24], five groups of indexes are used for the evaluation of the thermal performance of envelope components in free running buildings, using numerical simulations of the periodic heat. Solar transmittance index (STI) was also proposed by Barrios et al. [21] to rate the overall dynamic thermal behavior of an opaque building element when its external surface is subjected to solar radiation and indoor temperature is kept constant. These KPIs allow comparing different building designs determined by each specific envelope component performance. However, coupled effects of indoor building dynamics and individual building components are prevailing in free-running conditions. In addition, effects on outdoor environment are never assessed at building scale.

This paper aims at investigating the interaction between the envelope and its surrounding environment as well as the indoor thermal comfort during hot periods by building performance simulation of the entire year by determining cooling potential. We analyzed the simulated results for a typical commercial building through proposed KPIs and graphical representations of building energy fluxes. These indexes take into account the building dynamic behavior and coupled effects of passive cooling solutions. We evaluated and compared under various climates the performance of cooling solutions with regard to indoor and outdoor environments:

- cool roof (CR),
- night natural ventilation (NNV),
- combination CR and NNV, and
- solar panels as roof shading device (PV).

Nomenclature

C_{EP}	primary energy consumption, kWh/m^2
c_p	specific heat, kJ/(kg.K)
D	dissipated part, %
DH	discomfort degree-hours,°C.h
E	PV electric energy, kWh/m^2
G	heat gain fraction %
h	heat transfer coefficient, W/(m^2.K)
$\dot{m}$	mass flow rate kg/s
Q	heat quantity, kWh/m^2
S	building area, m^2
t	time, s
T	temperature,°C
U	floor U-value, W/(m^2.K)

Greek symbols

α	solar absorptance
τ	solar transmitivity
η	cooling potential or efficiency

Superscripts

heat	heating system
i	indoor
o	outdoor
other	internal loads
pv	photovoltaic
refl	reflected solar radiation
win	openings

Subscripts

a, A	air
C	convective exchanges
inc	incident solar radiation
I	infiltration
FRin, FRout	cooling indoor and outdoor
g	ground
LW	longwave heat transfer
op	operative temperature
rad	part of heat dissipated by SW and LW
ref	reference case
rm	external running means
sky	LW heat transfer with sky
SW	shortwave heat transfer
T	transmitted exchanges
uL	adaptive thermal comfort upper limit
V	ventilation
wi	inside wall surface
wo	outside wall surface
(+)	positive value
(-)	negative value