Energy and Buildings 107 (2015) 376–391

Contents lists available at ScienceDirect

Energy and Buildings

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

Geo-climatic applicability of natural ventilative cooling in the Mediterranean area

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ARTICLE INFO

Article history:
Received 9 May 2015
Received in revised form 24 July 2015
Accepted 22 August 2015
Available online 24 August 2015

Keywords:
Passive cooling
Natural controlled ventilation
Night cooling
Climate feasibility
GIS analysis
Dynamic simulation

ABSTRACT

The present study aims at assessing the geo-climatic potential applicability of controlled natural ventilation (CNV) as a natural ventilative cooling (NVC) technique in the Mediterranean area. This assessment was carried following two approaches: (1) a climate-dependent evaluation of the NVC potential of different locations considering a "virtual space"; (2) a calculation of the NVC potential of different locations considering a "real" building through dynamic energy simulations.

According to the first approach, a method to assess the potential cooling energy demand as well as NVC was developed though a parametrical analysis of the typical meteorological year (TMY) related to 50 reference cities representing the variety of climate zones of the Mediterranean area.

Based on the second approach, the influence of local climate as well as building characteristics on NVC potential was assessed through dynamic energy simulations on an office building unit located in the 50 reference cities. The software *Design Builder* with *EnergyPlus* code was used to simulate the cooling energy reduction due to NVC over an extended period (May–October), varying building envelop physical parameters and AC/CNV configurations in a reduced sample of locations (8) selected amid the overall sample on the basis of Köppen–Geiger climate classification.

1. Introduction

The building sector (service and residential) is responsible for almost 40% of total primary energy consumption in industrialised countries [1]. This datum considers energy demand for space heating and cooling, hot water production, lighting, cooking and other appliances. In particular, in the USA, the residential sector alone consumes 23% of the total annual energy end use in all sectors, and 50% of that is used for space conditioning (heating and cooling) [2]. In addition, considering the global warming effect of a relentless trend of green-gas emission, the energy consumption for space cooling is rising in the national balance of several countries [3–5]. Within this framework, passive and hybrid solutions for cooling buildings are essential for reducing energy consumption (electricity) in the building sector. These solutions contribute to curb the global warming trend related to the high emission factor of electricity [6], whose primary source is green-gas-generating oil or gas in the majority of industrialised countries. As a matter of fact, nowadays technologies able to increase the efficiency of equipment and to reduce energy losses throughout the building envelope are consolidated and favoured in legislation, standards, and codes of practice. In near-zero-energy-buildings (NZEB) and, in the future, in net-positive-energy-buildings (NPEB), the ventilation factor for IAQ and the efficiency of air-conditioning systems will be important factors in the energy consumption balance of a building [1]. Passive and hybrid solutions for reducing "sol-air" increments and mitigating internal gains are essential technologies for decreasing, totally or partially, the energy necessary for cooling a building. Among these techniques, natural ventilative cooling (NVC) – i.e., cooling by controlled natural ventilation (CNV) [7] – is one of the most effective solutions, which has a relatively simple application. Although a sound design of a CNV system is a challenge in the current professional context because of the complexity of air-movement physics, it is nonetheless a valid alternative to air-conditioning systems and is cost-effective [8].

The present study aims to assess the potential of CNV applications for reducing cooling needs in locations of the Mediterranean basin, during the potential "cooling" season, extended here to the warmest half of the year around the summer solstice in order to cover all the selected locations. In particular, this paper takes into account the climate-related applicability, and relevant geographic distribution, of wind-driven airflow (for comfort ventilation) and temperature gradient (for environmental and structural cooling) [7], and proposes a new methodology based on "residual cooling

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http://dx.doi.org/10.1016/j.enbuild.2015.08.043

Nomenclature

NVC	natural ventilative cooling
TMY	typical meteorological year
CNV	controlled natural ventilation
CDH	cooling degree hours
CDH_{res}	residual CDH
CDH_{26}	CDH at a set-point temperature = 26 °C
CDH_{ad}	CDH at an adaptive set-point temperature
$CDH_{res\text{-}w}$	residual CDH when the virtual cooing potential due to wind-driven comfort ventilation is considered
$CDH_{res,g}$	residual CDH when the temperature gradient availability is taken into account
$CDH_{res,gEF}$	$CDH_{res,g}$ depending on its exploitation factor
EF	exploitation factor of $CDH_{res,g}$ depending on the applicability of temperature gradient for night cooling
$NCAP_{\Delta\theta}$	night cooling applicability potential
$NVC_{cl,p}$	climate-related potential for natural ventilative cooling
DBT	dry-bulb temperature
$\theta_{i,op}$	indoor operative temperature
$\tilde{\theta}_{ad}$	$\tilde{\theta}_{ad}$ as function of the external DBT during the preceding 12 h
$\theta_{o,rm}$	outdoor running mean temperature
$\theta_{o,m}$	outdoor monthly mean of daily min/max mean temperature
$\Delta\theta_{v,air}$	air velocity decrease perceived by a person as the effect of air movement
v_{air}	air velocity
v_{wind}	hourly wind velocity as taken from the TMY
θ_{com}	set-point air temperature for comfort
$\Delta\theta_{day}$	daily ambient temperature variation range
$\theta_{max,day}$	average maximum daily ambient temperature when cooling is needed
$\theta_{min,day}$	average minimum daily ambient temperature when cooling is needed
$\Delta\theta_{com\text{-}DBT}$	hourly difference between the set-point comfort temperature and ambient temperature

degree hours" (CDH_{res}). As a first step, climate-related applicability in a wide sample of locations of the Mediterranean area refers to "virtual" indoor comfort conditions – i.e., without reference to a real building – considering both a fixed set-point temperature approach as required by air conditioning (AC) and an adaptive comfort approach [7,9,10]. In a further development, this study reports the results of dynamic energy simulations on a case study, regarding the potential cooling reduction due to wind-driven and buoyancy-driven ventilation in an office building unit located in all 50 locations, while in a reduced sample of the analysed Mediterranean cities more simulations were carried out varying building envelop physical parameters.

2. Territorial climate-dependent cooling demand

The first step for assessing the geographical distribution of NVC potential within the Mediterranean coastal territory is to determine the "virtual" climate-related sensible cooling energy demand for each of the 50 reference cities, selected as a representative sample of the varying characteristics of the Mediterranean climate. This cooling demand depends on two main meteorological variable: solar radiation and ambient temperature. Seasonal data (May 1–October 31) of global solar radiation on horizontal surface for the reference cities are shown in Fig. 1. However, these data are presented as a useful knowledge for comparison, but no specific elaborations of these data are performed consistently to the objective of this study. Instead, cooling degree hours (CDH) as a synthetic parameter useful to characterise sensible cooling energy demand in the selected locations was calculated based on their TMYs from *EnergyPlus* data base [11]. Two different values of CDH were calculated: (a) based on an AC-related fixed set-point temperature (26 °C); (b) at varying values within a range based on the adaptive comfort approach.

Table 1
Classification of CDH_{26}.

Class	CDH_{26} range
Class 0a	0–500
Class 0b	500–1000
Class 1	1000–2500
Class 2	2500–5000
Class 3	5000–7500
Class 4	>7500

2.1. Cooling degree-hours – AC comfort model

The AC-related climate-dependent "virtual" cooling need for each location is represented by the parameter CDH_{26} (cooling degree-hours at a set-point temperature = 26 °C) calculated through the following equation:

$$CDH_{26} = \sum_{n} (DBT - 26) \quad \text{[only positive values]} \tag{1}$$

where DBT = ambient dry-bulb temperature, n = number of hours in the considered period.

Fig. 2 reports the CDH_{26} value for each location. A classification of CDH_{26} values is indicated in Table 1 and the relevant geo-referenced distribution in shown in Fig. 3.

As shown in Fig. 3, CDH_{26} distribution follows generally the latitude of the selected cities. As expected, very high cooling demands are located in southern Mediterranean areas and in the inland part of Spain. Central Mediterranean coastal cities are characterised by medium-to-low cooling demand, while the northern part shows low CDH_{26} values. Class 0a (no cooling need) is empty, meaning that all considered locations present an AC-related climate-dependent virtual cooling demand however small it may be.

2.2. Cooling degree-hours – adaptive comfort model

According to worldwide diffused HVAC standards such as ASHRAE 55-2013 and EN 15251:2008, an approach different from the conventional one described in Section 2.1 can be applied in naturally ventilated buildings, based on the adaptive comfort approach mentioned above [9]. Both standards indicate an adaptive comfort range based on the variation of the indoor operative air temperature as a linear function of the outdoor air temperature, considered as the monthly mean of daily min/max mean temperature in ASHRAE's and the running mean temperature – defined as the exponentially weighted running mean of the daily outdoor temperature – in EN's [15]. The upper and lower limits of the indoor operative air temperature are set, in both standards by shifting upward and downward the base linear function by degree steps in relation to different levels of expectation by users. Different temperature degree intervals are set by the two standards. EN 15251:2008, Annex A2, considers three categories corresponding to different levels of expectation: I = high level (±2 °C); II = normal level (±3 °C), III = acceptable, moderate (±4 °C) (Fig. 4a). ASHRAE's considers only two categories out of the base function (optimal conditions, 100% of