Applied Energy 113 (2014) 788–807

Contents lists available at ScienceDirect

Applied Energy

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

Building energy performance analysis by an in-house developed dynamic simulation code: An investigation for different case studies

Annamaria Buonomano *, Adolfo Palombo

DII, University of Naples Federico II, P.le Tecchio, 80, 80125 Naples, Italy

HIGHLIGHTS

- A new dynamic simulation code for building energy performance analysis is presented.
- The thermal behavior of each building element is modeled by a thermal RC network.
- The physical models implemented in the code are illustrated.
- The code was validated by the BESTEST standard procedure.
- We investigate residential buildings, offices and stores in different climates.

ARTICLE INFO

Article history:
Received 2 May 2013
Received in revised form 20 July 2013
Accepted 3 August 2013
Available online 3 September 2013

Keywords:
Building energy performance analysis
DETECt simulation
Heating and cooling demand and load
Dynamic temperature and heat fluxes profiles

ABSTRACT

A novel dynamic simulation model for the building envelope energy performance analysis is presented in this paper. This tool helps the investigation of many new building technologies to increase the system energy efficiency and it can be carried out for scientific research purposes. In addition to the yearly heating and cooling load and energy demand, the obtained output is the dynamic temperature profile of indoor air and surfaces and the dynamic profile of the thermal fluxes through the building elements. The presented simulation model is also validated through the BESTEST standard procedure.

Several new case studies are developed for assessing, through the presented code, the energy performance of three different building envelopes with several different weather conditions. In particular, dwelling and commercial buildings are analysed. Light and heavyweight envelopes as well as different glazed surfaces areas have been used for every case study. With the achieved results interesting design and operating guidelines can be obtained. Such data have been also compared vs. those calculated by TRNSYS and EnergyPlus. The detected deviation of the obtained results vs. those of such standard tools are almost always lower than 10%.

1. Introduction

In the last years a significant effort in the direction of buildings energy efficiency has been promoted by governments and scientific communities [1]. From this point of view, Building Energy Performance Standards (BEPS) codes are today an irreplaceable tool for analysing the buildings thermal behaviour and for reaching their energy efficiency. Remarkable research works have been recently carried out although such argument involves a lot of researches from decades. In particular, many BEPS codes have been developed or improved including tools for new technologies for building envelope or HVAC systems. In this framework, the scientific research field regarding the dynamic prediction of the building energy demand is still today productive and current. In addition, the recent Energy Performance Building Directive (EPBD), issued by the European Union, emphasizes the need of energy performance standards and requires the certification of all the new codes developed for BEPS analysis purpose in compliance with the related standards [1]. From this point of view, the BEPS tools for the dynamic assessment of heating and cooling demands are also recommended to be tested by several validation procedures. Among them, the EN 15625:2008 [2] and BESTEST [3] ones are adopted by international and/or legislative organizations [4,5].

Regarding the BEPS research field, a lot of building physical, statistical and hybrid analysis models have been recently developed and/or updated. Advantages and drawbacks of such BEPS methods are highlighted by detailed literature reviews [6,7]. Concerning the physical models many of them have been recently implemented in suitable computer codes for professional and/or scientific scopes [8–10]. They include simplified and complex detailed simulation tools. In the simplified ones, lumped capacitance methods, re-

* Corresponding author. Tel.: +39 0817682549; fax: +39 0812390364.
E-mail address: annamaria.buonomano@unina.it (A. Buonomano).

0306-2619/$ - see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.apenergy.2013.08.004

Nomenclature

A	heat exchange surface area (m^2)
a	surface unitary convection heat transfer coefficients (W/m^2 K)
B	solar reflectivity diagonal matrix (–)
BESTEST	referred to the BESTEST validation procedure
BEPS	Building Energy Performance Standards
C	thermal capacitance (J/K)
CDD	cooling degree day (Kd)
CI	BESTEST confidence interval
c	specific heat (J/kgK)
cooling	referred to HVAC system cooling mode
d	density (kg/m^3)
EPBD	Energy Performance Building Directive
F	internal surfaces view factors matrix (–)
f	external surface view factor (–)
G	Gebhart's matrix (–)
HDD	heating degree day (Kd)
k	conductivity (W/mK)
I	solar radiation flux (W/m^2)
$\bar{I}$	identity matrix (–)
I^0	vector of the total solar radiation directly received by the interior surfaces (W/m^2)
I^{int}	vector of the global solar radiation flux (W/m^2)
ISR	incident sun radiation (Wh/m^2 y)
M	building element
$\dot{m}$	mass flow rate (kg/s)
N	node of the thermal network
Q	energy demand (Wh/y)
q	unitary energy demand (Wh/m^2 y)
$\dot{Q}$	thermal load (W)
$\dot{q}$	thermal flux (W/m^2)
R	thermal resistance (K/W)
S/V	heat transfer surface to heated/cooled volume ratio (–)
T	temperature (K)
t	time (s)
v	wind velocity (m/s)
vent	referred to the dry air ventilation
W/W	window to wall surface area ratio (–)
x	horizontal distance between the vertical fin edge and the shadow (m)
y	vertical distance between the overhang edge and the shadow (m)
z	overhang and/or fin width (m)

Greeks letters

α	absorption factor (–)
β	hourly solar angle (°)
Γ_m	net long wave radiation load (W)
γ	thickness (m)
Δh_{vs}	water latent evaporation heat at 0°C (J/kg)
δ	hourly declination angles (°)
E_{LW}	emissivity matrix of the long wave radiations (–)
ε	emissivity (–)
ϑ_s	zenith angle of sun (°)
λ	latitude of the selected site (°)
$\boldsymbol{\Phi}$	solar and long wave radiations load (W)
ϕ	moist air relative humidity (%)
φ_s	azimuth of sun (°)
φ_p	azimuth of the building surface (°)
P_{LW}	reflectivity matrix of the long wave radiations (–)
ρ	reflectivity (–)
σ	Stefan–Boltzmann constant (5.67×10^{-8} W/m^2K^4)
τ	time step (s)
$\boldsymbol{\Psi}$	solar radiation load entering through windows (W)
Ω_{in}	dry air mass (kg)
ω	moist air specific humidity (g/kg)

Subscripts

DN	direct normal
gain	referred to the building internal gain
ext	external
fl	referred to the floor surface
FF	referred to the free floating regime
gl	referred to the glass surface
HVAC	referred to the HVCAC system
heating	referred to HVAC system heating mode
hor	referred to the horizontal building surface
in	referred to the indoor air
int	internal
lat	referred to the latent heat
m	referred to the building element
n	referred to the node of the thermal network
out	referred to the outdoor air
p	referred to constant pressure
sens	referred to the sensible heat
sky	referred to the sky vault
sol	solar
South	referred to the South building surface
sp	referred to the set point
tran	transmitted
vent	referred to the air ventilation
w	referred to the water vapour

Superscripts

beam	referred to the beam solar radiation
cond	referred to conduction
conv	referred to convection
diffuse	referred to the diffuse solar radiation
rad	referred to radiation
600	referred to the BESTEST qualification case 600
900	referred to the BESTEST qualification case 900

sponse factor methods, conduction transfer functions methods and finite difference methods are taken into account [11–16]. Complex tools are based on computational fluid dynamics approaches [17]. In several cases, these methods have also been combined [11,13,18–20]. Generally, the selection criteria for choosing among alternative physical methods to be adopt and developed basically depends on the complexity of the occurring building phenomena that have to be investigated, as well as on the fidelity and the accuracy of the dynamic simulation of the building's response.

Nowadays, thanks to the more powerful computers, detailed dynamic simulation models for whole building-HVAC system performance analyses are available. Through such BEPS tools the system behaviour in terms of energy use for heating, cooling, lighting, etc., as well as building indoor air and surfaces temperatures, can be predicted for the whole year, for a single season or for few hours. Some of these tools are also commercialised [8,21–23]. A summary about assumptions, features and limitations of such BEPS standards are reported in [24–26].

Although all these tools are capable of a high level of flexibility, recently many new in-house BEPS codes have been developed mostly for research scopes. In many of them, the thermal Resistance Capacitance (*RC*) network approach is still today widely