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Passive Cooling Load Ratio method

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ABSTRACT

The method Passive Cooling Load Ratio (PCLR) is an innovative simplified method which calculates the monthly cooling energy needs of a thermal zone where passive cooling systems are installed using the variables: cooling energy load and passive cooling potential. This new method is based on the Solar Load Ratio (SLR) that was previously developed for solar heating systems. Although, PCLR was theoretically developed for any passive cooling system, here it is applied to passive cooling based on ventilation strategies. In addition, this paper presents its application to an office room ventilation using: (i) forced cooled air from an earth-to-air heat exchanger (EAHE) and (ii) natural induced air by a solar chimney from the EAHE. Correlations were obtained for those systems, using the parameters that describe the local climate, the system type and its dimensions. The numerical model used to obtain the correlation functions when one of the systems is installed, associates previously developed numerical models with 5R1C model of ISO 13790. However, the PCLR method can be used to accurately estimate the cooling energy needs without using complex models for simulation. The error for all systems does not overcomes 5.2%, which is an acceptable variation for a simplified method.

1. Introduction

Currently, developed countries stress to reduce energy consumption in buildings that accounts for 20–40% of the total final energy [1]. The expected decrease caused by the improvement of the equipments energy efficiency is, by far, exceeded by the increase in number and use of domestic appliances, in residential sector, and electrical appliances such as information and communication technologies, in service sector [2]. To change this trend, a new kind of buildings should be further developed, the so called "nearly Zero Energy Buildings" (nZEB) [3], which should lay on two complementary action lines: reduce the energy demand and use renewable energy sources. For the near future, starting from 2020, all new buildings in the European Union must be nZEB, according to European Union Directive on Energy Performance of Buildings [4]. To pave the way for decreasing buildings energy demand, it is imperious to apply passive cooling and solar heating systems according to climate requirements, while keeping the comfort conditions for its occupants.

The calculation methods for cooling energy needs of International Standard ISO 13790 [5], both hourly and monthly, account for the beneficial effect of the solar shading, thermal inertia and radiative cooling. Other cooling strategies, such as ventilation, can be accounted, even if ISO 13790 does not explicitly define how, by the use of the adjustment factor correcting the external air temperature [6]. This approach is, however, difficult to implement because such adjustment factor is not defined for passive cooling systems. An explicit calculation methodology for passive cooling systems, such as for passive solar heating, is still missing; therefore, it can be argued that simplified methods for passive cooling systems should be developed and included in ISO 13790.

The term "passive cooling system" is here extended to any strategy, design feature or technology to the control or reduction of the cooling energy needs. Typically, passive cooling systems require no use of other sources of energy, besides those naturally available, or their use is very low compared to the benefit effect provided.

2. Passive Cooling Load Ratio method (PCLR)

2.1. The concept

The method Passive Cooling Load Ratio (PCLR) aims at bridging the ISO 13790 need for improvement by providing a simplified method for estimating cooling energy needs of a thermal zone, depending on the characteristics of the passive cooling system and the cooling energy load, i.e. the total cooling to be extracted. The PCLR method conceptually follows the Solar Load Ratio (SLR) [7], which applies to the characterization of passive solar heating systems.

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Nomenclature

a	empirical constant
b	empirical constant
c	isobaric thermal capacity (J kg^{-1} K^{-1})
c_D	discharge coefficient
g	gravitational acceleration (m s^{-2})
$\tilde{h}$	amplitude dampening exchange coefficient of air/pipe + soil (W K^{-1} m^{-2})
h	heat transfer coefficient (W K^{-1} m^{-2})
$\tilde{k}$	phase shift exchange coefficient of air/pipe + soil (W K^{-1} m^{-2})
k	empirical constant
$\dot{m}_a$	mass air flow rate (kg m^{-3})
v	velocity (m s^{-1})
s	solar chimney slope (°)
A	surface area (m^2)
D	pipe diameter (m)
G	global solar irradiation (W m^{-2})
H	thermal conductance (W K^{-1})
I	surface solar irradiation (W m^{-2})
N	number of cases
PCLR	Passive Cooling Load Ratio
PCLR*	temperature corrected PCLR
PCF	Passive Cooling Fraction
Pr	Prandtl number
Q	heat energy (J)
Q_{gn}	cooling energy load (J)
Q_{nd}	cooling energy needs (J)
Q_{ve}	ventilation cooling potential (J)
Ra	Rayleigh number
T	air or surface temperature (K)
T_0	absolute temperature at 0 °C (K)
U	overall heat transfer coefficient (W K^{-1} m^{-2})
V	volume (m^3)
X	pipe extension (m)
Y	solar chimney height (m)
Z	buried pipe depth (m)

Greek letters

α	surface solar absorption
β_i	angle of incidence (°)
β_r	angle of refraction (°)
ε	surface emissivity
η	refraction index
θ_0	first air temperature amplitude in the harmonic state
ϑ	temperature function
λ	thermal conductivity (W K^{-1} m^{-1})
μ	dynamic air viscosity (kg m^{-1} s^{-1})
$\hat{\mu}$	normalized error mean value, bias
ρ_a	air density
σ	Stephan–Boltzman constant
$\hat{\sigma}$	normalized error standard deviation, error
τ	surface solar transmission
ϕ	heat flow rate (W)
φ	volumetric air flow rate (m^3 s^{-1})
ω	angular frequency of temperature oscillation (rad s^{-1})
ΔT	thermal amplitude (K)

Subscripts

a	air
bw	black wall surface
c	critical
e	external air
f	floor
i	air inside the thermal zone
int	internal
is	internal-to-star
inf	infiltration air
j	hour
NUM	numerical methods
op	opaque element
p	air inside the pipe
PCLR	PCLR method
gl	glass surface
s	star
sc	air inside the solar chimney
sol	solar
sup	supply air
ve	ventilation air
w	window

The main idea of PCLR is to provide an estimative for cooling energy needs avoiding running simulations or complex models, whenever passive cooling systems are used. Therefore PCLR, as all simplified methods, quantifies the energy needs within an acceptable uncertainty or bandwidth, which for the monthly method of ISO 13790 was found to be 10% [8], using the parameter of standard deviation.

This innovative method proposed in this paper uses the PCLR parameter, defined as the ratio between the system cooling potential, here applied for ventilation Q_{ve}, and the cooling energy load Q_{gn}, by

$$\mathrm{PCLR} = \frac{Q_{ve}}{Q_{gn}} \tag{1}$$

Cooling energy needs can be directly calculated by

$$Q_{nd} = (1 - \mathrm{PCF})Q_{gn} \tag{2}$$

with PCF as the Passive Cooling Fraction, representing the contribution of the passive cooling system to extract the cooling energy load (see Fig. 1). The PCLR method, as SLR's, is based on empirical correlations of PCF as a function of PCLR depending on the system technology.

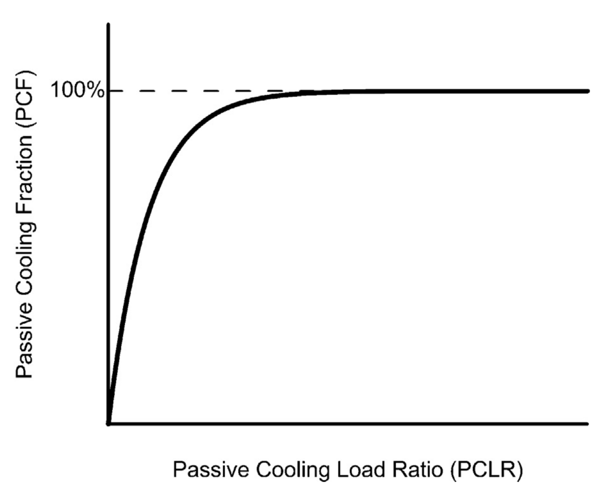

Fig. 1. Passive Cooling Fraction as a function of Passive Cooling Load Ratio.