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Transient model of a Professional Oven

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Abstract

Tackling the climate change by reducing energy consumption is among the biggest, most urgent challenges society is facing and requires a continuous efficiency improvement of thermal systems. Appropriate design strategies, developed a priori and then experimentally validated according to suitable test protocols on a prototype, are needed in order to reach potential energy saving targets. These strategies can successfully be implemented in the food service sector, where cooking appliances, in particular, present many possibilities for improving energy savings. Therefore, a valuable design methodology should take into account not only steady state operating conditions but also the transient behaviours of the device, which must be described by means of specially developed theoretical dynamic models. The operating profile of an oven, for example, consists of a sequence of unsteady phases (cavity heating-up, food introduction and extraction, switching from one cooking mode to another) interspersed with steady cooking phases. The dynamic model presented in this paper defines the energy conservation equations of a professional oven, where a high temperature thermal source positioned inside its cavity produces thermal power radiated and modulated over time, according to a suitable control strategy. In particular, when the temperature in the cooking zone of the cavity has reached a specified set point, this is thermostatically controlled in time, depending on the cooking phase. The resulting equation system is then solved by means of numerical methods. With this code, it is possible to support the design phase of both the structure and the control strategy of the oven. It permits, for example, to get a general understanding of the best possible configurations and combinations of insulation materials for the cavity walls or, with reference to the control strategy, to simulate different cooking procedures, with the aim of optimizing the operating sequence of the oven, reaching the maximum energy saving without reducing the cooking quality. The code, validated by comparison with a set of experimental data obtained with a current production model, will be applied in the design phase of a new line of high efficiency professional ovens.

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Keywords: Lumped capacitance method, professional oven

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1. Introduction

The current global environmental situation requires technical efforts for designing new systems and machines capable to minimize the overall energy consumption. Professional kitchens, having an average energy demand almost twice the amount used for domestic cooking, has a substantial energy saving potential. To meet the increasing demand for more sustainable kitchen products, it is necessary to develop suitable design strategies, based on theoretical models experimentally validated according to rigorous and significant test protocols on a prototype.

The models should take into account not only steady state operating conditions, but also the transient behaviours of the device, which must be described with specially developed theoretical dynamic models. In fact, transitory situations are very common and time consuming during the operating life of a professional cooking appliance: the operating profile of an oven, for example, consists of a sequence of unsteady phases (cavity heating-up, food introduction and extraction, switching from one cooking mode to another) interspersed with steady cooking steps.

To characterize the energy performances of the system it is necessary to identify and quantify the incoming and outgoing energy flows from the device, including the evaluation of internal and external heat transfers during both the transitory and the steady state phases. The scope of such an analysis is not only to do an energetic performance evaluation of a particular appliance but, more generally, to give support to the design phase, the material selection, the cooking phases evaluation and the control logic definition from the beginning.

The aim of this paper is the definition and validation of a model of a professional oven. Several studies dealing with the modelling of an oven can be found in the open literature: they can be organized according to five possible approaches, i.e. three or two dimensional CFD models, system modelling for control purposes, algebraic modelling and applications of the lumped capacitance method, as briefly discussed in the following review.

The most accurate and detailed 3D-CFD approach is adopted in [1], [2], [3]. In [1] authors present a model of an electric bread-baking oven, comparing the internal temperature profiles obtained with three radiation models.

Nomenclature

A	area $[m^2]$
c	specific heat capacity $[J/kgK]$
C	thermal capacity $[J/K]$
D	heater tube characteristic length $[m]$
F	view factor
h	convective coefficient $[W/m^2K]$
L	wall characteristic length $[m]$
$\dot{m}_{fan}$	fan mass flow $[kg/s]$
N	number of walls
Nu	Nusselt number
P_{el}	electric power $[W]$
P_{rad}	radiated power $[W]$
Pr	Prandtl number
$\overline{Pr}$	averaged Prandtl number
R	thermal resistance $[Km^2/W]$
R_g	overall glass thermal resistance $[Km^2/W]$
Re	Reynolds number
t	time $[s]$
T	temperature $[K]$
V	volume $[m^3]$
Greek symbols	
δ_{ij}	Kronecker Delta
Δx	spatial step [m]
ϵ	radiation emissivity
λ	thermal conductivity $[W/mK]$
ρ	density $[kg/m^3]$
σ	Boltzmann's constant $[J/m^2sK^4]$
Subscripts	
C	cooking zone
$cond$	conductive
$conv$	convective
e	external ambient
$g1, g2$	internal and external glass
g	glass
mC	coocking zone thermal masses
mP	power zone thermal masses
n	timestep
P	power zone
rad	radiation
$R1$	resistor external node
$R2$	resistor internal node
s	wall superficial internal node
w_i	*i-th* wall
w_i1	external superficial node
w_j	*j-th* wall