available at www.sciencedirect.com
ScienceDirect
journal homepage: www.elsevier.com/locate/ijrefrig

Performance evaluation and optimal design of supermarket refrigeration systems with supermarket model "SuperSim", Part I: Model description and validation

Y.T. Ge*, S.A. Tassou

Mechanical Engineering, School of Engineering and Design, Brunel University, Uxbridge, Middlesex, UB8 3PH, UK

ARTICLE INFO

Article history:
Received 26 May 2010
Received in revised form
7 November 2010
Accepted 24 November 2010
Available online 1 December 2010

Keywords:
Supermarket
Refrigeration system
Energy consumption
Modelling
Validation

ABSTRACT

Conventional supermarket refrigeration systems are responsible for considerable CO_2 emissions due to high energy consumption and large quantities of refrigerant leakage. In the effort to conserve energy and reduce environmental impacts, an efficient design tool for the analysis, evaluation and comparison of the performance of alternative system designs and controls is required. This paper provides a description of the modelling procedure employed in the supermarket simulation model 'SuperSim' for the simulation of the performance of centralised vapour compression refrigeration systems and their interaction with the building envelope and HVAC systems. The model which has been validated against data from a supermarket has been used for the comparison of R404A and CO_2 refrigeration systems and the optimisation of the performance of transcritical CO_2 systems. These results are presented in Part II of the paper.

Evaluation de la performance et conception optimale de systèmes frigorifiques pour supermarchés à l'aide du modèle ≪ SuperSim ≫. Partie I : description et validation du modèle

Mots clés : Supermarché ; Système frigorifique ; Consommation d'énergie ; Modélisation ; Validation

1. Introduction

A modern supermarket requires considerable amounts of electricity and gas for refrigeration, lighting, baking and the maintenance of a comfortable retail environment for the staff and customers. The total electrical energy consumption of grocery stores is approximately 12 TWh and represents approximately 3.5% of the UK's total electrical energy consumption (Tassou, 2007). More than half of the energy used in a modern supermarket can be attributed to refrigeration systems. Lighting accounts for between 20% and 25% and HVAC and ancillary services for the remainder (Tassou and Ge, 2008). The refrigeration system is also charged with a large amount of refrigerant, in the majority of cases HFC,

* *Corresponding author*. Tel.: +44 1895 266722; fax: +44 1895 256392.
E-mail address: yunting.ge@brunel.ac.uk (Y.T. Ge).
0140-7007/$ – see front matter © 2010 Elsevier Ltd and IIR. All rights reserved.
doi:10.1016/j.ijrefrig.2010.11.010

Nomenclature

A,B	coefficients
C_p	specific heat (J kg^{-1} k^{-1})
h	specific enthalpy (J kg^{-1})
HT	high temperature
LT	low temperature
m	mass flow rate (kg s^{-1})
N	number
Q	load, cooling capacity (W)
R	ratio
RH	air relative humidity (%)
T	temperature (K)
t	temperature (C)
V	volumetric flow rate (m^3 s^{-1})
W	power (W)

Greek symbols

ρ	density (kg m^{-3})

Subscripts

a	air
A, asw	anti sweat heater
ain	air inlet
aout	air outlet
case	display cabinet
cd	condenser, condensing
$c01$	cold room group 01
$c_1 \sim c_6$	coefficients
$d01,d02,03$	display cabinet groups 01,02
D, def	defrost
dew	dew point
evfan	evaporator fan
fan	fan
fl	full load
inf	infiltration
onefan	one fan
pl	part load
L,lat	latent
light	cabinet light
m	minimum
r	rated, refrigerant
rcd	refrigerant condensing
rin	refrigerant inlet
rout	refrigerant outlet
sd	saturated discharge
sen	sensible
sp	specified
ss	saturate suction
T, tot	total
wall	cabinet wall

which is directly responsible for significant CO_2 emissions due to refrigerant leakage from the system.

To increase the energy efficiency of supermarket refrigeration systems, several advanced technologies can be applied, which include more efficient components such as compressors and heat exchangers, combined heat and power and trigeneration in combination with sorption refrigeration systems, heat recovery, natural refrigerants and advanced control strategies and system integration (Tassou and Ge, 2008). For the evaluation and ultimate implementation of such technologies, simulation with an efficient and reliable system model could be the optimum way to compare an experiment which may be overly expensive and time consuming to be achievable otherwise.

There are currently four supermarket energy simulation software with built-in supermarket refrigeration system models in the open literature which are: “Cybermart” (Arias, 2004), “EnergyPlus” (EnergyPlus, 2009), “Retscreen” (RETScreen, 2009), and “SuperSim”. In addition, there are two other software for supermarket refrigeration systems (van der Sluis, 2004), “Econu Koeling” (Econu Koeling, 2003) and “ORNL Supermarket Spreadsheets” (ORNL, 2003). These, however, do not incorporate the simulation of the building and HVAC systems and will not be considered further in this paper.

The four supermarket energy simulation models universally recognize that the total energy consumption of a supermarket is the summation of the energy consumption of the various major subsystems such as the refrigeration systems, HVAC and the interaction between these subsystems. However, the methods used to predict the energy consumption of each sub system and the interactions between the subsystems are different. The HVAC energy consumption depends to some extent on the heating and cooling loads of the building envelope. For the building loads, all the supermarket models, with the exception of “Retscreen”, employ quasi-steady state modelling techniques and the Heat Balance Method to calculate the heating and cooling loads, albeit with differing modelling complexities. “CyberMart” considers the building to be a singular zone and calculates the heating and cooling loads from the heat balance of the room air, room surfaces and building structure (Dokka, 2001). In “EnergyPlus”, the cooling and heating loads are calculated from a comprehensive building simulation model which provides a coupled simulation of building loads, systems and plant. “Retscreen” considers the building as a single zone and calculates the heating and cooling loads in a steady state operation with the use of monthly mean climatic data. “SuperSim” is based on multizone building simulation within TRNSYS (2005), which is a transient system simulation program with a modular structure.

The HVAC models for each program are commonly based on the operation of air handling plant. Nonetheless, the ventilation and fresh air flow rates are treated differently within each program. In “Cybermart”, the fresh air flow is controlled by the space air quality whereas in “Retscreen” and “SuperSim” the fresh air quantity is treated as an input to the model. In “EnergyPlus”, the ventilation can be controlled by a schedule which can be modified in response to changes in the external and internal environment.

The modern supermarket refrigeration system consists of at least one low temperature (LT) and one medium or high-temperature (HT) circuit, depending on the size of the supermarket and the number and type of refrigerated display fixtures used. For each temperature circuit at part-load