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Refrigerant alternatives for high speed train A/C systems: energy savings and environmental emissions evaluation under variable ambient conditions

R. Mastrullo[a], A. W. Mauro[a,]*, C. Vellucci[a]

[a]Dipartimento di Ingegneria Industriale, Università degli Studi di Napoli Federico II, p.le Tecchio, 80 – 80125, Napoli

Abstract

The environmental concerns due to global warming are pushing A/C industries to new eco-friendly refrigerants in several fields. In this paper a model to simulate the dynamic evolution of the temperature inside an air-conditioned high-speed train compartment is presented. The dynamic modeling of both the reversible heat pump unit and the thermal loads of the cabin are presented, including the possibility of adapting the frequency of the compressor and the return air fraction for maintaining the internal comfort conditions. Under different dynamic load conditions (in terms of ambient temperature, solar radiation, train speed, number of passengers) the energy consumptions and the TEWI related to the use of new refrigerants, (like R1234yf and R1234ze), are calculated being the R134a a baseline for comparison.

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Keywords: train, energy saving, environmental effect, heat pump;

* Corresponding author. Tel.: +39 081 7682198
E-mail address: alfonsowilliam.mauro@unina.it

Nomenclature

A	surface [m^2]	*Subscripts*	
C	capacitance [$Wh\ m^{-2}\ K^{-1}$]	a	air inside cabin
COP	Coefficient Of Performance	amb	ambient
GWP	Global Warning Potential	aux	auxiliaries
Hz	hertz [s^{-1}]	ceiling	ceiling
$\dot{Q}$	power [kW]	ext	external

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T	temperature [°C]	furniture	furniture
TEWI	Total Equivalent Warming Impact [kgCO_2]	g	solar
U	heat transfer coefficient [W m^{-2} K^{-1}]	glass	glazing surfaces
Vol	volume [m^3]	hp	heat pump
c_p	specific heat at constant pressure [kJ kg^{-1} K^{-1}]	int	internal
k	thermal conductivity [W m^{-1} K^{-1}]	p	passengers
s	thickness [mm]	plant	floor
Greek symbols		rd	radiative
α	absorptivity coefficient	roof	roof
γ	curtains coefficient	side	left/right
ε	long wave emissivity	vertical	vertical
ϑ	time [s]	wall	wall of cabin
ρ	density [kg m^{-3}]		
σ	Stephan-Boltzmann constant		
τ	transmissivity coefficient		

1 Introduction

In order to decrease the concentration of greenhouse gases in the atmosphere F-gas regulation (EU Reg. 517/2014) is pushing A/C industries to phase at refrigerants which do not conform with threshold values of the global warming potential (GWP) [1], among which the most widely used refrigerants for heat pumps. In this paper a dynamic model to simulate the air conditioning of high speed train is presented. Up to now several thermal cabin models have been presented. For instance, other authors such as Li and Sun [3] have modelled a cabin coupled with an AC unit. Liu et al. [4] built a mathematic model to simulate dynamic cooling load of an air-conditioned train compartment. Maidment and Missenden [5] presented the evaluation of an underground railway carriage operating with a sustainable groundwater cooling system. Torregrosa-Jaime at al. presented a lumped-parameter model of a vehicle's cabin with thermal zones [6]. Luger et al. [7] introduced methodologies and tools to identify representative operating conditions of the heating, ventilation and air conditioning (HVAC) systems in passengers rail vehicles. Dullinger et al. [8] built a modular thermal simulation tool for computing energy consumption of HVAC units in rail vehicles. The dynamic modelling here presented combines the reversible heat pump unit and the thermal loads of the cabin and calculates, under different dynamic load conditions (in terms of ambient temperature, solar radiation, train speed, number of passengers), the energy consumptions and the TEWI related to the use of two HFOs refrigerants (R1234yf and R1234ze), being the R134a, one of the most used HFCs, a baseline for comparison. HFOs are low GWP fluids and they have been verified to be valid alternatives for HFCs [2]. First the cabin thermal model will be presented. Then the characteristics of the reversible heat pump and its modelling results in IMST-ART [8] will be shown. Finally a comparison among the three refrigerants considered in terms of energy consumption and TEWI will be shown.

2 Thermal cabin model

The dynamic model here presented has the aim of calculating the thermal load of a cabin of a high speed train during its travel and to couple its loads dynamically with the heat pump performance in order to estimate the energy consumption, while guaranteeing the comfort for passengers, both in summer and winter.

The cabin considered is 27 m long, 3 m high and 3.5 m wide. Besides 30 m^2 of glazing for each wall are assumed. The construction of vertical walls and ceiling is assumed to be 50 mm thick with polyurethane insulation (thermal conductivity of 0.026 W m^{-1} K^{-1}). A cavity separates the ceiling of the cabin by the external roof. The global thermal balance related to the cabin which provides the evolution of the internal air temperature T_a is represented by Eq. (1):

$$\left(Vol_{cab}\, c_{p,a}\, \rho_a + C_{furniture}\, A_{plant}\right)\frac{dT_a}{d\vartheta} = \dot{Q}_g(\vartheta) + \dot{Q}_{g,glass}(\vartheta) + \dot{Q}_{glass}(\vartheta) + + \dot{Q}_{int}(\vartheta) + \dot{Q}_{ext}(\vartheta) + \dot{Q}_p(\vartheta) + \dot{Q}_{aux}(\vartheta) + \dot{Q}_{hp}(\vartheta) \quad (1)$$