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Sensitivity Analysis of Energy Conversion for Effective Energy Consumption, Thermal Comfort, and Air Quality within Car Cabin

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Abstract

There are interactive performances of climatic control within a car cabin in energy consumption, thermal comfort, and air quality. This paper presents sensitivity analysis of those performance indices coupled with mathematical models of air conditions within a car cabin. Through sensitivity analysis, controlled variables are identified for the most influence on energy consumption, thermal comfort, and air quality in effective climatic control. The performance indices are defined from energy consumption of air conditioning unit, predicted mean vote, and concentration of carbon dioxide while mathematical models of air conditions within a car cabin are developed to determine quantitative impact from controlled variables under given operating conditions. Good agreement of simulated results with experimental data is reported for model validation of a sedan car. Some conclusive comments in case studies are recommended from the proposed methodology. In parking, reducing windshield transmissivity by 5% using cover decreases predicted mean vote index by 0.9%. During driving, amount of supply air and temperature can be adjusted to improve thermal comfort whereas energy consumption increases. It is found that decreasing temperature by 5% is superior since corresponding impact on energy consumption is less than increasing amount of supply air by 5% while a predicted mean vote can be decreased by 20.4%. On the other hands, increasing amount of supply air is the most effective way when thermal comfort and air quality are needed to be improved. Increasing amount of supply air by 5% results in changes of the predicted mean vote index and concentration of carbon dioxide by -17.5%, and -0.74%, respectively.

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Keywords: Sensitivity analysis; car cabin; energy consumption; thermal comfort; air quality.

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1. Introduction

Like an engine, performance of a car cabin becomes an important issue since people spend a lot of driving/transporting time within a car cabin. Thermal comfort, air quality, and energy consumption are considered performance indices [1]. Thermal comfort and air quality indicate environmental conditions for a driver and passengers within a car cabin. They also take a critical role in reducing car accidents if occupants feel comfortable and active. To achieve those conditions, air-conditioning unit is implemented while it consumes some amount of energy to make up air within a car cabin. In turn, amount of energy consumption is regarded as a performance index.

Some researchers have studied thermal comfort, air quality, and energy consumption within a car cabin. Their analytical works were developed for mathematical models, which describe mass and energy conversion of an air-conditioning unit [2], [3]. However, none of those works clearly defined effects of some variables within a car cabin on performance indices.

This paper presents sensitivity analysis of performance indices such as a predicted mean vote (PMV) index for thermal comfort, carbon dioxide concentration for air quality, and energy utilized by an air-conditioning unit for energy consumption. Through sensitivity analysis, controlled variable can be identified for the most influence on performances of a car cabin. This analysis results on the knowledge in finding the most effective actions to improve performances.

2. Methodology

2.1. Mathematical model

Mathematical models are developed to determine state variables of air conditions such as air temperature, humidity, and carbon dioxide concentration. This is important because those state variables are used to determine performances of a car cabin in next section. The energy and mass balances of a control volume are shown in Figure 1.

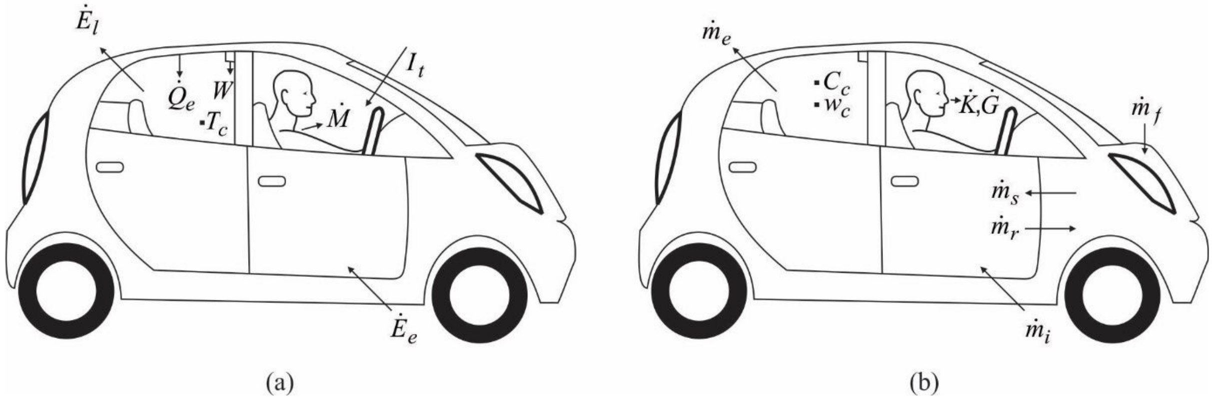

Fig. 1. Control volume of car cabin: (a) for energy balance and (b) for mass balance.

From Figure 1(a), air temperature of car cabin T_c is affected by energy entering the cabin $\dot{E}_e$, energy leaving the cabin $\dot{E}_l$, heat transfer with envelopes $\dot{Q}_e$, transmitted solar radiation I_t, metabolic rate from human body $\dot{M}$, and electrical works done inside the car cabin W.

Under steady state conditions, the energy equations of a car cabin can be written as:

$$0 = \dot{E}_e - \dot{E}_l + \dot{Q}_e + I_t + N\dot{M} + W \quad (1)$$