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"DEVELOPMENT OF EFFICIENT COOLING AND REFRIGERATION SYSTEM FOR SERVICE VEHICLES"

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ABSTRACT

The focus of this research is to provide a proof-of-concept for a high-efficiency vehicle air conditioning and refrigeration (VACR) system that may be used in service vehicles. The development of a high efficiency system can greatly contribute to green and sustainable development and environmental protection due to worldwide energy consumption and the environmental implications of air conditioning and refrigeration (A/C-R) systems. By generating real-time thermal and performance characteristics of the VACR systems used in the food transportation business, this study addresses a vacuum in the literature. Field data from pilot refrigerated service trucks is collected over various seasons of the year, and duty cycles are determined. Thermodynamic and performance simulations of VACR systems under steady state and transient operation circumstances are developed using mathematical models. The platform and concept developed can be used to the whole transportation industry, as well as stationary A/C-R systems

Key Words: VACR, A/C-R systems, vehicle, food transportation business

I. INTRODUCTION

Despite the fact that energy consumption and greenhouse gas (GHG) emissions from energy systems all over the world have received a lot of attention in recent decades, there is still a lot of room for improvement. According to the Intergovernmental Panel on Climate Change's fifth report, the average global surface temperature increased by 0.85 K between 1880 and 2012, hastening glacier melt and sea level rise [1, 2]. The transportation industry accounts for 22% of worldwide CO2 emissions, which contributes considerably to global warming [3, 4]. Refrigerated transportation accounts for about 31% of the food supply chain [5, 6]. Furthermore, mobile air conditioning and refrigeration systems account for almost 20% of total global refrigerant emissions [7]. Many stationary and mobile applications use air conditioning and refrigeration (A/C-R) systems to offer either comfortable conditions for people or a suitable environment for food and other temperature/humidity sensitive creatures/products. These systems use a lot of energy, which results in a lot of greenhouse gas emissions. A/C-R systems utilize more than 20% of total energy used in residential buildings and more than 25% in commercial buildings in the United States [8]. More than 26 billion gallons of fuel oil are utilized each year in the United States only to run air conditioning systems in light-duty automobiles [9, 10]. Vehicle air conditioning and refrigeration (VACR) systems increase fuel consumption by 12-17 percent in compact-midsize vehicles [11, 12].

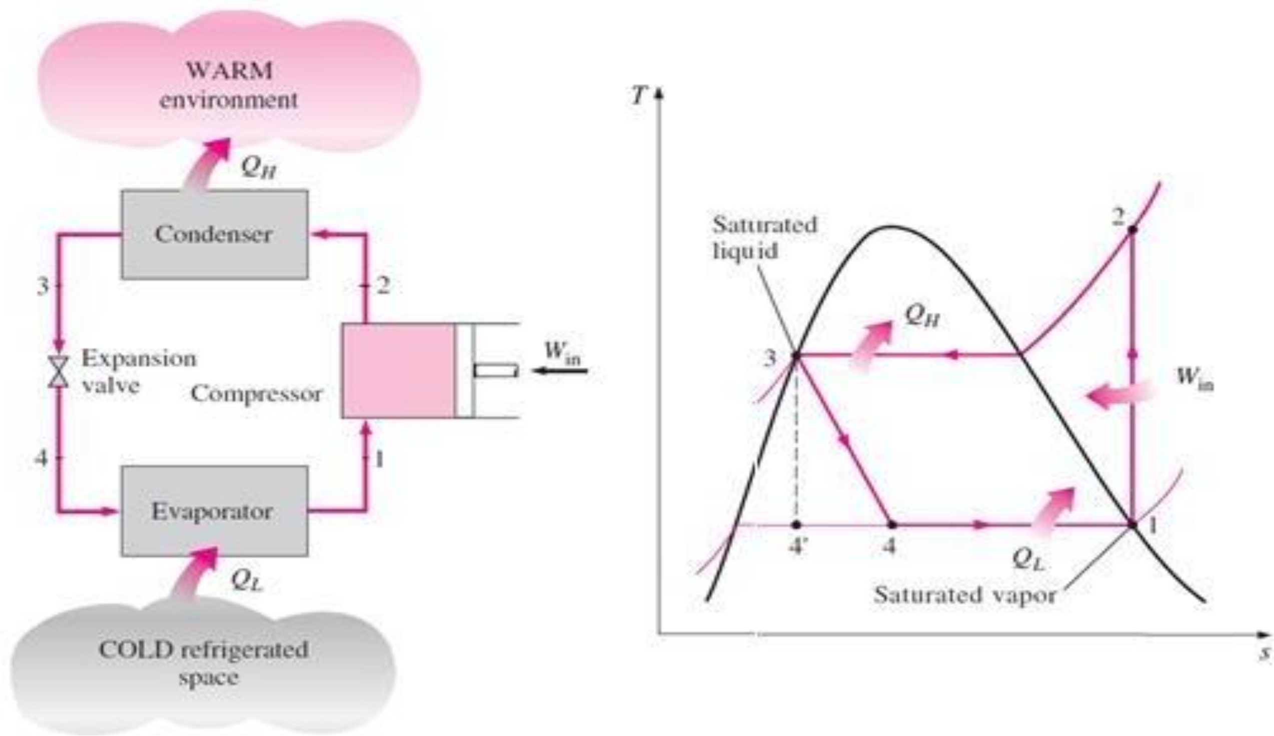

Figure 1 Schematic of a basic VCR cycle [14]

II. OBJECTIVE

Due to the low COP of the numerous VACR systems worldwide, any small improvement can bring a significant global impact. The relatively low COP of VACR systems is in part due to more frequent and inefficient on-off cycling of these systems, which is a result of the lack of intelligent control modules, the small size of the systems, and a more intense load variation. The more intense load variations in VACR systems are due to poor compartment insulation, the high frequency of opening and closing doors or windows, sun exposure, and movement of the vehicle. Accordingly, development of an optimally controlled, proactive VACR system with higher efficiency to replace existing inefficiently controlled VACR systems will have significant global improvement on energy consumption and the corresponding GHG emissions. The optimally controlled VACR system is equipped with a variable speed compressor and variable speed fans that enable the capacity of the system to be controlled instead of using on-off cycling. The focus of this research is on service vehicles; however, the developed concept and system

could be used in all sectors of the transportation industry. The work herein has been prompted by a collaborative research project with two local companies; Cool-It Group, an Abbotsford, BC based manufacturer of anti-idling battery-powered VACR systems for truck and vans; and Saputo Inc., Canada's largest dairy product processor, located in Burnaby, BC. The low COP of battery-powered VACR systems leads to a relatively short life for the batteries and highly affects the reliability of Cool-its products. Also, Saputo spends an enormous amount on fuel for their refrigerated trailers that are used to deliver dairy products every day. Due to the impact of VACR systems on countrywide fuel consumption and the environment, this research project is financially supported by the Natural Sciences and Engineering Research Council of Canada (NSERC) through an Automotive Partnership Canada(APC) Grant, No: APCPJ 401826-10.

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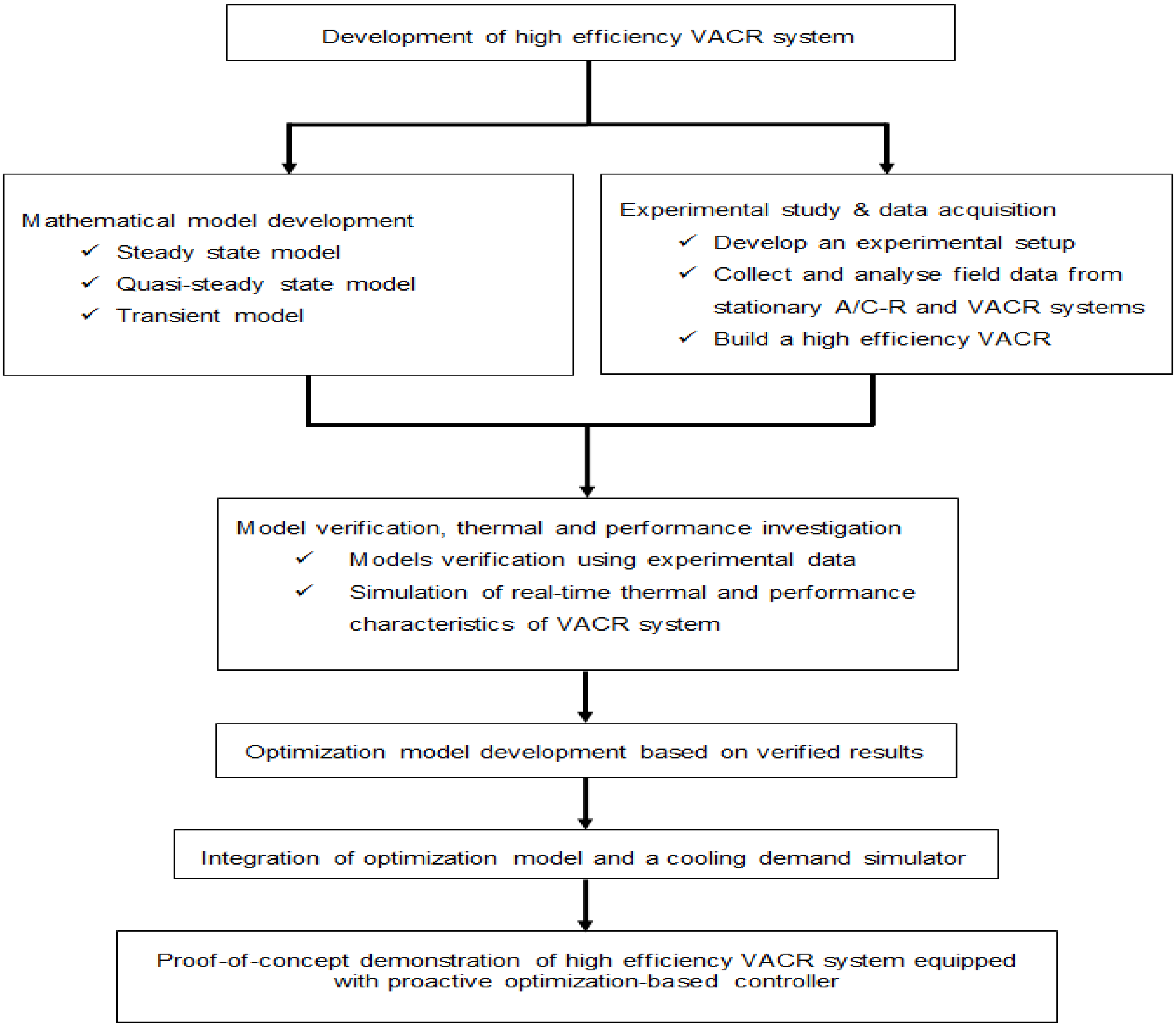
III. METHODOLOGY

Structure of work:



IV. EXPERIMENTAL DATA

To emulate the real-time working condition of a typical VACR system, a new testbed was designed and installed in LAEC. In this test bed, the VACR system is a battery-powered anti-idling device commonly found on trucks and vans. Figure illustrates a sample of this battery-powered anti-idling VACR installed on a long-haul truck's sleeper berth to prevent the truck engine from idling for air conditioning purposes when the truck is stationary.

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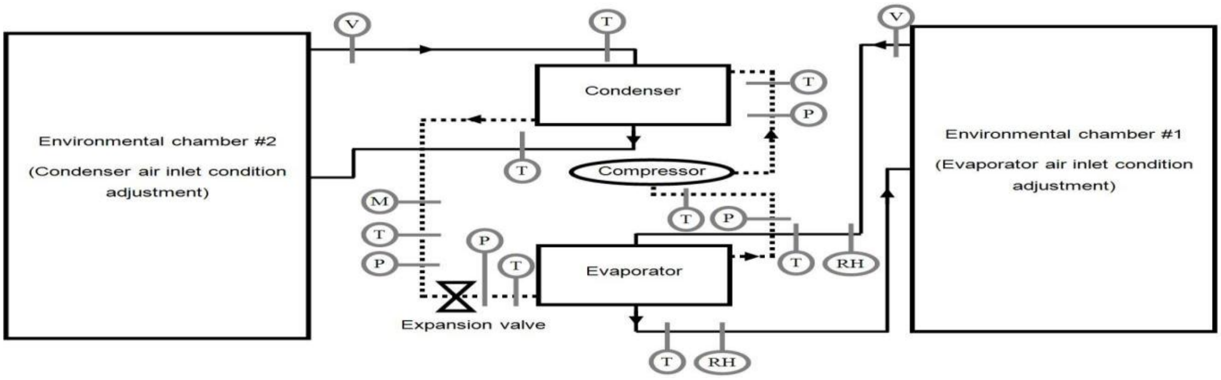

Figure 3 experimental setup schematic (solid lines = air flow; dashed lines = refrigerant flow; t = temperature, p = pressure, rh = relative humidity sensor; m = mass flow rate, v = velocity meter)

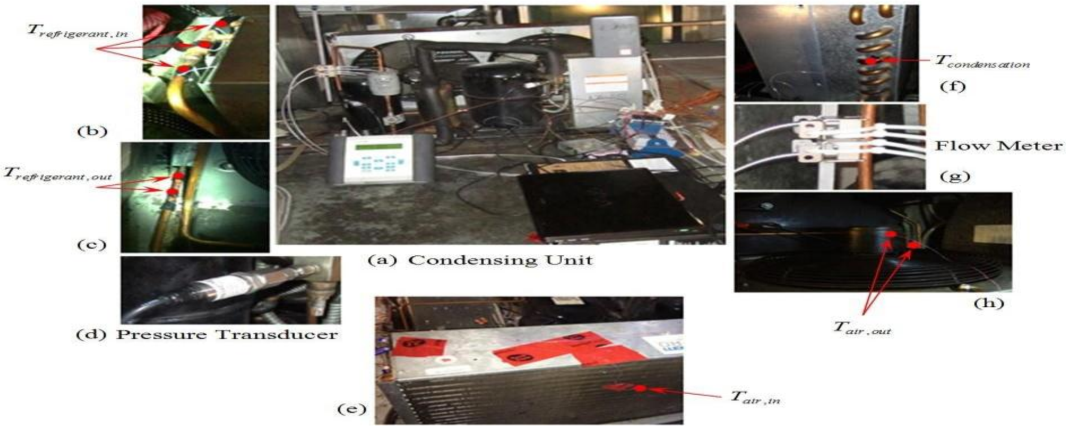

Figure 4 Installation of thermocouples, pressure transducers, and flow meters on the condensing unit.

V. RESULTS

The accuracy of the steady state model is tested using the created testbed in LAEC. The model validation is carried out in a wide range of temperatures, 20-60 oC for the condenser air inlet temperature (ambient temperature) and 10-50 oC for the evaporator air inlet temperature, to cover all of the working conditions of a real VACR system (the conditioned space temperature).

Results relevant to the studied stationary A/C-R system

The data from the walk-in freezer room (described in Chapter 3) is also used for steady- state model validation in addition to the data from the testbed developed in LAEC. Three important parameters of the examined system are represented in Figure 4.19: cooling power, input power, and evaporator outlet air temperature. This graph shows the time- averaged values of both the model outputs and the real-time measurements for various duty cycles. Sec ion 3.3.1 previously described the duty cycles (DT1–DT4). The comparison reveals that the simulation and measured parameters are in good agreement, with a relative difference of less than or equal to 9%. According to the findings, the refrigeration system's cooling power ranges between 1.75-2.05 kW depending on the duty cycle. DT1 (Weekend work-hours) is when the cooling power is at its peak. In addition, the refrigeration system's total input power ranges from 1.56 to 1.68 kW. The measurements have an error of 0.5oC for temperature, 1.5 percent for input power, and

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0.5 percent for cooling power, according to the uncertainty analysis.

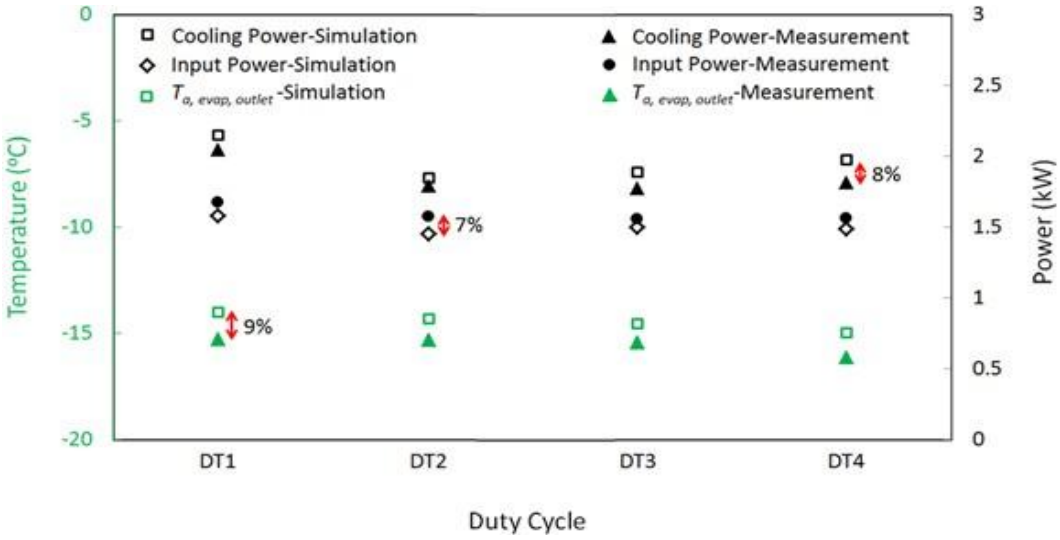

Figure 5 Validation of the model (simulation) results with the measured values, walk-in freezer room

The ageing of present A/C-R systems is a big issue. All of these systems will experience constant performance degradation as a result of ageing. The current COP of existing A/C- R systems should be established before developing measures to improve their performance. To discover the aging-related deviation, compare the acquired COPs to the design condition. The current COP departure from the design condition aids in the identification of possible energy savings for existing commercial refrigeration systems in a variety of applications. Based on modeling and observations for various duty cycles, Figure 4.20 depicts the current COP of the analyzed system. In addition to the current COP, the manufacturer's data for the measured operating circumstances is used to compute the system's design COP. The design COP is used to determine how far the system's current performance differs from the design condition. The results reveal that the observed and simulated current COP values are in good agreement, with a maximum relative divergence of 12%. The measured COP's uncertainty is assessed to be 2 percent.

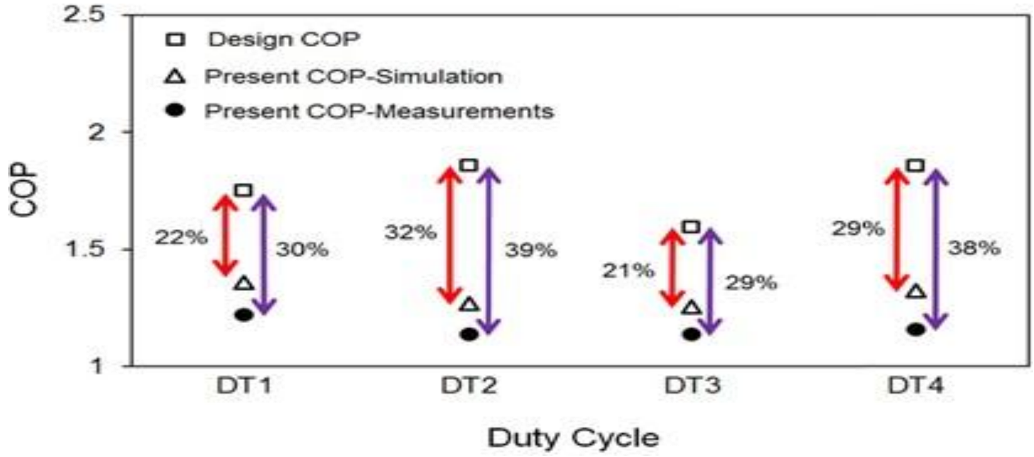

Figure 6 Present and design COP of the VCR system for different duty cycles

According to the findings, the system today has a lower COP than it did on the first day (design condition). The decrease in COP can be caused by a number of factors, including wear and tear, refrigerant leakage, and fouling on the condenser and evaporator coils. A comparison of the design and present COP of the selected system reveals a degradation of 29-39 percent, which has a substantial impact on the system's power usage. It's worth noting that an electric defroster is fitted on the system's evaporator coil to melt down the produced ice on a regular basis. The A/C-R system (with its defroster) presently consumes 16,300 kWh per year, which is 4,600 kWh per year higher than a new system, according to simulation and observations (brand new of the same condensing unit). Because of the much higher energy usage, it is necessary to either replace the current system with a more efficient A/C-R system or address the system's performance faults.

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On-site observations reveal that the system is new (less than ten years old), well- designed, and well-maintained. Based on the predicted COP values, it is clear that even with such a new refrigeration system, significant degradation occurs over time. Many refrigeration units are in use around the world that are older than the system under investigation. As a result, replacing or enhancing the efficiency of obsolete commercial refrigeration equipment can save a large amount of energy globally.

Implementing performance improvement technologies can have considerable results based on the predicted comparatively high energy consumption of this system and the large efficiency deterioration over its life cycle. During the tests, it was discovered that the timer-based defrosting system used a lot of electricity and generated a lot of heat in the freezer room. Continuous ice formation on the evaporator coil, which considerably affects the coil's thermal conductivity, necessitates the use of defrosting equipment in every freezer room. Timer-based defrosters, which are used in the existing A/C-R system, are one of the inefficient types that humidity-based defrosters can replace. During the defrost cycle (every 6 hours) in the current freezer room, the compressor is turned off and a 1,600 W heater is turned on to heat the surface of the evaporator coil and melt the generated ice layer. More than half of the defrosting cycles, notably during the restaurant's "off-hours" duty cycles, are unnecessary, according to on-site inspections and temperature/humidity readings. The measurements and calculations suggest that replacing the timer-based defroster with a humidity-based controlled type can save over 1,400 kWh/yr, or 9% of the overall energy usage of the VCR system.

VI. CONCLUSION

The created steady state, quasi-steady state, and transient models were validated and used to investigate the thermal and performance of stationary A/C-R and VACR systems in this chapter. The steady state model's results were validated using the testbed over a wide variety of operating circumstances and demonstrated a relative difference of less than 10.6% from experimental data. Furthermore, the accuracy of the steady state model was verified using data from a stationary A/C-R system, which revealed a maximum relative difference of 9%. The quasi-steady state model was tested using testbed data and revealed a maximum relative difference of 26 percent on dynamic parameters; however, the time- averaged parameters had a good accuracy of less than 8 percent relative difference. The transient model's correctness was also tested using field data from real VACR systems. The results demonstrated a good agreement on the transient characteristics of VACR systems, with a maximum relative difference of less than 8.5 percent.

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