Data driven modeling & control system design for HVAC system of an electric city bus - improving driving range & comfort

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Systems Design

Data Driven Modeling & Control System Design for HVAC System of an Electric City Bus – Improving Driving Range & Comfort

Modeling Air Quality & Thermal Dynamics for E-Bus & Designing a Multi-Zone Control Strategy

Executive Summary

October 2019

Sina Sarneizehdoost

Where innovation starts

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Public Executive Summary

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The design that is described in this report has been carried out in accordance with the rules of the TU/e Code of Scientific Conduct.

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Abstract	Fighting global warming is not possible unless every authority and industry defines goals in that regard. Moving towards e-mobility in public transport level and encouraging people to use this facility is one of the key solutions on the table at many municipalities. However, in northern and central Europe the range of e-buses is reduced up to 60% in winter conditions due to the demanded heating energy for passenger and driver comfort. This range anxiety introduces scheduling complexities, delays and additional costs for bus fleet owners. This document presents an approach to reduce the energy consumption of electric buses by appropriately managing the temperature and air quality in different zones of the bus cabin. A model based thermal and air quality control system is developed to realize this goal.
Keywords	E-Bus Thermal Management System, Thermal Control System, CO_2 Concentration model, Multi-zone modeling, Electric Buses, HVAC
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Foreword

The shift towards electric mobility has a positive impact on the environment. However, it comes with its challenges too, the range of the electric vehicle being one of the main ones. To enhance the range of the electric bus, the various subsystems have to be optimized, both in design as well as energy consumption. The climate system being one of the main energy consumers, a need for the development of an energy efficient thermal management system was realized. Sina's assignment involved the design of a thermal management system and the development of an air quality model of the bus cabin. He also had to improve the existing thermal model of the bus cabin. Both the thermal model and the air quality model are sufficiently validated. These models were then used to develop optimal controllers to regulate the cabin temperature and air quality, performing a trade-off between energy consumption and passenger comfort. The results show promising improvements of about 15% energy savings in the climate system, hence making a good step towards fighting range anxiety. Sina has made a good effort to make the usage of the models and thermal management system user friendly, which is very useful in future development and testing.

Roshni Digumoorthi,

Energy Management Specialist @ VDL ETS

Energy Management Team, Concept Development Department

September 27th, 2019

Preface

This report is the final assignment for the Professional Doctorate in Engineering (PDEng) degree in Automotive Systems Design (ASD) at Eindhoven University of technology (TU/e). The design and study represented in this report is developed under the collaboration between VDL Enabling Transport Solutions (ETS) and Eindhoven University of Technology. This project has been made possible by the funding of Electric Mobility Europe and the European Commission in the context of the COSTART Project, as part of the ERA-NET Co-fund scheme under Horizon 2020.

The main aim of this work is to represent a conceptual design of a smart Thermal Management System (TMS) that can consume less energy on HVAC system during the winter conditions in order to improve the driving range of VDL's electric buses, and to model the dynamic behavior of CO_2 concentration in the e-bus cabin to control it for human comfort goals and combined energy saving strategies. This report covers the high-level design of the TMS, and the derivation of fundamental requirements for its future development. Furthermore, basic saving strategies have conceptually showed insights on future developments of the system and next steps towards integration of electric mobility in public transport systems.

Chapter 1 and Chapter 2 are interesting for readers who are interested in having an overview of the context and challenges related to multi-zone thermal management of e-buses and smart control system design.

Chapter 3 and Chapter 4 are mainly devoted to technical details for thermal and CO_2 concentration models, therefore, these chapters are mainly interesting for domain specialists in thermal domains and particle concentration domains for human comfort.

Chapter 5 is describes the control techniques and strategies utilized to design a conceptual smart system which can manipulate systems modeled in previous chapters in order to obtain the desired goals of the work. This chapter can be interesting for domain specialists in control engineering and specifically thermal process control engineers.

Results reported in Chapter 6 can be particularly important for industrial partners such as VDL-ETS for defining the road map for future developments.

Sina Sarneizehdoost

September 17th 2019

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I am glad to mention a special word of thanks to my company supervisor Ir. Anouk Hol for her invaluable help at critical points of this project and Ir. Roshni Digumoorthi for her sharp comments and daily help during every single step of this work. I would like to expand my gratitude to the entire Concept Development Team at VDL ETS, for their thoughtful comments and questions during monthly team meetings and their contribution to such a friendly work environment which is valuable in the success of this work.

I would like to express my deep gratitude and appreciation to my TU/e supervisor, Dr. ir. Theo Hofman for his insightful comments and continuous guidance, every valuable comment was a key to solve a block I was facing along this work. Additionally, I am very honored for granting me the responsibility to represent TU/e in the COSTART project.

I like to use this opportunity to express my thankfulness to my senior ASD colleague Davide Occello for quality of his work and building a platform for me to continue this project. Also a special thanks goes to Dr. Peter Heuberger for granting me the opportunity to join ASD community and his endless support during the last two years. And I express my sincere thanks to Ellen van Hoof-Rompen, providing such a kind support for everyone, including me, in the ASD community. I would also like to extend my thankfulness to all my dear professors during my academic study for sharing their expertise, I daresay they have a significant contribution in this work.

I perceive this as an opportunity to express my warm gratitude to dear ASD / MSD / ST - 2017 colleagues for creating a unique experience of working together and exchanging fantastic ideas while enjoying a friendly teamwork.

At the end, my great thanks goes to my family and friends who have always been extremely supportive at every moment of my life.

Sina Sarneizehdoost

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Executive Summary

Aiming at zero emission and increasing demand for higher efficiency without sacrifice in performance has pushed the industry towards electrification. The automotive industry is not an exception to this transition. However, this transition is not similarly simple in every industry. One of the most important challenges in the automotive industry and specifically in public transport is the range anxiety which delays the integration of e-mobility in public transport fleets.

The challenge arises when e-buses experience severe weather conditions specifically in northern and central Europe, where the range of these buses is reduced up to 60% every winter due to heating and comfort requirements, a situation which introduces scheduling complexities for the bus fleet owners and increases the total cost of ownership for fleet operators and municipalities.

Currently HVAC systems of the electric buses are working independent of the number of passengers on board. In addition, comfort criteria such as CO_2 concentration have not been taken into consideration as a controllable parameter and it has usually been feed forward controlled according to the maximum capacity of the public transport vehicle. That results in consuming more energy in conditions when the vehicle is not running at full passenger capacity. Therefore, the potential for energy saving and consequently range extension is considerably high.

One of the greatest challenges in optimizing the energy consumed by the HVAC system in an e-bus is accuracy in modeling the dynamics of thermal behavior and comfort criteria behavior. First of all, there are limited studies in this domain for automotive applications and they are not sufficiently accurate. Thus, considerable effort goes to improving the accuracy of available models in the thermal domain and modeling and validation of CO_2 concentration dynamics.

Additionally, a definition of a multi-zone thermal management strategy in e-bus passenger cabin is proposed. This strategy is fitted to a conceptual thermal management and control system design in order to reduce energy consumption and follow the required trajectory dictated by comfort indicators. As a result, based on mutual control of CO_2 concentration and air temperature in specified zones, TMS is showing up to 15% energy saving in the HVAC system. This achieved energy saving can be used to extend vehicle range.

VDL is producing a variety of e-buses which are used in various weather conditions in northern and central European countries. In this regard, each product type comes with an HVAC system, and thus, improving the energy consumption by this system in every product can lead to an extension in the range of total fleet of public transport in target countries.

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