Towards an informative simulation-based application for energy saving in large passenger and cruise ships

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***Abstract*—Over the years, the need to save energy and efficiently manage its consumption becomes increasingly imperative. This paper reports on the development of a novel application for handling diverse energy consumption issues in large passenger and cruise ships. Our overall approach is based on a comprehensive agent-based simulation model, which takes into account spatial data concerning a ship's decks and position of energy consuming facilities, as well as data concerning the ship's passengers and their behavior during the operation of the vessel. The proposed application may predict energy consumption for a particular vessel and passenger group and accordingly facilitate informed decision making on energy saving matters.**

I. Introduction

Undoubtedly, energy saving is of paramount importance both for the protection of environment and the reduction of the associated consumption costs. As far as human constructions are concerned, the above issues have been thoroughly elaborated and reported in the related literature, mainly in the case of buildings (being they smart or not). To the best of our knowledge, no related research has been carried out in the case of large ships, which reportedly consume a large amount of energy. It is estimated that a large ship burns at least 150 tonnes of fuel per day and emits more sulphur than several million cars, more NO_2 gas than all the traffic passing through a medium-sized town and more particulate emissions than thousands of buses in London [1]. While the cruise ship industry starts taking its first steps towards an emission-free cruise, cruise travels are among the most carbon intensive in the tourism industry; the contribution of the cruise industry to global CO_2 emissions was estimated to 19.3 Mtons annually in 2010 [2].

This paper aims to contribute to the abovementioned research gap by reporting on the development of a novel application for the management of diverse energy consumption issues in large passenger and cruise ships. The proposed application builds on a sophisticated simulation model to predict energy consumption and give meaningful insights on diverse energy saving issues. The application is generic enough to cover requirements imposed by (i) different types of vessels, by taking into account detailed spatial data about the layout of the decks of a ship and the associated position of the energy consuming devices and facilities; (ii) alternative ship operation modes, corresponding to cases such as the ship being cruising during day or night, or being stopped at a port; (iii) different passenger groups in terms of their size and behavior, by considering that the energy consumption of many devices or facilities (e.g. restaurant, air condition etc.) depends on the number of passengers in or nearby them.

For the needs of the abovementioned simulation, we have adopted the agent-based modeling approach to focus on individual objects (i.e. passengers and energy consuming devices), their behavior, and their interaction. The models produced handle the underlying uncertainty and offer highly informative visualizations of the energy consumption in a ship. Moreover, the simulation results and associated reports derived in our approach enable decision makers to predict energy consumption patterns and accordingly model and assess alternative energy saving scenarios. The proposed application builds on the AnyLogic simulation software (https://www.anylogic.com/).

The remainder of this paper is organized as follows: Section II comments on related work aiming to justify and highlight the particularities of our approach. Section III describes our overall approach towards developing an informative application for predicting energy consumption and accordingly providing insights for energy saving in large passenger and cruise ships. Section IV reports on specific experiments carried out through the agent-based simulation module of our approach and presents indicative results and reports produced. Finally, Section V outlines concluding remarks and sketches future work directions.

II. Related Work

As mentioned above, no research has been reported in the literature concerning the management of energy consumption in large passenger and cruise ships. Due to this reason, the work discussed in this section concerns related approaches in (smart) buildings or parts of them (e.g. offices). As a general remark, we note that many of these approaches are based on simulation models and start utilizing machine learning (ML) algorithms.

An agent-based model of energy consumption in offices has been described in [3]. The paper elaborates diverse energy consumption issues occurring in an office and caused by the operation of various devices. A mathematical model to explain the energy consumption inside an office is presented and evaluated through three sets of experiments. Adopting a similar research direction, energy saving solutions implemented in buildings are described in [4]. The corresponding analysis took place in a health care institution with the aid of an algorithm implemented in the LabVIEW environment. Comparing different solutions, the proposed algorithm aims to find the best one in terms of their implementation effectiveness. A method to analyze the associated big data, making it easier to build functions for the prediction of energy consumption and the decision making about the energy efficiency optimization of various types of buildings, is proposed in [5]. As suggested, the combination of statistics and neural network algorithms can solve the key problems that occur in energy consumption approaches.

Motivated by the rapid development of modern network and communication technologies, as well as the increasing use of smart devices and sensors, an extensive review on the four main ML approaches (artificial neural network, support vector machine, Gaussian-based regressions and clustering) that have been applied in predicting and augmenting building energy performance is presented in [6]. As argued, one should thoroughly analyze the nature of available or collectable data and the particular application, to choose the most suitable approach. In any case, it is admitted that ML algorithms may enable stakeholders gain insights from energy usage data obtained under different scenarios. For instance, the ML-based smart controller for a commercial buildings HVAC (heating, ventilation, and air conditioning) system that is described in [7] managed to reduce its energy consumption by up to 19.8%. In another work [8], authors proposed a combination of Nearest Neighbor and Markov Chain algorithms to facilitate decision making on various energy management issues at a smart home.

Finally, a different perspective is adopted in [9] which elaborates the reduction of energy consumption in pumping stations. By comparing the energy consumption of a station during a 15 days period and what would the station consume in the same period after the energy audit, one may quantify the gain resulting from the use of the proposed management system. After examining the existing state of a pumping station, evaluating its energy performance and developing improvement actions, this work proposes a set of solutions improving energy consumption.

III. Our Overall Approach

The work reported here is carried out in the context of a two-year research project, which comprises four major phases, namely (i) analysis of energy consumers in large passenger and cruise ships, (ii) development of methods to analyze and process the associated data, (iii) development of basic services for the visual representation of energy consumption, and (iv) development of an innovative platform to facilitate the related decision making process. Through these phases, the project will develop contemporary methods to gather, aggregate and analyze heterogeneous data representing both the energy consumption in diverse devices and facilities and the concentration of passengers in different areas of a ship. In addition, the project will develop a set of novel services aiming to optimize the management of energy consumption. Finally, the project will produce a set of guidelines for energy saving in a ship.

Our overall approach adopts the Action Research paradigm, which aims to contribute to the practical concerns of people in a problematic situation. As such, it concerns the improvement of practices and strategies in the particular complex setting under consideration, as well as the acquisition of additional knowledge to improve the way stakeholders address issues and solve problems [10]. To better shape our approach, a series of meetings with shipping companies were conducted. Through them, we identified the types of devices and facilities that mainly affect energy consumption in the ship categories under consideration, and obtained valuable information concerning the parameters to be taken into account in energy consumption models (such as that energy supply in a ship is provided by a number of electric power generators, which – in most cases – are of different capacity and do not work in parallel). In addition, information collected concerned the layout of ship decks and its relation to the energy management issues investigated. Finally, we clarified issues related to the alternative types of passengers and how these may influence or affect alternative energy consumption and energy saving scenarios.

The project aims to enable stakeholders to predict the energy needs of a ship (e.g. to gain insights about the appropriate number of power generators to operate each time), facilitate predictive maintenance issues (e.g. better scheduling the required services of the related equipment as well as the corresponding manpower), and hopefully reduce the energy related operating costs. To fulfil these aims, our approach builds on agent-based simulation principles and techniques to model the passengers' behavior and its dependencies with a ship's facilities, devices and resources. AnyLogic is the simulation software tool selected. It provides a graphical interface (and language) for modeling complex environments and allows one to extend simulation models with Java code.

A basic assumption of our approach is that the energy demands in many sites of a ship (such as the restaurant, the night club, the kinder-garden etc.) depend on the number of passengers who gather at these sites at a given time. To estimate the populations gathered in these sites, we relied on the behavioral preferences that large subgroups of passengers have. For example, we assume that young passengers prefer to spend their time at nightclub from 10:00 pm to 3:00 am, while elderly passengers prefer to eat dinner at a fancy restaurant. Such assumptions enable us predict the gathered populations and, accordingly, the energy demands during day and night inside a ship. This approach facilitates the modeling of energy consumption, especially for ships that do not have sophisticated energy consumption monitoring and control systems.

In addition, according to our approach, the passengers' behavior is being considered and modelled through three basic scenarios corresponding to the ship (i) being moved during the day, (ii) being moved during the night, and (iii) being anchored at a destination or port. In the above scenarios, we expect different behaviors from passengers, which may result to different energy demands. Finally, to accommodate the spatial particularities of each ship, our approach pays much attention to the layout of each deck. These layouts provide us with the spatial data that are needed to calculate the movement of passengers inside the ship. AnyLogic offers a user-friendly import of sectional plans (views), thus enabling the production of a more realistic model of the distribution of ship passengers, facilities and devices. Taking into account what our models predict in terms of energy needs, we suggest different policies of energy management, aiming to reduce energy consumption.

A. Data Model

One of the main variables to be taken in to account concerns the passengers on board, as well as their composition in terms of type (customer or crew member), age, gender etc. As mentioned above, different age groups have different paths and habits; for example, elderly passengers go to sleep earlier than the kids, so the corridors have to have enough light to satisfy both groups. The difference between the age groups affects also the speed that an agent can have, which it will be also different from a person with special needs. Another important variable considered is the ship layout (at the deck level). These layouts provide information about the detailed coordinates of all ship locations, including passenger cabins and facilities of the ship. Each energy consuming device is also a variable in our model.

B. System Architecture

Figure 1 sketches the components and overall architecture of the proposed application. As shown, through user-friendly interfaces, stakeholders may build and run alternative energy consumption scenarios. These scenarios are populated with data that are either given by the user or already stored in the application's repository. The execution of scenarios is through the AnyLogic simulation engine, which results to the creation of illustrative reports and associated energy saving directions ('recipes'). A middleware component establishes the connection between the application's back-end and front-end, while also enabling the interoperability of the proposed application with external services.

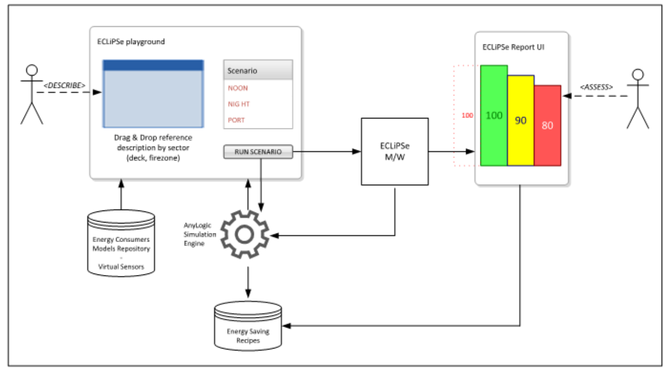

Fig. 1. The architecture of the proposed application

IV. Experiments

This section illustrates a particular set of experiments carried out to assess the applicability and potential of our application. For a specific vessel, we initially consider and import in the simulation software the original deck layouts, where all ship facilities and passenger cabins are mapped. For each individual group of passengers (e.g. young people, ages 15-25 years), we then create the corresponding daytime preferences concerning the ship's services. We also create a simple linear behavioral model, in which each individual group stays in a specific location for some time (and then returns to the cabins). We do this for every group of passengers and every time period to create a comprehensive daily routine for all passengers throughout the day. We are able to simulate diverse scenarios, which may easily be synthesized to create an illustrative energy consumption map for the whole vessel.

For the particular case reported in this section, we ran simulations concerning the second operation mode, in which the ship is moving during the night. We generated random samples of 500 passengers, assuming that the percentage of young passengers is between 17% and 20%. Moreover, we set the conditional probability of someone visiting the night club from 11:00 pm to 5:00 am, provided that he/she belongs to the young passengers group, to range from 40% to 60%. For the rest passengers, we assumed that only a 10% of them will visit the night club. We also set the time spent in the night club (from passengers of all age groups) to follow a triangular distribution with a lower limit 50 minutes, mode 95 minutes, and upper limit 110 minutes. Finally, we imported the layout of a specific deck, where detailed spatial data about the

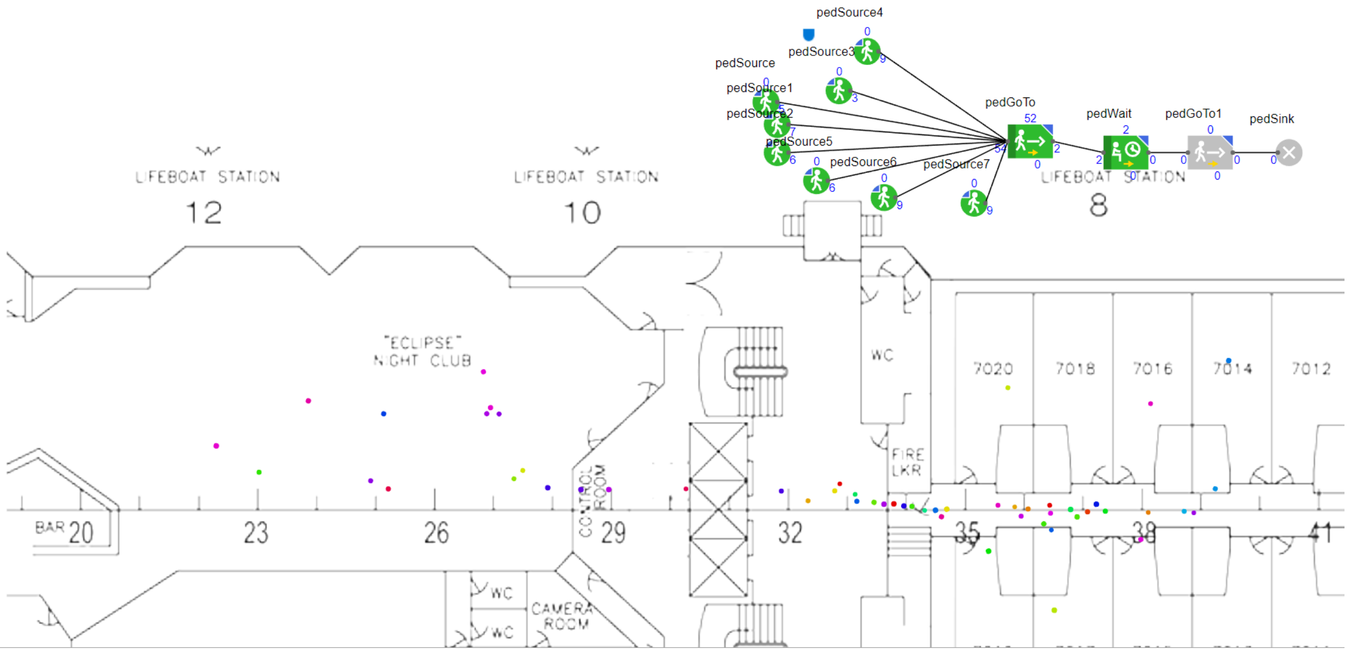

Fig. 2. An instance of a simulated energy consumption scenario on a specific ship deck

cabins and the possible pathways leading to the night club area are described. By running the corresponding simulations, we are able to visualize the possible concentration of passengers during the night at this specific area of the ship (see Figure 2). Consequently, by estimating the energy requirements of the night club with respect to the number of passengers hosted, we can calculate the possible energy needs for the particular time period and ship location (see Figure 3). Such estimations can be used for future predictions of energy consumption in cases where passengers are distributed in a similar way. Furthermore, the derived data can be statistically analyzed to reveal the data patterns and mechanisms that cause the particular energy demands.

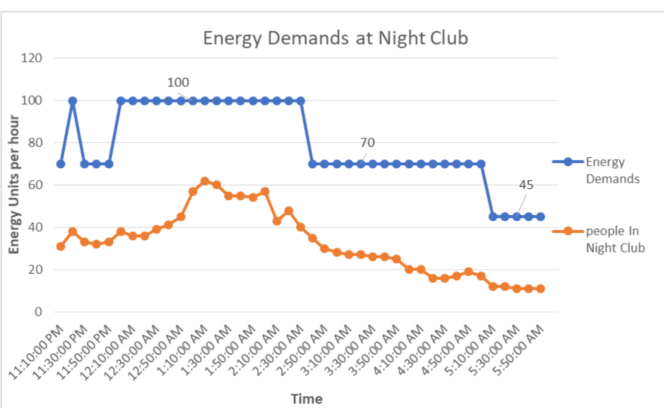

Fig. 3. Energy Demands per hour

V. Conclusions and Future Work

The application described in this paper advances the way stakeholders of large passenger and cruise ships deal with energy consumption issues, by building on a comprehensive and informative simulation model that facilitates the creation and assessment of alternative energy saving scenarios. We argue that our overall approach suits particularly to ships that are not equipped with state-of-the-art (smart) energy management sensors and devices. To accommodate this situation, our approach produces realistic data that can be analyzed and give insights for the mechanisms of energy consumption. The predicted energy demands may shape a set of rules ('recipes') to deal with diverse energy consumption and energy saving issues. Our future work directions include the integration of appropriate machine learning techniques with the simulation mechanism proposed in this paper (where, for instance, machine learning models are trained entirely through simulation), aiming to produce more robust predictions [11].

VI. Acknowledgement

The work presented in this paper has been co-financed by the European Union and Greek national funds through the Regional Operational Program "Western Greece 2014-2020", under the Call "Regional research and innovation strategies for smart specialization (RIS3) in Energy Applications" (project: 5038607 entitled "ECLiPSe: Energy Saving through Smart Devices Control in Large Passenger and Cruise Ships".

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