DYNAMICMODELLINGOFSHIPENVIRONMENTSWITHESP-R

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ABSTRACT

ESP-r is a powerful tool for simulating building environments and their various mechanical and electrical systems. It has potential for investigating and optimising the thermal performance of enclosed areas of ships and other ocean vessels. ESP-r allows the various elements of an environment such as geometry, topology, occupancy and ventilation systems to be considered in a dynamic, integrated manner. Here, we present an example model of a ship environment and use ESP-r to investigate the effects of various design modifications on the operating costs of the heating and ventilation system of one public area of the ship.

INTRODUCTION

Energy efficiency is being given increasing attention in many sectors. This is due to a number of factors including an awareness of the exhaustibility and environmental impact of fossil fuels (Barbir et al., 1990; Hanlon and McCartney, 2008; Wilkinson, 2008), environmental movements such as the Kyoto Protocol (Neuberg et al., 2003) and political events e.g. oil embargoes (Altavilla et al., 2004) which create price shocks.

Building simulation programmes (BSPs) offer a means to evaluate the energy requirements of a building and also to assess potential savings attainable through the use of energy saving components or other changes such as in the control strategies of air conditioning systems. BSP use is becoming more widespread partly due to improved user interfacing, an increase in computing power and a greater availability of physical data to support models (Hensen; Kusuda, 2001). In addition to determining energy efficiency, BSPs can be used in the assessment of compliance with building codes and also in dimensioning/sizing certain components.

Integrated simulation tools have the facility to exchange information between the various sub-domains as the simulation progresses. This interaction is depicted in figure 1. For instance, the thermal model determines the temperature outputs which drive a mass flowrate controller, which in turn provides inputs for the massflow aspect of the model. Integrated, dynamic simulation, though more demanding in terms of required inputs from the user and computing power, can give a more realistic and in-depth insight into the underlying thermal processes and performance of a building (Bartak et al., 2000), incorporating interactions between the elements of a building such as the geometry, topology and ventilation systems rather than considering their effects separately in a 'superposition', static approach. A computational approach may also be of use in the introduction of new components for which little or no application experience may be available (de Wilde and van der Voorden, 2004).

The principal use of these tools has been the simulation of static building structures. It is estimated that around one third of all primary sources of energy are consumed in the various systems of buildings (Altavilla et al., 2004; Hong et al., 2000; Neuberg et al., 2003). A new area of application is to be found in the energy analysis of ship environments. These could include smaller spaces such as cabins or crew offices, or larger public spaces like restaurants and bars.

The application of ESP-r to ships presents some additional challenges. The orientation of a building has important implications for the distribution of solar gains throughout the building and also for wind speed profiles. It is clear that the orientation of a ship is not constant. Secondly, the ship's external environment (e.g. temperature and humidity) is likely to vary, a fact that is of greater importance for longer duration simulations in which a ship's location and therefore external environment may vary significantly over the course of a simulation run. A vessel may also have specialised plant components for air conditioning or ventilation systems not found in static building constructions, for example components which incorporate heat exchange with sea water or engine output.

This paper describes some modelling extensions which are necessary for the marine application of the BSP approach. Finally, an example model is presented in order to demonstrate a basic approach to modelling a ship environment, and the application of this model in identifying potential savings from design modifications.

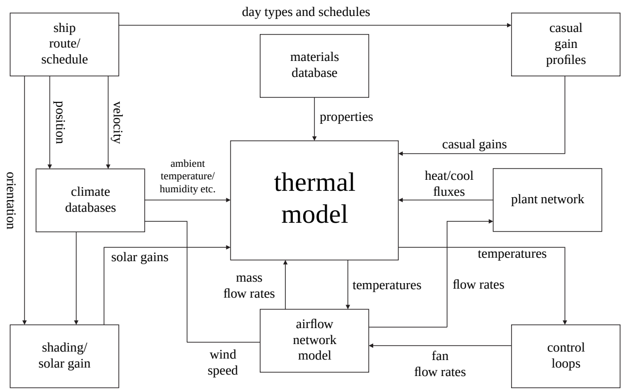


Figure 1: Interactions of sub-models.

EXTENSION OF METHODOLOGY TO SHIP ENVIRONMENTS

Although the basic mathematical engine of BSPs is applicable to the ship modelling context, it is necessary to augment the approach in order to address the mobile aspect of the vessel. Unlike buildings which use a climate profile database representing the ambient conditions of a fixed location, the ship will clearly be subjected to varying climate conditions. In addition to the physical location of the ship, the orientation (i.e. bearing) will change with time which affects the solar gains received by the various surfaces of the modelled space. The ship's movement itself induces relative wind speeds which are of the order of wind velocity. This aspect should be included in air flow network aspects. Therefore, the schematic in figure 1 contains some new inputs and furthermore, additional interactions which need to be included in ship models.

Implementation: Variation of Orientation and Climate

Creating a climate file for a non terrestrial location is not trivial in the sense that climate at a non terrestrial location may depend upon parameters like water temperature and current direction, geographical location in terms of latitude and longitude, proximity of land mass and climate experienced on nearby land masses. The ship route under study was predominantly near three terrestrial locations for which climate data was available (within 4 degrees of latitude and longitude). Given the nature of the route a distance weighted average climate of the three terrestrial locations was considered to be suitable. Wind velocity of the climate file was corrected by taking into account the ship's velocity.

Variation of orientation was studied by rotating the model in steps of 22.5 degrees and determining insolation and shading patterns at each orientation. Solar effects were imposed on the model using linear interpolation between these pre-simulated orientations.

It was not considered necessary to impose heat transfer coefficients for heat transfer with sea water for the exterior surfaces because the modelled spaces were above the water line. This however might be of importance when modelling spaces like crew quarters and engine rooms which predominantly lie below the water line.

It was also necessary to include day types different from the usual weekdays, weekends, holidays etc. found in static building models. For this purpose a day type specification facility was also developed and implemented. Three additional day types, namely ship days, port days and turnaround days, were used. Each of these day types can have a different occupancy and space conditioning schedule and control set points.

EXAMPLE MODEL - A FICTITIOUS SHIP RESTAURANT AREA

In order to illustrate how the BSP concept can be applied to a ship environment in practice, a model of a ship restaurant space was built and simulated in order to investigate the effects of a number of energy-savings strategies.

Geometry and Topology

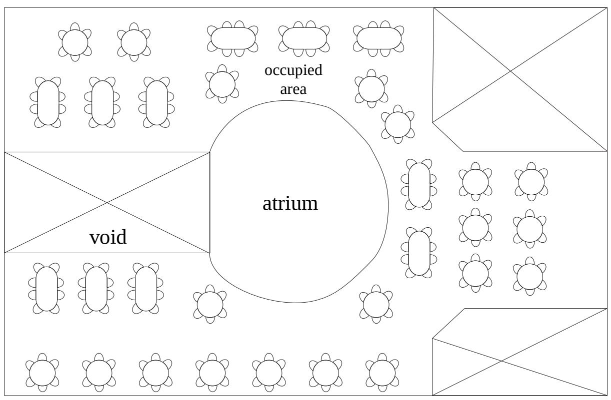
The environment is a restaurant consisting of an outer public seated area and a central atrium region. The restaurant has three levels located on different decks which are interconnected through the atrium region.

Each deck is modelled using various thermal zones as shown in figure 2. The port and starboard zones correspond to the occupied areas whilst the third is the central atrium region of a given deck.

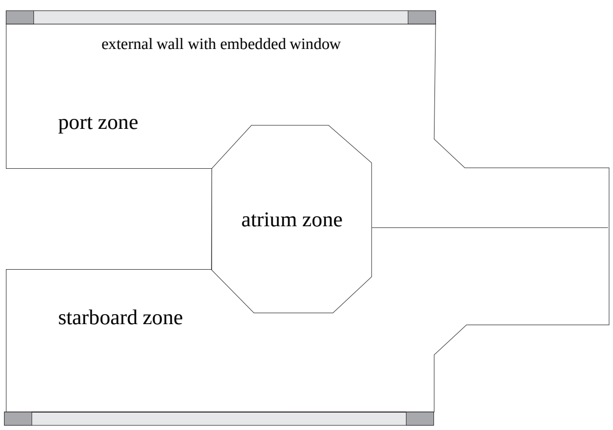
Air Conditioning System and Control

The restaurant is serviced by a variable air volume (VAV) system. Intake air from the external environment is firstly chilled to 12°C and the flow rate of this chilled air is varied using a fan. Should the temperature in the restaurant be lower than the desired set point, the air may be heated by opening a valve of a water loop heating system which thereby heats the incoming VAV system air with the fan flowrate being set to its minimum level. In the converse cooling scenario, the volume flow rate of the fan is increased in order to lower the temperature towards the setpoint. Figure 3 is a schematic of the air handling unit (AHU) used in the system.

The air handling units are modelled using a plant network which includes the fans, cooling coils, heating coils and ducting for each deck. At each level, the out-



(a) Restaurant layout.



(b) Implementation of model.

Figure 2: Plan views of ship environment. The restaurant is comprised of seated areas and a central atrium.

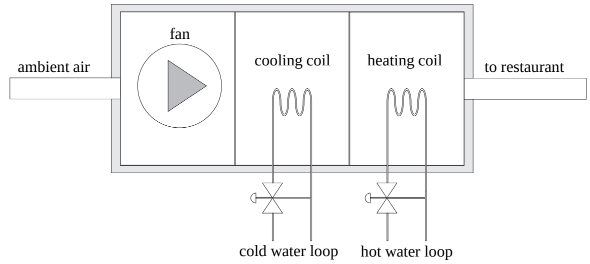


Figure 3: Schematic of air handling unit. The main elements are a fan, and cooling and heating coils.

put of the heating coil (representing the air after passing through the AHU) is delivered to the port zone of the building model, in this way providing the link between plant and thermal aspects of the ESP-r model.

Air movement (i.e. mixing) within the building is modelled using a mass flow network integrated with the thermal model. Air can move between port, starboard and atrium zones, and the various decks are interconnected through the atrium.

The set point temperature of the restaurant is nominally 22°C. The temperature of the chilled air of each deck is regulated to 12°C. Heating and cooling are regulated in feedback control loops which respectively sense the temperatures of the port zone (i.e. the public space) and the air after passing through the cooling coil in order to maintain the required setpoints through variation of heating and cooling fluxes. A proportional-integral scheme was applied. The overall control regime is shown in figure 4 and the variables used are defined in table 1.

In order to avoid the undesirable situation where the heating and cooling functions are acting simultaneously, the temperature set points of the two were separated by a small temperature band (0.2°C).

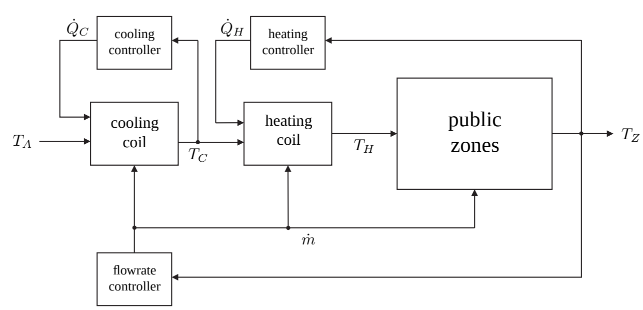


Figure 4: Block diagram of restaurant control system. Variables are defined in table 1.

An 'energy savings mode' was applied to some of the simulation runs (see next section); T_Z is allowed to float

Table 1: Variable definitions.

Variable	Description
T_C	Temperature of air after cooling.
T_H	Temperature of air after heating.
T_Z	Temperature of public (occupied) zones.
Q_C	Cooling flux of cooling coil.
Q_H	Heating flux of heating coil.
$\dot{m}$	Mass flow rate through AHU.

Table 2: Descriptions of the simulation scenarios.

Scenario	Minimum Fan Speed (relative to maximum)	Energy Savings	T_C during energy savings
Ref	40%	×	-
1	30%	×	-
2	40%	✓	12°C
3	30%	✓	12°C
4	30%	✓	15°C

in the range 20 - 24°C (i.e. there is a deadzone), with the fan at minimum speed and no additional heat flux being applied. Outside of this range heating or cooling action is taken so as to drive the temperature back within this range. This control strategy is applied when the restaurant is not in service, that is, those periods where there is little occupancy of the public zones [1].

Scenarios

The impacts of design modifications on heating and cooling demands were investigated by making small variations to the base case ESP-r model - referred henceforth as the 'reference scenario'. The basic control set-up uses the control regime as previously outlined, where the minimum speed of the fan was 40% of its maximum flow rate.

Four alternative scenarios were run and contrasted with the reference scenario. Small deviations were applied to the control regimes of these alternative models; the individual modifications are described in table . These included changes to the minimum flow rate of the fans, the use of the aforementioned energy savings mode and finally allowing the chilled air temperature to rise to 15°C during energy savings mode times. The scenarios were compared in terms of the overall heating and cooling loads for the given simulated period. Each scenario was run for one year in a Caribbean climate.

RESULTS

The heating and cooling loads required for the various scenarios are displayed in table 3. Savings relative to the reference scenario are achievable in each alternative control set-up.

Figures 5-8 show the time history of the temperatures, fan rates, heat fluxes and cooling loads for deck 1 for one day in July. 3 different scenarios are shown to demonstrate the different patterns observed by modifying the control parameters. In each case, the zone temperature is controlled closely to the setpoint, which varies depending upon whether or not energy savings mode is being applied.

[1]Energy savings were applied during the times 00:00-06:00, 10:00-16:00 and 23:00-00:00.

Table 3: Annual totals of heating and cooling loads for each scenario.

Scenario	Heating (MWhr)	Cooling (MWhr)
Reference	88.9	1590
Scenario 1	40.1	1450
Scenario 2	50.0	1540
Scenario 3	16.0	1350
Scenario 4	8.82	1280

DISCUSSION

The various scenarios demonstrate the savings achievable through small adjustments in the operation of the ship. The results show that considerable savings can be made simply by alterations in the control systems settings; such changes would not require additional components or technology and so would not be costly to implement.

In this study, the most significant gains were made in scenario 4 where the cooled air termperature is allowed to be the slightly higher value of 15°C. In the other scenarios, the energy savings mode had a greater effect on the heating load than cooling. This is because the times where it is applied are coincident with the times of low occupancy - i.e. where the demand for cooling is lower. It follows that during these time periods cooling is rarely required, even for a fixed setpoint of 22°C, and thus the energy savings mode had little impact.

Although the example presented here focuses on savings made through control modifications, it is clear that the methodology could also be applied to investigating other energy savings measures. For example, the reduction in energy required attainable using heat recovery from the exhaust air (via an enthalpy wheel, for instance)

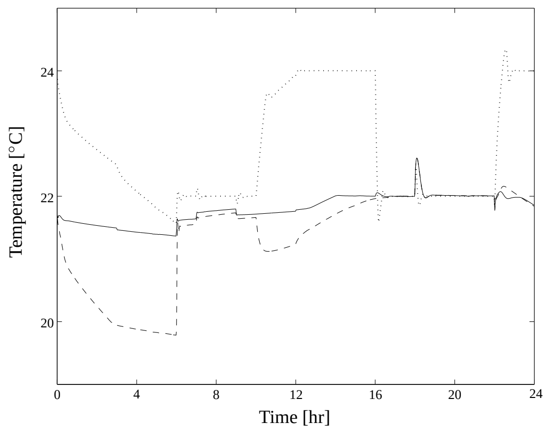


Figure 5: Zone temperature on deck 1 for typical day in July. Solid, dashed and dotted lines respectively represent reference, scenario 2 and scenario 4.

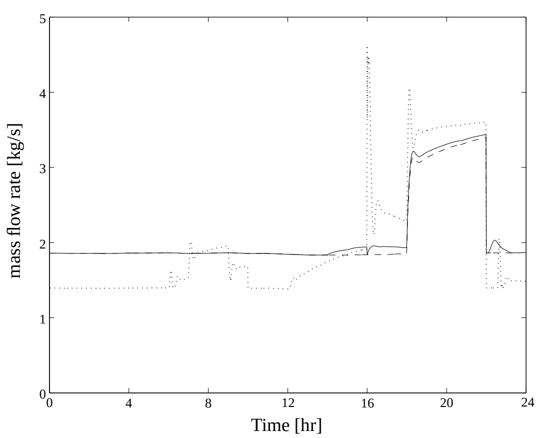


Figure 6: Mass flow rate of deck 1 fan for typical day in July. Solid, dashed and dotted lines respectively represent reference, scenario 2 and scenario 4.

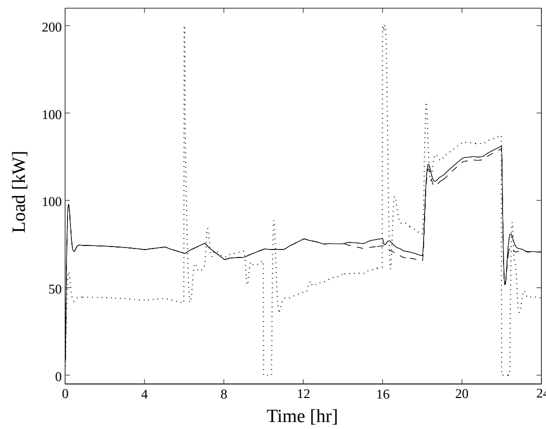


Figure 7: Cooling coil load on deck 1 for typical day in July. Solid, dashed and dotted lines respectively represent reference, scenario 2 and scenario 4.

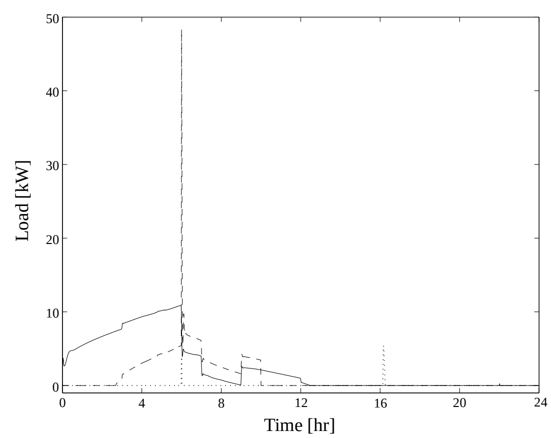


Figure 8: Heating coil load on deck 1 for typical day in July. Solid, dashed and dotted lines respectively represent reference, scenario 2 and scenario 4.

could be assessed using the modelling approach.

The dynamic nature of such a study, though more intensive to set up and also more expensive computationally, offers a greater depth of investigation that would be yielded through a more static approach. For example, the transient performance of the control system and its ability to respond to 'disturbances' such as changes in occupancy in order to maintain the setpoint may be assessed and optimised.

The study presented here represents a relatively small slice of an overall ship. In order to extend the approach to facilitate modelling of the whole ship, it may be impractical to model the entire vessel in a single model in the manner presented here. Instead, it may be more appropriate to partition the ship into smaller zones between which there is likely to be little thermal interaction. Dividing the ship according to its fire zones may present one methodology in this direction.

However, it may be that modelling the ship in its entirety is considered undesirable. It has been argued that given the uncertainty of models and difficulties in validation that their main application is in the contrasting of alternative design solutions and scenarios (Hensen; Hong et al., 2000). Therefore, used in this context, BSP technology would not be used to provide absolute figures on the energy requirements of the entire ship, but to assess design variations applied to individual areas of the ship.

CONCLUSIONS

ESP-r can be used to perform a dynamic analysis of the thermal performance of ship environments. Simulations may be run in order to determine the overall cost of a given heating and ventilation regime, assess potential energy savings available through design modifications, and finally to investigate the underlying dynamics of the system and performance of the control systems.

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