DOCTOR OF PHILOSOPHY

Development of a bioclimatic analysis methodology to evaluate the potential of passive design strategies in reducing HVAC loads of cruise ships operating within the Mediterranean

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Award date:
2017

Awarding institution:
Coventry University

Development of a Bioclimatic Analysis Methodology to Evaluate the Potential of Passive Design Strategies in Reducing HVAC Loads of Cruise ships operating within the Mediterranean

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(Volume I of II)

A thesis submitted in partial fulfilment of the University's requirements for the Degree of Doctor of Philosophy

September 2017

Coventry University

Dedication

I wish to dedicate this thesis to my mother and father - Alfons and Linda Kvilums - for supporting me throughout the trials and tribulations and forever encouraging the philosophy that there are no limits to my potential. You are indeed an inspiration and have provided me with stability and love. To that end, I wish you nothing but happiness for the rest of your days and that others may be fortunate enough to have you by their side.

Acknowledgements

I wish to express my sincere gratitude and appreciation to my principle supervisor Dr. Sean McCartan without whom, this thesis would not have been possible. His constant guidance and encouragement has been unwavering, and I am truly grateful for his support. In addition to this I would like to acknowledge the advice and support granted by my supervisors; Dr. James Shippen and Professor Shuli Liu. Furthermore, without the financial backing of Coventry University - who granted me an academic scholarship – this body of research would not exist. To this end, my gratitude also extends to this great academic institute.

My research has also received considerable guidance and support from Dr Yi Zhang and Dr Ivan Korolija, formerly Research fellows at De Montfort University who deserve special mention due to their technical support throughout this study.

Finally, I wish to thank my friends and colleagues at Coventry University for their continued encouragement and moral support.

PhD Declaration

The thesis presented, makes an original and unique contribution to research for several reasons. In the first instance; the thesis defines - using statistical analysis and existing climate classification systems – test conditions for the exploration of passive strategies within the Mediterranean Sea.

Secondly the thesis utilizes a mixed method approach to extend current understanding of Passive Design (PD) within the context of the marine environment and a parametric simulation methodology that explores its application within the philosophy of 'design driven innovation'. The primary output of this is a detailed load-based analysis of cabin zones on board cruise ships which provide an insight into the impacts of shading, interior heat gains sources (such as media equipment and lighting), glazing ratios, glazing properties, location and orientation as witnessed within perimeter zones of cruise ships.

Finally, the study combines climate and simulation data in a series of developed integrated design tools to visually communicate the potential of PD on a platform which is familiar to both engineers and architects – namely the bioclimatic psychrometric chart – which provides design direction for designers and engineers at the beginning of the design process. Additional works have addressed some of the issues regarding the implementation of PD through the conceptual development of an ultra-luxury catamaran cruise ship – in which integration compromises are discussed to acquire the best aesthetic design resolve.

Abstract

Until recently limited effort has been expended to improve energy performance in ships, due to relatively low operational costs and lack of stringent regulations concerning environmental impact. As a result, energy systems were designed to safeguard against worst case operational conditions and their design was based on experience or steady state calculations, which resulted in oversized ship components and plants, operating away from their optimum efficiency. Cruise ships operating in the Mediterranean use HVAC (Heating, Ventilation and Air Conditioning), which anecdotally represent 30% of the total energy consumption of the vessel (Boden 2014).

The aim of this study, was to identify the potential of solar Passive Design (PD) strategies (a proven architectural design approach) in reducing thermal loads on the HVAC system within the context of cruise ships operating in the Mediterranean (McCartan and Kvilums 2014a). This was achieved through the development of design tools adopting a bioclimatic methodology to support engineers and designers in making critical design decisions at the beginning of the design process - to effectively estimate the potential of PD for a given climatic range. The focus of this research was a quantitative thermodynamic analysis - through simulation - of the thermal environment of cruise ship cabins. This was executed using existing validated PD simulation tools from the architectural industry. Attention was placed on specific solar passive practices concerning the physical form of the façade and fenestration.

The simulation results showed the increase in shading depth from 0.5 to 2.0m in depth resulted in a decrease in annual combined heating and cooling loads of between 25.9% to 13.6% for a zone orientated in a northerly direction whilst a reduction between 60.5% to 40.2% was observed for zones orientated in a southerly direction. It appeared therefore, that zones in a southerly orientation benefited most from shading. Overall shading decreased annual sensible loads across all the test locations especially in locations with latitudes below 41.28°N. The application of solar passive technology reduced solar gains by as much as a 71.6% when a 2.0m shading device was added to south facing 80% glazed façade. A comparable decrease of 69.8% was also observed in relatively northerly territories such as Trieste for the same zone configuration. Overall, across all test locations a mean reduction of 54.6% is witnessed when shading is applied to a zone with an 80% glazed façade.

In addition to the physical adaptions made to the exterior façade, the optical and thermal characteristics of glazing systems were also considered; for a zone with an 80% glazed façade orientated south. The results indicated that combinations of glazing properties were found to

produce relatively low annual combined heating and cooling loads, which were between 39.06% to 53.68% less than the glazing systems which produced the highest loads. Overall the parametric study indicated that combined passive strategies resulted in the lowest annual heating and cooling loads as well as the lowest solar gains.

Naval Architects and interior designers have a key role to play when it comes to the design of future low-energy cruise ships. The preliminary design tool developed in this thesis contributes to the need for further development of design tools for solar PD strategies within cruise ships. This focuses on user-friendly visual tools that are easily interoperable within current architectural modelling software packages, and which generate clear and meaningful results that are compatible with the needs of a future interdisciplinary workflow of the Naval Architect and interior designer. The limited knowledge of solar PD technologies within the Naval Architect community, suggest the need for further skills development amongst Naval Architects and tool development to accelerate the implementation of these technologies in future cruise ship designs (Kanters 2014).

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Abbreviations

ABS	American Bureau of Shipping
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers. Founded in 1894, is a global society advancing human well-being through sustainable technology for the built environment
AH F	Annual Hourly Frequency - Relating to the hourly frequency within the year
BCL	Bioclimatic
BIM	Building Information Modeling
BREEAM	Building Research Establishment Environmental Assessment Method
CB	Comfort Boundary - Relating to the thermal comfort boundaries defined on the psychrometric chart
CDD	Coolding degree day - defined "as the sum of the differences between daily average temperatures and the base temperature" (ASHRAE. 2013) as calculated within section 3.1 - equations 5 to 6
DOE	Department of Energy
DNV	Det Norske Veritas -is an international accredited registrar and classification society headquartered near Oslo, Norway.
DHF	Direct Heating frequency
DNRAD	Direct Normal Radiation (W/m2)
DBT	Dry Bulb Temperature (°C)
EEDI	Energy Efficiency Design Index
EER	Energy efficiency Ratio
EPW	Energy Plus Weather Files (format of weather files with suffix - .epw)
JEPlus	Energy simulation management program (Zhang, Yi. 2014)
ENEP	Estimated Net Energy Produced
ECF	Evaporative Cooling Frequency
GA	General arrangement – in reference to the plan of rooms, spaces and people flow of a ship forming the blueprints of a build
GHILL	Global Horizontal Illuminance (lux)
GHRAD	Global Horizotnal Radiation (W/m2)
HDD	Heating degree day - defined "as the sum of the differences between daily average temperatures and the base temperature" (ASHRAE. 2013) as calculated within section 3.1 - equations 5 to 6.
HVAC	Heating Ventilation and Air Conditioning
HR	Humidity Ratio (kg/kg)
HCFCs	Hydro chlorofluorocarbon

IMO	International Maritime Organization
LEED	LEED, or Leadership in Energy and Environmental Design, is the most widely used green building rating system in the world. Available for virtually all building, community and home project types, LEED provides a framework to create healthy, highly efficient and cost-saving green buildings.
MARPOL 73/78	Maritime Pollution convention from 1973 with protocol in 1978.
MPPT	Maximum power point tracking
MAP	Mean annual precipitation (mm)
MAT	Mean annual temperature (°C)
NOAA	National Oceanic and Atmospheric Administration
NV F	Natural Ventilation Frequency - Relating to the
NER	Net Energy Ratio
NZEB	Net Zero Energy Buildings
NTCVF	Night Time Cooling Ventilation Frequency
NOX	Nitrogen oxide
Tmon10	Number of months where the temperature is above 10°C
PD	Passive Design - Relating to the processes and technologies used in architecture to maintain interior thermal comfort without the need for active heating or cooling methods
PHPP	Passive House Planning Package - is an easy to use planning tool for energy efficiency for the use of architects and planning experts.
PSHF	Passive Solar Heating Frequency (Hrs)
PEB	Positive Energy Buildings
Pdry	Precipitation of the driest month (mm)
Psdry	Precipitation of the driest month in summer (mm)
Pwdry	Precipitation of the driest month in winter (mm)
Pwwet	Precipitation of the wettest month in summer (mm)
Pswet	Precipitation of the wettest month in summer (mm)
Pwwet	Precipitation of the wettest month in winter (mm)
RET	Renewable Energy Technology
U Value	Represents the thermal transmittance and is the reciprocal of the R value. It determines the thermal transmittance per m^2 as a result of a temperature difference across the element.
RINA	Royal Institution of Naval Architects
SOLAS	Safety of Life at Sea
SEEMP	Shipping Energy Efficiency Management Plan
E+	Simulation software Energy Plus - Version 8.2 (DOE. 2014)
SHGC	Solar Heat Gain Coefficient - As defined within ASHRAE. (2009 - Chapter 15)

SOX	Sulphur oxides
AMJJAS	Summer is defined as the warmer of the 6 months throughout the year and encompasses the months of April, May, June, July, August, and September
Tcold	Temperature of the coldest month (°C)
Thot	Temperature of the hottest month (°C)
TMCF	Thermal Mass Cooling Frequency
TBT	Tributyltin
Pthreshold	Varies according to the following rules; if 70% of MAP occurs in winter then Pthreshold = 2 x MAT, if 70% of MAP occurs in summer then Pthreshold = 2 x MAT + 28, otherwise Pthreshold = 2 x MAT + 14
VOC	Volatile organic carbon
WBT	Wet Bulb temperature (°C)
ONDJFM	Winter is defined as the cooler of the 6 months throughout the year and encompasses the months of October, November, December, January, February and March
ZEB	Zero Energy Builiding

1.0 INTRODUCTION AND THESIS OUTLINE

This thesis is divided into eight chapters; 1) Introduction and Thesis Outline, 2) Literature Review, 3) Methodology – for a parametric study of passive strategies, 4) Results and Analysis – of the parametric study, 5) Methodology – for the bioclimatic analysis of significant cases 6) Results and Analysis – of the results presented in chapter 5, 7) Overall Discussion - of completed research and 8) Conclusion and Recommendations.

Chapter 1 - Introduction & Structure of Thesis; Provides the general structure of the research and defines its scope relative to the context of the marine industry. This chapter also addresses some of the poignant literature providing a background to this study whilst also introducing its aims, objectives and contributions to knowledge

Chapter 2 - Literature Review; reviews the implication of Passive Design within terrestrial architecture whilst reviewing previous studies relating to bioclimatic design tools to assess their potential in different climates. Literature is used to address how a bioclimatic methodology could be adopted as a transfer of innovation from architecture to the marine industry to reduce auxiliary loads through the adaptation of preliminary design tools within the initial design phase – thus providing the rationale for this research. Topics reviewed within this review include thermal comfort, passive architecture, bioclimatic design tools, computer simulation design tools, the psychrometric chart and current marine design practices. Concluding this review, four emerging themes were identified including structural form, building fabric, fenestration and a structures operational context which form preludes to the methodologies presented in chapter 3 and 5.

Chapter 3 – Methodology; defines the method adopted to address the thesis aims and objectives. Principally this includes a) A method for establishing test weather conditions to represent the test environment of the Mediterranean, b) the development of theoretical thermal test models c) the process of simulating passive strategies and managing simulation data whilst varying multiple parameters and finally d) the process for extracting, tabulating and representing data from simulations to compare zone performance in relation to sensible thermal loads and interior heat gains.

Chapter 4 - Results and Analysis; Presents an in-depth analysis and illustration of weather data and parametric simulation results. Within this, major trends in relation to the impacts of solar shading, glazing systems, exterior fenestration, interior heat gains, location and orientation of test zones are addressed.

Chapter 5 - Methodology; Presents the methodology for a second study detailing a bioclimatic analysis method to define the cause of high and low annual loads attributed by the passive strategies applied. In this instance, the chapter reconciles a method of assimilating simulation data to define specific environments most and least conducive to passive attributes using the bioclimatic psychrometric chart.

Chapter 6 - Results and Analysis; looks in more detail to significant cases identified within the parametric study using a simulation data analysis tool and the psychrometric chart to define bioclimatic regions and climatic characteristics where passive design would be most effective

Chapter 7 - Overall Discussion; provides a speculative review of the results in relation to the literature review presented in Chapter 2 and discusses the potential of a design tool fabricated from a bioclimatic psychrometric chart to assess the potential of Passive Design from weather data compiled from specific route itineraries. Following this, the wider meaning of the research is discussed through the conceptual development of an ultra-luxury cruise ship (shown in figure 51).

Chapter 8: Conclusion & Recommendations – provides a concise summary of the thesis argument and the main results. In addition to this, recommendations for further study are made, followed by a statement of how this research furthers the development of passive design within the marine industry.

1.1 Background

Passive Design (PD) refers to a design approach in architecture whereby, wind and solar energy are utilized to provide a comfortable internal environment. It has the potential to significantly reduce carbon emissions, fuel consumption and reduce the size of conventional HVAC (heating, ventilation & air-conditioning) systems as exemplified by 20,000 passive homes all over Europe (Feist 2010).

Bioclimatic design is an approach to achieve energy conservation in buildings based on an understanding of building design in the context of the surrounding climate (Milne and Givoni 1979). Having a scientific understanding of the environment to inform the geometry and form of a structure (Dahl 2013) leads to an equilibrium between interior heat gains and losses. Thereby reducing active forms of thermal conditioning for maintaining interior thermal comfort.

The application of passive technology to buildings developed by a bioclimatic methodology results in climate responsive architecture which minimizes thermal loads, and in some cases, removes the need for conventional HVAC systems. A low carbon design hierarchy as illustrated below (Brown 2010) (figure 1), highlights that PD would be a favorable strategy in supporting a low emissions agenda due to its low implementation costs combined with greater ecological benefits. It moves away from the conventional use of electrical energy in HVAC systems, by making use of the available heating and cooling potential within a given operational environment.

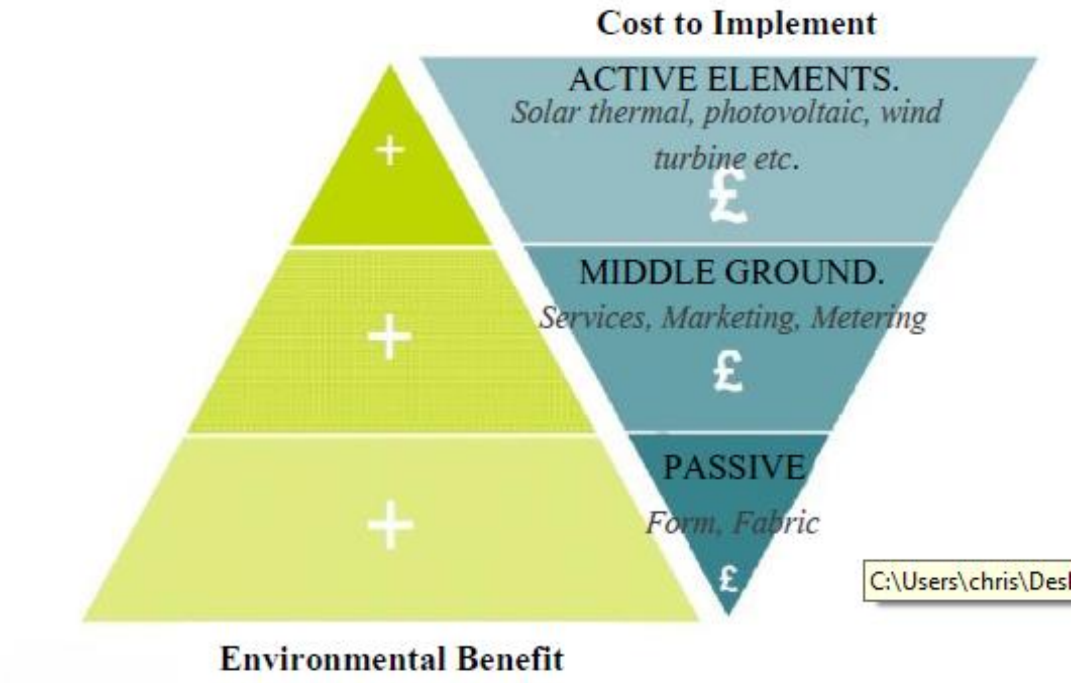

Figure 1 Low carbon design hierarchy illustrating PD as low-cost design solution with maximum environmental benefits (Brown 2010)

PD requires no active systems and completely relies on the environment to provide heating, ventilation and cooling. It is integrated into the structure and incorporated through the careful planning and design of the structures external morphology, thus incurring no additional construction costs, requires fewer components and ultimately a lesser embodied energy than traditional HVAC systems (McCartan and Kvilums 2013d). It is because of this implicit relationship of exterior form and interior design that PD needs to be addressed at an early stage within the design process. Where its' benefits within the architectural industry can be recognized using design tools such as Climate Consultant (Liggett 2008), Design Builder (DBS 2011) and Ecotect (Autodesk 2011).

The Mediterranean is a popular cruise destination and seconds only to the Caribbean. The Caribbean and the Mediterranean combined represent 67% of the global capacity for leisure cruises (Pallis and Papachristou 2015: 10). Figure 2 illustrates the distribution of cruise passenger visits across the Mediterranean in 2011. The significant distribution of certified Passive Houses within the latitudinal range of the Mediterranean (IPHA. 2016), identifies the potential for PD strategies to be applied to terrestrial structures in the region. This research will apply these design strategies to a cruise ship operating in this region with a view to identifying the potential to reduce auxiliary loads (HVAC and lighting), which given the considerable number of cruise passenger visits (figure 2) would significantly reduce the operating costs of vessel, as less energy requirement translates to less fuel consumption. A key challenge in the analysis of Marine PD is that the cruise ship changes latitude and orientation during passage. These parameters vary considerably from route to route, whereas PD applied to terrestrial architecture is dealing with a fixed structure which has constant latitude and orientation.

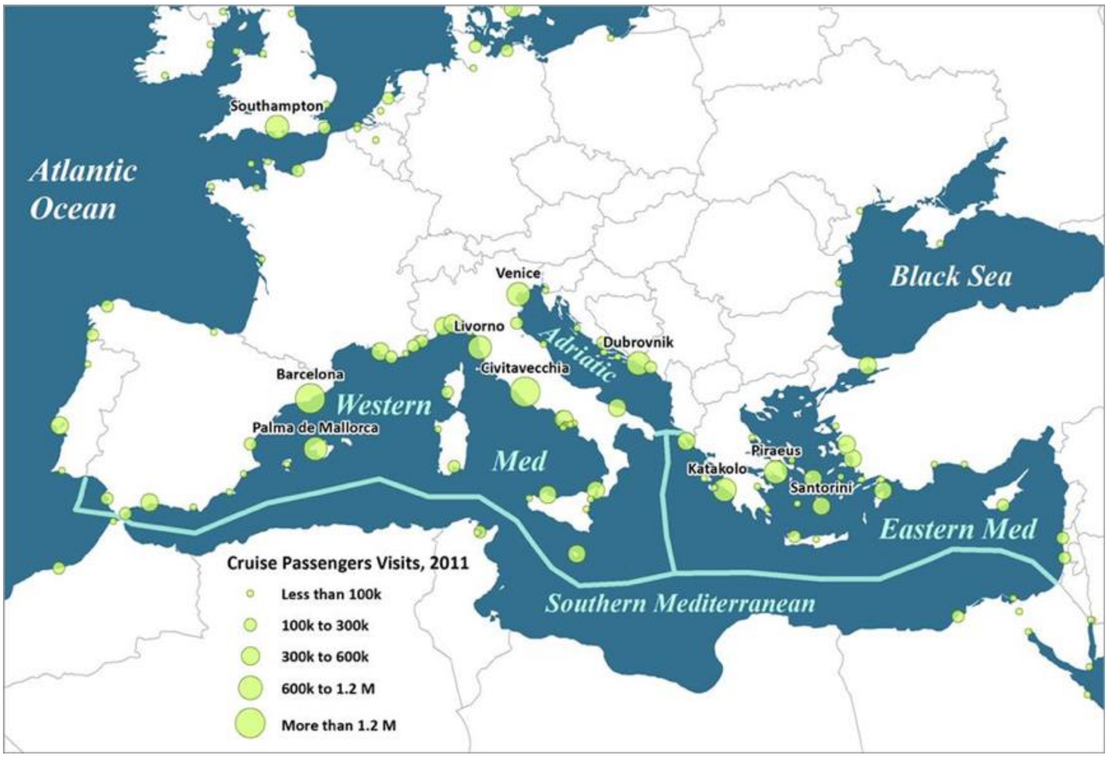

Figure 2 Cruise passenger visits within the Mediterranean basin for 2011 (Jean-Paul. 2013)

Harris, D et al (2014) developed a boat design Manifesto which states the importance of considering energy efficiency and sustainability measures at the beginning of the design process;

> In the "field of Naval Architecture, decisions in the design process, and their justification, are extremely important and influential. Although decisions are taken (and rationale expressed) during all phases of the design process, they are most important during concept design. It is estimated that 90% of the major design decisions have been made when less than 10% of the design effort has been extended (as illustrated by figure 3). These decisions have a direct influence on the quality of the resulting design. If improper or inferior decisions are taken, the resulting design can be suboptimal, or in the worst case, fail. Although design rationale occurs in multiple areas of concept design, it would be particularly valuable during the configuration design of complex vessels… Identification of interaction rationale is important in ship design

because it motivates proper analysis (in design) and forms the basis of compromise or trade-off decisions. Without knowledge of the interactions in the design, it is difficult to understand the consequences of compromises. Rationales can also provide an increase in the relative quality of knowledge in the ship design process. The “Knowledge - Cost- Freedom” curve shown in Figure 3, illustrates the benefits of increased knowledge during the initial stages of design. As knowledge becomes obtainable earlier in the design process, design freedom increases, committed costs can be postponed to a later point in the design cycle and overall design time can be reduced. This is especially important during periods of reduced capital reinvestment in complex ships”

An interactive design approach adopted by Duchateau et al (2013), allows the architect to explore several design alternatives. “This insight is then used by the naval architect to steer and control the design exploration process through a feedback mechanism within the approach” (as illustrated in figure 4). This empowers the naval architect to not only identify, but also act upon the emerging relationships between requirements and the design, which can then either be avoided within the interactive approach or communicated to the stakeholders in support of a better requirements elucidation process. On cruise ships HVAC loads constitute between 30% to 40% of the fuel consumption (Boden 2014). A reduction in internal loads would in turn reduce the amount of energy consumed by the HVAC system, thus driving down its need, size, use and ultimately fuel consumption. The bioclimatic methodology to achieve a climate responsive structure is well established within the architectural industry yet no tools exist for its assessment within the operational context of the cruise ship industry. There is therefore a need to develop parametric design tools to effectively engage Naval Architects in marine PD.

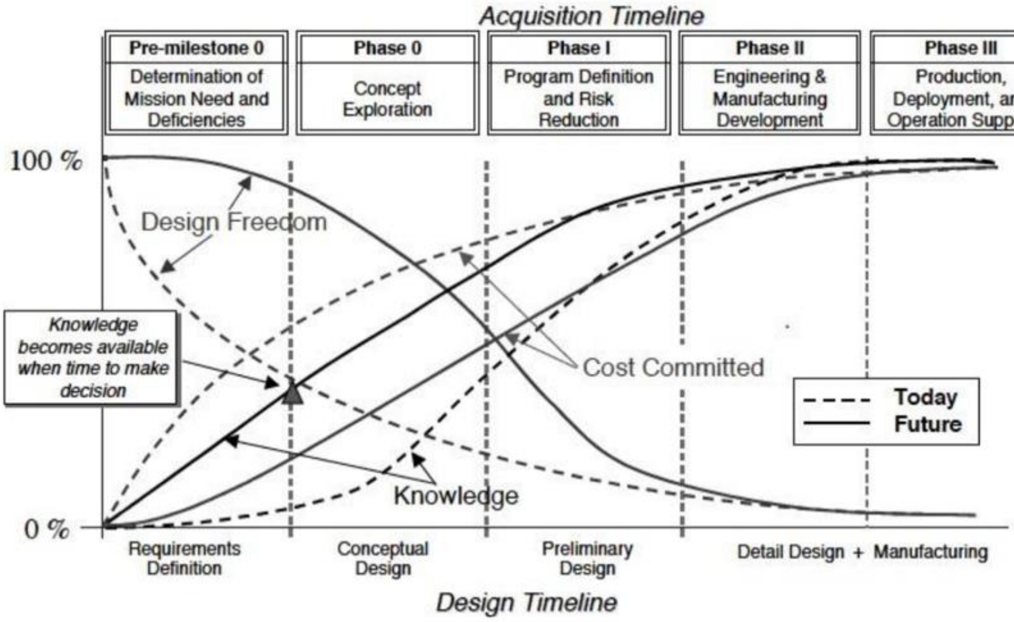

Figure 3 Distribution of cost, knowledge and design freedom during the preliminary stages of design (DeNucci 2012)

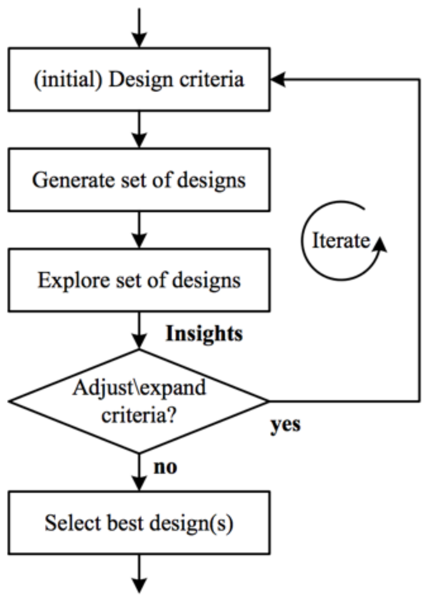

Figure 4 Interactive and iterative design exploration workflow as proposed by Duchateau (2013) cited from Harris et al. (2014)

While PD is not currently addressed within design practices of the cruise ship industry, latest trends in legislation identify vessel emissions and hence energy consumption to be key factors informing the design process. On this basis, PD offers a significant potential for a Transfer of Innovation (TOI) from terrestrial to marine architecture, providing both ecological and economic benefits to the industry.

The industries developing ecological consciousness is reflected in the immergence of a number of voluntary and mandatory standards from classification societies such RINA, Lloyds Register, China Classification Society, Det Norske Veritas (DNV) and the American Bureau of Shipping. Some of the most radical emerging standards and environmental performance indices include; the Environmental Ship Index, EEDI (Energy Efficiency Design Index) and the Ship Energy Efficiency Management Plan (SEEMP) (Stuer-Lauridsen, et al. 2014).

RINA, one of the founders of IACS (International Association of Classification Societies) has shown a commitment to environmentally friendly shipping, by launching a new goal-based class notation in 2014 called GREEN PLUS. The voluntary notation is based on an environmental performance index which covers all aspects of the vessel's impact on the environment, including carbon emissions.

This RINA class notation will be granted to new vessels which make a significant investment "in design solutions, on-board equipment, and operational procedures which contribute to an improvement in environmental performance beyond the minimum levels required by international regulation on environmental protection. The goal-based approach, rather than prescriptive one, ensures sufficient in-built flexibility to allow designers the latitude to choose those tools which they deem to be most appropriate, subject to achieving an assigned value in an environmental index. This is particularly thought to encourage the introduction of modern technologies; which RINA experts will evaluate on a case by case basis" (Riviera Maritime Media Limited. 2017).

Silversea is one of the first cruise ship operators to have complied with the RINA Green Star classification notation – which are constructed with units that prevent water and air pollution. In addition to this Silversea had requested Fincantierie (One of the largest ship builders in the world) to adopt the latest fuel saving technologies within the design process. Fincanterie adopted several schemes to achieve this standard and focused on the three principal areas of HVAC, lighting and Hull coating technology. Technologies adopted included; the use of LED lighting and HVAC systems enabled with frequency converters allowing for air conditioning to match the real time demand within accommodation spaces. The resulting vessel became Silverseas new flagship called "Silver Muse" – launched in April 2017 – significantly succeeding its sister ship "Silver Spirit" in terms of energy efficiency (Fincantieri. 2017).

The design paradigm shifts in the development of this vessel - involved Fincantieri designing the air conditioning system themselves, as part of a wider strategy to design as many aspects of the vessel as possible. This new business model of “in-house” design and build are a significant departure from conventional practices of turnkey applications from sub-contractors. The main reasons behind this paradigm shift are cost reduction and the need for innovation. It is recognized that by designing internally the company increases knowledge and capability in a range of areas making the design and build process adaptable to technology innovation which is otherwise not possible when decentralizing control, information and design via sub-contractors defined at the beginning of the process.

The UK classification authority is Lloyds Register – which has also developed environmental classification rules and notations for ships. In this instance if a vessel fulfils criteria beyond the MARPOL 73/78 class rules– it can be awarded the ECO Loyds Register notation. The classification rules contained within this notation target pollution areas and waste management strategies including; $C0_2$, NO_x, SO_x, CFCs, HCFCs, Refrigerants, VOC, black water treatments, bilge water treatment, ballast water, garbage, TBT, noxious liquid substances, SEEMP and scrapping policy’s (Stuer-Lauridsen et al. 2014).

The cruise ship “Carnival Vista” built in 2016 – was the first Carnival ship to acquire the Lloyds Register ECO notation. It achieved this through the adaptation of a sophisticated power management systems which enabled an optimization of its diesel engines – reducing fuel use and ultimately emissions. Other technologies included a heat recovery system within its exhaust gas boilers, and energy efficient LED lighting systems (Kalosh 2016).

Overall a review of relative literature from industry opinion leaders and authorities - suggests an industry movement towards a reduction in fuel use and emissions as well as a growing consciousness of water pollution and waste streams.

1.2 Hypothesis

PD implementation within architecture has resulted in an 80 – 90% reduction in total energy consumption in modern homes compared to conventional designs. This is achieved through a scientific analysis of annualized weather patterns and the natural environment at the building's geographical location. This analysis specifies the following physical parameters: building orientation; adequate insulation; air tightness; shading; effective placement of glazing systems and the maximization of desirable air flows to improve thermal comfort.

In order to maintain thermal comfort of their guest, cruise ships operating in the Mediterranean use HVAC systems with set point temperature control, which anecdotally represent 30% of the total energy consumption of the vessel. The Energy Efficiency Design Index (EEDI) and the Ship Energy Efficiency Management Plan (SEEMP) entered into force in January 2013. The EEDI applies to new ships greater than 400 gross tonnes (GT) and varies with ship type, size and function. It is a measure of the amount of carbon dioxide (CO_2) emissions per tonne-nautical mile. A smaller EEDI value means a more efficient ship in terms of energy consumption per tonne-nautical mile (ICCT 2011). A reference level was established for each ship type upon which incremental staged reductions are required every five years. The regulation currently does not apply to cruise ships and other specialty vessels for which deadweight tonnage is not an adequate representation of transportation capacity (ICCT 2011). The staged EEDI targets are:

- An overall 10% improvement target in vessels' energy efficiency applies to new ships built between 2015 and 2019.
- Ships built between 2020 and 2024 will have to improve their energy efficiency between 15% and 20%, depending on the ship type.
- Ships delivered after 2024 will have to be 30% more efficient.

In addition to the EEDI regulation, the new Chapter 4 of Annex VI (IMO. 2011) requires all ship operating companies to develop and maintain a SEEMP, which provides a mechanism for monitoring efficiency performance over time and forces consideration of modern technologies and procedures to optimize performance (Fafalios 2012) . Given these potential future energy efficiency targets for the cruise ship industry and the significant potential savings in operation costs. Based on a consumption of 1200 ton of HFO for a 7 day cruise at a cost of $650 per ton, for a vessel operating 40 weeks per year this would amount to a bunkering cost of $31.2 million, with the HVAC anecdotally represent 30% of the total energy consumption of the vessel representing a bunkering costs of $9.36 million (Boden 2014). The first hypothesis proposed in this thesis is that the Transfer of Innovation (TOI) of PD from terrestrial architecture to cruise ships operating in the Mediterranean will significantly reduce the energy consumption of the HVAC system and therefore CO_2 emissions.

The focus of this research will be a quantitative thermodynamic analysis by simulation of the thermal and visual environment of the key perimeter zones, namely, cabin, lounge and dining room. This will be achieved through the adaptation of validated PD simulation tools from the architectural industry. This study focuses on specific solar passive practices concerning the physical form of the façade and fenestration leading to the control of solar flux into the interior and the regulation of the thermal and visual environment of the key perimeter zones.

A pivotal consideration in the implementation of PD within a cruise ship is the variation of both latitude and orientation of a vessel during passage making, which varies depending on cruise itinerary. To this end the second hypothesis proposed by this thesis is that a frequency analysis of climate types experienced by the vessel will enable the suitability of specific PD technologies to be evaluated.

1.3 Aims

The primary aim of this study, is to identify the potential of PD (a proven architectural design approach) in reducing thermal loads and peak loads on the HVAC system within the context of marine pleasure vessels such as cruise ships and superyachts.

In doing so, it hopes to support an argument for the use of PD as a cost effective and relatively simple method (as opposed to technologies such as photovoltaics, wind turbines and solar thermal etc.) to reducing auxiliary loads and emissions through maximizing free heating and cooling potential via the interior and exterior environment.

A further aim, would be that this research creates design tools to support critical design decisions at the beginning of the design process via a bioclimatic methodology to allow engineers and designers to effectively estimate the type of passive strategy to employ for a given climatic range.

Overall, this research intends to address the technical and aesthetical implications of PD within the context of the marine industry and form the basis for further research in this area whilst promoting the development of design tools for specific passive strategies – bringing economic and ecological benefits to the industry.

The above defines the intent and purpose of this thesis – this can be summarized as follows:

- To develop and propose a marine bioclimatic methodology which allows for the investigation of how climate impacts the thermal performance of key perimeter zones on a vessel and how this performance is affected by the application of key PD strategies
- To define the potential for PD as a means of reducing interior thermal loads placed on the HVAC systems – addressing its potential role in aiding compliance to emerging emissions legislation
- To develop a platform on which a bioclimatic strategy can be conceived, to encourage experimentation and to increase knowledge input at the begging of the design process

1.4 Objectives

Following the aims defined in section 1.3 – the objectives below are intended to define the goal posts of this thesis into specific, measurable, achievable, realistic actions that is considerate of the time granted for this research. The objectives of this study can be defined as follows.

- To define, justify and compose a test climate database – using historical weather data for the testing passive strategies for areas commonly used by leisure vessels such as superyachts and cruise ships
- To construct **prototype thermal models** of perimeter zones affected by the exterior environment for use within simulations to test the influence of PD on thermal loads to the detail demanded at the initial phases of the design process for a first order analysis
- To define the geometry and properties of the **passive technologies to be tested** as identified by a literature review. This includes primarily strategies that vary solar gains and other interior heat gain sources encompassed within section 1.5
- To **develop a parametric methodology** that would enable the individual and combined effects of passive strategies to be recognised on interior thermal loads
- Develop and **design annual, monthly and hourly data extraction, tabulation and illustration tools** that would allow for major trends on sensible loads to be recognised as a consequence of the application of passive strategies
- Propose **new bioclimatic methods of assessing the potential of PD** to aid decision making in the begging in of the design process for designers and engineers whilst also exploring – through conceptual development - the aesthetical and technical implications of application

The term "thermal loads" is in reference to the energy added or subtracted from a zone by the HVAC system to maintain thermal comfort – or to maintain interior conditions within the defined heating and cooling set points (Autodesk 2015).

1.5 Scope of research

The study proposes that PD can be adopted as a design methodology to reduce interior thermal loads on board – this is considered to the extent by which interior heat gain sources and interior heat losses can be controlled by passive strategies to reduce the sensible heating (L_h) and cooling load (L_C). This relationship is illustrated formulaically below as defined within Kreider, Curtiss, Rabl (2010).

$$L_h(\mathrm{W}) = Q_{loss}(\mathrm{W}) - Q_{int}(\mathrm{W}) \quad (1)$$

$$L_C(\mathrm{W}) = Q_{int}(\mathrm{W}) - Q_{loss}(\mathrm{W}) \quad (2)$$

Sensible gains from the occupants of the zone (Q_{people}), equipment - such as media devices and computers (Q_{equip}), lighting (Q_{lights}) and solar gains from the glazing apertures (Q_{sol}) are considered as the primary dependant variables influenced by the application of passive strategies – the sum of which is known as the zones internal gains (Q_{int}).

$$Q_{int}(\mathrm{W}) = Q_{sol}(\mathrm{W}) + Q_{people}(\mathrm{W}) + Q_{lights}(\mathrm{W}) + Q_{equip}(\mathrm{W}) \quad (3)$$

Losses from the building fabric are defined by the structures insulative properties (U_o) expressed by its U value (W/m²K). The rate of heat transfer is expressed as a function of area (A_o) (in units of m^2) and the temperature difference across the exterior interface between the interior and exterior temperature ($T_{in} - T_{amb}$) (in units of Kelvin –'K'). These variables are considered constant within this study and are defined as per discussions with industry and the ISO 7547 (ISO. 2002). Formulaically losses can be expressed as follows.

$$Q_{loss}(\mathrm{W}) = U_o\, A_o(T_{in} - T_{amb}) \quad (4)$$

Sensible heating loads (L_h), sensible cooling (L_C) and latent conditioning are also considered dependant variables but are not considered within this study as indicative of those loads experienced on board due to the use of Ideal Loads calculation methods which assumes a HVAC system of 100% efficiency. CAV (constant air volume) and VAV (Variable air volume) are typical of the types of the HVAC systems found on board. Although there have significant advances in these systems – evidently, they are not 100% efficient. Thus, the heating and cooling loads profiled within the simulations conducted within this study cannot be used to provide absolute values on the electrical energy required to maintain the interior temperatures within the heating and cooling set points specified – but are otherwise indicative of the thermal requirements of the zone and can be used to signify periods of high heating or cooling which has been deemed adequate for the purposes of the aims and objectives described in section 1.3 and 1.4. In summary, this research is not concerned within the development or detailing of HVAC systems but is otherwise focused on the thermal loads placed on it.

It is recognized that detailing such a complicated system would require expert knowledge of boilers, chillers, air handling units, fan coils and ducting systems to establish an accurate thermal test model which would necessitate detailed validation methods and is otherwise not provided by authority's institutes such as the IMO (International Marine Organization) or Lloyds register. In a way, this highlights a short falling within the marine industry which is in stark contrast to the architectural industry which provides freeware such as Energy plus (DOE 2015a) and highly detailed well researched thermal models with complete HVAC systems as provided by the US Department of Energy (DOE) and collated within such works as "U.S. Department of Energy: Commercial Reference Building Models of the National Building Stock" (Deru et al. 2011).

As a result, this research has had to embark on the construction of hypothetical thermal models based on such standards as the ISO 7547 (ISO. 2002) and the ABS Passenger Comfort Guide (ABS. 2014) - which have facilitated in the development of test models that are relevant to the intent of a study conducted at the initial design phase but is otherwise not exhaustively detailed so as to encompass; HVAC particulars, thermal bridges or structural infiltration rates. Instead hypothetical models which assume steady state conditions and well mixed interior air have been constructed and empirically validated through the comparison of industry calculation methods.

As a basis for the development of a hypothetical thermal models – the "Helios" project featured in figure 5 below – was a virtual ship design developed for the purposes of investigating the potential of PD and became the case study adopted within this research. The form, location and geometry of cabins, dining areas, lounges and entertainment spaces were constructed based on benchmarking studies to provide typical room volumes and configurations for the development of digital thermal models as pictured in figures 6 below.

Although within this research specific passive strategies relating to the energy balance of cabin zones were considered - defining the current scope of the works - the Helios design has also featured in a number of white papers allowing for further exploration and engagement within industry at several RINA conferences, in which the potential for other PD solutions such as natural lighting and natural ventilation was discussed. Appendix 7.2 to 7.4 present the white papers referenced.

Figure 5 Aft exterior three-quarter perspective of the Helios project (Top), Fwd exterior three-quarter perspective of the Helios project (Bottom) – A 78m ultra-luxury catamaran cruise ship

Figure 6 Digital thermal models of the exterior cabins constructed for the Helios project – developed in the software program "DesignBuilder" (DBS. 2011) for the purposes of thermal simulation within EnergyPlus (DOE 2015a).

An industrial design approach to the hypothetical ship design - manifested a holistic methodology which consequently necessitated the requirement of a GA - as illustrated in figure 7. Although beyond the scope of this thesis - a significant feature of the GA, (which is further elaborated in appendix 7.2) is the use of external vertical window louvers in perimeter facades of several decks which take advantage of pressure differentials across the vessel during desirable climatic periods to induce cross ventilation. In addition to this the GA is configured in such a way that naturally induced air flows are funneled through connecting corridors to stairwells, which operate as ventilation shafts. A combination of stack ventilation methods as well as venturi apertures are used in these exhaust shafts to maximize air flow.

Figure 7 Helios GA – A 78m Luxury Catamaran

The development of small scale projects such as Helios, has also allowed for an exploration of the aesthetical elements of interior zones – to this degree the influence of the design style and colour could be explored in the context of their impact on natural lighting potential. Figure 8, illustrates two interior designs presented for the Helios project - with varied interior surface reflectance and colour schemes impacting the amount of natural light. Although a thorough investigation of natural lighting is beyond the scope of the works presented in this thesis it is discussed at length in other published works by the author in appendix 7.3. It offers a valuable insight into the potential of PD and the need for further research in this area – which is currently very limited.

Figure 8 Conceptual realization of two interior colour schemes for the outboard cabins of the luxury catamaran - Helios. Light high surface reflectance interior (Left), Dark low surface reflectance (Right).

In essence the application of an industrial design methodology to the aims and objectives of the thesis – stimulated the creation and development of Helios – which not only became a fundamental reference case for this research but also facilitated in widening its current scope - in highlighting some of the more practical issues of PD adoption; including the impact of reducing glazing apertures on natural lighting potential and user experience whilst also identifying difficulties in reaching fire regulations compliance when adopting natural ventilation strategies.

The principles of PD can be applied in effect to any structure which has a thermal interaction within its environment – thus it could also apply to a range of marine structures including superyachts, ferries, RORO boats, shipping containers and indeed any other boat which has the requirements for a conditioned interior zone. Due to project time restraints however, this research focusses primarily on interior zones located within a mid-range cruise ship. The rational for this is based in the fact that the environment of operation can be more tightly approximated as opposed to perhaps a private yacht, they typically have highly glazed superstructures and they provide a commercial context in which the potential of PD can be rationalized economically.

Additionally, this research does not consider all worldly climate types due to imposed time constraints. To do so would perhaps involve works to define the potential of PD within extreme cold climates near the poles and extremely hot climates near the equator. Each scenario would necessitate the employment of very different passive strategies. Thus, the scope of climates considered has been condensed to the Mediterranean. The rationale for this is based on this area being the second most popular cruise destination in the world (Cruise Market Watch. 2012) as well as possessing an abundance of certified passive houses in similar latitudinal ranges (IPHA. 2016) – indicating that it is already plausible strategy in terrestrial structures operating in temperate environments (Feist 2006a).

The term “PD” within this study - is relating to such strategies as, solar shading, natural lighting, adapting glazing ratios, introducing high performance glazing systems, orientation and reducing interior heat gain sources. It therefore does not provide a comprehensive review of all passive technologies such as evaporative cooling, thermal mass, night ventilation, thermal syphons, trombe walls etc. Such methods would require a detailed level of design testing and industry specific knowledge. This is prevalent in such technologies as natural ventilation and evaporative cooling which may introduce warm humid, salty sea air into the interior. The impacts of which are not recognized within the aforementioned variables and are beyond the scope and resource of this study.

Overall, the scope of this research could be summarised as a body of works that defines the potential for relevant passive strategies in reducing sensible thermal loads placed on HVAC systems for common perimeter zones on cruise vessels operating within Mediterranean climates. This has determined through a detailed understanding of climate and the application of a bioclimatic methodology. To this degree this body of works has been considered valuable from the perspective of identifying the potential to reduce fuel consumption and emission but also in identifying the role of the interior and exterior stylist in influencing the thermal performance of a vessel. Barriers to its implementation and its aesthetical compromise have also been addressed anecdotally – identifying overall, the current lack of design tools available and the need for further works in this area of research.

The scope of the research is limited in terms of the climatic range explored and the level of detail within the thermal models constructed for a simulation-based analysis. This is revealing of the lack of public data available - which is otherwise in stark contrast to the architectural industry. The quality of the output data however, is relevant to the level of detail necessary at the formative and conceptual phase of the design process which has been empirically validated within this study.

1.6 Contribution to Knowledge

The study derives the impact of passive strategies through a parametric methodology and the development of pre-design tools to inform the design process. The contributions can be summarized as follows:

1. An analysis of sensible annual and peak thermal loads of perimeter zones when adopting passive strategies identifying key trends in the application of PD on marine vessels
2. An analysis of the range of climate types a cruise vessel operating within the Mediterranean is likely to be exposed to and how this implicates the performance of passive strategies
3. Data extraction, tabulation, illustration and analysis tools which assimilates climatic and simulation data onto a psychrometric bioclimatic chart for use as a pre-design tool to provide design direction of passive strategies based on a deep understanding of climate.
4. Identification of the role the exterior and interior designer on the thermal performance of the zone in the manipulation of form, fabric and fenestration
5. Identified barriers to the implementation of PD within the marine industry and the short fallings of the current bioclimatic methodology in providing PD direction that is considerate of a vessels mobility

2.0 LITERATURE REVIEW

The aim of the literature review is to obtain current information from relevant literature to provide the setting for the research within the context of the thesis aims and objectives. The literature review presented in this chapter therefore, will aim to a) Identify the factors which rationalize the use of PD within the architectural industry and its potential as a transfer of innovation (TOI) into the marine sector, b) Identify current interior thermal specifications expected within marine interiors and the role of thermal comfort, c) To Identify Current Methodologies adopted to analyses the impact of Passive Strategies in high performance terrestrial structures, d) To review case studies which exercise relative PD principles in buildings situated in different climatic contexts and e) To determine the necessary ingredients that nurture PD within the design workflow that enable successful adaptation.

2.1 Cruise Ship Energy Profiling and HVAC systems

Movements towards sustainable design within the marine industry have only recently been stimulated due to the recent legislation development such as the EEDI that demand new ships to be 10% more efficient beginning 2015, 20% more efficient by 2020 and 30% more efficient from 2025 (ICCT 2011). Prior to this, a focus on lowering design and construction costs and a lack of stringent compulsory regulation resulted in systems that were developed based on the worst scenario of operational conditions negating nominal conditions and thus resulting in systems operating away from their optimum efficiency. Sfakianakisa, and Vassalos (2013) carried out a study focused on the energy use of HVAC to allow for power consumption to be analyzed at the beginning of the design process. This provided an estimation of energy and consequently fuel use in a number of scenarios and configurations to allow for experimental design and optimization. To do this a "good model" was developed of accommodations spaces which specified the geometrical and topological factors. This process of energy modeling allowed for the development of an energy efficient HVAC system. The study concluded that due to recent requirements to reduce greenhouse gas emissions – energy modeling offers a novel means of monitoring thermal flows on ships operating in different scenarios. The disadvantages of such a methodology is that topology modeling is time consuming and requires considerable effort. The study stated that the optimization of HVAC systems on cruise ships is easily justifiable as "HVAC is responsible for roughly 1/3 of total power consumption".

Baldi Marty et al (2015) carried out an energy analysis of a passenger ship (with a capacity of 1800) operating within the Baltic sea is conducted. The operational profile of the ship suggests that it spent most of its time sailing (59%) whilst 34% of the time was spent in port and 7% in a mode of maneuvering. The energy analysis within this case study identified that propulsion was the main energy consumer at 41%, followed by heating at 34% and electric power consumers at 25%. The study concluded therefore, that the main potential for energy efficiency came mainly from the hybridization of the propulsion system, followed by a reduction in heat losses (via the exhaust for example) with waste heat recovery systems. The author goes on to state the in balance of heat availability and demand could be overcome through the use thermal storage which could reduce the fuel needed by auxiliary boilers by up to 7%.

Dodworth (2009) highlighted that increasing fuel prices and the environmental impacts of shipping are key motivators for energy efficient design. He asserted that although the industry has focused on the improvement in propulsion there is a rationale for the optimization in HVAC systems, as it contributes to 30% of all energy use on board cruise vessels. Despite this, the marine design process tends to focus on the “worst case scenario” whereas there are few provisions taken to consider how the design will perform over its lifecycle. The study adopted a building simulation approach in which hourly data is used to define the dynamic energy flows in HVAC and refrigeration under different conditions and operational profiles. A comparison of the dynamic simulation results revealed that the maximum load calculation method currently employed within the industry results in a high margin above the maximum expected load. Where the that maximum cooling design specification was 32% higher than the maximum identified by dynamic simulation. Similarly, when considering more stringent design conditions as specified by the ISO 7547 (2002), the cooling capacity was 58% greater than required. The dynamic modeling approach to energy in marine design allows for opportunities in optimization and encourages an integrated approach to the design of marine systems. The study concluded that the use of dynamic simulation software as used within the terrestrial architectural industry would give more accurate results and less conservative outcomes than conventional static modelling approaches. Indicating that there is a potential for the reduction in HVAC size and therefore a potential reduction in upfront costs. The dynamic modeling systems used in architecture however, would need to be extended and adapted to simulate the dynamic variation in latitude and orientation of cruise ships under passage and the seasonal variations of itinerary.

2.2 Passive Design and Net Zero Emission Buildings

PD refers to a design approach that uses natural energy flows such as sunlight, to heat, cool, or light a building. Passive solar or passive cooling design takes advantage of the environment to supplement heating and cooling demands in reach thermal comfort (Bainbridge 2011: 4). Systems that employ PD require very little maintenance and reduce a building’s energy consumption by minimizing or eliminating mechanical systems used to regulate indoor temperature and lighting (Sustainable Sources. 2015). PD strategies are reviewed in Appendix 1.0. Therefore, a well-designed, well-constructed structure will minimize the use of active systems resulting in the reduction in use of active methods of cooling, heating, and ventilation systems, and artificial lighting (Bainbridge 2011). To achieve this, it is necessary to adopt a methodology which seeks to understand the terrain and biomes such that the structure works in situ with its environment and harvests natural resources native to its location (Visitsak 2007:26). The underlining workflow of bioclimatic design methodology is demonstrated as a linear process in figure 9, understanding of climate is the starting point of the workflow and paramount to achieving PD solutions for a given location. (Bondars 2013).

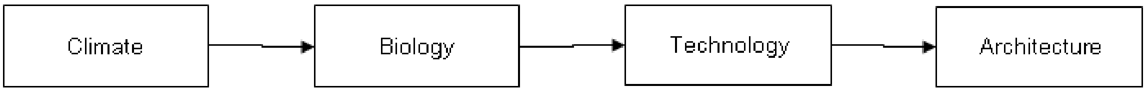

Figure 9 bioclimatic design methodology as posed by Olgyay (1979) (cited in: Bondars (2013))

A common tool used to explain and illustrate the various thermal dynamic processes needed to condition air and the thermal conditions of the interior is represented by the psychometric chart in figure 10. Originally developed by Willis H. Carrier in 1904 it has undergone significant developments over the years and is frequently used even today by HVAC practitioners and building engineers. It defines the properties of moist air with reference to its temperature (ºC), its humidity ratio (kg/kg), its relative humidity (%), its wet bulb temperature (ºC), its enthalpy (kJ/kg-air), and its specific volume (m^3/kg). The psychometric chart is one of the primary tools in this study as it allows for the plotting and illustrating of the external climate, the interior thermal environment, and the range of conditions which are considered by various sources as being thermal comfortable for human inhabitants. Its ability to plot the various processes such as sensible cooling, sensible heating, humidification, dehumidification, and evaporative cooling which occur on this chart will allow for a clearer design focus when selecting appropriate passive technologies. The bioclimatic comfort zone in figure 10 is found to be within the range 19.7ºC and 25.6ºC. Givoni amended this to include the ability of individuals to adapt their environment and extended the comfort zone from 18ºC to 29ºC with a lower humidity limit of 4g/kg (0.004 kg/kg) and an upper humidity ratio of 17g/kg (0.017kg/kg) as seen in figure 10. One of the key factors in developing the bioclimatic chart is in defining the region of thermal comfort. The ASHRAE comfort zones are formulated by the principles of the PMV model. This is derived from steady state climate chamber data and is otherwise more appropriate for conditioned zones. However, the aforementioned does not take into consideration the adaptive theory (Szokolay 2004: 202-224), asserted by Givoni (1994:102) that individuals living in hotter climates are more comfortable at higher temperatures (Lomas 2004). This is addressed in his further works which consider acclimatization by expanding the comfort temperatures between 18º and 29º and humidity levels from 4g/kg to 17g/kg as comfortable as adopted in the bioclimatic studies conducted by Bodach, Lang, Hamhaber (2014(b)) in identifying climatic responsive techniques for buildings in Nepal. Theories in Thermal comfort are reviewed in Appendix 1.3 for architectural and marine purposes. Key studies adopting a bioclimatic assessment methodology for different climates to determine PD potential, are reviewed In Appendix 1.4.

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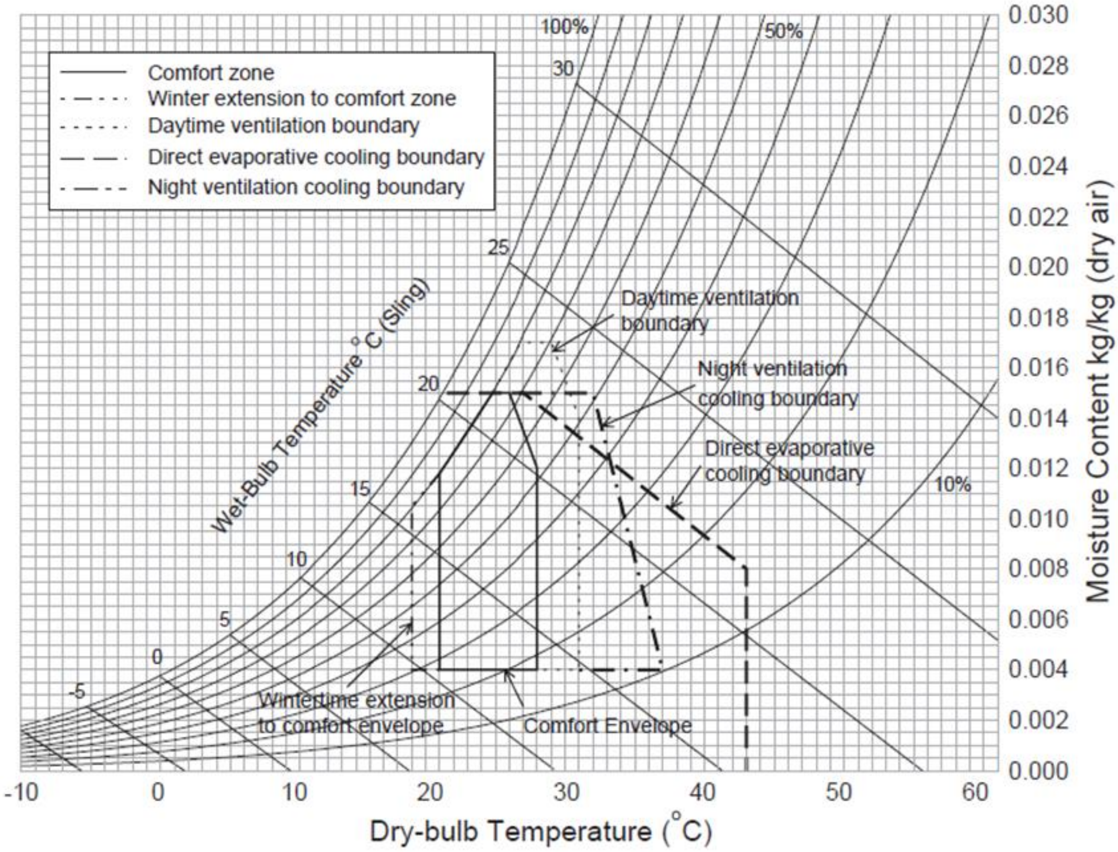


Figure 10 A building bioclimatic chart after Givoni (1992) for developed countries (Lomas 2004)

In terms of PD strategies – shading through means of horizontal overhangs, louvers or recessed windows are perhaps the most common and well-known form of PD. In essence, it forms a rudimental method of controlling solar gains. "In order to obtain high energy efficiency of a passive house building, sufficient reduction of solar heat loads is particularly important … and can be achieved by shading" (Feist et al. 2012: 135). The design guidelines from ASHRAE (2013) indicate that shading of fenestration alone can in some instances reduce solar heat gain by as much as 80%. A detailed review of fenestration and glazing systems is presented in Appendix 1.5 and 3.12.

In review – there were many studies which detailed the improvement in cooling loads as a result of shading. A common overlap was the combined use of natural lighting resulting in even greater reductions in cooling loads and on site electrical energy use. Kim et al. (2012) used the simulation software IES to conduct a comparative analysis of a range of shading systems including; louvers, overhangs and light shelves for an apartment building within the hot humid climate of South

Korea. The study combined the practices of natural lighting and shading resulting in a 70% reduction in the Colling load. The works of Cheng (2007) concurred that careful consideration of shading geometry could support a natural lighting scheme resulting in even greater energy reductions than shading alone.

Adaptive louvers as opposed to static shading systems - offer a hybrid passive strategy. Niccolò (2012) devolved this principle through an adaptive shading algorithm to alter the configuration of louvers based on solar geometry in an office building in Millan (Italy). The works concluded that the angles and geometry of louvers delivering the best performance - are defined by the geographical relationship of the building within its environment, in terms of location, orientation and time of year. Hammad (2010) conducted a study using dynamic louver systems for an office building situated in the hot dry climates of Abu Dubai. The study shows that the shading system was able to reduce thermal loads between 28.57% - 34.02% for west, east and southerly facing facades. A significant finding is that the gains of a dynamic shading strategy are marginal compared to an optimized static louver design.

Kolokotsa et al (2010) asserts that buildings are responsible for 40 % of energy used around the world. Thus, there is an increasing demand to improve their efficiency and ultimately reduce their ecological impact. To do this they must; "use zero-net energy; foster a healthy and comfortable environment for the occupants; be grid-friendly, yet economical to build and maintain". To meet international carbon initiatives the EU has galvanized the transformation of its building stock by implementing legislation stating the at all new buildings by 2019 are to conform to zero energy and emission standards (European Union, 2010). These demands have resulted in the emergence of NZEB (Net Zero Energy Buildings) and PEB (Positive Energy Buildings) buildings with the latter generating more energy than what is required to perform building functions. The study states that an essential ingredient in achieving such high-energy performance buildings, are thermal simulation models and design tools.

NZEB and PEB are an evolution of Passive sustainable design. The concept of which is to minimize energy consumption using passive strategies whilst supplementing additional energy needs through renewables (such as wind turbines, solar panels for example). Kolokotsa et al (2010) outlines some of the examples of several mature strategies to improve efficiency including;

- Improvement of the building fabric, i.e. improvement of insulation, increase of thermal mass, cools materials, phase change materials, etc.

- Innovative shading devices.
- Incorporation of high efficiency heating and cooling equipment, e.g. AC equipment with higher EER, heat pumps combined with geothermal energy or solar collectors, solar air-conditioning, etc.
- Use of renewables (solar thermal systems, buildings' integrated photovoltaics, hybrid systems, etc.).
- Use of "intelligent" energy management, i.e., advanced sensors, energy control (zone heating and cooling) and monitoring systems.

Kolokotsa. et al (2010) goes on to state that the 'Real Time' computational Coupling of energy production with energy demand in relation to building systems - through smart energy management can yield significant benefits;

- The energy production installation may not be extremely oversized to cover the building's energy and indoor environmental quality requirements and therefore the initial investment costs may be decreased.
- The energy production can be maximized by suitable decisions, i.e. MPPT.
- The extra energy produced in a specific period may either be used for storage and coverage of the peak demand in the proceeding period
- Extreme weather conditions can be met on a yearly basis with suitable control actions.

The study is significant in this research as it highlights the static view point of the calculation methods currently adopted within the architectural industry to formulate existing performance metrics such as the ENEP and the NER. However, as per the benefits a dynamic view could yield benefits both on an economic and ecological basis – especially at the operational stage - allowing for dynamic and responsive architecture. Real time dynamic performance indicators could be acquired by onsite smart meters leading to real time optimization and control of PEB and NZEB systems as illustrated in figure 11. Such a strategy may be even more relevant in the context of marine structures based on their constant variation in environmental conditions and operation behavior.

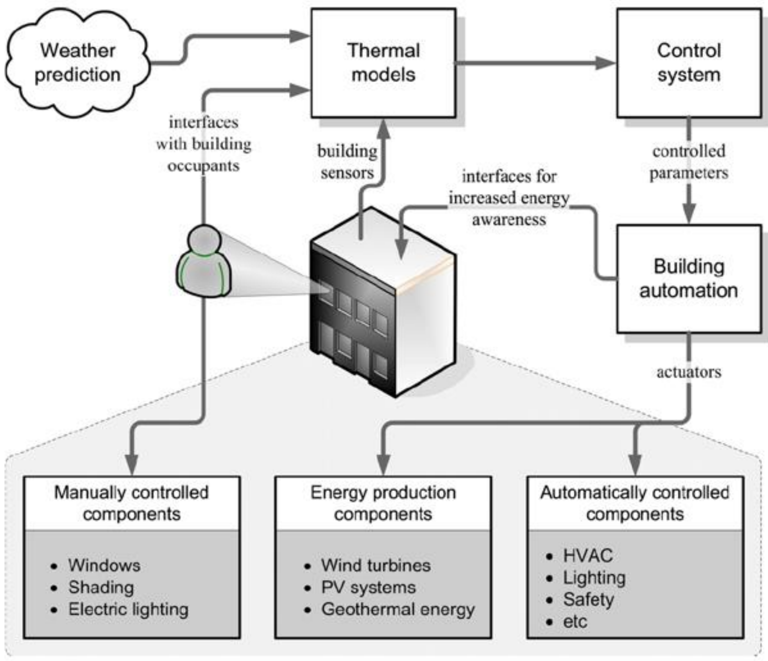


Figure 11 The components of ZEB/PEB architecture during real-time operation (Kolokotsa, et al (2010))

The study concludes that the simulation of building that accurately reflect the dynamic behavior of the thermal interactions between itself, the occupants and the environment are otherwise critical in the prediction the response of thermal and renewable energy production as well as in the assessment of energy efficiency measures. Thus, thermal simulation models that incorporate all components of a building, and are capable of efficiently and accurately predicting the dynamic response of the system are essential for the effective implementation of control strategies. These models being critical to achieving the increased efficiencies and improved operational performance required for the successful implementation of Net Zero Energy Buildings. Appendix 1.1 reviews the case study of a detached house which was analyzed for three climates with a NZEB design tool, developed to gain insights into the economic factors of NZEB solutions and the influence of the climatic context. In short, the study highlighted how a near 300% difference can be observed between an economically efficient and economically inefficient NZEB; in terms its upfront costs and life cycle costs.

Li, D. (2013) defines the base philosophies of ZEB. The first is; design optimization through the implementation of energy efficiency design measures (EEMs) which reduces energy demand and use. The second philosophy is; the integration of RETs (Renewable Energy Technologies) which supplements the remaining energy demand which might include the use of; solar panels, wind turbines, solar thermal, heat pumps and district heating and cooling technology. The net sum of the energy demand over energy supply is therefore zero. EEMs are necessary in many instances as the potential for onsite energy generation is sometimes limited. The study identifies three main subcategories of EEMs. The first is 'building envelopes' including; insulation, thermal mass, high performance glazing, radiant barriers and natural lighting which is implemented via an interrogation of the fenestration within the exterior. The second subcategory relates to the internal conditions and encompasses the interior design conditions (defined by the selected thermal comfort model) and internal heat loads (induced by lighting, occupants and electrical equipment). A reduction in internal heat loads can reduce the need for cooling – and reduce the energy requirements for air conditioning systems. The third subcategory relates to Building services – including HVAC system, electrical lighting systems and lift (or escalators). The study provided a review of work pertaining to the ZEB and the development of EEMs as well as RET. Key findings included;

- Adoption of the ZEB design practices are being formulated into energy standards and codes in light of depleting resources and ongoing environmental damage. This is highlighted by the emergence of new building energy performance directives which requires that all new buildings must be "nearly zero energy buildings by the end of 2020 in EU countries" (European Union, 2010).
- Thermal insulation is less effective in cooling dominated buildings especially in buildings with high interior heat gains. Whereas daylighting and the advancement in lighting technology has high energy saving potential.
- Finally, ZEB play an important role in the nurturing of a more energy efficient building stock however, further works are needed in order to encourage development including; "life-cycle cost and environmental impacts analysis, climate change, and social policy issues".

Overall the ZEB concept offers a significant opportunity for a TOI (Transfer of Innovation) to the cruise ship industry through a reduction in HVAC loads which currently accounts for 30% of energy requirement and hence fuel consumption. Passive strategies can be used to minimize energy use and increase energy efficiency whilst PV technology could be used to supplement auxiliary systems such as lighting. ZEBs offer a significant opportunity for a TOI (Transfer of Innovation) to the cruise ship industry as 30% of energy requirement and hence fuel consumption is due to HVAC and lighting requirements However, Marszala et al. (2011) reports that the architectural industry are lacking in a clear definition of the ZEB concept - whereby a review of literature identified a broad range of energy, economic and ecological performance indices and “no clear standardized support for a ‘zero’ calculating methodology”. For ZEB to implemented within a legislative movement towards a less energy intensive building stock – “it is a key issue to develop a physically convincing, robust and communicable calculation methodology that reflects the concept and facilitate the work of both architects and engineers in designing Zero Energy Buildings”. Currently there are voluntary standards such as LEED or BREEAM that address some of the strategies exercised within a ZEB however, they cover a much broader field and reward sustainable design initiative, yet they do not provide an explicit framework for achieving ZEB’s. Overall the study asserts a need for a robust definition and calculation methodology for the ZEB concept to be readily adopted. Prerequisites for the developing a definition of ZEB were identified by Marszala, et al. (2011) and included; (1) the metric of the balance, (2) the balancing period, (3) the type of energy use included in the balance, (4) the type of energy balance, (5) the accepted renewable energy supply options, (6) the connection to the energy infrastructure and (7) the requirements for the energy efficiency, and the indoor climate.

2.3. Building Simulation Modelling

Nielsen (2005) presented a simplified simulation tool – ‘BuildingCalc’ - which gave reliable results compared to the detailed tool BSim. The simulation tool provided hourly simulation results to evaluate the energy demand of buildings including; “Solar shading, venting, ventilation with heat recovery systems and variable insulation”. The tool required only a few parameters and is posed as a useful application for the initial design stage investigations allowing for the support of decision making. The study indicates that the potential for PD initiatives can be evaluated using steady state conditions and basic thermal dynamic equations to a reasonable accuracy. The passive house planning package PHPP (Feist et al. 2012) is an example of how empirical methods can be used to provide a systematic framework for the accreditation of energy efficiency. The PHPP has been extensively validated and bases its accreditation on steady state calculations and accurate climate data to anticipate performance.

Petersen and Svendsen (2010), in a similar way also uses a simplified building simulation program called iDbuild to make performance predictions at the early stages of building design. It is a development on conventional simulation software in that its output is presented in such a way as to inform the design process and provide design direction - thus preventing the need for unnecessary design iterations. The study poses that the traditional “performance-based design” process (as illustrated in figure 4) identifies whether if a design proposal reaches a specific performance requirement but does not provide advice in instances where undesirable performance Is observed leading to a vast number of alternative design interactions. The study highlights that the number of alternative iterations can be reduced If feedback on elements leading to undesirable performance can be identified. A new subtask therefore is added to the conventional "performance-based design" process called - 'parameter variation' (as illustrated in figure 12). In this instance parameters are varied from base case values in a Differential Sensitivity analysis approach allowing for the consequence of variation to be known and in doing so providing direction in reaching an optimal design solution. "Parameter Variation" minimizes trial and error analysis. The tool presented creates a platform for 'consequence-conscious' design decisions at the beginning of the design process.

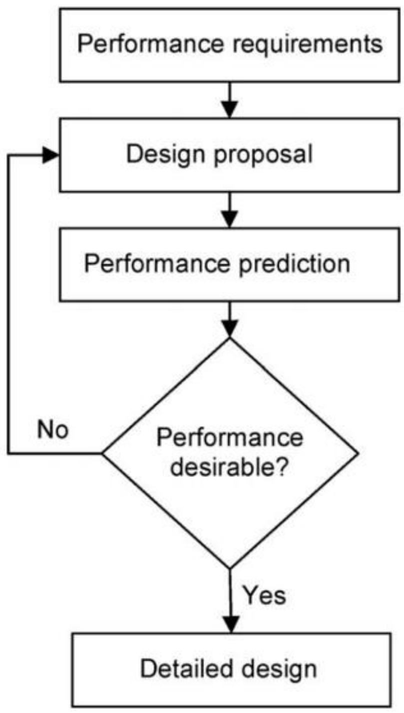


Figure 12 flow diagram illustrating the sub tasks in a 'performance-based design' process

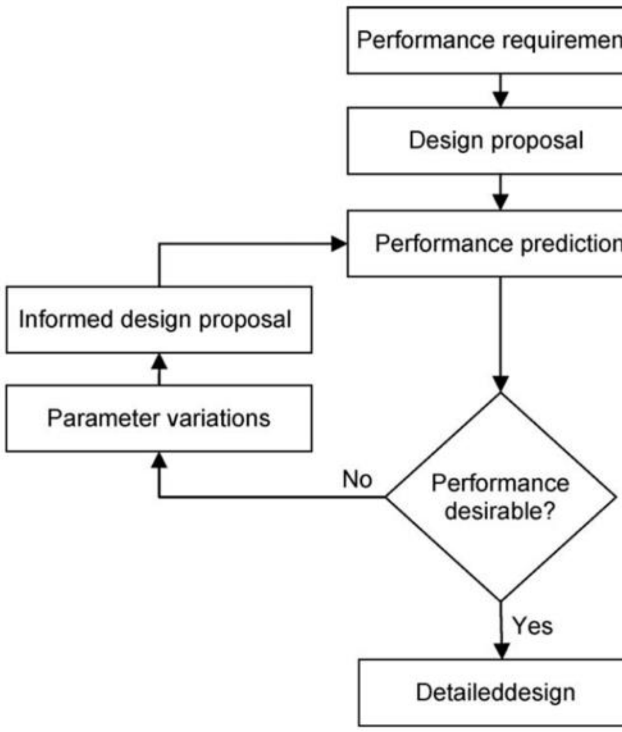


Figure 13 Flow diagram illustration the expansion of the traditional workflow as proposed by Petersen and Svendsen (2010), with the addition of the subtask - 'Parameter Variations'

Schlueter (2009) States that building simulation is mostly conducted after the design phase and thus does not inform the decision-making process. The study proposes a simplified prototypal tool that is fully integrated into the BIM software allowing building performance indices to be visualized - providing instantaneous energy calculations. Simulation results are typically based on energy balance equations allowing for thermal demands to be estimated. Figure 14 illustrates how thermal gains and losses occur around the building interface within the environment. Transmission losses through the building fabric and ventilation losses through the building envelope – equate to the zone balance energy losses. These can be compensated through interior gains caused by appliances, occupants and solar gains reducing the need for active heating. Internal heat gain sources are reviewed in greater depth in Appendix 1.6.

Additional energy input is required to provide building auxiliaries such as lighting and ventilation. The sum of interior gains and losses equates to the energy demand. The study compares the simulation results from the prototypal tool - to commercial grade software in which the results showed less than 5% variation – validating its use a pre-design tool. The study concludes that the incorporation of building performance analysis and BIM software - within the design workflow – will allow for an integrated view of buildings at the beginning of the design process.

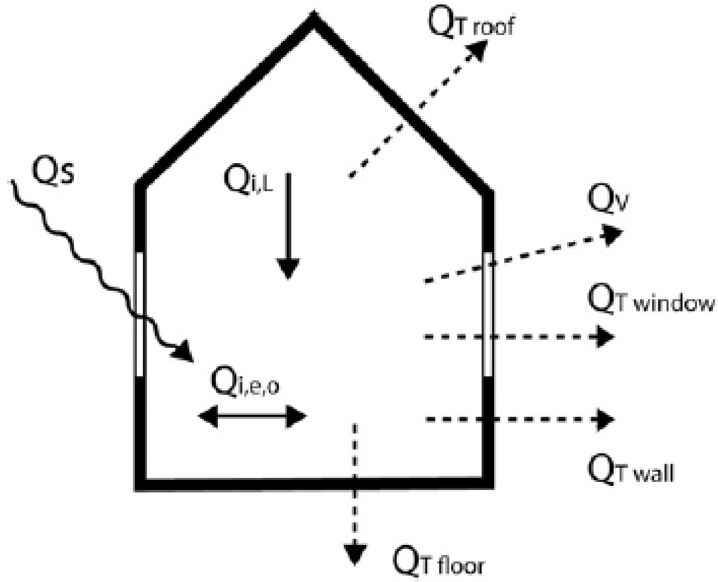


Figure 14 Schematic of energy model proposed by (Schlueter,A. 2009) illustrating the primary energy flows considered within thermal models including; Q_s – Solar heat gains through window, $Q_{i,L}$ – Internal heat gains from lighting, $Q_{i,e,o}$ – internal heat gains created by the occupants, Q_{Troof} – Transmission heat loss/gain through the roof, Q_v – ventilation heat losses/gains, $Q_{Twindow}$ – Transmission heat loss/gain through windows, Q_{wall} – Transmission heat loss through the wall, Q_{Tfloor} – Transmission heat loss/gain through the floor.

Negendahl (2015) conducted a study to identify the level of integration of building simulation software at the beginning of the design phase with the aims of a) identifying who operates building calculation models and b) identifying the best way of integrating geometric and building calculation models. The study identifies three types of integration (as illustrated by figure 15) including; user integration– which encompasses the integration of different professionals, Model integration – which concerns computation automations within design tools and Building Performance Simulations, Tool Integration – which includes the technical calculations and details of specific tool and interoperability. The study concludes that optimization of buildings through Building Simulations is easily calculable due to energy performance indices. Research identifies that regardless of the user integration, Building Performance Simulation is likely to improve the performance of buildings when integrated within the initial design stage however, a mixed skills team with expertise representing specific disciplines will achieve the best performance solutions.

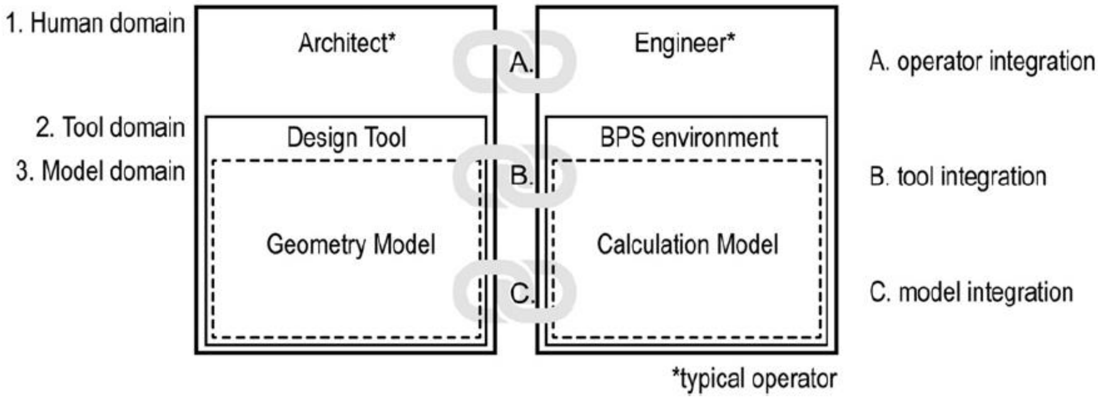


Figure 15 Three types of integration: 1) integration in the human domain, 2) integration in the tool domain, 3) integration in model domain. As proposed by Negendahl et al. (2015)

In further conclusions Negendahl et al (2015) identified that several developments had been in made in current integrated dynamic tools which aided information feedback and multidisciplinary collaboration however, such design tools lack standardized formats and interoperability methods.

Critical modelling case studies are reviewed in Appendix 1.2, the insights of these workflows will be used to inform the development of a parametric design methodology. They include: the REHVA definition and energy calculation methodology for NZEB implementation (Kurnitski, et al. 2011); a review of energy simulation programs; study to develop representative simulation building energy data sets as well as to benchmark models (Attia 2012a); and socio-technical experiment in which building designers were trained to use building thermal physics to inform design decision making (Souza. 2013).

Wang et al. (2009) presents possible solutions for zero energy building design in the UK. Through an implementation of the simulation software EnergyPlus and TRNSYS 16. Simulations conducted enable for facade design studies that consider building materials, window sizes and orientations. TRNSYS is used for the investigation of the feasibility of zero energy houses with renewable electricity, solar hot water system and energy efficient heating systems within the context of climatic conditions observed in Cardiff (north wales). Various design methods are compared and optimal design strategies for typical homes and energy systems are provided. The whole design process can be summarized into three steps:

- An analysis of local climate data is of primary importance in order to make use of the local climate condition for promoting zero energy homes.

- The application of PD methods and advanced facade designs to minimize the load requirement from heating and cooling through building energy simulations.
- Through the use of TRNSYS to investigate various energy efficient mechanical systems and renewable energy systems including photovoltaic, wind turbines and solar hot water system to enable system design optimizations.

The current thesis will address the first two steps in the above outlined process with a view to determining the potential of PD as a prelude to and foundation for the design of the accommodation areas of a cruise ship as a zero-energy boat.

2.4 Summary of the literature Review

This chapter provides a review of available literature pertaining to PD and its integration within architectural practices such as NZEBs. A limited number of articles were found to directly define the testing, analysis and implementation of PD within the context of marine structures, indicating a gap within the current literature. Despite this, PD strategies were referenced in several key articles including; the integration of high-performance glazing, improved insulation, shading and natural ventilation in effort to support low emission sustainable shipping to meet emerging legislation such as the EEDI and to avoid increasing fuel costs.

In summary, the literature reviewed identifies the significance of computer simulation in the exploration of design alternatives to inform the decision making at the beginning of the design process. Studies developed steady state empirical design tools to provide sufficient guidance on design alternatives at the beginning of the design process which is currently exercised by such standards as the PHPP (Feist et al. 2012) to derive specific energy performance targets. Petersen and Svendsen (2010) proposes an alternative to the conventional "performance based design" process in which the utilization of BIM software can facilitate in exploring 'parameter variations' in way of a Sensitivity Analysis - allowing for consequence-conscious design decisions in the initial design phase. Simulation information management software such as JEplus, as proposed by Zhang and Korolija (2010) coupled with BIM software, was identified as a parametric simulation tool that would support this methodology. This will be adopted within this research to identify the impacts of PD alternatives. A prerequisite step to this, was identified by Wang et al (2009) whereby a climatic analysis is critical to the promotion of ZEB in which a bioclimatic assessment of the environment would allow for first order estimations of the potential of PD as outlined within key studies Hassaan and Mahmoud. (2011), Bodach, Lang, Hamhaber (2014b) and Nguyen and Sigrid (2014b).

This research works within the 'Tool Domain' as defined by Negendahl (2015) as calculation models are already well defined within building simulation software. Sfakianakisa and Vassalos (2013) demonstrated the development of analysis tools using dynamic simulation software to model on board HVAC systems and recognized the current need to tailor models to factor the maritime environment. Limited literature was found relating to the 'human domain' within the context of the marine design process - although sociotechnical studies identified the significance of a multidisciplinary team in the overall development of energy efficient buildings.

3.0 METHODOLOGY; PARAMETRIC ANALYSIS OF PD STRATERGIES ON THERMAL LOADS

The following methodology outlines the procedure for the simulation and testing of specific passive strategies on perimeter zones of marine vessels, in multiple orientations and locations, using the thermal simulation engine – ‘EnergyPlus’ (DOE 2015a; Crawley 2000). A number of parameters are varied using parametric modelling simulation management software JEplus (Zhang and Korolija 2012; Zhang and Korolija 2010) - as illustrated in the parameters tree outlined in figure 22. In this part of the study primary dependent variables include the annualized sum of; sensible heating (kWh), sensible cooling (kWh), solar gains (kWh) and interior gains (kWh) such as equipment and lighting. The following outlines the methodology of the parametric study as per the flow diagrams provided in figure 16 and 17. The details of each step are considered in detail in the subsequent sections;

- **Selection of appropriate test climates:** Given that internal thermal loads are impacted by the exterior climatic environment, a primary step within the parametric study is to consider what weather conditions in which to simulate the selected passive strategies. This will be achieved by a) defining a popular area for cruise ships through an analysis of port frequency data b) by selecting a climatic region which indicates that it can support passive technology c) defining a series of test conditions which reflects and represents the defined region by comparison to conventional climate classification systems and finally d) an analysis of climatic indices to ensure that the full range of conditions within a climatic region are reflected within the selected test locations and weather data. The sourcing of appropriate simulation weather data is discussed in Appendix 3.1.
- **Development of prototype thermal models for the testing of passive strategies**; This Will be achieved via the 3D interface of the whole systems analysis software ‘Design builder’(Design Builder 2012). This program is integrated in to the main simulation engine - Energy Plus. Specifications of the thermal properties of the thermal mode will be acquired by addressing, key marine design guidelines, marine legislation and by conducting interviews with industry. Passive strategies are constructed and varied in accordance to the parameters tree presented in figure 22 using the parametric data management programme JE plus.
- **Extraction of climate and simulation data**; A comparative analysis between the simulation results and climate is a necessary step within the bioclimatic design process. To achieve this; data is extracted from the simulation results (which are produced in the format of a ‘CSV’ file) and the relative climate file (which is formatted as an ‘EPW’ file)

into a numerical database via Matlab (Mathworks. 2014). Statistical analysis and calculations are then conducted to analyse and arrange the data which is then output into a spreadsheet for the tabulation and illustration of results via Microsoft Excel (Microsoft 2010).

- **Simulation and climate analysis**: Analysis of the simulation results is conducted in excel spreadsheets and represented in tables, time series plots, bar charts, frequency charts, scatter plots colour coded density tables. The primary dependant variable analysed include the sensible heating (kWh), sensible cooling(kWh), latent conditioning (kWh), lighting loads (kWh), solar gains (kWh) and equipment loads (kWh). These key simulation outputs are analysed in relation to location (climate), orientation, shading depth, internal gains, glazing size and glazing type. Climate is analysed in conjunction within the above dependant variables through the use of the aforementioned data representation techniques as well as the psychrometric chart.

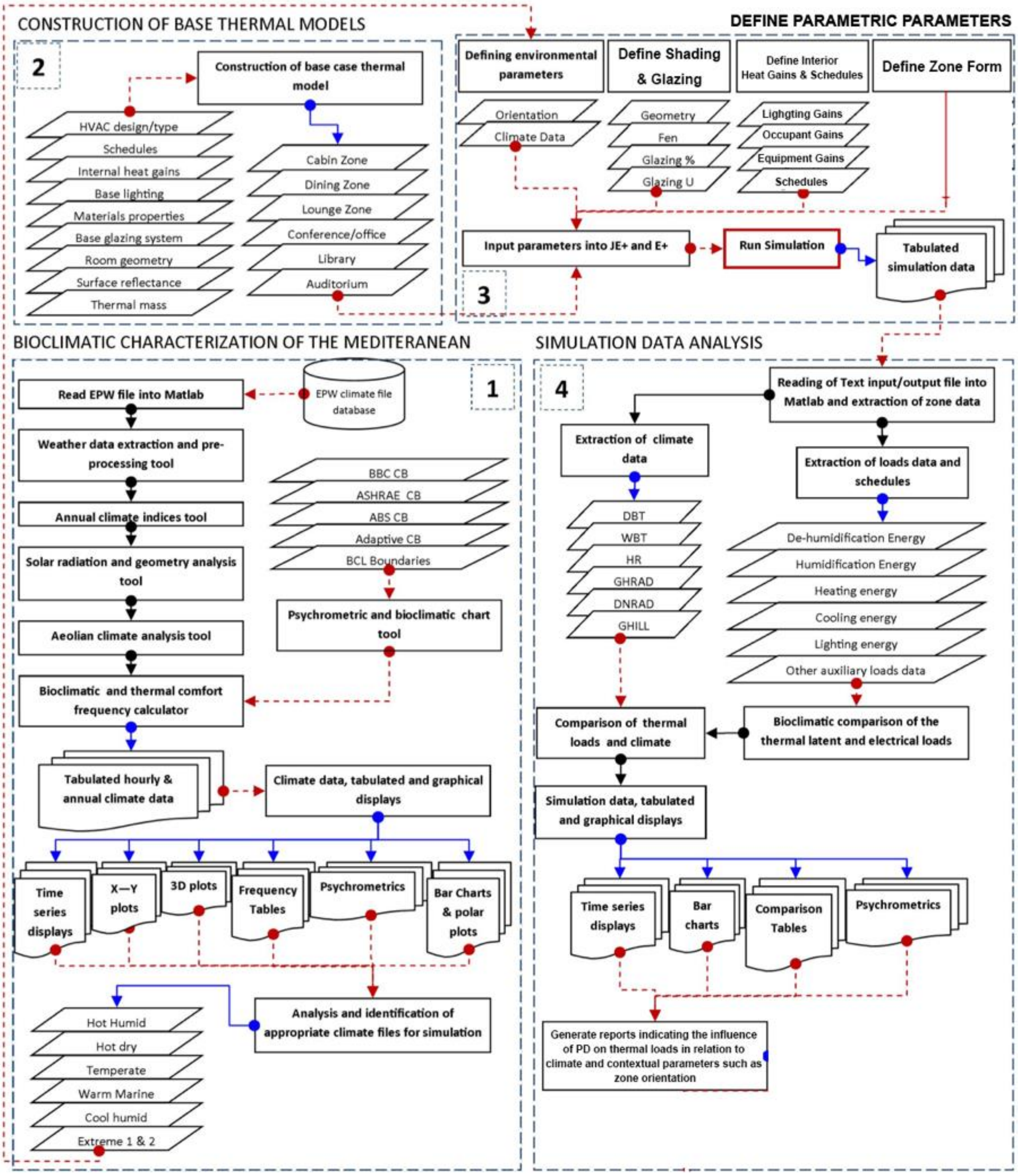


Figure 16 - A schematic flow diagram illustrating the procedures of the methodology developed for this research. The flow diagram has been inspired by the works of Visitsak, (2007:44) who conducted similar bioclimatic research for terrestrial structures

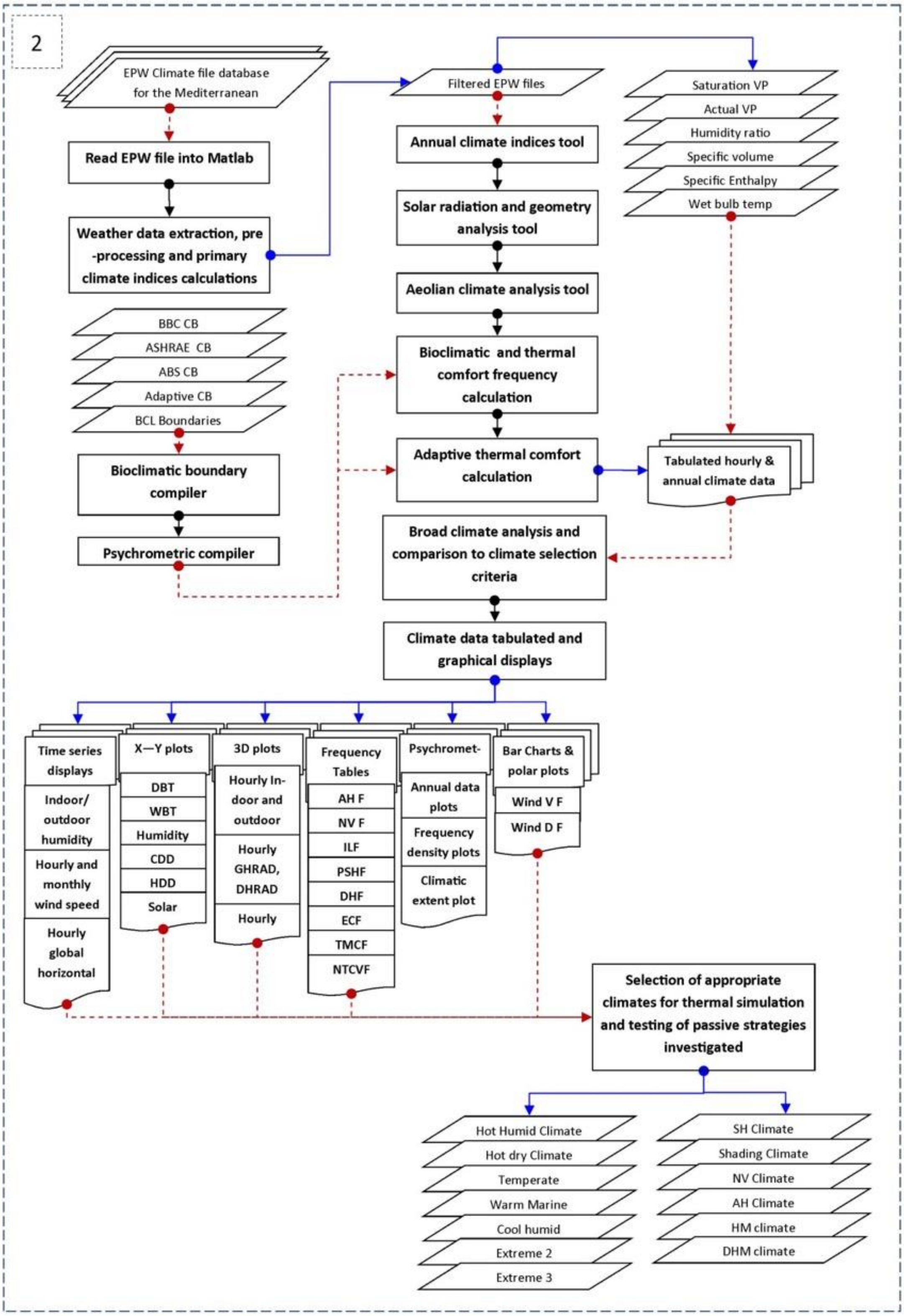


Figure 17 A schematic of the initial climatic and bioclimatic characterization of weather files to find appropriate test weather conditions for simulation and comparative analysis of passive strategies

3.1 Climate Selection Criteria based on Existing Climate Classification Systems

Now over 100 years old the Koppen climate classification systems is perhaps one of the most well-known and popular means of climate classification that was derived from earlier works of Grisebach published in 1866. It is based on the climatic variables of precipitation (in mm) and temperature (in °C) and is delineated by the distribution of flora (Harding 2006). Its five climates types (A-E) is graphically illustrated (in figure 18) in a geographical map which has recently been updated by the Department of Civil and Environmental Engineering at Melbourne University with climate records from the Global Historical Climatology Network (GHCN) version 2.0 dataset – containing 12,396 precipitation and 4,844 temperature stations (Peel 2007). The information was then interpolated using a two-dimensional thin plate spline (Peel. 2007).

A section of the updated Koppen-Geiger map is presented in figure 18. This shows the geographical distribution of climate types within the Mediterranean basin. This image is referenced after processing the climate data in accordance to the above selection criteria to prevent duplication of climate types within the data set and to ensure that all climate types are considered within the analysis of passive strategies. As per the works of Peel (2007) – the assorted colours are representative of different climatic features. In short, the blue colures represent tropical biomes, Red/pink/orange represent arid/dry biomes, Green represents mild temperate biomes, Violet/Blue represents continental biomes and Grey represents polar biomes (NOAA. 2008). The colours and labels within figure 18 are further defined within table 1.

According to figure 18, climates approaching the southern latitudes of the Mediterranean, exhibit dryer conditions such as “BWh” and “BSh”. The northern latitudes show cooler conditions and include classification types: “Cfb”, “Csb” and “Cfa”. The dominant climate type within the central latitudinal area appears to be the ‘Csa’ climate type.

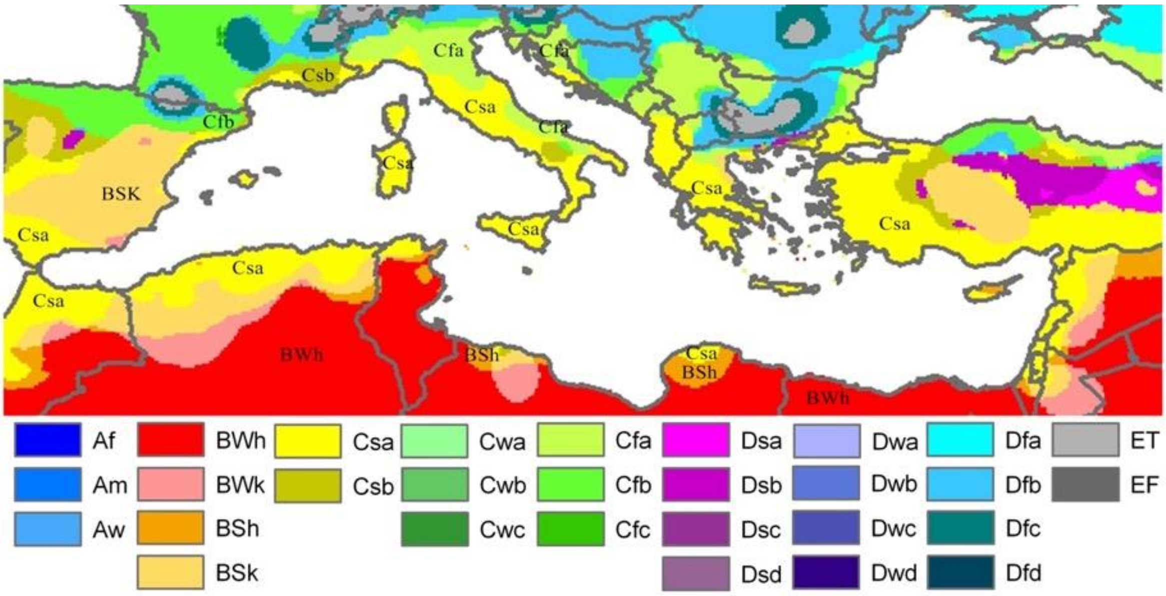


Figure 18 Koppen- Geiger Climate Classification system for Mediterranean test zone (Peel, M.C. 2007). Definitions for the different descriptors represented within this image are further defined within table 1 below.

The terms in table 1 are defined within the works of Peel (2007); "MAP = mean annual precipitation, MAT = mean annual temperature, Thot = temperature of the hottest month, Tcold = temperature of the coldest month, Tmon10 = number of months where the temperature is above 10, Pdry = precipitation of the driest month, Psdry = precipitation of the driest month in summer, Pwdry = precipitation of the driest month in winter, Pswet = precipitation of the wettest month in summer, Pwwet = precipitation of the wettest month in winter, Pthreshold = varies according to the following rules (if 70% of MAP occurs in winter then Pthreshold = 2 x MAT, if 70% of MAP occurs in summer then Pthreshold = 2 x MAT + 28, otherwise Pthreshold = 2 x MAT + 14). Summer (winter) is defined as the warmer (cooler) six-month period of ONDJFM and AMJJAS."

Table 1 Defines the descriptors represented within the Koppen-Geiger classification map illustrated in figure 18

1st	2nd	3rd	Description	Criteria*
A			Tropical	Tcold = 18
	f		Rainforest	Pdry = 60
	m		Monsoon	Not (Af) & Pdry = 100–MAP/25
	w		Savannah	Not (Af) & Pdry < 100–MAP/25
B			Arid	MAP < 10×Pthreshold
	W		Desert	MAP < 5×Pthreshold
	S		Steppe	MAP = 5×Pthreshold
		h	Hot	MAT = 18
		k	Cold	MAT < 18
C			Temperate	Thot = 10 & 0 < Tcold < 18
	s		Dry Summer	Psdry < 40 & Psdry < Pwwet/3
	w		Dry Winter	Pwdry < Pswet/10
	f		Without Dry season	Not (Cs) or (Cw)
		a	Hot Summer	Thot = 22
		b	Warm Summer	Not (a) & Tmon10 = 4
		c	Cold Summer	Not (a or b) & 1 = Tmon10 < 4
D			Cold	Thot = 10 & Tcold = 0
	s		Dry Summer	Psdry < 40 & Psdry < Pwwet/3
	w		Dry Winter	Pwdry < Pswet/10
	f		Without Dry season	Not (Ds) or (Dw)
		a	Hot Summer	Thot = 22
		b	Warm Summer	Not (a) & Tmon10 = 4
		c	Cold Summer	Not (a, b or d)
		d	Very Cold Winter	Not (a or b) & Tcold < –38
E			Polar	Thot < 10
	T		Tundra	Thot > 0
	F		Frost	Thot = 0

The second climatic classification system adopted within this study is the USA's - ASHARE Climatic Zoning System (developed by the American Society of Heating, Refrigerating, and Air-Conditioning Engineers.). This classification system attempts to define heating and cooling requirements based on the indices of heating degree days (HDD) and cooling degree days (CDD) (ASHRAE, 2007). This system has been adopted as it can be easily formulaically calculated based on hourly weather data and is a system which has been developed to represent a region with large variants in climatic conditions – namely north America.

Heating and cooling degree days as specified by the ASHRAE climate classification system - are used to determine the degree and frequency of outside dry bulb temperature above a specific base temperature to estimate active heating and cooling energy use (CIBSE 2006). To do this the following equations with a base temperature (T_{base}) of 10ºC and 18ºC are to be used within the consolidated weather database. The heating and cooling degree days are defined "as the sum of the differences between daily average temperatures and the base temperature" (ASHRAE 2013).

$$HDD = \sum_{i=1}^{N} \left(T_{base} - \overline{T}_i\right) \quad (5)$$

$$CDD = \sum_{i=1}^{N} \left(\overline{T}_i - T_{base}\right) \quad (6)$$

HDD and CDD specifications for climate types ranging from type 1 (representing hot climates) to 8 (representing cold climates) are defined within the ANSI/ASHRAE/IESNA Standard 90.1-2007 Normative Appendix B – Building Envelope Climate Criteria (Tables B-2, B-3, and B-4).

Additional climate selection criteria are also to be considered which address the contextual and operational parameters of a cruise ship within the Mediterranean which are detailed in appendix 3.2 and 3.3. Additional geographical considerations are also to be addressed such as height above sea level and proximity to the coast which is further defined within appendix 3.2. Weather files from weather stations that do not conform to these additional parameters are to be rejected from the study.

3.2 Construction of Thermal Models

A review of mid-sized cruise vessels provided by industry for research purposes, informed the geometrical parameters of perimeters zones which were considered for the application of passive strategies. Perimeter zones – or zones with glazing apertures were the only types considered within this study as interior zones are not directly influenced by solar gains or heat transfer induced by exterior conditions. Cabin zones on cruise ships were principally investigated within this study, due their dominance of the exterior façade of cruise ship superstructures and for their morphology which typically exhibited high glazing ratios.

DesignBuilder (DBS 2011) is a state-of-the-art graphical user interface to EnergyPlus (the thermal and lighting simulation), that allows the development of meaningful energy models, for initial exploration (Wasilowski,H. 2009). It will be used therefore as the primary means of data input and construction of the thermal models presented within this study.

Relevant literature and resources have been referred to within this study to create various aspects of the thermal model. Occupancy profiles for instance have been constructed based on information collated from the reference building stock provided by the U.S Department of Energy (Deru 2011). Profiles for occupancy, lighting and equipment loads were adopted from Hotel en-Suite rooms from this database – in order to reflect the likely use of cabins on board a cruise vessel. Currently there are no other data sources which indicates typical occupancy behaviour on board cruise vessels. Occupancy however, is particularly relevant to this study - given that plug loads are so closely related to it (Wasilowski 2009).

Thermal comfort, internal heat gains and lighting requirements for zone specific tasks have been referenced the ABS passenger comfort guide (ABS 2014). A method of adopting worse case scenarios as suggested by relative HVAC sizing standards such as the ISO 7547 (ISO. 2002) has also heavily influenced simulation parameters including thermal properties of external walls, ceilings, floors, windows and internal loads, (McCartan and Kvilums, 2014a). The following text provides an in-depth discussion on the particulars of the selection of interior zones as well as the process to construct and represent them in thermal simulation models.

3.2.1 Selection Criteria of Test Zones

A study of the GA revealed that there are many zones which could be impacted by passive strategies however, considering the limitations of the simulation model in respect to the number of variables which could be analysed and the limited amount of accessible primary data input - the following considerations were applied to the selection of a test zones which would then be used for the parametric simulation of passive strategies;

- The zones must be on or above the weather deck to avoid contrary application and implementation based issues, such as sea keeping which are beyond the scope of this research; and to focus attention on areas that are otherwise more heavily influenced by the decisions of designers and stylist's.
- Zones are not to be located near to high heat gains areas or by zones where the potential thermal tranmission losses are high or unpredicable. This might include but is not exclusive to regions such as those close to or below the water line, zones located to high heat gain areas such as engine rooms, exhaust shafts and other service based rooms for air handling units or electrical service rooms. This is based on a lack of data pertaining to the scheduling of internal thermal loads and the thermal exchanges between theses zones and others.
- The zone must have solar access or be influenced by appertures which permit the external environmental influence interior thermal loads

Within this study, the modelling set up does not consider the inter-thermal behavior of the zone to other internal zones and assigns an adiabatic relationship between all of its interior surfaces – thermally isolating the zone so that only the exterior wall and glazing element can impact the interior thermal loads. Following the above criteria and an analysis of the GA of a mid sized cruise vessel (MS Norwegian Gem – Norwegian Cruise line) – the passenger outboard cabins were considered for further parametric analysis.

3.2.2 Test Zone Parameters

All material data, HVAC and lighting specifications were compiled into one IDF file and input in accordance to the building model checklist presented in the article - "Computerized Building Energy Simulation" by James P. Waltz (2010).
The construction of internal and external elements has been based on the advised calculation methods presented within the ISO 7547 (ISO. 2002) and the works presented within Byun L.S 2010. The thermal characteristics of each of the envelope elements are tabulated in appendix 3.4 below and remain constant throughout all of the parametric studies.

Other additional parameters that are considered constant throughout each of the test zones include;

- The outdoor supply airflow should not be less than 0,008 m3/s (8 l/s) per person (ISO. (2002))
- The air temperature supplied to the room shall be no more than 10ºC lower than the average temperature (cooling mode) (ISO. (2002))
- The air temperature supplied to the room shall not be more than 23ºC higher than the average temperature of the space (Heating mode) (ISO. (2002))
- The air temperature provided should be between 18 ºC to 26.5ºC (ABS 2014)
- The relative humidity range should be between 30% to 70% (ABS 2014)
- Air velocity should shall not exceed 0.5m/s (ABS 2014)
- Infiltration of external air will be except from thermal balance calculations as the exterior façade is assumed air tight
- Thermal and optical properties of exterior wall elements are adopted in accordance to the ISO 7547 (ISO. 2002). Properties and construction of the external wall elements are presented in appendix 3.4
- Thermal and optical properties of glazing systems adopted are in accordance to the ISO 7547 (ISO. 2002) and a literature review of materials from glazing manufacturers. Properties and construction of external glazing systems are presented in appendix 3.5

3.2.3 Geometry & Layout of the Cabin Zone

In this study, the standard cabins are considered as long narrow zones (2.9m (L) x 6.3m (W)) - which comprises of an exterior window leading to a balcony with a maximum depth of 1.5m. The interior Walls have a U value of 0.6 (W/m². K) and an internal height of 2.2m. The exterior wall also has a U value of 0.6 (W/m². K) and a single window placed at 2.1m above the interior floor and has a constant width of 1.2 m spanning the exterior envelope of the cabin as illustrated in figure 19. Within the parametric study the glazing ratio is altered from 20% to 80% at intervals of 10% (which excludes the window frame). Each successive increase in glazing percentage – is acquired through a vertical extension of the bottom ledge from the top of the window sill.

Shading devices such as the overhang and side fins are altered simultaneously from 0m to 2.5m at increments of 0.5m. Side fins are modelled on the exterior of the cabin zones as they are typical appendages to the cabin morphology – and are considered necessary to ensure occupant privacy. Figure 19 shows the plan view of the zone and the interior arrangement of interior walls. Details of glazing and wall areas at different glazing percentages are presented in appendices 3.11 and 3.12.

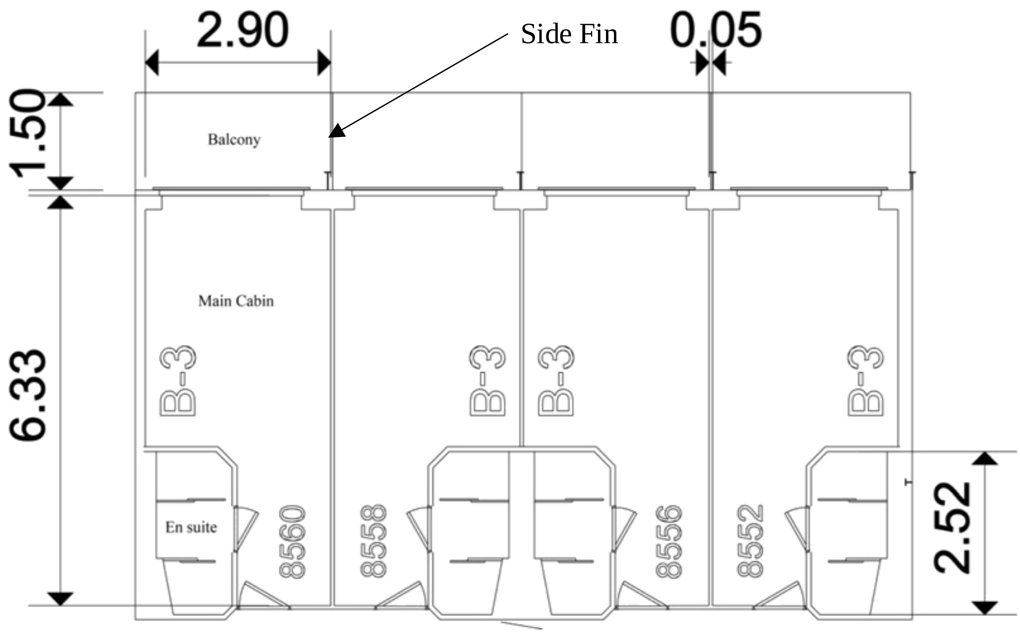


Figure 19 Schematic of Cabin Zone Geometry – as taken from a relative cruise vessel case study

3.2.4 Operational Schedules of the Cabin Zone

The occupancy schedule from which thermal loads requirements are calculated have been constructed based on source data supplied by the Technical Report, produced by NREL – "U.S. Department of Energy Commercial Reference Building Models of the National Building Stock" (Deru et al. 2011) and the ASHRAE 90.1 simulation group. From the information provided the occupancy schedules of hotel guest rooms from the work of Jiang et al. (2008) were chosen as representative of the occupancy schedules of cabins on board. The schedules were adopted as no other more accurate sources were identified. The occupancy schedule - as illustrated in figure 20 assumes 2.0 occupants - where for most of the day (daylight hours) the room is vacant. The study assumes the same schedule is adhered to all year round with no weekend or holiday schedule variance.

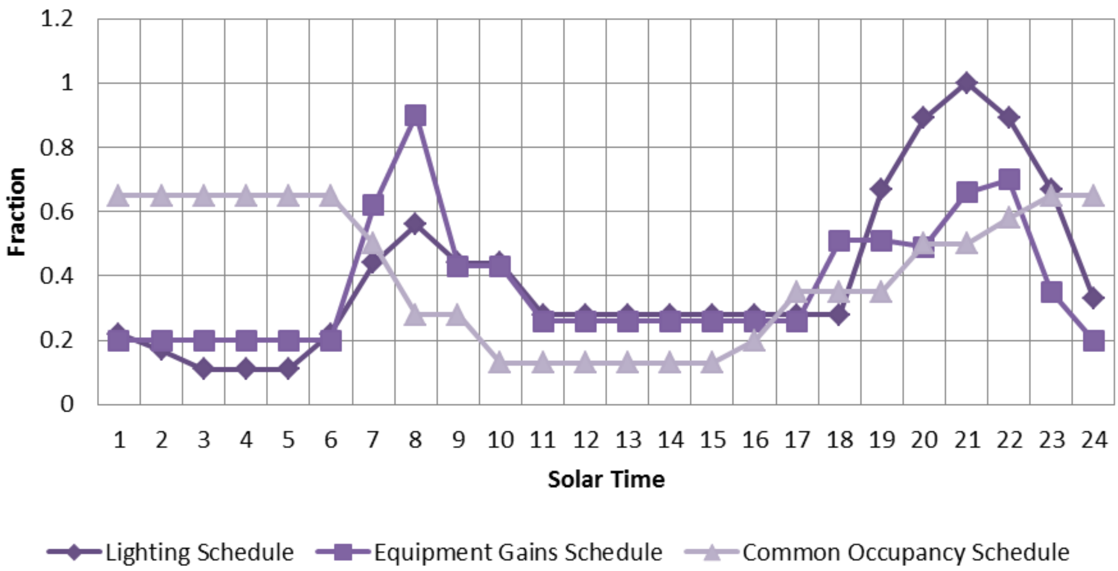


Figure 20 Primary schedules used within the cabin zone to define and model thermal and lighting requirement

Lighting and equipment gains schedules were also defined by the reference building stock buildings (Deru et al. 2011). For the cabin zones lighting and equipment schedules were taken from the hotel guest room - weekday profiles. Figure 21 provides an hourly time series graph of the summation of the internal gains.

Information collated from the above sources have allowed for the tabulation of internal gains data - presented in table 2. Using the schedules considered above a loads profile over one day defines anticipated load fluctuation – identifying that peak internal thermal loads occur in the morning between 6am and 9am and in the late afternoon between 7pm – 11pm.

Table 2 Geometric, Ventilation and internal gains properties of hotel guest rooms from DOE representative building stock – Large Hotel (Deru et al. 2011)

REFERENCE BUILDING INTERNAL LOADS (HOTEL GUEST ROOM)										
Area m^2	Vol. m^3	m^2/ person	1989 Lights Wm^2	2004 Lights Wm^2	Elec. Proc. W/m^2	Gas Proc. W/m^2	Vent. L/s	Exhst L/s	Infil. ACH	SWH L/h
39	119	26.01	19.09	11.84	6.8	0	14.2	0	0.37	4.7

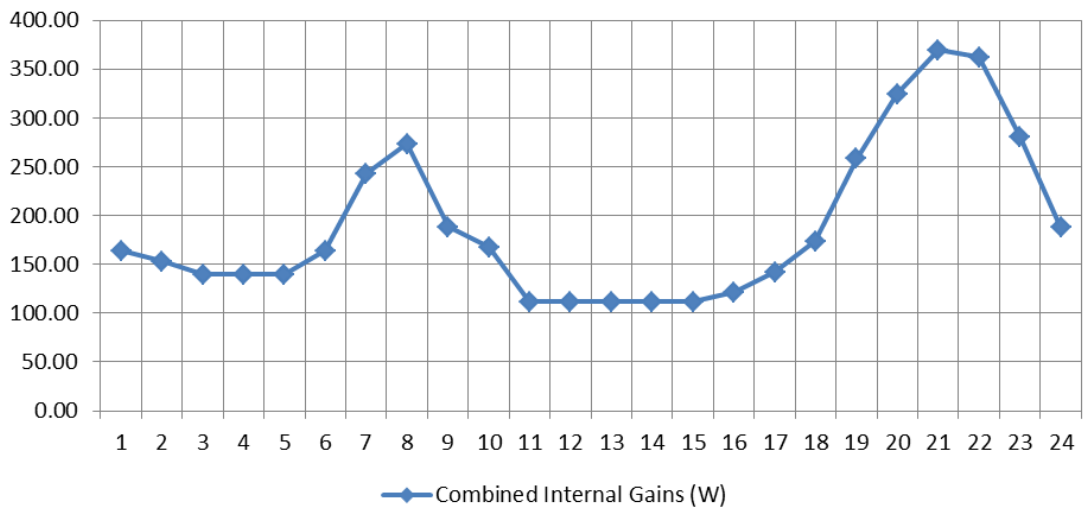


Figure 21 Hourly summation of internal loads (W) for cruise cabins using profile data from Hotel guest room representative models and gains data from Deru et al. (2011) (Table 2).

Considering the calculation methods presented in the ISO 7547 (ISO. 2002) the internal winter loads (without solar gain) are calculated as being ~0.41 kW. Where fluorescent lighting is considered at $8W/m^2$, equipment loads equate to 6.8 W/m^2 and the sensible contribution due to 2 occupants combined is 140 W. In the summer months the occupant, equipment and lighting loads are considered as constant but solar gains increase resulting in peak internal loads of ~ 1.08 kW. This assumes the zone has a 30% glazing ratio with solar gains equating to 350 W/m2, in accordance to a clear glass window with no internal or exterior shading.

The specific schedule profiles and gains data for each of the schedules used within this study are presented in appendix 3.11.

3.3 Parametric Simulation of Passive Strategies

A parametric methodology was adopted for this research as it would allow for multiple variations in passive strategies and allow for the level of holistic resolve required to capture the integrated effects of form, fabric, and fenestration on thermal loads. This parametric methodology also allows for the rapid exploration of design alternatives and to establish dependencies between variables. The use of an open source parametric tool 'jEPlus' was employed to enact this approach in which the specific variables explored are illustrated in the parameters tree in figure 22. 'JEplus' provides a convenient way of interfacing EnergyPlus and provides a means of executing thousands of independent simulations, reducing simulation time and (Zhang and Korolija 2010) presenting an efficient analysis tool for the architectural industry (Zhang and Korolija 2012).

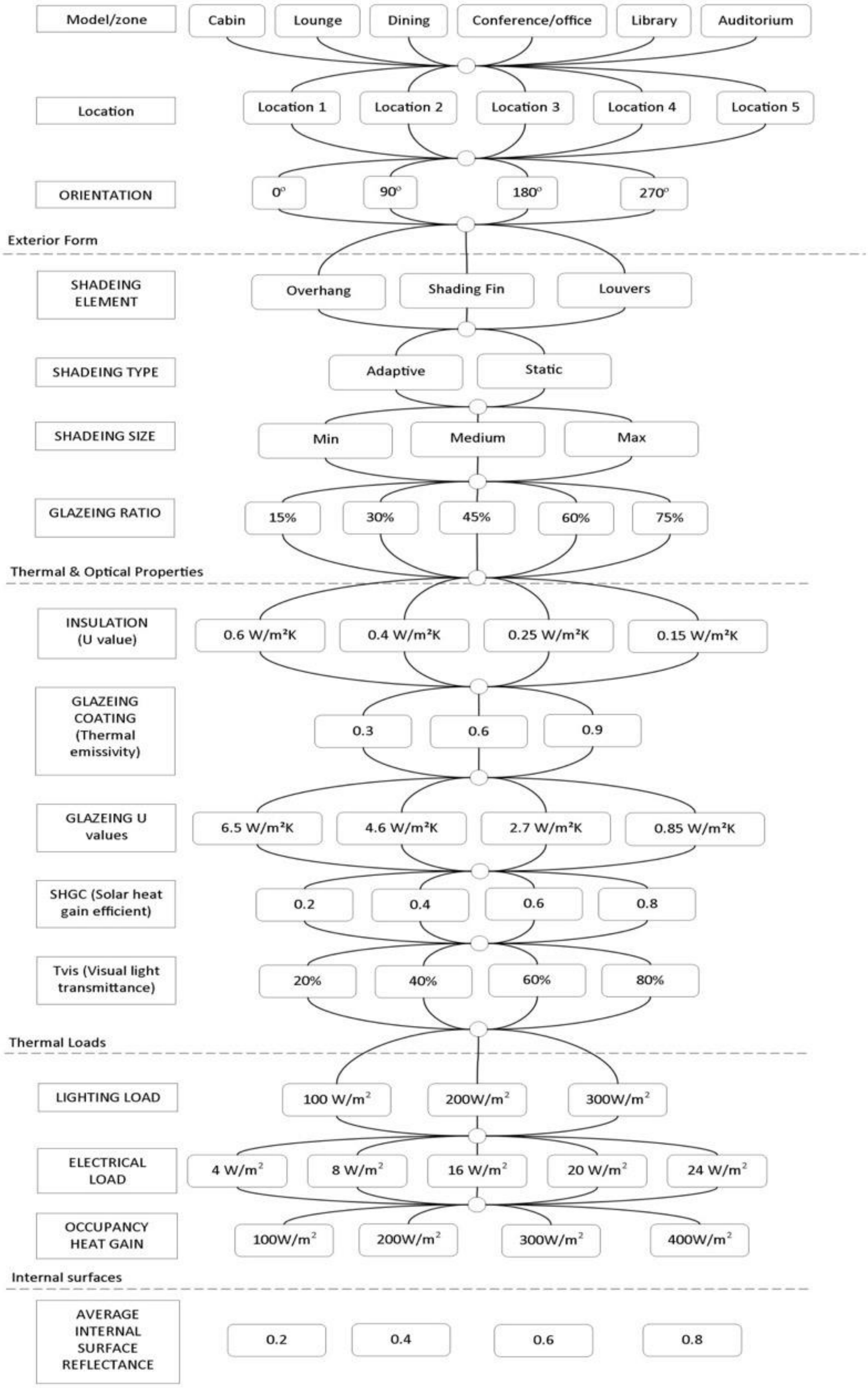


Figure 22 A Parameters tree adapted from Zhang and Korolija (2010) illustrating the variables considered within the parametric simulation executed within this thesis along with

indicative values. Actual values of the parametric study are defined within section 3.2. Wall insulation and occupancy heat gains remain constant throughout all simulation conducted. Shading systems considered within the parametric study include Overhangs (formed by balcony's) and Side Fins. Shading systems such as louvers are beyond the scope of this study although they are addressed by the author in other works as defined within appendix 7.2

3.4 A Parametric Approach

The ‘EnergyPlus’ whole systems dynamic simulation software was used in this study to carry out the thermal modelling of different models exhibiting different passive strategies. To handle the number of ‘EnergyPlus’ jobs the parametric managing software ‘JEplus’, was employed to handle the input and output files of different thermal models, as illustrated in figure 23. The construction of each thermal model and the input parameters covering the breadth of the parameters tree in figure 22 will be defined in the following subsequent sections. This strategy was chosen over other methods in that it aids in the analysis of substantial amounts of data and that it allows for the simulation of varying parameters; locations and orientations. In addition, it allows for simultaneous attributes of natural lighting to be accounted which relates to internal heat gains as illustrated in figure 22.

A more in-depth review of the selected simulation engine is covered in appendices 3.6 and 3.7. The data is extracted via JEplus and controlled via matlab as defined within appendix 3.8. Data is arranged in accordance to the ‘Job index’ file output which is generated by the simulation. Matlab adopts the unique identifier within this file to extract simulations with the specific parameters relating to parameters tree. This is addressed in appendix 3.9.

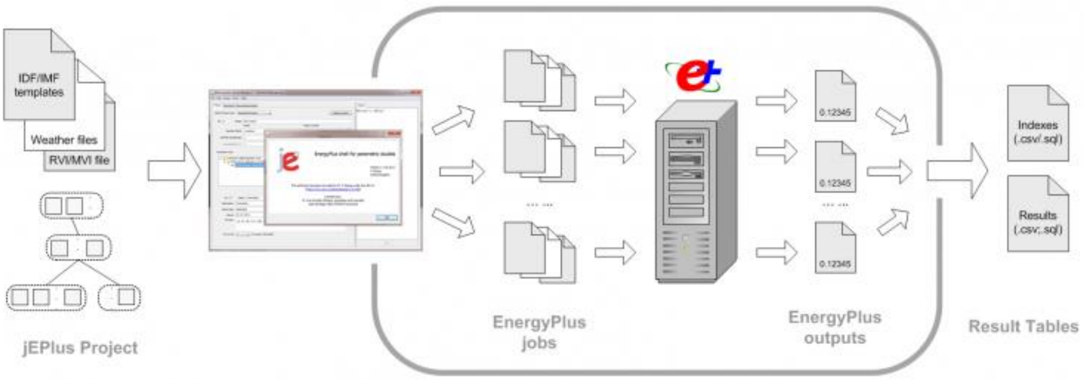


Figure 23 Schematic illustrating information flow between the thermal simulation engine and the parametric managing software JEplus (Zhang and Korolija 2010)

3.5 Handling Simulation Data and Post Processing

Raw data produced by the Energy Plus was in the format of a tabulated CSV file. Annual hourly, monthly sum and annual sums of data were produced in this process for the following variables of each simulation recorded. This includes variables such as; Internal Latent Gains (J), Gains from Occupants (W), Total transmitted Solar Radiation (W), Transmitted solar radiation rate (W), Window heat gain rate (W), Window heat loss rate (W), Conduction heat transfer rate – for partition walls, exterior walls, floors and ceilings (W), Zone mean radiant air temperature (ºC), Zone mean air temperature (ºC), Zone operative temperature (ºC), Zone air system sensible heating rate (W), Zone air system sensible cooling rate (W), Humidity (%), Zone mechanical ventilation air change per hour (ACH), Mean monthly PMV, Mean Monthly PPD, ASHRAE 55 simple model summer clothes not comfortable time (Hours), ASHRAE 55 simple model winter clothes not comfortable time (Hours), Zone Ideal Loads Supply air total heating rate (W), Zone Ideal Loads Supply air total cooling rate (W), Zone mean humidity ratio (kg Water/kg Dry Air), Electricity Facility (J), Interior Equipment Electricity (J), Interior lights Electricity (J), District heating (J) and District Cooling (J).

Each of these variables were converted to kWh using the equations below and tabulated using Matlab (Mathworks. 2014) and Microsoft Excel (Microsoft Corporation 2010).

$$kw = \frac{E(J)}{1000\ \times t(s)} \quad (7)$$

$$E_{(kWh)} = P_{(kW)} \times t_{(hrs)} \quad (8)$$

The above variables were used to determine the relationship between passive architecture and climate for cabin zones on board cruise ships. The analysis has adopted a range of graphical displays including; time series scatter plots, bar charts, and colour coded psychrometric density plots following the methodology outlined by the PhD thesis of Visitsak (2007) – who conducted a similar study on terrestrial structures. Simulation output data is compared to the empirical calculation methods presented in ISO 7547 (ISO. 2002), CIBSE (2003), Kreider, Curtiss and Rabl (2010), ASHRAE (2013) and Santamouris (1996) and Is considered in more detail in appendix 3.11.

Weather data is extracted and handled separately and is addressed in appendix 3.10.

3.6 Summary of Methodology for Parametric Analysis

A parametric study is to be conducted on a prototype thermal model of a representative cabin zone in defining the consequence of passive strategies on common perimeter zones on cruise ships in an effort to fulfil objectives presented in section 1.4. This type of zone was selected for parametric analysis due to its dominance of the external façade occupying a large percentage of the glazed exterior (above the weather deck) on most common cruise ships.

The thermal models presented in this chapter have been constructed using whole systems architectural modelling software - Design Builder (Version 4.6) and then simulated using the thermal simulation engine – EnergyPlus (Version 8-5-0). JEplus (version 1.6.3) linked to EnergyPlus, managed the parametric simulation process and varied thermal parameters within the thermal model via implemented macros embedded within the IDF model file. Considering all variants as illustrated in figure 22 – the parametric simulation resulted in over 10,000 separate simulations which were managed by the above programs and post processed using Matlab and Excel.

This selected zone type represents some of the smallest zone types on board and has a very high glazing to floor area ratio of 0.28 (when the façade exhibits an 80% glazed facade). This ratio makes it highly influenced by internal heat sources and in particular solar gains which attribute significantly to its thermal performance. The lighting load for this zone was set at 8W/m^2, with other miscellaneous equipment equating to 6.8 W/m^2. The zone was intended for a maximum of two occupants which have an assumed sedentary metabolic level– equating to a sensible load 70W (140 W for two people). With an internal floor area of 21 m^2 – and with solar gains at 250 W/m^2 the maximum instantaneous internal cooling load equates to 2004.47 W or 95.45 W/m^2. Explicit information regarding the thermal model and control schedules can be found in appendix 3.11.

Set point temperatures for this zone were set at between a minimum of 21ºC to a maximum of 24ºC. This was based on information provided by the American Reference Building Stock for Hotel en-suite bedrooms (Deru et al. 2011). This reference case was adopted as it was considered as being similar in use and function as accommodation spaces on board cruise ships. Thus, occupancy schedules, lighting schedules and equipment schedules have also been adopted accordingly.

It is important to note that unlike other thermal models presented in this study both an overhang, balcony and side fins were incorporated as shading devices within this thermal model. These appendages were simultaneously increased in depth along with the depth of the main exterior overhang. This was to reflect the conventional morphology of an exterior balcony.

Appendices 3.8,3.9 and 3.10 address the data extraction method used to process simulation data which is otherwise tabulated and handled by Matlab. Figure 22 illustrates the various elements of the prototype thermal model which were varied in the systematic parametric thermal simulation. Elements which were varied included; shading depth, glazing percentage, intensity of internal gains, glazing type, orientation and location.

4.0 RESULTS AND ANALYSIS

In this chapter data is analyzed and presented from the parametric simulations to define the potential of PD for ships operating within the Mediterranean climate as defined within the aims and the objectives of this research. To define this potential – hypothetical thermal models have been produced (as presented in section 3.2) where the application of passive strategies has been tested via a parametric methodology. The results and analysis of the resulting data in this section are presented in two main parts.

The first part (presented in section 4.1); Is an analysis of the weather database illustrated in figure 1A and 1B in appendix 3.1, in which weather data is systematically analyzed using well established climate classification systems to accurately define the coastal environment in which cruise vessels reside. The analysis thus derives a range of critical weather conditions to conduct test simulations of the hypothetical models defined in section 3.2. This process has been introduced to reduce the test climates to economize on computer simulation time and to focus the study on contrasting climate types – reducing over a thousand weather files to 11. This process derived suitable test climates that reflect the broad range of conditions within the Mediterranean coast line whilst also minimizing the duplication analysis.

The second part (presented in section 4.2); Is a parametric simulation study of cabin zones using the software – EnergyPlus (DOE 2015a) and JEplus (Zhang and Korolija 2014), which allows for multiple variations in exterior form, location and orientation. The analysis thus, presents the impact on interior gains and thermal loads through the implementation and variation of passive strategies.

Finally, a summary is presented on the impact of the passive strategies explored identifying how a psychrometric bioclimatic assessment method could be used to further define the performance of passive strategies in relation to the different test climates types explored within this study.

4.1 Formulating Test Weather Conditions

In this study, the test climates are to be selected from the Mediterranean basin - the test base area for this research. The selected test weather files will formulate the primary test conditions for the parametric thermal simulation study presented in section 4.2.

4.1.1 Analysis of Critical Climatic Indices

Applying the geographical selection criteria presented in appendix 3.2 – the original weather database can be reduced from over 80 different locations (illustrated in figures 4A and 4B in appendix 3.1) to 55 weather files. The following is an analysis of those weather files in accordance to the climatic indices raised in Chapter 3 and addressed in appendix 3.3 which have been referred to as additional selection criteria. Key climatic variables considered in this instance include; the dry bulb temperature, solar radiation and relative humidity. Appendix 4.1 to 4.3 statistically describe the climatic trends apparent within this filtered dataset, to get an understanding of the range and breadth of climatic conditions within the coastal regions of the Mediterranean.

4.1.2 Selecting Test Locations for Parametric Analysis

Considering the geographical, contextual and climatic selection criteria defined in the Methodology – the following analyses a number of indices to ensure that all weather types are included within the parametric analysis as defined by recognized and established climate classification systems. To achieve this – the climate analysis presented in section 4.1.1, the ASHRAE HDD (heating degree days) and CDD (cooling degree days) calculation methodology, and the Koppen Classification system (as represented by figure 18) were used to compile a specific set of test locations.

To calculate HDD and CDD equations 5 and 6 were developed using Matlab to determine the thermal bias of each weather file and to determine the type of climate as per the "Climate Classification for Building Energy Codes and Standards" (Briggs et al., 2003) and the ANSI/ASHRAE/IESNA Standard 90.1-2007.

Overall the climatic indices denoted in section 4.1.1 were held as the senior selection criteria as an empirical relationship could easily be established between outdoor temperatures and solar radiation. Second to this was Koppen and ASHRAE climate classifications which has ensured that the selected climates capture the range of climate types within the Mediterranean. Table 11 and 12 in appendix 4.6, shows that this process has captured a wide range of climate types. Additional contextual criteria are also considered and presented in appendix 4.5.

4.1.3 The Selected Weather Files

As a result of the analysis process, 11 test locations were considered and are formally presented in appendix 4.6.

4.1.4 Bioclimatic Analysis of Test Locations

A detailed climatic and bioclimatic analysis is presented in Appendices 4.7, for each selected test climate. This following provides a summary of the characteristics and how the selected climates are spread across the psychrometric bioclimatic chart as proposed by Milne and Givoni (1979). This has been used as an indication to the type of passive strategies that would be effective in such climates and to define the range of passive strategies that might be plausible given the climatic characteristics of the selected test locations. To aid visual clarity the extent of annual hourly climatic conditions has been represented by a bounding dotted line on the bioclimatic psychrometric chart. Figures 24, 25, 26 and 27 show primary climate types expressed by the climatic classification system and annual mean temperatures. This includes a) Mixed humid relatively cool climates b) Mixed humid climates relatively warm c) Warm humid and warm dry climates and d) Hot dry climates. The psychrometric charts have been constructed through the use of Matlab adopting the methodology as proposed by Ngai (2015). The psychrometric chart in this configuration allows for an assessment of exterior climate in relation to the established thermal comfort parameters displayed - which are defined by the ANSI/ASHRAE Standard 55 (2010) for winter and summer CLO levels.

4.1.4.1 Mixed Humid (4a) cool climates

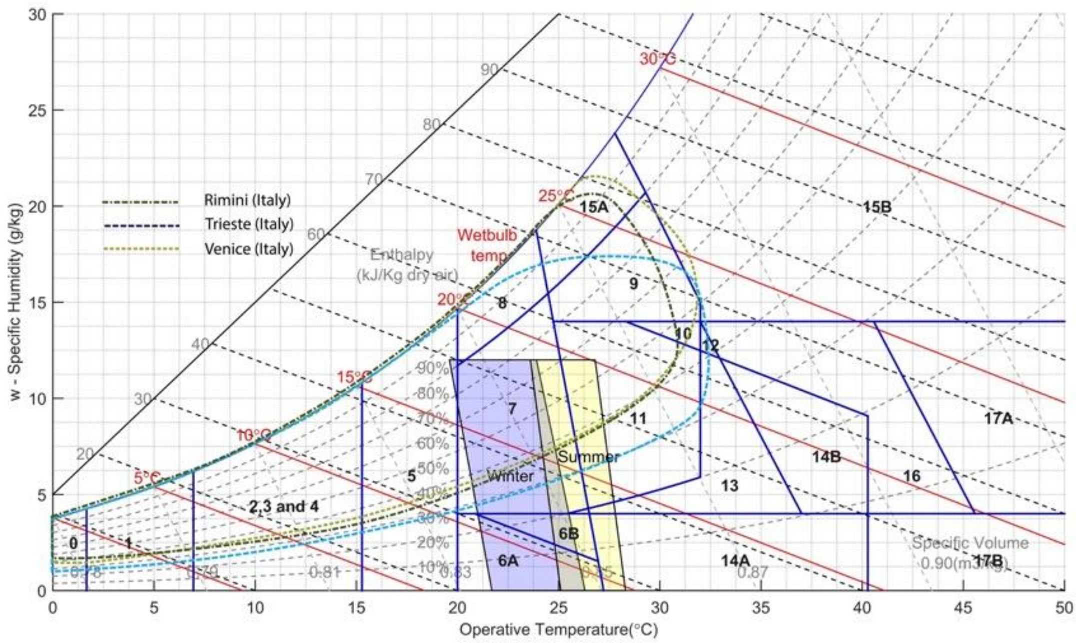


Figure 24 Psychrometric chart indicating the boundary range of the annual hourly weather data for Rimini (Italy) Trieste (Italy) and Venice (Italy) with bioclimatic boundaries as defined within Watson and Labs (1983).

4.1.4.2 Climate Type 4A & 4B (Mixed Humid and Mixed Dry Climate)

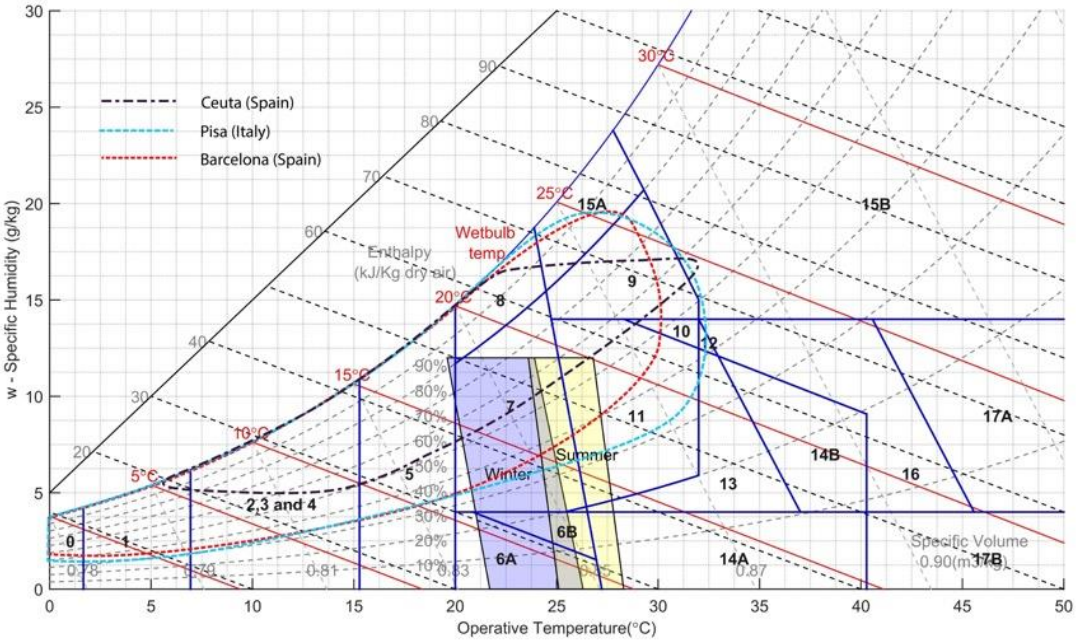


Figure 25 Psychrometric chart indicating the boundary range of the annual hourly weather data for Ceuta (Spain) Pisa (Italy) and Barcelona (Spain) with bioclimatic boundaries as defined within Watson and Labs (1983).

4.1.4.3 Climate Type 3C (Warm Marine)

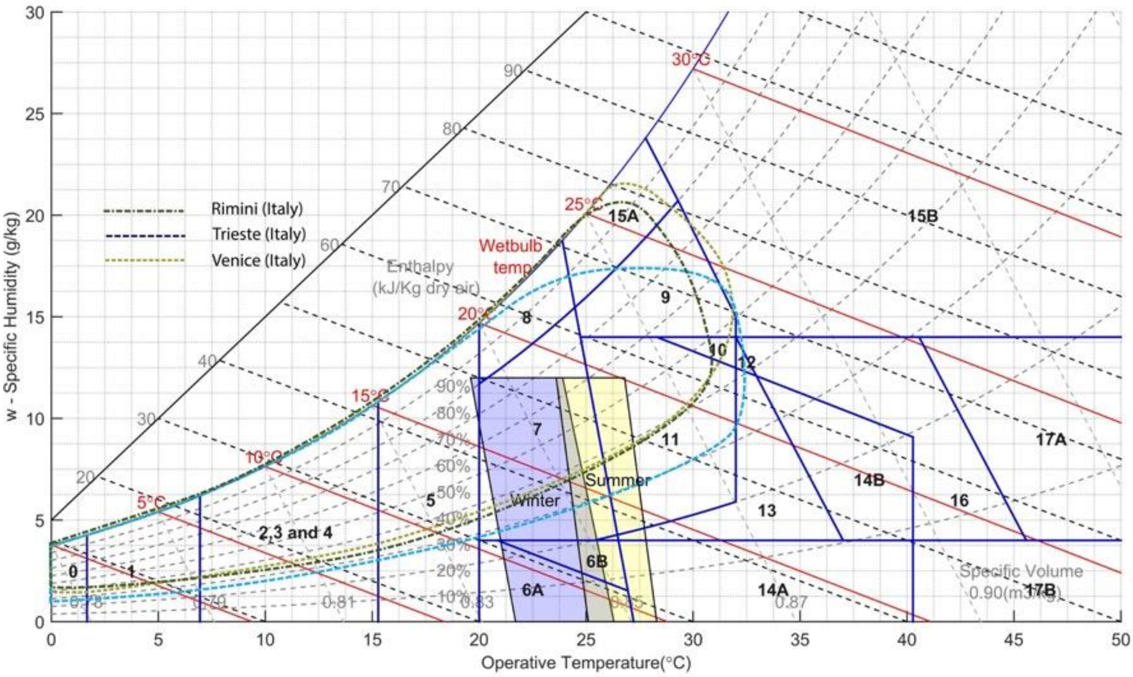


Figure 26 Psychrometric chart indicating the boundary range of the annual hourly weather data for Telavi (Israel) Athens (Greece) and Alicante (Spain) with bioclimatic boundaries as defined within Watson and Labs (1983).

4.1.4.4 Climate Type 3A & 3B (Warm Humid and Warm Dry Climate)

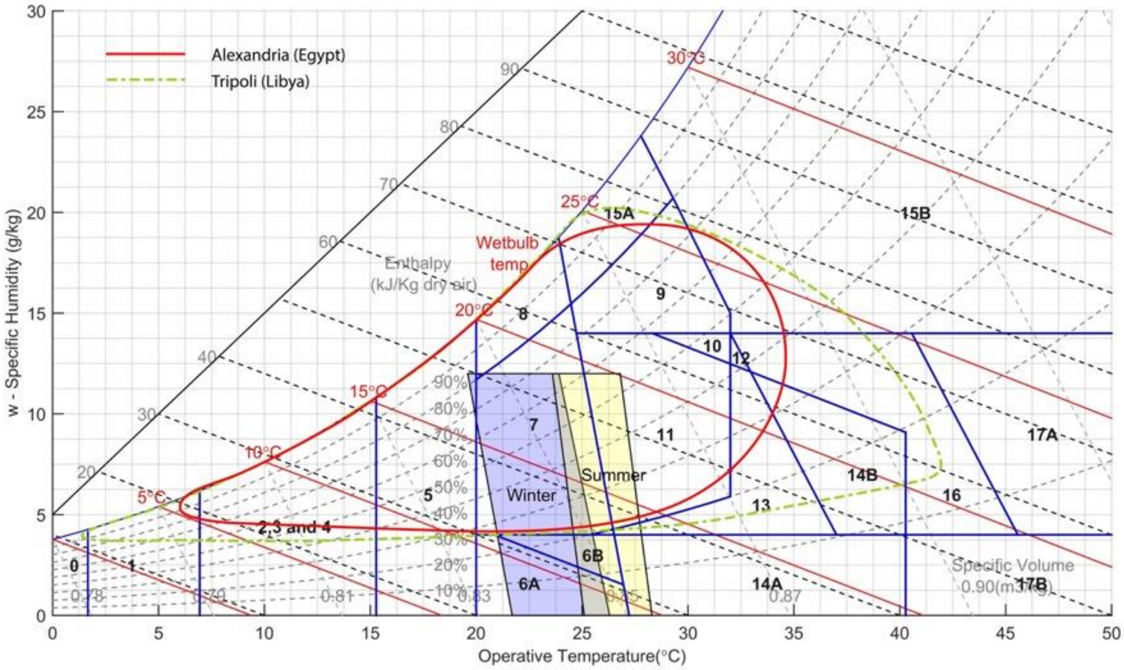


Figure 27 Psychrometric chart indicating the boundary range of the annual hourly weather data for Alexandria (Egypt) and Tripoli (Libya) with bioclimatic boundaries as defined within Watson and Labs (1983)

4.1.5 Bioclimatic Analysis Based on Existing Indices

The test locations identified in section 4.1.3 were used to provide the test conditions for the simulations of the theoretical cabin zone. Table 3 shows a range of climatic and bioclimatic characteristics of the 11 test locations. A bioclimatic analysis of the 11 test climates based on the works of Milne and Givoni (1979) is presented in appendix 4.15 – identifying a high potential for passive solar heating.

A significant index investigated - is the annual hours above 24°C (as defined within Table 3 column 9 and illustrated in figure 28), which has been used as a climatic indicator of when sensible cooling is required. Hours above this temperature, represents the frequency of outdoor conditions above the cooling set point temperature for the stimulations conducted in the parametric analysis presented in Chapter 4.2. From Table 3 we can see the locations with the highest frequency within these parameters include; Tripoli (30.6%), Alexandria (25.3%) and TelAviv (25.0%). Conversely the regions with the lowest frequency are: Trieste (7.9%), Rimini (8.0 %) and Venice (11%). Additionally, these locations indicate a high annual frequency of hours below 15°C - a common heating base temperature. This paradox suggests that a mixed approach to PD including passive heating and passive cooling strategies would be necessary in reaching ultimate passive performance.

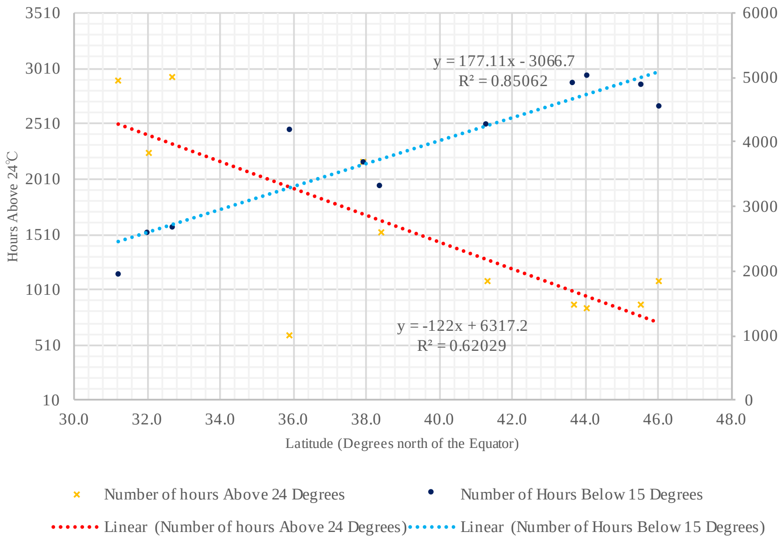


Figure 28 Scatter plot of the annual frequency of hours above 24°C and below 15°C for each test location based on heating and cooling degree base temperatures described in the works of Rosa et al. (2015) and Anjomshoaa and Salmanzadeh (2017)

Table 3 Key climatic and bioclimatic indices of all 11 test climates as presented in appendix 4.6

Location	Country	Latitude	Longitude	Annual Mean Temperature (°C)	Annual Mean Global Horizontal Radiation (W/m2)	Annual Mean Exterior Relative Humidity (%)	Annual Mean Wind Speed (m/s)	Number of Hours Above 24°C	Number of Hours Below 15°C	Thermal Comfort Region (R7) as defined by Milne (1979)	2004 ASHARE Thermal Comfort Region
Alexandria	Egypt	31.2	30.0	20.4	191.8	69.7	4.0	2898	1964	2516	782
Tel Aviv	Israel	32.0	34.8	18.9	218.9	71.0	3.0	2255	2612	1904	1031
Tripoli	Libya	32.7	13.2	20.3	196.7	81.6	3.7	2943	2670	1844	1028
Ceuta	Spain	35.9	-5.3	16.1	194.9	86.0	6.7	610	4199	986	115
Athens	Greece	37.9	23.7	17.9	173.1	61.6	3.8	2170	3701	2301	1499
Alicante	Spain	38.4	-0.5	17.8	230.0	66.1	6.7	1528	3323	2169	1133
Barcelona	Spain	41.3	2.1	15.7	143.7	74.0	3.4	1088	4276	1627	503
Pisa	Italy	43.7	10.4	14.2	89.1	80.2	2.4	883	4916	1112	514
Rimini	Italy	44.0	12.6	12.7	105.7	78.2	2.1	856	5043	1229	420
Venice	Italy	45.5	12.3	13.1	91.4	79.7	2.0	882	4892	1251	482
Trieste	Italy	46.0	14.0	14.4	76.9	79.5	2.6	1097	4564	1788	948

4.2 Parametric Simulation Analysis

The data is analyzed in accordance to the key passive strategies exercised within the parametric simulation. The data output is considered in terms of the impact to interior thermal loads. For all of the test locations, the analysis is formatted as follows.

1. The first part of the analysis; looks at the range of **climatic and bioclimatic conditions** in which the theoretical thermal model was simulated. Using existing bioclimatic assessment models and climatic indices, it identifies climate types that are likely to support a passive strategy as well as those climates that are more demanding in terms of their requirement for active heating and cooling. Additionally, this process facilitates in defining the scope of this study and is addressed in section 4.1
2. The second stage of the analysis; reviews the **impacts of shading** as the primary passive solar strategy employed within this research. It accomplishes this through comparing zones with incremental variations in shading depth (m) on zones with varying glazing percentages
3. The third aspect of the analysis; reviews the **influence of internal heat gains** sources from equipment, lighting, occupants and solar gains
4. The fourth part of the analysis; identifies the impacts of thermal model specifications in respect to the **optical and thermal properties of glazing systems** on the thermal loads and solar heat gains
5. The final part of the analysis; compares all the simulations conducted to determine the parameters which derive the **lowest interior thermal loads**. In this part of the analysis the combined annual heating and sensible cooling loads are reviewed to determine the combination of passive strategies and weather conditions that are most conducive to delivering low annual thermal loads. This if further addressed in Chapter 6

A summary of the analysis outlined above is provided in section 4.3 where the impacts of passive strategies are discussed and an overall assessment of the potential of PD within the context of a key perimeter zone is presented.

4.2.1 The Impact of Passive Shading

The shading depth of a horizontal overhang was adjusted between 0m and 2m in increments of 0.5m and tested with varying glazing percentages to determine its impact on annual thermal loads. The following analysis has been conducted on cabin zones with an 80% glazed façade. Cabin zones are otherwise typically highly glazed and present within perimeter zone of cruise vessels. The following analysis, examines the impact of shading within the parametric simulation results which are represented in the example parametric simulation report P1.1N – P1.2N and P1.1S – P1.2S (of appendix 4.16). The key independent variables in this analysis are: glazing size (represented as a percentage of the external facade); location and shading depth (m). Key dependent variables analyzed in this section include: total heating (kWh), sensible cooling (kWh), and solar gains (kWh).

4.2.1.1 Impact on combined sensible loads

Tables 4 and 5 show the influence of shading on the annual combined total heating and sensible cooling loads in both a northerly and southerly orientation for all 11 test locations.

Table 4 Annual sum of sensible cooling and total heating loads from simulation results for a cabin zone with an 80% glazed façade and variable horizontal overhang depth, orientated in a northerly direction

Location	Lat	Lon	Annual Sum of Total heating and Sensible Cooling (kWh)				Difference in thermal Conditioning From 0.5m to 2.0m (kWh)	% Decrease From 0.5m to 2.0m
			Overhang Depth; 0.5m	Overhang Depth; 1.0m	Overhang Depth; 1.5m	Overhang Depth; 2.0m		
Alexandria	31.2	30	1477.82	1234.22	1159.42	1095.14	382.68	25.9%
Tel Aviv	32	34.82	1182.25	1015.24	970.37	928.30	253.95	21.5%
Tripoli	32.67	13.15	1533.09	1327.83	1269.44	1218.12	314.97	20.5%
Ceuta	35.89	-5.29	786.90	618.90	573.53	536.92	249.98	31.8%
Athens	37.9	23.73	1250.49	1090.22	1046.87	1008.93	241.55	19.3%
Alicante	38.37	-0.5	1088.71	900.27	846.10	802.37	286.34	26.3%
Barcelona	41.28	2.07	1007.15	862.95	821.09	787.50	219.65	21.8%
Pisa	43.67	10.38	995.95	871.88	833.06	801.99	193.97	19.5%
Rimini	44.03	12.62	1131.22	1030.60	1001.37	977.30	153.93	13.6%
Venice	45.5	12.3	1239.60	1125.89	1090.50	1062.08	177.51	14.3%
Trieste	46	14	1205.67	1074.42	1032.18	998.44	207.23	17.2%

Table 5 Annual sum of sensible cooling and heating loads from simulation results for a cabin zone with an 80% glazed façade and variable horizontal overhang depth, orientated in a southerly direction

			Annual Sum of Total heating and Sensible Cooling (kWh)				Difference in thermal Conditioning From 0.5m to 2.0m (kWh)	% Decrease From 0.5m to 2.0m
Location	Lat	Lon	Overhang Depth; 0.5m	Overhang Depth; 1.0m	Overhang Depth; 1.5m	Overhang Depth; 2.0m		
Alexandria	31.2	30	2583.20	1818.30	1484.58	1240.62	1342.58	52.0%
Tel Aviv	32	34.82	2219.73	1516.47	1223.79	1015.25	1204.49	54.3%
Tripoli	32.67	13.15	2575.44	1813.04	1507.71	1301.96	1273.48	49.4%
Ceuta	35.89	-5.29	1861.71	1123.84	821.00	623.24	1238.48	66.5%
Athens	37.9	23.73	2183.23	1478.29	1221.20	1066.70	1116.52	51.1%
Alicante	38.37	-0.5	2495.13	1634.50	1259.08	986.26	1508.87	60.5%
Barcelona	41.28	2.07	1915.68	1207.43	948.13	783.88	1131.80	59.1%
Pisa	43.67	10.38	1447.63	918.25	775.92	725.54	722.08	49.9%
Rimini	44.03	12.62	1598.50	1078.36	958.46	920.84	677.66	42.4%
Venice	45.5	12.3	1628.63	1117.02	1008.87	974.48	654.16	40.2%
Trieste	46	14	1602.62	1098.03	966.46	918.98	683.64	42.7%

In reviewing the annual combined total heating and sensible cooling loads, it was observed that the incremental increase in the depth of shading devices caused a decrease in annual cumulative loads in both orientations.

For a cabin in a Northerly orientation (as represented in table 4), **the greatest decrease in annual combined sensible loads** was observed in the locations of Ceuta, Alicante and Alexandria with, a relative decrease of 31.8%, 26.3 and 25.9% in annual loads respectively by increasing the horizontal shading depth from 0.5m to 2.0m. **The lowest decrease in terms of combined sensible loads** was observed at the higher latitude locations of Rimini and Venice, where a relative decrease of 13.6% and 14.3% respectively was witnessed. Comparatively, in a zone orientated in a southerly direction (represented in table 5) it was observed that Ceuta (Lat:35.89°N) showed the greatest reduction in annual combined loads, followed by Alicante, representing a relative decrease of 60.5% and 52% respectively. **L**ocations between 44.03°N and 46.0°N showed the lowest decrease in annual loads.

Overall a greater decrease in annual loads occurred in zones orientated in a southerly direction when shading was increased from 0.5 to 2.0m in depth. Within the parametric results the influence of increasing the horizontal shading device from 0 to 0.5m was negligible in both southerly and northerly orientations. As expected the influence of shading was most effective in locations with higher solar radiation. The impact of shading was less impactful therefore, in locations within higher latitudes.

Figures 29 and 30 illustrate how the annual combined total heating and sensible cooling loads decrease with an incremental increase in horizontal shading depth, for North and South orientations respectively. The relationship between orientation and shading depth is shown in Table 6. Where we can see that the change in depth from 0.5m-1.0m and the South orientation have greater effect on reducing the combined sensible load.

Table 6 Variation in decrease of combined sensible load with shading depth and orientation

Change in depth (m)	North	South
0.5-1.0	13.7%	33.3%
1.5-2.0	4.1%	12.9%

Overall shading can be said to decrease annual sensible loads across all the test locations especially in locations with latitudes below 41.28°N. The greatest decrease in annual loads are observed in Alicante (Spain), Alexandria (Egypt) and Tripoli (Lebanon) in both a southerly and northerly orientation. Within these locations, the sensible cooling load represents between 99.84% to 100% of the combined total heating and sensible cooling loads for the year in zones with a 0.5m horizontal shading system facing south. Locations which appear least affected by the application of shading include; Pisa (Italy), Rimini (Italy), Venice (Italy), and Trieste (Italy) – which have latitudes greater than 43.67 °N. In these locations, the sensible cooling load represents between 78.54% to 89.33% of the combined total heating and cooling for the year when considering a zone with a 0.5m horizontal shading system facing south. The heating to cooling ratio for the zone therefore appears influential in determining the impact of a passive shading system. Regardless of this, shading is effective in reducing the combined sensible loads of the zone as the gains made in reducing the sensible cooling load outweigh the increase in total heating.

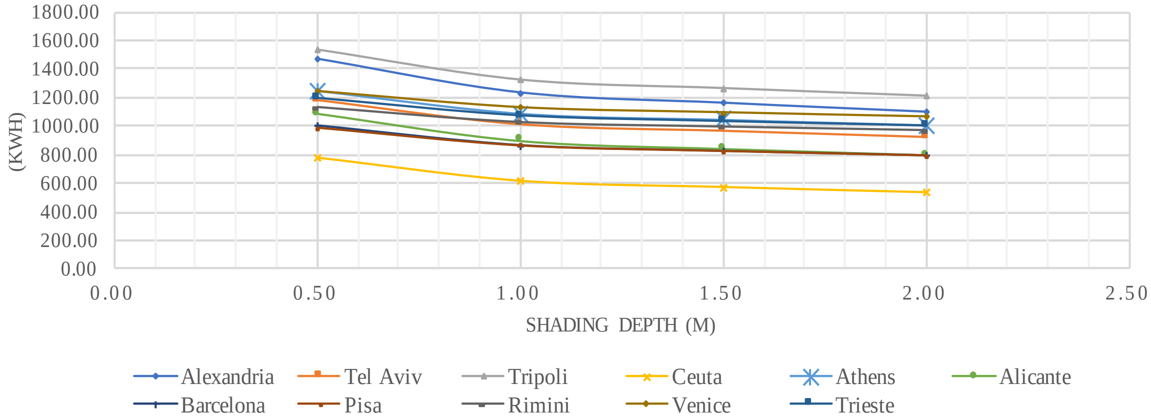


Figure 29 Line graph of the annual combined sensible loads for a zone orientated in a northerly direction with an 80% glazed façade and varying horizontal shading depths

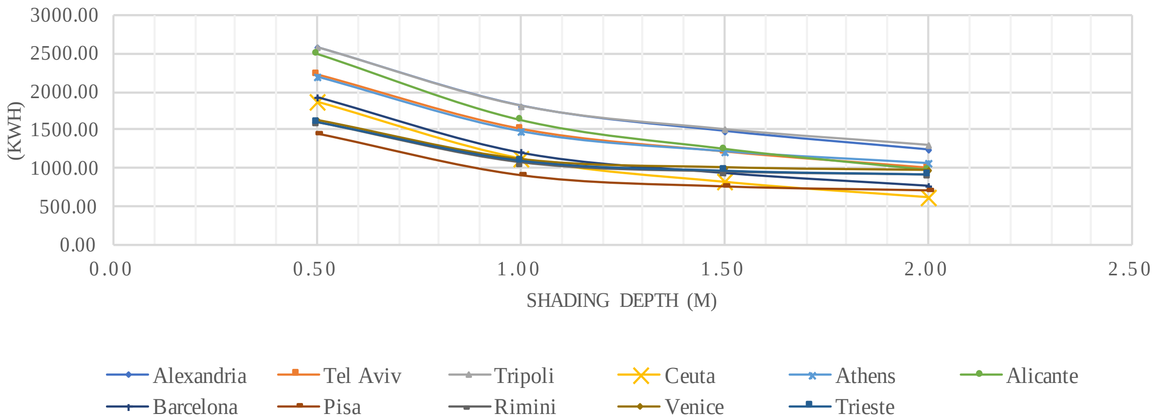


Figure 30 Line graph of the annual combined sensible loads for a zone orientated in a southerly direction with an 80% glazed façade and varying horizontal shading depths

4.2.2 The influence of Interior Heat Gains

In this study, interior equipment, lighting and occupant load gains vary in accordance to the schedules presented in appendix 3.11. The following analyses the impacts of interior heat gains on annual thermal loads.

Tables 1.0 to 4.1 in appendix 4.9 compares the increase in heating loads as a result of removing the primary variable interior heat gains including; equipment and lighting. Tables 5.0 to 8.3 in appendix 4.9 compares the increase in sensible cooling loads whilst tables 9.0 to 12 represent the net increase in combined heating and sensible cooling loads as a result of removing interior heat gains. Overall appendix 4.9 provides a tabulated summary of the detailed results analysis data presented in sections P1.3 N.B – P1.6 N.D and P1.3 S.B – P1.6 S.D (of sample parametric analysis report presented in appendix 4.16). To identify the influence of interior thermal loads on annual heating and sensible cooling loads, the lighting loads and the equipment loads were reduced to zero equating to a reduction in the total daily peak heat gains of 272.06 W per day.

The summarized comparison tables presented in appendix 4.9, allow for the relative impacts of shading depth (m), orientation and glazing size (glazing percentage) to be observed in each of the test locations considered. Significant cases as described in the following sections are illustrated within tables 4.0 – 4.3, 8.0 – 8.3 and 12.0 – 12.3. The influence of internal heat gains was considered in zones with varied glazing percentages from (20% to 80%) and with varying shading depths from 0-2.0m in all 11 test locations presented in table 3.

4.2.2.1 Impact of internal gains on combined sensible loads

The impact of internal heat sources on the combined annual heating and cooling load is considered in greater detail in figures 16 and 17 within appendix 4.8. These scatter plots, indicate the reduction in combined annual total heating and cooling loads as a result of minimizing interior heat gains in relation to a locations mean dry bulb temperature (°C). Figure 17 illustrates the relationship between the combined annual sensible loads and the test locations annual mean global horizontal solar radiation (W/m^2). Figures 19, 20 and 21 consider the same variables for zones orientated in a northerly orientation.

Key findings represented within the analysis include; the increased reduction in annual loads as a result of eliminating interior heat gains (including lighting and equipment), especially in locations with relatively high solar radiation levels and high mean annual temperatures. This is particularly relevant for zones with a large glazed façade orientated in a southerly direction. Similar trends are also observed within zones orientated in a northerly direction although a stronger correlation was observed between the reduction in annual loads and the locations mean annual temperature. The lowest combined annual loads in both a northerly and southerly orientation was observed in locations with a mean annual temperature of ~16 °C. Indicating a significant balance point temperature. In each location, the zone with the greatest reduction in combined annual loads as a result of eliminating interior heat sources appeared to vary in terms of glazing size. This phenomenon is not covered in detail within this analysis, but the information suggests the existence of an "ideal glazing size" as described within the works of Ghisia (2005) and Tzempelikos (2005). Finally, in general a net decrease in annual loads was observed by eliminating interior heat gains – indicating their significance as a passive strategy however, in some instances a net increase in annual loads was observed. This was particularly evident in locations in latitudes of 43.67°N and above, in zones operating in a northerly orientation, with small glazing percentages and deep shading devices. The combination in a reduction in solar gains and interior gains reduces the passive free heating potential of the zones and therefore increases the need for active heating. The annual heating to cooling ratio is posed as a significant index in establishing the control of interior heat gains as a passive strategy on board.

4.2.3 Passive Design and its Influence on Solar Gains

Solar gains play a key role in the heating and cooling requirements of the zone. This section analyses this independent from other internal heat gain sources such as equipment and lighting.

The following analysis, reviews the variations in the annual sum of solar gains as the primary dependent variable in accordance to the variation in glazing percentage, shading depth, orientation and location. In this analysis, we have focused on simulations adopting a mid-range glazing system as the impacts of glazing systems will be analyzed separately. The glazing system adopted by the simulations conducted in this analysis are summarized within table 7 below. The results and detailed analysis for each of the test locations are presented sections P1.3. N. A and P1.3. S. A of the sample report presented in appendix 4.16. The following provides a summary of the results presented in these appendices.

Table 7 Characteristics of Glazing Element (Type E) used within the parametric simulation and analysis of solar gains within the cabin zone.

U Value (W/m2-K)	2.5
Solar Heat Gain Coefficient (SHGC)	0.53
Visible Transmittance (Tvis)	0.72
Area at 80% Glazed Façade (m^2)	5.73
E+ Glazing Modelling Method	Simple Glazing

An overview and comparison of the annual solar gains for each of the test locations is presented in Appendix 4.10, which compares the annual solar gains for a) A zone with a north facing façade, with 20% glazing and no shading b) A zone with a north facing façade with 20% glazing and a 2.0m balcony with overhang and side fins c) A zone with a north facing façade, with 80% glazing and no shading, and d) A zone with a north facing façade with 80% glazing and a 2.0m balcony with overhang and side fins. In addition, these zone configurations are also used to analyze the impacts of on a zone orientated in a southerly direction. The analysis of solar gains is presented in 4 parts; The first parts reviews the impacts of orientation and shading (presented in appendix 4.12), the second part reviews the variation of solar gains due to a change in location (presented in appendix 4.13), the third part reviews the combined influence of glazing size and shading (presented in appendix 4.14), finally the fourth part reviews the combined impacts of glazing size, zone orientation and shading on annual solar gains – as presented in section 4.2.3.1.

4.2.3.1 The Influence of Combined PD Strategies

Figures 31 to 32 are bar charts that summarize and compare the influence of different passive strategies (such as shading and glazing size) on the combined sum of annual solar gains for a zone situated in a northerly and southerly orientation within the test location of Alicante (South Spain). The trends defined below are also representative of the other test locations as presented in table 1.0 to 4.1 of appendices 4.10 - although solar gains overall are less than witnessed in this location, due to lower amounts of solar insolation present. Several zone configurations are considered to define the combined impacts on solar gains – which are discussed in more detail below.

In configuration one (represented in blue in figures 31 and 32) we observe the impacts of orientation. In Alicante for a zone with no shading and an 80% glazed facade - an increase in solar gains from to 779.1 kWh to 2401.3 kWh per annum is observed (Δ 1622.2 kWh – an increase of 208.2%), when comparing annual simulations of zones orientated in a northerly direction to the same zone in a southerly direction. In Trieste (as illustrated in figure 32), an increase in solar gains is also observed from to 646.0 kWh to 1390.3 kWh per annum (Δ 744.3 kWh – an increase of 115.2%). Across all locations considered in this study, an annual mean reduction in solar gains between 67.1% to 53.0% can be achieved by orientating a zone in a northerly direction for a zone without a shading device.

In configuration two of the bar chart (represented in orange in figures 31 and 32) we identify the impacts of glazing size and orientation. For a zone in Alicante (represented in figure 31) with an 80% glazed façade orientated south, a reduction from 2401.3 kWh to 521.5 kWh per annum can be achieved when decreasing the glazing percentage from 80% to 20% (Δ 1879.8 kWh – a decrease of 78.3%). The same zone orientated in a northerly orientation also observes a reduction in annual solar loads from 779.1 kWh to 174.1 kWh (Δ 605 kWh representing a 77.6% decrease). When considering the same zone in Trieste facing in a southerly direction a reduction is observed from 1390.3 kWh to 300.1 kWh (Δ 1090.2 kWh representing a 78.4% decrease) whilst in a northerly orientation the zone witnesses a decrease from 646.0 kWh to 142.3 kWh (Δ 503.7 kWh representing a 77.9% decrease). Across all locations in a zone with an 80% glazed façade and no shading – a mean decrease in annual solar gains of 77.78% is expected for zones in the north and 78.36% for zones in the south when the glazing percentage is reduced from 80% to 20%.

The third configuration (indicated in grey in figures 31 and 32) identifies the impacts of shading on a zone with 80% glazed façade. When comparing a zone simulated in Alicante, with and without shading in a southerly orientation we observe a reduction in annual solar gains from 2401.3 kWh to 681.6 kWh (Δ 1720.2 kWh representing a 71.6% decrease). In the north, there is also a reduction from 779.1 kWh for a zone without shading to 349.6 kWh for a zone with shading (Δ 429.5 kWh representing a 55.1% decrease). When comparing a zone simulated in Trieste (as illustrated in figure 32), with and without shading in a southerly orientation we observe a reduction in annual solar gains from 1390.3 kWh to 419.3 kWh (Δ 971.0 kWh representing a 69.8 % decrease). In the north, there is also a reduction from 646.0 kWh for a zone without shading to 281.7 kWh for a zone with shading (Δ 364.3 kWh representing a 56.4 % decrease). Overall, across all test locations a mean reduction of 54.6% is witnessed when shading is applied to a zone with an 80% glazed façade for zones in a northerly orientation, whilst a 74.1% reduction is witnessed when shading is applied to a zone in a southerly orientation.

The fourth configuration (indicated in yellow) represents zones with a reduced glazing percentage (20% - comparable to a port hole) combined with a deep shading system (including side fins, overhang and balcony of 2.0m depth) – consequently reducing any direct beam radiation on the glazing system. In comparison to all configurations we identify this as being the most effective at reducing annual solar gains. The following compares the combined impact of shading and a reduced glazing size to a zone with an 80% glazed façade and no shading.

For a south facing façade in Alicante as represented in figure 31 - we observe a reduction from 2401.3 kWh to 135.7 kWh when shading and a reduced glazing percentage is adopted (Δ 364.3 kWh representing a 56.4 % decrease). For a northerly orientated façade, we observe lower interior solar gains and a reduction from 779.1 kWh to 82.1 kWh (Δ 697.0 kWh representing a 89.5 % decrease). When applying shading and a reduced glazing size to a zone in Trieste, we observe similar trends. For a southerly orientated zone, we observe a reduction from 1390.3 kWh to 93.9 kWh (Δ 1296.4 kWh representing a 93.25 % decrease), whilst for a zone orientated in a northerly direction we observe a reduction from 646.0 kWh to 64.9 kWh (Δ 581.1 kWh representing an 89.9 % decrease). Overall across all locations the application of shading and a reduced glazing size as a passive strategy can reduce annual solar gains by a mean of 89.6% for zones orientated in a northerly direction and by a mean of 94.1% for zones orientated in a southerly direction.

The analysis presented in figures 31 and 32 compares the locations of Alexandria and Trieste. These locations were compared as they represented locations with the lowest and highest annual solar gains as per the southerly orientated zone represented in appendix 4.13. The trends discussed however, are indicative of all the test locations presented in this study.

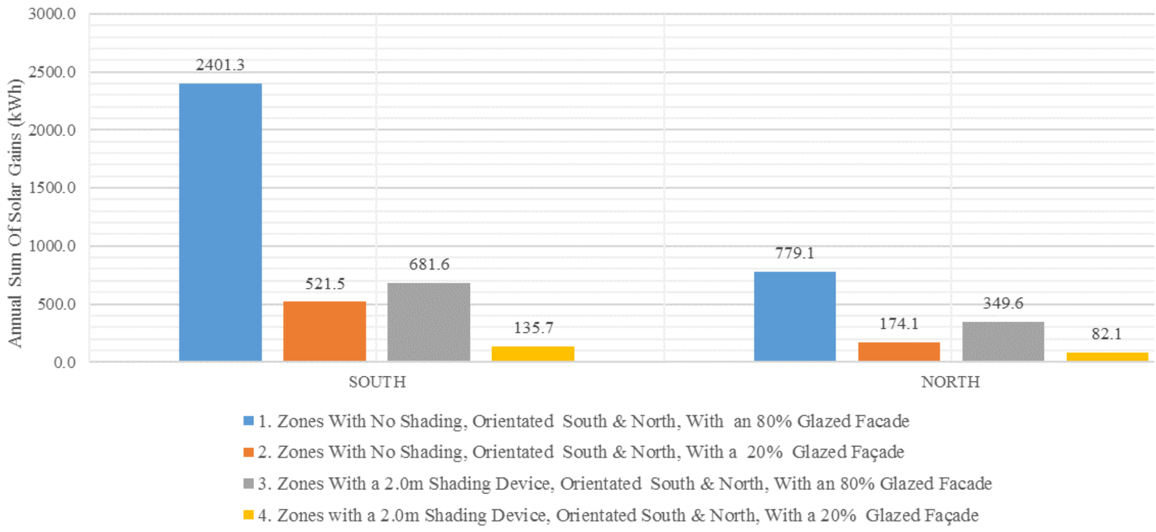


Figure 31 Comparison of annual solar gains for different zone configurations – for simulations conducted in Alicante (Spain)

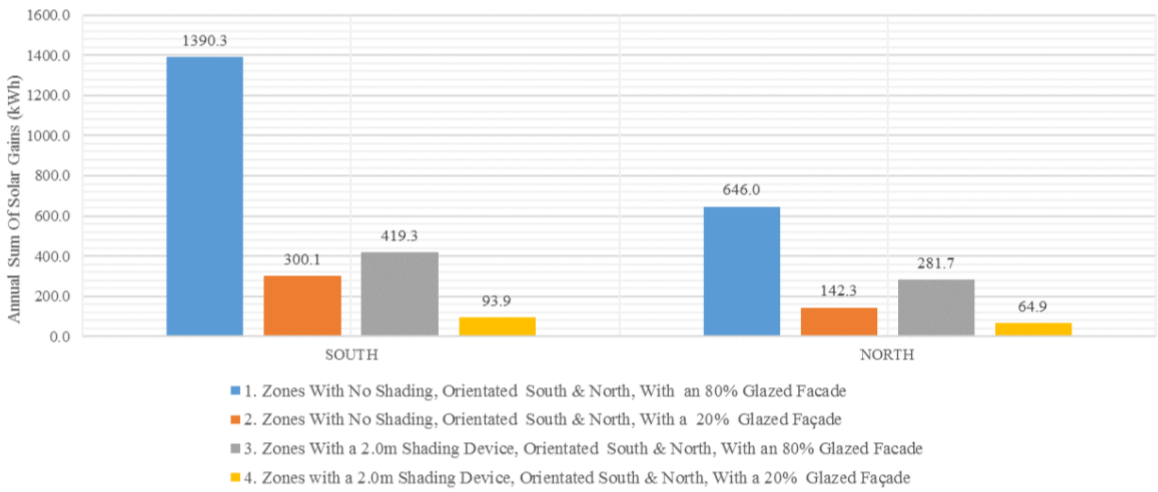


Figure 32 Comparison of annual solar gains for different zone configurations – for simulations conducted in Trieste (Italy)

4.2.4 Analysis of Glazing Type

Sections P2.1. N and P2.1. S of the example parametric analysis chart summarizes the impact of different glazing systems as defined within appendix 3.5 - independently by exploring the annual heating and cooling requirements for a zone with 80% glazing and no exterior shading in both a southerly and northerly orientation. Properties of each of the glazing systems are presented in table 8.

In each case where the annual simulation results of each window type are reviewed, the SHGC and the U value, the mean temperature and the solar radiation are the independent variables. Formulas presented in appendix 3.11 define the impact of the SHGC on the transmittance of solar radiation, whilst the U value as indicated in defines the degree of heat transfer which occurs at the interface due to temperature differences across it. The analysis therefore focuses on these variables to define the relative impact of glazing systems on board. The effects on heating, cooling and combined heating and sensible cooling loads are considered below.

Table 8 Properties of glazing systems employed within the parametric study from type A to G. Each glazing system varies in U value and SHGC value. Their properties are defined by relative standards and marine glazing literature - as defined within appendix 3.5

Name	U Factor (W/m2/k)	SHGC	Visible Transmittance
Type A	1.653	0.585	0.783
Type B	1.34	0.329	0.578
Type C	1.382	0.48	0.68
Type D	2.549	0.698	0.781
Type E	2.5	0.53	0.72
Type F	5.383	0.71	0.93
Type G	5.242	0.414	0.674

4.2.4.1 Influence of Glazing on the Combined Loads

Figures 33 and 34 illustrates the information in tables 2.1 and 5.1 of appendix 4.11. In these illustrations, the combined heating and sensible cooling loads is represented as the annual sum of both the total heating loads and the sensible cooling load.

Figure 33 illustrates that for a zone orientated in a northerly direction - glazing systems type ‘F’ and type ‘D’ produces the highest combined heating and sensible cooling loads across all the test locations. On the contrary, glazing systems type ‘G’ and type ‘B’ produced the lowest annual loads which were between 30.53% to 46.42% less than loads produced by comparative glazing systems. The highest reduction in combined loads, when comparing these glazing systems, was observed in Venice where by a reduction from 1790.54 kWh to 959.44 kWh was observed (Δ 831.11 kWh – representing a 46.42% reduction in annual loads).

Figure 34 illustrates the combined heating and sensible cooling loads for a zone orientated in a southerly direction. As expected the combined loads in this orientation are significantly higher. In this instance glazing system type ‘D’ and type ‘F’ – were also found to produce the highest combined loads across all locations. Whereas, glazing systems type ‘G’ and ‘B’ were also found to produce the lowest annual combined loads which were between 39.06% to 53.68% less than loads produced by comparative glazing systems. The highest reduction in annual loads, through the application of high performance glazing was observed in Alicante with a zone adopting a Type ‘G’ to a Type ‘D’ glazing system - where by a reduction from 3500.83 kWh to 1868.46 kWh was observed (Δ 1632.37 kWh – representing an 46.63% reduction in annual combined loads)

Comparative analysis indicates that glazing system type ‘G’ produced the lowest sensible cooling loads in both zone orientations – especially in zones with a southerly orientation. This is likely to be due to the glazing systems low SHGC values of 0.4, that reduces the amount of solar heat gains into the interior and otherwise contributes to the cooling load. This is particularly relevant in the case of Alicante which has very high solar insolation levels. Furthermore, this glazing system has a high U factor which would otherwise facilitate in heat loss from the zone which is particularly favorable for a zone with a high cooling load bias. In addition to this - it is observed in table 5.1 of appendix 4.11 - that this glazing system seems to be more favored in the hotter climates, which have higher solar insolation levels such as Alexandria, Tel Aviv, Ceuta, Alicante and Barcelona – especially in zones with a southerly orientation. Whereas glazing system type ‘B’ is preferred in the cooler climates such as Pisa, Rimini, Venice and Trieste. This is thought to be due to the system having a lower U value preventing heat loss in the cooler months of the year and thus reducing the annual combined sum of heating and cooling requirements. This is most notable in the zones orientated north, where by the glazing system type ‘B’ is favored across all zones. In this instance both low SHGC values and low U values are favored reducing solar gains whilst also minimizing heat loss during the heating period resulting in lower combined annual heating and sensible cooling loads.

Glazing system ‘D’ produced the highest cooling requirement followed by type ‘F’ in zones orientated in both directions. Glazing system type D has a U factor of 2.5 $W/m^2/K$ and a SHGC of 0.70 whilst glazing system type ‘F’ has a U factor of 5.383 $W/m^2/K$ and a SHGC value of 0.7. In comparison to the other glazing systems presented in table 8, both glazing systems have high SHGC values and relatively high U factors.

For zones situated in a northerly direction glazing system type ‘F’ produced the highest combined annual thermal loads across all locations except for Ceuta and Alexandria. In which the differences in performance were marginal. However, type ‘F’ glazing system has a lower U value encouraging heat loss through the façade – especially in the winter months. High solar gains, coupled with high heat loss would result in both high heating and sensible cooling loads equating to high annual thermal loads. For zones in a southerly orientation there is a similar scenario however, type ‘F’ glazing system appears to be more dominant in the northerly climates and type ‘D’ appears more prevalent in hotter climates. To this end the lower U value glazing insulates the zone preventing heat loss via the façade in the hotter climates – whilst it permits heat loss in the cooler climates.

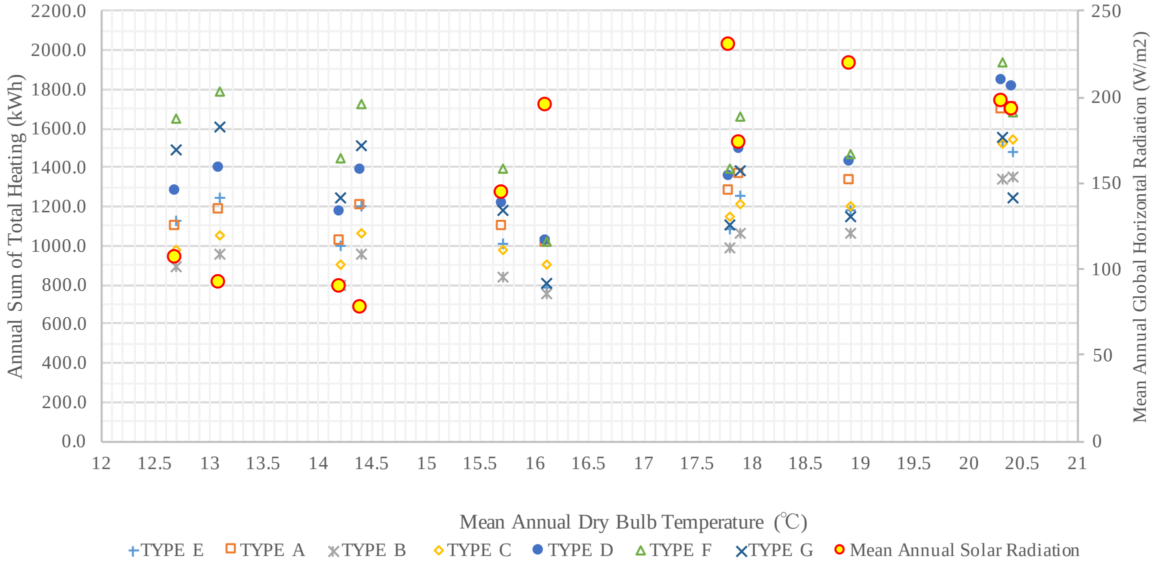


Figure 33 Annual sum of heating and sensible cooling loads for zones orientated in a northerly direction, with an 80% glazed façade and no shading - adopting variouse glazing systems. Annual loads are plotted againt the test locations mean annual temperature and the mean global horizontal solar radiation levels

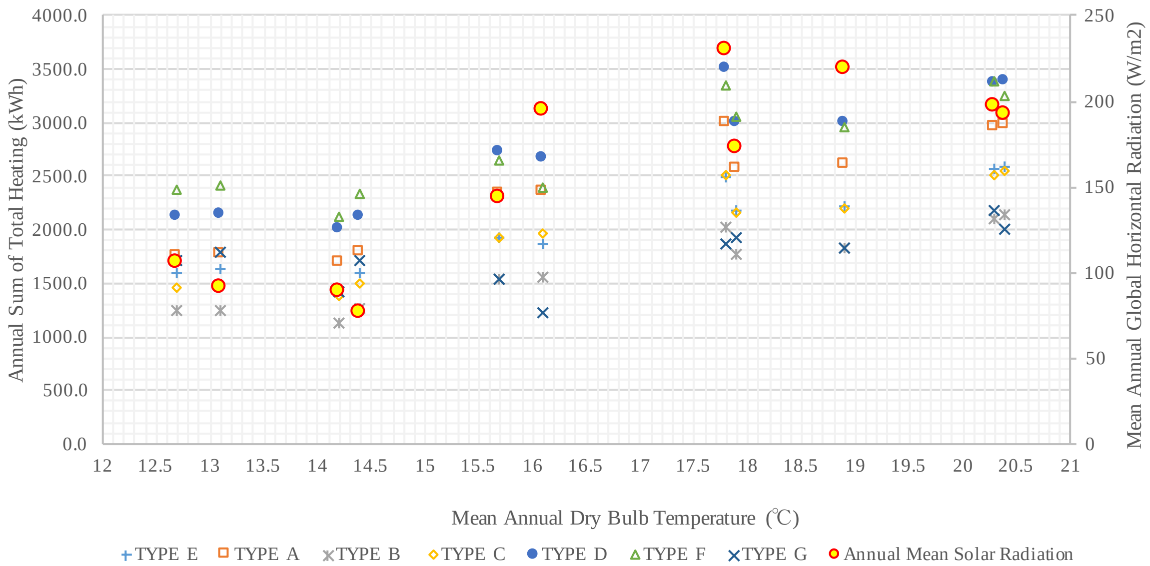


Figure 34 Annual sum of heating and sensible cooling loads for zones orientated in a northerly direction, with an 80% glazed façade and no shading - adopting variouse glazing systems. Annual loads are plotted againt the test locations mean annual temperature and the mean global horizontal solar radiation levels

4.3 Summary and Conclusion

Section 4.1 presents an analysis of over 80 Mediterranean weather files, each comprising of 8760 hours of data for 33 different climatic variables - to deduce 11 test climates which are to reflect the broad range of conditions existing within Mediterranean basin and subsequently reflecting the conditions a ship is likely to experience.

It has accomplished this by firstly; applying contextual criteria which ensure that the test files are from weather stations within close proximity to the coast line (< 10km) and were close to sea level to maintain appropriate barometric pressure (between 0m – 81m above sea level). Secondly, the filtered climates were then analyzed further, using mean monthly and annual climatic and bioclimatic indices to identify climatic extremes which is presented in appendix 4.1 to 4.3. Thirdly, a consideration was placed on high frequency ports to represent the modal climates a cruise ship is likely to be docked in. The chosen weather files were then compared to well-known climate classification systems including; Koppen-Geiger Classification (Peel 2007) and the ASHRAE International Climate Zone Definitions (ASHRAE 2007) - to identify how the climates are characterized by other models as well as to get an appreciation for the breadth and extent of climate types considered within this study. The process leading to these tabulated results presented in appendix 4.4 and 4.5 and summarized in the tables presented in appendix 4.6.

The tabulated results of each of the test locations is presented within appendix 4.7 in both climatic indices and bioclimatic indices are addressed. Each weather file data is graphically illustrated using the bioclimatic psychrometric chart in which bioclimatic boundaries were also plotted as defined within Watson and Labs (1983). This allowed for a preliminary assessment of the passive strategies which could be incorporated within zones with low interior heat gains, initially indicating that both passive heating and cooling strategies could be employed within the locations analyzed. In addition to this the study developed a frequency density algorithm in Matlab, following the works of Visitsak, Sopa. (2007), to aid the visualization of weather in relation to the psychrometric properties of air, bioclimatic boundaries as well as temperature set points and the ASHRAE thermal comfort boundaries.

In conclusion, the analysis presented in section 4.1 has assimilated both climatic, bioclimatic and contextual criteria to derive 11 test climates from available weather data collated from sources including the; IWEC, IGDG, SWEC, IMS and the ETMY as presented within appendix 4.6. The selected test climates have been compared to conventional and existing climate classifications and are considered representative of the conditions likely to be witnessed by a cruise ship, in port, operating within the Mediterranean Basin. For this reason, they are used within parametric simulations studies to define the potential of passive strategies on board.

Overall, the range of climatic conditions encompassed within the selected climates include; annual mean temperatures between 20.4 ºC and 12.7 ºC, mean annual relative humidity's from between 61.55% to 85.97% and annual mean global horizontal radiation levels between 76.9 W/m^2 to 230 W/m^2. An in-depth analysis of the climatic, geometric, contextual and bioclimatic factors for each of the selected test climates is considered within appendix 4.7.

Section 4.2 provides an analysis of simulation data generated from a parametric study using whole systems analysis software EngergyPlus (DOE 2015a) and JEplus (Zhang and Korolija 2014) adopting the test weather conditions defined within section 4.1. In this several passive attributes of a hypothetical thermal cruise ship cabin model were varied and included; the variation of shading depth to overhangs and side fins, a variation in glazing percentage of the external facade, a variation in glazing U (w/m^2/K) and SHGC value, a variation in internal gains from equipment and lighting, a variation in orientation from north to south and variation in location. The results of the simulation, produced ideal loads data allowing for a first order analysis of the impacts of passive strategies on monthly annual solar gains, total heating and sensible cooling loads. Tabulated reports – created via Matlab for each parametric study for all 11 test locations were analyzed in section 4.5. Appendix 4.16 provides a sample of the report generated for each of the test locations.

The first part of the parametric study presented in appendix 4.7 includes an analysis of the test climates in relation to the bioclimatic chart developed by Milne and Givoni (1979). The analysis identifies that between 61% to 88% of the year across all of the locations presented in table 3 reside within bioclimatic conditions 2 to 5 and 7 indicating a high potential for the application of PD within the Mediterranean. The Passive strategies such as Solar heating and the use of Interior heat gains as a free heat source, seem to be the dominant strategies suggested by the bioclimatic analysis. However, tables 3 and 4 on each page of the appendix 4.7 also identify that there are a high number of hours where outdoor temperatures exist above the cooling set point of 24°C and within the combined bioclimatic regions of 8 to 17a – suggesting a need for active sensible and latent conditioning especially in southerly locations (<32.67°N) such as Tripoli (Libya), Alexandria (Egypt) and Tel Aviv (Israel).

Section 4.2.1 shows the **impact of shading** on a zone with an 80% glazed façade adopting glazing system type E. In reviewing the annual combined total heating and sensible cooling loads, it was observed that the incremental increase in the depth of shading devices - derived a subsequent decrease in annual cumulative loads in both orientations.

By increasing the shading depth from, 0.5 to 2.0m in depth a decrease in annual combined heating and sensible cooling loads was observed between 25.9% to 13.6% for a zone orientated in a northerly direction whilst a reduction between 60.5% to 40.2% was observed for zones orientated in a southerly direction. It appeared therefore, that zones in a southerly orientation benefited most from shading. This was most notable in the test locations of Alicante (Spain – Lat:38.37°N) where a decrease in annual loads from 2495.13 kWh to 986.26 kWh was observed (Δ 1508.87 kWh a decrease of 60.5%). Comparatively, the lowest decrease was observed in Venice (Italy) which showed a decrease in annual loads from 1628.63 kWh to 974.48 kWh (Δ 654.16 kWh a decrease 40.2%). Overall shading can be said to decrease annual sensible loads across all the test locations especially in locations with latitudes below 41.28°N. Shading appears most effective in zones with a high cooling demand which was witnessed in locations, where mean annual temperatures vary from 17.8°C to 20.4°C (a mean of 19.5°C) and Global horizontal solar radiation ranges from 191.8 W/m^2 to 230 W/m^2 (a mean of 206.2W/m^2) per annum. Within these locations, the sensible cooling load represents between 99.84% to 100% of the combined total heating and sensible cooling loads. Finally, it was noted that there was no impact on annual loads when increasing shading from 0.0m to 0.5m in depth.

Appendix 4.8 and 4.9 addresses the **impact of internal gains**. To analyze these impacts all glazing percentages were investigated (20% to 80%) with varying shading depths from 0-2.0m. Occupant gains were kept constant in all simulations considered.

Overall, the removal of equipment and lighting results in a 69% reduction in internal peak heat gains (excluding solar gains). The analysis identified that the greatest reduction in combined annual loads was observed in hot climates with high sensible cooling loads such as Alexandria in which a 31.4% reduction in annual loads was observed. However, in some instances, its reduction has a detrimental impact on the combined loads in instances when a lack of solar gain and low exterior temperatures results in a need for active heating. This was significantly encountered in simulations conducted in the test locations of Rimini, Venice and Trieste - in simulations conducted in a northerly orientation with a large shading device.

Section 4.2.3 presents the data and analysis from the parametric simulations in which **solar gains** were observed. In this instance both shading depth, orientation and glazing size were varied in all the test locations. A strong relationship was observed between the test simulations annual sum of solar gains (kWh) and the test locations mean annual global horizontal radiation levels (w/m^2).

Simulations conducted on zones with a large glazed façade, without shading and orientated in a southerly orientation received the greatest annual solar gains. This was mostly observed in Alicante (South Spain) in which annual solar gains were 72.7% greater than that compared to Trieste – which observed the lowest annual solar loads.

In Alicante, a 71.6% decrease in solar gains was observed when a 2.0m shading device was added to an 80% south facing glazed façade. A similar decrease of 69.8 % decrease was also observed in Trieste for the same zone configuration. Overall, across all test locations a mean reduction of 54.6% is witnessed when shading is applied to a zone with an 80% glazed façade for zones in a northerly orientation, whilst a 74.1% reduction is witnessed when shading is applied to a zone in a southerly orientation. The analysis identifies that the most effective means of reducing solar gains is to combine both passive strategies of reduced glazing size and increased shading.

Section 4.2.4 reviews the **impacts of glazing type**; in this instance, a range of glazing systems outlined in table 8 were included within the parametric study. Systems adopted varied in U value from 1.34 W/m^2/K to 5.4 W/m^2/K and SHGC values from 0.41 to 0.71. The influence of glazing was notable on zones with a high glazing percentage in which a reduction in both solar gains as well thermal transmittance across the building façade were witnessed. For a zone with an 80% glazed façade orientated south - glazing systems type 'D' and type 'F' were found to produce the highest combined loads across all locations. Whereas, glazing systems type 'G'4 and 'B' were also found to produce the lowest annual combined loads which were between 39.06% to 53.68% less than loads produced by comparative glazing systems.

Overall, the above data and analysis; identifies the potential of PD in reducing interior loads which can be achieved across all the test locations. The degree to which this reduction occurs depends on the heating and cooling demand which are dependent on location and orientation. These contextual factors of climate and orientation are intrinsic to marine vessel operation. The study asserts this as one of the problems in modelling the potential of PD.

A bioclimatic analysis methodology would otherwise allow for a deeper understanding of loads in relation to climate furthermore, a detailed hourly analysis is required other than annual means analysis to fully understand this relationship. As per the above parametric analysis it is not yet clear how they impact interior loads – thus a detailed analysis methodology is presented in the following chapter which presents a detailed analysis tool allowing for a more comprehensive understanding of the relationship between climate and performance.

5.0 METHODOLOGY; A BIOCLIMATIC PSYCHROMETRIC ANALYSIS

The methodology presented in this chapter is developed to further investigate the outputs of the first methodology presented in Chapter 3 by adopting a bioclimatic analysis methodology. This approach is outlined in the works of Visitsak (2007) – where by the use of the bioclimatic chart - allows for the analysis of interior thermal demands in relation to climate - enabling the characterization of the thermal behavior of a structure - in relation to its surrounding weather conditions. For this reason, the bioclimatic psychrometric chart is commonly used by architects and engineers – to discern the relationship between climate and thermal comfort parameters, whilst also identifying "the prospective application of passive strategies" at the beginning of the design process (Pires et al. 2014) (Ayman and Mahmoud. 2011).

Being able to characterize the thermal behavior of a zone in relation to changing climatic conditions is particularly relevant in analyzing the potential for passive strategies in the marine context as a vessels location is constantly changing with time and so is the climate it is exposed to. This study therefore, aims to identify whether if conventional terrestrial bioclimatic tools can be adopted to zones within marine structures to identify outside conditions when heating and cooling is required and to illustrate the impacts of passive technologies using a visual basis to provide PD direction at the begging of the marine design workflow. The process to achieving this is outlined below.

1. **An assessment of the region using conventional terrestrial bioclimatic assessment methods and the psychrometric chart**; This is achieved through the development of the psychrometric chart using Matlab and the plotting of climate data onto its axes as demonstrated in the psychrometric charts presented in appendix 4.7. The spread and frequency of conditions across the bioclimatic psychrometric chart in relation to the thermal comfort zone will be analysed to establish a thermal bias towards the requirement of passive heating and or passive cooling with respect to the test weather conditions outlined in section 4.1. PD potential will be pre-assessed using existing and commonly used bioclimatic models to provide a broader bioclimatic context, enabling the identification of other passive strategies in terrestrial structures. This will be achieved by recording the frequency of external conditions that lie within specific bioclimatic boundaries asserted by the GM chart as defined within the works of Watson and Labs (1983). This principle of using frequency density is outlined and adopted within the

methodology created within the works of Visitsak (2007) – who has conducted a similar study on terrestrial structures.

2. Simulating zones in climates with elevated temperatures and high solar gain potential for defining extremes within the psychrometric chart relative to the test climates that are presented within this study; This will be achieved by a comparative analysis of the parametric simulation results and reviewing the parameters (as defined within the parameters tree illustrated in figure 22) which exhibited high and low annual thermal loads. Table 9 provides a list of the significant simulations that were considered for detailed analysis within this chapter. The output data unlike the parametric simulation results presented in chapter 4 will produce hourly loads data to more accurately identify the relationship between external conditions and interior thermal loads
3. **Bioclimatic analysis of psychrometric conditions leading to the requirement of active sensible conditioning**; This will be achieved through the mapping of outdoor conditions onto the psychrometric chart - when sensible heating and or cooling occurred. Using a frequency density algorithm this will visually illustrate the range and density of exterior conditions leading to active sensible conditioning. Additional methods of analysis and statistical representation include; xy scatter plots, line graphs, time series graphs, bar charts, polar diagrams and frequency tables. These will be used to define the relationship between sensible conditioning and exterior climatic conditions. The dependant exterior conditions that will be considered in this analysis include; the outdoor dry bulb temperature (ºC), relative humidity (%), absolute humidity (g/kg), global horizontal solar radiation (W/m^2), diffuse horizontal solar radiation (W/m^2), direct normal solar radiation (W/m^2), wind speed (ms) and wind direction (°). The independent variables considered in this analysis include; sensible heating (kW), sensible cooling (kW), lighting loads (kW), Occupant loads (kW), Equipment loads (kW), Solar gains (kW), Heat gains and losses from windows (kW), heat gains and losses from exterior walls (kW), combined sum of heat gains and losses (kW). The data will be analysed in both hourly, mean monthly and mean daily time series allowing for both seasonal variations and daily operational schedules to be recognised
4. **Bioclimatic analysis of outdoor psychrometric conditions resulting in no active conditioning;** This will be considered in an equivalent way to the previous step (step 3) where by outdoor conditions will be compared to interior loads when no active conditioning occurred i.e. when no heating or cooling was required to maintain interior conditions within the set point temperatures. Periods of no active conditioning will be accounted by a frequency density algorithm which will count and recording exterior

conditions throughout the annual simulation where active sensible conditioning = 0 and active sensible cooling = 0.

5. **Comparative analysis of zones with high and low annual loads**: Using the analytical methods described above a comparative analysis will identify the impacts of PD. This will be achieved by comparing simulations of zones with and without passive technologies such as shading, reduced glazing percentage, reduced interior gains and orientation.
6. **Defining bioclimatic regions from the above analysis**; in the above steps, analysis procedures have been outlined – matlab will be used to tabulate and represent simulation and climate data in a fashion such that outdoor outdoor conditions can be defined when no active conditioning occurs. This independent variable will be used to evaluate the influence of passive strategies. The climatic conditions when these periods occur – will be plotted onto the bioclimatic psychrometric chart to identify bioclimatic regions.

5.1 Defining Test Criteria for Detailed Analysis

As per the parametric analysis presented in chapter 4.0 the combined application of passive strategies has resulted in the greatest decrease in thermal loads. To identify the attributes which resulted in the highest and lowest annual loads to the simulation data is to be arranged in a systematic order.

5.2 Extraction and analysis of simulation data

The psychrometric chart allows exterior conditions to be plotted onto a chart which describes the properties of moist air. Engineers and architects can navigate around this chart and identify the psychrometric processes necessary to condition a body of warm air towards those that are required for thermal comfort.

Psychrometrics is the study and measurement of the properties of moist air encompassing parameters such as temperature, enthalpy, dry and wet bulb temperatures. The comfort and health of occupants require that these parameters lie within a narrow range (Kreider, Curtiss and Rabl 2010). This can be achieved through active or passive technologies and mapped on the psychometric chart. Common psychrometric processes are illustrated in figure 35 and include; humidification, dehumidification, evaporative cooling, sensible heating sensible cooling and chemical dehydration or hydration. For the purposes of this research sensible heating and cooling are the focus although latent loads are also considered within the simulation models.

The following outlines the construction of the psychrometric chart, as well as the methods used to extract and present climate and simulation data which will be used to display the relationship between climate and interior thermal loads as well as the impact of passive strategies' through a comparative analysis of the simulations whose parameters are defined within table 9.

5.2.1 Construction of the psychrometric chart

As can be seen from figure 35, the abscissa of the psychrometric chart provides an initial range of dry bulb temperatures (T_{db}) with the y axis representing the absolute humidity (w).

Thermodynamic principles are exercised here - whereby for a given dry bulb temperature the saturation pressure can be calculated and plotted on the psychrometric chart formulating the saturation line. The formulas used to develop each variable and the definitions of variables in this section are from publications by Al-Azri et al (2012) and Kreider, Curtiss, Rabl (2010) and are presented in appendix 5.0.

The equations in appendix 5.0 are compiled within Matlab to formulate the psychrometric chart (illustrated in figure 36) where by TMY (Typical Metrological Year) data is plotted to assess the outdoor climate in relation to human thermal comfort and other bioclimatic regions outlined in in Chapter 1. The resulting psychrometric chart is shown in figure 37.

Figure 35 Illustration of the various lines on the psychrometric chart which correlate to various moist air properties. (a) Represents the lines of constant relative humidity, (b) constant wet and dry bulb temperature, (c) constant humidity ratio, (d) constant specific volume and (e) constant enthalpy (Kreider, Curtiss and Rabl 2010:121)

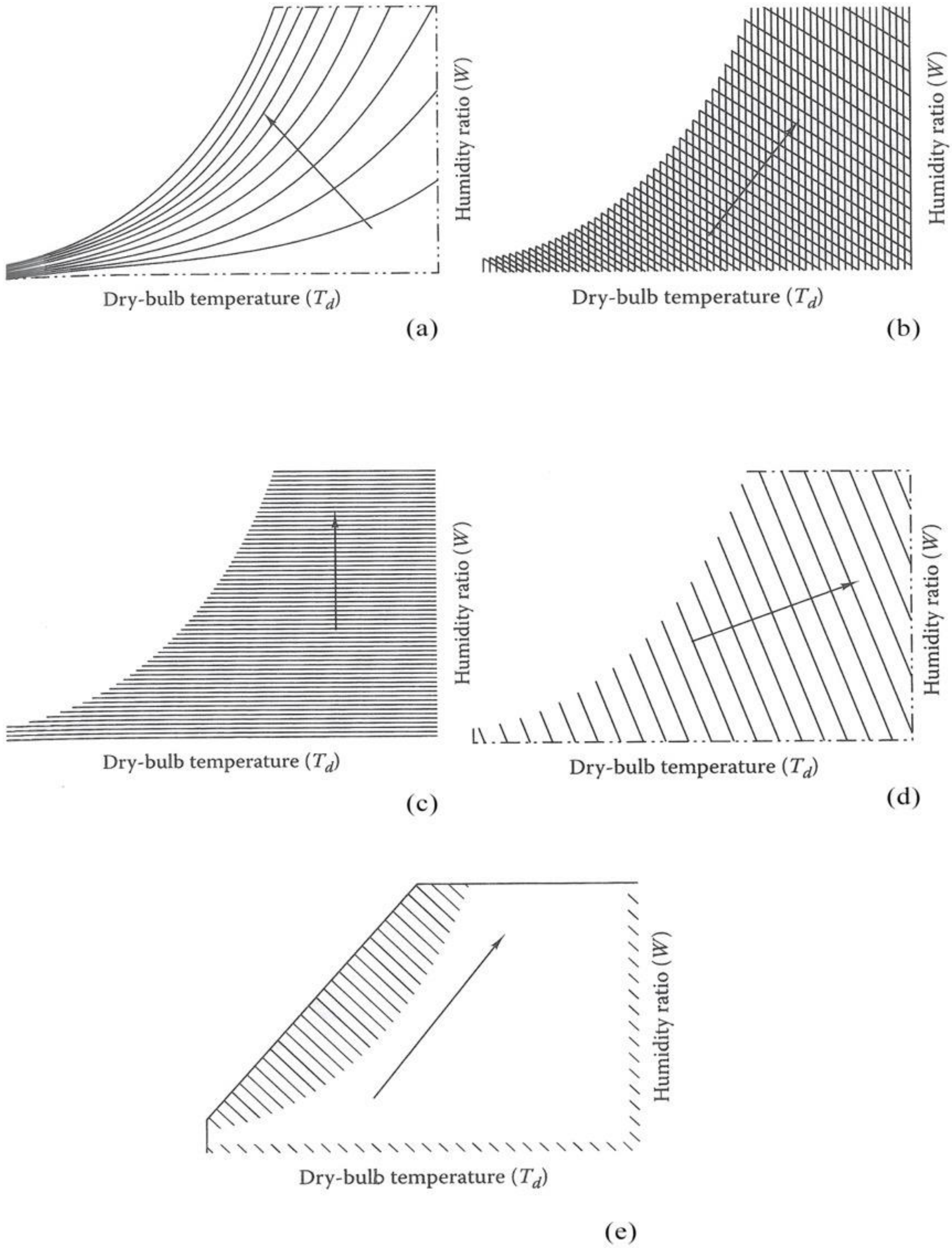
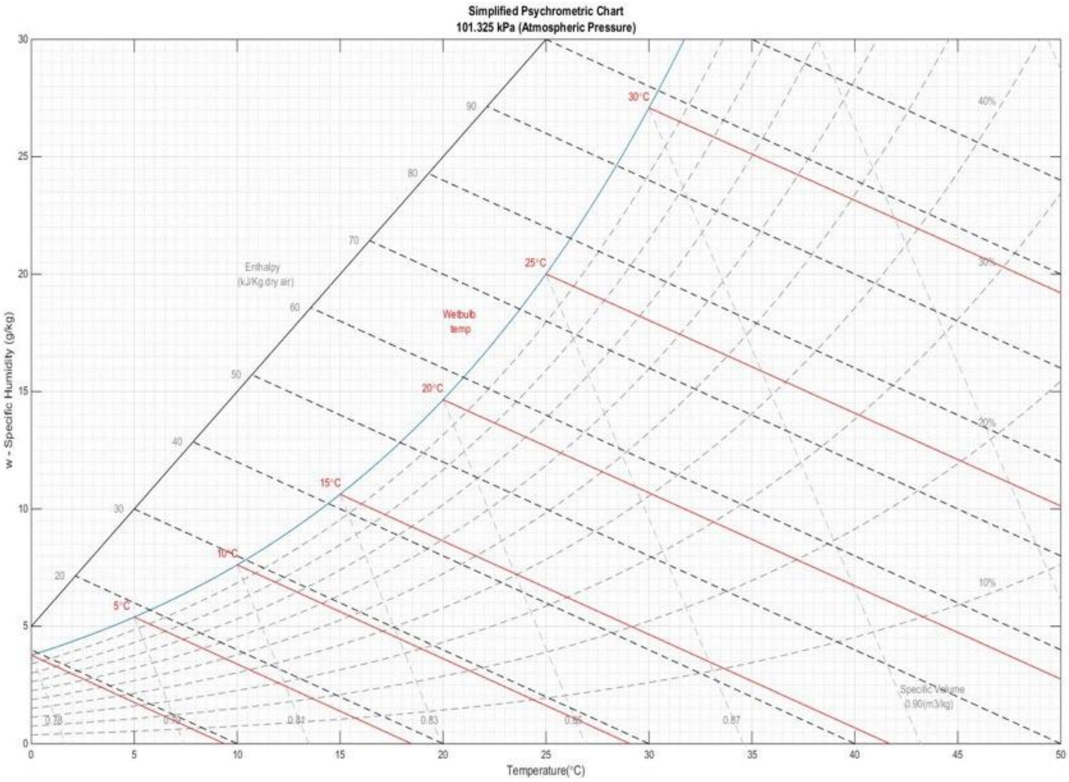


Figure 36 Resulting psychometric chart developed in accordance to the algorithms presented in Al-Azri et al (2012) , Kreider, Curtiss and Rabl (2010) and the ASHRAE handbook of fundamentals (ASHRAE. 2013).

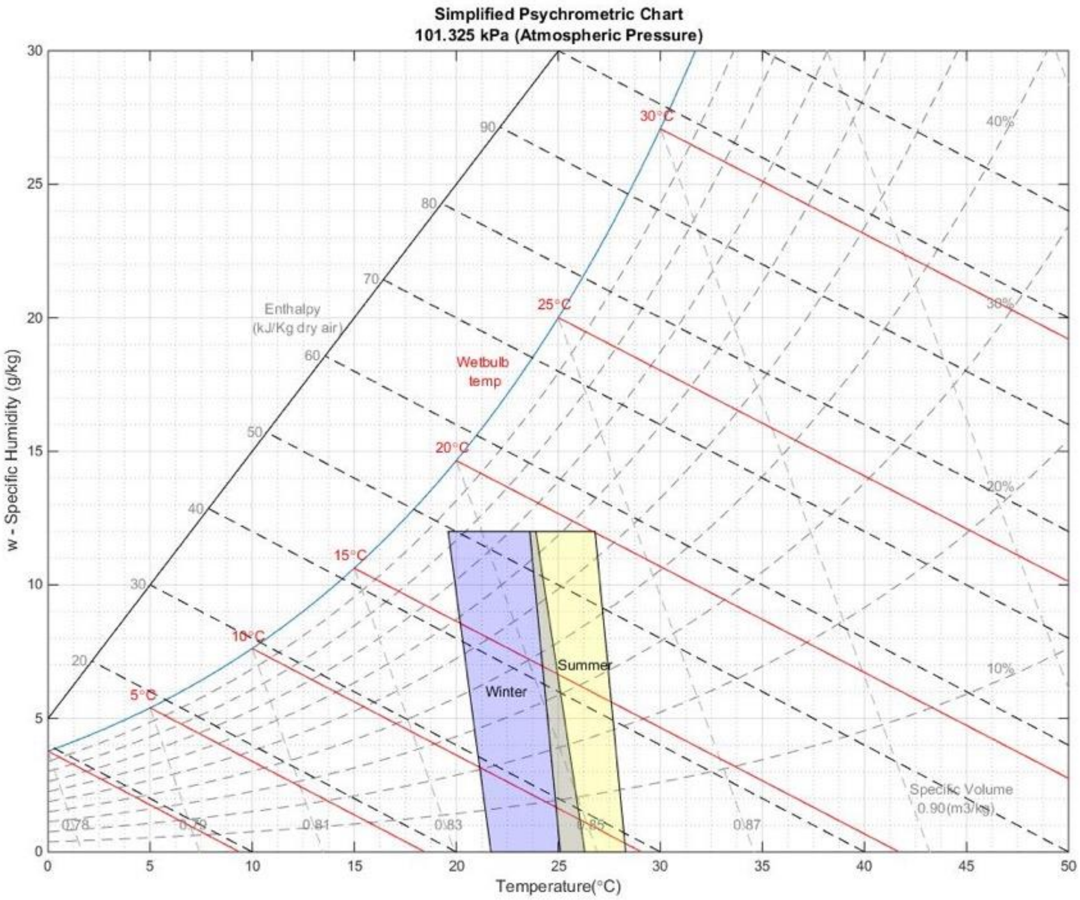


5.2.2 Overlaying the thermal comfort model

The ASHRAE standard 55 – 2010, defines comfort boundaries to assess thermal comfort. This will be used to evaluate interior climatic conditions and offer a reference to the designer as to when exterior air will need to be conditioned. This has been referenced as the primary comfort model due to its presence in the ABS passenger comfort guide (ABS 2014) and its relationship to the ISO 7730, which is also referred to within the standard. Overlaying these boundaries onto the psychrometric chart shows the variation in thermal comfort due to the seasonal change in occupant clothing from 1.0 clo to 0.5 clo from winter to summer respectively. The coordinates of the winter and summer boundaries are defined within the ASHRAE Fundamentals Handbook (ASHRAE 2013):

The matlab code used to create the graph are based on the simplified psychrometric chart program developed by Ngai (2015). Additional comfort requirements specified by the ABS passenger comfort guide include an upper and lower relative humidity level of 75% to 35%. It is assumed that this might be to prevent mold growth and condensation within sensitive zones of the ship and provide ultimate user comfort. From a psychrometric perspective – conditions existing outside these aforementioned conditions boundaries would require latent and or sensible conditioning by the HVAC system.

Figure 37 Psychrometric chart developed in Matlab with the winter and summer thermal comfort boundaries outlined by ASHRAE standard 55, based on data provided within the ISO 7730, for people wearing 1.0 and 0.5 clo clothing during primarily sedentary activity (≤1.1 met) with air speed ≤ 0.2 m/s.

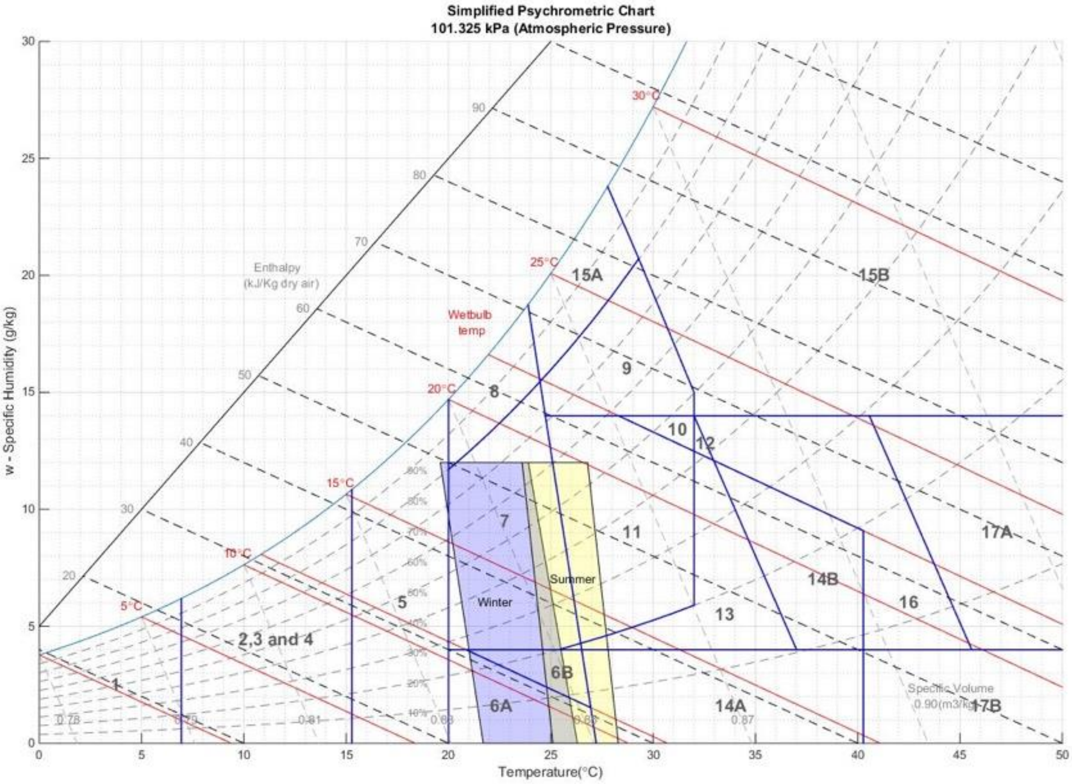


5.3 Bioclimatic Psychrometric Analysis

For the purposes of this study, the psychrometric bioclimatic chart developed by Givoni and Milne (1979) is defined as a commonly used existing bioclimatic analysis tools and has been used in prior studies identified within the literature for the bioclimatic assessment of European countries. For this reason, it has been used to bioclimatically asses the climates presented in section 4.1.

The bioclimatic boundaries for the psychrometric chart presented in figure 38 follows the detailed description outlined in Watson and Labs (1983) and the PHD thesis of Visitsak (2007). Bioclimatic regions for solar gains, internal gains and natural ventilation are of particular interest as they relate directly to the passive strategies employed within this study of shading, glazing systems and natural lighting. The bioclimatic boundaries as illustrated in figure 38 are described in detail in appendix 1.7.

Figure 38 illustration of the bioclimatic chart employed within this study, as defined by Watson and Labs (1983) and defined within appendix 1.7. Bioclimatic boundaries in this instance are indicated by thin blue lines dividing the psychrometric chart into 21 sections.



5.4 Mapping Climate Data onto the Psychrometric Chart

In discretizing the primary axis of the psychrometric chart the ‘meshgrid’ function in Matlab which replicates input vectors into a grid structure, was used to create small bins of specific dry bulb temperature and humidity ratio ranges. The bin sizes in this study are defined by equally distant dry bulb temperatures of 0.5ºC increments and equally distant humidity ratios at increments of 0.5 g/kg. This increment size also determines the size of successive frequency bins and is defined by the variable ‘fac’. The mesh gird output is then vectorized into the variable ‘XYF’, forming a list of co-ordinates that represent temperature and humidity ratio ranges. Variables ‘r’ and ‘c’, record the row and column size of the grid so that the vector, ‘XYF’ can be reshaped again after processing. A summary of this process is presented in appendix 5.1 whilst a the full matlab sequence used to analysis climate and simulation data is presented in appendix 5.2.

In addition to the above - Using the bin sizes as defined by the ‘Mesh grid’ function – a ‘for loop’ is applied which searches the cached weather data within certain restraints. This allows for weather data to be collated during night periods (when solar insolation is zero) and or during the day time periods (when solar insolation is greater than zero). If the data within the ‘n’th’ interaction of the ‘for loop’ conforms to these restraints – a count of the value of ‘1’ is recorded. This at the termination of the ‘for loop’ a frequency data set is created allowing the author to evaluate the frequency of specific conditions within specific constraints.

The analysis requirements within this study demands the annual cumulative frequency of more than just ambient climatic variables thus, the above algorithm is extended to encompass additional conditional statements outlined in the following section.

5.5 Mapping simulation Data onto the Psychrometric Chart

As part of the analysis of the climate database, a bioclimatic approach is necessary to consider the properties of moist air in extension to other climatic indices. Illustrating climate in a psychrometric chart gives rise to a greater understanding of the thermal processes taking place and is useful in that it illustrates the relationship between climate, thermal comfort boundaries and the bioclimatic boundaries as established by Milne and Givoni (1979) and other bioclimatic charts as reviewed in chapter 2.

Within the initial bioclimatic analysis of the Mediterranean basin, a frequency calculation is conducted on each of the climate data files to determine the frequency of specific climatic conditions within each of the boundaries outlined by Milne and Givoni (1979). This information is used as an initial assessment to identify climates which are most favorable for each design strategy allowing for the identification of suitable test climates for each passive strategy. More importantly a similar algorithm as presented in appendix 5.3 – which is used to collate the frequency of periods of heating, cooling and non-heating and cooling periods within specific climatic conditions allowing for a direct bioclimatic assessment between – thermal comfort, existing bioclimatic boundaries and specific weather conditions.

5.6 Verification and Validation of Results

Considering a static empirical basis for the evaluation of sensible and latent loads, the following literature has been referenced, CIBSE (2003), Kreider, Curtiss and Rabl (2010), ASHRAE (2013) and Santamouris (1996), where by interior design conditions will be considered on the basis of ASHRAE standard 90.1 for Energy Saving conditions, ASHRAE standard 55 for thermal comfort and the guidelines provided by the ISO 7547 (ISO. 2002) and the ABS passenger comfort guide (ABS 2014). By comparing the simulation results to the calculations presented within these key references – the data output of the methodology can be interrogated to ensure that they reflect expected outcomes are within respectable orders of magnitude. This process is covered in more detail in appendix 3.11 which was also applied to the results presented in Chapter 4.

5.6.1 Steady State Calculations and Balance Point Temperatures

The study adopts the concept of the balance point temperature to ascertain the conditions of equilibrium. As per the bioclimatic workflow demonstrated in the works of Nguyen and Sigrid (2014b) the outdoor conditions at which an equilibrium occurs between the interior environment determine significant bioclimatic boundaries.

"The building balance point temperature (T_{bal}) is the outdoor air temperature required for the indoor temperature to be comfortable without the use of any Mechanical heating or cooling" (Utzinger and Wasley 1948). The design of fenestration, structural form, and orientation and building fabric - control interior gains and losses such that they can contribute favorably or unfavorably to the internal energy balance of the zone which in turn dictates the need for active systems. An equilibrium between energy losses and gains, is the ideal in which a PD methodology strives - and is acquired through a detailed understanding of climate, structural design and occupant requirements.

In this study, internal gains (Q_{int}) include sensible gains from the occupants of the zone (Q_{people}), equipment - such as media devices and computers (Q_{equip}), lighting (Q_{lights}) and solar gains from the glazing apertures (Q_{sol}).

$$Q_{int} = Q_{sol} + Q_{people} + Q_{lights} + Q_{equip} \quad (8)$$

These gains can be beneficial in the heating periods and reduce active heating methods and counter beneficial in the cooling period. The heating load (L_h) can be represented as:

$$L_h = Q_{loss} - Q_{int} \quad (9)$$

And equally the sensible cooling load (L_C) can be expressed as:

$$L_C = Q_{int} - Q_{loss} \ (10)$$

Where Q_{loss} represents thermal losses through the building fabric (Q_e) and infiltration (Q_{inf}) – which can be represented as follows:

$$Q_e = U_e A_e (T_{in} - T_{amb}) \quad (11)$$

$$Q_{inf} = \dot{m}_i C_p (T_{in} - T_{amb}) \quad (12)$$

Combining these equations, we obtain an expression for heat loss:

$$Q_{loss} = \left(U_e A_e + \dot{m}_i C_p\right)(T_{in} - T_{amb}) \ (13)$$

This can be simplified to;

$$Q_{loss} = U_o A_o (T_{in} - T_{amb}) \quad (14)$$

Where U_o and A_o is a conglomerate expression accounting for the heat transfer rate due to conductance transfer across the zone envelope and the sensible heat required to condition the infiltration air. Substituting this equation into expression 9 we get;

$$L_h = U_o A_o (T_{in} - T_{amb}) - Q_{int} \quad (15)$$

As the interior temperature is dictated by the thermostat temperature (T_{in}), the balance point temperature (T_{bal}) can be obtained through a rearrangement of the above equation such that:

$$T_{bal} = T_{in} - \frac{Q_{int}}{U_o A_o} \ (16)$$

In this instance, the part of the equation after the minus sign indicates the ratio between the heat gains (numerator) and the heat losses (denominator). If the interior gains are greater than the losses then there is no requirement for heating (Bobenhausen 1994). Tables within appendix 3.11

summarises gains and potential losses based on outdoor conditions during winter and summer conditions as specified by the ISO 7547 (ISO. 2002) – which is conventionally used for the sizing of marine HVAC systems.

Following this empirical evaluation – the form (geometry orientation and size), function (which influences internal gains) and solar access - all have influence on the overall thermal performance of the zone. Solar gains would have a influence on heating and cooling loads in zones with a high glazing to floor area ratio, whilst zones with low glazing floor area to ratios would otherwise be more influenced by the internal gains of the zone (expressed in W/m^2).

The aim in applying passive technologies and adopting it as a design methodology within the marine sector is to extend the exterior environmental conditions in which interior zones will not require active thermal conditioning whilst maintaining occupant thermal comfort. This form the economic and environmental basis; in which a reduction in thermal loads reduces operational costs and emissions.

5.7 Summary of Methodology

This chapter has discussed the methodology used in this study including the construction of the psychrometric chart using Matlab, simulation of significant simulations as presented within the parametric study analysed in chapter 4.0. In short, the methodology outlines the procedure for mapping and analysing weather data and simulation data onto the psychrometic chart in order to define significant outdoor conditions when an equilibrium occurs following the principles methods defined within the works of Visitsak (2007), Nguyen and Sigrid (2014b) and Bodach (2014 a).

In addition to this a data extraction and analysis tool was developed allowing for both the hourly and monthly variation in thermal load in respect of climate to be illustrated using scatter graphs, bar charts, time series plots, polar plots and the psychrometric chart. This tool will allow for the direct comparison of significant simulations with apposing strategies as presented in table 9 allowing for a detailed understand of how high and low annual combined loads are attributed.

Several EnergyPlus input files are to be created based on the findings presented in chapter 4.0 allowing for a more detailed analysis of the specific design strategies and simulated using the prepared weather files of the representative cities.

Several techniques are presented in this methodology to analyze and present the data, with an emphasis on a bioclimatic analysis process. Therefore, this Chapter focused on the techniques used to analyze and present the data on the psychrometric chart. Matlab was used to extract, analyze and display the data.

Location and orientation are significant factors in this analysis as they were found in chapter 4 to influence energy savings with rising latitude and total annual solar radiation correlating with the work of Reinhart (2002). Orientation has been explored by Bodart and Herde (2002), - an appreciation of solar geometry in relation to orientation and location is essential and plays a fundamental role in shading geometry (Niccolò, et al. 2012; Kim, et al. 2012) as well as sensible thermal loads. In this study, the phenomena of direct beam radiation are addressed through varying balcony depth within the thermal model as a primary shading device. This has a significant effect on the reduction of the direct beam fraction into the interior (McCartan and Kvilums, 2013c). The methodology presented therefore would offer a more detailed synopsis of how these passive strategies influence seasonal loads in contrast to the analysis presented in chapter 4 which has the capabilities of displaying only in an annualized format. Table 3 illustrates the climatic and location parameters that are extracted from the simulation and climate files for further analysis.

6.0 RESULTS AND ANALYSIS

In completion of the parametric study (covered in Chapter 4) which simulated zones in a range of climates across the Mediterranean - it is possible to identify the passive characteristics which were most and least conducive in reducing solar gains as well as the annual heating and cooling requirements. The zones which exhibited the highest and lowest combined heating and cooling loads are therefore, the subject of further enquiry and are analyzed using the psychrometric chart –a common analysis tool used to assess the thermal needs of a building at the initial design stage. The table presented within appendix 6.1 defines the thermal model specifications of the zone simulations which have been selected for further analysis.

The considered test weather conditions and the individual zone traits are to be analyzed and graphically represented adopting the analysis techniques presented in the works of Visitsak (2007) – who conducted a similar study on terrestrial structures. Such methods allow for climate and thermal loads to be simultaneously represented leading to an understanding of bioclimatic boundaries.

A bioclimatic boundary in this research is considered as a hypothetical boundary plotted onto a psychrometric chart which marks the outdoor climatic conditions in which a transitional thermal state is observed in the interior of a zone. An interior "state" could be defined as thermally comfortable, thermally too hot or thermally too cold. These interior states could also be defined as the outdoor conditions when; a) No additional active conditioning is required b) active cooling is required or c) Active heating is required. The psychrometric chart therefore, enables the illustration of these transitions whilst also providing design direction by allowing direct comparison of weather conditions in relation to thermal comfort parameters, interior thermal loads, set point temperatures and calculated balance point temperatures.

Interior states can be varied due to the incorporation of specific passive strategies which alter the ratio between heat gains and losses as illustrated in appendix 3.11, the placement of bioclimatic boundaries on the psychrometric chart also marks the impact of specific passive technology.

The psychrometric chart is favorable in terms of a detailed analysis as it adequately describes the behavior of a moist body of air (as defined within figure 35) and can capture the traits of both interior and exterior conditions simultaneously. In graphically illustrating the impact of passive strategies it makes an appropriate assessment method for engineers and designers. Within the psychrometric charts presented within this chapter (such as in figure 40) specific active and non-active conditioning periods are represented by colored dotted lines. The charts are denoted as follows; Red Boundaries 'A', 'B', 'C', 'D', 'E' and 'F' represent the 1^{st},5^{th},10^{th}, 90^{th}, 95^{th}, and 99^{th} percentile ranges of when active heating occurs. The blue Boundaries 'G', 'H', 'I', 'J', 'K' and 'L' represent the 1^{st},5^{th},10^{th}, 90^{th}, 95^{th}, and 99^{th} percentile ranges of when active cooling occurs. The green Boundaries 'M', 'N', 'O', 'P', 'Q' and 'R' represent the 1^{st},5^{th},10^{th}, 90^{th}, 95^{th}, and 99^{th} percentile ranges of when no active heating or cooling occurs.

The analysis presented, offers a more detailed analysis than that compared to presented in chapter 4.0 by allowing simulation data to be presented in both an hourly and monthly time series format. In this instance, a data extraction and analysis tools was developed to allow for a deeper understanding of passive architecture in relation to thermal demands and the exterior climate. The output of this tool is in the format of an excel report which provides analysis in the subcategories of; 1) Interior and exterior dry bulb and latent conditions, 2) Internal heat gains and losses analysis, 4) Climatic Psychrometric analysis, 5) Bioclimatic psychrometric analysis, 6) Psychrometric and detailed analysis of outdoor conditions during periods of heating 7) Psychrometric and detailed analysis of outdoor conditions during periods of cooling and 8) Psychrometric and detailed analysis of outdoor conditions during non-heating and cooling periods. The reports for each of the simulations investigated in this chapter as per table 9 are presented in appendices 6.5 to 6.18 and are discussed in detail in sections 6.5 to 6.8 of this chapter.

6.1 Characteristics of High and Low Performance Zones

The parametric analysis revealed the impacts of, shading, glazing type, glazing size, orientation and interior thermal loads on the combined annual heating and cooling loads. The parametric study revealed that a combination of multiple passive strategies offers the best reduction in interior loads. The particulars of the passive strategies resulting in the lowest annual combined heating and loads however, varied in accordance to the environmental context and in particular the zones orientation.

Tables 1.0 to 1.1 of Appendix 6.0, tabulates the combined heating and cooling loads for simulations conducted in all the test locations, in which the highest annual combined loads were observed. Tables 2.0 to 2.1 tabulates the combined heating and cooling loads for simulations that produced the lowest annual loads. These tables were developed by arranging simulation results in accordance to their combined annual heating and cooling load. In Tables 1.0 to 1.1 for instance – annual combined values were arranged in descending order in which the simulation with the highest combined value was recorded along with its zone characteristics including; orientation, glazing percentage, the glazing system type, shading depth and internal gains status. The same procedure was conducted in producing the results of tables 2.0 to 2.1, in which the values were arranged in ascending order to identify the simulation with the lowest combined annual load.

The parametric analysis conducted in chapter 4.0 - showed that thermal loads differ vastly when orientation and glazing percentage are altered thus the process of arranging simulations in order of their combined annual loads was conducted for zones with 20%, 50% and 80% glazing in both a northerly and southerly orientation. Overall, the above procedure would allow for the identification of the impact of weather conditions, zone configurations leading to high annual loads and zone configurations leading to low annual loads. A comparative analysis of relative zones therefore, would identify what is the most effective passive strategy for a given orientation, location and glazing percentage allowing for an assessment of the potential of PD for a given location and a comparative analysis of both desirable and undesirable PD traits.

6.2 Simulations with High Annual Thermal Loads

Tables 1.0 to 1.1 of Appendix 6.0, indicates the combined annual thermal loads for the simulations which had the highest need for active conditioning of interior air.

Across all simulations tabulated within this table, it was indicated that zones with a large glazing façade (at 80%) and orientated in a southerly direction - produced the highest combined annual loads across all test locations. The highest annual loads were observed in Tripoli at 3601 kWh per annum followed by Alicante at 3501kWh per annum and Alexandria at 3376kWh per annum. Simulations conducted in the test weather conditions of Tripoli, possessed high annual loads across all glazing percentages relative to other zones, whilst simulations conducted In Pisa possessed the lowest annual loads across all glazing percentages considered.

For zones orientated in a northerly direction, it was also observed that zones with a large glazing percentage had the highest heating and cooling requirement. Simulations conducted in Tripoli, again represented the highest annual loads with monthly annual combined heating and cooling loads of 1981kWh per annum. High loads were also observed in Venice and Alexandria. Tripoli possessed high annual loads across all glazing percentages relative to other zones orientated north, whilst simulations conducted In Ceuta, possessed the lowest annual loads across all glazing percentages considered.

Glazing size appears to be highly influential on monthly annual combined heating and cooling loads. In tables 1.0 to 1.1 of appendix 6.0, the reduction in the sum of monthly annual loads as a result of reducing glazing percentage from 80% to 20%, is on average across all test locations - between 43.9% and 58.2% depending on zone orientation. In addition to this, orientation also appears to have a significant impact, particularly in zones with a high glazing percentage in hotter climates. In this instance, it was observed that for zones with an 80% glazed façade changing its orientation from south to north can reduce the combined monthly annual loads from between 45.0% to 61.1% for simulations conducted in Alexandria, TelAviv, Tripoli, Ceuta, Athens, Alicante and Barcelona and between 21.9% to 28.1% for simulations conducted in Pisa, Rimini, Venice and Trieste.

Overall, the highest annual loads were observed in zones with an 80% glazed façade orientated south where mean annual combined loads across all locations, equated to 2832 kWh. The lowest combined annual thermal loads were observed in zones orientated north with a minimal 20% glazed façade - attributing to mean annual loads of 906 kWh across all locations.

Table 12 of Appendix 6.4 – Indicated the characteristics of an 80% glazed zone resulting in high annual loads. In this instance, they were identified as being; a zone orientated in a southerly direction, minimal shading (at 0.5m depth), high internal heat gains and glazing systems type D & F. Type D systems have U values of 2.549 $W/m^2/K$ and SHGC values of 0.7 and were represented in simulations conducted in locations such as Alexandria, Tel Aviv, Ceuta, Alicante and Barcelona. Type F systems have U values of 5.383 $W/m^2/K$ and SHGC values of 0.7 and were represented in locations such as Tripoli, Athens, Pisa, Rimini, Venice and Trieste. The same glazing types and zone configurations were also observed in zones with high annual loads and glazing percentages of 50%.

6.3 Simulations with Low Annual Thermal Loads

Tables 2.0 to 2.1 of Appendix 6.0, indicates the combined annual thermal loads for the simulations which had the lowest combined monthly annual heating and cooling loads.

Across all simulations tabulated within this table, it was indicated that zones with a small glazing façade - produced the lowest combined annual loads across all test locations. The top lowest annual loads were observed in Ceuta (Spain) at 199 kWh per annum for a zone in a southerly orientation with a 20% glazed façade. The lowest annual loads for a simulation conducted on a zone with a northerly orientation were also observed in Ceuta.

Unlike the simulations which produced high annual loads as represented in tables 1.0 and 1.1 of appendix 6.0, the impact of glazing size appears to be less influential on annual combined heating and cooling loads. As indicated in table 2.0 to 2.1 of appendix 6.0 - the reduction in the sum of monthly annual loads because of glazing, is on average across all test locations - between 21.19% and 20.3% depending on zone orientation. In general, it can be stated that the lowest combined annual loads in this instance are witnessed in zones orientated south.

For zones orientated in the north it was observed that zones with a large glazing percentage had higher annual loads when compared to those zones with smaller glazing percentages. Simulations conducted in Venice indicated the highest annual loads amongst all the test locations with a requirement of 826 kWh per annum with an 80% glazed facade. High loads were also observed in Trieste and Rimini. Thus, amongst the simulations that produced the lowest annual loads the simulations conducted in Venice (and other cooler climates) produced the highest thermal demands relative to the data set presented in table 2.0 to 2.1. Sections 6.7 presents a detailed analysis of simulations conducted in Venice due to its significance in the above data set which attempts to explain this phenomenon.

Overall, the highest annual loads were observed in zones with an 80% glazed façade orientated north where mean monthly annual combined loads across all locations, equated to 616 kWh as per table 2.0 of appendix 6.0. The lowest combined annual thermal loads were observed in zones orientated south with a minimal 20% glazed façade with mean annual loads of 454 kWh as per table 2.1 of appendix 6.0.

For zones with an 80% glazed façade orientated south, the characteristics resulting in low monthly annual loads as indicated in table 11.0 of Appendix 6.4, included; large shading devices between

1m to 2m in depth and the incorporation of glazing system type B. Type B systems have U values of 1.34 W/m^2/K and SHGC values of 0.33. In addition to these characteristics it was also observed that low internal heat gains were preferred in all instances except for simulations conducted in Rimini and Venice which represent the coolest weather conditions within the dataset, with mean annual temperatures ranging from 12.7ºC to 13.1ºC respectively. Similar characteristics were also observed for zones orientated north, with large shading devices, type B glazing systems and low internal heat gains preferred – except for the test locations of Pisa, Rimini, and Venice. The same traits were also observed for zones simulated with a 50% glazed façade as indicated by table 5.0 of Appendix 6.3.

Zones with a 20% glazed façade orientated south, were found to produce the lowest combined monthly annual loads as noted above. Characteristics leading to this as indicated by table 3.0 of Appendix 6.2 include; Shading devices between 1m to 2 m in depth, a type B to C glazing system and low internal gains. The modal shading depth was at 1.0m in this instance with typically low internal heat gains, except for the test locations of Rimini and Venice. Comparable results were also observed in zones orientated north except for internal heat gain sources which were preferred to be low, except for the locations of Pisa, Rimini, and Venice as indicated in table 1.0 of appendix 6.0.

6.4 Comparative Analysis of Zones with High and Low Annual Loads

Tables 3.0 to 3.1 of appendix 6.0, describe the values which define the decrease in annual loads by comparing the zones with the highest annual loads to the lowest annual loads. In effect this illustrates the potential reduction in annual loads when applying the passive strategies investigated within this study.

Table 3.0 indicates the reduction in combined monthly annual loads as a result of applying passive strategies to those zones orientated north. In all scenarios, a reduction in annual combined monthly loads was observed. The **greatest reduction is observed in the zones simulated in Alexandria, Tel Aviv and Tripoli** in zones with a highly-glazed façade in which a mean reduction of 68.3% occurred. The **lowest reductio**n is observed in zones simulated with a 20% glazed façade in the test locations of **Barcelona, Pisa and Trieste** where a mean reduction of 29.7% Is observed in the monthly annual combined heating and cooling loads.

Table 3.1 indicates the reduction in combined monthly annual loads as a result of applying passive strategies to those zones orientated south. In comparing the two tables it is identified that zones orientated south witness a greater reduction in annual loads when PD is employed than compared to zones orientated north. Simulations conducted in the test locations of **Alexandria, Tripoli and Alicante witnessed the greatest reduction** in annual loads especially in zones with an 80% glazed façade where a mean reduction of 84.4% was observed. Zones with the **lowest reduction in annual loads were observed in Pisa, Venice, Rimini and Trieste** and possessed a 20% glazed façade in which a mean reduction of 38.5% was observed.

Table 9 below summarizes the aforementioned simulations, in which their characteristics are presented. The zones presented in this table represent the scope of the impact of PD on thermal loads across the Mediterranean as determined by the methodology adopted within this study.

Table 9 Significant simulations and their attributes resulting in high or low combined annual loads as identified through sorting simulations results in ascending and descending order in accordance to their combined annual loads following an analysis of the parametric simulation results presented in chapter 4.

SIM ID	Location	Orientation (North/South)	Glazing Percentage	Glazing Type	Shading Depth(m)	Internal Gains HIGH/LOW	Sum of Annual Occupant Gains (kWh)	Sum of Annual Solar Gains (kWh)	Sum of Annual Equipment Gains (kWh)	Sum of Annual Lighting Gains (kWh)	Interior Gains Total (kWh)	Sum of Annual Total Heating (kWh)	Sum of Annual Sensible Cooling (kWh)	Sum of Annual Sensible Loads (kWh)
S01	Tripoli	S	80%	F	0.5	HIGH	520	3017	221	668	4427	9	3592	3601
S02	Tripoli	S	80%	B	2	LOW	550	268	0	0	817	6	713	719
S03	Ceuta	S	20%	B	1	LOW	569	144	0	0	713	108	91	199
S04	Ceuta	S	20%	D	0.5	HIGH	524	630	221	668	2043	0	1024	1024
S05	Ceuta	S	80%	B	2	LOW	568	283	0	0	851	143	132	275
S06	Ceuta	N	80%	F	0.5	LOW	577	1158	0	0	1734	661	372	1033
S07	Ceuta	S	80%	D	0.5	HIGH	510	2905	221	668	4304	4	2652	2656
S08	Ceuta	N	80%	B	2	LOW	576	170	0	0	746	247	117	364
S09	Pisa	S	80%	F	0.5	HIGH	559	2163	221	668	3611	436	1681	2117
S10	Pisa	S	80%	B	1	LOW	570	406	0	0	976	335	217	552
S11	Venice	N	20%	F	0.5	LOW	578	205	0	0	783	789	175	964
S12	Venice	N	20%	B	2	HIGH	558	32	221	668	1478	202	467	669
S13	Venice	S	80%	F	0.5	HIGH	561	2102	221	668	3552	710	1711	2421
S14	Venice	S	80%	B	2	HIGH	558	205	221	668	1652	245	534	778

6.5 Analysis of Passive Design on Interior Loads in Tripoli (Libya)

In Appendix 6.0, tables 1.0 to 1.1 indicate that - Tripoli, was the location in which the greatest combined heating and cooling loads were observed. This section presents an analysis of two simulations conducted in this location - S01 and S02 which are defined within table 9 (page 122). S01 represents the parameters resulting in the greatest annual loads whilst simulation S02 represents the best reduction achievable within this location as a result of the application of passive strategies as outlined within the parameters tree in figure 22. In each case a detailed analysis report is generated by a program developed in Matlab (as outlined within chapter 5) and is documented in appendices 6.5 and 6.6.

The climate within which the highest annual loads were observed is best illustrated by figures (a),(b),(c) and (d) of page 1 within the detailed analysis presented in Appendix 6.5 (for simulation S01) and 6.6 (for simulation S02). In this location, an annual mean temperature of 20.3°C was observed with a mean annual relative humidity of 66.6%. Peak outdoor temperatures were between 1.6°C and 45.6°C representing a large range of temperatures. In Accordance to the ASHRAE classification system the location exhibited 3938 CDD (at base 10°C) and 657.95 HDD (at base 18°C) and represented the Koppen climate type Bsh (Arid/Hot), and the ASHRAE climate type 2B (Hot dry). Overall the test location of Tripoli represented conditions with the highest CDD value within all of the test weather conditions represented within this study, ranked second highest in terms of mean annual temperatures and third highest in terms of mean annual global horizontal solar radiation.

6.5.1 Analysis of simulations with high loads

Zone parameters adopted by simulation S01, produced the greatest combined annual loads within this study equating to 3601 kWh. Traits exhibited by this zone as indicated by Appendix 6.1 include a zone orientated in a southerly direction, with an 80% glazed facade, a minimal shading device (0.5m depth), with all interior gains turned on and a glazing system (Type 'F') which had both high 'U' values and SHGC values (as per table 9 in section 3.2). Results of the simulations conducted are discussed in appendix 6.19.

Parameters resulting in high annual loads included high solar gains attributed by a glazing system with a high SHGC. Figure (a) of page 3 of Appendix 6.15 demonstrate how solar gains and other interior heat gain sources vary throughout the year. The combined annual sum of heat gains from occupants, equipment, lighting and solar gains equates to 3866.63 kW per annum in S01. In an annual comparative analysis of the interior heat gains, it is observed that the combined monthly heat gain from occupants equates to 518.88 kW per year (representing 13.4% of the annual combined interior heat gain sources) to the thermal loads of the zone, interior lighting attributes 668.06 kW per year (representing 17.3%), electrical equipment attributes to 220.88 kW per year (representing 5.7%) whilst solar gains attribute to 2458.82 kW per year (representing 63.6%).

Additionally, the external façade with a high U value attributed by a low performance glazing system created high heat gains and losses through the zone fabric that fluctuate with outdoor temperatures as illustrated by figures 'b' and 'd' of page 3 of appendix 6.15. These figures indicate that the greatest gains and losses are experienced in the months of Oct, Sep and Nov with monthly combined sum of gains and losses equating to 356.9kW, 343.6 kW and 302.4 kW respectively. This coincided with the months of high cooling as illustrated in figure 'c' on page 2 of the analysis presented in the appendix. The lowest was observed in the months of Feb, Mar and Apr equating to 204.7 kW, 196.0 kW and 157.8 kW respectively. This coincided with months of low active cooling and the months in which the greatest frequency of non-heating and cooling hours were observed.

6.5.2 Analysis of Simulations with low loads

For a zone situated in the same location and orientation with an 80% glazed façade, the application of the passive strategies as defined by simulation S02 - has resulted in a reduction of the combined annual loads of 2882 kWh to 719 kWh per annum, representing an 80.1% decrease. This was achieved through the application of passive strategies including; increasing the shading depth of the external shading system to 2.0m depth, decreasing interior heat gains to a bare minimum and by incorporating a high-performance glazing system (Type 'B' as characterized in table 7) which had both low U and SHGC values. Results of the simulations conducted are discussed in appendix 6.20.

Parameters resulting in low annual loads included shading systems and high-performance glazing which significantly reduced solar gains and heat gains and losses through the glazing element. As heat gains from lighting and equipment were excluded in this instance occupant gains represented the largest interior heat gain source equating to 549.32 kW per year - representing 66.6% of the annual combined interior heat gain sources (which includes solar gains).

6.5.3 Comparative Analysis

Figure 39 is a 3D bar chart comparing the annual loads for S01 and S02. The above analysis of Simulations S01 and S02 identified that cooling was the dominant thermal requirement in both instances. In the analysis of S01 it was evident that the combined internal gains resulted in high cooling loads of 2793.31 kW per annum. Solar gains were the dominant interior gain in this instance at 2459kW representing 63.6% of the combined annual interior gains. The analysis of S02, indicated that the best passive strategy from the parameters exercised within this study worked to reduce cooling's load to 557.89kW (a reduction of 2235.42 kW- 80%) and solar gains to 274.9 kW (representing a reduction of 2183.92kW – 88.8%). Passive Shading therefore, is deduced as the most effective passive strategy.

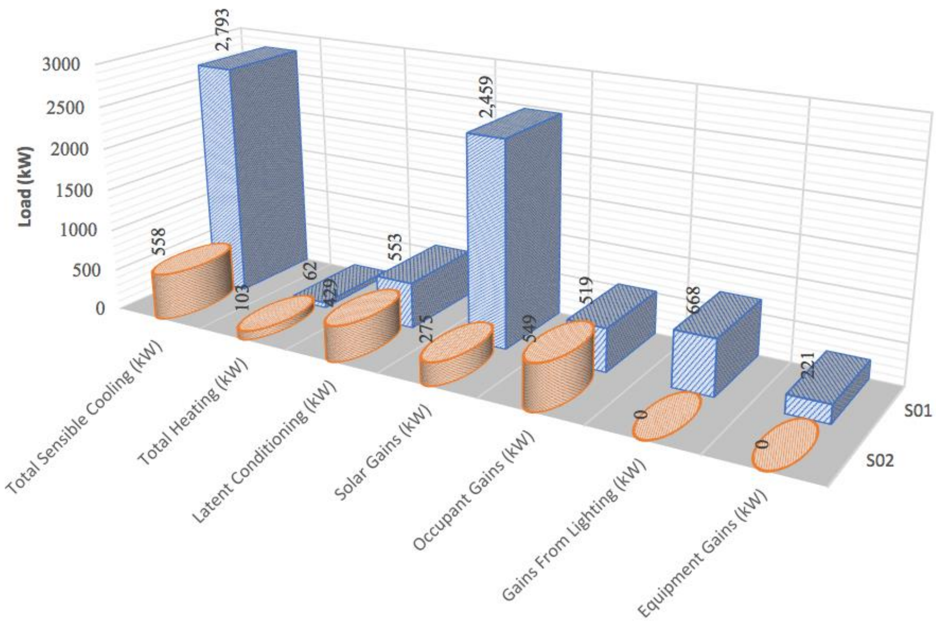


Figure 39 Comparative analysis of annual loads for simulations S01 and S02 illustrating the influence of the application of passive strategies

Figure (a) of pages 10, 12, and 14 within the appendix of 6.5 and 6.6 are psychrometric frequency density charts which represent the occurrence in which heating, cooling and non-heating and cooling occurred. Figure 40 below summarizes the range of exterior conditions during these thermal states for the simulation results of S01 whilst figure 41 represents the simulations results of S02.

In S01 heating occurred when exterior temperatures ranged between 6.0ºC and 20.0ºC based on the 10^{th} and 90^{th} percentile range with mean hourly temperatures of 11.1ºC. Mean hourly interior gains during this period equated to 0.024 kW and peak heating loads equating to 0.39kW. In S02 represented by figure ‘d’ in page 11 of appendix 6.6, there was an increase in heating, which occurred when outdoor temperatures ranged between 6.5 ºC and 14.0 ºC based on the 10th and 90th percentile with mean hourly temperatures of 10.1ºC whilst mean heat gain and losses equated to 0.001kW with peak loads equating to 0.24kW. Overall there was a reduction in range of outdoor temperatures in which heating occurred as well as reduction in peak loads of 38.5%.

In S01 represented by figure 40, cooling occurred when exterior temperatures ranged between 14.5ºC and 32.6ºC (Δ18.1 ºC) based on the 10th and 90th percentile range with mean hourly temperatures of 23.3ºC. Mean hourly interior gains during this period equated to 0.362 kW and peak cooling loads equating to 0.97kW. In S02 represented by figure 41, there was a decrease in cooling, which occurred when outdoor temperatures ranged between 20.0 ºC and 34.0 ºC (Δ14 ºC) based on the 10th and 90th percentile with mean hourly temperatures of 26.4ºC whilst mean heat gain and losses equated to 0.063kW with peak loads equating to 0.44kW. Overall there was a reduction in range of outdoor temperatures in which cooling occurred as well as reduction in peak loads by 54.6%. In addition to this, the region in which cooling occurred has shifted right on the psychrometric chart and the frequency of cooling hours reduced from 6574 hours per annum to 4568.

In S01 as represented by figure 40, periods of non-heating and cooling occurred between 9.0ºC and 17.0ºC (Δ8 ºC) based on the 10th and 90th percentile range with mean hourly temperatures of 12.71ºC. Mean hourly interior gains during this period equated to 0.002 kW. In S02 represented by figure 41, non-heating and cooling periods occurred when outdoor temperatures ranged between 11.4 ºC and 20.1 ºC (Δ8.7 ºC) based on the 10th and 90th percentile with mean hourly temperatures of 15.8ºC. Overall there was shift in the conditions to the right of the psychrometric chart when non-heating and cooling conditions occurred. In addition to this, the application of passive strategies increased the frequency in which no active heating and cooling occurred from 1488 hours to 2678 hours.

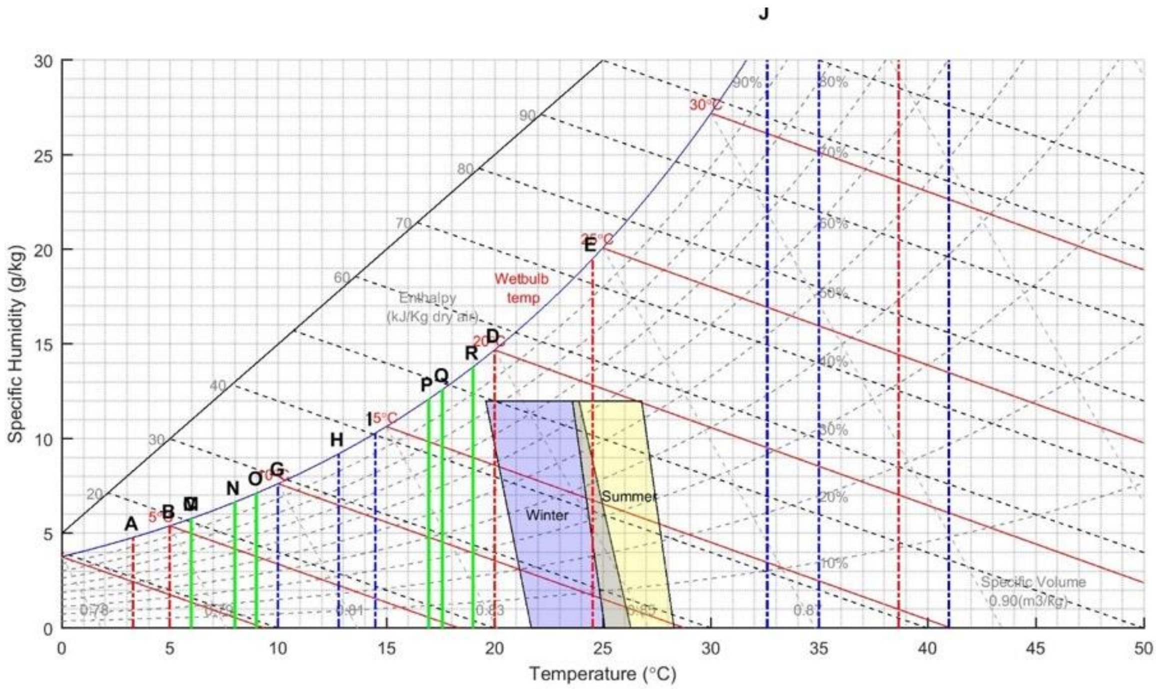


Figure 40 A Psychrometric chart indicating the 1st,5th,10th,90th,95th and 99th percentile ranges for outdoor temperatures during heating (indicated by red dotted lines – A,B,C,D,E,F), cooling (indicated by blue dotted lines – G,H,I,J,K,L) and non-heating and cooling periods (indicated by the green lines – M,N,O,P,Q,R)for simulation S01

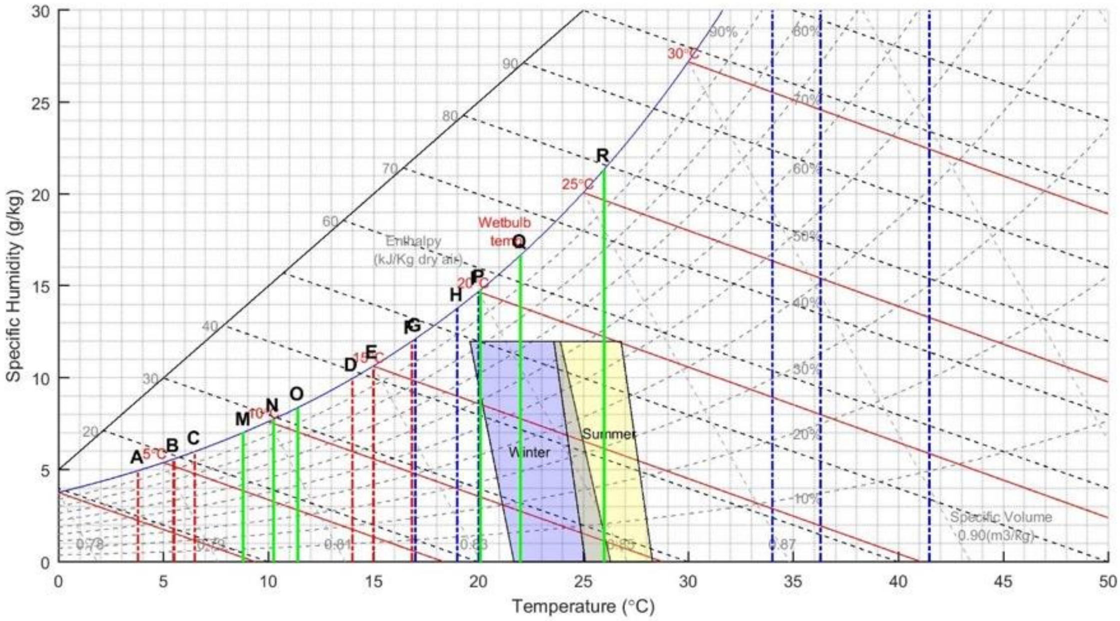


Figure 41 A Psychrometric chart indicating the 1st,5th,10th,90th,95th and 99th percentile ranges for outdoor temperatures during heating (indicated by red dotted lines – A,B,C,D,E,F), cooling (indicated by blue dotted lines – G,H,I,J,K,L) and non-heating and cooling periods (indicated by the green lines – M,N,O,P,Q,R)for simulation S02

6.6 Analysis of Passive Design on Interior Loads in Ceuta (Spain)

In Appendix 6.0, tables 2.0 to 2.1 indicate that Ceuta was the location in which the lowest combined heating and cooling loads were observed for all glazing percentages. This section focuses on two simulations conducted within the parametric analysis and are defined as S03 and S05, as defined within table 8. S03 represents the parameters resulting in the lowest combined annual loads which was identified as a zone with a 20% glazed façade. S05 represents the parameters resulting in the lowest combined loads for a zone with an 80% glazed façade. In each case a detailed analysis report is generated. Simulations S04, S06, S07 and S08 are also referenced within the below analysis.

The climate within the test location of Ceuta, is best summarized by figures (a), (b), (c) and (d) of page 1 within the detailed analysis presented in the appendix 6.7. In this location, an annual mean temperature of 16.1°C was observed with a mean annual relative humidity of 86.0 %. Peak outdoor temperatures were between 5.6°C and 32.2°C. In Accordance to the ASHRAE classification system the location exhibited 2403.8 CDD (at base 12°C) and 961.9 HDD (at base 18°C) and represented the Koppen climate type - CSa (Hot Summer – Mediterranean Climate) and ASHRAE climate type 4A (Mixed Humid).

6.6.1 Analysis of simulations with low loads and a 20% glazed facade

Simulation S03 represents zonal parameters resulting in the lowest annual combined heating and cooling loads witnessed within this study, equating to 199 kWh per annum. Traits exhibited by this zone as indicated by Appendix 6.2 include a zone orientated in a southerly direction, with a 20% glazed facade, shading (at 1.0m depth), with minimal interior gains and a glazing system (Type 'B') which has a 'U' value of 1.34 $W/m^2/k$ and a SHGC value of 0.329.

Appendix 6.7 illustrates the results for simulation S03. This indicates that throughout the year there was a heating to cooling ratio of 1:0.882– where by cooling accounted for 46.9% of the combined sum of heating and cooling load throughout the year. The results of the simulation are discussed in appendix 6.21. Figure 42 below compares the loads profiles for simulations S03 and SO4. In reference to table 9 – simulation S04 represents a zone that for a given glazing percentage (at 20%) had the highest loads for a zone in a southerly orientation situated in Ceuta.

Parameters resulting in low annual loads include a high-performance glazing system which reduced solar gains significantly. This is indicated by the bar chart (figure d) on page 2 of the analysis presented in the appendix in which; the combined monthly heat gain from occupants equates to 568.30 kW per year (representing 79.7% of the annual combined interior heat gain sources) to the thermal loads of the zone, whilst solar gains attribute to 145.17 kW per year (representing 20.3%). Figure 42 illustrates the significance of these factors in reducing annual cooling loads which for both simulations S03 and S04 – appears to be the dominant thermal demand.

Additionally, the reduced glazing percentage increases the overall U value of the exterior wall as it has a lower U value than any of the glazing systems used within this study. This reduces heat gains and losses via the exterior façade which is illustrated by figure 'b' of page 3 of the appendix. Furthermore, as the exterior temperatures rarely go above the mean interior temperature – there is hardly any occasions when heat gains are attributed to interior heat gains from the external facade. These factors combined, result in low interior heat gains, low cooling loads and low heating loads.

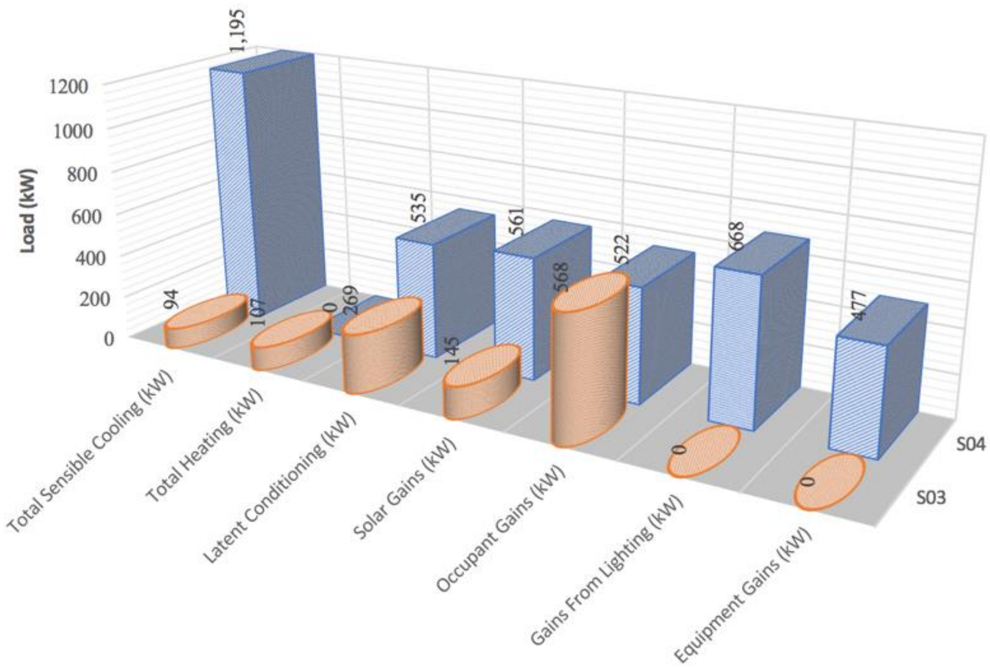


Figure 42 Comparative analysis of annual loads for simulations S03 and S04 illustrating the influence of the application of passive strategies for a zone with a 20% glazed façade

6.6.2 Analysis of simulations with low loads and an 80% glazed facade

Simulation S05 was also conducted in Ceuta and situated in a southerly orientation but has an 80% glazed façade. This simulation represents the lowest interior annual loads for a zone with this glazing percentage whilst simulation S07 represents the highest. As per Appendix 6.4, the attributes leading to the low annual loads witnessed by S05 - was achieved through the application of the same passive attributes adopted by simulation S03. These parameters are discussed further in the comparative analysis below. Figure 43 indicates that solar gains and therefore, glazing types and solar protection from shading - is incredibly important in reaching low annual thermal loads in this location.

Appendix 6.9 illustrates the detailed analysis conducted on simulation S05. In summary, the simulation results indicate an annual heating to cooling ratio of 1:1.01 – where by cooling accounted for 50.3% of the combined sum of heating and cooling load throughout the year. An analysis of the simulation results for S05 are presented in appendix 6.22.

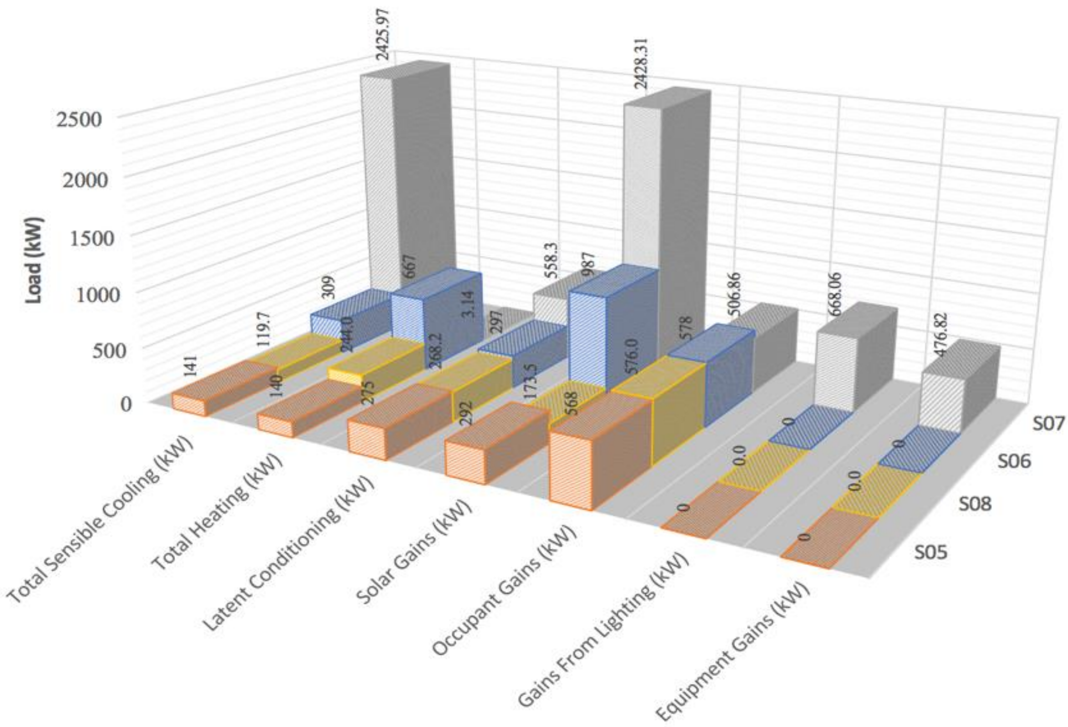


Figure 43 Comparative analysis of annual loads for simulations S05, S06, S07 and S08 illustrating the influence of the application of passive strategies for a zone with an 80% glazed façade

6.6.3 Comparative Analysis

Ceuta presented itself as a location with weather conditions most conducive to harboring reduced interior loads. Its weather conditions coupled with the application of passive strategies leads to a high frequency of hours in which no heating or cooling was required.

Figure d on page 11 of Appendix 6.9 and 6.7, indicate that when outdoor temperatures go below 16.1°C – active heating is required and is apparent in both S03 and S05 simulations - indicating an important balance point temperature. Furthermore, figures 'd' on page 13 of Appendix 6.9 and 6.7 indicate that active cooling is required when outdoor temperatures go above 16.1°C.

The identification of this significant balance point temperature highlights an outdoor condition that is otherwise representative of a bioclimatic or thermal boundary. This has been most evident in the analysis of S03 and S05 due to their being low internal heat gain sources and mean outdoor temperatures witnessed within the test location of Ceuta which over the year is 16.06 °C thus identifying the reason for a large frequency of non-heating and cooling hours within these simulations. Figures 44 and 45 highlight the range of outdoor conditions when non-active heating and cooling occurs for both simulations S03 and S05. This illustrates how the non-active heating and cooling range is centralized around the mean temperature of the location leading to a high frequency of non-active conditioning and low annual thermal loads.

When considering simulations of zones with a small glazing percentage (20%) conducted in the test location of Ceuta, figure 42 presents a bar chart illustrating the load profiles for simulations S03 and S04. S03 represents the simulations with the lowest combined heating and cooling load whilst S04 represents the loads of the zone with the highest annual loads due attributes which include; high interior heat gains from equipment and lighting and high solar gains due a glazing system with a high SHGC and limited shading. Combing the passive attributes outlined by simulation S03 as defined within Appendix 6.1 results in a reduction of annual heating and cooling loads of 83.2%.

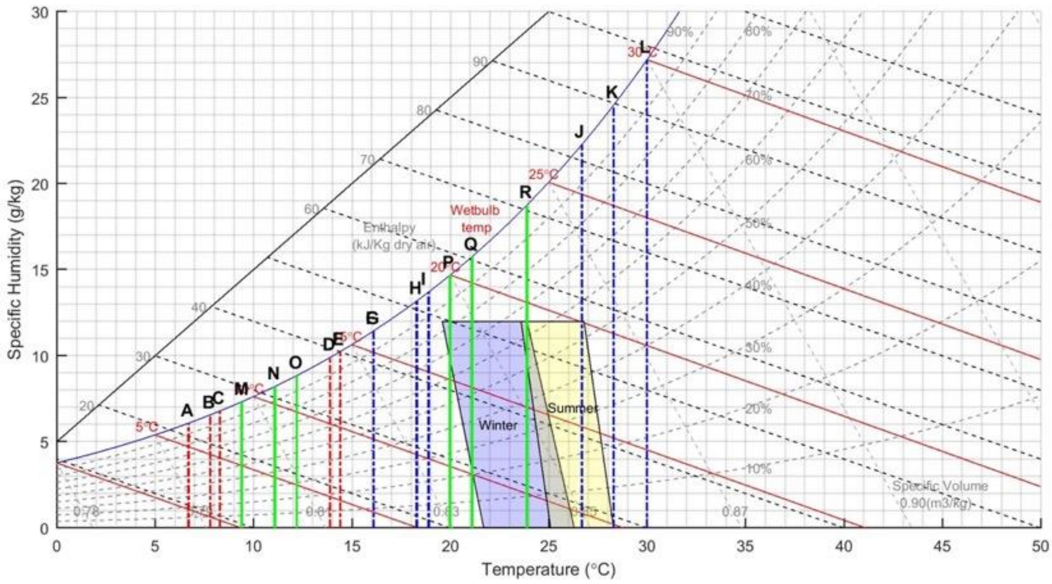


Figure 44 A Psychrometric chart indicating the 1st,5th,10th,90th,95th and 99th percentile ranges for outdoor temperatures during heating (indicated by red dotted lines – A,B,C,D,E,F), cooling (indicated by blue dotted lines – G,H,I,J,K,L) and non-heating and cooling periods (indicated by the green lines – M,N,O,P,Q,R)for simulation S03.

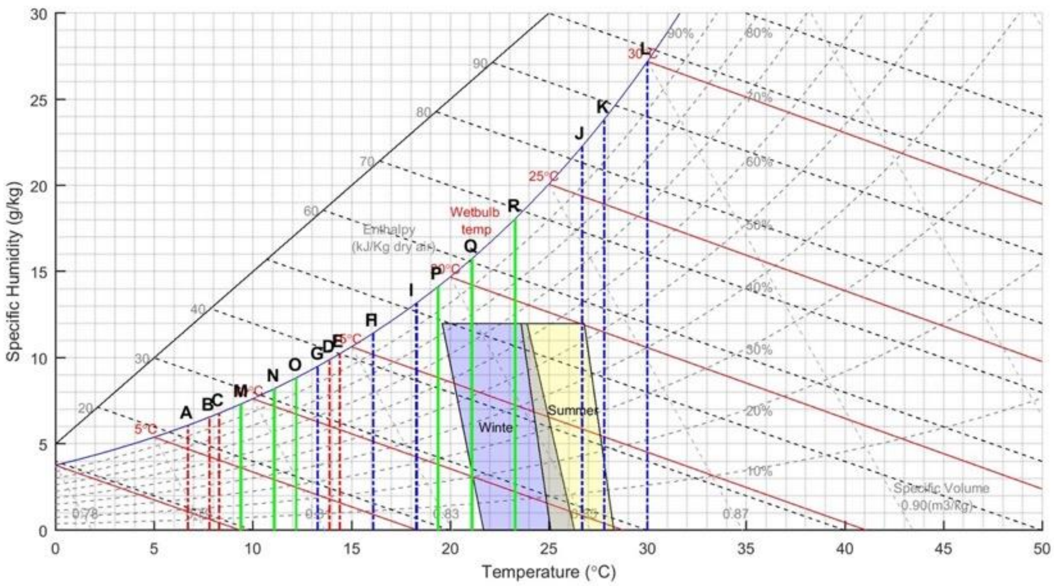


Figure 45 A Psychrometric chart indicating the 1st,5th,10th,90th,95th and 99th percentile ranges for outdoor temperatures during heating (indicated by red dotted lines – A,B,C,D,E,F), cooling (indicated by blue dotted lines – G,H,I,J,K,L) and non-heating and cooling periods (indicated by the green lines – M,N,O,P,Q,R)for simulation S05.

6.7 Analysis of Passive Design on Interior Loads in Venice (Italy)

In Appendix 6.0, tables 2.0 to 2.1 indicate the combined annual heating and cooling load for zones producing the lowest annual loads as per the parametric study conducted in chapter 4.0. The test locations of Venice, produced the highest annual loads within this data set across all considered glazing percentages and is therefore, the subject of further enquiry. Table 2.0 to 2.1 of appendix 6.0 also indicates that the test locations of Rimini and Trieste also produced high loads and are representative of the cooler climates within the test climates considered within this study. This section presents an analysis of four simulations conducted in this location – S11, S12, S13 and S14 which are defined within table 9 (page 122). Simulations S11 & S12 represents zones with parameters resulting in the highest and lowest annual loads respectively, for zones with a 20% glazed façade. Simulations S13 & S14 in the same way, represent zones with an 80% glazed façade.

The weather data extracted from a weather station in Venice – is best summarized by figures (a), (b), (c) and (d) of page 1 within the detailed analysis presented in appendix 6.15. In this location, an annual mean temperature of 13.1°C was observed with a mean annual relative humidity of 79.7%. Peak outdoor temperatures were between -5.7°C and 33.5°C. In Accordance to the ASHRAE classification system the location exhibited 1869.3 CDD (at base 12°C) and 2224.6 HDD (at base 18°C) and represented the Koppen climate type Cfb (Temperature, Oceanic Climate), and ASHRAE Climate type 4A (Mixed Humid). Overall this test climate represents one of the coolest within the test locations represented within table 3 (page 74), with one of the highest number of heating degree days.

Simulations S11 and S12 are analyzed to provide a comparative analysis of zones with high and low annual loads within the location of Venice for zones with a 20% glazed facade. An analysis of the detailed simulation report is presented within appendix 6.23. Simulations S13 and S14 are analyzed to provide a comparative analysis of zones that have an 80% glazed façade. An analysis of the detailed simulation report is presented within appendix 6.24. A summary of the analysis for all the simulations (S11, S12, S13 and S14) conducted in the test location of Venice is presented in the comparative analysis below.

6.7.1 Comparative Analysis

Simulations conducted in Venice are exposed to a cooler climate relative to the other test weather conditions considered within this study with a mean annual temperature of 13.1°C. Simulations S11, S12, S13 and S14 are considered in the above analysis and indicate the impacts of the application of passive strategies in cooler climates. The annual loads profile for each of the considered simulations are graphically represented in figure 46.

In comparing simulation S11 and S12 - Simulation S12 shows the impacts of passive technology (including; shading, increased interior heat gains, and an improved glazing system (type B)) in reducing the combined annual heating and cooling loads by 22.01%. Figures ‘a’, ‘b’, ‘c’ and ‘d’ on page 3 within the detailed analysis of S11 and S12 represented in appendix 6.15 and Appendix 6.16 – indicate that this was achieved by a) reducing heat losses through the glazing element b) by increasing free heating via equipment and lighting and finally c) limiting interior heat gains by incorporating shading and a glazing system with a low SHGC. The application of these strategies increased the number of non-heating and cooling hours by 824 in comparison to simulation S11. The period of non-heating and cooling seemed to correlate with the balance point temperatures of the zones in question. For simulation S11, this appeared to be between ~17°C to ~18°C whilst for simulation S12 this appeared to be ~8°C. The application of passive strategies, shifts the balance point temperature closer to the mean annual temperature of the location in which the simulation is conducted and thus increasing the frequency of non-heating and cooling hours. In simulation S11, a majority of the outdoor monthly temperatures are below the balance point temperature for this zone leading to a heating to cooling ratio of 1:0.214 signifying a high requirement for active heating. As the balance point temperature of simulation S12 is much lower at ~8°C we witness a higher number of non-heating and cooling hours within the months of March and November which have mean monthly temperatures of 7.7°C and 8.7°C respectively.

When comparing simulations S13 and S14 – a similar comparison is observed as per the above. Simulation S13 to S14 shows the impacts of passive technology on zones with an 80% glazed façade showing its effect on the combined heating and cooling loads – indicating a reduction in annual loads of 59.8% (as illustrated in figure 46). In comparison to simulations S11 and S12 the influence of passive strategies is greater when compared to S13 and S14 - due to a substantial increase in glazing percentage – thus altering the window to floor area ratio.

Figures ‘a’, ‘b’, ‘c’ and ‘d’ on page 3 within the detailed analysis of S13 and S14 represented in appendix 6.17 and Appendix 6.18 – indicate that a significant reduction in annual loads was achieved by a) reducing heat losses through the glazing element by improving its thermal performance and thus decreasing the annual heating load considerably, especially in the winter months and b) improving the solar protection of the zone by incorporating a low SHGC glazing system. The latter being most poignant when comparing the impacts of PD within S13 and S14 as illustrated in figure 49. Interior heat gains from equipment, lighting and occupants remained constant in both simulations thus the influence of solar gain was most significant.

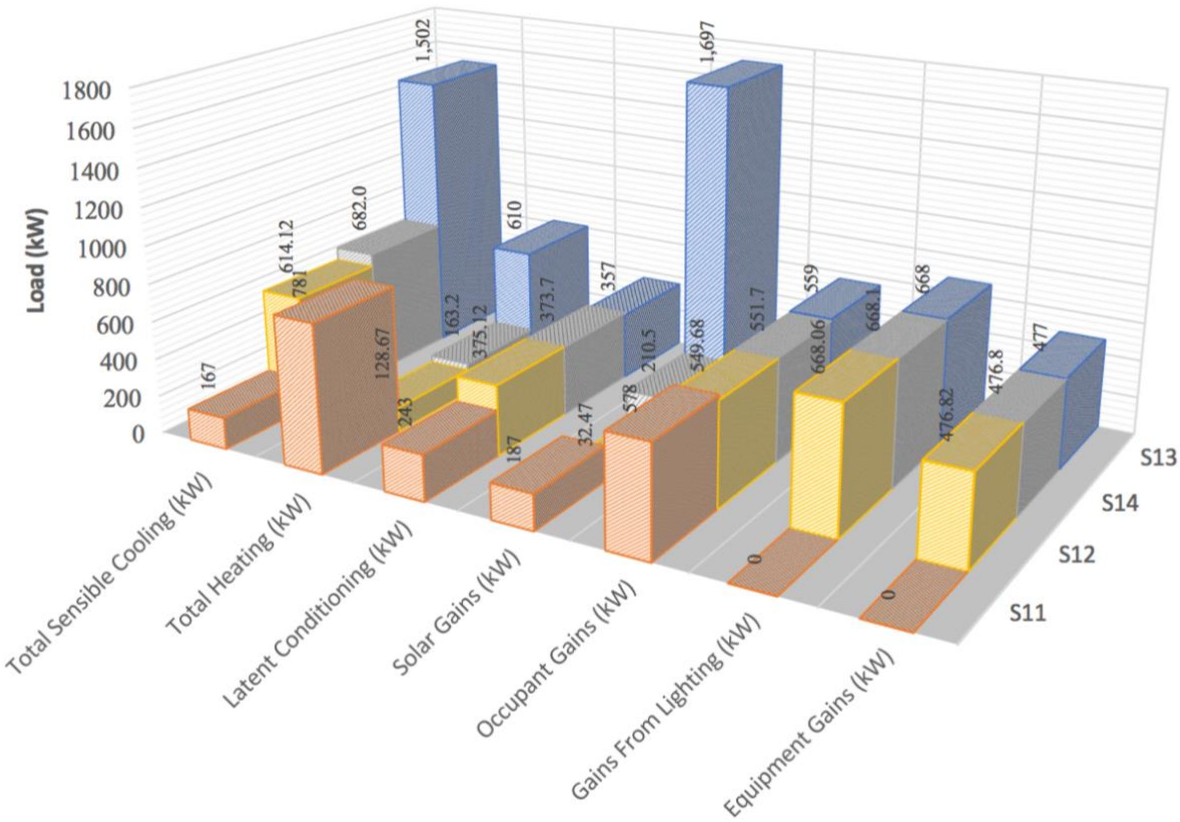


Figure 46 Comparative analysis of annual load profiles for simulations S011, S12, S13 and S14 - illustrating the influence of the application of passive strategies for zones with 20% and 80% glazing

In comparing simulations S13 and S14 – the application of PD strategies had a positive impact on annual loads decreasing the heating and cooling loads whilst increasing the number of non-heating and cooling hours by 906 hrs (as indicated by page 14 within appendix 6.17 and 6.18). Figure 47 compares the outdoor temperature ranges for when heating, cooling and non-active conditioning occurs for simulation S13, with figure 48 representing the same parameters for simulation S14. When comparing the two figures - they illustrate that the application of PD shifts the period of heating left of the psychrometric and reduces its range from -3.8°C to 12.4°C to

4.2°C - 9.1°C – resulting in a reduction of heating hours of 1198. In addition to this a narrowing of the outdoor temperature when active cooling was observed from between 4.2°C - 30.6°C (illustrated in figure 47) to 9.8°C - 20.7°C (illustrated in figure 48).

In section 6.3, simulations were compared against each other to identify characteristics resulting in the lowest annual heating and cooling loads. The results for this are presented in table 2.0 and 2.1 of appendix 6.0. It is worth noting that during this analysis Venice was identified as having the highest loads within this dataset when compared to simulations conducted in other locations. When considering the detailed analysis presented in appendix 6.23 and 6.24 – the reasons for this are as follows;

1. The location of Venice represents one of the coolest climates presented within this thesis with a mean annual temperature of 13.1°C and one of the highest number of hours per year below 15°C at 4892 hours (as per table 3). These factors contribute to extremely high heating demands especially in zones that have high glazing percentages with low U values.
2. Despite high heating demand – zones with limited solar protection also have a high demand for active cooling. Page 3 of appendix 6.17 presents the detailed analysis results for simulation S13 where this is the case. A high glazing percentage combined with a low SHGC could therefore also account for a high cooling demand.

Overall the combined factors resulting in both a high heating and cooling load coupled with the specific climatic conditions lead to a comparatively high annual thermal demand. When referring to table 2 in appendix 6 – similar climates represented by Rimini, Venice and Trieste also had comparatively high loads due the combined factors listed above.

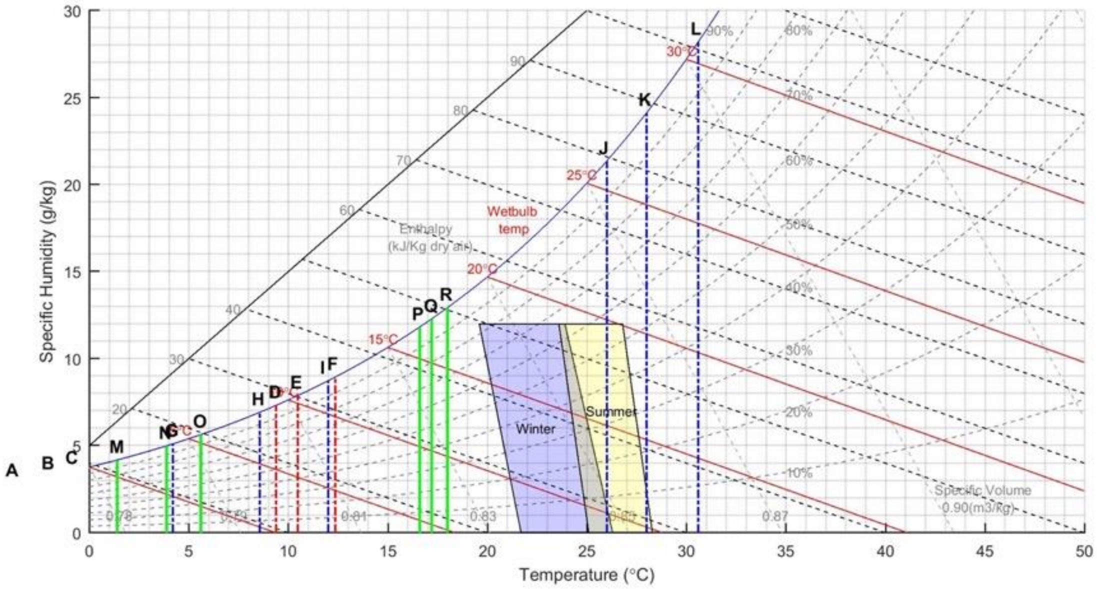


Figure 47 Psychrometric chart indicating the 1st,5th,10th,90th,95th and 99th percentile ranges for outdoor temperatures during heating (indicated by red dotted lines – A,B,C,D,E,F), cooling (indicated by blue dotted lines – G,H,I,J,K,L) and non-heating and cooling periods (indicated by the green lines – M,N,O,P,Q,R)for simulation S13.

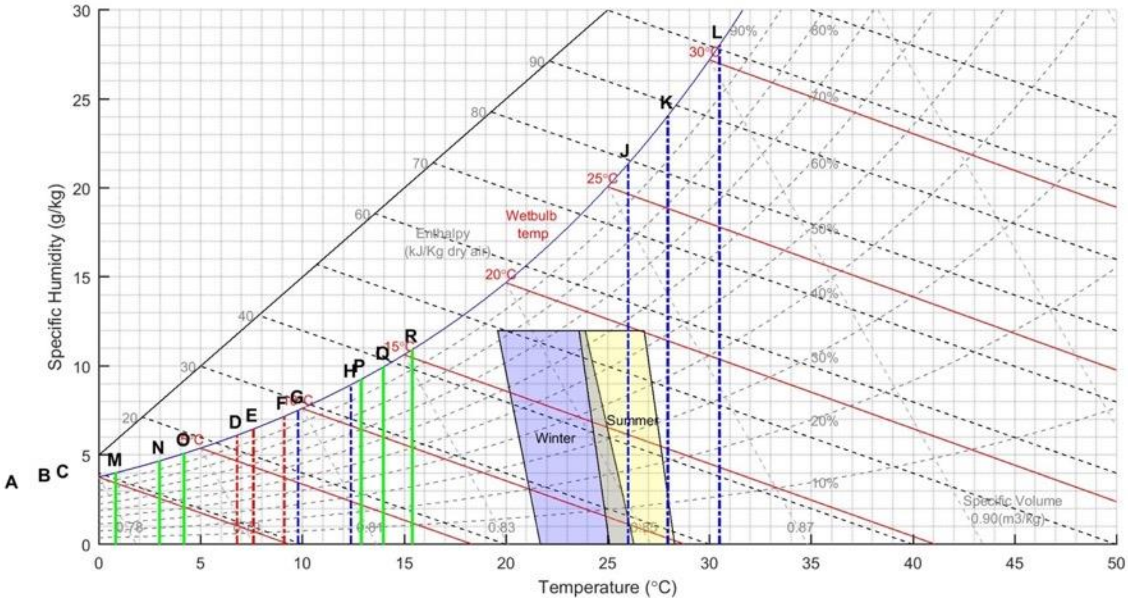


Figure 48 Psychrometric chart indicating the 1st,5th,10th,90th,95th and 99th percentile ranges for outdoor temperatures during heating (indicated by red dotted lines – A,B,C,D,E,F), cooling (indicated by blue dotted lines – G,H,I,J,K,L) and non-heating and cooling periods (indicated by the green lines – M,N,O,P,Q,R)for simulation S14.

6.8 Summary and Discussion.

Tables 1.0 to 1.1 of appendix 6.0 indicated the simulations with the highest monthly annual combined heating and cooling loads from the parametric study conducted in chapter 4. The analysis identified that the simulations with the highest annual loads typically had a large glazing percentage of 80%, were orientated south, had small shading devices, high interior heat gains and glazing systems with high U and SHGC values. Across all locations, as per table 1.1 in appendix 6.0, these factors resulted in a mean monthly annual combined heating and cooling load of 2832kWh. The highest loads in this instance were observed in simulations conducted in Tripoli, and Alexandria. The lowest loads within these tables were represented by zones in a with a 20% glazed façade and are observed in simulations conducted in Ceuta and Pisa. In review of the data represented in tables 1.0 to 1.1 – it was evident that location, orientation and glazing size had a key influence on the annual loads. This was most evident in simulations conducted in hotter climates on zones with a highly-glazed facade.

The lowest monthly annual combined heating and cooling loads from the parametric study conducted chapter 4.0, were tabulated in tables 2.0 to 2.1 of appendix 6.0. Overall a reduction in the combined monthly annual loads were observed across all test locations as a result of the application of passive strategies presented in Chapter 5.

The simulations with the lowest loads were observed in zones with a small glazing percentage of 20% orientated south, with a shading device of between 1m to 2m in depth, with mostly low internal heat gains and glazing systems with low U and SHGC values. Across all test locations, these factors resulted in a mean monthly annual combined heating and cooling load of 454kWh. The highest combined loads were observed in zones with a high glazing percentage (80% glazed façade) in a northerly orientation, resulting in mean monthly annual loads of 616 kWh. In both instances low internal heat gains, shading systems and glazing systems with low SHGC and U values were shown to derive the lowest annual combined loads. Glazing percentage and orientation were also shown to have an influence on zone performance but the greatest variation in annual loads was observed across simulations as a result of different weather conditions in which a reduction of between 55.6% to 69.6% could be observed when comparing annual loads. Weather and location therefore, has a fundamental impact on the performance of a PD strategy in reducing interior loads. The test location of Ceuta in this instance was observed to uphold the lowest annual loads whereas the test locations of Tripoli and Venice were shown to have the highest.

The analysis presented an overview of significant simulations which are defined within Table 9 which contains the simulations that were considered for a more detailed analysis due to their significance in terms of producing high annual loads, low annual loads and or were shown to be least affected by the application of passive strategies.

Sections 6.5 provides a detailed **analysis of the simulations conducted in Tripoli** and are represented by simulations S01 and S02. Here zones with an 80% glazed facade are compared in a southerly orientation, in one of the hottest test locations considered within this study with a mean annual temperature of 20.3°C and a range between 1.6°C and 45.6°C as illustrated in the psychrometric frequency plot in figure 49. The detailed analysis report generated by the analysis tool for both simulations are presented in appendix 6.05 and 6.06 – which allowed for a more detailed understanding of interior loads in relation to the exterior climatic conditions.

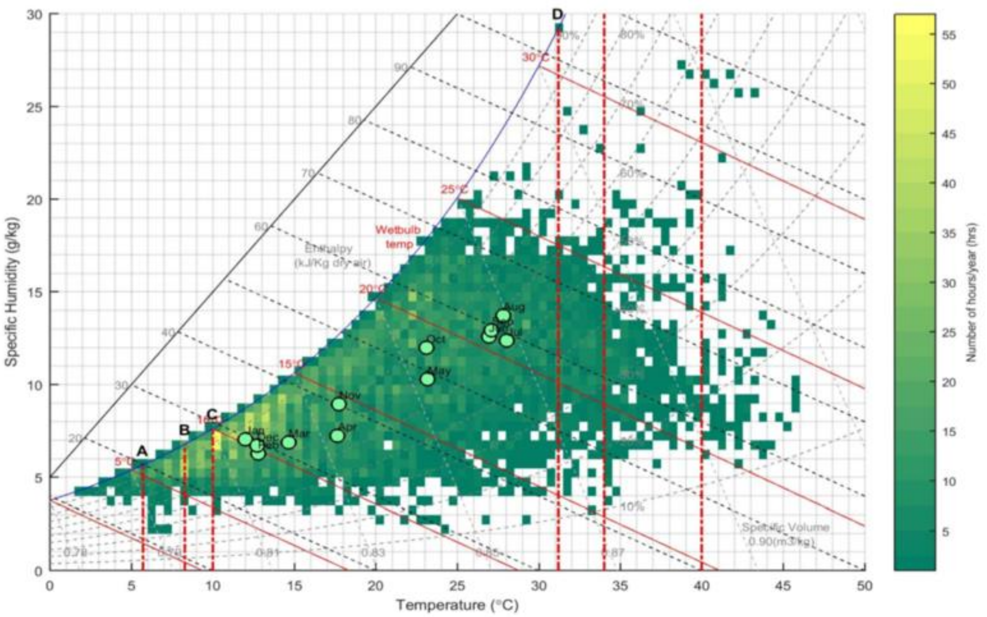


Figure 49 Psychrometric chart illustrating the frequency of conditions throughout the year for weather conditions witnessed within Tripoli (Libya), with monthly mean conditions indicated by green dots. The Red Boundaries 'A', 'B', 'C', 'D', 'E' and 'F' represent the 1st,5th,10th, 90th, 95th, and 99th percentile ranges of outdoor conditions

In the case of simulation S01 – solar gains represent 63.6% of the combined annual interior gains. Despite high heat losses via the glazing element – high interior gains led to requirement for continual cooling and interior conditions which fell outside of the heating and cooling set point temperatures. In the case of simulation S02 we find that the addition of passive elements such as shading and a high-performance glazing element lead to a significant reduction in solar gains and a reduction in the heat gains and losses through the building fabric, whilst interior conditions fluctuated as expected between the heating and cooling set points. Figures 'd' on page 11 and 13 of appendix 6.06 show that heating and cooling rapidly increase when outdoor temperatures are above and below ~17°C respectively – indicating a significant balance point temperature. In relation to simulation S01, represented by the same figures in appendix 6.05 – we find that the balance point temperature is less distinguished and in the case of cooling is much lower at around ~10°C. This correlates with the yearlong cooling requirements due to the mean monthly temperatures ranging much higher at between 12.0°C to 28°C.

Overall in the results of simulation S01 periods of non-heating and cooling occurred between 9.0ºC and 17.0ºC (Δ8ºC) based on the 10^{th} and 90^{th} percentile range with mean hourly temperatures of 12.71ºC. Mean hourly interior gains during this period equated to 0.002 kW. In simulation S02, non-heating and cooling periods occurred when outdoor temperatures ranged between 11.4 ºC and 20.1 ºC (Δ8.7 ºC) based on the 10^{th} and 90^{th} percentile with mean hourly temperatures of 15.8ºC. Overall there was shift in the conditions to the right of the psychrometric chart when non-heating and cooling conditions occurred. In addition to this, the application of passive strategies increased the frequency in which no active heating and cooling occurred from 1488 hours to 2678 hours.

Section 6.6 – summarizes a detailed analysis of **simulations conducted in Ceuta** – which was the location in which the lowest annual loads across all test locations were observed as per the parametric study, indicated within tables 2.0 and 2.1 of appendix 6.0. The climatic range for this location is illustrated in psychrometric chart presented in figure 50 below.

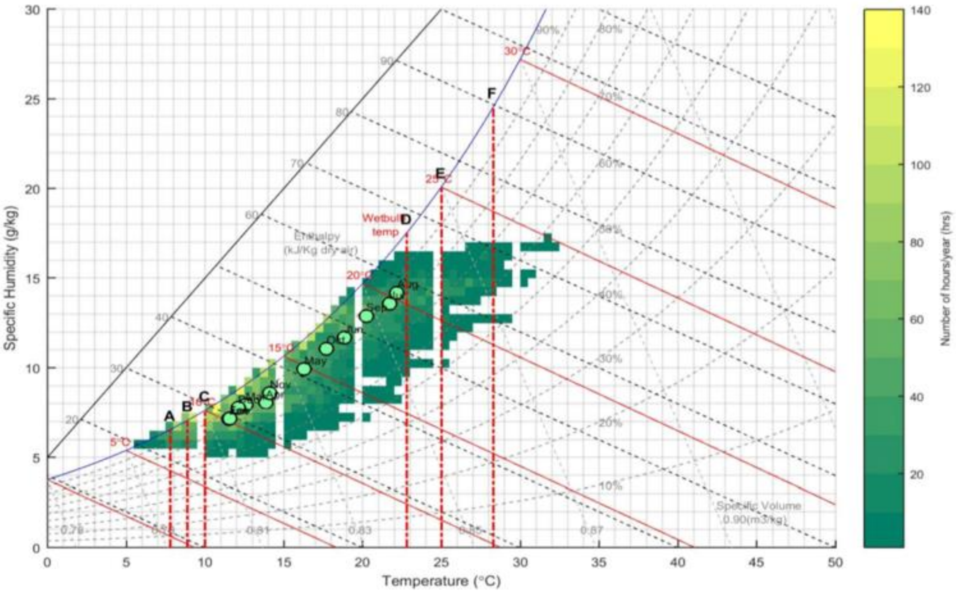


Figure 50 Psychrometric chart illustrating the frequency of conditions throughout the year for weather conditions witnessed within Ceuta (Spain), with monthly mean conditions indicated by green dots. The Red Boundaries 'A', 'B', 'C', 'D', 'E' and 'F' represent the 1st,5th,10th, 90th, 95th, and 99th percentile ranges of outdoor conditions

The detailed analysis compares zones on a southerly façade for both a 20% glazed façade and for an 80% glazed façade. Both zone types in this instance exhibited similar passive characteristics including; low internal heat loads (acquired by the removal of lighting and equipment loads) and low solar gains, which was achieved by adopting shading and glazing systems with low SHGC.

The psychrometric frequency density chart presented in Appendix 6.5 indicates that the weather conditions of this location are more concentrated - than in any other test location considered within this study with mean monthly temperatures ranging between 11.5°C and 22.2°C (Δ10.7°C). Furthermore, it was evident that despite its low latitude its mean annual temperature is comparatively low yet Its solar radiation levels are comparatively high.

These unique climatic parameters as shown in figure 50 - are significant in simulations conducted in this area due to their relation to the balance point temperatures - which are shown to be similar for both simulations S03 and S05. In simulation S03, Periods of cooling occurred mostly and increased rapidly when outdoor temperatures were above 16.1°C whilst periods of heating occurred mostly and increased rapidly when temperatures were below 16.1 °C. Mean outdoor temperatures during the period of non-heating and cooling were 15.872° and frequented 4348 hours of the year (49.6%). Thus, it is possible to state that a high frequency of non-heating and cooling can be expected when the zone is in equilibrium and when there is a high frequency of outdoor temperatures that closely match the balance point temperature of the zone as indicated by the detailed analysis of simulations S03 and S05 in Ceuta.

Sections 6.7 provides a detailed analysis of the simulations conducted in Venice and are represented by simulations S11, S12, S13 and S14. Here zones with an 80% glazed facade are compared in a southerly orientation, in one of the coldest test locations considered within this study with a mean annual temperature of 20.3°C and a range between 1.6°C and 45.6°C. The detailed analysis report generated by the analysis tool for all simulations is presented in appendix 6.05 and 6.06 – which allowed for a more detailed understanding of interior loads in relation to the exterior climatic conditions.

As per the simulations conducted in Ceuta and Tripoli - The application of passive strategies, shifts the balance point temperature closer to the mean annual temperature of the location in which the simulation is conducted and thus increasing the frequency of non-heating and cooling hours. In simulation S11, a majority of the outdoor monthly temperatures are below the balance point temperature for this zone leading to a heating to cooling ratio of 1:0.214 signifying a high requirement for active heating. As the balance point temperature of simulation S12 is much lower at ~8°C we witness a higher number of non-heating and cooling hours within the months of March and November which have mean monthly temperatures of 7.7°C and 8.7°C respectively.

In conclusion, the detailed analysis allowed to for a more comprehensive understanding of climate and interior thermal loads allowing for the identification of why and how some simulations produced extremely high annual heating and cooling loads whilst others produced comparatively low annual loads. Overall the lowest loads are achieved through the application of a combined passive strategy typically comprising of reduced glazing sizes, increased shading and the inclusion of high performance glazing. The application of passive strategies is best realized through an understanding of the balance point temperature in relation to climate which can be graphically represented on the psychrometric chart in the form of a bioclimatic boundary. The application of passive strategies results in lower annual loads and a higher frequency of non-heating and cooling hours which was observed graphically on the psychrometric chart. The detailed analysis report generated via matlab and tabulated in excel serves as a useful pre-design analysis tool in identifying significant loads within the test zone considered and allows for the identification of balance point temperatures and the climatic factors resulting in peak loads. It is thought that the application of passive strategies also allows for lower fluctuations in interior dry bulb and operative temperatures suggesting that passive strategies allows for a more stable interior thermal environment and higher levels of thermal comfort. In addition to thermal comfort it was also evident that in comparing zones with high and low annual loads, a significant reduction is observed in peak loads suggesting that the application of passive strategies can also aid in reducing HVAC capacity and ultimately HVAC system size resulting an indirect reduction in both power and fuel consumption.

7.0 OVERALL DISCUSSION

The primary aim of this study, was to identify the potential of PD (a proven architectural design approach) to reduce thermal loads on the HVAC system within the context of cruise ships operating in the Mediterranean. A further aim, was to create design tools to support critical design decisions in the preliminary design process through a bioclimatic methodology to allow engineers and designers to effectively evaluate the type of solar passive strategy to employ for a cabin in a given climatic range. In terms of the potential of PD to reduce thermal loads through a solar passive strategy. The thermal simulation model of the cabin evaluated a range of values for the following physical parameters: the variation of shading depth to overhangs and side fins; glazing percentage of the external facade; glazing U (w/m2/K) and SHGC value; internal gains from equipment and lighting; orientation from north to south; location. In summary, an analysis of shading as presented in section 4.2.1 indicated that the increase in shading depth from 0.5 to 2.0m in depth resulted in a decrease in annual combined heating and cooling loads of between 25.9% to 13.6% for a zone orientated in a northerly direction whilst a reduction between 60.5% to 40.2% was observed for zones orientated in a southerly direction. Shading therefore as expected is especially effective in south facing facades and is particularly relevant for climates with annual mean temperatures above 14.4°C - where cooling is the dominant load.

Overall shading can be said to decrease annual combined loads across all the test locations especially in locations with latitudes below 41.28°N. The application of solar passive technology reduced solar gains by as much as a 71.6% when a 2.0m shading device was added to an 80% south facing glazed façade. A similar decrease of 69.8 % decrease was also observed in Trieste for the same zone configuration. Overall, across all test locations a mean reduction of 54.6% is witnessed when shading is applied to a zone with an 80% glazed façade. **Section 4.2.4** reviews the **impacts of glazing type;** For a zone with an 80% glazed façade orientated south - glazing systems type ‘D’ and type ‘F’ were found to produce the highest combined loads across all locations. Whereas, glazing systems type ‘G’ and ‘B’ were found to produce the lowest annual combined heating and cooling loads - which were between 39.06% to 53.68% less than loads produced by comparative glazing systems. Overall the parametric study indicated that combined passive strategies resulted in the lowest annual heating and cooling loads as well as the lowest solar gains.

Critical to the evaluation of PD was the characterization of climate within the coastal regions of the Mediterranean. The variation in cruise itinerary for a given vessel can be significant, so the ability to analysis the range of PD solutions (as presented within the parameters tree) within the context of the broad Mediterranean climate – was necessary to determine the variation in performance of static passives strategies. The evaluation of climate has identified the following key issues:

- Two climatic classification systems; the ASHRAE climate zoning (Thevenard 2013) and the Koppen Giger classification system (Peel. 2007) were adopted to characterize over 80 different annual hourly weather files acquired from the IMO, each constituting 8760 hours' of over 33 climatic variables which are otherwise considered suitable for testing and evaluation of buildings for simulation purposes (DOE 2015b). Additional statistical analysis was used via Matlab to identify extreme climates, whilst geometric and contextual criteria was applied to the dataset to derive 11 test climates that are considered representative of the weather conditions exposed to by vessels operating within this area. Overall, the range of climatic conditions encompassed within the selected climates include; annual mean temperatures between 20.4 ºC and 12.7 ºC, mean annual relative humidity's from between 61.55% to 85.97% and annual mean global horizontal radiation levels between 76.9 W/m2 to 230 W/m2. An in-depth analysis of the climatic, geometric, contextual and bioclimatic factors for each of the selected test climates is considered within appendices 4.4 to 4.6. Currently there is no freely available and validated weather data that define the weather conditions endured by a cruise ship operating within the Mediterranean. Terrestrial weather files taken from weather stations within close proximity to the coast (<5 km) were therefore substituted for the purposes of this study.
- ASHRAE developed a climate classification for the purposes of "characterizing the performance of energy efficiency measures for buildings" (ASHRAE Transactions, vol. 109, pt. 1). The Passive House Planning Package (Feist et al. 2012) supports this notion that energy efficiency of buildings is intrinsic to the exposed weather conditions where by outdoor dry bulb temperatures and solar insolation are key factors in establishing heat transmission as defined within its thermal energy balance equations. The ISO 7547 (ISO. 2004) is also a key reference in this study which provides a calculation method for peak heating and cooling loads to establish HVAC capacity. The article asserts extreme outdoor conditions for calculations of peak loads of -20 ºC for winter and +35 ºC for summer. The climate analysis conducted within this study however, indicated monthly mean dry bulb temperatures varying between 20.3 ºC to 28.0 ºC in Tripoli and between 1.6ºC to 22.3 ºC in Rimini Italy. Currently climatic test conditions for specific regions are not provided by the marine industry only climatic extremes.

- The study also addresses the potential for PD by adopting the conventional bioclimatic chart developed by Milne and Givoni (1979). The analysis identifies that between 61% to 88% of the year across all the locations presented in appendix 4.15 reside within bioclimatic conditions 2 to 5 and 7 indicating initially a high potential for the application of PD within the Mediterranean. However, this traditional model is considered unsuitable for the purposes of assessing the potential of marine PD – as its bioclimatic boundaries are formed on traditional outdated terrestrial building methods particularly suited for "residential and office buildings, where heat gain is minimal" (Al-Azri et al. 2012). It is recognised however, that the bioclimatic chart can otherwise be adapted to a multitude of different climates and building types as portrayed within the works of Anh-Tuan. (2014).

The further aim, was to create design tools to support critical design decisions in the preliminary design process through a bioclimatic methodology to evaluate solar passive strategies, was achieved through the development of a detailed analysis tool in Matlab. This tool presented data in the format of hourly time series graphs, monthly time series graphs, annual bar charts and psychrometric charts in which weather conditions were plotted using a frequency density algorithm (Presented in Appendix 5.4). Simulation S01 as defined in table 9 – represented the simulation that produced the highest annual loads within the parametric study and was therefore the subject of further investigation. The detailed analysis tool developed in this research, generated reports in the format presented in appendix 6.5 - in which it was identified that in this simulation - solar gains represented 63.6% of the combined annual interior gains - resulting in year-round cooling, high peak loads and interior conditions outside the set point temperatures. Simulation S02 showed how PD can be used to reduce annual loads which was achieved through increased shading, reduced interior heating gains and a high-performance glazing element leading to a significant reduction in solar gains and a reduction in the heat gains and losses through the building fabric. In this simulation, it was observed that heating and cooling rapidly increase when outdoor temperatures are above and below ~17°C respectively, indicating a significant balance point temperature. Simulation S03 conducted in the weather conditions of Ceuta - as defined within table 9 produced the lowest annual loads within the parametric study. The study revealed that this was due to an effective shading strategy and high-performance glazing which minimized heat loss and gains through the zone fabric. Periods of cooling in this instance were observed to increased rapidly when outdoor temperatures were above 16.1°C whilst periods of heating occurred mostly and increased rapidly when temperatures were below this temperature. Mean outdoor temperatures during the period of non-heating and cooling were 15.872° and frequented 4348 hours of the year (49.6%). The unique climatic parameters are significant in simulations conducted in this area, as mean outdoor temperature conditions relate closely to the balance point temperature witnessed - which are shown to be similar for both simulations S03 and S05. Thus, a key finding is that a higher frequency of non-heating and cooling periods is observed when the exterior temperatures relate more closely to the balance pointe temperature of the zone. Furthermore, when passive strategies are applied a significant reduction in interior heat sources such as solar gains, lighting and equipment is observed - in turn this increases the significance of the zone fabric and in doing so increases the relevance of exterior temperatures in influencing interior thermal loads, over solar radiation conditions.

The study proposes therefore that the psychrometric chart can be used as a pre-design assessment tool to define weather conditions in relation to the balance point temperatures and thermal comfort boundaries. In this instance, a detailed annual hourly simulation has been used to define the 'energy signature' of the zone and consequently the balance point temperature (Utzinger and Wasley. 1948) as per the methodology outlined within the works of Anjomshoaa (2017). However, a simplified empirical method as proposed in the works of Nguyen and Sigrid (2014b) - using steady state calculation methods can also be used to formulate bioclimatic boundaries relevant to the thermal comfort requirements and the thermal properties of the structure. In this study the periods of heating, cooling and non-heating and cooling were used to define the range of dry bulb conditions in which active and non-active periods occurred on the psychrometric chart. The application of different passive strategies was shown to alter these conditions in which non-active conditioning occurred – providing a visual comparative analysis tool. It is recognized however, that improvements in the thermal model and a more comprehensive weather data set would allow for greater definition in bioclimatic boundaries.

In this study, the use of simulation software allows for a more detailed hourly time series analysis as well as the possibility of incorporating seasonal strategies highlighting the potential for more adaptive design solutions. It also allows for the identification of peak loads, which provides an opportunity in which to target specific conditions on which to specify PD solutions – which might be a necessary step in vessels exposed to a wide range of climatic conditions beyond the Mediterranean. This notion is supported within the parametric simulations results, which identified that optimal passive configurations (from the parameters displayed in figure 22) varied in accordance with the solar and dry bulb temperature environments. The study therefore indicates that static passive strategies - such as shading systems which have a constant horizontal depth – that are unable to adapt to solar or climatic conditions are otherwise unable to provide optimal performance due to a vessels constant variation in orientation and weather conditions underway.

It is realized therefore, that a hybrid Passive system, which adapts to the climate of operation that alters the architecture of the vessel in line with “real time “climatic conditions would provide superior performance in terms of reducing HVAC loads.

7.1 Assumptions and limitations of the methodology

While the methodology applied was based on the implementation of a 'BESTEST' validated simulation tool from the architectural industry, it is important to consider the accuracy of the results based on the assumptions of the model and the limitations of the methodology. The impact of fenestration on the combined heating and cooling load was considered by increasing the glazing percentage by increments of 10% from 20% to 80%. The shape of the glazing apertures is based on the technical drawings provided by C.C. Jensen A/S Window Technology (CJS. 2006), the Bohamet drawings (Bohamet,. 2015) for non-opening windows and the ISO 3903:2012 (BSI, 2012b) which also specifies fasteners and gasket dimensions. The modelling method used however, does not account for the changes in thermal conductivity or idiosyncrasies created by complex hinge mechanisms and other thermal bridges. Additional research would be necessary to test the frame using two dimensional or three-dimensional finite element heat transfer analysis programs such as THERM as in the works of Mitchell et al. (2013). The dimensions of the frame are maintained for each incremental change in glazing percentage within the parametric study. Glazing to wall ratios above 50% are constructed using full breadth horizontal apertures and increased vertically until the maximum 80% glazing ratio is met. (window modeling methods – solar gain)

As summarized in this chapter, the variation in orientation and location, and the associated variation in temperature and solar insolation are significant, in that they impact the suitability of a given passive strategy on board. Since a given solar passive strategy will be more effective in only a specific climate, latitude and orientations, as indicated by the results analysis presented in sections 4.2.3 in chapter 4.0. The methodology applied therefore, is limited in that it can only be used to express annual trends due to the annualized simulation process, which is a common terrestrial architectural practice. The study captures through this method the potential of PD within the Mediterranean basin coastal areas used by cruise ships. As such it is suitable initial parametric design tool, as a given glazing configuration can be examined for a range of locations and the implementation of a controlled shading system can be examined to provide PD optimization in accordance with ZEB principles. To determine the actual real time and annual energy requirements to achieve full ZEB accreditation, hourly analysis would be required for a range of itineraries in both the Mediterranean and the Caribbean, as most vessel interchange between these two areas of operation during the year. A detailed statistical analysis of these simulations would enable the optimal PD configuration to be selected and the minimum sizing of a HVAC system, which would increase the interior volume available for accommodation. As part of this process the renewable energy system would also be explored and optimized.

Finally, the study was limited to solar PD strategies as these are easily implementable in terms of the architecture and design of the vessel. In comparison, the use of natural airflow would require a completely new vessel architecture to address the concerns of fire safety regulations. Furthermore, the PD principles exercised on cabin zones could arguably be applied to other zone types such as dining rooms, lounges, bars and other recreational areas with perhaps larger more exposed fenestrations – these are currently areas of further research.

7.2 Application of Passive Design in Reducing Emissions and Operational Costs

The methodology applied clearly shows the potential to identify how solar PD strategies can significantly reduce thermal loads and consequently the HVAC energy requirement in the Mediterranean at a preliminary design stage. A key factor here is the need to optimize the PD strategy based on latitude and orientation within the Mediterranean, this required adaptability is in accordance with the design principles of ZEB as delineated in the literature review. The additional energy requirements could be provided by PV implementation as approximately 50% of cabins on a cruise ship have outward facing balconies. Given the high solar radiation levels in the Mediterranean, which are the cause of the seasonal variation in cooling load, the use of PV provides a renewable energy source synchronized with the cooling load. Malvoni, Paolo and Congedo (2017) reported on a study which examined the influence of climatic characteristics of South-eastern Italy on the performance of a photovoltaic system. The study provides an analysis tool to estimate the performances of PV units on cruise ships operating in the Mediterranean.

7.3 Social Technical Issues in the application of Passive Design

Brown and Vergragt. (2008) – identifies that large scale development in technology is the necessary component towards a sustainable future. To implement this transition – changes in established and existing institutions and existing professional practices are required. The study identifies that “Higher order learning” ranging from the individuals to society in general is required to do this and Is particularly relevant in cases “that depend mainly on the synthesis of existing technologies and know-how to achieve radical reductions in energy and material consumption”. One way of nurturing this type of learning is through experimentation with emerging technologies and services. In a Bounded Socio-Technical Experiment (BSTE) the study developed a framework for mapping and monitoring the educational process in a case study of the development of a ZEB in Boston. The participants possessed a broad range of expertise and skills sets. Their contributions to the development of the building were based on; “professional training, self-interest, socialization through membership in political and professional groups as well as deeply held values and beliefs contribute to the variability". These differences were broadly categorized into 4 themes including;

- Problem solving according to pre-determined objectives;
- Problem definition with regard to the particular technology–societal problem coupling;
- Dominant interpretive frames;
- Worldview.

Key findings included; that learning took place on both an individual and group level. On an individual level this corresponded to developments in problem definitions whilst on the group level – "learning consisted of participant turnover until congruence in worldviews and interpretive frames was achieved". The outcomes of this study are relevant in the context of this research as it identifies that innovative design is not simply brought about by the introduction of technology or software, but also requires the integration of clearly delineated products and processes where by sustainability is achieved by the "deep learning of individuals, groups, professional societies and other institutions". These considerations are equally valid in marine design where the workflow and technology approach offers a significant opportunity for PD and ZEB as a TOI (transfer of innovation) from architecture.

The sociotechnical considerations of involving PD within the design workflow of naval architects was considered within this research through participating in a number of RINA conferences that stimulated discussion around the topic of PD within the marine industry (As defined within appendix 7.1 to 7.4). In addition to this, organized meetings and open discussion amongst key practitioners within the industry were conducted to gain an understanding of how PD might be integrated into the conventional design process. Anonymized personal discussions were held with industry – where by the current understanding of contextual issues relating to the integration and application of PD was discussed. This identified that there is "much discussion about passive cooling methods within the yachting community" (Shallcross. 2013). However, three key issues were identified.

- The first is that the specification of the vessel is largely client driven and thus the motive to reduce operational costs may not even be addressed – even more so when many yards are bidding for a project in order to win business. Furthermore, this Is unlikely to be driven by the technical team if there is not a necessity to do so. This issue could therefore be summarised as; a lack of drive or necessity which is otherwise derived via the client or in some cases – legislation. This is further compounded by the ideology of simplicity and the reduced inclination towards implementation of new and unfounded technology which might deter investors in supporting higher upfront costs.

- Another issue identified is the dispersion of "cost centres" which become ever more disconnected thus, upfront costs become critical to operational costs despite potential and significant long term cost savings. The term 'cost centres' in this instance is used to represent stakeholders which could otherwise be the proprietor of a vessel who may be isolated from the impact of operational cost. A naval architect consultancy, provided the example where by the proprietor would buy a boat and then lease it out to an operator – in which case the investor wants the "the lowest cost ship to start with" and would not directly benefit from a reduction in operational costs
- A third issue raised was the lack of connectivity within the design process and the lack of a feedback loop to inform new builds. "There is no feedback loop from what is designed back round to how it performs and then back round to how you would modify the design next time".

Several meetings were held with terrestrial architectural firm to establish the differences in design and construction methods which allows for the integration of PD within the design workflow. A key differential was that contractors such as HVAC engineers would work in-house and operate software which was used by all parties including architects and architectural technologists. Furthermore, Passive Technology appears more established within the architectural industry as indicated by the literature review which is fully supported by reference case studies, in depth training programs and software as defined within the works of Crawley (2008). Finally, the ecological credentials of commercial builds in terrestrial structures in the UK for example are assessed by a points based system derived by such standards set out by BREEAM (Building Research Establishment Environmental Assessment Method) which provide a list of tried and tested methods to implement, technologies order to achieve a specific ecological status. One of the key points raised was that building design for sustainability is based on a structure that is static, whereas, marine vessel conditions are constantly in flux – which would incur heavy initial design analysis and the specification of operational conditions which might not remain constant thought the life cycle of the vessel. Well established and validated software that captures the variation in climate and orientation therefore might provide an efficient means of introducing PD practices within the marine industry, although some adaptation to the commercial and operational aspects of pleasure cruises would be required.

Kanters, J. (2014); asserts that architects and designers play a key role in a low energy future of buildings providing the proper design tools and practices are fully integrated within the design process. To identify the current barriers and methods used within the development of solar architecture - the study carries out an international survey coupled with semi structured interviews. The study is significant as the research presented in this thesis, addresses the architectural industry as a senior mentor and source for the development of PD within the marine sector however, the works of Kanters, J. (2014) indicated the need ; "for further development of design tools for solar architecture, focusing on a user-friendly, visual tool that is easily interoperable within current modelling software packages, and which generates clear and meaningful results that are compatible with the existing work flow of the architect". The study also concluded that despite great awareness of solar architecture there is a need "for further skill development amongst architects and tool developments to accelerate the implementation of these technologies". These conclusions coupled with the aforementioned works of Brown and Vergragt. (2008) and the interviews presented; suggest that the introduction and development of design tools alone will not be sufficient in the adaptation and nurturing of PD within marine structures. To this degree further works are necessary in defining a relative integrative design workflow and in developing the necessary tools for effective application.

7.4 Implementation of Marine Passive Design through an Industrial Design methodology

A more incremental way to facilitate learning toward socio-technical system change, is through small scale design projects aimed at developing, testing and introducing modern technologies and services. To this end, McCartan and Kvilums (2013c) (See Appendix 7.2 for full paper) developed a case study of a parametric design to engage in discourse with practitioners from the passenger vessel industry at the RINA conference; Design and Operation of Passenger Ships (20-21 November – 2013). The design shown in Figure 51, evolves the concept of sustainable luxury by implementing the principles of PD. The development of the concept enabled the exploration of the implementation of PD principles via an industrial design process. This design was developed through investigation of typical cabin geometry found on mid-sized cruise ships and became the basis of investigation for this research. The GA illustrated in figure 7 - informed the construction of digital thermal models but also highlighted some of the issues of implementing PD such as its compliance with SOLAS Chapter II-2 fire regulations.

Figure 51 Render of rear 3/4 view of catamaran eco-luxury cruise ship (McCartan and Kvilums 2013c)

In further work McCartan and Kvilums (2014b) (See Appendix 7.4 for full paper), presented an application of Marine PD with an emphasis on the utilization of natural lighting and shading. The study developed on the works of Tzempelikos and Athienitis (2007 (a)) who identified a paradoxical relationship between shading, natural lighting and the glazing to wall ratio of a zone. This relationship is illustrated in figures 52, which indicates that an increase in glazing size increases natural light into the zone and thus reducing the need for artificial lighting. In the same instance, it also increases solar gains.

Establishing an ideal glazing to wall ratio therefore is critical in developing optimal performance designs. Based on these findings an Eco luxury catamaran (illustrated in figure 51) was developed to explore the implications of daylighting on perimeter cabin zones.

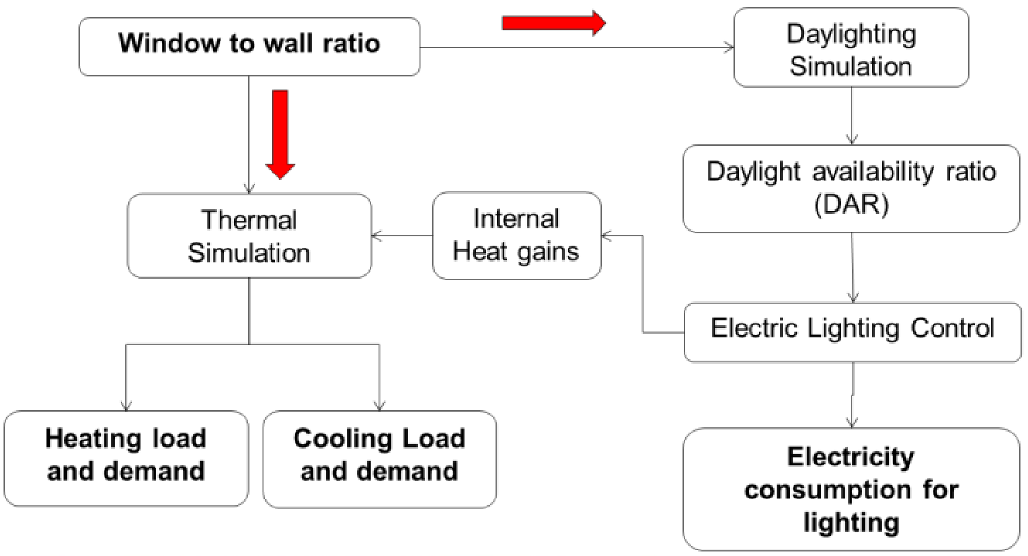


Figure 52: Schematic illustrating the integrative impacts of glazing on thermal and lighting loads (McCartan and Kvilums 2014b). Cited in Tzempelikos and Athienitis (2007 (b))

The study explored both a static overhang and automated louver shading systems with various operational and solar based controls including;

- An Occupancy based control system; whereby louvers would fully close when occupancy is 0 and fully open when the room is otherwise occupied. This is based on a predicted occupancy schedule based on hotel guest data and inferred information from cruise trip itineraries.
- Solar tracking control system; in which the louvers automatically adjust their profile angle to solar geometry when incidence radiation is above 100 W/m2 – but otherwise remain horizontal to avoid obstruction to view when solar gains are considerably low.

As per figure 53 – the study identified that an occupant-based louver control strategy was the most effective in reducing annual cooling loads, followed by a solar controlled system with the simple static louvered system delivering the least reduction in annual loads. However, following an industrial design process, a further consideration was that the louver-based system would obstruct the occupants view. To overcome this, compromises in other variables such as glazing size were considered in such a way as to provide the same performance as a louver-based control system but without interfering with occupant satisfaction and pleasure. Overall natural light and visibility were considered important design factors opposing the implementation of high performance PD. These factors are covered in detail in the works of Nicolantonio (2014), addressing the factors of window placement and interior color however, the study does not address the implications on HVAC loads. This significant interdisciplinary crossover, highlights that stylists have a considerable influence on the overall energy performance of the building.

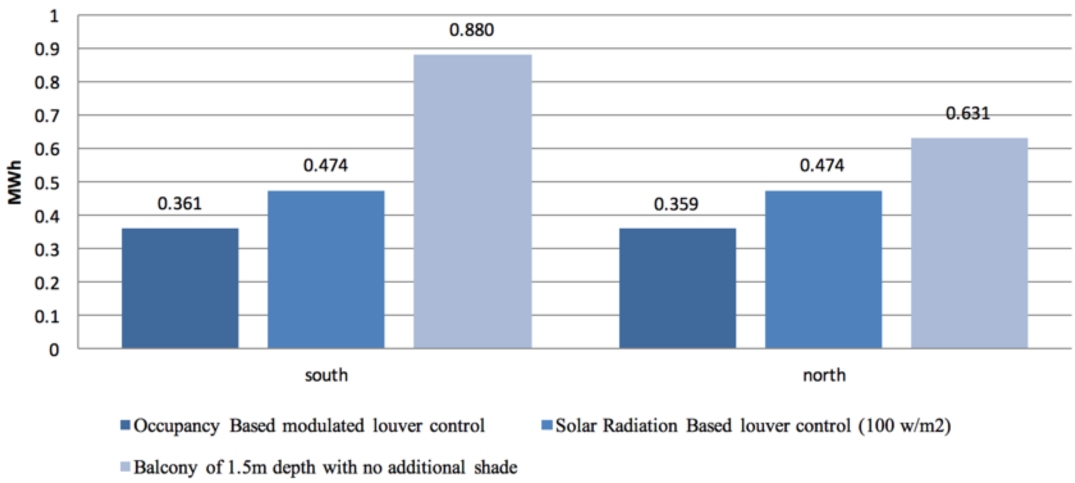


Figure 53 Effects of louver control on annual sensible cooling loads (MWh) on south facing cabins in comparison to a static overhang shading device

Having identified the influence of shading systems a further investigation was conducted on the potential of an integrated natural lighting scheme – which supplements the PD shading strategy in reducing the electrical consumption of lighting. The paradoxical relationship as defined by figure 52, illustrates that a natural lighting scheme is only effective so long as it does not increase solar gains and consequently cooling loads beyond the energy saved by the natural lighting scheme.

A prerequisite to the implementation and simulation of a natural lighting scheme was the interrogation of interior spaces through 'Lux Maps' as illustrated in figures 54, 55 and 56. In the study presented, cabin zones, dining zones and lounges were investigated under a CIE overcast sky conditions as defined by the ISO 15469 (2004) as advised by the works of Carvalho Cabus, (2002).

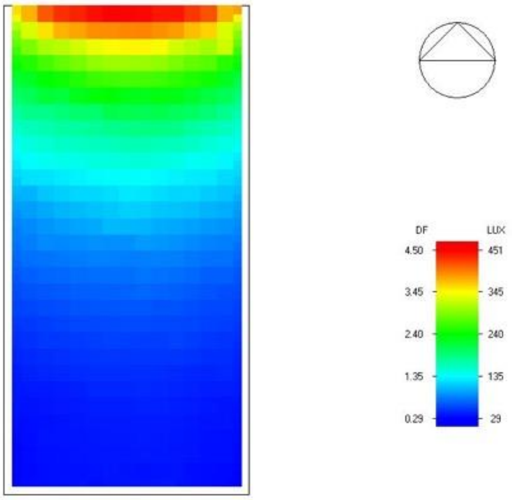


Figure 54 Lux map of cabin zone with 90% glazed facade, generated with CIE overcast sky

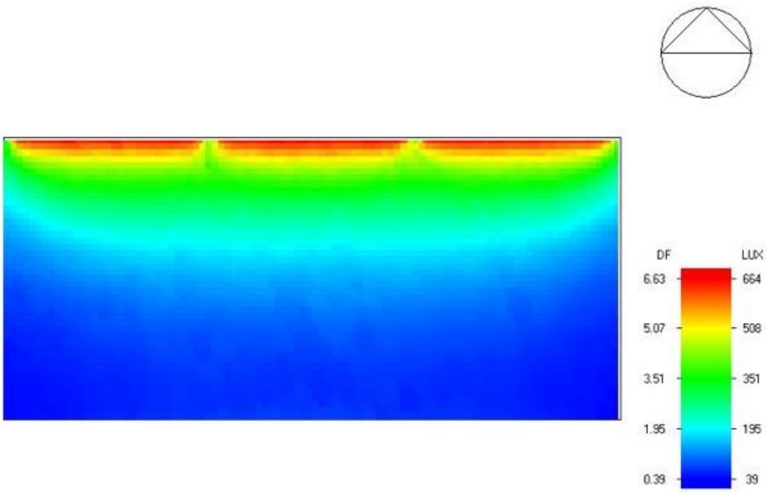


Figure 55 Lux map of day/lounge zone with 90% glazed facade, generated with a CIE overcast sky

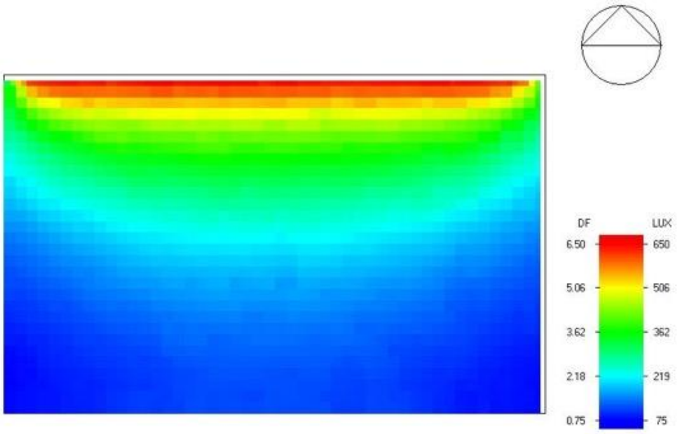


Figure 56 Lux map of dining zone with 90% glazed facade, generated with a CIE Overcast sky

The colored lux maps identified that natural lighting could be achieved in all of the zones considered to a certain room depth – beyond which the penetration of natural light is unable to comply with the lighting level specification as defined within the ABS Passenger Comfort guide (ABS 2014). Key findings from this study included;

- For cabin zones orientated south with a 1.5m shading overhang an idealized glazing percentage of 20% was identified resulting in a 9.8% reduction in lighting loads via a simple occupancy-based lighting control strategy. However, it was evident that beyond 30% glazing, cooling loads began to rapidly increase, identifying a saturation point
- Overall when considering ergonomic requirements of individuals and obstructions to view within a cabin zone, a more suitable glazing percentage would fall between 50 to 60%. Resulting in a 16.7% to 22.7 % increase in global loads from the idealized percentage as illustrated in figure 57. Even so this is still 28.23% to 20.44% less than the total loads experienced in a zone with an 80& glazed facade
- The ideal glazing size for the day/lounge zone is indicated as being 30% for a southern façade, as shown in figure 58. At this percentage, the zone operates 24.96% better than the same zone with 10% glazing and 45.61% better than the same zone with 90% glazing. The results for the day/lounge zone were considered significant in that they identified that a daylighting strategy has a greater impact on zones with a higher daytime occupancy and higher visual task illuminance requirements

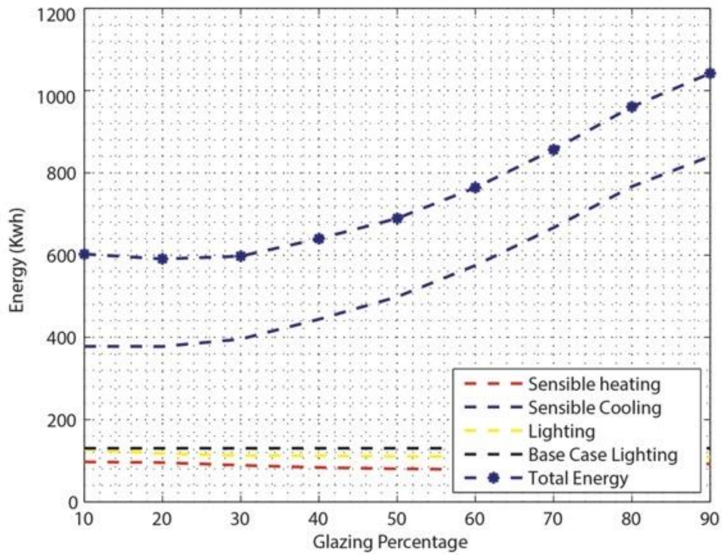


Figure 57 Thermal loads and electrical lighting loads for South facing Cabin Zones with different glazing percentages, with a 1.5m shading overhang operating in Barcelona (Spain)

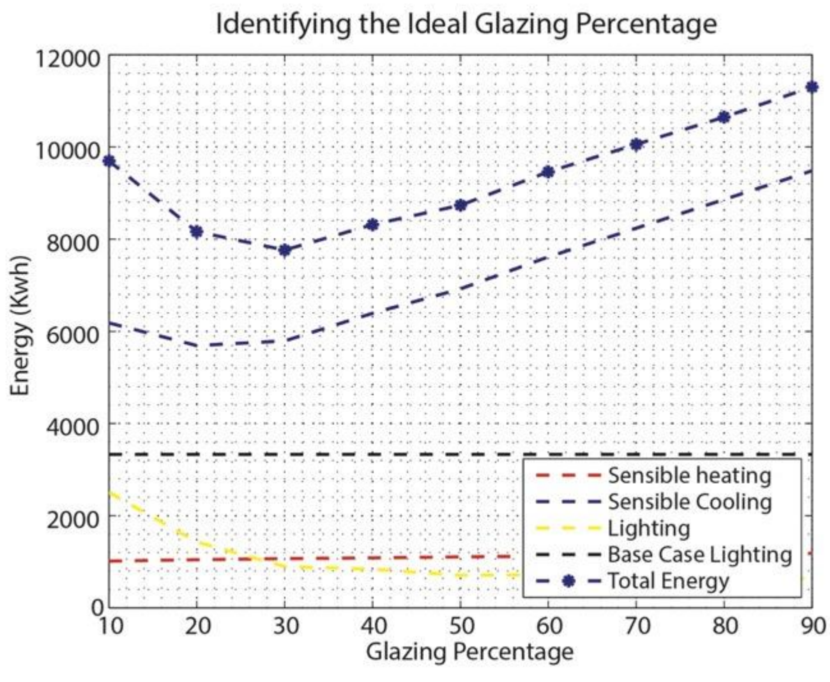


Figure 58 Annual Thermal loads and electrical lighting loads for Day/Lounge Zones with different glazing percentages, with no shading, situated in a southerly orientation in Barcelona (Spain)

The study identified that the zones geometric form as well as its function and use have a key influence on its overall thermal performance - especially when a natural lighting scheme is combined with a shading strategy. Integrative metrics such as the daylight utilization ratio (DUR) were therefore introduced. The DUR represents the "fraction of working time in a year during which sufficient daylight is available on the work plane surface" (Tzempelikos and Athienitis 2007a) and facilitates in estimating the suitability of a natural lighting scheme for a given zone type. In addition, the influence of interior surface reflectance was considered following the works of Duff (2012) who identified that a significant energy savings could be gained from improving interior surface reflectance. In particular Carvalho Cabus (2002); found that ground planes and overhangs play a significant role in the amount of light reflected into the room and consequently its illuminance. Combining these factors the study identified that environments even with lower natural light availability (such as the levels witnessed in Venice) – could adopt a daylighting strategy within the context of passenger ship zones, with the annual "DUR index being improved by 38.0% for cabin zones, 23.5% for day/lounge zones and 6.0% for dining zones, when comparing rooms with improved surface reflectance" as defined within table 10.

DUR values for zones with 30% glazing facing north with wall and ceiling surface reflectance at SLL code, 2009 suggestions			
	Cabin Zone	Day/Lounge Zone	Dining Zone
Venice	.2233	.5011	.4703
Barcelona	.2421	.5873	.5499
Cairo	.3022	.6473	.5851
DUR values for zones with 30% glazing facing north with wall and ceiling surface at a higher reflectance as per the SLL code, 2012 suggestions			
Venice	.3086	.6191	.4986
Barcelona	.3436	.7309	.5826
Cairo	.3864	.7891	.6086

Table 10: Daylight utilization ratio for different zones with different interior surface reflectance levels based on prior and updated SLL code suggestions as defined within CIBSE – (2012:67)

This experimental exercise identified the potential for an interdisciplinary design tool in which designers, engineers and architects all play a role towards the passive performance of an interior space. The exercise nurtured 'higher order learning' as proposed by Brown and Vergragt. (2008) and in doing so identified the importance of considering design elements as a whole, in a nonlinear iterative design process – allowing for radical resource efficiency (Lovins 2013). A single passive strategy therefore, cannot be considered in isolation, as one solution could be to the detriment of another.

In the works of McCartan and Kvilums (2013e) and McCartan and Kvilums (2014b) (presented in appendix 7.3 and 7.4), it was identified that an idealized glazing size could be in conflict with aesthetic and commercial factors, in that a smaller glazing ratio combined with shading would reduce or obstruct the view outboard. This was particularly relevant in the case of cabin zones where window size has a proportional relationship to the cost of the cabin. Similarly, in dining zones – sitting occupants would not want to be at eye level with a shelf or sideboard. Aesthetic and ergonomic factors were considered in this instance and overcome using the methods defined below and illustrated in figures 59, 60, 61 and 62.

- One method was to visually suggest that the window extends from floor to ceiling using venetian blinds. The blinds in this instance are disguising a bulkhead rather than a glazing element but visually extend the windows appearance.
- In addition to this a combination of bright, light colours were used as well as the incorporation of materials with high reflectance near glazed areas – allowing light to permeate deeper into the zone in support of a natural lighting strategy.

Figure 59: 3D perspective view looking inboard of a cabin - with features allowing natural lighting to permeate deeper into the zone including; higher reflectance flooring nearer the glazing aperture and a bright light color scheme

Figure 60: Cabin 3D perspective, looking outboard - with windows featuring a venetian blind mechanism combined with a low-level LED lighting scheme, visually extending the appearance of the glazed area from the floor to the ceiling whilst minimizing the 'window to wall ratio'

Figure 61: 3D perspective of a Dining room looking outboard - with windows featuring a venetian blind mechanism; ergonomically considered to not obstruct the view of occupants seated whilst minimizing the actual 'window to wall ratio'

Figure 62: 3D perspective of a Dining room looking outboard - with windows featuring a venetian blind mechanism; ergonomically considered to not obstruct the view of occupants seated whilst minimizing the actual 'window to wall ratio'

7.5 PD Design Development through Parametric Optimization

The parametric approach adopted within this study allowed for the multiple variations in the passive strategies from the parameters tree illustrated in figure 22, resulting in over 100, 000 individual annual simulations. The degree of variation however, was limited by resources and the time allocated to this research. More finite variations for example in shading depth and glazing size could have revealed optimal configurations and a wider number of parameters could have been tested. This highlights the need to develop a parameter sensitivity analysis in order to minimize computational time and cost in delivering key design parameter boundaries as part of the preliminary design process.

Hopfe (2011) concurs that Building performance simulation (BPS) is an invaluable resource in providing design direction for specific design solutions. The study identifies that methodologies incorporating BPS can be improved through the use of uncertainty and sensitivity analysis which among others provides the following benefits:

- With the help of parameter screening it enables the simplification of a model
- It allows the analysis of the robustness of a model
- It makes aware of unexpected sensitivities that may lead to errors and/or wrong specifications (quality assurance)
- By changing the input of the parameters and showing the effect on the outcome of a model, it provides a “what-if analysis” (decision support)

Attia et al. (2013) consulted 165 publications and interviewed 28 optimization experts with the aim of addressing the gap and needs of integrated Building Performance Optimization (BPO) tools in the design and development of NZEB. The findings indicated the significant breakthroughs in evolutionary algorithms in solving highly constrained; building parameters, HVAC systems and renewable energy optimization problems. Furthermore – it was identified that they could be customized to accommodate specific optimization problems. In this instance further works could adopt this BPO method to accommodate variation in climate types witnessed by the operation of cruise vessels. The study further identified that the existing limitations of BPO tools included model uncertainty, computation time, difficulty of use and a steep learning curve. These are the challenges that must be overcome in the development of Marine PD parametric design tools.

Hernandez and Kenny (2010) evolved the concept of NZEB and expanded its definition by incorporating the concept of ‘net energy’ - based on a methodology accounting for the embodied energy of building components together with energy use in operation. A definition of life cycle zero energy buildings (LC-ZEB) was proposed, as well as the use of the net energy ratio (NER) as a factor to aid in building design with a life cycle perspective. This would be an extremely useful tool to apply to cruise ship design as it would bridge the gap between current practices in Naval Architecture and the principles of the Circular Economy, while also addressing the issues of PD and ZEB. Examining this theme further Srinivasan et al. (2011) commented that approaching an NZE building goal based on current definitions is flawed for two principal reasons:

- NZE only deals with the energy required for operations and related emissions
- it does not establish a threshold which ensures that buildings are optimized for reduced consumption before renewable systems are integrated to obtain an energy balance.

The author recognizes that the aforementioned strategies to improve building performance through thermal Simulations and evolutionary Optimization - would be more readily integrated within the marine industry if they were to be developed within interfaces and systems already familiar by the industry within current design practice. One such program is the 3D modeling program RhinoCeros (McNeel & Associates. 2017). ‘ShadeRade’ – developed within the works of Sargent,J. et al (2011) at Harvard University merges this program with building simulation software Energyplus (DOE 2015a) providing an interactive, informative design and optimization tool for shading systems within a 3D visual environment. It is the intention of the author in further works to adapt this application to the morphology of ships creating a visually communicative multidisciplinary platform to allow for the analysis and testing of passive strategies, providing rapid initial assessments and therefore, design direction at the beginning of the design process.

8.0 CONCLUSIONS AND RECOMMENDATIONS

The first objective of this research was to collate annualized weather data to represent test conditions of coastal regions of the Mediterranean basin. This was achieved by applying a number of geographical and contextual indices – to hourly EPW data arranged by the WMO. The critical activity in using this data was to capture the breadth of distinctive climatic conditions within the Mediterranean in accordance with established climate classification systems. **The second objective** was to develop a thermodynamic simulation model of a cabin to evaluate solar PD strategies, this was achieved using a validated well established architectural simulation package. The physical parameters of the simulation model where determined from appropriate marine standards whereas occupancy and other simulation schedules were based on representative commercial buildings developed by the United States DOE. **The third objective** was to define a parameters tree detailing the range of values for the geometry and physical properties of the solar passive technologies to be evaluated. Following a literature review the research presented focused on key independent variables including; location, orientation, glazing size, glazing type, shading and internal heat gain sources such as lighting and equipment. In fulfillment of **objective four** – a methodology was developed whereby the parameters were controlled by the data management software 'JEPlus' that passed the parameters through the simulation engine 'Energyplus', resulting in over 10,000 individual simulations. **The fifth objective** was to develop simulation data extraction and visualization tools that would allow for the major trends on sensible loads because of solar PD to be recognized. This was conducted for both the parametric simulation analysis (presented in Chapter 4) and the detailed analysis of significant simulations conducted in Chapter 6. Post simulation processing tools developed in Matlab achieved this objective through a range of, time series charts, bar charts, scatter graph charts and energy signature plots. **The sixth and final objective** was to propose new bioclimatic methods for assessing the potential of solar PD for designers and engineers to aid decision making at the beginning of the design process. This was achieved firstly through the development of climatic, contextual and geographical indices to identify significant weather files that represent the full range of conditions as per the traditional climate classification systems and thus reducing analysis time. The second component of the proposed methodology was the development of a detailed analysis tool that used a range of graphical representation techniques to directly compare solar PD solutions within the same climatic conditions. The conventional bioclimatic psychrometric chart (as represented by Milne and Givoni (1979)) was evaluated for this purpose and developed using a frequency density algorithm as a bioclimatic tool to communicate frequencies of specific climatic conditions as well as heating and cooling periods in relation to specific thermal comfort parameters and bioclimatic boundaries. A key aspect of the sixth objective was conceptually exploring the aesthetical and technical implications of applying the new method. To this end the author developed two Bounded Socio-Technical Experiments (BSTE) one based on louver control of natural lighting of a cabin and the other on the use of natural lighting within the interior design process. While these studies were not evaluated they served to engage professionals in the cruise industry sector through RINA conferences in the principles of Marine PD.

In summary, an analysis of shading as presented in section 4.2.1 indicated that the increase in shading depth from 0.5 to 2.0m in depth resulted in a decrease in annual combined heating and cooling loads of between 25.9% to 13.6% for a zone orientated in a northerly direction whilst a reduction between 60.5% to 40.2% was observed for zones orientated in a southerly direction. It appeared therefore, that zones in a southerly orientation benefited most from shading. Overall shading can be said to decrease annual sensible loads across all of the test locations especially in locations with latitudes below 41.28°N The application of solar passive technology reduced solar gains by as much as a 71.6% when a 2.0m shading device was added to an 80% south facing glazed façade. A similar decrease of 69.8 % decrease was also observed in Trieste for the same zone configuration. Overall, across all test locations a mean reduction of 54.6% is witnessed when shading is applied to a zone with an 80% glazed façade. Section 4.2.3 reviews the impacts of glazing type; For a zone with an 80% glazed façade orientated south - glazing systems type 'D' and type 'F' were found to produce the highest combined loads across all locations. Whereas, glazing systems type 'G' and 'B' were found to produce the lowest annual combined heating and cooling loads - which were between 39.06% to 53.68% less than loads produced by comparative glazing systems. Overall the parametric methodology indicated a bias towards the requirement for passive cooling strategies especially for zones operating in regions below the latitudes 43.67°. The study also indicated that combined passive strategies led towards the lowest annual heating and cooling loads as well as the lowest solar gains.

The research presented within this study indicates that the façade design of the ship could be optimized based on a deep understanding of climate, thermal comfort and the zones internal heat gains and losses. PD can be incorporated within the conceptual design process to facilitate the acclimatization of any vessel façade to minimize energy consumption. Design direction using a detailed simulation analysis and a bioclimatic chart can facilitate in defining the attributes of properties of shading, glazing and façade form, which vary in accordance to location and orientation. It is therefore, clear that an optimum design cannot be achieved through conventional symmetrical ship design practices, an adaptive façade or the use of responsive smart materials therefore might offer greater resolve and automated acclimatization which would need to be verified via a cost benefit analysis that simultaneously considers weight as key performance and feasibility metric. This aligns with the literature of architectural practice, which states that an absence of effective simulation tools or integrative design practices would lead to compromises within the overall energy performance, resulting in a sub-optimal design. Tzempelikos and Athienitis (2007a) Azari and Kim (2013) Kanagaraj and Mahalingam (2011).

Naval Architects and interior designers have a key role to play when it comes to the design of future accommodation areas in low-energy cruise ships. Proper design tools and working methods are required to support an efficient integrated design process. The preliminary design tool developed in this thesis contributes to the need for further development of design tools for solar PD strategies within cruise ships, focusing on a user-friendly, visual tool that is easily interoperable within current architectural modelling software packages, and which generate clear and meaningful results that are compatible with the needs of a future interdisciplinary work flow of the Naval Architect and interior designer. The limited knowledge of solar PD technologies within the Naval Architect community, suggest the need for further skill development amongst Naval Architects and tool development to accelerate the implementation of these technologies in future cruise ship designs.

Any cruise ship itinerary within the Mediterranean basin represents a variation in orientation and location, and the associated variation in temperature and solar insolation are significant, in that they impact the suitability of a given passive strategy on board. Since a given solar passive strategy will be more effective in only a specific climates, latitudes and orientations, (as indicated by the results analysis) the methodology applied appears to be limited in that it can only be used to express annual trends, which is a common terrestrial architectural practice. The study captures through this method the potential of PD within the Mediterranean basin coastal areas used by cruise ships. As such it is suitable as a parametric design tool, as a given glazing configuration can be examined for a range of locations and the implementation of a controlled shading overhang distance system can be examined to provide PD optimization in accordance with ZEB principles. To determine the actual real time and annual energy requirements to achieve ZEB principles, hourly analysis would be required for a range of itineraries in both the Mediterranean and the Caribbean, as popular cruise destinations. A detailed statistical analysis of these simulations coupling itinerary information and collated onsite weather data - would enable the optimal PD configuration to be selected. Therefore, peak loads could be reduced leading to a smaller HVAC capacity - increasing the interior volume available for accommodation and a reduction in fuel consumption. As part of this process a renewable energy system would help facilitate in other auxiliary loads working towards the concept of ZEB in the marine sector.

8.1 Recommendations & Further Work

The following outlines some of the recommendations to the current body of work;

- EnergyPlus offers two primary ways to model glazing systems a) full spectral model or b) the average spectral model – in this study the latter was used as specific data regarding the layer by layer properties of industry glazing systems (that would have allowed for the variations in angular incident insolation) – was unobtainable. In which case the “Simple Window Model” approach was adopted which “offers a reasonably good alternative to the full spectral model” (Lyons 2010) and is based on the bulk layer calculations found in the works of Arasteh and Kohler (2009). A full spectral analysis however might yield greater accuracy in solar gains results - as well as provide the opportunity to test electrochromic and thermochromic glazing systems as a passive strategy.
- Parametric studies in this research are based on thermal models developed in accordance to several maritime design codes such as the ISO 7547 (ISO. 2002) and information gathered from relative works such as Boden (2014). However, an ideal loads analysis procedure was adopted and assumes a HVAC system that is 100% efficient. The Operational behaviour, technical system details and specific coefficients of performance (COP) therefore, are negated from the current model. The incorporation and development of a more detailed HVAC systems (incorporating fan, pumps and boiler details) would allow for a more comprehensive understanding of the behaviour of the zone in relation to passive strategies and would enable the realization of energy use in terms of fuel thus quantifying the cost savings as a result of its implementation. Furthermore, heat recovery systems, re-circulation of air and or enthalpy recovery systems were not considered in this study and may otherwise increase the significance of PD as an Energy Efficiency Measure (EEM). Finally, further works towards the development of accurate freely available thermal models for marine design research would serve as a significant and valuable starting point for energy efficiency studies thus fostering experimentation and development in this sector.
- Occupancy profiles are based on anticipated cruise ship itinerary data and occupant behaviour from guest suites in hotels based on the works of Jiang (2008) provided within the reference the buildings of Deru, et al. (2011). Further works therefore, would develop statistical models of occupancy in cabins and other zones on board a cruise ship, allowing for more accurate estimations of occupancy levels and plug loads such as lighting and equipment

- A limited number of climate files and a sparse data density in coastal area weather files - might permit microclimatic characteristics to be omitted from the analysis. This has resulted in a methodology adopting existing climate classification models. However, in order to capture the variation in climatic conditions for a given itinerary as well as the influence of ‘apparent wind’ induced by the motion of the vessel– onsite real-time data collection methods should be used in further works so as to quantify the impacts of static PD strategies and to define the potential of hybrid or automated Passive Technology.
- A major assumption in the current thermal models is the adiabatic relationship existing between interior zones. Thus, specific interior heat transfers and transmission of boundaries below the water line are neglected from this current study limiting the thermal exchanges considered. Further works therefore, would work to extend current single cell model to capture the idiosyncratic thermal exchanges allowing for an investigation into the unique thermal behaviour of marine vessels

In addition to the above, the study does not acknowledge the emergence of specific progressive passive strategies including roof ponds (Bainbridge. 2011: 45), cooling towers (Dahl 2013), trombe walls (Ruiz 2005), evaporative cooling (Lomas. 2004) and new found technologies such as light weight thermal mass (Bainbridge. 2011:18). To this degree, the research cannot define the potential of PD in its totality and is otherwise limited to the simulation capabilities of EnergyPlus (Crawley 2000). Furthermore, the study does not provide a detailed economic and ecological investigation pertaining to the viability of PD to which there is a need for further research. However, as per the works of Watson and Labs (1983) a substantial number of passive strategies and their impact as identified by this study can be measured and marked onto the psychometric bioclimatic chart making it a plausible pre-design tool for the assessment of PD within the Marine Industry. Onsite data collection methods followed by a comparative analysis of thermal simulation models would be the natural next step of this research to expand and develop the thermal models and design tools presented.

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