Adapting Commercial Building Information Modelling software for the design of a complex Naval Vessel Heating Ventilation and Air Conditioning System.

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Synopsis

This paper provides an overview of how Building Information Modelling (BIM) software has been used for the design and build of the new Type 31 (T31) Frigate. With BIM software traditionally used in the building services industry, a bespoke approach has been undertaken to ensure it is appropriately utilised for marine applications.

Due to the complex nature and the tight timescales of the T31 Frigate programme, traditional spreadsheet and hand calculation methods were inadequate. It was, therefore, necessary to identify and develop a new approach for the design of the platforms Heating Ventilation and Air Conditioning (HVAC) system.

The BIM software packages were adapted to be capable of meeting marine design standards which enabled the complete ductwork system to be modelled in 3D. This allowed for dynamic design calculations and simulations of the ship's HVAC system to be undertaken from concept to detailed design stages. This was conducted for both normal operating and Chemical, Biological, Radiological and Nuclear (CBRN) configurations which is a vital capability in advancing the design of Naval vessels.

The complex ductwork model has been developed by using three software packages; Autodesk REVIT, MagiCAD Ventilation and Integrated Environmental Solutions (IES). This paper covers the ductwork model and focuses on AutoDesk Revit and MagiCAD, with inputs from an IES thermal model.

A semi-automated process has been established between the three software packages to allow for design development and maturity to easily be embodied into the ship's model at any stage of the Concept, Assessment, Demonstration, Manufacture and In-Service (CADMID) cycle.

This new approach provides the capability to undertake multiple detailed calculations and dynamic simulations of the entire system. Examples include:

- Detailed ductwork sizing calculations with parameters configured to the equipment manufacturer's requirements, specific to the marine environment.
- Original Equipment Manufacturer (OEM) components, from cabin units and nozzles to flow balancing and fire dampers integrated into the 3D model.
- Pressure drop calculations for high and low pressure ductwork systems, including inline components such as fire dampers, balancing dampers and non-return valves. The results of which feed into the fan sizing calculations.
- Critical path identification on all systems to aid both the design and commissioning stages.
- Ability to conduct system balancing simulations during the early design stages. This has the benefit of firstly, identifying areas of high noise induced by throttling the air, providing an opportunity to modify the design. Secondly, providing a baseline for the flow control damper adjustment settings to aid the commissioning process.
- Calculate initial sound levels for each compartment to ensure compliance with Lloyds Register Crew and Embarked Personnel Accommodation Comfort (LR CEPAC) regulations.

The paper will expand on the approach and methodology discussed and how it supports the design life cycle of the T31 HVAC System, giving examples of how it has been incorporated.

Key Words; HVAC simulation, HVAC Design, BIM

Author's Biography

Henry Stephens is a Chartered Senior Mechanical Engineer, he joined Babcock International in 2015 as a graduate and has been working in the Mechanical Engineering Group since 2017. Henry specialises in the design and analysis of marine systems. With a focus on HVAC and marine cooling systems, most recently the HVAC design for the Type 31 Frigate.

1 Introduction

A requirement arose to identify a new approach for modelling the Heating, Ventilation and Air Conditioning (HVAC) ductwork system for the design and build of the new Type 31 Naval vessel. The traditional spreadsheet and hand calculation approach was assessed as 'not appropriate' for this project due to the timescales and resources available.

Therefore, taking inspiration from the Building Information Modelling (BIM) approach used in the building services industry where computer simulation and modelling has been common practice for many years. Research identified a method that could be adapted for the marine industry and to streamline the HVAC ductwork design process. Enabling the entire vessel's ductwork systems to be modelled and analysed in 3D provides the benefit of understanding the full system characteristics at an early design stage. This helps to reduce the overall risk of the HVAC design by performing a system balance and predict indicative compartment noise levels.

2 History of BIM

To understand the benefit of adopting a Building Information Modelling BIM approach within the ship building environment, the following summary provides the brief overview, for further reading see history of BIM (Modeling, 2022).

The first concept and application of BIM started in the 1970s and has been continually developing since to meet industry requirements. It is only in the past 20 years that BIM has been adopted as common practice for the construction industry. Figure 1 illustrates the overall process and how each aspect is connected in a continuous improvement cycle.

The BIM concept aims to improve the overall design through the CADMID cycle, enabling the different disciplines to integrate in a seamless manner. No matter the stage of the project, the BIM process allows for design development and modification, minimising delays and cost. Adapting the latest processes and procedures that have seen decades of development in the building service industry and implementing it for the benefit of a complex Naval vessel is the premise of this paper.

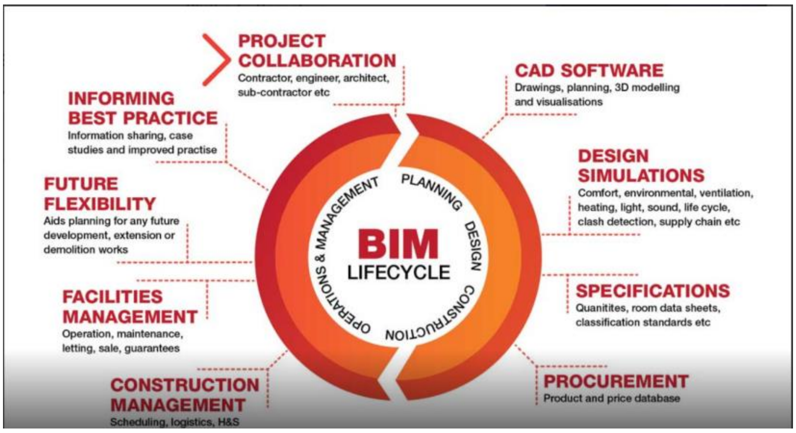


Figure 1 - BIM Cycle (What is BIM, 2022)

3 Marine HVAC Modelling Utilising BIM Technology

The design process has been adapted from the Building Services Industry for a ship environment enabling the design and development of a complex warship's HVAC system.

To assist with the design process, three software packages were identified; Integrated Environmental Solutions Virtual Environment (IES) (IES, 2022), Autodesk Revit (Autodesk, 2022) and MagiCAD (MagiCAD, 2022). This paper focuses on the REVIT/MagiCAD model and process development for the ductwork systems. To provide context a summary of the software packages has been included.

3.1.1 Environmental Model

An Environmental model was developed using IES, where the internal environmental conditions, temperatures, humidity, CO_2 levels and flowrates required are calculated. The flowrates for each compartment are exported from the IES model and linked to the Revit Ductwork model.

A full explanation of the Environmental Modelling process developed for Naval Vessels can be seen in Environmental Modelling and Simulations (Abbas, 2018).

3.1.2 Ductwork Model

The entire ductwork system for the vessel has been modelled and analysed to ensure the systems can deliver the required flowrate to maintain the internal conditions calculated with the IES model. The process developed allows for links between the Environmental model and the ductwork model to be established.

Autodesk Revit is a BIM software that provides the ability to design and model all aspects of a building from the structure to building services. For the purpose of adapting the software for the marine environment only certain elements of the software specific to the HVAC duct work have been utilised when designing the HVAC system.
MagiCAD is an addin for Revit which provides enhanced capabilities for modelling and analysing building services – Mechanical, Electrical and Plumbing (MEP). The ventilation module of MagiCAD has been utilised for the Marine HVAC system as discussed in this paper.

4 Model Creation

Adopting and customising a method more commonly associated with the building services industry to create a 3D model of a Naval Vessel, provides many benefits compared to hand calculations.

4.1 Ship Geometry Generation

A simplified 3D shell model of the vessel was created from 2D general arrangement drawings. Each deck was modelled from the keel upwards, including compartment bulkheads, deckheads and false ceilings for routing the ductwork, where appropriate. This process can be transferred to any ship design and allows for the structure to be created very accurately and efficiently.

Due to the organic shape of the Naval vessel, modelling and time restraints of the specific project, the compartments that are bounded by the hull have been modelled as a cube. This is highlighted in Figure 2 showing the profile of the hull. The compartments affected are in fact, slightly larger than designed. This has been assessed as having a negligible impact on all aspects of the analysis.

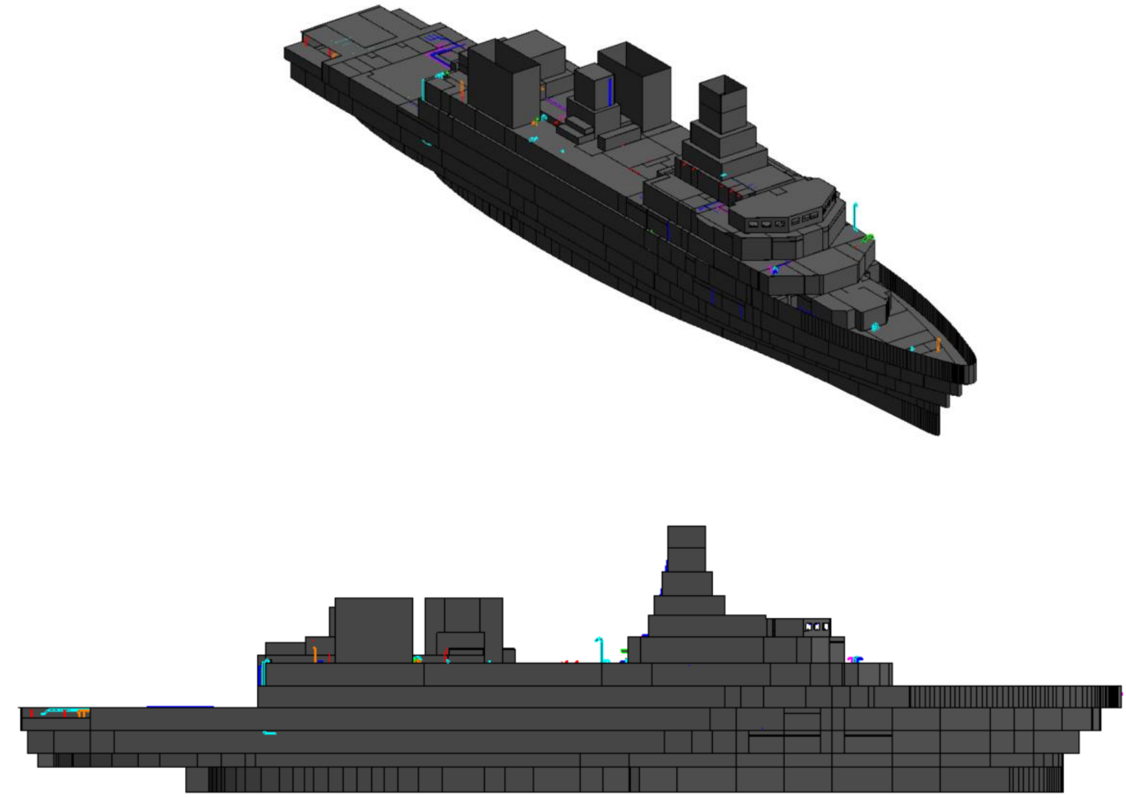


Figure 2a and 2b - 3D model of the Type 31

4.2 Ductwork Routing

The ductwork systems are grouped into one of the following six categories:

- AC supply
- AC return
- Sanitary Exhaust
- Mechanical Supply
- Mechanical Exhaust
- Natural Ventilation

The vessel has been divided into several zones to maintain watertight integrity and fire segregation. The duct has been routed throughout the ship geometry adhering to the separate zones, terminating in the relevant compartments. To ensure there is redundancy in any critical system there are specific cross connections between these zones which have been modelled and analysed.

The resulting route contains all the major bends, junctions, plenums, and changes in elevation. This is vital for the pressure, critical path, and indicative sound calculations.

An example of an individual supply and return system that has been modelled using this process and used for the analysis is shown in Figure 3 and Figure 4 respectively.

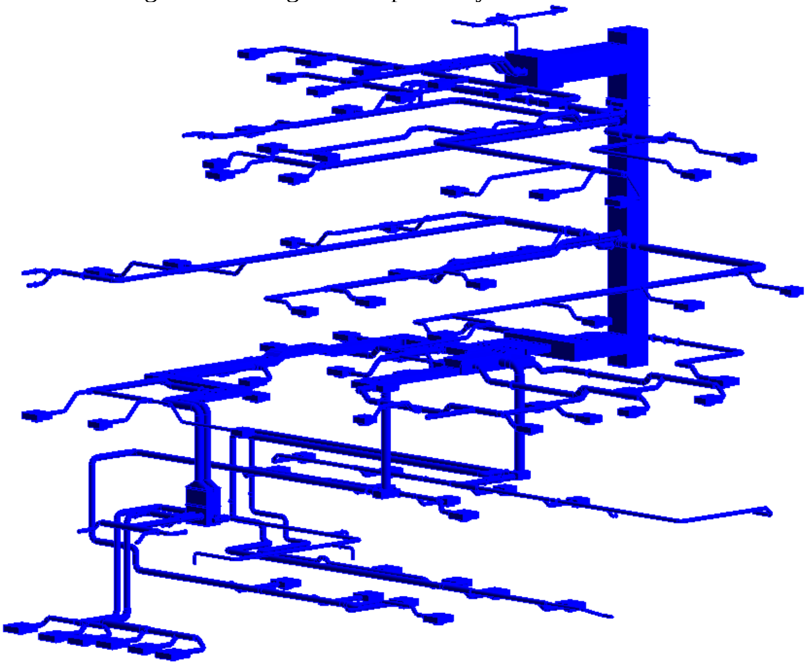


Figure 3 - Example of a Supply Ductwork system

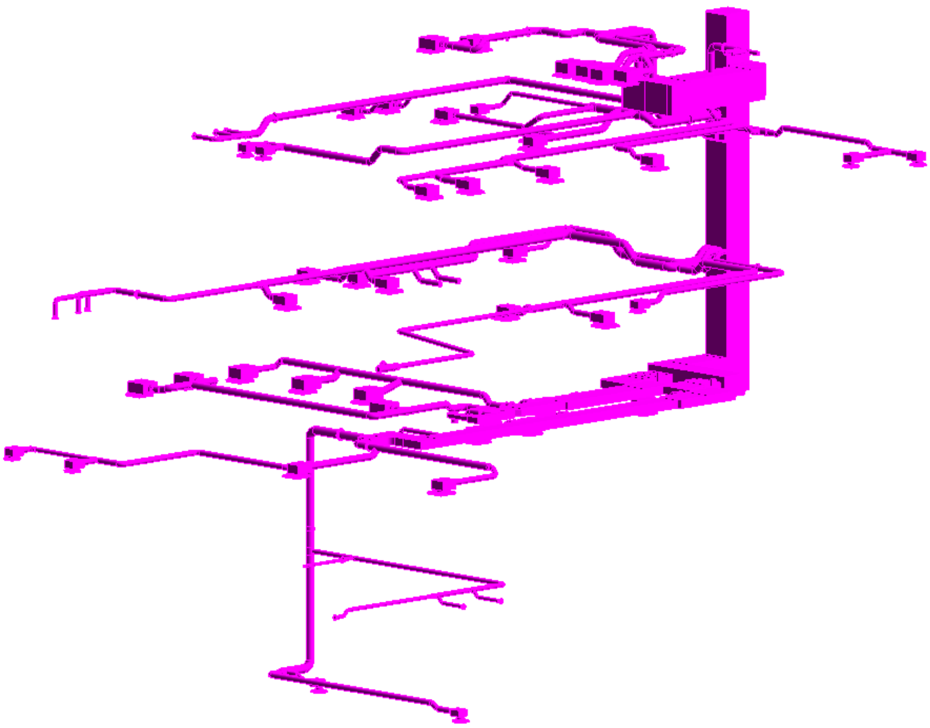


Figure 4 - Example of a Return System

With all systems drawn, Figure 5 shows a slice of how the model looks at the false ceiling height. This provides an open view of all the HVAC duct systems that are located on this deck.

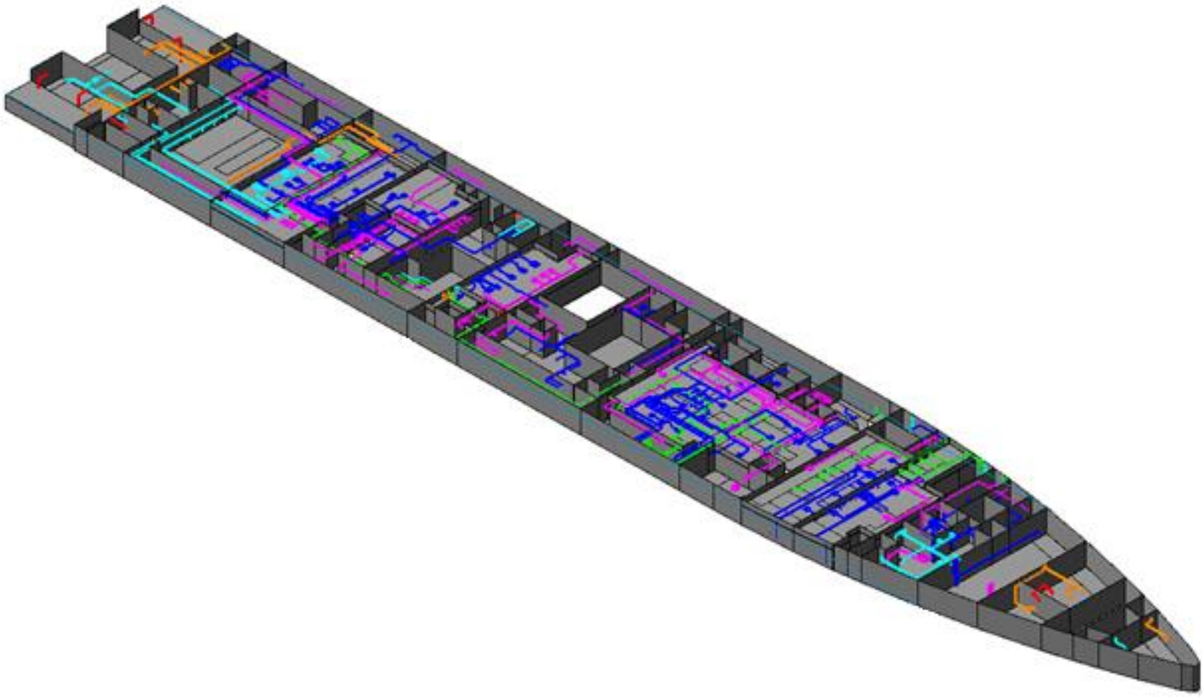


Figure 5 - Slice view of a deck showing all systems

5 Design Parameters

The system design parameters required to perform the analysis of the HVAC duct system are key to the success and reliability of the entire process. There are basic parameters that need to be defined to facilitate any calculation, whether that be a hand or computer simulation. These include:

- The velocity limits for each size of duct and duct system
- Pipe roughness - Thin walled spiro duct and Steel duct
- Pressure drop limit per length of duct
- Bend radius of bends
- Length of transition pieces
- Type of duct connection – tap or tee
- Maximum pressure drop limit for each inline component allowed

6 Original Equipment Manufacture components – Inline and air terminals

The dependability of any calculation always relies on the accuracy of the data and inputs as stated. The ability to model the exact OEM components that will be installed in the final build of the vessel provides numerous benefits for any project.

This capability arose from the developments in the building service industry. There is a vast library of components available that can be used for a variety of applications, mainly focusing on the built environment. There is a growing availability of components that are applicable solely to the marine environment and these have been used where appropriate. However, for bespoke projects such as a Naval Vessel design there are limitations. In this situation, a process was developed and custom components have been modelled integrating the technical performance data, allowing for detailed analysis of that component in the corresponding duct system.

OEM components that have been used include balancing dampers, exhaust and return cabin units, air valves, nozzles, fire dampers, gas tight dampers, shut off dampers and non-return dampers. Bespoke components modelled specifically for this project within the marine industry are high pressure supply cabin units.

7 Data Transfer Links between the Environmental model and the Ductwork model.

The key to the efficiency and accuracy of the process is the link between the environmental model and the ductwork model. Utilising the common compartment codes for both models enabled a semi-automated method to be developed linking the two. This was a vital step to ensure the flowrates calculated in the Environmental model are transferred to the ductwork model correctly.

The flowrate calculated in the Environmental model is the overall flow for the compartment, therefore, based on this value the number and type of air terminals are selected. The air flowrates are imported from the Environmental model into the ductwork model via a spreadsheet in a semi-automated manner. This enables the flow to be distributed evenly to the corresponding air terminals within the compartments. However, due to the unique nature of a marine HVAC system there are certain areas where uneven distribution between air terminals cannot be avoided. In this case, a manual process has been developed for these compartments.

The benefit of both the semi-automated and manual process of importing and exporting the correct flowrates results in the spreadsheet acting as the self-checking procedure. Regardless of the number of updates to the compartment flowrates required throughout the project, this semi-automated process ensures the errors are reduced and limits any delays to the project.

8 Differences between the Built Environment and Marine Applications.

The purpose of BIM was originally designed for use in the building services industry and applicable to the standards and common practices used within this field. To facilitate the use of a BIM process within the marine industry there were vital differences that required adaptations to be made to enable reliable and accurate calculations for a Naval vessel’s HVAC system, these critical differences are discussed in the following section:

8.1 Chemical, Biological, Radiological and Nuclear conditions

The threats to a Naval vessel could change in a split second. Therefore, it is of paramount importance the vessel can react to the ever-changing demands. One of the most serious threats to life on board is a Chemical, Biological, Radiological or Nuclear (CBRN) attack.

When the vessel is in a CBRN arrangement the flowrate and pressure are higher for the return side compared to normal operation. Therefore, developing a 3D model to simulate the CBRN condition configuration enabled a fan duty point to be calculated for both normal and CBRN configurations, aiding the selection of a suitable Variable Frequency Drive. This resulted in only one fan per AC system being required for both configurations, saving space and cost.

The 3D model helps to build confidence in the HVAC system and ensures the fans, Air Filtration Units (AFU), and duct can deliver the required level of airflow and oxygen to sustain life on board.

8.2 Space Constraints

The additional equipment required to support the functions of a warship such as combat and mission systems causes challenges with spatial integration throughout the ship.

The benefit of developing a 3D ductwork model of the design allows for any integration issues to be easily modelled and analysed, ensuring minimal delay to the project. This enables the system to be at a mature state at the Design stage of the CADMID cycle, reducing the risk when estimating the pressure drops for sizing fans and other inline duct components.

8.3 Location

The location of a building is fixed and only exposed to a specific weather profile throughout a year. Whereas a marine vessel by the nature of its operations, travels the world experiencing a wide range of external environmental conditions. For the purpose of this paper the effects of location on the vessel have been considered using the environmental modelling mentioned in section 3.1.1, ie humidification, heat and cooling demands and dew points. The duct work model has focused on the duct route, sizing and materials used to provide confidence the vessel can operate in the varying climates required.

The example discussed in this paper was for a constant air volume system, therefore, consideration of varying the flowrates depending on climate and number of personnel has not been considered. However, there is the ability to capture a variable air volume system if the project requires using the aforementioned process and software.

9 Simulations/ calculations

Using a BIM approach in the design of a marine HVAC system provides the ability to undertake detailed calculations and informed design decisions at all stages of the CADMID cycle. The process outlined below helps to de-risk the design at the early stages, providing the technical analysis to inform the selection of all equipment relating to the duct systems, from fans to dampers and air terminals. This saves both time and cost along with the ability to perform an initial balance of the duct systems.

9.1 Duct sizing

The duct sizing calculation can be customised depending on the standards selected for the project. The standard used for this paper is specific to a manufacture supplying the ductwork and associated equipment. Ensuring the ductwork system can deliver the required air flowrate across the entire ship commences with the correct duct sizing. For this example, there are six different sizing methods for the various systems from high pressure to low pressure and sanitary ventilation.

The duct sizing report in Figure 6 provides a detailed breakdown of each segment of duct allowing every section to be scrutinised in detail, ensuring the HVAC systems can deliver the required flowrate to the individual compartments.

Location	Level	Node	Type	Series	Product	Size	Old size	L [m]	Insulation	qv [l/s]	v [m/s]	dp/L [Pa/m]	Sizing method	Warnings
	02 Deck False	333	TAP	Marine	ILRU-160	160			P/15	168.5	8.4			
	02 Deck False		DUCT	Marine	SR-160	160		0.9	P/15	168.5	8.4	5.87	nevenco sizing	
	02 Deck False	422	FLOWDAMPE		DIRU 160	160			P/15	168.5	8.4			
	02 Deck False		DUCT	Marine	SR-160	160		0.4	P/15	168.5	8.4	5.87	nevenco sizing	
	02 Deck False	520	FLOWDAMPE		DIRU 160	160			P/15	168.5	8.4			
	02 Deck False		DUCT	Marine	SR-160	160		9.5	P/15	168.5	8.4	5.87	nevenco sizing	
	02 Deck False	305	T-BRANCH	Marine	TCPU-160-125	160/125	160/160		P/15	168.5	8.4			
	02 Deck False		DUCT	Marine	SR-125	125	160	1.7	P/15	122.5	10.0	11.15	nevenco sizing	
	02 Deck False	306	T-BRANCH	Marine	TCPU-125-100	125/100	160/100		P/15	122.5	10.0			
	02 Deck False		DUCT	Marine	SR-100	100		0.8	P/15	61.3	7.8	9.20	nevenco sizing	
	02 Deck False		BEND-45	Marine	BU-100-45	100			P/15	61.3	7.8			
	02 Deck False		DUCT	Marine	SR-100	100		0.2	P/15	61.3	7.8	9.20	nevenco sizing	
	02 Deck False		BEND-45	Marine	BU-100-45	100			P/15	61.3	7.8			
	02 Deck False		DUCT	Marine	SR-100	100		0.5	P/15	61.3	7.8	9.20	nevenco sizing	
	02 Deck False	423	SUPPLY		RS35-C01-08	100				61.3	7.8			
	02 Deck False		REDUCER	Marine	RCFU-125-100	125/100	160/100			61.3	5.0			
	02 Deck False		DUCT	Marine	SR-100	100		1.1	P/15	61.3	7.8	9.20	nevenco sizing	
	02 Deck False		BEND-90	Marine	BU-100-90	100			P/15	61.3	7.8			
	02 Deck False		DUCT	Marine	SR-100	100		0.1	P/15	61.3	7.8	9.20	nevenco sizing	
	02 Deck False		BEND-60	Marine	BU-100-60	100			P/15	61.3	7.8			
	02 Deck False		DUCT	Marine	SR-100	100		0.1	P/15	61.3	7.8	9.20	nevenco sizing	
	02 Deck False		BEND-60	Marine	BU-100-60	100			P/15	61.3	7.8			
	02 Deck False		DUCT	Marine	SR-100	100		0.1	P/15	61.3	7.8	9.20	nevenco sizing	
	02 Deck False	424	SUPPLY		MS35-C00-08	100				61.3	7.8			

Figure 6 - Sizing Report

9.2 System Pressure

The system pressure determines how successful a design is in being able to deliver the correct air flow into the specific compartments. The system pressure report shown in Figure 7 provides the detailed information of the flow and pressure within each segment of duct to fully understand the system performance.

Location	Level	Node	Type	Series	Product	Size	L [m]	Insulation	qv set [l/s]	qv [l/s]	v [m/s]	dpt [Pa]	K factor	dp/L [Pa/m]	pt [Pa]	pst [Pa]	adj.	qv [%]	Warnings
	3 Deck Fals		DUCT	Marine	SR-125	125	0.2	P/15	77.0	77.0	6.3	0.8		4.62	197.2	173.5			
	3 Deck Fals		BEND-45	Marine	BU-125-45	125		P/15	77.0	77.0	6.3	4.3	0.181		196.4				
	3 Deck Fals		DUCT	Marine	SR-125	125	0.5	P/15	77.0	77.0	6.3	2.3		4.62	192.1	168.5			
	3 Deck Fals		REDUCER	Marine	RCFU	125/100			77.0	77.0	6.3	1.6	0.028		189.9				
	3 Deck Fals	260	SUPPLY		RS35-C01-0	100			77.0	77.0	9.8	188.3			188.3		0.00	100	
	3 Deck Fals		DUCT	Marine	SR-125	125	0.2	P/15	20.0	20.0	1.6	0.1		0.39	67.1	65.5			
	3 Deck Fals		REDUCER	Marine	RCU-125-80	125/80			20.0	20.0	1.6	0.7	0.078		67.0				
	3 Deck Fals		DUCT	Marine	SR-80	80	1.3	P/15	20.0	20.0	4.0	4.5		3.48	66.2	56.7			
	3 Deck Fals		BEND-90	Marine	BU-80-90	80		P/15	20.0	20.0	4.0	4.5	0.469		61.8				
	3 Deck Fals		DUCT	Marine	SR-80	80	0.5	P/15	20.0	20.0	4.0	1.7		3.48	57.3	47.8			
	3 Deck Fals		BEND-90	Marine	BU-80-90	80		P/15	20.0	20.0	4.0	4.5	0.469		55.6				
	3 Deck Fals		DUCT	Marine	SR-80	80	0.3	P/15	20.0	20.0	4.0	1.2		3.48	51.2	41.7			
	3 Deck Fals	454	CONN.NOD			80			20.0	20.0	4.0	50.0			50.0			100	
	2 Deck Fals	279	TAP	Marine	ILRU-125	125		P/15	115.0	115.0	9.4	68.4	1.182		676.5				
	2 Deck Fals		DUCT	Marine	SR-125	125	0.4	P/15	115.0	115.0	9.4	4.1		9.89	608.1	555.4			
	2 Deck Fals	455	FLOWDAM		DIRU 125	125		P/15	115.0	115.0	9.4	49.4			604.1		10	100	
	2 Deck Fals		DUCT	Marine	SR-125	125	9.6	P/15	115.0	115.0	9.4	95.1		9.89	554.7	502.0			
	2 Deck Fals		BEND-90	Marine	BU-125-90	125		P/15	115.0	115.0	9.4	17.1	0.325		459.6				
	2 Deck Fals		DUCT	Marine	SR-125	125	1.5	P/15	115.0	115.0	9.4	15.3		9.89	442.5	389.8			
	2 Deck Fals	502	FLOWDAM		DTU 125	125		P/15	115.0	115.0	9.4	24.4			427.2		10	100	
	2 Deck Fals		DUCT	Marine		125	0.3	P/15	115.0	115.0	9.4	3.0		9.89	402.8	350.1			
	2 Deck Fals		BEND-90	Marine	BU-125-90	125		P/15	115.0	115.0	9.4	17.1	0.325		399.8				
	2 Deck Fals		DUCT	Marine	SR-125	125	1.0	P/15	115.0	115.0	9.4	10.3		9.89	382.6	329.9			
	2 Deck Fals		BEND-90	Marine	BU-125-90	125		P/15	115.0	115.0	9.4	17.1	0.325		372.3				

Figure 7 - Pressure Report

9.3 Critical Path Identification

The critical path of an individual HVAC system is a key characteristic that requires calculation. Being able to undertake this utilising a 3D simulation not only provides a visual representation helping to identify any issues or errors but reduces the time it takes. The result of the critical path determines the selection of the fan required for the individual system. If the critical path is seen to be significantly higher than most of the other duct branches this has a negative impact on the fan selection. The process developed allows for easy identification of duct areas causing high-pressure. The duct system can be easily modified to reduce the critical path pressure drop and bring it closer to the other branches in the system, positively affecting the selection of the fan.

The critical path identification also aids the placement of inline components such as flow control dampers. Figure 8 shows the critical path route (highlighted in green) for a supply duct system.

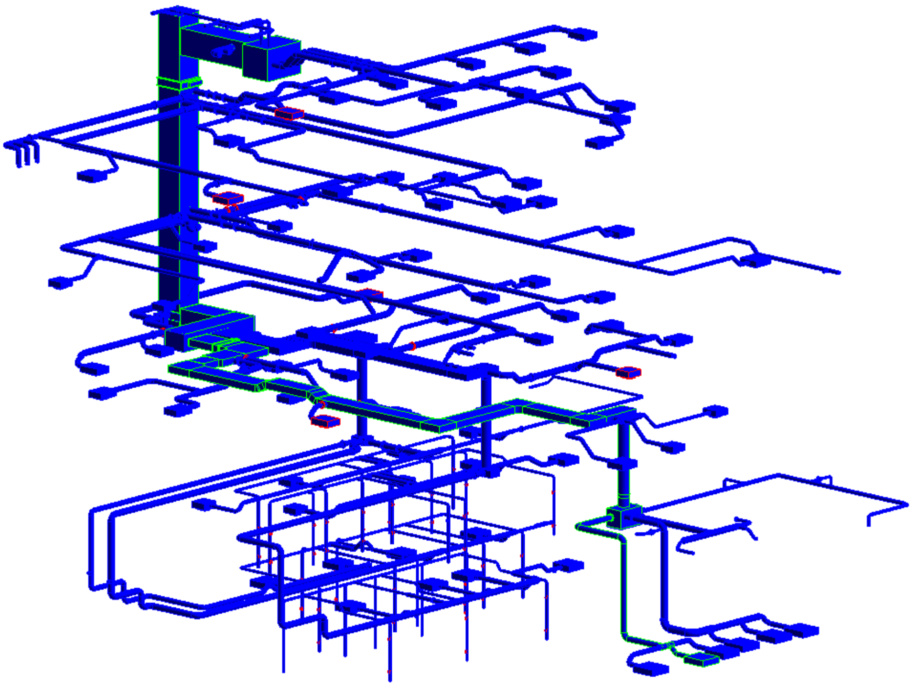
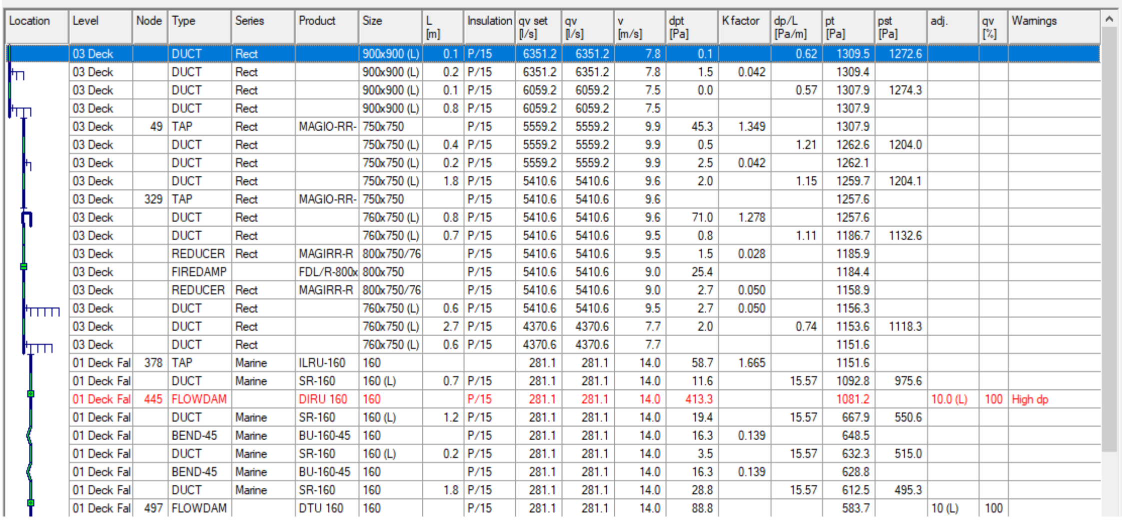


Figure 8 - Critical Path Identification

The critical path report in Figure 9 is a part of the overall system pressure report discussed in section 9.2 and allows for the critical path route to be isolated from the report and each segment of duct to be analysed in detail.



Location	Level	Node	Type	Series	Product	Size	L [m]	Insulation	qv set [l/s]	qv [l/s]	v [m/s]	dpt [Pa]	K factor	dp/L [Pa/m]	pt [Pa]	pst [Pa]	adj.	qv [%]	Warnings
	03 Deck		DUCT	Rect		900x900 (L)	0.1	P/15	6351.2	6351.2	7.8	0.1		0.62	1309.5	1272.6			
	03 Deck		DUCT	Rect		900x900 (L)	0.2	P/15	6351.2	6351.2	7.8	1.5	0.042		1309.4				
	03 Deck		DUCT	Rect		900x900 (L)	0.1	P/15	6059.2	6059.2	7.5	0.0		0.57	1307.9	1274.3			
	03 Deck		DUCT	Rect		900x900 (L)	0.8	P/15	6059.2	6059.2	7.5				1307.9				
	03 Deck	49	TAP	Rect	MAGIO-RR-	750x750		P/15	5559.2	5559.2	9.9	45.3	1.349		1307.9				
	03 Deck		DUCT	Rect		750x750 (L)	0.4	P/15	5559.2	5559.2	9.9	0.5		1.21	1262.6	1204.0			
	03 Deck		DUCT	Rect		750x750 (L)	0.2	P/15	5559.2	5559.2	9.9	2.5	0.042		1262.1				
	03 Deck		DUCT	Rect		750x750 (L)	1.8	P/15	5410.6	5410.6	9.6	2.0		1.15	1259.7	1204.1			
	03 Deck	329	TAP	Rect	MAGIO-RR-	750x750		P/15	5410.6	5410.6	9.6				1257.6				
	03 Deck		DUCT	Rect		760x750 (L)	0.8	P/15	5410.6	5410.6	9.6	71.0	1.278		1257.6				
	03 Deck		DUCT	Rect		760x750 (L)	0.7	P/15	5410.6	5410.6	9.5	0.8		1.11	1186.7	1132.6			
	03 Deck		REDUCER	Rect	MAGIRR-R	800x750/76		P/15	5410.6	5410.6	9.5	1.5	0.028		1185.9				
	03 Deck		FIREDAMP		FDL/R-800x	800x750		P/15	5410.6	5410.6	9.0	25.4			1184.4				
	03 Deck		REDUCER	Rect	MAGIRR-R	800x750/76		P/15	5410.6	5410.6	9.0	2.7	0.050		1158.9				
	03 Deck		DUCT	Rect		760x750 (L)	0.6	P/15	5410.6	5410.6	9.5	2.7	0.050		1156.3				
	03 Deck		DUCT	Rect		760x750 (L)	2.7	P/15	4370.6	4370.6	7.7	2.0		0.74	1153.6	1118.3			
	03 Deck		DUCT	Rect		760x750 (L)	0.6	P/15	4370.6	4370.6	7.7				1151.6				
	01 Deck Fal	378	TAP	Marine	ILRU-160	160			281.1	281.1	14.0	58.7	1.665		1151.6				
	01 Deck Fal		DUCT	Marine	SR-160	160 (L)	0.7	P/15	281.1	281.1	14.0	11.6		15.57	1092.8	975.6			
	01 Deck Fal	445	FLOWDAM		DIRU 160	160		P/15	281.1	281.1	14.0	413.3			1081.2		10.0 (L)	100	High dp
	01 Deck Fal		DUCT	Marine	SR-160	160 (L)	1.2	P/15	281.1	281.1	14.0	19.4		15.57	667.9	550.6			
	01 Deck Fal		BEND-45	Marine	BU-160-45	160		P/15	281.1	281.1	14.0	16.3	0.139		648.5				
	01 Deck Fal		DUCT	Marine	SR-160	160 (L)	0.2	P/15	281.1	281.1	14.0	3.5		15.57	632.3	515.0			
	01 Deck Fal		BEND-45	Marine	BU-160-45	160		P/15	281.1	281.1	14.0	16.3	0.139		628.8				
	01 Deck Fal		DUCT	Marine	SR-160	160	1.8	P/15	281.1	281.1	14.0	28.8		15.57	612.5	495.3			
	01 Deck Fal	497	FLOWDAM		DTU 160	160		P/15	281.1	281.1	14.0	88.8			583.7		10 (L)	100	

Figure 9 - Critical Path Report Example

9.4 System Balance

Balancing an HVAC system is traditionally undertaken during the commissioning phase of a project, which proves to be costly and could potentially delay the project if issues arise such as an increase in noise generated. The ability to simulate the balancing of the air flow of the HVAC duct systems using the duct model, helps reduce the risk of costly modifications during the commissioning phase if the noise limits are not achieved. Just like the duct sizing and system pressure calculations, each segment of the duct system and air terminal can be balanced in the duct model as individual branches or as a complete system.

Performing an initial system balance in the design stage when using the exact OEM components, provides a mature starting set point for all main dampers and air terminals. The calculated settings can be directly applied to the corresponding dampers and air terminals during the installation phase, saving time during the commissioning stage thus making it a more streamline process.

Undertaking a system balance at an early stage helps to mitigate the risk of high levels of noise induced by over throttled dampers or air terminals. Where areas with high pressure drops and corresponding high noise are identified, informed design decisions can be made with regards to number of flow dampers required, enabling the pressure drop to be divided over a cascade of flow control dampers.

9.5 System Indicative Noise

The sound produced by the HVAC system on board a vessel is another performance characteristic that has traditionally been an area of concern. Mainly because the only time it can be measured is during the commissioning phase. If noise limit breaches are identified at the commissioning stage, this will be both a costly and untimely evolution.

Having the ability to predict the indicative sound levels in each compartment supplied with an HVAC system at the early stages of the CADMID cycle, saves both time and money. This is a major advantage for any project as any issues identified at the design stage can be solved relatively easily, in contrast to issues identified during a commissioning stage. Compartments with strict sound limits can be de-risked and informed design decisions can be made before the ship is built to reduce the noise levels to within design limits. This can be achieved by one of the following design changes, selecting appropriate silencers, changing the flow damper configuration and/or selecting a different type of air terminal.

Sound attenuation data is built into the air terminals and greatly aids the HVAC indicative sound calculation, an example of the data associated to a cabin unit is shown in Figure 10 . This is an iterative process, therefore, depending on the results of the sound level analysis, the most appropriate air terminals with the right sound attenuation properties can be selected.

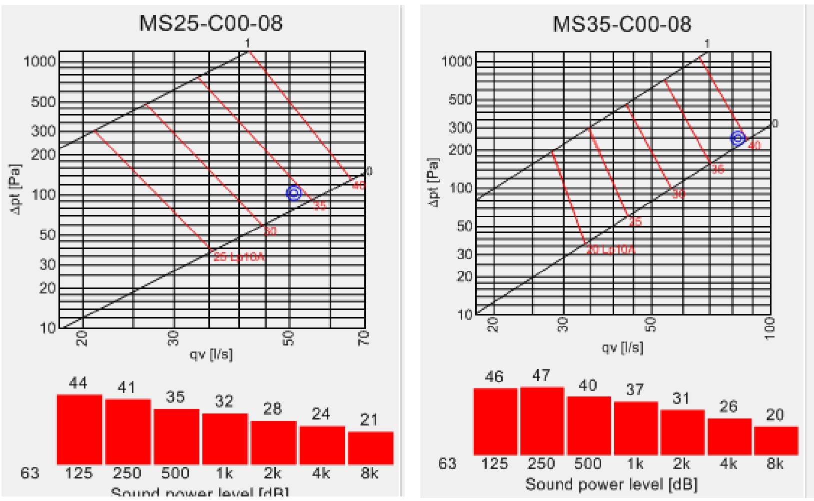


Figure 10 – Attenuation and pressure data for a supply cabin unit

The process allows for the technical data of the fan to be added to the individual duct system to permit more accurate sound power calculations. Depending on the exact fan selected, will determine if the actual OEM fan with built in data is placed in the ductwork model or, aspects of the fan data such as pressure and sound power readings are added manually at the precise location of where the fan would be installed.

The sound data from equipment other than HVAC that is installed within a compartment is often very mature at the design stage. Therefore, it can be added to the indicative HVAC noise to determine the combined values.

Examples of the indicative sound levels can be seen in Figure 11. This calculation provides an easy visual display for the sound levels in each compartment along with an Excel export if required. Each colour represents a different sound level. Depending on the standards used, the noise limits for occupied and un-occupied spaces can be determined. Informed design decisions can be undertaken regarding the requirement for silencers.

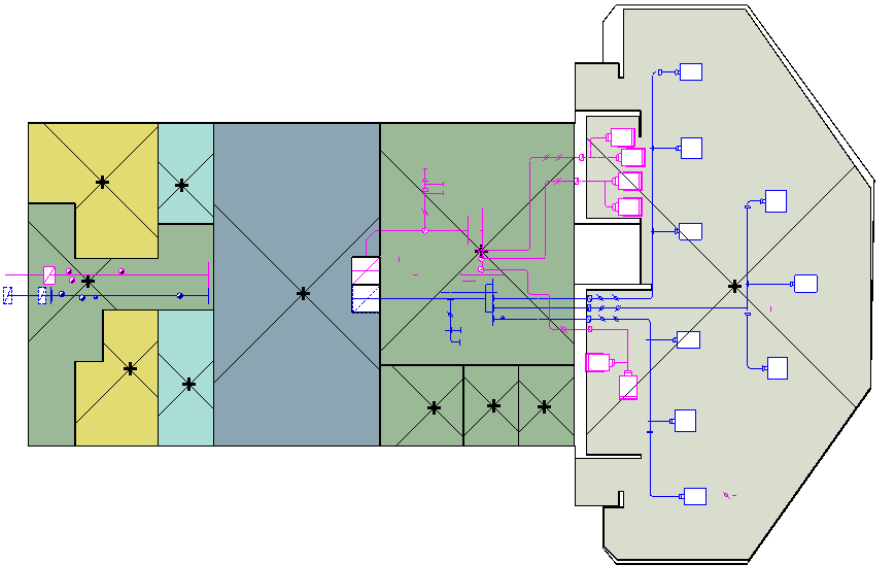


Figure 11 - Indicative Sound Levels

10 Conclusion

The modelling approach discussed in this paper has enabled the entire HVAC network for a complex Naval vessel to be modelled and analysed in detail. The ship contains more than 60 individual systems and over 3500 duct segments supplying over 300 compartments to be analysed in detail.

All ducts have been checked to ensure they are below the critical velocity limits both pre and post the balancing process. This is a major advantage as velocities post physical balancing are not always known when balancing is only conducted after the system has been installed. The chance of excess duct velocities occurring which can lead to excess noise is reduced. Analysing the duct velocities and indicative sound levels at the design stage allows for design changes to be made early. This reduces the overall risk and provides a level of confidence that duct systems can meet the required performance specification.

Developing a dynamic 3D model at the concept stage of a project provides vital benefits throughout the design life cycle. This is of particular importance during the system integration phase of a project, allowing for real time adjustment and calculations to be undertaken. This provides the ability for the system to be fully assessed and informed design decisions undertaken. Having the ability to perform an initial balance of the system in the design stage is a great advancement for the marine HVAC system. This vital step provides a level of risk mitigation reducing the number of expensive physical modifications post installation.

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12 References

Abbas, Y. (2018). Environmental Modelling and Simulation for Naval Ships. *INEC 2018*.

Autodesk. (2022, 6 7). *Revit: BIM software for designers, builders and doers*. Retrieved from Autodesk: https://www.autodesk.co.uk/products/revit/overview?term=1-YEAR&tab=subscription

IES. (2022, 06 24). *Integrated Environmental Solutions*. Retrieved from IES VE: https://www.iesve.com/

MagiCAD. (2022, 6 5). *MagiCAD for Revit*. Retrieved from MagiCAD: https://www.magicad.com/uk/what-is-magicad-for-mep/

Modeling, B. I. (2022, 05 30). *History of BIM*. Retrieved from Building Information Modeling: https://onlinebimeducation.com/2017/05/04/history-of-bim/

What is BIM. (2022, 07 04). Retrieved from BIM today: https://www.pbctoday.co.uk/news/digital-construction/bim-news/what-is-bim/40457/