Coursework 2

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Blending Jameel

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Introduction

Design teams coordinating the specifications of a design project shapes how the project comes to life. From architects to on-site personnel, communication is deemed to be the most essential tool to coordinate the detailing of the building. Architects, using their profound imagination, have the capability to create a complex yet aesthetic design which leads to discussions between the parties on how the complex design can come to life by creatively producing innovative ideas to turn form into functionality in the real world (Anon., 2021). According to Re-thinkingthefuture.com, many cases in the past years have been discarded due to high costs, unrealistic designs and political reasons hence design projects need to be planned before construction work commences (Arora, 2021). A design project covers every aspect relating buildings including form, building services, sustainability etc.

Building services are a major aspect of a buildings design, in terms of sizing and selection of systems, location of major plant rooms and equipment, the pathways taken for distribution and allocation of services, including HVAC, electricity, and plumbing and the placement of vertical service risers. An appropriate system installed in a building can not only ensure its comfort, functionality, and efficiency but also help in achieving overall strategies and standards.

The following report goes into depth of the systems and technologies used for building services (i.e., HVAC, plumbing, lighting) along with their sizing and location to altogether provide a sustainable design from the design proposal discussed in stage 1. It goes into detail about the specific design recommendations with a project plan that connects the services components to the construction plan of the building. For every significant system, comprehensive scheme designs and plant room layout drawings are shown. Technologies, and tools used for the design project, along with the projected energy use and carbon emissions with a sustainable design.

The following is a basic understanding of the sizing of the building services in this design project:

- Water pipe sizing to the appropriate fixtures
- Pump sizing according to the flow rate
- Duct sizing using benchmarks
- Fan sizing for appropriate air handling units
- Electrical loads and lighting services in 2 rooms
- Project Costing and project planning
- Adaptation to climate change with sustainable measures

Following the basics of the building services, the table below showcases the characteristics of the building designed in stage 1.

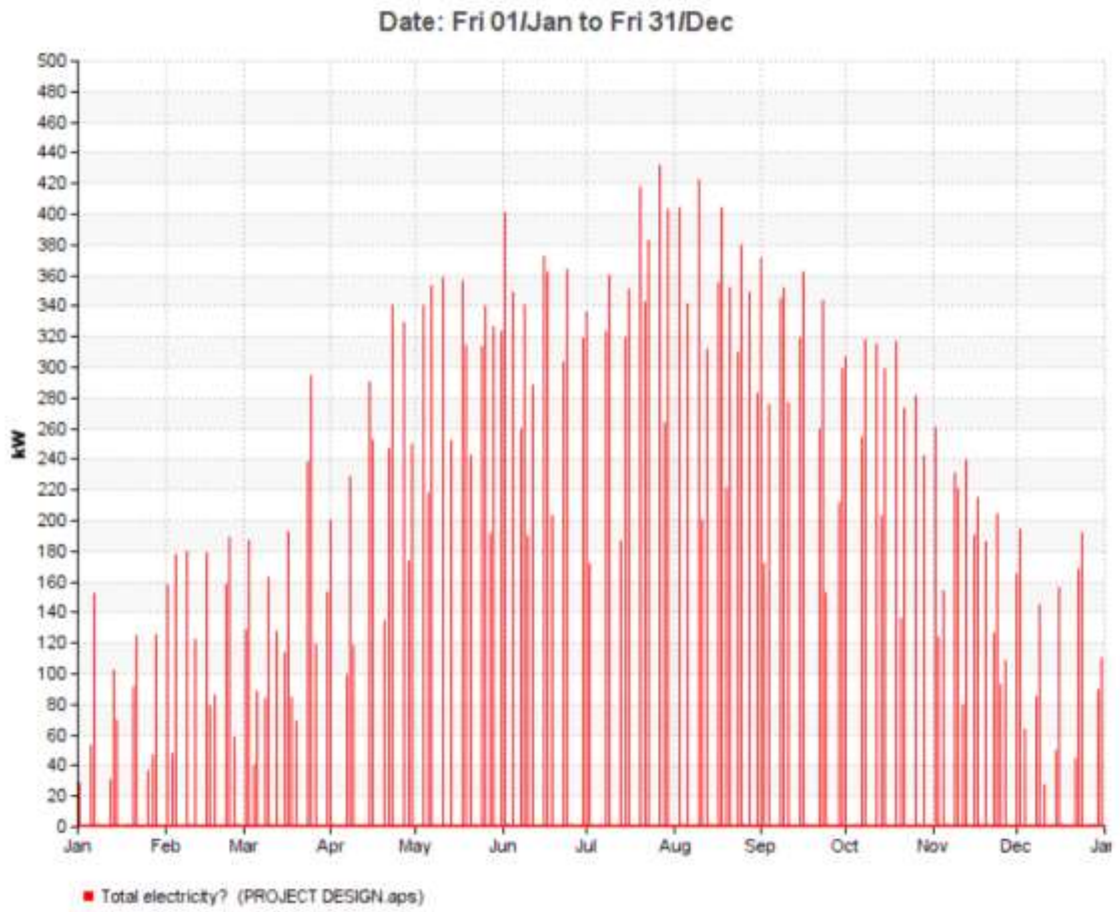
Project Name	Blending Jameel
Location	Al Jaddaf, Dubai, UAE
Floor Area	2,322 m^2
Functionality	Commercial Building (Auditorium, Offices, Meeting Rooms)
Architects	Heriot Watt University
Proposed Construction Date	Late 2024*

Table 1. Overview of the design proposal (Stage 1)

Figure 1. Illustrates the form of the building

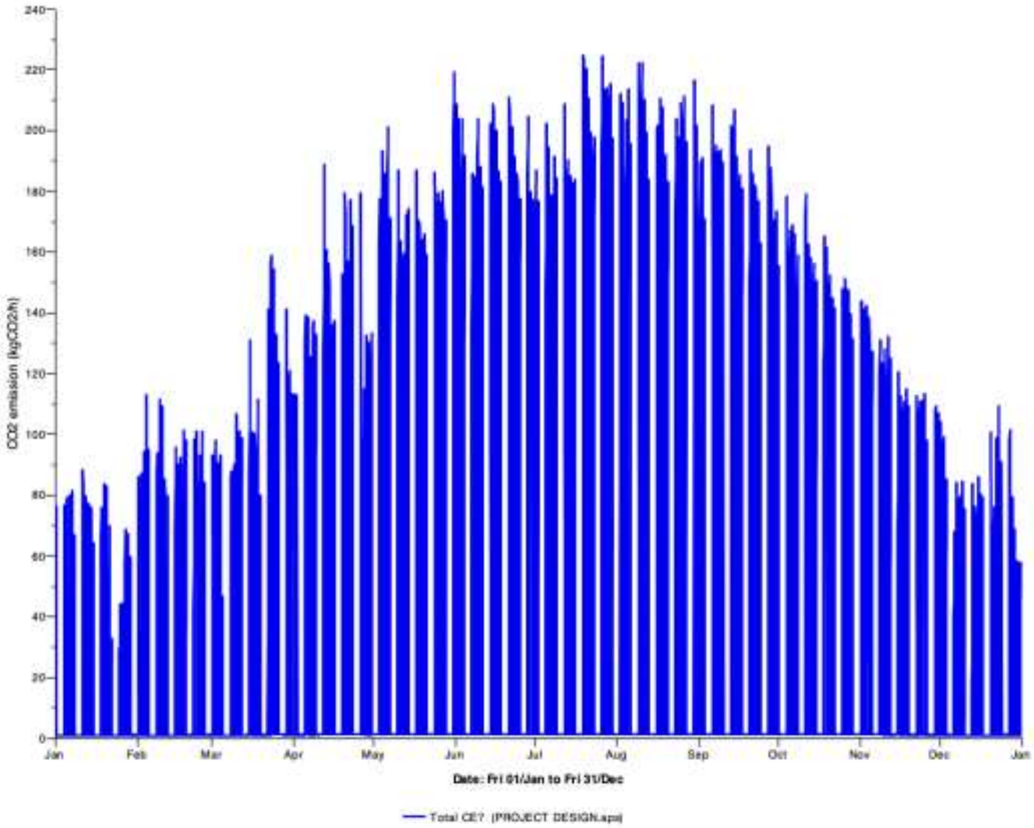
Energy and Carbon

Energy-efficiency:
Building energy performance is the total energy consumption by the building including electrical consumption from HVAC, pumps, lighting and more. IES-VE was used in stage 1 of this design project to create graphs/tables to show energy consumption. Energy-efficient measures such as occupancy sensors are implemented to reduce electricity consumption by lighting.
Due to the limitations of the software IES-VE, the energy consumption was not altered. Following is a graph that shows electricity consumption on a yearly basis.



Most electricity is consumed during July/august due to high cooling loads which increase the consumption by HVAC system.
The total electricity consumption of this design project was compared to CIBSE guideline. According to CIBSE benchmarks, a building with electrical consumption within 180 kWh/m2 is deemed to have a good energy performance. The electrical consumption of this design project is 162.3 kWh/m^2 which meets the benchmark.

Carbon emission:
In addition to energy consumption, it is crucial to evaluate any extensive carbon emissions that could lower the buildings performance.
The following graph shows the carbon emission values taken from IES-VE. Just like energy consumption, these values also remained constant due to the limitations of IES-VE.



The building has carbon emissions of 84.2 kgCO2/m2 which is above the benchmark provided by CIBSE i.e., 75.1 kgCO2/m2. The building has implemented measures such as installation of solar panels however they are not illustrated on IES-VE which could be a reason why carbon emissions are higher.

Plumbing

Plumbing services in a building relate to the water supply to the various fixtures and the drainage systems to remove blackwater and greywater. Fixtures include, wash hand basins and water closets located within the bathrooms which need to have constant water supply. Plumbing layout showcases how the water will be supplied to the required areas through pipes, valves, storage tanks and a pump.

The importance of planning a plumbing system via a software before initial stages of construction can help gain an understanding of the system's layout, required specifications and makes it easier to understand the performance gap between software simulations and real-world implications.

This design project clearly demonstrates and discusses the main steps involved in obtaining a substantial and practical piping layout for the designed building using of schematic drawings to the drafting views of the plumbing system.

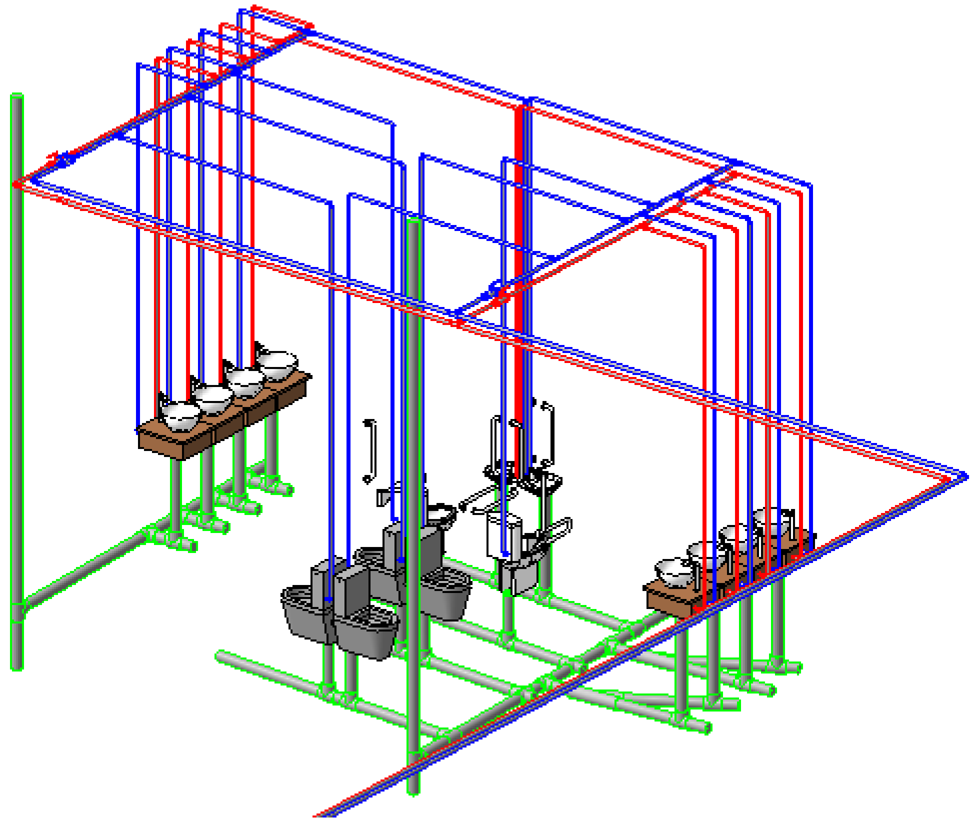


Figure 2. 3D overview of the pipeline layout of this design project.

It is crucial to take step by step measures to correctly size the piping and pump, as it aids in mapping out the desired system to have a complete overview of how the system will throughout the building. Furthermore, allows an area of discussion regarding the practicality of the software-designed system and how it is applied in the real world.

Moving onto this design project's specifications, the following steps were taken to obtain a substantial plumbing layout:

1. *Identifying the placement of the fixtures*
2. *Determining the positioning of the boilers, pumps and storage tanks*
3. *Designing the best possible route for pipeline*
4. *Drainage systems for each bathroom*
5. *Sizing the pipes according to the demand units of the fixtures*
6. *Calculate all the fittings pressure losses*
7. *Using pressure drop, size the pump using Grundfos*

1.1 Placement of the fixtures

Progressing from Stage 1 of the design proposal where the floor plans, function and form were determined, the fixtures were placed accordingly to show interpretation of the function of the room however, the practicality for system layouts wasn't taken into consideration. Therefore, this section identifies the placement of the fixtures to determine the best possible pipeline layout.

The building consists of two bathrooms, both with similar placement of fixtures. The following table breakdowns the number of fixtures for each bathroom in the building:

Bathroom 1	**Instances**		**Bathroom 2**	**Instances**
Water Closets	4		Water Closet	4
Wash Hand Basins	8		Wash Hand Basin	8
Accessible Water Closets	2		Accessible Water Closet	2
Accessible Wash Hand Basins	2		Accessible Wash Hand Basin	2

Table 2. Instances in each bathroom of the design project.

Each fixture is placed accordingly to meet the requirements for substantial water supply which will be discussed later in the report. The following image demonstrates the placement of the various fixtures, mentioned above:

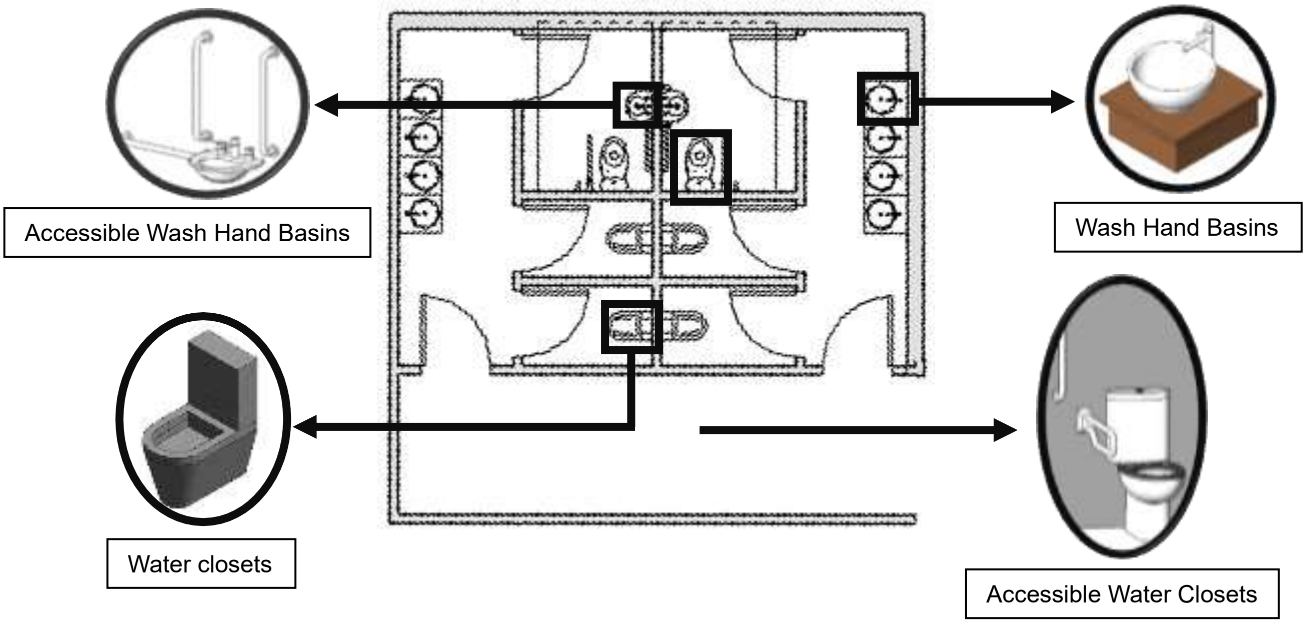


Figure 3. Illustrates the positioning of the various fixtures in the bathroom

Moving on from the instances of the fixtures, one of the aspects regarding pipeline layouts factor in the materials used. Cost efficiency, maintenance issues and practicality are factors affecting the options regarding piping materials. Moreover, both hot and cold-water supply lines differ when it comes to material. Taking that into consideration, the following characteristics of pipes are chosen for this design project:

Supply line	Pipe Material	Abbreviation	Image
Cold Water Supply	Polyvinyl Chloride	PVC	 Link:https://rzbmco.com/product/hp-pvc-pipes-atlas/
Hot Water Supply	Cross-Linked Polyethylene	PEX	 Link: https://www.rifeng.com/article/qusetions-about-pex-tubing-you-should-know

Table 3. Pipe Materials chosen for this design project

The main difference between the selected material is that PEX pipes have a tendency to withstand high temperature, up to 200°C, being the most suitable option for hot water supply (Anon., 2022). Whereas, similarities between the two materials chosen are easy installation, easy maintenance, relatively cheap and don’t corrode (Yevgen, 2022).

1.2 Positioning of components

A number of components are required to complete the basics of a piping system. It can be challenging to choose methods according to engineers and positioning them within the building designed by the architects. Since an architect’s focus is on design and form rather than the practicality of the building service, an engineer is required to inform how the building can be functional and if any design modifications are needed.

Choosing the desired components and placing them according to the building form is important since it shapes how the pipes will travel and map out within the false ceiling of the building. Obscuring pipes that travel from the pump to the fixtures via bends and fittings need to have a clear enough path, preferably the straightest path to reduce the amount of pressure drop resulting in better quality pumps and low investment required in the building.

The initial stages of the design from the architects were lacking service areas for building services, hence, engineers prompted an area specifically for service requirements corresponding to the service provided by the room, e.g., pump room, electrical room, AHU.

The placement of the service areas were done strategically to reduce noise levels from the main areas; if any maintenance is required to any service area, main areas aren't disturbed by the circulation of the maintenance management.

The following image demonstrates the positioning of the pump room and bathrooms that need to be supplied with water in this design proposal:

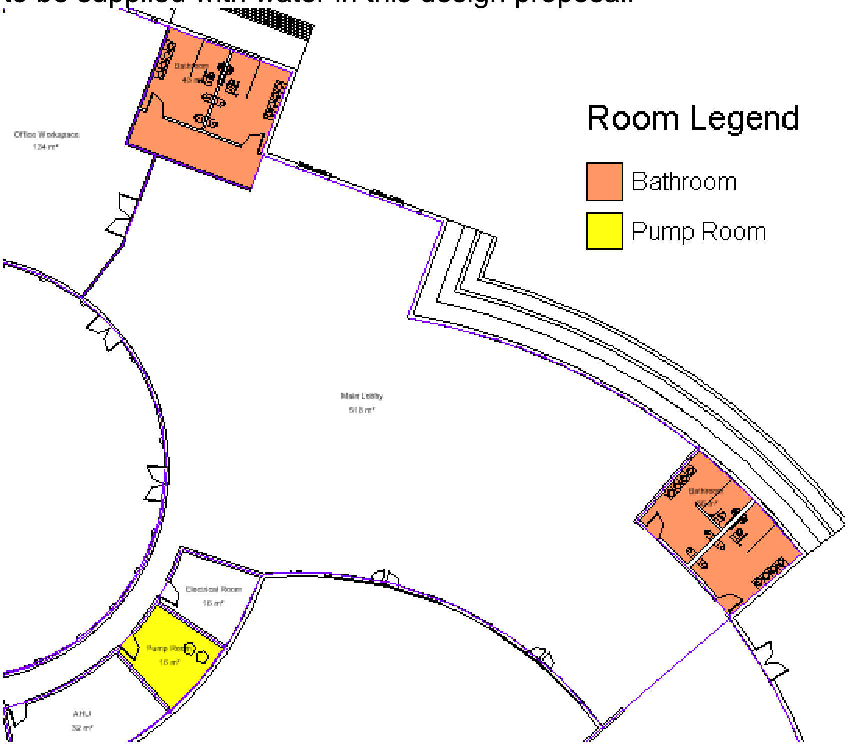


Figure 4. Placement of the bathrooms and the pump room

The distance between the pump room and bathroom 1 (left) is around 24m whereas the distance to bathroom 2 (right) is around 28m. The significance of the distance is discussed in further detail later in the report.

The pump room in the building consists of the following components:

- Water heater
- Pump
- Underground water tank

Two water heaters are located in the pump room for both bathrooms. The system is divided in order to bring reasonable results for pipe sizing.

Figure 5. Section of the pump room showcasing the two boilers

The pump, after sizing, will be located next to water heaters. As the system is divided into two, the pumps will be allocated accordingly to the requirements of the bathroom. The underground water tank is right below the pump room with connections from the outside to provide water for fire emergencies. The placement of this water tank is important to minimize the distance between the tank and the pump to reduce pressure losses.

1.3 Pipeline Layout

The building's pipeline layout describes the path and mapping of the pipes in the false ceiling keeping in mind that this is not the only building service aspect that needs to travel through the ceiling.

Pipes travels through the false ceiling and not through the walls because, according to Emergy, pipeline situated in the false ceiling is deemed to be the best possible way as it is proven to have an easier access point to the pipe for maintenance and leakage tests, moreover, any future changes to the system can be done without extensive construction work i.e., reworking on the walls.

Being a commercial building, it is important to reduce maintenance levels as it can disrupt the main office areas. Accordingly, having a straight-line pipeline layout can increase satisfactory levels of the occupants and energy-efficient measures of the building.

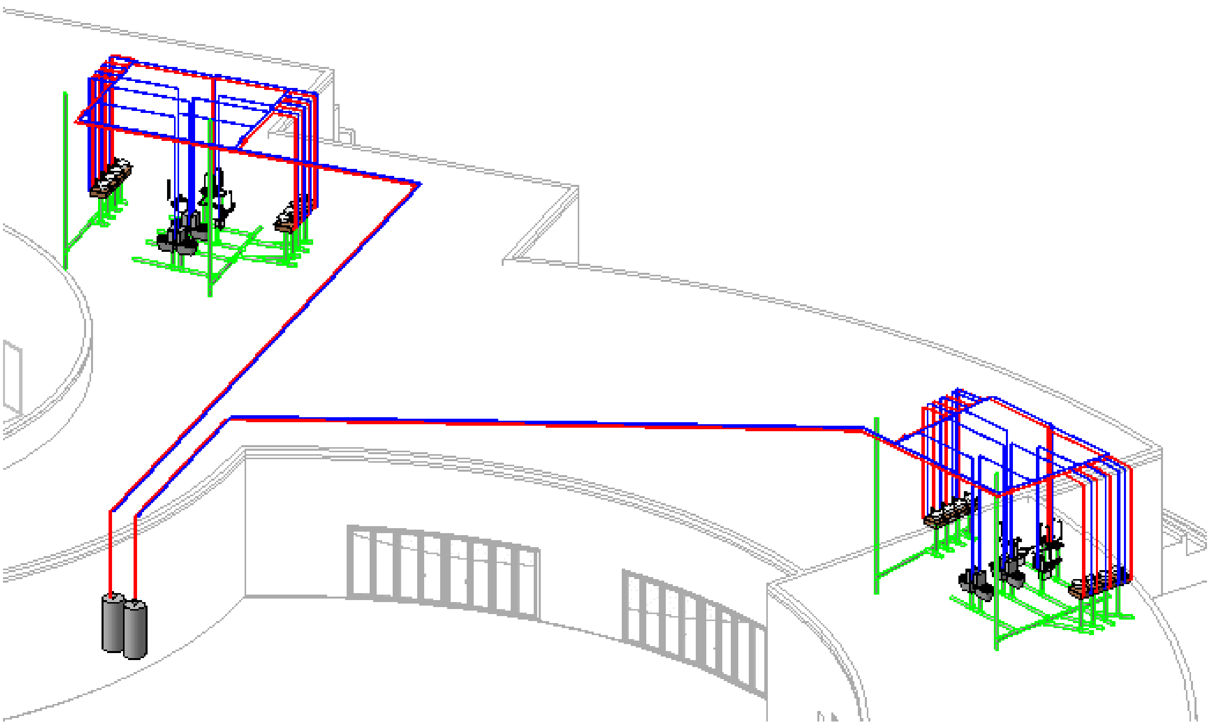
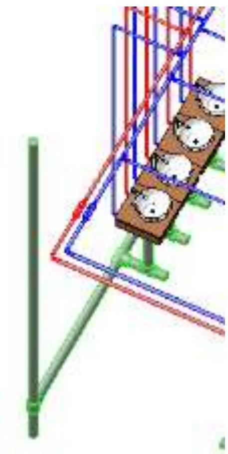


Figure 6. Overview of the pipe system from the water heater to the respective bathrooms

The piping layout specifications for the building is as follows:

1.4 Drainage systems

The drainage systems of this design project were very simple to design. The entire building's wastewater system is a stack system. A stack system is a vertical pipe within the walls or a service area which connects drainage from all the floors and uses gravity to lead wastewater to the sewer underground.
Stack system is used throughout the UAE, as it doesn't use a pump to dispose off the wastewater and doesn't contribute to the electricity consumption of the building.



The image on the right indicates the stack system designed for this design proposal. The top end is open to air as air is required to prevent collection of waste water in the pipe leading to lower maintenance required.

The stack goes one meter into the ground fixes to the main drainage pipe from the Dubai Electricity and Water Authority (DEWA)

Branch drains from the water closets and wash hand basins connect to the main stack pipe at a 2-degree slope. Taking advantage of gravity and neglecting the use of any energy.

Details about the drainage system are discussed further in the pipe sizing section.

Stack sizing

1.5 Pipe Sizing

Pipe sizing describes the difference in pipe diameter and the flow rates of each pipe from the pump to the fixtures.

Bathroom 1		
Supply	Length (m)	Vertical Branching
Cold Water Supply	55.30	16
Hot Water Supply	53.03	10
Bathroom 2		
Supply	Length (m)	Vertical Branching
Cold Water Supply	64.67	16
Hot Water Supply	51.92	10

Table 4. Specifications of the pipe layout

The diameter differs due to the flow rate required in each pipe; diameter is directly proportional to the flow rate, as flow rate increases, diameter of the pipe increases. Subsequently, other factors such as velocity of water supply also increases as diameter increases.

Using standards, CIBSE Guide C, this design project calculated pipe sizes for the fixtures by tabulating the standardized demand units. Applying a frequency of 300hz for each of the fixtures, meaning a gap of 300 seconds between the usage of each appliance, the demand units were taken accordingly from the table below:
Utilizing the demand units from the above table ensures that the building complies with the building standards for future certifications.

CIBSE Guide C is then used to determine the flow rate, velocity, diameter and head loss in meters per meter run for the pipes leading into the fixtures. This was done accordingly to determine the initial flow rate and pipe size which leads to the calculations regarding the remaining pipes entering the bathroom from the pump.

The method used to determine the sizes of the rest of the branch and main pipes was to accumulate all of the flow rates which leads to the branch pipe. The main pipe flow rate is then determined by adding up the flow rates entering the branch pipes which essentially establishes the flow rate from the pump itself.

The following example of the graph from CIBSE Guide C was used to determine the flow rate, velocities and diameter of the water closets:

Type of appliance	Capacity (litres)	Flow rate (litres/sec)	Demand (seconds)	Frequency (seconds)	Usage ratio	Prop of base appl. ratio	Prop of base appl. flow rate	Demand figure	Demand unit
Basin , 15mm sep. taps	5	0.15	33	1200	0.282	1.00	1.00	1.000	1
	5	0.15	33	600	0.055	2.00	1.00	2.000	2
	5	0.15	33	300	0.110	4.00	1.00	4.000	4
Basin, 2 × 8mm mix tap	5	0.08	33	1200	0.028	1.00	0.53	0.533	1
	5	0.08	33	600	0.055	2.00	0.53	1.067	1
	5	0.08	33	300	0.110	4.00	0.53	2.133	3
Sink, 15mm sep./mix tap	12	0.2	60	1200	0.050	1.82	1.33	2.424	2
	12	0.2	60	600	0.100	3.64	1.33	4.848	5
	12	0.2	60	300	0.200	7.27	1.33	9.697	10
Sink, 20mm sep./mix tap	18	0.3	60	600	0.100	3.64	2.00	7.273	7
Bath, 15mm sep./mix tap	80	0.3	266	4800	0.055	2.02	2.00	4.030	4
	80	0.3	266	2400	0.111	4.03	2.00	8.061	8
	80	0.3	266	1200	0.222	8.06	2.00	16.121	16
Bath, 20mm sep./mix tap	80	0.5	266	3000	0.089	3.22	3.33	10.747	11
WC Suite, 6 litre cistern	4.5	0.1	60	1200	0.050	1.82	0.67	1.212	1
	4.5	0.1	60	600	0.100	3.64	0.67	2.424	2
	4.5	0.1	60	300	0.200	7.27	0.67	4.848	5
Shower, 15mm head	6	0.08	300	2700	0.111	4.04	0.53	2.155	2
	6	0.08	300	1800	0.167	6.06	0.53	3.232	3
	6	0.08	300	900	0.333	12.12	0.53	6.465	6
Urinal, single bowl/stall	0	0.003	1500	1500	1.000	36.36	0.02	0.727	1
Bidet, 15mm mix tap	0	0.08	33	1200	0.028	1.00	0.53	0.533	1
	0	0.08	33	600	0.055	2.00	0.53	1.067	1
Hand spray, 15mm	0	0.08	75	1200	0.067	2.27	0.53	1.212	1
Bucket sink, 15mm taps	0	0.15	60	3600	0.017	0.61	1.00	0.606	1
Slop hopper, cistenr only	7.5	0.1	75	600	0.125	4.55	0.67	3.030	3
Slop hopper, cistern/taps	7.5	0.2	60	600	0.100	3.64	1.33	4.848	5
Clothes washing m/c, dom.	5	0.2	25	600	0.042	1.52	1.33	2.020	2

Table 5. CIBSE Guide C - Table 14 - Simultaneous Demand

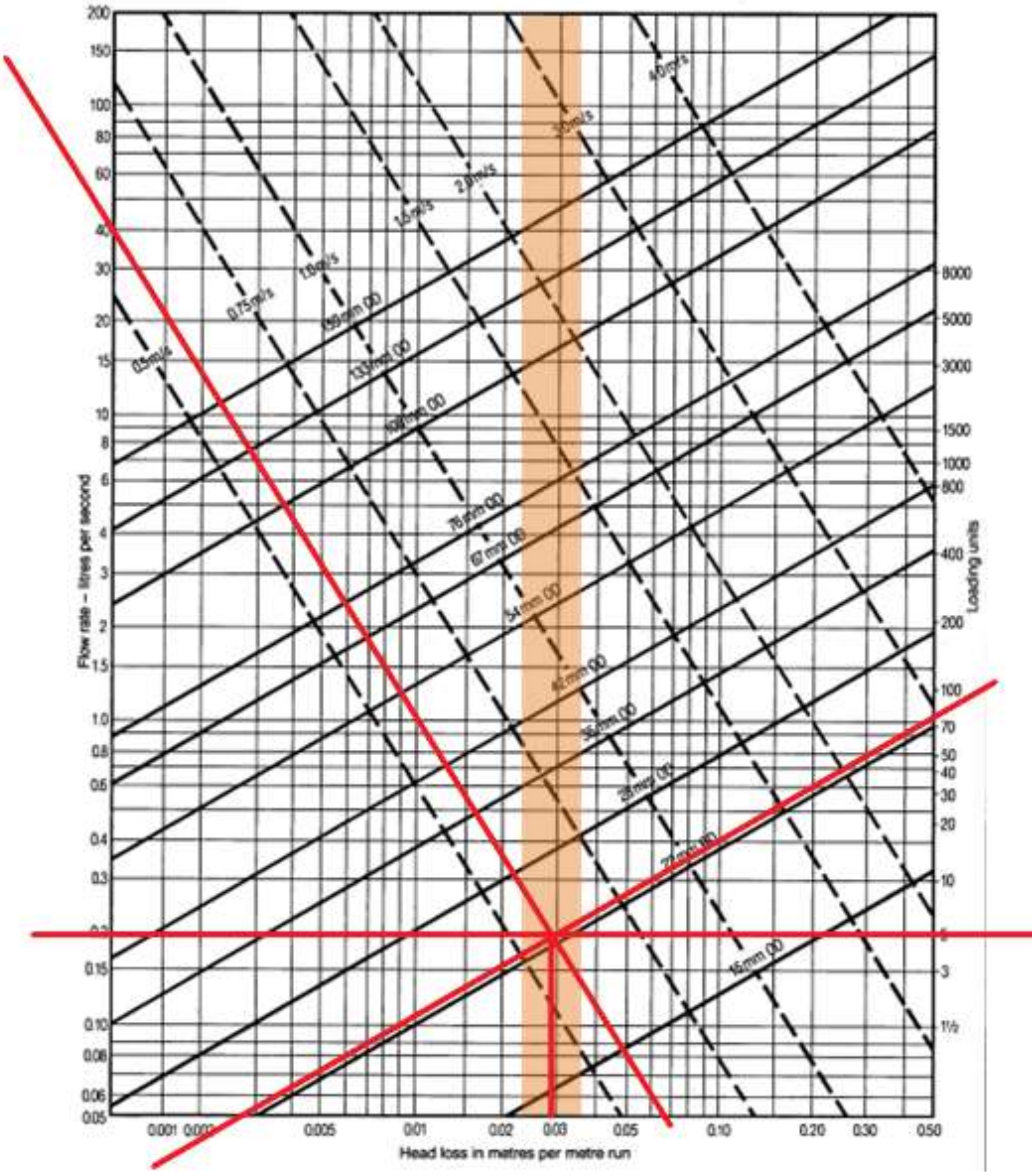


Figure 7. Filled out graph from CIBSE Guide C for the water closets

The same graph was made for the wash hand basins to determine the required aspects regarding the pipe sizing.
The highlighted part on the figure is a standard pressure drop between 250 – 350 Pa/m or 0.025 – 0.036 m/m. This standard was used along with the demand units to create the various lines to calculate the different values regarding the pipe sizing. The following table indicates the values obtained from the CIBSE Guide graph for the fixtures:

COLD WATER SUPPLY BATHROOM 1 WATER CLOSETS									
Ref.	Pipe Ref.	Flow Rate (l/s)	Length (m)	Diameter (mm)	Head Loss (m/mh)	Velocity (m/s)	Pipe loss (m/h)	Elbows	Tees
Bathroom 1 (WC01)	CWS01	0.2	0.062	23	0.03	0.58	0.00186	4.6	0
Bathroom 1 (WC02)	CWS02	0.2	0.062	23	0.03	0.58	0.00186	4.6	0
Bathroom 1 (WC03)	CWS03	0.2	0.062	23	0.03	0.58	0.00186	4.6	0
Bathroom 1 (WC04)	CWS04	0.2	0.062	23	0.03	0.58	0.00186	4.6	0
Bathroom 1 (WC05)	CWS05	0.2	0.062	23	0.03	0.58	0.00186	4.6	0
Bathroom 1 (WC06)	CWS06	0.2	0.062	23	0.03	0.58	0.00186	4.6	0

COLD WATER SUPPLY BATHROOM 1 WASH HAND BASINS									
Ref.	Pipe Ref.	Flow Rate (l/s)	Length (m)	Diameter (mm)	Head Loss (m/mh)	Velocity (m/s)	Pipe loss (m/h)	Elbows	Tees
Bathroom 1 (WHB01)	CWS07	0.3	0.062	26	0.029	0.68	0.001798	7.8	0
Bathroom 1 (WHB02)	CWS08	0.3	0.062	26	0.029	0.68	0.001798	7.8	0
Bathroom 1 (WHB03)	CWS09	0.3	0.062	26	0.029	0.68	0.001798	7.8	0
Bathroom 1 (WHB04)	CWS10	0.3	0.062	26	0.029	0.68	0.001798	7.8	0
Bathroom 1 (WHB05)	CWS11	0.3	0.062	26	0.029	0.68	0.001798	7.8	0
Bathroom 1 (WHB06)	CWS12	0.3	0.062	26	0.029	0.68	0.001798	7.8	0
Bathroom 1 (WHB07)	CWS13	0.3	0.1	26	0.029	0.68	0.0029	7.8	0
Bathroom 1 (WHB08)	CWS14	0.3	0.1	26	0.029	0.68	0.0029	7.8	0
Bathroom 1 (WHB09)	CWS15	0.3	0.1	26	0.029	0.68	0.0029	7.8	0
Bathroom 1 (WHB10)	CWS16	0.3	0.1	26	0.029	0.68	0.0029	7.8	0

HOT WATER SUPPLY BATHROOM 1 WASH HAND BASINS									
Ref.	Pipe Ref.	Flow Rate (l/s)	Length (m)	Diameter (mm)	Head Loss (m/mh)	Velocity (m/s)	Pipe loss (m/h)	Elbows	Tees
Bathroom 1 (WHB01)	HWS01	0.3	0.062	26	0.029	0.68	0.001798	7.8	0
Bathroom 1 (WHB02)	HWS02	0.3	0.062	26	0.029	0.68	0.001798	7.8	0
Bathroom 1 (WHB03)	HWS03	0.3	0.062	26	0.029	0.68	0.001798	7.8	0
Bathroom 1 (WHB04)	HWS04	0.3	0.062	26	0.029	0.68	0.001798	7.8	0
Bathroom 1 (WHB05)	HWS05	0.3	0.062	26	0.029	0.68	0.001798	7.8	0
Bathroom 1 (WHB06)	HWS06	0.3	0.062	26	0.029	0.68	0.001798	7.8	0
Bathroom 1 (WHB07)	HWS07	0.3	0.1	26	0.029	0.68	0.0029	7.8	0
Bathroom 1 (WHB08)	HWS08	0.3	0.1	26	0.029	0.68	0.0029	7.8	0
Bathroom 1 (WHB09)	HWS09	0.3	0.1	26	0.029	0.68	0.0029	7.8	0
Bathroom 1 (WHB10)	HWS10	0.3	0.1	26	0.029	0.68	0.0029	7.8	0

Figure 8. Water Supply to the fixtures for Bathroom 1

COLD WATER SUPPLY BATHROOM 2 WATER CLOSETS									
Ref.	Pipe Ref.	Flow Rate (l/s)	Length (m)	Diameter (mm)	Head Loss (m/mh)	Velocity (m/s)	Pipe loss (m/h)	Elbows	Tees
Bathroom 2 (WC11)	CWS17	0.2	0.1	23	0.03	0.58	0.003	4.6	0
Bathroom 2 (WC12)	CWS18	0.2	0.1	23	0.03	0.58	0.003	4.6	0
Bathroom 2 (WC13)	CWS19	0.2	0.1	23	0.03	0.58	0.003	4.6	0
Bathroom 2 (WC14)	CWS20	0.2	0.1	23	0.03	0.58	0.003	4.6	0
Bathroom 2 (WC15)	CWS21	0.2	0.062	23	0.03	0.58	0.00186	4.6	0
Bathroom 2 (WC16)	CWS22	0.2	0.062	23	0.03	0.58	0.00186	4.6	0

COLD WATER SUPPLY BATHROOM 2 WASH HAND BASINS									
Ref.	Pipe Ref.	Flow Rate (l/s)	Length (m)	Diameter (mm)	Head Loss (m/mh)	Velocity (m/s)	Pipe loss (m/h)	Elbows	Tees
Bathroom 2 (WHB17)	CWS23	0.3	0.1	26	0.029	0.68	0.0029	7.8	0
Bathroom 2 (WHB18)	CWS24	0.3	0.1	26	0.029	0.68	0.0029	7.8	0
Bathroom 2 (WHB19)	CWS25	0.3	0.1	26	0.029	0.68	0.0029	7.8	0
Bathroom 2 (WHB20)	CWS26	0.3	0.1	26	0.029	0.68	0.0029	7.8	0
Bathroom 2 (WHB21)	CWS27	0.3	0.1	26	0.029	0.68	0.0029	7.8	0
Bathroom 2 (WHB22)	CWS28	0.3	0.1	26	0.029	0.68	0.0029	7.8	0
Bathroom 2 (WHB23)	CWS29	0.3	0.1	26	0.029	0.68	0.0029	7.8	0
Bathroom 2 (WHB24)	CWS30	0.3	0.1	26	0.029	0.68	0.0029	7.8	0
Bathroom 2 (WHB25)	CWS31	0.3	0.1	26	0.029	0.68	0.0029	7.8	0
Bathroom 2 (WHB26)	CWS32	0.3	0.1	26	0.029	0.68	0.0029	7.8	0

HOT WATER SUPPLY BATHROOM 2 WASH HAND BASINS									
Ref.	Pipe Ref.	Flow Rate (l/s)	Length (m)	Diameter (mm)	Head Loss (m/mh)	Velocity (m/s)	Pipe loss (m/h)	Elbows	Tees
Bathroom 2 (WHB17)	HWS11	0.3	0.1	26	0.029	0.68	0.0029	7.8	0
Bathroom 2 (WHB18)	HWS12	0.3	0.1	26	0.029	0.68	0.0029	7.8	0
Bathroom 2 (WHB19)	HWS13	0.3	0.1	26	0.029	0.68	0.0029	7.8	0
Bathroom 2 (WHB20)	HWS14	0.3	0.1	26	0.029	0.68	0.0029	7.8	0
Bathroom 2 (WHB21)	HWS15	0.3	0.1	26	0.029	0.68	0.0029	7.8	0
Bathroom 2 (WHB22)	HWS16	0.3	0.1	26	0.029	0.68	0.0029	7.8	0
Bathroom 2 (WHB23)	HWS17	0.3	0.1	26	0.029	0.68	0.0029	7.8	0
Bathroom 2 (WHB24)	HWS18	0.3	0.1	26	0.029	0.68	0.0029	7.8	0
Bathroom 2 (WHB25)	HWS19	0.3	0.1	26	0.029	0.68	0.0029	7.8	0
Bathroom 2 (WHB26)	HWS20	0.3	0.1	26	0.029	0.68	0.0029	7.8	0

Figure 9. Water supply to the fixtures for Bathroom 2

The tables above give a clear overview on the values obtained from the CIBSE Guide C graph. The main focus from these tables are the flow rates and diameter of pipes.

Using the flow rates from the tables above, the method to work back towards the pump to establish the maximum flow rate needed which is then used to size the pump accordingly. Tabulating the instances of each fixture in the bathroom respective of hot and cold-water supply, next, accumulating that flow rate to obtain the flow rate within the branch pipes.

		Indiv Flow Rate (EACH)	Instances	Total Flow Rate	Flow rate entering to branch pipe (l/s)	Total Flow Rate in Main Pipe (l/s)
HWS LINE	LHS WHB Bathroom 1	0.3	5	1.5	1.5	3
	RHS WHB Bathroom 1	0.3	5	1.5	1.5	

LHS	Left Hand side
RHS	Right Hand Side
CWS	Cold Water Supply
HWS	Hot Water Supply
WHB	Wash Hand Basin
WC	Water Closet

		Indiv Flow Rate (EACH)	Instances	Total Flow Rate	Flow rate entering to branch pipe (l/s)	Total Flow Rate in Branch Pipe (l/s)	Total Flow Rate in Main Pipe (l/s)
CWS LINE	LHS WHB Bathroom 1	0.3	5	1.5	1.5	2.1	4.2
	LHS WC Bathroom 1	0.2	3	0.6	0.6		
	RHS WHB Bathroom 1	0.3	5	1.5	1.5	2.1	
	RHS WC Bathroom 1	0.2	3	0.6	0.6		

Figure 10. Tables indicate the procedure to determine the maximum flow rate in the main pipes (Bathroom 1)

HWS LINE	LHS WHB Bathroom 2			Flow rate entering to branch pipe (l/s)	Total Flow Rate in Main Pipe (l/s)
	Indiv Flow Rate (EACH)	Instances	Total Flow Rate	1.5	3
	0.3	5	1.5		
	RHS WHB Bathroom 2			Flow rate entering to branch pipe (l/s)	
	Indiv Flow Rate (EACH)	Instances	Total Flow Rate	1.5	
	0.3	5	1.5		

LHS	Left Hand side
RHS	Right Hand Side
CWS	Cold Water Supply
HWS	Hot Water Supply
WHB	Wash Hand Basin
WC	Water Closet

CWS LINE	LHS WHB Bathroom 2			Flow rate entering to branch pipe (l/s)	Total Flow Rate in Branch Pipe (l/s)	Total Flow Rate in Main Pipe (l/s)
	Indiv Flow Rate (EACH)	Instances	Total Flow Rate	1.5	2.1	4.2
	0.3	5	1.5			
	LHS WC Bathroom 2			Flow rate entering to branch pipe (l/s)		
	Indiv Flow Rate (EACH)	Instances	Total Flow Rate	0.6		
	0.2	3	0.6			
	RHS WHB Bathroom 2			Flow rate entering to branch pipe (l/s)	Total Flow Rate in Branch Pipe (l/s)	
	Indiv Flow Rate (EACH)	Instances	Total Flow Rate	1.5	2.1	
	0.3	5	1.5			
	RHS WC Bathroom 2			Flow rate entering to branch pipe (l/s)		
	Indiv Flow Rate (EACH)	Instances	Total Flow Rate	0.6		
	0.2	3	0.6			

Figure 11. Tables indicate the procedure to determine the maximum flow rate in the main pipes (Bathroom 2)

Following the clear demonstration of the flow rate for the main pipe, the diameter, velocity and pressure drop from the main pipe is yet to be tabulated, hence stating that, using CIBSE Guide C as a benchmark to understand the fluid flow in the pipes using the flow rate from the figure above.

The following table from CIBSE Guides indicate the various aspects regarding the pipe sizing from the pump and the branch pipe:

Table 4.14 Flow of water at 75°C in copper pipes — *continued*

COPPER, TABLE Z

WATER AT 75°C

q_m = mass flow rate — $kg.s^{-1}$
c = velocity — $m.s^{-1}$
$\Delta p/l$ = pressure drop per unit length — $Pa.m^{-1}$
l_e = equivalent length of a component for $\zeta = 1$ — m

Δp/l	c	12 mm		15 mm		22 mm		28 mm		35 mm		42 mm		c	Δp/l
		q_m	l_e	q_m	l_e	q_m	l_e	q_m	l_e	q_m	l_e	q_m	l_e		
92.5		0.023	*0.3*	0.044	*0.5*	0.130	*0.8*	0.258	*1.2*	[illegible]	[illegible]	0.777	*2.0*		92.5
95.0		0.023	*0.3*	0.045	*0.5*	0.132	*0.8*	0.261	*1.2*	[illegible]	[illegible]	0.789	*2.0*		95.0
97.5		0.024	*0.3*	0.046	*0.5*	0.134	*0.8*	0.265	*1.2*	[illegible]	[illegible]	0.800	*2.0*		97.5
100.0		0.024	*0.3*	0.046	*0.5*	0.136	*0.8*	0.269	*1.2*	[illegible]	[illegible]	0.812	*2.1*		100.0
120.0	0.30	0.027	*0.3*	0.051	*0.5*	0.151	*0.8*	0.298	*1.2*	[illegible]	[illegible]	0.899	*2.1*		120.0
140.0		0.029	*0.3*	0.056	*0.5*	0.164	*0.9*	0.325	*1.2*	[illegible]	[illegible]	0.979	*2.1*		140.0
160.0		0.031	*0.4*	0.061	*0.5*	0.177	*0.9*	0.351	*1.2*	[illegible]	[illegible]	1.06	*2.2*		160.0
180.0		0.034	*0.4*	0.065	*0.5*	0.189	*0.9*	0.375	*1.3*	[illegible]	[illegible]	1.13	*2.2*		180.0
200.0		0.036	*0.4*	0.069	*0.5*	0.201	*0.9*	0.397	*1.3*	[illegible]	[illegible]	1.19	*2.2*	1.0	200.0
220.0		0.038	*0.4*	0.073	*0.5*	0.212	*0.9*	0.419	*1.3*	[illegible]	[illegible]	1.26	*2.2*		220.0
240.0		0.040	*0.4*	0.076	*0.5*	0.223	*0.9*	0.440	*1.3*	[illegible]	[illegible]	1.32	*2.3*		240.0
260.0		0.041	*0.4*	0.080	*0.5*	0.233	*0.9*	0.460	*1.3*	[illegible]	[illegible]	1.38	*2.3*		260.0
280.0		0.043	*0.4*	0.083	*0.5*	0.243	*0.9*	0.480	*1.3*	[illegible]	[illegible]	1.44	*2.3*		280.0
300.0	0.50	0.045	*0.4*	0.087	*0.5*	0.252	*0.9*	0.498	*1.3*	[illegible]	[illegible]	1.50	*2.3*		300.0
320.0		0.047	*0.4*	0.090	*0.5*	0.262	*0.9*	0.517	*1.3*	[illegible]	[illegible]	1.55	*2.3*		320.0
340.0		0.048	*0.4*	0.093	*0.6*	0.271	*1.0*	0.535	*1.4*	[illegible]	[illegible]	1.60	*2.4*		340.0
360.0		0.050	*0.4*	0.096	*0.6*	0.280	*1.0*	0.552	*1.4*	[illegible]	[illegible]	1.66	*2.4*		360.0
380.0		0.052	*0.4*	0.099	*0.6*	0.288	*1.0*	0.569	*1.4*	[illegible]	[illegible]	1.71	*2.4*		380.0
400.0		0.053	*0.4*	0.102	*0.6*	0.297	*1.0*	0.585	*1.4*	[illegible]	[illegible]	1.75	*2.4*		400.0
420.0		0.055	*0.4*	0.105	*0.6*	0.305	*1.0*	0.601	*1.4*	[illegible]	[illegible]	1.80	*2.4*		420.0
440.0		0.056	*0.4*	0.108	*0.6*	0.313	*1.0*	0.617	*1.4*	[illegible]	[illegible]	1.85	*2.4*	1.5	440.0
460.0		0.057	*0.4*	0.110	*0.6*	0.321	*1.0*	0.633	*1.4*	[illegible]	[illegible]	1.89	*2.4*		460.0
480.0		0.059	*0.4*	0.113	*0.6*	0.328	*1.0*	0.648	*1.4*	[illegible]	[illegible]	1.94	*2.4*		480.0
500.0		0.060	*0.4*	0.116	*0.6*	0.336	*1.0*	0.663	*1.4*	[illegible]	[illegible]	1.98	*2.4*		500.0
520.0		0.062	*0.4*	0.118	*0.6*	0.344	*1.0*	0.677	*1.4*	[illegible]	[illegible]	2.03	*2.5*		520.0
540.0		0.063	*0.4*	0.121	*0.6*	0.351	*1.0*	0.692	*1.4*	[illegible]	[illegible]	2.07	*2.5*		540.0
560.0		0.064	*0.4*	0.123	*0.6*	0.358	*1.0*	0.706	*1.4*	[illegible]	[illegible]	2.11	*2.5*		560.0
580.0		0.066	*0.4*	0.126	*0.6*	0.365	*1.0*	0.720	*1.4*	[illegible]	[illegible]	2.15	*2.5*		580.0
600.0		0.067	*0.4*	0.128	*0.6*	0.372	*1.0*	0.733	*1.4*	[illegible]	[illegible]	2.19	*2.5*		600.0
620.0		0.068	*0.4*	0.131	*0.6*	0.379	*1.0*	0.747	*1.4*	[illegible]	[illegible]	2.23	*2.5*		620.0
640.0		0.069	*0.4*	0.133	*0.6*	0.386	*1.0*	0.760	*1.5*	[illegible]	[illegible]	2.27	*2.5*		640.0
660.0		0.070	*0.4*	0.135	*0.6*	0.392	*1.0*	0.773	*1.5*	[illegible]	[illegible]	2.31	*2.5*		660.0
680.0		0.072	*0.4*	0.138	*0.6*	0.399	*1.0*	0.786	*1.5*	[illegible]	[illegible]	2.35	*2.5*		680.0
700.0		0.073	*0.4*	0.140	*0.6*	0.405	*1.0*	0.799	*1.5*	[illegible]	[illegible]	2.39	*2.5*		700.0
720.0		0.074	*0.4*	0.142	*0.6*	0.412	*1.0*	0.811	*1.5*	[illegible]	[illegible]	2.43	*2.5*		720.0
740.0		0.075	*0.4*	0.144	*0.6*	0.418	*1.0*	0.824	*1.5*	[illegible]	[illegible]	2.46	*2.5*		740.0
760.0		0.076	*0.4*	0.146	*0.6*	0.424	*1.1*	0.836	*1.5*	[illegible]	[illegible]	2.50	*2.6*	2.0	760.0
780.0		0.077	*0.4*	0.149	*0.6*	0.431	*1.1*	0.848	*1.5*	[illegible]	[illegible]	2.53	*2.6*		780.0
800.0		0.079	*0.4*	0.151	*0.6*	0.437	*1.1*	0.860	*1.5*	[illegible]	[illegible]	2.57	*2.6*		800.0
820.0		0.080	*0.4*	0.153	*0.6*	0.443	*1.1*	0.872	*1.5*	[illegible]	[illegible]	2.60	*2.6*		820.0
840.0		0.081	*0.4*	0.155	*0.6*	0.449	*1.1*	0.884	*1.5*	[illegible]	[illegible]	2.64	*2.6*		840.0
860.0		0.082	*0.4*	0.157	*0.6*	0.455	*1.1*	0.895	*1.5*	[illegible]	[illegible]	2.67	*2.6*		860.0
880.0		0.083	*0.4*	0.159	*0.6*	0.461	*1.1*	0.907	*1.5*	[illegible]	[illegible]	2.71	*2.6*		880.0
900.0		0.084	*0.4*	0.161	*0.6*	0.466	*1.1*	0.918	*1.5*	[illegible]	[illegible]	2.74	*2.6*		900.0
920.0		0.085	*0.4*	0.163	*0.6*	0.472	*1.1*	0.929	*1.5*	[illegible]	[illegible]	2.77	*2.6*		920.0
940.0		0.086	*0.4*	0.165	*0.6*	0.478	*1.1*	0.940	*1.5*	[illegible]	[illegible]	2.81	*2.6*		940.0
960.0		0.087	*0.4*	0.167	*0.6*	0.483	*1.1*	0.951	*1.5*	[illegible]	[illegible]	2.84	*2.6*		960.0
980.0		0.088	*0.5*	0.169	*0.6*	0.489	*1.1*	0.962	*1.5*	[illegible]	[illegible]	2.87	*2.6*		980.0
1000.0	1.0	0.089	*0.5*	0.171	*0.6*	0.494	*1.1*	0.973	*1.5*	[illegible]	[illegible]	2.90	*2.6*		1000.0
1100.0		0.094	*0.5*	0.180	*0.6*	0.521	*1.1*	1.03	*1.5*	[illegible]	[illegible]	3.06	*2.6*		1100.0
1200.0		0.099	*0.5*	0.189	*0.6*	0.547	*1.1*	1.08	*1.6*	[illegible]	[illegible]	3.21	*2.7*		1200.0
1300.0		0.103	*0.5*	0.198	*0.7*	0.572	*1.1*	1.13	*1.6*	[illegible]	[illegible]	3.35	*2.7*		1300.0
1400.0		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	2.14	*2.1*	[illegible]	[illegible]		1400.0
1500.0		0.112	*0.5*	0.214	*0.7*	0.619	*1.1*	1.22	*1.6*	[illegible]	[illegible]	3.63	*2.7*	3.0	[illegible]
1600.0		0.116	*0.5*	0.222	*0.7*	0.642	*1.1*	1.26	*1.6*	2.30	*2.2*	3.76	*2.7*		1600.0
1700.0		0.120	*0.5*	0.230	*0.7*	0.663	*1.1*	1.30	*1.6*	2.38	*2.2*	3.88	*2.8*		1700.0
1800.0		0.124	*0.5*	0.237	*0.7*	0.685	*1.2*	1.35	*1.6*	2.46	*2.2*	4.00	*2.8*		1800.0
1900.0		0.128	*0.5*	0.244	*0.7*	0.705	*1.2*	1.39	*1.6*	2.53	*2.2*	4.12	*2.8*		1900.0
2000.0		0.132	*0.5*	0.251	*0.7*	0.726	*1.2*	1.43	*1.6*	2.60	*2.2*	4.24	*2.8*		2000.0

Figure 12. An example for the branch pipe of the cold-water supply of this design project (Baaaaadeea Aamir)

The above procedure was done for every single supply line to reach accurate readings for the main and branch pipes.

The table below is a summary of the values obtained from the CIBSE guides:

HWS					
	Flow Rate	Dia	Velocity (m/s)	Length Factor (le)	Pa/m
Branch Pipe	1.5	35mm	2	2	740
Main Pipe	3	42mm	3	2.6	1100

CWS					
	Flow Rate	Dia	Velocity (m/s)	Length Factor (le)	Pa/m
Branch Pipe	2.1	35mm	3	2.1	1400
Main Pipe	4.2	42mm	4	2.8	2000

Table 6. Summary of the results obtained from the CIBSE Guide table .

This concludes the pipe sizing for this design project as the 42mm diameter pipes must be used from the pump to the first branch pipe which then reduces to 35mm diameter relative to the flow rate. The branch pipes further reduce in size when leading into the appropriate fixtures dividing the flow rate equally amongst the pipes.

1.6 Fittings pressure loss calculations

Fitting pressure drop for a plumbing system can be defined as the pressure loss occuring within the pipes due to fittings such as bends and tees, along with the elevation changes from the pump and the pipes leading into the fixtures. The methods used to counter such problems are either gravity based or pumped through pipes.

Since it is a single storey building, this design project focuses on a booster pump to supply water. A water transfer system can be too extensive and consume more energy than required as a transfer system uses a transfer pump to pump water to a water tank on the roof which then pumps water to the required areas. Therefore, a simple dual pump system would be the best option for the building.

After determining the pipeline's flow rate, the following steps help in gaining an understanding of the fittings pressure loss within the building:

- Tabulate all the fittings for each pipeline (Cold and Hot water)
- Determine the initial and final diameter
- Usage of CIBSE Guide C as a reference to determine the K-Values
- Find the final pressure loss from both K-Values
- Find the final pressure loss per meter (Pa/m)

The fittings attached to each bathrooms pipeline have been tabulated in the table below, clearly indicating the calculations required for each fitting in the piping system.

Bathroom 1		
Supply	Tees	Elbows
Cold Water Supply	16	1
Hot water Supply	10	1
Bathroom 2		
Supply	Tees	Elbows
Cold Water Supply	17	0
Hot water Supply	9	2

Table 7. Showcases the fittings in each supply line

The table above can now be utilized to determine the K-Values respective to each of the fittings. The final pressure drop for each fitting will differ according to the reduction or enlargement.

It is necessary to work out the diameter difference between the fittings and the pipe. This design project utilizes a step-by-step strategy, making it easier to understand the values obtained in a table. CIBSE Guide C requires the cross-sectional area of the smaller pipe divided by the bigger pipe to obtain the A2/A1 readings. The following is an example of the calculations:

Diameter of main pipe: 42 mm
Diameter of branch pipe: 35 mm

$$\frac{A_2}{A} = \frac{d_2^2}{d_1^2} = \frac{35^2}{42^2} = 0.69$$

Using the same example, CIBSE Guide C provides with a standard K-Value readings for each fitting which can be worked out using the following formula:

$$\frac{y2 - y1}{y - y1} = \frac{x2 - x1}{x - x1}$$

Where:

Y = ? (K Value)
Y1 = A1 (From CIBSE)
Y2 = A1 (From CIBSE)

X = A2 (Area of Circle from Diameter Difference)
X1 = A2 (From CIBSE)
X2 = A2 (From CIBSE)

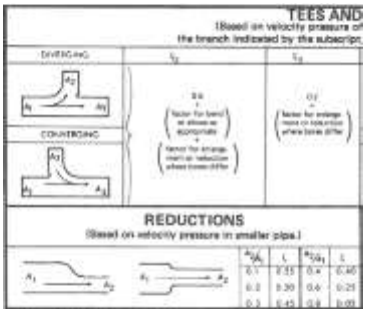


Figure 13. Reference from CIBSE Guide C for fittings K-Value

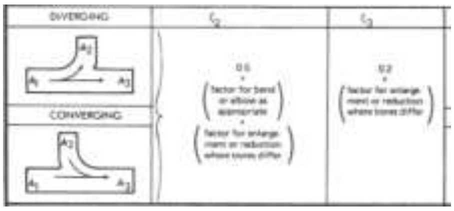
The above figure demonstrates the K-Values for the fittings. As A2/A1 was calculated at 0.69, the following calculation can be done to obtain the final K-Value readings.

	A2	A1	
X1 =	0.6	0.25	= Y1
X =	**0.69**	?	= Y
X2 =	0.8	0.05	= Y2

$$\frac{0.05-0.25}{?-0.25} = \frac{0.8-0.6}{0.69-0.6}$$

Hence, Y = 0.15

The CIBSE Guide table then assists in calculating the actual readings for the tee fittings for pressure loss by reduction or enlargement. In this example pipe reduction is taking place, hence the following calculations take place:



K2	K3
0.5 + 0.15 + 1 = **1.65**	0.2 + 0 = **0.2**

Figure 14. Callout from CIBSE Guide that entails the K-Values for tees

The calculations prove that for K2, 0.15 is being used for the reduction, 1 is the K-Value for the bend and for K3, 0 is being used due to no enlargement or reduction.

Last step of the process before obtaining the pressure loss per meter, the length factor and pressure drop from Table 6 is used to multiply with the K-Values above to find each of the fittings pressure loss. With that, the following table can be made:

Cold Water Bathroom 1	Ini. Dia (mm)	Final Dia (mm)	A2/A1	K from Reduction	K2	K3	le	Pa/m	Final Pressure Loss (Pa) (k2)	Final Pressure Loss (Pa) (k3)
Tee (BP1)	42.00	35.00	0.69	0.15	1.65	0.20	2.80	1400.00	6468.00	784.00
Tee (WCP01)	35.00	23.00	0.43	0.38	1.88	0.20	2.10	2000.00	7896.00	840.00
Tee (WCP02)	35.00	23.00	0.43	0.38	1.88	0.20	2.10	2000.00	7896.00	840.00
Tee (WCP03)	35.00	23.00	0.43	0.38	1.88	0.20	2.10	2000.00	7896.00	840.00
Tee (WCP04)	35.00	23.00	0.45	0.38	1.88	0.20	2.10	2000.00	7896.00	840.00
Tee (WCP05)	35.00	23.00	0.43	0.38	1.88	0.20	2.10	2000.00	7896.00	840.00
Tee (WCP06)	35.00	23.00	0.43	0.38	1.88	0.20	2.10	2000.00	7896.00	840.00
Tee (WHBP01)	35.00	26.00	0.55	0.20	1.70	0.20	2.10	2000.00	7150.16	840.00
Tee (WHBP02)	35.00	26.00	0.55	0.20	1.70	0.20	2.10	2000.00	7150.16	840.00
Tee (WHBP03)	35.00	26.00	0.55	0.20	1.70	0.20	2.10	2000.00	7150.16	840.00
Tee (WHBP04)	35.00	26.00	0.55	0.20	1.70	0.20	2.10	2000.00	7150.16	840.00
Tee (WHBP05)	35.00	26.00	0.55	0.20	1.70	0.20	2.10	2000.00	7150.16	840.00
Tee (WHBP06)	35.00	26.00	0.55	0.20	1.70	0.20	2.10	2000.00	7150.16	840.00
Tee (WHBP07)	35.00	26.00	0.55	0.20	1.70	0.20	2.10	2000.00	7150.16	840.00
Tee (WHBP08)	35.00	26.00	0.55	0.20	1.70	0.20	2.10	2000.00	7150.16	840.00
Tee (WHBP09)	35.00	26.00	0.55	0.20	1.70	N/A	2.10	2000.00	7150.16	N/A
Tee (WHBP10)	35.00	26.00	0.55	0.20	1.70	N/A	2.10	2000.00	7150.16	N/A
Elbow (BP2)	42.00	N/A	N/A	N/A	1.00	N/A	2.80	1400.00	3920.00	N/A
								Total	141809.61	

Table 8. All fittings pressure loss for cold water supply in bathroom 1

The same procedure was done for each water supply line for the rest of the building as well.

After calculating the following table can be constructed by adding the final pressure losses for the water supply lines:

Supply	Length (m)	Total Pressure Loss (Pa)	Pa/m
CWS Bath 1	55.30	141809.61	2564.37
HWS Bath 1	53.03	43427.30	818.92
HWS Bath 2	51.92	42067.90	810.24
CWS Bath 2	64.67	135832.74	2100.40

Table 9. Final pressure loss per meter

Evaluating the table above, it can be stated that the pressure drops are deemed to be too high, or close to being unrealistic. This is because the water supply has a high flow rate which results in high pressure drops. Moreover, all the fittings and fixtures are being supplied by one big main pipe which can lead to higher pressure drops.

For future projects, zoning will also be taken into deep consideration by having a plant or pump next to or near the required areas for water supply to divide pipelines between them and not having one main pipe supplying to all the fittings and fixtures.

1.7 Pump Sizing

Pump sizing is the most important thing when water supply is the main area of discussion. An undersized pump can lead to a lower flow rate being supplied to the specified areas, meanwhile, an oversized pump can cause unnecessary energy consumption, excessive noise levels and reliability issues that can cost more in maintenance than satisfaction of the users. Although it is still better to have a slightly oversized pump rather than having it undersized as an undersized pump wouldn't be able to achieve the flow rate required for zones whereas a slightly oversized pump would still be able to do so.

Taking all the calculations above, a standard pump sizing service is provided by Grundfos. Grundfos is a company which provides solutions regarding pumps and has an online calculator with algorithms to provide the best pump based on the zone's requirements.

For this design project, the Grundfos pump selection was used to determine the best pump which can be utilized within the building. Using the Grundfos pump selection, a few values such as the maximum flow rate and the vertical height of the pipeline layout were added. As mentioned before, plumbing layout is divided into 2 pumps to ensure maximum efficiency, thus, maximum flow rate of 7.2 l/s is inputted into the calculator with a maximum vertical height of 4.7m.

After inputting such values into the calculator, the Grundfos pump selector provided a sensible pump meeting the building requirements. The pump is as follows:

HYDRO MULTI-E 2 CRE 20-3

No. 99133098

Figure 15. Pump provided by Grundfos

The pump provided above is a dual pump suitable for water distribution with energy efficient measures for pressure boosting. The water temperature chosen for this calculator was 18^{O}C which is in compliance with CIBSE Guide G and states that the cold-water supply should be at around 5^{O}C – 20^{O}C.

The pump performance curves are as follows:

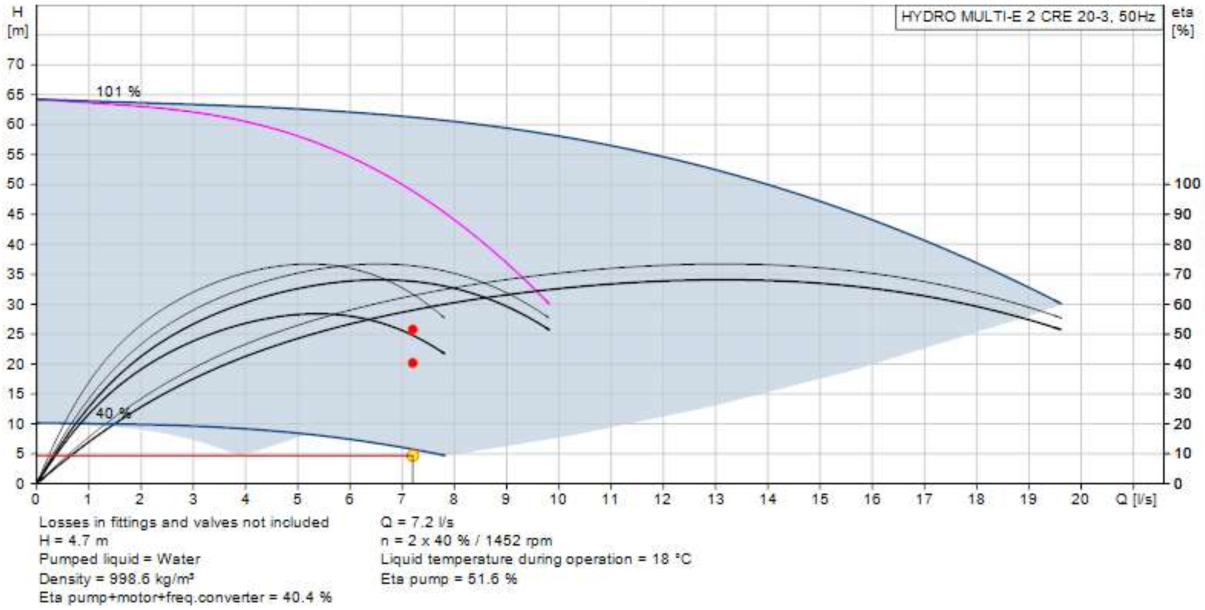


Figure 16. Pump performance curve from Grundfos

The performance curve above indicates that when the pump system is operating to provide 7.2 l/s at 4.7m, the two pumps simultaneously work at a 40% rate with a 1452 rpm. Entailing that the pump works at minimum noise levels.

The Grundfos pump sizing tool provides the load profile associated with the pump which is discussed further later in this report.

Once the pump size is determined, it can be added into the model to gain an understanding and overview of how the building will house the pump for the necessary zones.

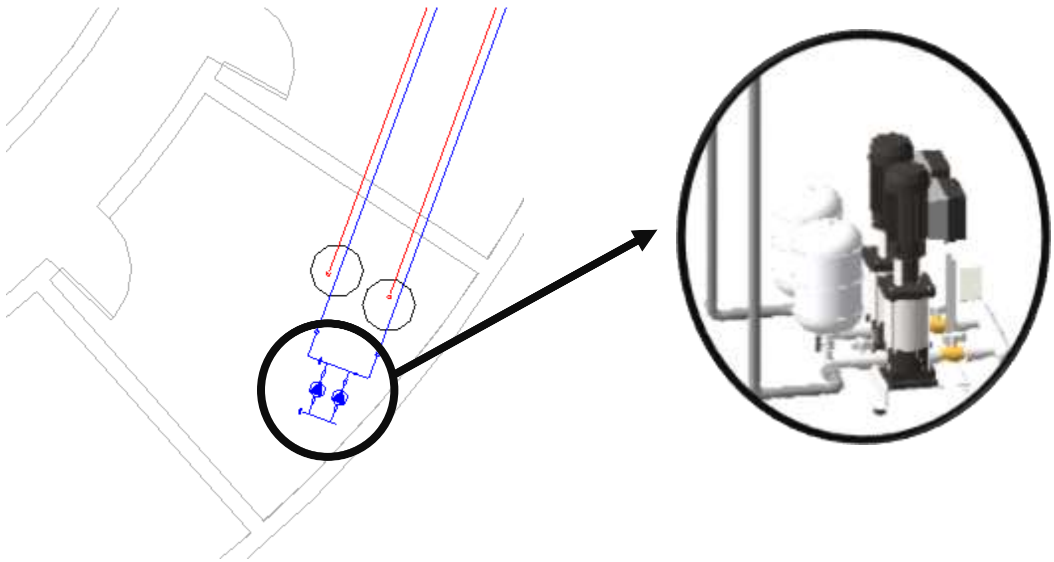


Figure 17. Shows the placement of the pump in the pump room

Some limitations regarding the pump in the model suggest that the actual BIM representation of the pump from Grundfos could not be found.

HVAC

HVAC systems are responsible for heating/cooling a space and help in removing moisture from the surrounding air which reduces indoor humidity to provide thermal comfort to occupants. The heating/cooling load is the amount of energy that is needed to be removed or added to the space in order to maintain an optimum temperature. The system's capacity indicates how much heating or cooling the unit can provide. Therefore, load calculation plays an extremely crucial role in order to determine the right size of a HVAC system. An oversized system will not operate long enough and will turn on and off repeatedly which causes poor ventilation and leads to an unpleasant moistness in the room. On the other hand, under-sized units must operate continuously to maintain the desired temperature which results in high energy costs and poor indoor comfort. A right sized HVAC system will operate more efficiently and use much less energy; indoor air quality will be consistent, and the system will meet its expected life span.

AHU (air handling unit) is a component of a HVAC system that filters, distributes and cools air into an area via a duct. An AHU consists of heat recovery units which minimize the amount of energy needed for air conditioning; the exchanger mixes internal and external air which lowers the temperature contrast when air enters the coil. The fans can operate in accordance with the required flow which altogether lowers the climatic impact and energy consumption. The location and size of the AHU are two important factors to ensure that the unit can adequately distribute fresh air according to the room size.

The designed building is located in the UAE which has a hot-humid climate; therefore, it does not require any heating, and this detailed designed proposal for HVAC system only focuses on the cooling system.

Steps:

- Determining the ventilation rate (Volumetric Flow Rate)
- Decide the number of outlets within the zones using the grid system
- Preparing layout drawings of the duct system
- Sizing the duct systems
- Sizing the fans according to the duct systems

2 .1 Volumetric Flow Rate Calculations

Volumetric flow rate, in a HVAC system, relates to the measurement of the flow of a substance in this case, air, through an object over specified period of time. Usually measured in cubic meter per second, flow rate determines the sizing of a HVAC system, in this case, air handling units.

The main focus for this section is to determine the flow rates of this design project.

To determine the volumetric flow rate, the first step is to tabulate the cooling load. Stage 1 of the design proposal experienced a designed model in a simulation software, IES, which analyzed how the building would function in the real world. Using standards, occupants, infiltration rate, and heat gains from components were inputted to determine the cooling load for each zone.

The following table can be constructed using the same values from IES.

Space	Cooling Load (kW)	Cooling Load (W)
Auditorium	211.5	211500
Meeting Room 1	4.1	4100
Meeting Room 2	3.6	3600
Meeting Room 3	3.4	3400
Main Office	4.2	4200
Office Workspace	18.4	18400
Main Lobby/Café	90.9	90900
Workshop 1	10.9	10900
Workshop 2	9.4	9400
Workshop 3	9.4	9400
Lab 1	11.3	11300
Lab 2	20.3	20300
Lab 3	18.8	18800
Exhibition Space 1	28.8	28800
Exhibition Space 2	30.6	30600

Table 10. Cooling loads for every space

After determining the cooling load for each space, the following formula can be used to calculate the mass flow rate in kg/s:

$$Q = m_C p \Delta T$$

Rearranging the formula for 'm':

$$m = \frac{Q}{c_P \Delta T}$$

Where:

Q = Cooling load (W)
m = Mass Flow Rate (kg/s)
c_P = Specific Heat Capacity of air (1005 J/(kg ^{O}C))
ΔT = Temperature Difference (^{O}C)

Following is an example to determine the mass flow rate of the Auditorium of the building.

$$m = \frac{Q}{c_P \Delta T} = \frac{211500}{(1005\ X\ (22.5 - 18.5))} = 46.77 \text{ kg/s}$$

Subsequently, the mass flow rate can easily be utilized to determine the volumetric flow rate of the zone in m^3/s by dividing the mass flow rate to the density of air (1.225 kg/m^3).

Hence, 46.77/1.225 = 38.18 m^3/s

this procedure was carried out for each space, and the results are tabulated below.

Space	Cooling Load (kW)	Cooling Load (W)	Room temp Setpoint (OC)	Supply Air (OC)	ΔT	Mass flow rate (kg/s)	Volumetric flow rate (m3/s)
Auditorium	211.5	211500	22.5	18	4.5	46.77	38.18
Meeting Room 1	4.1	4100	23.5	18	5.5	0.74	0.61
Meeting Room 2	3.6	3600	23.5	18	5.5	0.65	0.53
Meeting Room 3	3.4	3400	23.5	18	5.5	0.62	0.50
Main Office	4.2	4200	23.5	18	5.5	0.76	0.62
Office Workspace	18.4	18400	23.5	18	5.5	3.33	2.72
Main Lobby/Café	90.9	90900	23.5	18	5.5	16.45	13.42
Workshop 1	10.9	10900	23.5	18	5.5	1.97	1.61
Workshop 2	9.4	9400	23.5	18	5.5	1.70	1.39
Workshop 3	9.4	9400	23.5	18	5.5	1.70	1.39
Lab 1	11.3	11300	23.5	18	5.5	2.04	1.67
Lab 2	20.3	20300	23.5	18	5.5	3.67	3.00
Lab 3	18.8	18800	23.5	18	5.5	3.40	2.78
Exhibition Space 1	28.8	28800	23.5	18	5.5	5.21	4.25
Exhibition Space 2	30.6	30600	23.5	18	5.5	5.54	4.52

Table 11. Volumetric flow rate for each zone

Some design limitations regarding the Auditorium and parts of Main Lobby suggested that the cooling load levels couldn't be met using air handling units and diffusers. This is because the Auditorium has a full glass ceiling with heavy cooling load. Moreover, access points for the diffusers on a curved wall would require custom made vents according to the curves, requiring higher investment in terms of thermal comfort levels. Therefore, alternative measures are implemented to meet the thermal comfort requirements of both zones.

Stand-Alone Air conditioners are used in these spaces. The following table showcases the cooling system in the auditorium.

Auditorium	Area (m2)	Req. Vol. Flow rate	Assum. Of Floor Standing Unit Vol. Flow Rate (m3/s)	No. of units req.	Actual Number of units in the Space
	378	38.18	3.5	10.91	11

Table 12. Stand Alone AC specifications for the area

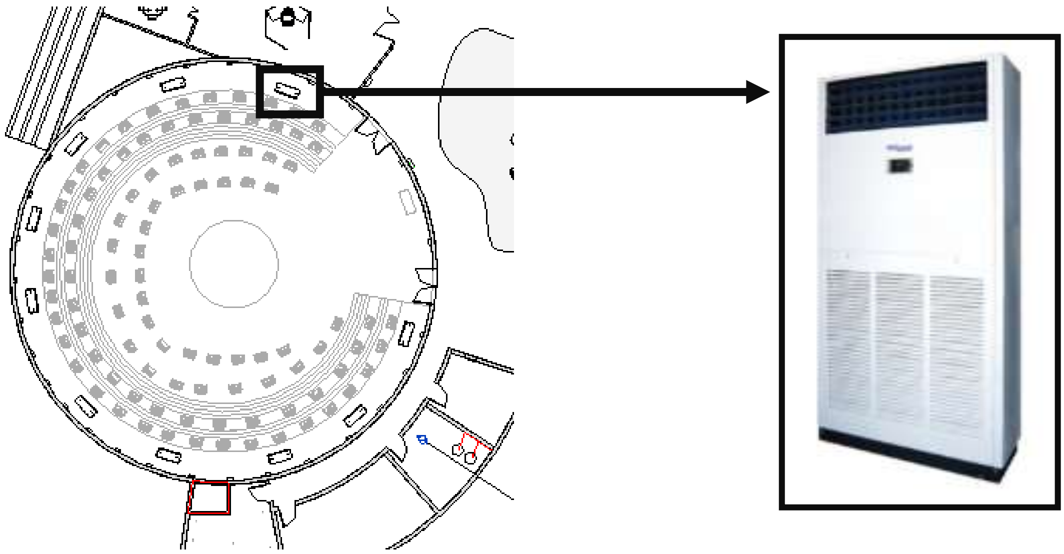
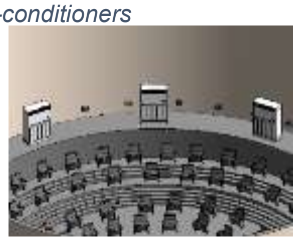


Figure 18. The actual standalone AC placement in the Auditorium.
Link:https://www.supergeneral.com/ae/product/120000-btus-floor-standing-air-conditioners



The above demonstration of the air conditioners in the audiorium are placed strategically, as shown in the figure on the right. As cold air sinks and warm air rises, cold air from the 10 units placed above height level will cool the air efficiently without any extensive measures to cool the area from diffusers.

The following table determines the stand-alone AC recommendations for the left side of the main lobby.

Main Lobby (Left)	Diffuser removed	Req. Vol. Flow rate	Actual Flow Rate of unit (m3/s)	No. of units req.	Actual Number of units in the Space
	7	1.47	0.58	2.53	3

Table 13. Specifications for the stand-alone AC in the main lobby

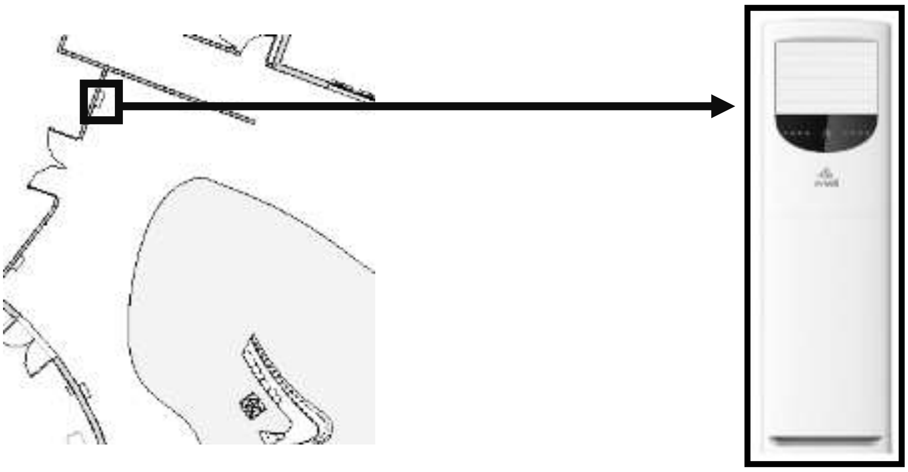


Figure 19. Placement of the stand-alone AC in the left side of the main lobby

This measure was taken because the design experienced small issues regarding the false ceiling not having enough space to fit the diameter of the ducts for the diffusers in this zone. Since the false ceiling itself is 1000mm in height, the diameter was exceeding 1000mm which is impractical in this situation

This will be carefully considered for future projects, and the engineers and architects must communicate more frequently about building service problems.

2 .2 Preparation of diffusers

This design project utilizes ceiling diffusers rather than other forms of ventilation such as ground cooling or through the walls. The placement of the ceiling diffusers is fairly simple as industry standards use an implication of a grid spacing methods, typically, 1.5 – 3m between the diffusers; the spacing of diffusers between the wall and the outlet is typically half.

The following image is an overview of the spacing done in one of the areas of the building.

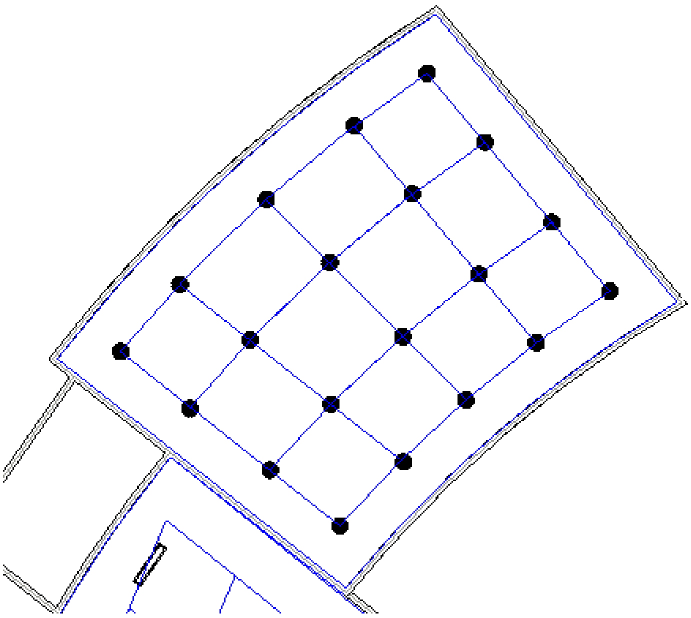


Figure 20. The diffuser placement in the Exhibition Space 1

The black dots represent the diffusers within the space with the blue lines indicating the spacing between them.

After applying the gird-spacing method, the following table can be constructed, showing number of outlets per room.

Space	Area (m2)	No. of Diffusers
Exhibition Space 1	201	20
Exhibition Space 2	201	18
Workshop 1	85	4
Workshop 2	72	4
Workshop 3	60	4
Lab 1	72	4
Lab 2	85	4
Lab 3	85	6
Main Lobby/Café	662	63
Main Office	25	4
Office Workspace	134	14
Meeting Room 1	15	1
Meeting Room 2	15	1
Meeting Room 3	15	1

Table 14. Showcasing the number of diffusers in each area

2 .3 Duct Sizing

Duct size determines the amount of volume flow rate and air velocity travelling to the diffusers. Duct sizing has a significant impact on the thermal comfort of users, energy efficiency and also improves indoor air quality by diluting pollutants.

This design project supplies fresh air into the zones using an air handling unit, and since, UAE climate doesn't allow buildings to house a heating system hence the commercial building can only house a cooling system without concern.

It is important to accurately space the AHUs to meet the requirements for each zone because this building has a complex curved design with zones varying in distance from each other.

The ducts can be sized accurately by using CIBSE Guide B duct sizing chart for each room. Using the volumetric flow rate and assuming the pressure drop to be less than 1 Pa/m, the charts were filed out for each AHU.

Duct sizing is similar to piping sizing system; flow rates from the diffusers are added up to establish the flow rates in the branch ducts. Using the flow rate from the branch duct, the main ducts flow rate can be determined.

The first step of the process is to determine the volume flow rate per diffuser, the following calculations are done:

	Area (m2)	No. of Diffusers	Volume Flow rate per room (m3/s)	Volume Flow rate per diffuser (m3/s)	Velocity (m/s)	Diameter (mm)	Pressure Drop (Pa/m)
Exhibition Space 1	201	20	4.52	0.23	3	350	0.22
Exhibition Space 2	201	18	4.25	0.24	3	350	0.24
Workshop 1	85	4	1.61	0.40	3	450	0.18
Workshop 2	72	4	1.39	0.35	3	400	0.2
Workshop 3	60	4	1.39	0.35	3	400	0.2
Lab 1	72	4	1.67	0.42	3	450	0.21
Lab 2	85	4	2.76	0.69	3	600	0.16
Lab 3	85	6	2.8	0.47	3	450	0.24
Main Lobby/Café	662	63	13.42	0.21	4.5	250	1
Main Office	25	4	0.65	0.16	3	300	0.23
Office Workspace	134	14	2.72	0.19	3	300	0.34
Meeting Room 1	15	1	0.53	0.53	3	500	0.18
Meeting Room 2	15	1	0.53	0.53	3	500	0.18
Meeting Room 3	15	1	0.53	0.53	3	500	0.18

Table 15. Showcasing the volumetric flow rate per diffuser

The above figures were tabulated via previous results to determine the flow rate per diffuser for each room. The velocity for each duct was chosen from BSRIA (1990) Design Recommendations for Room Air Distribution Systems since velocity requirements for each area differ for thermal comfort and noise levels. Lastly, the diameter and pressure drop were determined using CIBSE Guide B graph which is discussed in more depth later.

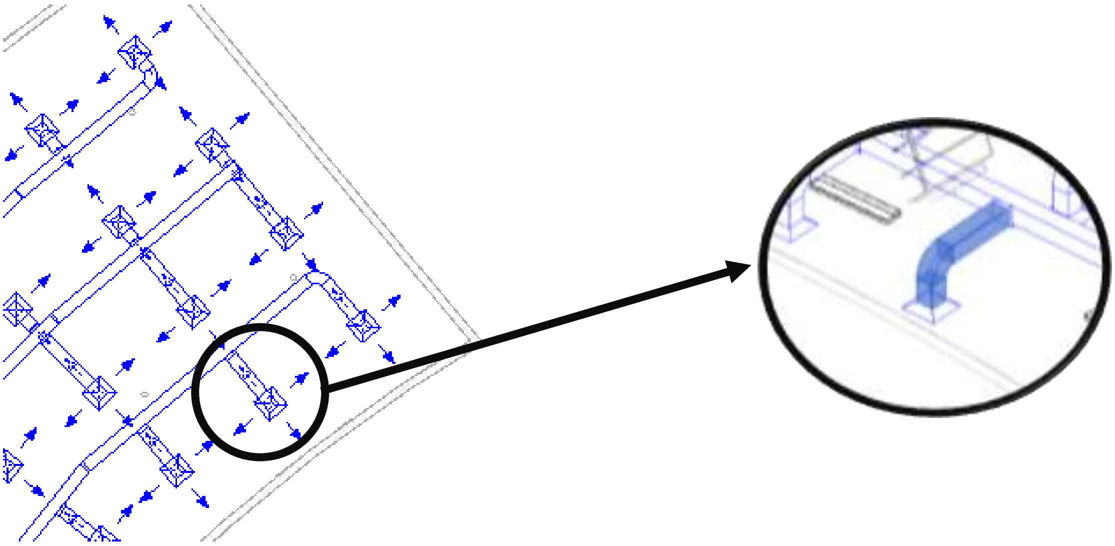


Figure 21. Illustrates the implication of the diameter from the Table above

The above images were taken from the Revit model, showcase the diameter calculated in Table 10 and placement of that duct.

After duct sizing of diffusers, the process of sizing of the branch and main ducts is simplified. As mentioned before, the flow rates from the diffusers are added up to determine the volumetric flow rates of the remaining ducts.

Some design limitations include the complex form of the building which forced the HVAC system to be divided into different AHUs for each of the zones. This provides the required air flow rates for each zone respectively.

The following steps were taken to establish the maximum flow rate:

- Recognize each branch duct and main duct within the zone
- Establish the number of diffusers connected to each duct
- Calculate the total flow rate within the duct
- Determine the velocity, diameter and pressure drop from duct sizing chart
- Measure the length of each duct to determine the pressure drop in pascals (Pa)
- Determine all the fittings loss from CIBSE Guide

- Tabulate the Index run to determine the required air flow rate

First few steps into the duct sizing of a building are straightforward due to simplification of required values as the total number of diffusers in each zone is mentioned in Table 10.

To be more precise about the division of zones with respective AHU to cover the required cooling levels of the areas, the building is divided into 7 zones with 7 AHUs connected to each one of them to power the ventilation system.

The area of discussion for this example focuses on AHU 1 of this design project.

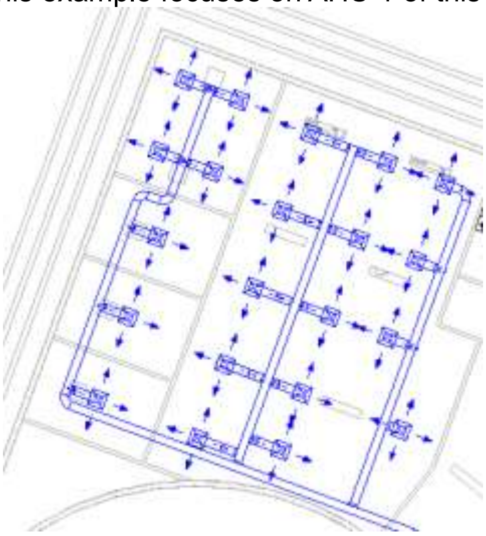


Figure 22. Zone 1 ducting system powered by AHU 1

For zone 1 of the building, figure 22 illustrates that five branch pipes are connecting into one main pipe which returns to the AHU. This includes meeting rooms, main office and office workspace,

As the flow rate for each diffuser is already tabulated, the following calculations are done:

Duct Ref.	VFR per Diff	Diff con. To Duct	Total VFR
BD01	0.16	4.00	0.64
BD02	/	/	0.64
BD03	0.53	3.00	1.59
BD04	0.19	10.00	1.90
BD05	0.19	4.00	0.76
MD01	/	/	5.53

Ref.	Reference
BD	Branch Duct
MD	Main Duct
VFR	Volume flow rate

Table 16. Demonstrates the total volume flow rate in each duct

Observing the above table, each branch duct holds a total volume flow rate which effortlessly adds up to achieving the volume flow rate within the main duct.

Utilizing the information above, velocity, diameter and pressure drop for each of duct ia determined via duct sizing chart from CIBSE Guide B.

The following image demonstrates the procedure to determine the necessary aspects:

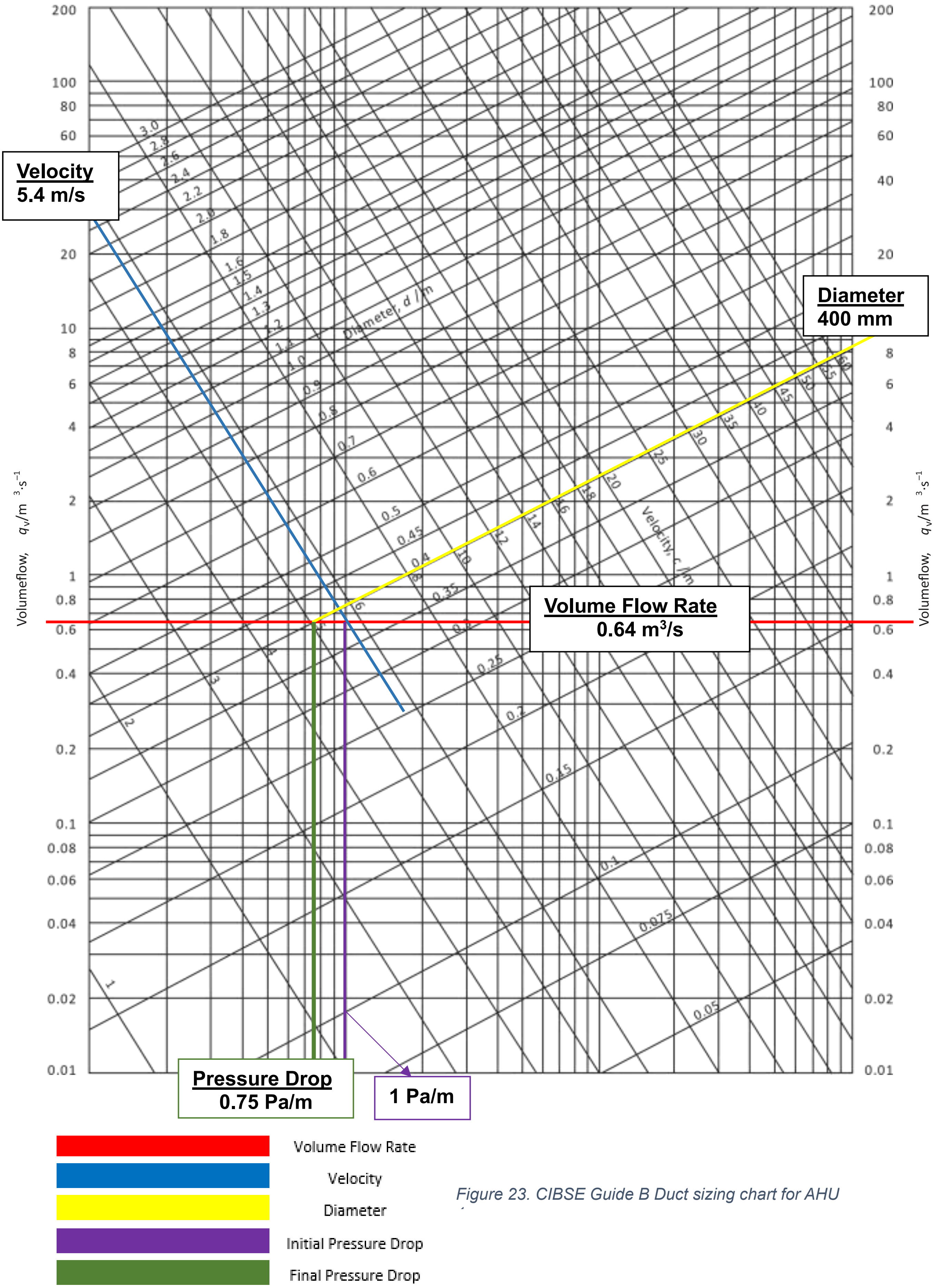


Figure 23. CIBSE Guide B Duct sizing chart for AHU

The above chart indicates the procedure to determine the velocity, diameter and pressure drop for Zone 1 for the first branch duct in the system.

Before conducting the procedures, only the total flow rate for the first branch duct in Zone 1 was obtained which is insufficient to complete the graph therefore an initial pressure drop assumption of 1 Pa/m is taken as per good industry measures. Using that, the initial diameter line is placed connecting to the initial pressure drop of 1 Pa/m along with the velocity line. The velocity line remains constant throughout, however, since diameter of ducts in the industry has standard sizes of increments of 5-10 minimum, the diameter rounds up to meet the industry standards. From there, the final pressure drop can be obtained and tabulated to determine the total pressure drop of the whole system.

This procedure was done for every single branch and main duct for the whole system. This example served to describe the process to obtaining the various aspects to find the volume flow rate.

To conclude calculating the total pressure loss from the ducts, the length of each duct was measured from Revit to multiply the length with the pressure drop obtained from the CIBSE Guide B graph to achieve the final pressure loss.

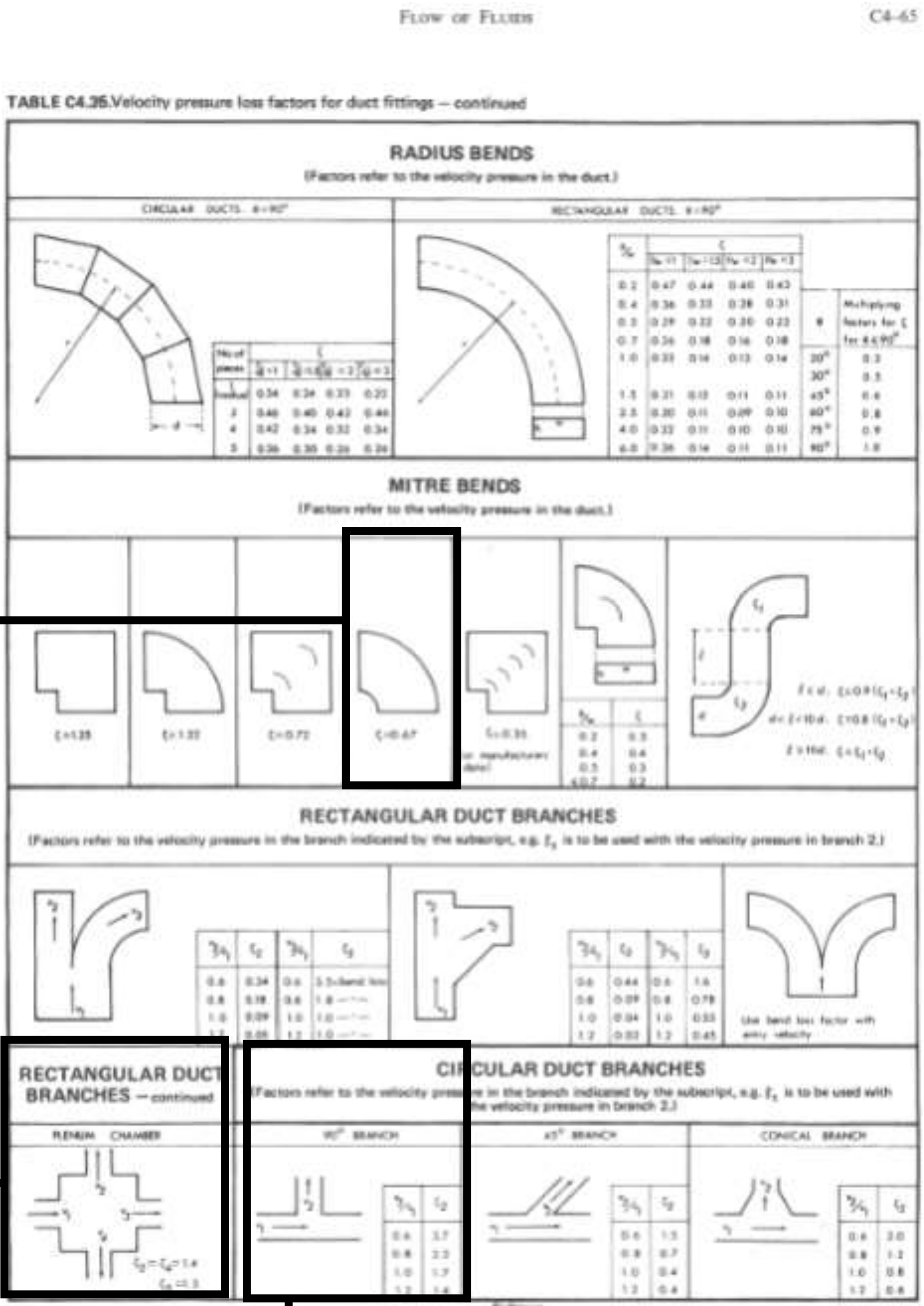
The following table demonstrates every aspect calculated to determine the final pressure loss.

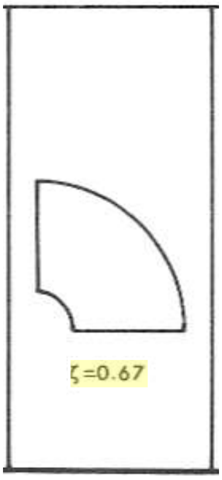
Zone 1								
Meeting Rooms 1-3 / Main Office / Office Workspace								
Duct Ref.	VFR per Diff	Diff con. To Duct	Total VFR	Velocity (m/s)	Diameter (mm)	Length (m)	Pressure Drop (Pa/m)	ΔP
BD01	0.16	4.00	0.64	5.40	400.00	4.28	0.75	3.21
BD02	/	/	0.64	5.40	400.00	0.49	0.75	0.37
BD03	0.53	3.00	1.59	6.40	600.00	7.58	0.49	3.71
BD04	0.19	10.00	1.90	7.10	600.00	12.23	0.90	11.01
BD05	0.19	4.00	0.76	5.70	450.00	11.84	0.60	7.10
MD01	/	/	5.53	9.20	900.00	35.42	0.78	27.63

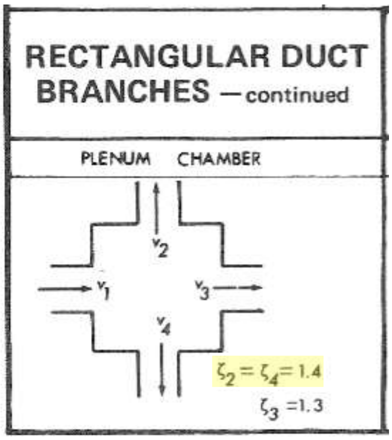
Table 17. Final pressure loss readings for each duct in Zone 1

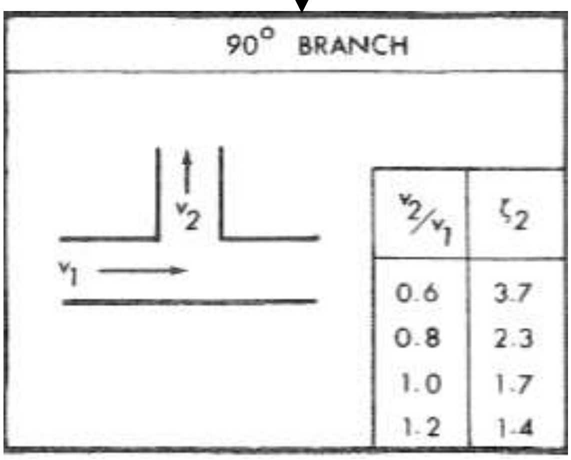
Moving onto fittings pressure loss, it is similar to the procedure of the piping system. Using CIBSE Guides to calculate K-Values for each of the fittings eases the process. When compared to the piping systems the duct fitting pressure loss calculations are relatively easier as only one K-Value is needed for each of the fittings.

Tees, bends and plenum chambers are the types of fittings used in this duct system. The following table from CIBSE Guide demonstrates the K-Values used for this project.









Using the same example to calculate the K-Value for the tees, the velocities to the diffuser and duct are considered. The image on the right indicates that the CIBSE Guide suggests that the velocity difference between the ducts, V2/V1, will determine the K-Value for the fitting. Duct BD03 in zone 1 connects to multiple tees leading into diffusers, hence, the tee K-Value can be used multiple times for that duct. The calculations are as follows:

$$\frac{v_2}{v_1} = \frac{3}{6.4} = 0.46\, m/s$$

V2/V1=0.46 rounded up according to the CIBSE Guide would be 0.6, hence K-Value for the tee would be 3.7.

The following table is a summary of all the fittings used in this design project:

Fitting	K-Value
Plenum Chamber	1.40
Bend	0.67
Tee	(CIBSE)
Outlet	1.00

Table 18. Summary of the fittings used in this Design project

Utilizing the above information, dynamic pressure is calculated using the following formula:

$$\frac{1}{2}\rho v^2$$

Where:
ρ = Density of air (1.225 kg/m^3)
v =Velocity (m/s)

The dynamic pressure is then used to calculate the final pressure loss from the fitting in (Pa). Following the example, the summary tables of the fittings pressure loss from AHU 1 in Zone 1 of this project are as follows.

	Fittings	K-Value	Velocity	1/2 ρv2	ΔP (Pa)
BD01	Plenum Chamber	1.40	5.40	17.86	25.00
	Plenum Chamber	1.40	5.40	17.86	25.00
	Outlet 1	1.00	3.00	5.51	5.51
	Outlet 2	1.00	3.00	5.51	5.51
	Outlet 3	1.00	3.00	5.51	5.51
	Outlet 4	1.00	3.00	5.51	5.51
	Fittings	K-Value	Velocity	1/2 ρv2	ΔP (Pa)
BD02	Bend	0.67	5.40	17.86	11.97
	Bend	0.67	5.40	17.86	11.97
	Fittings	K-Value	Velocity	1/2 ρv2	ΔP (Pa)
BD03	Tee (Right)	3.70	6.40	25.09	92.83
	Tee (Right)	3.70	6.40	25.09	92.83
	Tee (Right)	3.70	6.40	25.09	92.83
	Outlet 1	1.00	3.00	5.51	5.51
	Outlet 2	1.00	3.00	5.51	5.51
	Outlet 3	1.00	3.00	5.51	5.51
	Fittings	K-Value	Velocity	1/2 ρv2	ΔP (Pa)
BD04	Tee (Left)	3.70	7.10	30.88	114.24
	Tee (Right)	3.70	7.10	30.88	114.24
	Plenum Chamber	1.40	7.10	30.88	43.23
	Plenum Chamber	1.40	7.10	30.88	43.23
	Plenum Chamber	1.40	7.10	30.88	43.23
	Plenum Chamber	1.40	7.10	30.88	43.23
	Outlet 1	1.00	3.00	5.51	5.51
	Outlet 2	1.00	3.00	5.51	5.51
	Outlet 3	1.00	3.00	5.51	5.51
	Outlet 4	1.00	3.00	5.51	5.51
	Outlet 5	1.00	3.00	5.51	5.51
	Outlet 6	1.00	3.00	5.51	5.51
	Outlet 7	1.00	3.00	5.51	5.51
	Outlet 8	1.00	3.00	5.51	5.51
	Outlet 9	1.00	3.00	5.51	5.51
	Outlet 10	1.00	3.00	5.51	5.51
	Fittings	K-Value	Velocity	1/2 ρv2	ΔP (Pa)
BD05	Tee (left)	3.70	5.70	19.90	73.63
	Tee (Left)	3.70	5.70	19.90	73.63
	Tee (Right)	3.70	5.70	19.90	73.63
	Bend	0.67	5.70	19.90	13.33
	Fittings	K-Value	Velocity	1/2 ρv2	ΔP (Pa)
MD01	Tee (Right)	3.70	9.20	51.84	191.82
	Tee (Right)	3.70	9.20	51.84	191.82
	Bend	0.67	9.20	51.84	34.73

Table 19. Fittings pressure loss in Zone 1

After fittings pressure loss, the total pressure loss per zone can be tabulated without concern.

The following table showcases the total pressure loss from the HVAC system of this project.

Spaces	AHU Ref.	Pressure Drop (Pa)

Meeting Room/ Main Office/ Office Workspace	AHU 1	1553.14
Main Lobby (Central)	AHU 2	1639.61
Main Lobby (Right) / Half café	AHU 3	1911.22
Half Café / Workshops	AHU 4	913.46
Labs	AHU 5	880.17
Exhibition Space 1	AHU 6	1201.49
Exhibition Space 2	AHU 7	1477.32
Total		**9576.41**

Table 20. Total pressure loss from the HVAC System

The HVAC system experiences a total pressure loss of 9576 Pa, which is considered excessive. The limitations of HVAC systems were placement of the plant room and the distribution across the building.

The diffuser placement would correct, however, some specifications such as the total fittings pressure loss can vary depending on the standards used. The AHU rooms within the building are deemed to be small to house the sizes of AHUs, moreover, limitations regarding the false ceiling having a total height of 1m suggest that there isn't enough room for the duct systems to run throughout the building. A few miscommunications with the architects led to this unfortunate circumstance. For future projects, every aspect will be considered. Sizing of the AHU rooms will need to practically be the most important as such issues can limit the work and cause unwanted delays in a project.

2 .4 Fan Sizing

Fan sizing of an AHU is crucial for energy efficiency measures as an oversized fan will generate excess air flow rate energy resulting in excess noise disturbing neighboring areas, meanwhile, an undersized fan will not supply the required air flow rate for specified zones.

As mentioned before, the zones have been divided into 7 AHUs to comfortably provide the required air flow rate.

An Australian-based company Armcor provides air solutions for a building. Air handling units from Armcor were used in this project for each zone. Installing AHUs from one company as a bulk order would be cost-efficient and maintenance issues regarding each AHU can be solved easily by Armcor maintenance with utmost professionalism.

The sizing of the fans relates to the total volume flow rate the AHU must provide in the specified zones. The following table determines the total volume flow rate required for each zone, and the respective AHUs from Armcor that is suitable for the zone specifications.

Spaces	AHU Ref.	Pressure Drop (Pa)	Volume Flow Rate (m3/s)	m3/h	l/s	AHU - ARMCOR
Meeting Room/ Main Office/ Office Workspace	AHU 1	1553.14	11.06	39816	11060	AHU - 12000
Main Lobby (Central)	AHU 2	1639.61	10.92	39312	10920	AHU - 12000
Main Lobby (Right) / Half café	AHU 3	1911.22	13.86	49896	13860	AHU- 14000
Half Café / Workshops	AHU 4	913.46	24.96	89856	24960	AHU - 25000
Labs	AHU 5	880.17	30.7	110520	30700	AHU - 25000
Exhibition Space 1	AHU 6	1201.49	9.2	33120	9200	AHU - 10000
Exhibition Space 2	AHU 7	1477.32	8.64	31104	8640	AHU - 10000
	Total	9576.41				

Table 21. Total volume flow rate for zones and the respective AHU's

Using the brochures provided on Armcor's website, fan performance curves of various AHUs in the building were evaluated to determine the total static pressure (Pa) in the AHU.

Utilizing the above information, the electrical power of the fan can be evaluated for discussion in the Electrical Services section.

The following image shows the fan performance curve for AHU-4 of the building.

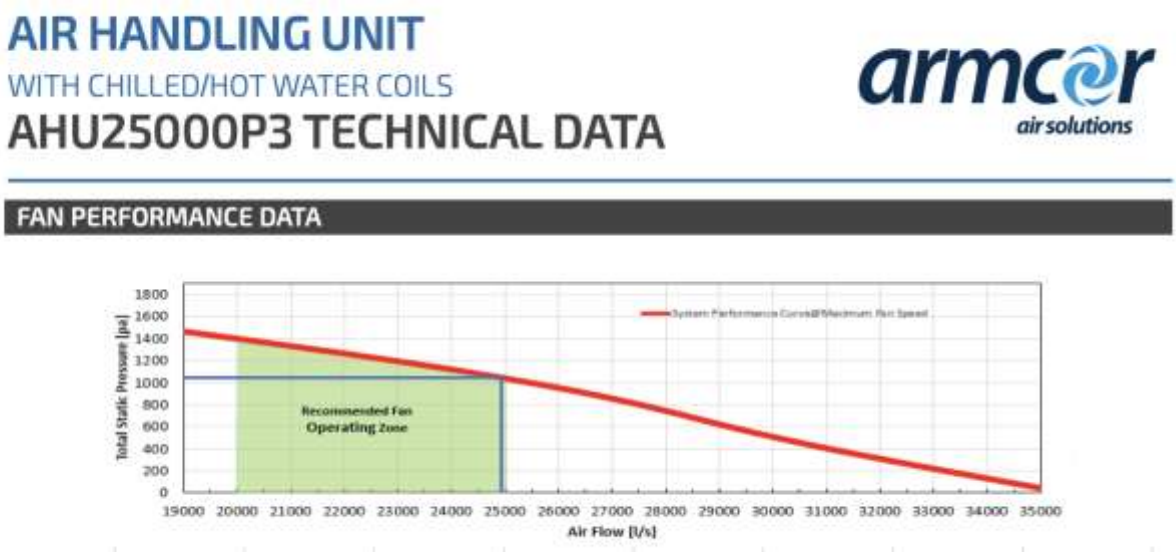


Figure 24. Fan performance curve from the armcor brochure panel for AHU-4

Figure 24 shows that the total static pressure for AHU-4 at 24,960l/s is around 1050Pa.

Using this information, an online calculator is used to determine the electrical power of the AHU. The following formula is used:

$$p = \frac{(P_a \; X \; Q)}{600}$$

Where:

P = Power (kW)
Pa = Pressure in Bars
Q = Flow rate (l/m)

Link: https://hydraulicsonline.com/technical-knowledge-hub-news/hydraulic-calculations-and-formulas/

The formula is applied to the example of AHU-4 as follows:

$$p = \frac{(0.0105 \; X \; 1497600)}{600} = 26.21 \text{ kW}$$

Evaluating the above calculations, it can be determined that AHU-4 has a desired electrical power of 26.21 kW to function at the flow rate calculated.

This procedure was done for each AHU chosen to establish the electrical power and the total static pressure of the AHUs. The process for fan sizing is summarized in table 22.

AHU	Airflow (l/s)	Airflow (l/m)	Airflow (m3/hr)	Model	Pressure (Pa)	Pressure (Bars)	Electrical Power (kW)
AHU 1	11060	663600	39816	AHU 12000	1440.00	0.0144	15.93
AHU 2	10920	655200	39312	AHU 12000	1460.00	0.0146	15.94
AHU 3	13860	831600	49896	AHU 16000	1450.00	0.0145	20.10
AHU 4	24960	1497600	89856	AHU 25000	1050.00	0.0105	26.21
AHU 5	30700	1842000	110520	AHU 25000	430.00	0.0043	13.20
AHU 6	9200	552000	33120	AHU 10000	1300.00	0.0130	11.96
AHU 7	8640	518400	31104	AHU 10000	1400.00	0.0140	12.10

Table 22. Pressure and electrical power for each AHU

Electrical Services

Having an accurate electrical services system in a building can be deemed as the most important aspect, as it is the main reason why various electrical components within the building function. Some examples include, computers, monitors, projectors and lighting must be powered at all times for occupant's control.

The following are details regarding the electrical services of this building:

- Preliminary load demand for two rooms including AHU and pumps
- Determine the transformer size
- Draw out the single line diagram

The electrical service in a building includes many components which complete the circuit, main inclusions being a circuit board, fuse, main switches and a transformer. Hence, the first part for this design detail suggests the preliminary load demand for the zones. The chosen zones for this design project are the office workspace and the main office.

The first step of the process is to determine the total room area with the necessary equipment loads using standards from BSRIA BS 9 / 2011. The following table is constructed:

Room	Area (m2)
Office Workspace	134
Main Office	25
Total	**159**
Appliance	**Loads from BSRIA (W/m2)**
Lighting	30
Small Power	10
AC	60
Computer	270

Table 23. Summary of floor area and loads from BSRRIA

The above table demonstrates the floor area and the loads for each electrical component. The values from the table above can now be utilized to determine the total power needed for the zone. Electrical services for this design project also mention the AHU and pumps electrical power. The electrical power for the AHU was determined in the HVAC section whereas the pump specifications for electrical services are as follows.

Electrical data

IE Efficiency class	IE5
Power (P2) main pump	5.5 kW
Mains frequency	50 / 60 Hz
Rated voltage	3 x 380-415 V
Rated current	20.6 A
Start. method	electronically
Enclosure class (IEC 34-5)	IP54

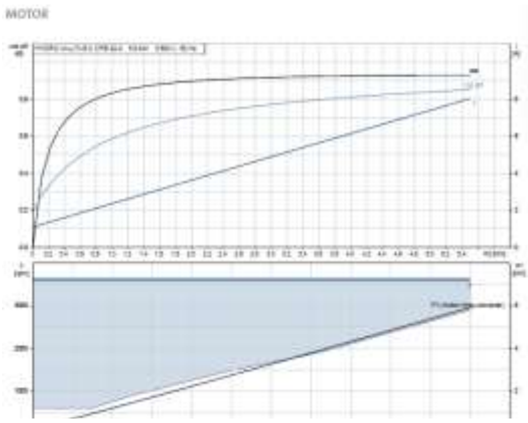


Figure 25. Demonstrates the specifications of the water pump from Grundfos

Evaluating the information above, it can be stated that each pump has an electrical power of 5.5kW.

The following table summarizes the procedure to determine the total power requirements:

	Load	Area	Power (W)
Lighting	30	159	4770
Small Power	10	159	1590
AC	60	159	9540
Computer Room	270	159	42930
AHU - 1	/	/	15930
Pump	/	/	11000
		Total	**85760**
	Future Expansion	25%	21440
		Preliminary load demand	**107200**

Table 24. Calculations regarding the preliminary load

Using the above values, the following calculations can be made to figure out the kVA readings to determine the size of the transformer:

107.2 kW rounded up to 110 kW

kVA = kW/pf

kW = 1.07

pf = power factor = 0.8

kVA = 110/0.8 = 137.5 kVA

137.5 kVA rounded up to 140 kVA

Hence the calculations prove that the building service requires a transformer size of under 140 kVA.

The following transformer can be used within the building to meet the electric requirements.

MT-DOE16-1P-480V-140KVA-120.240V-N3R Isolation Transformer

Phase: Single Phase
Frequency: 60 Hz
kVA: 140
Primary Voltage: 480 V
Primary FCAN: None
Primary FCBN: None
Secondary Voltage: 120/240 V
Winding Material: Aluminum
Efficiency: 0.9881
No Load Losses: 344W
Full Load Losses: 4,916W

Figure 26. 140 kVA transformer from Larson Electronics

The above transformer is suitable to provide the electrical requirements for the building.

Utilizing the transformer, a sensible single line diagram can be constructed as follows:

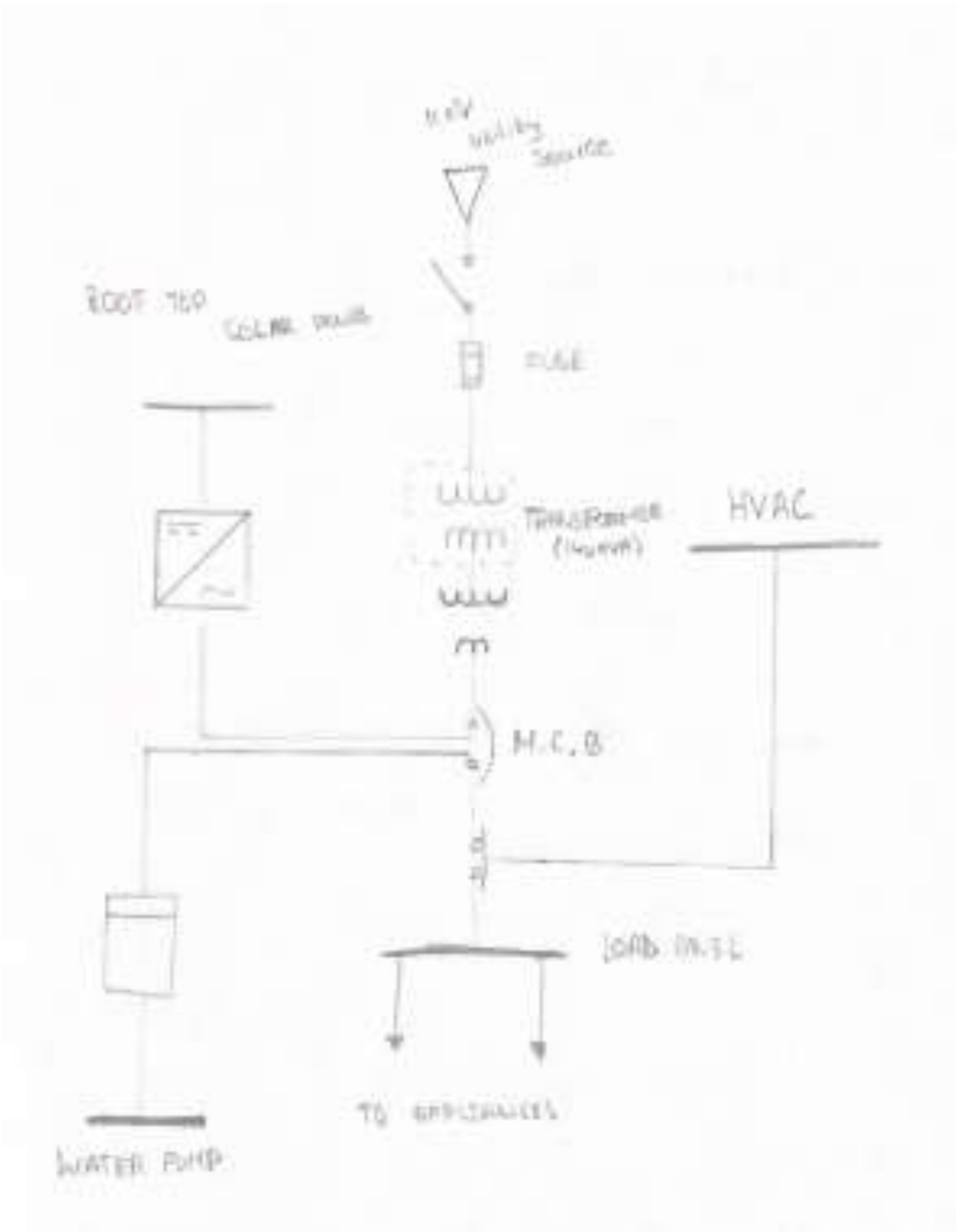


Figure 27. Single line diagram for the two areas

Figure 28. Symbol sheet for the single line diagram

Lighting

A well-lit area provides visual comfort to the occupants. Lighting in a commercial building specifically should be taken into deep consideration as the buildings function is to keep occupants focused, hence, warm and dim lighting will not be suitable for this type of a building. White-blue lighting is preferred as it would be perceived differently than that of warm lighting. Bright lights cause occupants to focus for longer periods of time which indefinitely improve productivity within the building.

A building of similar function to that of this design project would like to experience a healthy and more derived environment when it comes to productivity. Using Dubai building codes to determine the minimum lux level requirements of a space, the lighting for the office workspace and the main office was determined via an online calculator.

The online calculator, Omni Calculator, uses the floor area and the function of the area to determine the number of luminaires within an office. The lighting in such an area has to be utilized for longer periods of time, was daylighting in these areas aren’t substantial enough to provide lighting for the whole area.

According to the Dubai Building Codes, the lux levels in an office should be a minimum of 200 lux.

The building utilizes LEDs throughout as they are deemed the most efficient form of lighting in the modern day. According to LenaLighting.com, LEDs are proved to be 18% more efficient. The following table summarizes the benefits of LEDs as compared to the previous lighting appliances.

Type of Light Bulb		
60- Watt Incandescent Bulb	14-Watt Fluorescent Bulb	12-Watt LED
		
Energy Usage – 60W	Energy Usage – 14W	Energy Usage – 12W
Lumens - 870	Lumens – 900	Lumens - 1300
Bulb Lifetime – 750hr	Bulb Lifetime – 10,000+hr	Bulb Lifetime – 50,000+hr

Table 25. Difference between the types of bulbs.

After concluding with LEDs being the most obvious choice for building implementation, the following lighting solutions have taken place for this design project.

LEDs used from TRILUX	Lumens/Bulb	Connected Load (W)	Luminous Efficacy (lm/W)	Color Temp (K)	Locations
ArimoFit Sky M59 PW19 53-840 ETDD	5300	42	126.2	4000	Lobby, Offices and Exhibition Spaces
ArimoFit M84 PW16 30-840 ETDD	3000	22	136.4	4000	Meeting rooms, Main Office and Service Rooms
Avelia C09 OA 2600-830 ETDD 01	2550	30	85	3000	Bathrooms

Table 26. The lighting specifications used in the building

All the LEDs are from TRILUX which benefits the project by cost effectively installing the lights within the building. TRILUX provides the BIM models for the specified lights in the office workspace and the main office resulting in accurate drawings.

The online calculator was used by inputting the various values calculated above to determine the number of luminaires per area.

The following table is a summary of the inputted values within the calculator.

Room	Lux (lx)	Lumen per bulb	Area (m^2)
Office Workspace	200	5300	134
Main Office	200	3000	25

Table 27. Summary of the inputted values of the calculator

Office Workspace Luminaire Calculations

Main Office Luminaire Calculations

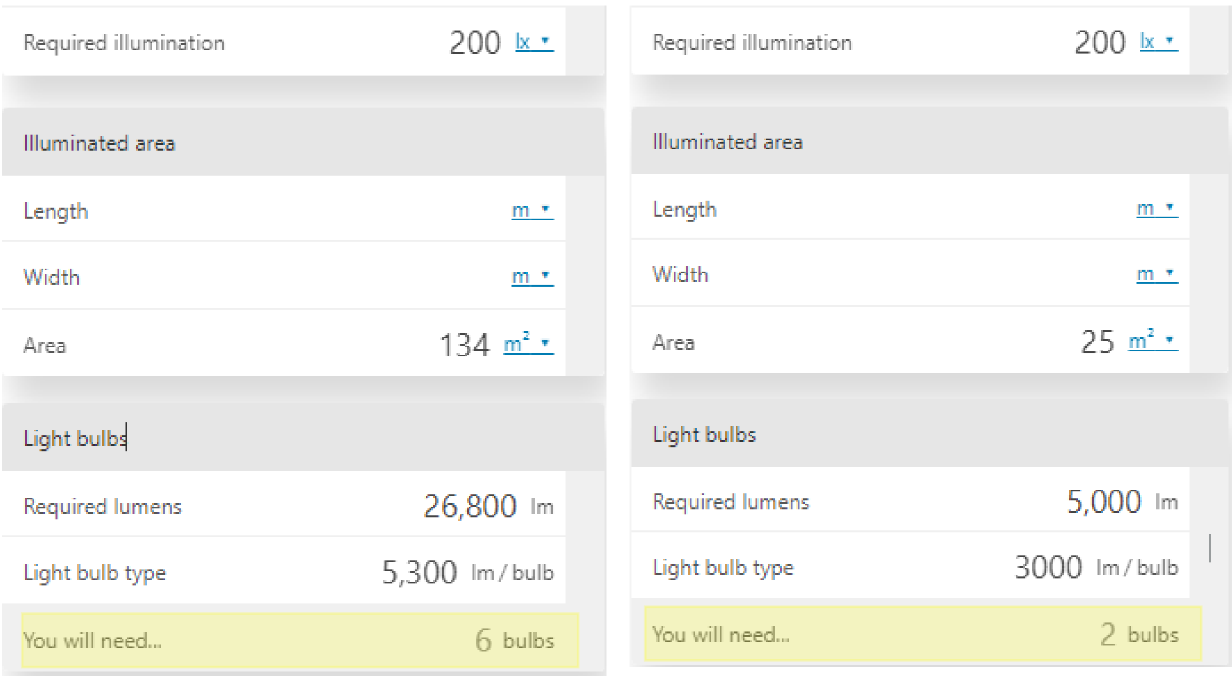


Figure 29. Demonstrates the number of bulbs required within the specified spaces.

Following the above information, the detailing of the placement of the luminaires within the space can be done as follows:

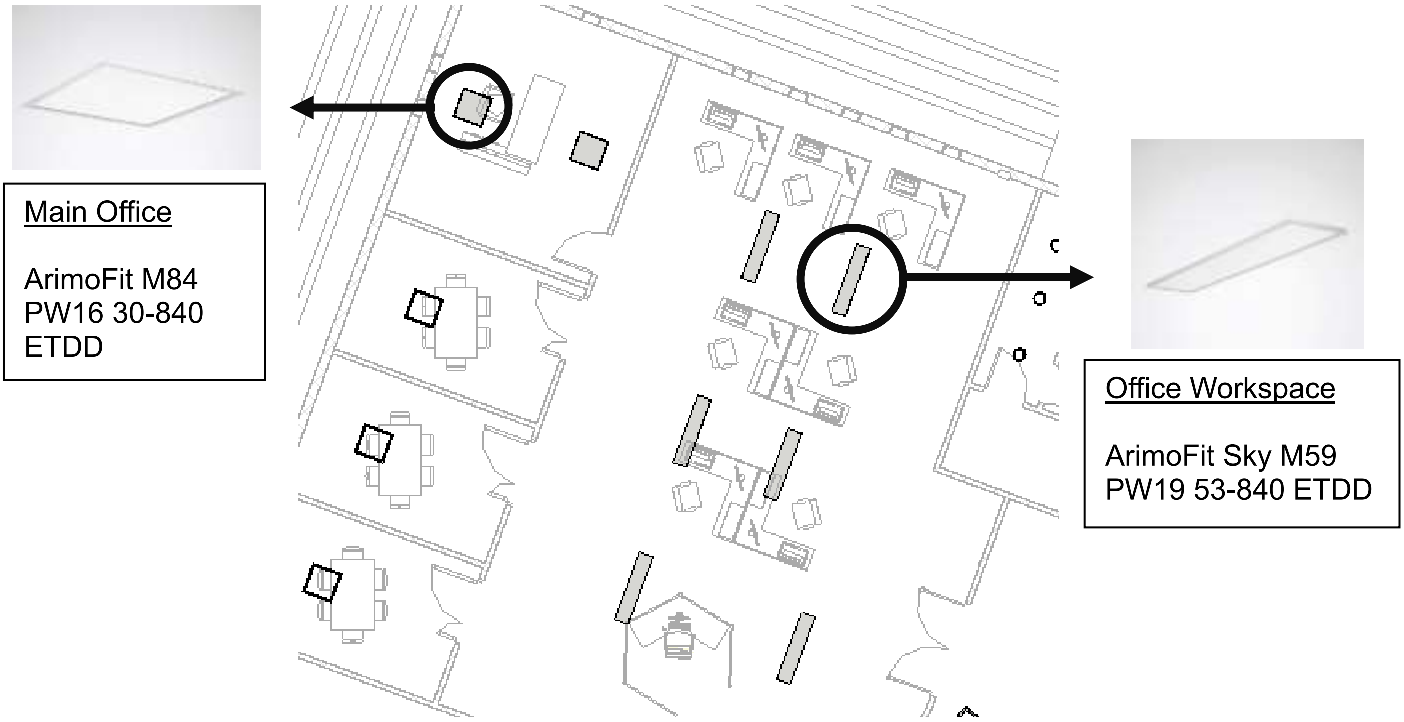


Figure 30. Overview of the placement of the lighting fixtures in the Revit Model

Project Planning

Using a Gantt chart, a project plan can be made which covers the projected timeline in which the project can be completed. The following are the steps that can be taken into consideration for project planning:

1. **Site Inspection and preparation**: Reporting the site conditions for understanding of removal of debris from the site e.g., trees, roots (2 Weeks)
2. **Excavation:** Utility trenches, excavation for foundation works (4 Weeks)
3. **Construction Works:** Complete operation of foundation works on site (6 Weeks)
4. **Grey Structure:** Internal and External wall construction (9 Weeks)
5. **Roofing:** Installation of the roof (10 Weeks)
6. **Initial Finishes:** Plastering and tiling (7 weeks)
7. **Services:** MEP Servicing (8 Weeks)
8. **Final Finishes:** Painting and decoration (4 Weeks)
9. **Fixtures:** Flooring, bathrooms and offices (10 Weeks)

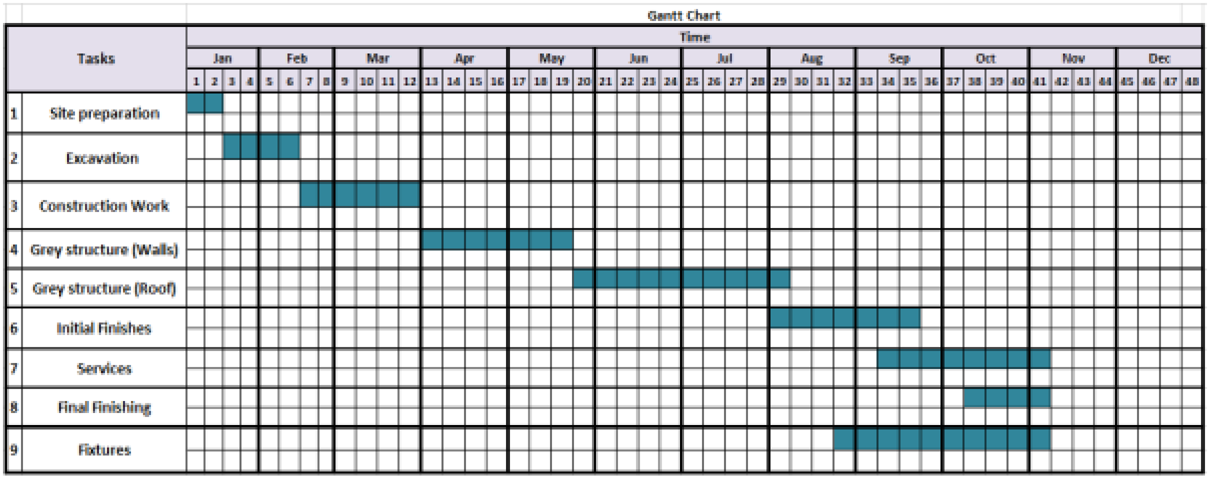


Table 28. Demonstrates the project planning

Making the Gantt chart as simple as possible and focusing on one thing rather than multiple at the same time proves to improve productivity and time management skills.

Project Costing

Cost planning is done using SPON'S Architects' and Builders' Price Book and Spon's Mechanical and Electrical Services Price Book. Unit rate (£) for each main item is calculated and shown below.

HVAC system:
Air-conditioning units

AHU's	model	airflow (m3/hr)	airflow (m3/s)	pressure (pa)	£
AHU 1	AHU 12000	39816	11.06	1440	70,639
AHU 2	AHU 12000	39312	10.92	1460	70,639
AHU 3	AHU 16000	49896	13.86	1450	70,639
AHU 4	AHU 25000	89856	24.96	1050	98,699
AHU 5	AHU 25000	110520	30.7	430	95,586
AHU 6	AHU 1000	33120	9.2	1300	55,058
AHU 7	AHU 1000	31104	8.64	1400	47,825
					£509,085

Duct –

duct diameter (mm)	number of ducts	total length (m)	£ per meter	total price (£)
350	2	14.29	73.16	1045.5
400	3	18.1	73.73	1334.5
450	5	42.2	80.21	3384.9
500	3	33.58	83.68	2810.0
600	7	55.72	130.58	7275.9
700	8	99.07	140.36	13905.5
800	3	15.95	148.06	2361.6
900	17	99.58	167.78	16707.5
				£48825.0

Water installation:

Item	Unit	Range £
5.4 Water Installations	m² GIA	49.00 to 67.00

Using the total area: 2322 m^2 and £60/m^2:
The cost for water installations is £139320.

Electrical system:
Transformer costs £15,060.78

Item	Unit	Range £
5.8 Electrical Installations Lighting installations (including lighting controls and luminaires)	m² NIA	125.00 to 165.00

Using the total area: 2322 m^2 and £150/m^2:
The cost for electrical installations is £348300.
The total electrical system costs £348300 + £15,060.78 = £363,360

An estimated cost for the services of the building is £1,060,590.

Conclusion

This detailed design proposal concludes by thorough discussion and calculations regarding the building services of Blending Jameel.

Plumbing services include the domestic cold and hot water supply for the bathrooms, along with the drainage stack system the building utilizes. Through standards the values and sizing were calculated which allowed for ease of practicality in the real world.

The mechanical services included the HVAC System of the building. Zonal air handling units were allocated to allow ease of thermal comfort throughout the building. Using standards to tabulate the diameter size of the ducts, velocity of air through the ducts, along with the pressure drop from the ducts. The fittings pressure drop was also calculated to determine the index run through the mechanical system. Which led to figuring out the size of the fan through fan performance curves of actual AHUs used in the real world.

Electrical services then proved how the electricity supply to the various electrical appliances would function. Along with sizing of a transformer to determine the placement of the transformer within the building.

Lighting solutions include LEDs for maximum energy efficiency within a building. Comparing the various lighting types to determine the best possible solution for the building. Real world implications proved from TRILUX to establish a working and practical environment for the building.

In conclusion, the building services section for this detailed design proposal suggests a clear demonstration on how to size the various services. This design proposal experienced a lot of limitations regarding the Revit model and architectural drawings which caused a few setbacks regarding the detailing of the drawings.

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Appendix A – Architectural Drawings