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Improving the Ventilation System of an Air-Conditioning System in a Five-Star Hotel at Ezulwinini Kingdom Eswatini

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Abstract

Heating, Ventilation and Air Conditioning systems (HVAC) are designed primarily to provide environmental thermal comfort in a building. Since the weather pattern and climatic conditions have changed drastically due to industrialisation. The world has experienced very high or low temperatures due to climate change and therefore an efficient HVAC system is pivotal. Currently there are less regulation in the designing of HVAC systems except ASHRAE which has data for refrigeration systems. There is a serious problem when designing an efficient and cost-effective HVAC systems due to complexity of operating parameters and variables during operation. In the current study we have designed an HVAC system that is very efficiently and cost effective. Load on the system was calculated on maximum occupancy and extreme outside temperatures. Calculations were done as per ASHRAE Handbook fundamentals by using Carrier HAP software. As a result of this design, we got LEED silver rating. As a result of this design, we got LEED silver rating with an emission free HVAC system, with very low Global Warming Potential and Ozone Depletion Potential providing the best indoor air quality. However, the chillers are more expensive for are heat recoveries but are to be used in pre-heating domestic water for the building during cooling demands. In addition, BMS (Building Management System) interface increases the system efficiency with less down time.

Keywords: Heating, Ventilation, Air Conditioning systems, and designed

1. INTRODUCTION

The hospitality industry envisage growth by a substantial percentage in every year, the hotel and restaurant business will experience an exponential growth in the decade through a high number of tourists, thus a five-star hotel investment is made in the kingdom of Eswatini. The growth in tourism industry in Africa has brought the awareness of the importance in healthy and comfortable living environment. Given the fact that, Five Star hotels are businesses, the core mission of its operational is to make profit. Thus, the fundamental principle of designing an HVAC system is to make it more efficient. Whilst ensuring that guests are satisfied as well as providing a comfortable work environment for staff. It is therefore important to cut cost in the design and running of HVAC systems. HVAC is an acronym of Heating, Ventilation and Air-conditioning which is an arm of mechanical engineering which helps achieve good indoor air quality and human comfort in a building. HVAC system is also important and essential in many hospitality industries, laboratories, hospital, manufacturing processes in rubber industries and many more. This is a vehicle of exchanging or replacing air in any zone or space to provide good indoor air quality. This process involves humidity and temperature control, oxygen replenishment, removal of odours, smoke, dust particles in the air and many more.

Global warming has exposed the world to sharp rise of temperature, the increase in scarcity in energy (increase in entropy) and unusual climatic changes experienced in recent years. This has caused an increase in heating and cooling technologies demand, thus HVAC systems have a wide applicability ahead. Having good indoor air quality is very important in a recreational monumental building like a hotel is important, for occupants spend most of their time indoors thus HVAC system has a strong correlation with health and productivity occupants. HVAC system design for a Five Star Hotel is critical component and if done carefully, energy efficient system at an affordable implementation and operational costs. Although, designing an HVAC system is complex task since there are a number of parameters which needs to be considered. This includes site, system parameters, selection of proper thermal load tonnage, owner's project requirement (OPR) and system specification. For, if not properly done, the required thermal comfort and LEED silver rating cannot be achieved.

2. METHODOLOGY

Heating, ventilation and Air-conditioning system design depends on a number of factors hence, the climatic condition of the building site location is paramount. Thus it is important to considered the standard climatic. It is relatively hot in summer at Ezulwini, so we consider the summer as a design condition. Cold southeast winds in winter brings a humid climate from mid-April to end of August. Below is a tabulated temperature details for Ezulwini.

Table 1: Design temperatures

EXTERNAL CONDITIONS	
Dry Bulb Temperature (summer)	30 ºC
Wet Bulb Temperature (summer)	27 ºC
Dry Bulb Temperature (winter)	8.0 ºC
Wet Bulb Temperature (winter)	4.3 ºC

Table 2: Indoor temperature design conditions

	LOCATION	ROOM TEMP. SUMMER /WINTER[1]	RELATIVE HUMIDITY
1	Guest Rooms	▪ 21 ± 2 ºC	▪ 50% ±10% RH
2	Restaurants	▪ 21 ± 2 ºC	▪ 50% ±10% RH
3	Gym/ Fitness Centre	▪ 21 ± 2 ºC	▪ Not Controlled
4	Offices	▪ 21 ± 2 ºC	▪ Not Controlled
5	Kitchens	▪ 24 ± 2 ºC	▪ Not Controlled
6	Laundry	▪ 23 ± 3 ºC	▪ 50% ±10% RH
7	Shops	▪ 21 ± 2 ºC	▪ Not Controlled
8	Conference Rooms	▪ 21 ± 2 ºC	▪ Not Controlled
9	Lift/Lobbies/Main Lobby	▪ 21 ± 2 ºC	▪ Not Controlled
10	All day café	▪ 21 ± 2 ºC	▪ 50% ±10% RH
11	Sky Walk	▪ 21 ± 2 ºC	▪ Not Controlled
12	Computer/Server Rooms	▪ 22 ±0 ºC	▪ 50% ±10% RH
13	Storage Rooms	Not Controlled	▪ Not Controlled
14	Plant Rooms	▪ 24 ± 0 ºC	▪ 50% ±10% RH
15	Business Centre	▪ 21 ± 2 ºC	▪ Not Controlled
16	House Keeping/ Workshop	▪ 24 ± 2 ºC	▪ 50% ±10% RH
17	Common Toilets	▪ Air transferred from corridors	▪ Not Controlled

In addition to that, building plan and orientation has an effect thermal loads of a zone or space, which must be taken into consideration for an optimal HVAC system design for the five star hotel. A plan view of the six-storey hotel, with three wings (North, Centre and South Wing) is shown in Appendix. This design is in accordance with green building design concept.

3. THERMAL LOAD CALCULATION

Finding the total tonnage of the HVAC system is important in order to select a good system, thus load calculation is required. Whereby, thermal load is the amount of heat transfer to the system which must be removed to the desired comfort and set point temperatures. It also helps in acquiring information for system sizing, equipment selection and system design. There are two categories which form thermal load and these:

1. Heating load – these are calculated to obtain amount of heat loss from the building in the winter to derive the set point heating capacities.
2. Cooling load – these are calculated to determine the heat gain in the building in summer to obtain the required cooling capacity for the set comfort.

The core objective, is to design an HVAC system for summer, which requires cooling load calculations. The system must be divided into two main parts and these are: internal heat gain and external heat gain. These is further broken down into:

1. External Heat gain
   a) Heat gain through the walls and roof
   b) Heat gain through window, door and partitions
2. Internal Heat gains
   a) Heat gain through people
   b) Heat gain through lighting
   c) Heat gain through electrical appliances etc.

Internal or Sensible heat gain in given by

$$q_{sp,t} = N_{p,t} (SHG_p)$$

Where,

qsp,t = sensible heat gain by occupants (W)

Np,t = number of occupants in the conditioned space at time "t"

SHGp = sensible heat gain of each person (W)

[1] The actual operational temperatures will be dependent upon the "Hysteresis" of the installed controls & MEP Plant

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Since people in a conditioned space releases latent heat thus latent heat gain from people is given by:

$$q_{lp,t} = N_{p,t}\,(LHG_p),\text{ with}$$

LHGp = latent heat gain of each person.

Heat gain due appliances is calculated by:

$$q_{appl} = W(Usage\ Factor),\text{ with}$$

$$q_{appl.} = 167500\ W$$

Table 3: Internal load design conditions

HEAT GAINS					
	Location	**People (W/Person)**		**Lighting (W/m²)**	**Equipment (W/m²)**
		Sensible	**Latent**		
1	Guest Rooms	68	35	11	600W per Room
2	Restaurant	75	65	15	5
3	Gym	72	60	12	30[2]
4	Offices areas	72	60	12	20
5	Kitchen	85	55	13	350[3]
6	Laundry	85	79	15	30[4]
7	Shops	72	60	18	20
8	Conference Rooms	72	60	15	5.4
9	Lobby	72	60	12	5
10	All day dining	75	65	15	5
11	Sky Walk	75	65	15	5
12	Computer/Server Rooms	-	-	16	500[5]
13	Storage Rooms	-	-	10	-
14	Plant Rooms	-	-	15	10
15	Business Centre	72	60	12	20
16	Common Toilets	-	-	10	5

External Heat gains

Heat gain through the windows, walls and roof is given by,

$$\boldsymbol{q_{so,t} = A_{s,t}(SC)(SHGF_t) + A_{sh,t}(SC)(SHGF_{sh,t})}$$

Where,

$q_{so,t}$ = solar heat gain

$A_{s,t}$ = sunlit area of the window at time t, m^2

SC = shading coefficient

$SHGF_t$ = heat gain at time 't' considering orientation, latitude, month and hour (W/m^2)

However for vertical surface facing the north orientation is taken as $SHGF_{sh,t}$. Conductive heat gain due to the indoor-outdoor temperature difference is given as:

$$\boldsymbol{q_{win,t} = U_{win}A_{win}(T_{o,t} - T_r)}$$

Where,

U_{win} = overall heat − transfer coefficient of window and frame

A_{win} = gross area including glass and frame m^2

$T_{o,t}$ = outdoor temperature at time t considering month, hour and location (℃)

[2] To suite ELV Equipment Selection
[3] To accommodate kitchen equipment selection
[4] To accommodate equipment selection
[5] To accommodate equipment selection

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U-factors for the calculation of the building envelope heat transmission load shall be based in the design considerations regarding construction panels. This is expressed as

$$U^{-1} = \frac{1}{h_1} + \frac{l_1}{k_1} + \frac{l_2}{k_2} + \frac{1}{h_2} \dots,$$

Where:

U = Overall heat transfer coefficient (W/m^{2}K)

h_1 = Outdoor convective heat transfer coefficient (W/m^{2}K)

h_2 = Indoor convective heat transfer coefficient (W/km^{2}K)

l_1 and l_2 = thickness of layers (m)

k = Conductive heat transfer coefficient (W/m^{2}K)

The value of conductive heat transfer coefficient for different types of material is tabulated below:

Table 4: External wall U-value design condition

		Thickness (mm)	Mass(kg)/m^2	U-Value (W/m^{2}K)
1	Outside Surface Resistance (Plaster)	20	482	**1.72**
2	Brickwork with air chamber	230		
3	Inside surface resistance (Plaster)	20		

Table 5: Roof U-Value design conditions

		Thickness (mm)	Mass(kg)/m^2	U-Value (W/m^{2}K)
1	Waterproofing	-	575	**1.81**
2	Screed	50		
3	Reinforced Concrete	250		
4	Air Space	-		
5	Plaster board Ceiling	-		

Table 6: Intermediate Slabs U-Value design conditions

		Thickness (mm)	Mass(kg)/m^2	U-Value (W/m^{2}K)
1	Carpeting	6	356	**1.86**
2	Screed	50		
3	Reinforced Concrete	250		
4	Air Space	-		
5	Plaster board Ceiling	-		

Table 7: Ground Floor Slab U-Value design conditions

		Thickness (mm)	Mass(kg)/m^2	U-Value (W/m^{2}K)
1	Carpeting	6	356	**1.89**
2	Screed	50		
3	Reinforced Concrete	350		
4	Waterproofing	-		

Table 5: Internal Partition Walls U-Value design conditions

		Thickness (mm)	Mass(kg)/m^2	U-Value (W/m^{2}K)
1	Inside Surface Resistance (Plaster)	20	291	**1.61**
2	Brickwork with air chamber	230		
3	Inside surface resistance (Plaster)	20		

Table 9: Windows U-Value design conditions

		Thickness (mm)	Mass(kg)/m^2	U-Value (W/m^{2}K)
1	Double glazed window	3.2	291	**3.21**
2	Frame (Aluminum)	-		
3	Airgap	5		
4	Shading coefficient	-	-	**0.28**

Ventilation

Duct sizing can be defined by many theories such as:

- Equation friction
- Static regains
- Total pressure
- Velocity reduction
- Constant velocity

Duct sizing was carried out using equation friction method in according to procedures described in the ASHRAE handbook of fundamentals and SMACNA HVAC duct construction standards. The system is sized for a constant pressure loss per unit length of the duct i.e the equal friction method. This theory was applied for both supply and extraction system sizing.

Pressure drop in duct shall not exceed 1 mm H_2O/m and the corresponding air velocity not to exceed 7-9 m/s in the main ducts and 3-7 m/s in the branches.

For other elements, the following velocity shall not be exceeded:

- Dry filters (face velocity): 1,5-2,8 m/s
- Bag filters (face velocity): 1,5-2,5 m/s
- Coils (free velocity): 2-2,8 m/s

In air-conditioned rooms, the experienced velocity shall not be exceeded of 0,25 m/s. Ducts are to be properly sealed to allow for minimal to no leakage and are tested by means of a pressure test in accordance with section 6.4.4.2.2 of ASHRAE 90. Below is calculated data for supply main ducts and branches:

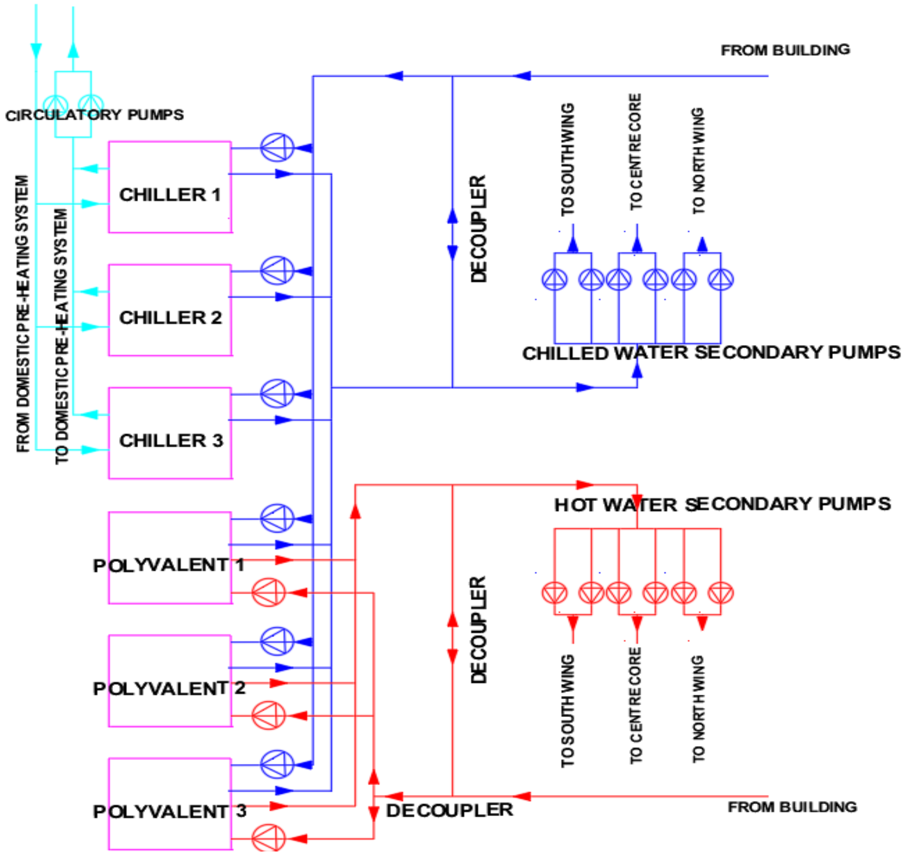
Air distribution

The return duct is a necessity for every HVAC system, this maintain both indoor pressure and air quality in a zone. The exhaust air grill is in the bathrooms whereas the supply through air grills is in the guest room. This will serve both bathroom extraction and guest room return air.

Chilled/Hot Water Reticulation System

The polyvalent heat pump uses a four pipe system for simultaneously and independent production of hot and cold water for heating and cooling building spaces with two independent hydronic circuits. The system is more efficient if both cooling and heating needs are required. This is ideal for the hotel due to its orientation and number of zones. The system consists of two water circuits; constant primary loop and variable secondary loop. The Primary side of the heating or cooling circuit contains the polyvalents or chillers as well as the primary pumps. In this circuit the polyvalent or chillers heat or cool the water which is circulated around by the primary pumps in a continuous loop between the chillers or polyvalent and the decoupler. The primary and secondary circuits are connected via a Decoupler or sometimes known as a Common Header. The primary water flows into this to provide heated or chilled water to the secondary circuits.

The secondary circuit is then used to serve the cooling/heating coils associated with FCU's and AHU's located inside the building. The secondary pumps are equipped with variable frequency drives (VRF) to vary chilled/hot water flow within the system to meet required operating conditions as shown below.



Each chiller plant is connected to common headers which enable an easy changeover of duty chiller/polyvalent. Air vents in pipework distribution will be provided at all high points with drain cocks at all low points. A strainer is provided on the secondary chilled water flow pipework, one per tower floor and per FCU and AHU to prevent dirt and contamination entering the FCU/AHU unit circuit.

All secondary pumps are provided with duty and standby pump. Primary pumps do not have redundancy. All plant containing rotating/dynamic machinery will be designed with anti-vibration mounts/inertia bases to prevent structure borne transmissions.

Temperature control

Each building space temperature is controlled individually by its own thermostat which modulates a throttling valve for flow in a fan coil unit (FCU) or air handling unit (AHU). FCU are used in generally for small cooling/heating loads, while AHUs cover large areas and may require ducting. AHUs are mainly used for fresh air supply.

Lifecycle Cost analysis

We considering a 25 year life cycle of the HVAC system. This analysis comprises of capital cost, operational cost, and maintenance cost.

Capital Cost - as per the market condition, the overall initial costs are high due to large equipment.

Operational Cost - more significant energy efficient plant which serves operating cost.

Maintenance Cost - chiller systems have a low maintenance cost.

3. CONCLUSION

Global warming and industrialisation of our environment has seen an increase in entropy thus affecting human comfort in the hospitality industry. HVAC system is considered to be one vehicle in addressing the problem faced by the world as it also help improve human health and productivity. This paper provides an essential framework of designing the load calculation to be the equipment sizing. For comfort conditioning, four pipe system gives most appropriate temperature set point with AHUS supplying most appropriate fresh air volumes in the building. Evidently the best HVAC systems cannot be designed or selected according to the design of a building, but the building has to be designed with respect to HVAC systems.

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