Building Envelope Optimization and Cost-Effective Approach in HVAC to Support Smart Manufacturing

Shamir Talkar, Amit Choudhari, and Pavan Rayar

Abstract To fulfill the demand for modern products, nowadays industries are growing and expanding their manufacturing units at very faster rate. But due to space constraints, there are some restrictions in expanding longitudinally so the only option is to expand laterally, i.e., increasing the number of floors. In many manufacturing units, there is a need to implement optimized and effective HVAC system. The main power consumers in most buildings are HVAC, apart from lighting systems which accounts nearly 60–65% of the total building load. The first step in energy savings on HVAC systems is to reduce the cooling load. The amount of electricity for air-conditioning systems used depends on the cooling load, i.e., the amount of heat the system must remove. In order to support the purpose of a smart and intelligent manufacturing process refining the measurement of heat loads using different methods, and enhancing the insulation used in the building envelope will result in enormous energy savings in HVAC by reducing the tonnage of heat load by creating a stronger and effective barrier to minimize the heat contribution from the air and results in saving money.

Keywords Demand · Expansion of industries · Space constraints · Number of floors · Optimized and effective HVAC

1 Introduction

In order to understand the cooling load required by the building, major emphasis needs to be given to the building envelope. During the headload calculations, there

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S. Talkar (✉)
Arkk Consulting, MEP, Mumbai, India
e-mail: shamirtalkar@gmail.com

A. Choudhari
Worley, Mumbai, India

P. Rayar
Department of Production Engineering, Dwarkadas J. Sanghvi College of Engineering, Mumbai, India

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are different variables like U-factor for wall, glass, roof and some constant factors like outdoor temperature its relative humidity, solar gains, heat dissipation through lights, equipment and humans. There is no control over the constants, except the variables by using glass having innovative film technology, using wall and roof with insulation and air cavity. Therefore, by controlling the U-factor, i.e., by changing the different configuration, the total aggregate heat entering indoors can be restricted [1]. This leads to a reduction in headload tonnage, thereby resulting in savings. By using this methodology in the future, there is a great scope of saving energy and manufacturing various façade wall panels and glass having excellent U-values which will bring about a significant difference in load reduction. After researching and analyzing in the field of HVAC, its ever-increasing demand due to attaining thermal comfort within the premises has led to increased energy demand and higher electricity bills. Also, the conventional methods of generating electricity further lead to environmental impacts. Therefore, a reduction in HVAC load will not only result in lower energy consumption but also reduce the energy bills and have less impact on the environment. In this research paper, there are improved ways of reducing the cooling load by means of improving the building envelope. This research paper shows reduction in the cooling load by comparing three different sets of options by changing the conditions and the U-values.

2 Overview of the Research Paper

The building envelope acts as the door between indoor and external climatic conditions. It potentially controls the building climatic response [2]. The building envelope should be designed to preserve energy significantly. Well-designed building envelope maximizes daylight, natural ventilation (access to fresh air) and views to the exterior and enables to modulate solar heat gain and control/reduce noise. Building envelope components and their configuration largely determine the amount of heat gain or loss and wind that enters inside the building and extent of natural ventilation in the building [3].

The primary components of building envelope which affect the performance of a building are,

(a) walls,
(b) roof,
(c) fenestration (openings with or without glazing),
(d) floor, etc. (Fig. 1).

Heat can be generated in various ways, and they are either directly or indirectly. Some of the sources are as follows:

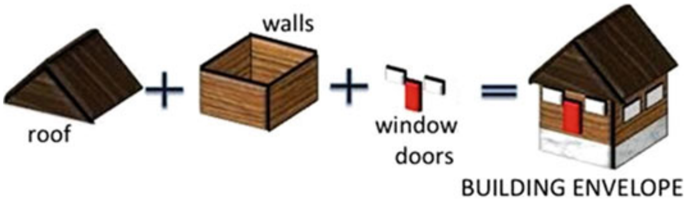

Fig. 1 Basic building envelope incorporating various primary components

2.1 Solar Heat Gain [4]

The radiation from the sun enters the interior design spaces in three modes—conduction, convection and radiation.

2.2 Heat from Human Beings

Occupants are another major source of heat gain in the interiors of the structure. Humans consume hundreds of calories every day as food, and part of this energy is released as heat to the surroundings during the metabolic processes.

2.3 Outdoor Air Heat

The warm outside air is called outdoor air or ambient air. Since it is warmer than the air inside the building spaces, when it enters the spaces it tends to increase the indoor average room temperature.

2.4 Heat from Electrical and Electronic Appliances

Indoor spaces are loaded with electrical and electronic appliances such as lightning fixtures, television sets, coffee machines, water heaters, etc. These appliances consume electricity and release a part of it in the form of heat in the air-conditioned spaces.

3 Research Methodology

For research purpose, the building selected to do this analysis is a Ground + 10 Floors Multi-Purpose Center situated in Pune as a base plan for calculations.

3.1 A Conventional Approach to Heat Load Calculations

In this approach, heat load calculation was done based on U-values of standard materials used as building envelope. Architects/civil consultants/engineers use the conventional approach in designing facades. The materials used are as follows:

Summer conditions: [5]
Indoor temperature: 75.2 °F [6]
Outdoor temperature: 101 °F
Glass: double pane regular glass
Properties:
Solar heat gain co-efficient (SHGC)—0.80
U-value—0.55 BTU/HR-FT^2—°F
Wall: (inside) 25 mm plaster + 100 mm brick + 25 mm plaster
Properties:
U-value—0.35 BTU/HR-FT^2— °F
Roof: 100 mm RCC
Properties:
U-value—0.63 BTU/HR-FT^2— °F
Light load: 0.75 W/ft^2.

3.2 B Option 1

In this approach, heat load calculation was done based on improved set of U-values of materials used as building envelope.

The glass and wall configuration used in this approach are as follows:
Summer conditions:
Indoor temperature: 75.2 °F
Outdoor temperature: 101 °F
Glass: double pane regular glass with film
Properties:
Solar heat gain co-efficient (SHGC)—0.28
U-value—0.26 BTU/HR-FT^2— °F
Wall: 25 mm plaster + 200 mm AAC Block + 50 mm insulation + 25 mm plaster
Properties:
U-value—0.06 BTU/HR-FT^2— °F

Fig. 2 Using a fan with an air conditioner leads to savings

Roof: 100 mm RCC + 40 mm insulation
Properties:
U-value—0.09 BTU/HR-FT^2— °F.

3.3 C Option 2

In this approach, heat load calculation was done based on the same set of U-values used in Option 1 as well as increasing the indoor conditions. We have also added ceiling fans in the conditioned space [7]. A perfect combination of saving electricity is making use of the fans as well as the air conditioner. Ceiling fans can create a breeze that makes people in the room feel cooler and more comfortable. With a ceiling fan running, you can raise the thermostat of the air conditioner by 3–4 degrees with no reduction in comfort. Increasing the temperature on the air conditioner can reduce your electricity bills significantly (Fig. 2).

3.4 Headload Comparison

As we can see from Table 1, when the building headload is calculated using conventional approach to walls and glass, the tonnage of refrigeration required to cool the building comes to 240 TR. On the other hand, when these walls and glass configurations are improved the tonnage reduces to 190 TR and when the same U-values are used along with ceiling mounted fans, the tonnage further drops to 170 TR. This

Table 1 The table shows a summary of tonnage required for the entire building premises

Approach	TR	
1	Conventional with normal U-values	240
2	Option-01 with improved U-values	170
3	Option-02 with U-values as per Option-01 and fans	150

show that the tonnage difference between the conventional approach and Option 2 comes to nearly 90 TR (Table 2).

4 Comparison of Capital and Operational Expenditures

The comparison gives us a summary of the initial capital investment required and the operational expenditures for conventional approach as well as Option 1 and 2. Section A shows the capital investment of all 3 options, this included cost for variable refrigerant flow system, wall insulation, roof insulation, glass film, ACC blocks, brick blocks and ceiling fans. Section B shows the operational expenditures for 1 year based on the electrical consumption of all the 3 options. Section C shows the comparison with the annual maintenance charges subjected to every option and 10 years of CAPEX AND OPEX cost difference between the 3 options (Table 3).

5 Results

From Table 4, we understand that,

When we compare conventional system and Option 1, we achieve savings right from the second year. The column named difference shows yearly saving when compared to conventional system, i.e., if the building is designed as per Option 1, we achieve savings shown as in column number 4. Similarly, when we compare conventional system and Option 2, we achieve savings right from the very first year. The column named difference shows yearly saving when compared to conventional system, i.e., if the building is designed as per Option 2, we achieve savings shown as in column number 7.

6 Conclusion

The building envelope is a door to the outside environment and its performance is directly proportional to the HVAC load within the premises. Also, with the rise in urbanization, cities are growing vertically, due to lack of availability of land. This results in tall buildings/towers/skyscrapers. HVAC system deployed in such towers will impact hugely on energy consumption. Smart manufacturing of wall panels with sandwiched air cavity, insulation, even glass panels with low-E coats improved the U-values used for headload calculation leading to reduced tonnage for HVAC system.

From the above results for the envelope of the building, the following parameters were improved;

1. Occupancy comfort

Table 2 Sample heat load of the building premises

Area (Ft^2)	1333.70	Height (FT)	10.50	Vol. (Ft^3)	13,999	Room	Room-1	
	Area/qty	Sun gain		BTU/h		DBT	% RH	GR/LB
Room sensible loads					Outside	101	28	83.2
Glass exp					Room	75.2	55	72
N	289	11	0.80	2545		25.8		11.2
E	155	11	0.80	1363	Occupancy	20		
S	289	11	0.80	2545	CFM/PER	5	100	CFM
W	0	165	0.80	0	CFM/SQFT	0.06	80	
NE	0	11	0.80	0	No. of ACPH	1	233	CFM
SE	0	11	0.80	0	**F.A. CFM**	**233**		
SW	0	113	0.80	0	Correction factor		6	
NW	0	118	0.80	0	**Bypass factor**		0.176	
Walls exp								
N	119	10	0.35	415				
S	119	22	0.35	913	People	20.00		205
W	0	18	0.35	0	Appliances			
NE	0	16	0.35	0	Room latent heat sub-load			
SE	0	24	0.35	0			Safety	5%
SW	0	20	0.35	0	Room latent heat			
NW	0	12	0.35	0	Room total heat			
Roof	0	38	0.63	0	Sensible	233.31	25.8	0.88992
All glass	733	25.8	0.55	10,405	Latent	233.31	11.2	0.56032
Partition	0	20.8	0.40	0	**Grand total heat (BTU/HR)**			
Ceiling	667	20.8	0.44	6103				
Floor	1334	20.8	0.48	13,316	**Sensible heat**		0.92	
O/D air	233	25.8	0.1901	1144	**Factor**			
People	20	1	245	4900	Indicated ADP of		54.59	
HP	0	1	2545	0	Selected ADP of		52	
Lights (W)	1000	1	3.4	3401	Dehumidified rise of		19.12	
APP.	100	1	3.4	340	**CFM/ft^2**		**2.00**	
Room sensible heat sub-load				49,009	**SQFT/TR**		**240.35**	
Fan HP %	0.08	Safety	5%	6126	**Dehumidified air CFM**		**2670**	
Room sensible heat				**55,135**	**Tonnage**		**5.55**	

Table 3 Comparison of capital and operational expenditure

S. No.	Description	Conventional system	Option 1	Option 2
	TR required for premises	240	170	150
	Type of system	VRV	VRV	VRV
A	Capital expenses			
	Total AC cost	20,400,000.00	14,450,000.00	12,750,000.00
	Fans			500,000.00
	Roof insulation		550,000.00	550,000.00
	Wall insulation		704,000.00	704,000.00
	Glass film		60,60,032.00	6,060,032.00
	ACC blocks		1,224,248.00	1,224,248.00
	Brick blocks	244,849.00		
	Total cost	20,644,849.00	22,988,280.00	21,788,280.00
B	Operating expenses			
	Power consumption (KW)	264	187	165
	Diversity	0.8	0.8	0.8
	Total load	211.2	149.6	132
	Kw/TR	1.1	1.1	1.1
	Power consumption—TRHRS	493,363.20	349,465.60	308,352.00
	Cost of electricity/KWHR	10.00	10.00	10.00
	Energy charges	4,933,632.00	3,494,656.00	3,083,520.00
	Total electric charges/year	4,933,632.00	3,494,656.00	3,083,520.00
C	Comparison			
	Capital investment	20,644,849.00	22,988,280.00	21,788,280.00
	At the end of first year			
	Electrical charges	4,933,632.00	3,494,656.00	3,083,520.00
	Total recurring costs	4,933,632.00	3,494,656.00	3,083,520.00
	Total accrued cost	25,578,481.00	26,482,936.00	24,871,800.00
	At the end of second year			
	Electrical charges	4,933,632.00	34,94,656.00	3,083,520.00
	AMC charges	450,000.00	318,750.00	281,250.00
	Total recurring costs	5,383,632.00	3,813,406.00	3,364,770.00
	Total accrued cost	30,962,113.00	30,296,342.00	28,236,570.00
	Summary (CAPEX + OPEX)	Conventional system	Option 1	Option 2

(continued)

Table 3 (continued)

S. No.	Description	Conventional system	Option 1	Option 2
	CAPEX	20,644,849.00	22,988,280.00	21,788,280.00
	First year	25,578,481.00	26,482,936.00	24,871,800.00
	Second year	30,962,113.00	30,296,342.00	28,236,570.00
	Third year	34,518,133.00	33,714,549.50	31,615,402.50

Assumption Considering electrical cost for 8 h with 80% diversity

Table 4 Comparison of capital and operational expenditures

Year	Conventional system	Option 1	Difference	% Saving in OPEX	Option 2	Difference	% Saving in OPEX
	(₹)	(₹)	(₹)		(₹)	(₹)	
1	2	3	4	5	6	7	8
CAPEX	20,644,849	2,29,88,280	No returns		2,178,828	No returns	
First year	25,578,481	26,482,936			2,487,180	706,681	2.8%
Second year	30,962,113	30,296,342	665,771	2.2%	2,823,657	2,725,543	8.8%
Third year	34,518,133	33,714,549	803,583	2.3%	3,161,540	2,902,730	8.4%

2. Energy efficiency
3. Reduction in cooling tonnage and energy use
4. Energy cost savings.

This reduction in tonnage due to an optimized envelope reduced the size of the HVAC system, which lead to high energy conservation and lower energy bills.

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