A STUDY OF HVAC SYSTEM IN MULTI-STORIED OFFICE BUILDINGS

A DISSERTATION

Submitted in partial fulfillment of the requirements for the award of the degree

of

MASTER OF ARCHITECTURE

By

P. PRAKASH

DEPARTMENT OF ARCHITECTURE AND PLANNING
INDIAN INSTITUTE OF TECHNOLOGY ROORKEE
ROORKEE - 247 667 (INDIA)

JUNE, 2008

CANDIDATE'S DECLARATION

I hereby certify that the work which is being presented in the dissertation entitled **'A Study of HVAC System in Multi-Storied Office Buildings'** in partial fulfillment of the requirement for the award of the degree of **MASTER OF ARCHITECTURE** submitted in the **Department of Architecture and Planning** of the Institute is an authentic record of my own work carried out during the period from Jul 2007 to Jun 2008 under the supervision of **Dr. P.S. Chani** and **Prof. Rita Ahuja.**

The matter embodied in this dissertation has not been submitted by me for the award of any other degree.

Place: Roorkee

Dated: 27th Jun 2008

Prakash

(P.PRAKASH)

This is to certify that the above statement made by the candidate **P.PRAKASH** is correct to the best of my knowledge.

Dated: Jun 2008

Dr. P.S. Chani

(Guide)

Dept. of Architecture & Planning

IIT Roorkee

Prof. Rita Ahuja

(Co- Guide)

Dept. of Architecture & Planning

IIT Roorkee

ACKNOWLEDGEMENT

At last after finishing my studies, when I look back, I see faces of many people that have become important part of my life during all that time I was here. They have helped me to complete I my studies and achieve my goals. Now when I have the chance I did like to wish all of them for their help and support.

Firstly, I would like to express my gratitude to my guides **Dr. P.S. Chani** and **Prof. Rita Ahuja,** for their guidance and also for a strong support throughout my course of study here. My sincere thanks also go to, **Prof. S.Y. Kulkarni,** Head of the Department for his help during my course of study. I also wish to thank all the faculty members of the Department of Architecture & Planning helping me in my studies.

I would like to Mr. Rakesh Sharma from DLF Architectural Section for his help in my case-studies. I would also like to express my thanks to Rashmi Tijare & Sunny Thakur for their invaluable help during my case studies.

I would also like to express my thanks also to my friends Ravi Jain, Anil Bairwa, Bibhu Prasad Tripathy, Seepika Chandra, Farheen Bano, Monalisa Bharadwaj and Saumya Agarwal. I would also like to pay my sincere gratitude to families of Khan sir and Firoz sir for making my stay in Roorkee quite a memorable experience.

Last but not the least I will like to thank my parents for their support and encouragement all through these times. Without them I would never be able to accomplish anything in my life

Prakash

Dated: 30th June 2008 **(P.PRAKASH)**

ABSTRACT

Building services act as life line of any building. During earlier times when the architects were sole in charge of the building operations they were also the service engineers. Since at that had a knowledge of all the operations that are to be carried out and thus carried it out under their own supervision most of the ties they were able to create architectural masterpieces. However in today's context as the functions and demand have become more diverse and complex architects are sharing their responsibilities with specialists.

These specialist (or service engineers as we may call them) just look into one aspect or requirement and deal with them accordingly. They are mostly unaware of the impact that there work would establish on other aspects of building design. It is the duty of architect to act as a co-coordinating media between all the service engineers to have a balanced approach towards design. For this purpose it is necessary for an architect to have at least an understanding of all the aspects that are to be carried out in building so that he can guide others and make necessary changes that suits to design requirements accordingly.

HVAC is one such aspect of building design that is transferred to a service engineer for detailing out. In general architects don't get too much involved into it as it takes a lot of numerical calculations to design it. But even then an architect if broadly understands the functioning and components of the HVAC system can use it to his own style for better results.

In this dissertation all the factors of HVAC that are responsible for making up a good design of building have been tried to be studied through literature and case studies to determine how in reference of HVAC buildings could be made better.

CHAPTER 2 SERVICES IN AN OFFICE BUILDING

CHAPTER 3 A STUDY OF HVAC SYSTEM

CHAPTER 5 CASE STUDIES

CHAPTER 6 FINDINGS AND SUGGESTIONS

CHAPTER 3 A STUDY OF HVAC SYSTEM

CHAPTER 5 CASE-STUDIES

CHAPTER 1

This chapter gives introduction to the problem of the pertaining system and what parts would be studied and what Is to be exempted from study and what steps will be taken in this dissertation to study those problems.

INTRODUCTION

1.1 INTRODUCTION TO THE TOPIC

With the globalization India has opened its doors to many big international corporations who are setting up their office here in India itself. What follows this event is the rapid increase in the number of buildings that are being constructed to meet the demand of new buildings that has been created. Most of the buildings that would be built in future would be multi-storied office buildings, even higher than what we are seeing today because we have scarcity of land.

Advent of new companies has led to demand of vast number of office buildings. Office buildings have become one of the prime contributors to building industry perhaps preceded only by housing. Recent research carried out by McKinsey NASSCOM estimates the total demand for office space to go up to 500 million sq.ft. in the next 10 Years with IT/BPO contributing 60-70%. The remaining 25-40% shall be met by non-IT and manufacturing sectors.

An office is an architectural and a social phenomenon, whether it is a tiny office such as a bench in the corner of a street of extremely small size or through entire floors of buildings up to and including massive buildings dedicated entirely to one company. In modern terms an office usually refers to the location where white-collar workers are employed.

While offices can be built in almost any location in almost any building, some modern requirements for offices make this more difficult. These requirements can be either legal or technical. Alongside such other requirements such as security and flexibility of layout, this has led to the creation of special buildings which are dedicated only or primarily for use as offices. An office building is a form of commercial building which contains spaces mainly designed to be used for offices.

The primary purpose of an office building is to provide a workplace and working environment for administrative and managerial workers. These workers usually occupy set areas within the office building, and are usually provided with desks, PCs and other equipment they may need within these areas.

However thses office building does not run on their own. As per the need they and nature of work to be carried out they require different type of building sevices to be provided in the office building. Building services are considered to be the life line for any type of building. Services form the baseline for proper functioning of the building. Quality of services provided in a building often comes out as a deciding parameter for the quality of design of that particular building.

Building services can be defined as the utilities and services supplied and distributed within a building generally related to the building environment, including: heating, air-conditioning, lighting, water supply services, drainage services, electrical supply, gas supply, fire protection, and security protection. These services are required to be integrated along with the planning of the building.

The services primarily affect the interiors in terms of air conditioning versus individual sound proofing, lighting and sufficient provision for the ever growing number of electronic/electrical devices office tenants require. But the effect is not essentially confined to interior space but also affect the built form.

HVAC is one such service which is affected by design and is affecting the design of any multi-storied office building to such an extent that it now seems irrational to consider it as an aspect to dealt by someone else than the architect in its totality. There is a need for conscious effort that would lead to better designed results.

HVAC has many design components that need to be integrated in any building. While it is possible that some of the components may not be having any affect on the building design or its structure but HVAC as a system as a tremendous impact on the same. It not only affects the floor plans but also the aesthetic appearance and the structural system.

HVAC should be studied by an architect to understand its various effects and the ways it could be manipulated to suit our needs of design.

1.2 IDENTIFICATION OF THE PROBLEM

In present context where the services are becoming further complex, architects are leaving the service part of any building for the service engineers to accomplish. Architects are developing services with respect to design and requirements even though still a lot of work is to be done in this field. Providing a feature that is a part of service requirement is often considered it to be a design feature. But we can not neglect the fact that many a things that we are providing here in our building are service component that are often used without deep thinking. Impacts that it could cause on overall form, planning and organization of spaces and elements are not considered. We have to move up from some sub conscious treatment to carefully designed efforts.

Unlike the earlier times when we are far behind Western countries in respect to technology and material, but today we can quote the same difference. As a result of globalization we can have the technical knowledge of what is happening in west nearly the same time when it happens. We are now no short of technology or investment. Even then we don't have many structures made in India that could be called of global standard. Here in the very essence of our planning lies in the problem of our relying on others for the better products. We are copying architecture of services which have evolved over time keeping in consideration their climatic, social, religious, energy concerns and all other factors that are involved in design.

HVAC in present context is considered to be a service that is rendered by a specialized mechanical engineer. It is true that with the increasing complexity in the design and requirements for an office building it is impossible for an architect to carry out the designing and detailing of all the services that are provided in an office building. However an architect should be able to look into services in a broader concept. This dissertation aims to study the effect of HVAC on building design and determine some basic aspects that should be kept in mind while conceptualizing any design.

1.3 AIMS AND OBJECTIVES:

Aim of this dissertation *is to study HVAC system in any multistoried office buildings to have an idea of what are the possible problems in providing HVAC with respect to design of building and what could be the possible solutions.*

To achieve this aim following objectives are identified-

- Identifying services and their integration in an office building.
- Relevance of service provision with respect to building design.
- Understanding services system in an existing building.
- Understanding HVAC system and its components.
- Analysis of system to understand shortcomings in our modus opernadi.

1.4 SCOPE

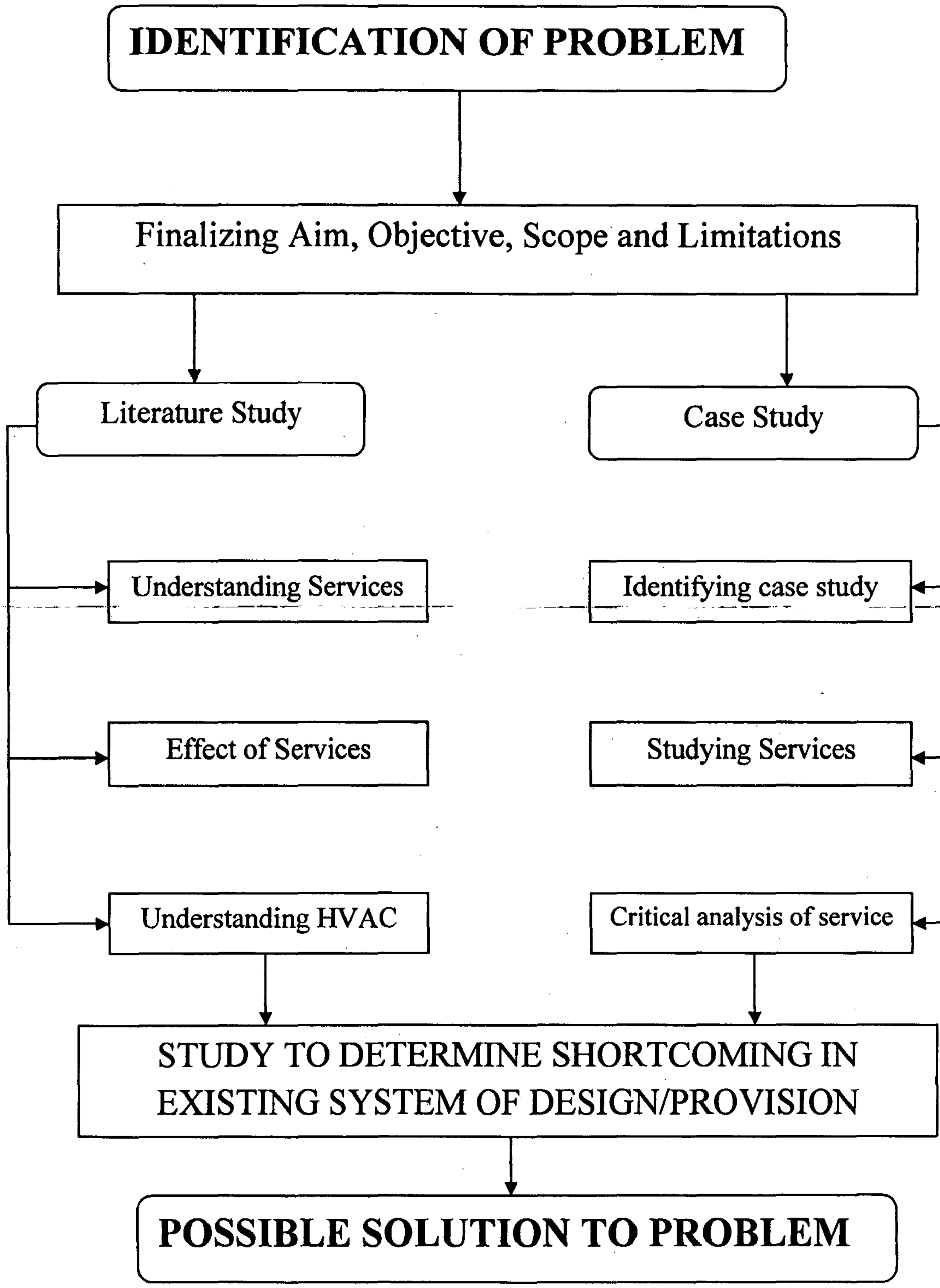
The study will be limited to the development of office building in metropolitan cities.

Study will focus on the office buildings which have multiple users and the services are shared among the users because it is more likely that we will have buildings shared between various users rather than a building which is under sole possession of only one firm. The reason being most of the offices being opened are outhouse of a company which has already operational somewhere else.

Focus will be on HVAC system only. Effects of factors affecting the climate on the HVAC system will be considered in brief only.

No calculations are carried out in the dissertation regarding HVAC load and Heat transfer.

1.5 METHODOLOGY



CHAPTER 2

This chapter gives information on various services that perform in any office building. It discusses with how and where to provide the services and its effect on the design of building.

SERVICES IN AN OFFICE BUILDING

2.1 Introduction

Any office has the following functional requirement that should be fulfilled for its proper operation.

a) Efficiency
b) Security
c) Productivity
d) Modularity

Any office building that has to be designed must undergo a check on the above mentioned parameters to see if it is has the potential for meeting the demands of different users. These parameters are a must for the success of design.

2.2 Different services in an office building

Various building services in an office building [Fig.2.1].

a) Electrical services
b) Mechanical services
c) Plumbing services
d) Circulation services
e) Communication services
f) Safety and security services of life and material.

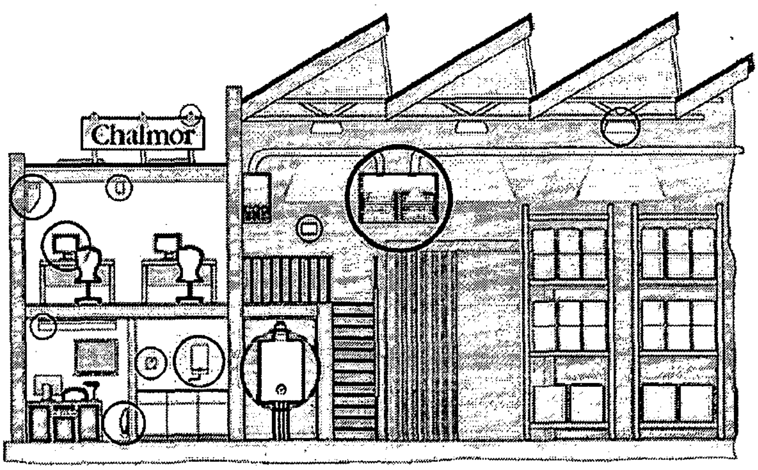


Fig 2.1 various services in a Building

Source: http://www.chalmor.co.uk/services.asp

2.2.1Electrical service

Electrical services refer to the provision and maintenance of all the electrical appliances that are operated inside the building. Refinements are needed in the provision of distribution system and user appliances.

Electrical services include the electrical appliances, wiring, control panels, distribution boards, and alternate energy source and safety devices.

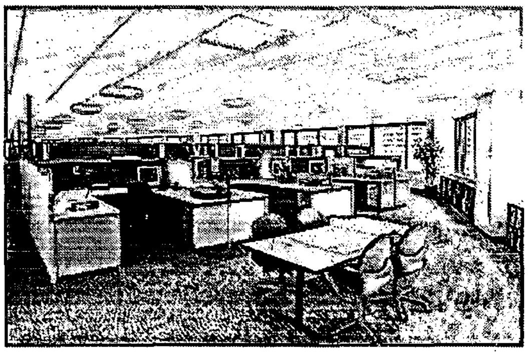


Fig 2.2 Lighting in an office building

Source: http://www.lightingtaxdeduction.org/technologies/tips.html

2.2.2 Mechanical Service

Mechanical services the requirement for any building to keep the air quality at the most desirable level to ensure the optimal performance of individuals working there. Provision of mechanical services ensures the same.

Various components of mechanical services are (as shown in Fig 2.3) plant unit, ducts, circulation unit, control unit, fan units etc.

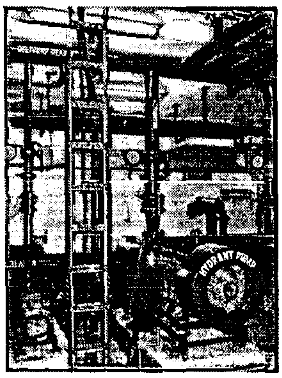


Fig 2.3 Mechanical service in office building

Source: Author

2.2.3 Plumbing service: In many of the metropolitan cities where there is short of clean water supply it becomes necessary to avoid wasteful usage of water in operation of a building.

Various components of a plumbing system are: storage tank, distribution lines, fixtures, waste lines, pumping and cleaning units etc.

2.2.4 Circulation services: In a high rise office building major circulation is done via lifts and for emergency purposes staircases are used. Proper design of circulation affects various other components like space consideration, load on other services etc.

Its component could be classified as staircase, lift wells, lifts, machine room etc.

2.2.5 Communication services: For an office building these services are of vital importance. A small malfunctioning in this particular service could have a drastic impact on the functioning of office building. Not only one has to look over the sufficient amount of service but also its expandability and security of data.

Various components are telephony, internet services, LAN services, telex services etc.

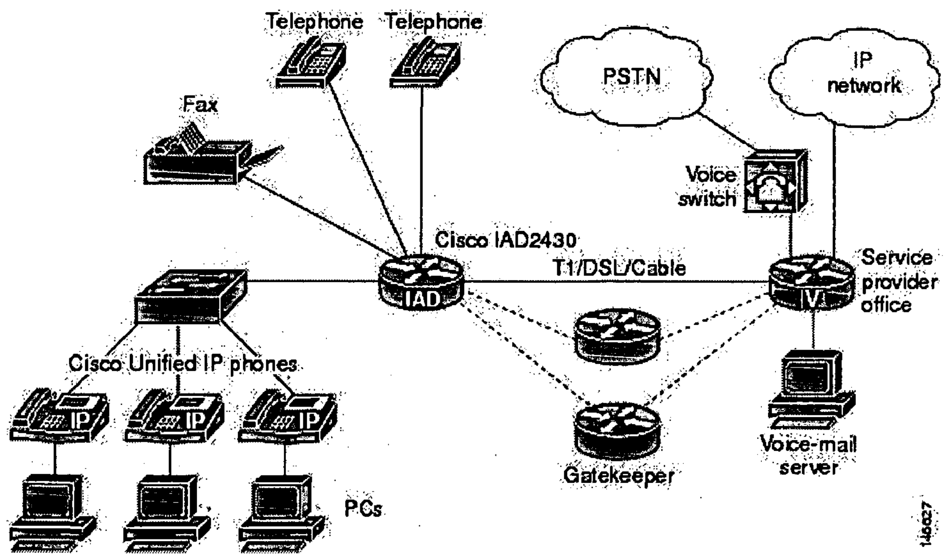


Fig 2.4 Network Diagram for Communication service in office building

Source: http://www.cisco.com/en/US/docs/voice_ip_comm/cucme/admin/configuration/guide/cmeover.html

2.2.6 Safety and security services of life and material: A building would not be called a good one if it cannot ensure proper safety of inhabitants. Safety not only from accidents but also man made threats. Safety and security components include the fire fighting systems, sensors, CCTV's, card system.

2.3 Factors affecting the provision of services

a) *Building type*: The requirement of different buildings types is different. The need of a hospital varies from that of an auditorium.

b) *Size and shape of building:* A multi-storied building where all the activities are limited to small ground coverage will need a different approach as compared to a school with low blocks separated from each other.

c) *Type of construction*: certain building construction technologies may prove easy for providing services than other.

d) *Certain design features*: Some specific feature may help or hinder the convenience of providing services. For example use of raised floors, hollow partition may make the services easy to provide.

e) *Number of services to be provided*: the number of services to be provided depends on the building type. More the number of services to be provided more are the complexity of design integration.

f) *Location of services* is a very critical factor while designing a building. A huge amount of space is dedicated for providing services only. It could be further classified into the location of plants and equipments and location of services runs.

   Generally the service areas are provided in the basement of building. However some of the building services can be provided on the terrace of the building. These service could be chiller plant, treatment units, control centre.

   If the building is considerably high then it is always suitable to provide a mechanical floor [see Appendix 1]. Providing a mechanical floor not only makes the services more efficient but also reduces the load on the building services.

Some aspects that should be kept in mind while deciding location of plant rooms and equipments are as follows:

a) They require a clearer decision to be taken than that for service runs.
b) They are less flexible in nature.
c) Large portion of building is left specifically for them so the space that is left should be utilized wisely and economically.

Various locations for service runs to be provided in an office building are as under:

a) Above suspended ceilings
b) Roof void (portal frame, trusses)
c) Within floor structures, raised floors.
d) Along skirting, Wall structure/ hollow partitions
e) Face of external and internal walls

(Reference: *Barton, Paul.K. Building services integration*)

Knowledge of the above mentioned factors is important when we think of economy of provision of service in an office building in addition to the flexibility and aesthetic aspects. For example when ever we are using a service floor we are reducing the cost that is to be spent on controlling and distributing the service (for example it is of high use to produce effective pressure for water supply and air conditioning) which otherwise would be costly to maintain. Also if carefully planned they can be modified as per the requirement of area to provide maximum comfort to the occupants

2.4 Effect of placement/planning of service on building

Service provided in a building will affect the design of building, whether it does so directly or indirectly. There could be several factors which could be affected; some of them are as under:

2.4.1Layout of building: Planning of the service core affect how the floor plans are made. It affects the flexibility which the plan provides and the comfort level of the occupants.

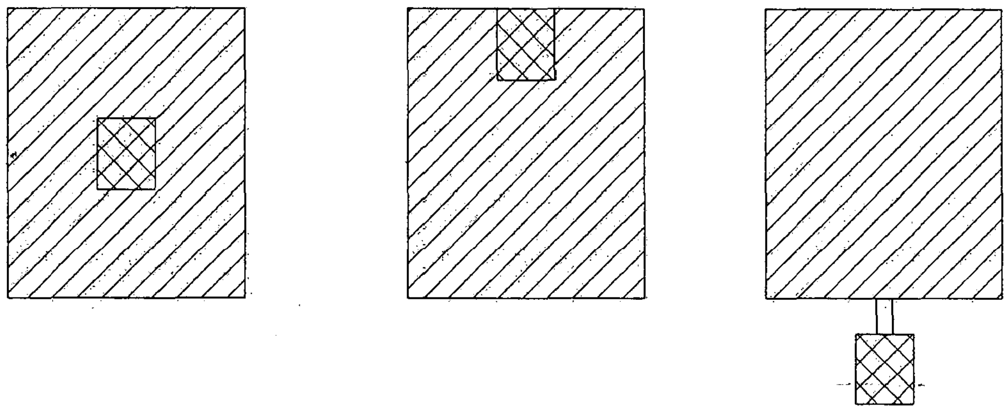


Fig.2.5: Different arrangement of cores in an office building

Source: Author

The service core can be located either centrally inside the building or at the periphery or outside the building. Each of these plans has their own merits and demerits.

For any office building centrally located core is the most advantageous condition as it provides with the maximum flexibility of space, ease of movement and distribution of rental space.

Service core at one end is most suited when the design requirement is to provide an entire floor to a single tenant.

External service core is rarely used but was earlier used under conditions where either disturbance from the service core were to be avoided or the natural light which is disturbed by core has to be retained.

2.4.2 Economy of the building: Type and nature of the services provided in a building determines the cost of the building. This cost includes both; installation cost as well as the operational cost. It could be done by reducing number of service cores. For example as all know that any service core essentially consists of pair of lifts, staircases and ducts. Installation cost of a single passenger lift varies from Rs 15-20 lakh depending upon the specifications. So even if one core is reduced a significant saving is made.

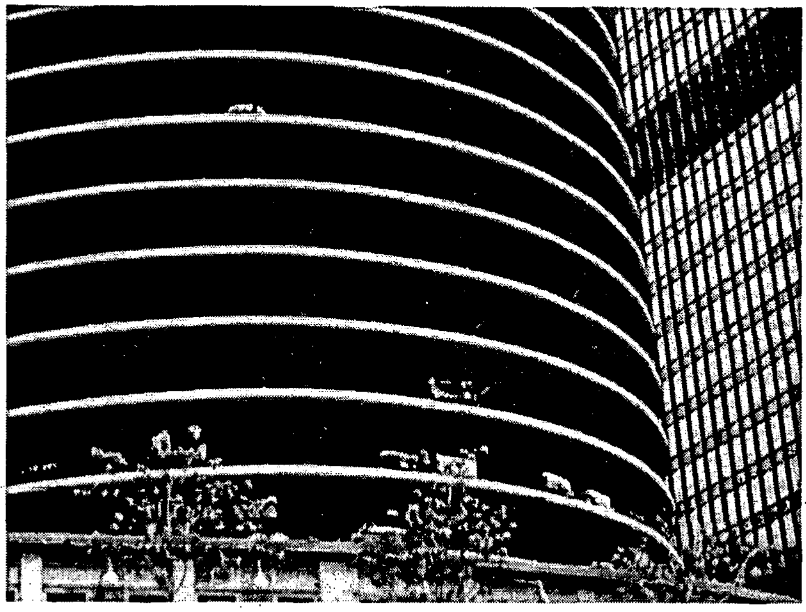


Fig.2.6: Multi storied car park IBM Building, Chicago
Source: http://picasaweb.google.com/lh/photo/1KaMhPnD-AHKdOIX_osYmA

Where cost of land is very high the size of a service core could be a crucial factor in determining the cost of the building. Under such circumstances the service core should be designed as to make best possible utilization of available commercial space. Such types of cases are quite common in our metropolitan cities nowadays. In places like Delhi and Mumbai where land costs is sky high we can't afford to loose space. Such incidents lead us to tighten our plans and also the services. This is primarily the reason why we mostly go for basement parking solutions. In addition to it we have some buildings where we have a separate block for car parking connected to main building on each floor or become an integrate part of the block[Fig 2.6].

2.4.3 External appearance: some times the arrangement/provision of the building services affects the external elevation/ views of the building. Such types of buildings were a common design practice in the earlier 20th century under the name of High-tech buildings. In these building services were made exo-skeleton thus giving it a look that it was highly technology dependent, façade was prominently was a display of service lines, ventilation ducts, and exposed framework. Examples of it can be Pompidou Centre [Fig 2.7] etc.

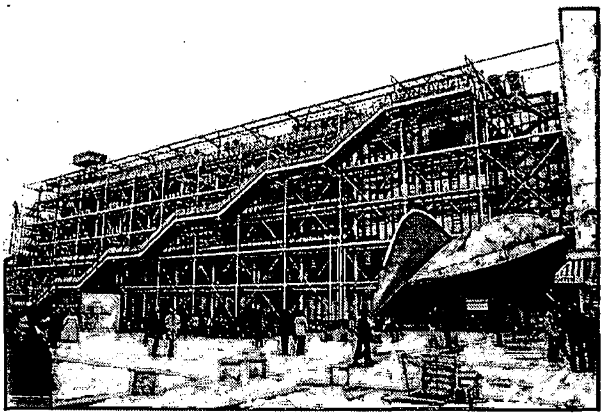


Fig.2.7: Pompidou Centre with services on external façade giving it's a characteristic feature
Source: http://www.galinsky.com/buildings/pompidou/index.htm

2.4.4 Development evolution of building form: Various services provided in a building plays a vital role in growth/ evolution of the building plan. The building form could be bionic/ organic or rigid and modular, arrangement of geometric form all affected by services. For example in HSBC Hongkong, [fig 2.8] the idea behind the built form was to upgrade the service components periodically as to suit the changing needs of occupants.

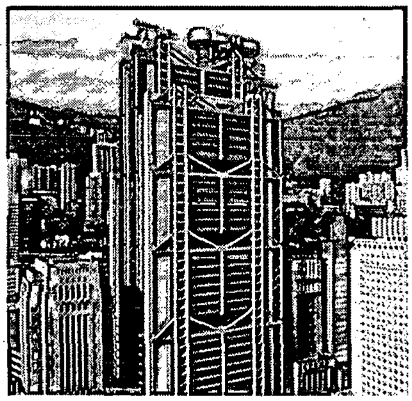


Fig.2.8: HSBC Hongkong, with its modular form
Source: http://www.skyscrapers.com

The above mentioned effects can be explained by taking examples of individual services in different office buildings. These examples are as under:

1) Lighting

Proper lighting is of high importance in office buildings because desk jobs cause lot of strain on human mind. So if while designing the architect decides that he wishes to reduce load on operations as well as improving the surrounding quality he might be providing

a. Atrium with adequate day lighting and mechanism to permit direct light into a centrally lit space or workspaces via windows etc for maximum period of time. An example of it can be seen in office of U.S. Environmental Protection Agency headquarters in Denver where a skylight atrium is used to provide skylight to nine stories below.

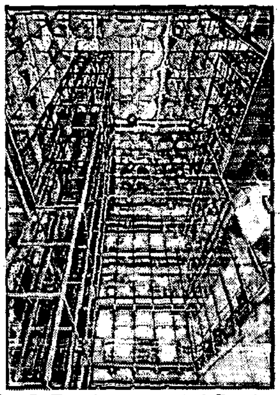


Fig.2.9: Fins in atrium of US Environmental Protection Agency HQ, Denver

Source: http://www.skyscrapers.com

b. Interior layout in an office should be such that maximum numbers of work stations have access to the natural light. While providing natural lighting it should be kept in mind that precaution to check glare should be done beforehand. It could also create additional feature on the façade thus changing the aesthetics.

   Often when we are providing openings we do it for aesthetic purpose. Effect of them on light service is often put to secondary importance. If the opening are considered to be an element of service than a calculated prediction can thus save a lot of load on services and save a lot of money for clients in cities like Gurgaon where offices with 6000 staff capacity have to spend more than 108 lakh per month on power backup during power cuts

2) *Service for circulation/movement:*

a) In any office with multiple offices on same floor the entrances to the offices is largely depended on how the service core is oriented. Wherever there is lift lobby entrances are defined from those areas only. This is furthermore important when common service facilities like toilets are concerned.

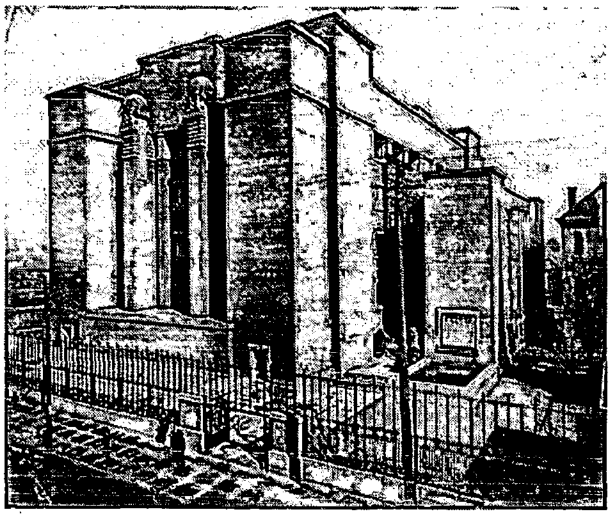


Fig.2.10: Larkin Building with service cores are at the corners.

Source: http:// www.commons.wikimedia.org

b) Circulation with in the building is determined by the number and position of fire escape/exits. It is mandatory to have access to fire escapes from each office. So whatever type of the office it be it would be necessary for the office interior plan to provide unrestricted path to these exits in case of emergencies.

An example of the effect of circulation on design could be seen in One Shelley Street in Sydney. The building has a new system of lifts in which the passenger selects their floor on the ergonomically designed landing station. An LCD display then notifies the passenger which lift they should take in order to reach their desired floor with the least amount of stops in between. This is ideal for managing morning, lunch and afternoon periods where passenger traffic is at its peak. This dramatically reduces the buffer area needed by users for waiting thus considerably reducing the size of lift lobby.

3) *HVAC:*

While designing for ventilation architect should design for more use of natural air rather than same air circulated continuously in the building. This may not always be possible in multi-storied buildings. Wherever natural features are provided it leads to creation of intermediate terrace garden, peripheral openings.

Irrespective of how much focus is on natural climatic control, the fact is for controlling indoor environment of building artificial systems are needed. HVAC system is not only most space consuming of all the services (with the plant system and ducts running all over the building). A carefully designed HVAC system not only reduces the heating and cooling loads thus saving cost of running and installation but also gives better aesthetic appearance to the overall built form.

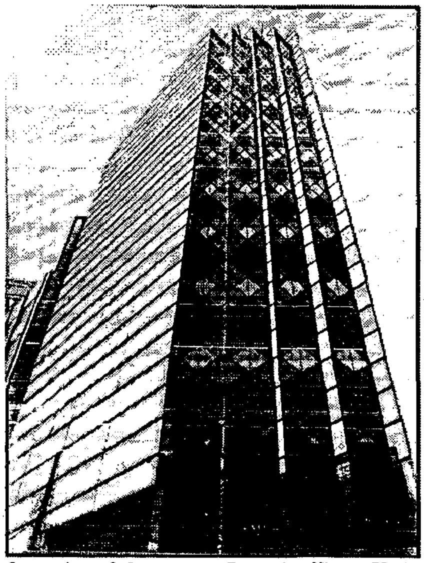


Fig.2.11: Clean façade of Aoyama Doori office, Tokyo

Source: http://www.zombiezodiac.com/rob/ped/archives/tokyo/skyscraper_i_love_you.html

Thus what is seen today in a properly designed building for HVAC system are clean surfaces (as exposed ducts lead to high load), green vegetation on intermediate levels, intermediate terraces, intelligent use of glass in façade and other such features.

4) *Communication:* It is often misunderstood that communication means only providing some hard wires or wire free network. Even if we are talking of the data transfer it would not be limited to only transfer of files on computer or a bunch of papers. It could be much more like TRANSPORTAS, a building where we don't view the information but we are a part of information.

Fig.2.12: NY Stock Exchange.
Source: http://www.nationalgeographic.com/destinations/New_York_City/Lower_Manhattan.html

A simpler version of effect of communication services on office building could be seen in the offices of stock exchange buildings (as shown in Fig 2.12) where all the data is displayed in a big central room and whole lot of activity revolves around it. Thus the design is such that activity has to be confined in a single big room where every person can have access to data displayed.

2.5 Effect of Services on Modular Furniture Systems

In corporate office in place of using separate desk and chairs and then making cubicles around them we have modular workstation with pre-fitted systems as per need.

However we must understand what these needs are. These needs are affects by the nature of work to be performed in these workstations and thus what all services they would need. For example if manual work station is to be done than the services provided will be a few power points, a light source according to working area and a point for communication.

But if the same work be done on computer than same workstation will have to be modified slightly so as to be as efficient as before. It would need more power outlets, more than one type of communication ports, light that does not produces glare to screen and preferably more area an might be more of win flow since the heat produced would be more.

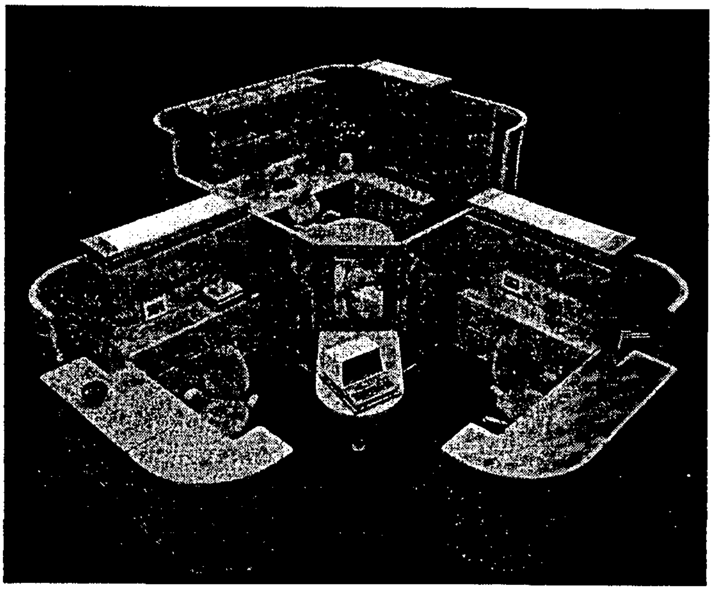


Fig.2.13: A typical workstation.

Source: Hascher, Rainen –Office Building Design Manual

Similarly if a direct light source for reading is provided than it governs the height and opening of panels above head level.

Thus we can say that, as the need changes, service requirement changes which in turn affect the design of that particular workstation.

2.6 Inferences

Various conclusions that can be deduced after this study are as under:

1) Prior to design of building different building services to be provided should be decided. Adding later on does not give us the desired result. Also service should be considered simultaneously with building design so that a more effective relation could be developed.

2) With advancement in technology, prediction of what new services could come into usage is not an easy task. So the provision needs to be flexible enough so as to accept any new change. We have different ways to provide building services like under floor, above ceiling, in walls. All these modes should be able to be allowed to be used in future.

3) Building services are a major factor in economy of building. So the building services should be chosen wisely so that not only initial but also the running cost is optimal.

4) Building services effects design and vice versa. Thus it is important to carefully provide building services in design. It ensures the best possible utilization of internal floor plans.

5) Building services has a deep impact on the external facade of the building. What and How with respect to building services should be carefully selected so as to have a better aesthetical appearance.

6) Before providing space for work station the nature of activity to be performed should be assessed. This ensures the optimal level of comfort with respect to services that are provided with it.

7) Always prefer for such system design solutions which ensures maximum efficiency of building system.

CHAPTER 3

This chapter deals with the study of HVAC system in any building. This chapter looks into working of various components, functions and type of HVAC systems that are installed in a building.

A STUDY OF HVAC SYSTEM

3.1 Introduction to HVAC

HVAC stands for Heating, Ventilation, and Air-Conditioning—three closely related fundamental functions found in homes, offices, and other building structures.

A HVAC System, by ASHRAE (American Society of Heating, Refrigerating and Air-Conditioning Engineers) definition, is a system that must accomplish four objectives simultaneously. These objectives are to: control air temperature; control air humidity; control air circulation; and control air quality.

The beginning of HVAC started as early as second century, when a lot of Roman cities were using a central heating system known as hypocaust. This was further popularized during the Industrial Revolution as big factories used it. Turning point in history was in 1902 with the invention of refrigerative chiller by Willis Havilland Carrier. It led to abandoning of ancient and climatic responsive architecture as it can be used to cool any sort of boxy building.

- The primary use of HVAC is to regulate room temperature, humidity, and air flow, hereby ensuring that such elements remain within their acceptable ranges. Effective control of such factors minimizes health-related risks. A very humid atmosphere impairs the body's ability to regulate body temperature as it prevents the evaporation of sweat. High humidity also decreases physical strength, which usually leads to fatigue. An unhealthy surrounding can also affect people's thinking abilities. Hypothermia, heat stroke, and hyperpyrexia, among others, are some of the illnesses that may also occur. These symptoms can be reduced through practical measures such as increased ventilation and decreased temperature (Reference: *Mull Thomas E., HVAC Principals and Application Manual, Tata McGraw Hill*).

3.2 Importance of HVAC

HVAC systems are of great importance to architectural design efforts for four main reasons. First, these systems often require substantial floor space and/or building volume for equipment and distribution elements that must be accommodated during the design process. (See Table 3.1)

HVAC System Space Requirements as a Percentage of Gross Building Floor Area

Gross Floor Area (ft2)	Domicile-related Occupancies	Institutional Occupancies	Assembly-based Occupancies	Laboratory Occupancies
10,000	6 %	8 %	9 %	11 %
50,000-100,000	4 %	6 %	7 %	10 %
500,000	3 %	4 %	5 %	8 %

Table 3.1 Source: Grondzik, Walter; vital signs- HVAC components and System

Second, HVAC systems constitute a major budget item for numerous common building types. (See Table 2)

Management, Operation or Design Problems in Commercial Buildings

Basis of Problem	Relative Frequency
Heating, ventilating and air conditioning	5.4
Elevators	2.7
Building design	1.5
Loading docks	1.2
Indoor air quality	1.0
Cleaning services	1.0

Table 3.2 Source: Grondzik, Walter; Vital signs- HVAC components and System

Third, the success or failure of thermal comfort efforts is usually directly related to the success or failure of a building's HVAC systems (when passive systems are not used) -- even though the HVAC systems should be viewed as part of the larger architectural system.

Last, but not least, maintaining appropriate thermal conditions through HVAC system operation is a major driver of building energy consumption. It contributes to 65% of total energy consumption and 19% of total cost of the building (as per Madison Gas and Electric, Wisconsin, U.S.)

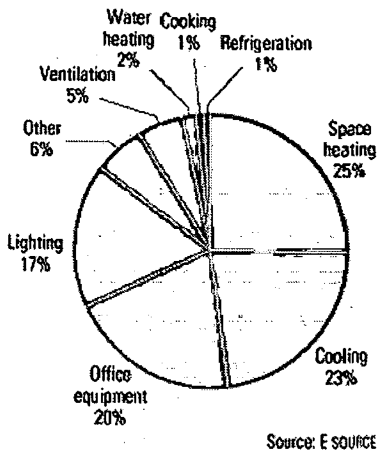


Fig 3.1 contribution of various activities in energy consumption

Source: http://www.mge.com/business/saving/madison/CEA_03.html

3.3 Working of HVAC system

Each building has a characteristic exterior air temperature, known as the balance point temperature, at which the building in use would be able to support thermal comfort without the need for a heating or cooling system. At the balance point temperature, which is strongly influenced by internal loads and envelope design, building heat gains and losses are in equilibrium so that an appropriate interior temperature will be maintained naturally and without further intervention. When the outside air temperature falls below the balance point temperature, heat losses through the building envelope will increase – and interior air temperature will drop unless heat is added to the building to compensate. A system that provides such additional heat is called a heating system. When the outside air temperature exceeds the balance point temperature, heat gain through the building envelope will upset thermal equilibrium and cause the interior air temperature to rise. A system that removes such excess heat is called a cooling system.

Heat may be added or removed by an artificial system, which is termed an active systems approach. An active system has the following general characteristics: it normally utilizes purchased energy for its operation, it requires special-purpose components that serve no other major building function, and it is generally relatively independent of the underlying architectural elements of the building.

Alternatively, heat may be added or removed by a system designed to make use of naturally occurring environmental forces. Such a system is termed as a passive system. A passive system has the following general characteristics: it utilizes renewable site resources for energy inputs, it usually involves components that are integral parts of other building systems, and it is usually so tightly interwoven with

Control of an HVAC system is critical to its successful operation. The issue of system control leads to the concept of HVAC zoning. During the design process, a zone is defined as a region of a building that requires separate control if comfort is to be provided for occupants. For example, it may not be possible to successfully condition a below ground office area and a glass enclosed atrium from a single control point.

To provide comfort, each space must be provided with its own control -- the climate control system must be designed to accommodate separate thermal zones. In an existing building, a zone is easily identified as an area operated from a single control point (typically a thermostat in an active system). Zoning is very much an architectural responsibility as it requires an understanding of building function and schedules. Typically the two key elements to consider when establishing thermal zones are differential solar radiation exposures (a north facade versus an east facade) and differential operating schedules and loading requirements (an occasionally used assembly hall versus a normally occupied office suite). Thermal zones must be established very early in the HVAC system design process (Reference: *Haive R.W., HVAC System Design Handbook, McGraw Hill, 1997*)

Active HVAC systems may be designed to condition a single space (or portion of a space) from a location within or directly adjacent to the space. Such a system is known as a local system. Other HVAC systems are designed to condition several spaces from one base location. Such a system, easily identified by components that distribute conditioning energy across space boundaries, is known as a central system.

Various functions that any HVAC system has to perform in a building are as follows

3.3.1 Heating

Heating systems may be classified as *central* or *local*. Central heating is often used in cold climates to heat private houses and public buildings. Such a system contains a boiler, furnace, or heat pump to heat water, steam, or air, all in a central location such as a furnace room in a home or a mechanical room in a large building. The system also contains either ductwork, for forced air systems, or piping to distribute a heated fluid and radiators to transfer this heat to the air.

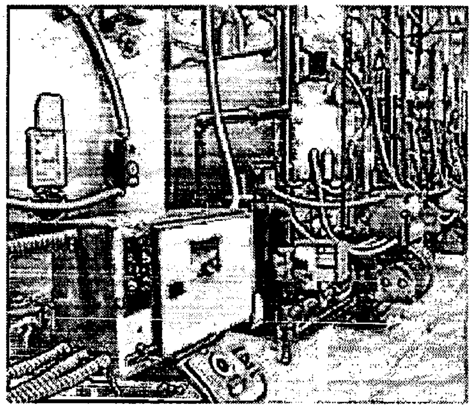


Fig 3.2 Boilers for Heating

Source: http://contractors-mechanical.com/heating-hvac.htm

In boiler fed or radiant heating systems (Fig 3.1), all but the simplest systems have a pump to circulate the water and ensure an equal supply of heat to all the radiators. The heated water can also be fed through another (secondary) heat exchanger inside a storage cylinder to provide hot running water.

Forced air systems send heated air through ductwork. During warm weather the same ductwork can be used for air conditioning. The forced air can also be filtered or put through air cleaners.

Heating can also be provided from electric, or resistance heating using a filament that becomes hot when electricity is caused to pass through it. This type of heat can be found in electric baseboard heaters, portable electric heaters, and as backup or supplemental heating for heat pump (or reverse heating) system.

The heating elements (radiators or vents) should be located in the coldest part of the room and typically next to the windows to minimize condensation. Cold air drafts can contribute significantly to the subjective feeling of coldness than the average room temperature. Therefore, it is important to control the air leaks from outside in addition to proper design of the heating system.

3.3.2 Ventilation

Ventilating is the process of "changing" or replacing of air in any space to remove moisture, odors, smoke, heat, dust and airborne bacteria. Ventilation includes both the exchange of air to the outside as well as circulation of air within the building. It can be of two types

a) Mechanical ventilation: "Mechanical" or "forced" ventilation is used to control indoor air quality. Excess humidity, odors, and contaminants can often be controlled via dilution or replacement with outside air. However, in humid climates much energy is required to remove excess moisture from ventilation air.

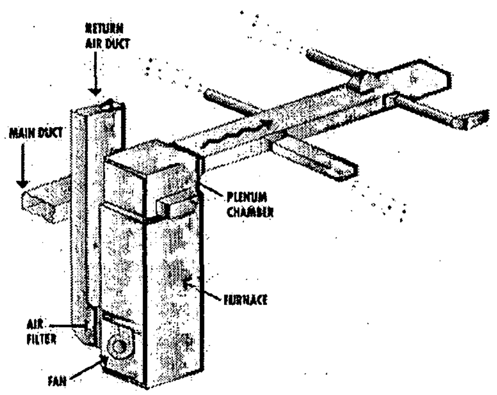


Fig 3.3 Schematic diagram for Mechanical Ventilation

Source: http://www.verdatech-inc.com/residential/vent.html

b) Natural ventilation: Natural ventilation is the ventilation of a building with outside air without the use of a fan or other mechanical system. It can be achieved with operable windows when the spaces to ventilate are small and the architecture permits. In more complex systems warm air in the building can be allowed to rise and flow out upper openings to the outside (stack effect) thus forcing cool outside air to be drawn into the building naturally through openings in the lower areas.

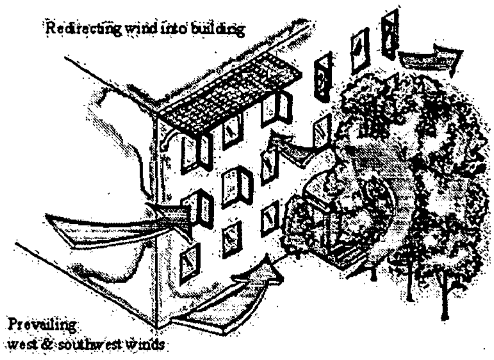


Fig 3.4 Natural Ventilation in a Building

Source: http://greenbuildings.santa-monica.org/images/la2a.jpg

These systems use very little energy but care must be taken to ensure the occupants' comfort. In warm or humid months, in many climates, maintaining thermal comfort only through natural ventilation may not be possible therefore conventional air conditioning systems are used as backups.

3.3.3 Air-Conditioning

Air Conditioning and refrigeration are provided through the removal of heat. The definition of cold is the absence of heat and all air conditioning systems work on this basic principle. Heat can be removed through the process of radiation, convection and conduction using mediums such as water, air, ice, and chemicals referred to as refrigerants. In order to remove heat from something, you simply need to provide a medium that is colder -- this is how all air conditioning and refrigeration systems work (Fig 3.5).

An air conditioning system, or a standalone air conditioner, provides cooling, ventilation, and humidity control for all or part of a house or building. The Freon or other refrigerant provides cooling through a process called the refrigeration cycle. The refrigeration cycle consists of four essential elements to create a cooling effect.

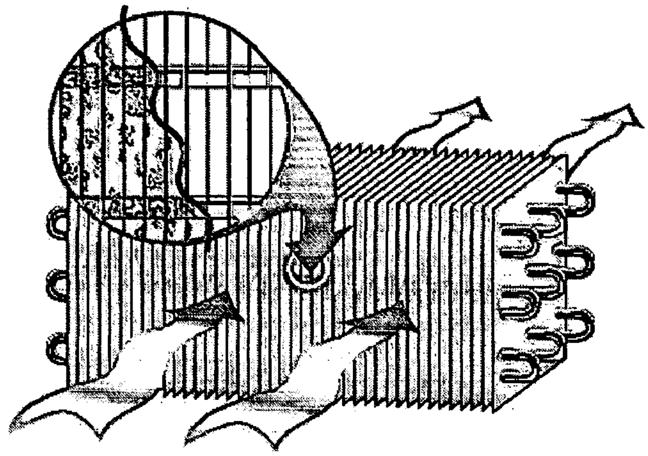


Fig 3.5 Sketch showing air conditioning process

Source: http://www.wynnsusa.com/maint_ac.aspx

A compressor provides compression for the system. This compression causes the cooling vapor to heat up. The compressed vapor is then cooled by heat exchange with the outside air, so that the vapor condenses to a fluid, in the condensor. The fluid is then pumped to the inside of the building, where it enters an evaporator. In this evaporator, small spray nozzles spray the cooling fluid into a chamber, where the pressure drops and the fluid evaporates. Since the evaporation absorbs heat from the surroundings, the surroundings cool off, and thus the evaporator absorbs or adds heat to the system. The vapor is then returned to the compressor. A metering device acts as a restriction in the system at the evaporator to ensure that the heat being absorbed by the system is absorbed at the proper rate.

Central air conditioning systems are often installed in modern residences, offices, and public buildings, but are difficult to retrofit because of the bulky air ducts required. A duct system must be carefully maintained to prevent the growth of pathogenic bacteria in the ducts. An alternative to large ducts to carry the needed air to heat or cool an area is the use of remote fan coils or split systems. These systems, although most often seen in residential applications, are gaining popularity in small commercial buildings. The coil is connected to a remote condenser unit using piping instead of ducts.

Dehumidification in an air conditioning system is provided by the evaporator. Since the evaporator operates at a temperature below dew point, moisture is collected at the evaporator. This moisture is collected at the bottom of the evaporator in a condensate pan and removed by piping it to a central drain or onto the ground outside. A dehumidifier is an air-conditioner-like device that controls the humidity of a room or building. They are often employed in basements which have a higher relative humidity because of their lower temperature (and propensity for damp floors and walls). In food retailing establishments, large open chiller cabinets are highly effective at dehumidifying the internal air.

Air-conditioned buildings often have sealed windows, because open windows would disrupt the attempts of the HVAC system to maintain constant indoor air conditions.

3.4 Components of HVAC

3.4.1 Cooling and heating source components

a) Furnace

A furnace is a heating system component designed to heat air for distribution to various building spaces. Small-capacity furnaces that rely on natural convection for heat distribution would be classified as local systems and usually effectively condition only one space. Furnaces equipped with fans to circulate air over greater distances or to several rooms would be found in central systems. All four heat source categories are used with furnaces, including on-site combustion, electric resistance, solar energy, and heat transfer (heat pumps).

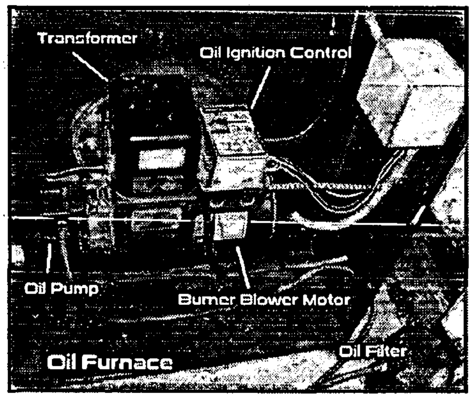


Fig 3.6 Components of an Oil Furnace

Source: http://www.high-performance-hvac.com/hvac-photos/HVACPhotos/oil-furnace-and-oil-controls.htmlx

A furnace is a packaged assembly of components that normally includes a heat-source element (burner or coil), a fan (for central units), and an air filter (as shown in Fig 3.6)

b) Boiler

A boiler (shown in Figure 3.7) is a heating system component designed to heat water for distribution to various building spaces. As water can not be used to directly heat a space, boilers are only used in central systems where hot water is circulated to delivery devices (such as baseboard radiators, unit heaters, convectors, or air-handling units). Boilers are commonly designed to utilize two of the four basic heat sources: on-site combustion (coal, oil, natural gas, propane) and electric resistance.

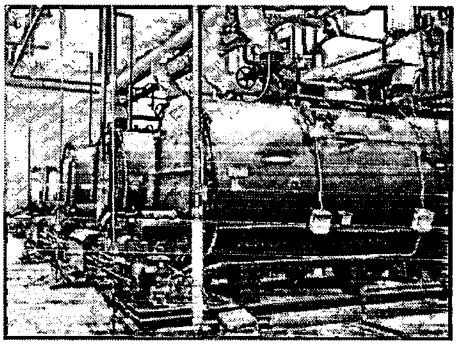


Fig 3.7 Boilers in an HVAC system

Source: http://www.high-performance-hvac.com/hvac-photos/HVACPhotos/3_commercial_boilers.html

Boilers are a packaged assembly of components that normally includes a heat-source element (burner or electric resistance coil) and some volume of water storage. Depending upon design intent, a boiler may produce either hot water or steam. An on-site solar energy collection system may serve in lieu of a boiler. Heat transfer systems (heat pumps) likewise may serve as a substitute for a boiler.

c) Portable Heaters

Numerous consumer appliances are available to provide spot heat wherever needed. Portable heaters are normally occupant selected and "installed", often to supplement conditions provided by another (presumably less than successful) heating system. Such portable devices, however, might collectively constitute a complete building heating system.

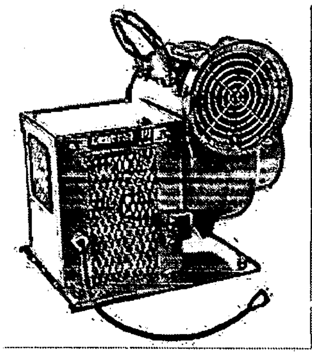


Fig 3.8 Portable Heaters in an HVAC system

Source: http://www.hvacrentals.com/topics.php?TID=708

Portable heaters are designed to operate as local systems serving a fairly small area. Small-scale electric resistance heaters are also available as built-in to provide a permanent, localized source of heat.

d) Electric Baseboard Radiation:

Sometimes called electric strip heaters, baseboard radiation is a fairly common heat source and heating system. Compact heating elements enclosed in protective and decorative linear housings, as shown in Figure 3.9, are permanently installed along the lower part of one or more room walls -- near the intersection with the floor. Room air heated by the resistance element rises and is replaced by cooler room air, establishing a continuous convective flow of warm air while in operation.

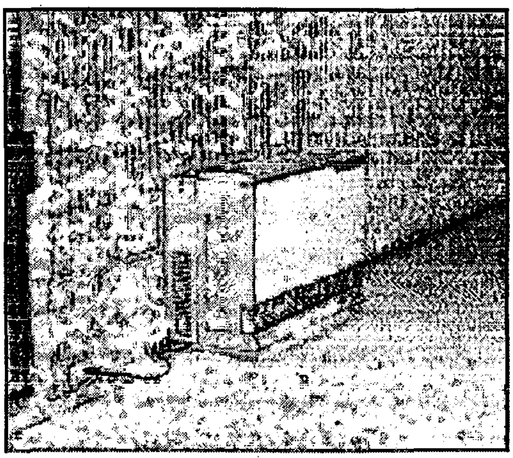


Fig 3.9 Electric baseboard radiation heaters in an HVAC system

Source: http://www.hvacrentals.com/topics.php?TID=708

e) Solar Thermal Collector:

Solar collectors may be used to heat air or water for building heating purposes. Water-heating collectors may replace or supplement a boiler in a water-based heating system. Air-heating collectors may replace or supplement a furnace. As solar energy in an active solar system is typically collected at a location remote from the spaces requiring heat, solar collectors are normally associated with central systems. Solar water-heating collectors may also provide heated water that can be used for space cooling in conjunction with an absorption refrigeration system.

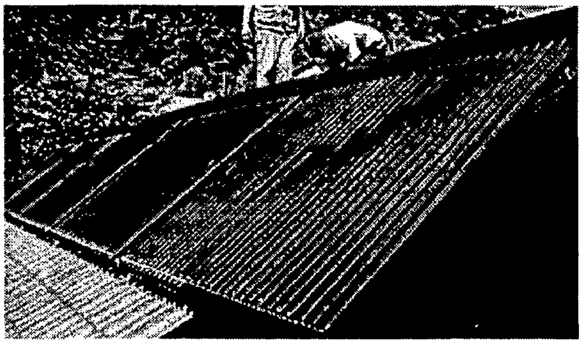


Fig 3.10 solar thermal collectors on installed on roof

Source: http://www.solarpanelsplus.com/solar-air-conditioning/

f) Heat Pump:

A heat pump is a reversible cycle vapor compression refrigeration unit. Through the addition of a special control valve, heat flow in a mechanical refrigeration loop can be reversed so that heat is extracted from the outside air (or ground water or soil) and rejected into a building. The purpose of a conventional refrigeration cycle is to establish heat flow in the opposite direction.

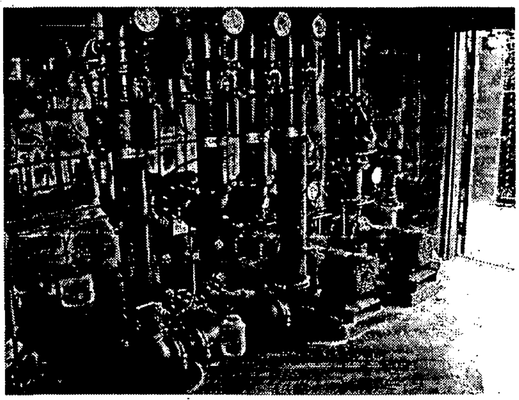


Fig 3.11 Heat Pumps in an office building

Source: http://www.dorseyengineering.com/Special.htm

g) Vapor Compression Refrigeration Unit

The most commonly used active cooling approach involves the operation of a vapor compression refrigeration cycle to induce heat to move in a direction contrary to gross environmental temperature differences. During the overheated period, the outside air temperature is usually not just above the balance point temperature but also above the indoor air temperature. Under such conditions, heat flow will be from higher to lower temperature (from outside to inside). Maintaining thermal comfort during the overheated period requires that heat be removed from a building, not added to it.

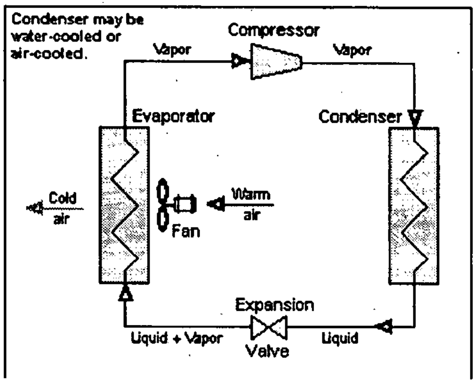


Fig 3.12 typical single stage vapor compression refrigeration

Source: http://en.wikipedia.org/wiki/Refrigeration

Through a series of artificially maintained temperature and pressure conditions in a heat transfer fluid (refrigerant), established through the action of four primary components, a refrigeration system can induce heat to flow from inside a cooler building to a warmer outside environment.

h) Evaporative Cooling Unit

In hot dry climates, usable cooling effect may be obtained from the evaporative cooling process. Evaporative cooling is a basic psychometric process in which air is sensibly cooled while it is simultaneously humidified. An evaporative cooler is a packaged unit that contains components to govern this process in a manner that can produce reasonable cooling capacities. Dry air is pulled into the evaporative cooler by a fan. The dry air is passed through some porous media that is wetted with water.

As the air contacts the water spread over the media, much of the water evaporates. The energy required to evaporate the water comes from the air. As the air passes through the cooling unit it is humidified – but also cooled.

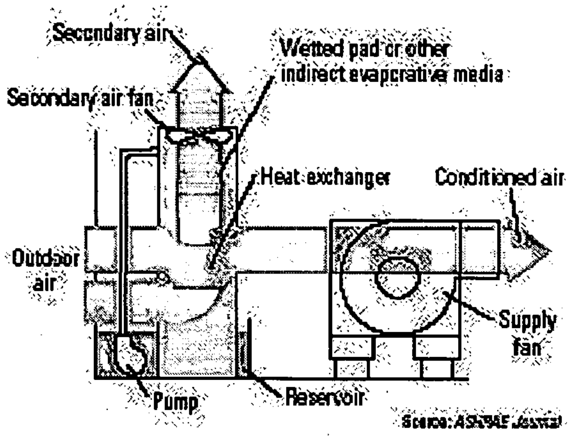


Fig 3.13 schematic drawing of an evaporative cooling unit

Source: http://www.coloradoefficiencyguide.com/measures/hvac.htm

i) Chiller:

A chiller is a refrigeration unit designed to produce cool (chilled) water for space cooling purposes. The chilled water is then circulated to one or more cooling coils located in air handling units, fan-coils, or induction units. Chilled water distribution is not constrained by the 100 foot separation limit that applies to DX systems, thus chilled water-based cooling systems are typically used in larger buildings. Capacity control in a chilled water system is usually achieved through modulation of water flow through the coils; thus, multiple coils may be served from a single chiller without compromising control of any individual unit.

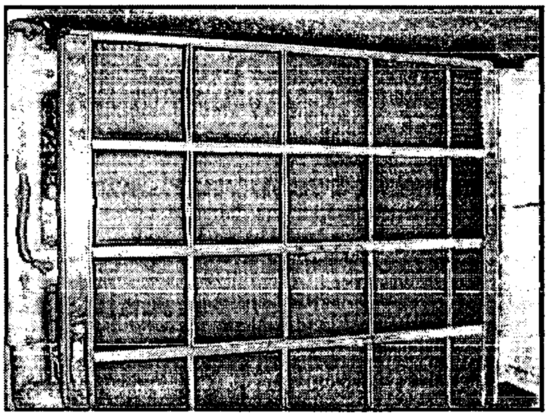


Fig 3.14 A typical chiller

Source: Author

j) Air-Cooled Condenser:

An air-cooled condenser, Figure 3.15, is a heat rejection device, installed outside of the building envelope, through which refrigerant is circulated. As the refrigerant comes into indirect contact with outside air, heat is exchanged from the relatively hot refrigerant to the relatively cooler air.

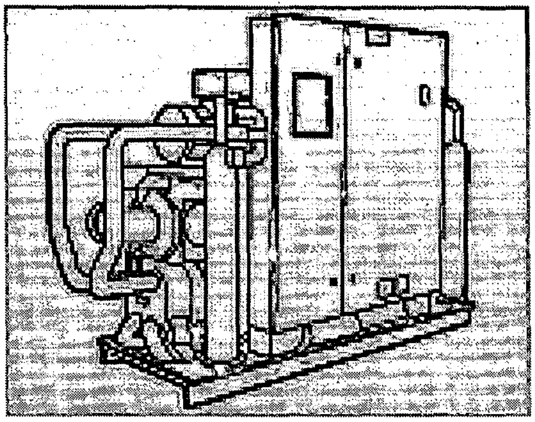


Fig 3.15 sketch of a typical Air Cooled Condensor

Source: http://www.trane.com/Commercial/Dna/View.aspx?i=979

Heat exchange is enhanced by fan-forced flow of large volumes of air across the heat exchange coils. An air-cooled condenser is a sensible heat exchange device, where the magnitude of heat flow is a function of the temperature difference between the refrigerant and the outside air dry bulb temperature.

k) Cooling Tower:

A cooling tower, Figure 3.16, is a heat rejection device, installed outside of the building envelope, through which condenser water is circulated. Refrigerant in the refrigeration cycle is condensed in a refrigerant-to-water heat exchanger. Heat rejected from the refrigerant increases the temperature of the condenser water, which must be cooled to permit the cycle to continue. The condenser water is circulated to the cooling tower where evaporative cooling causes heat to be removed from the water and added to the outside air. The cooled condenser water is then piped back to the condenser of the chiller. A cooling tower is a latent heat exchanger, where the magnitude of heat flow is a function of the quantity of water that is evaporated - which is primarily a function of the relative humidity of the outside air.

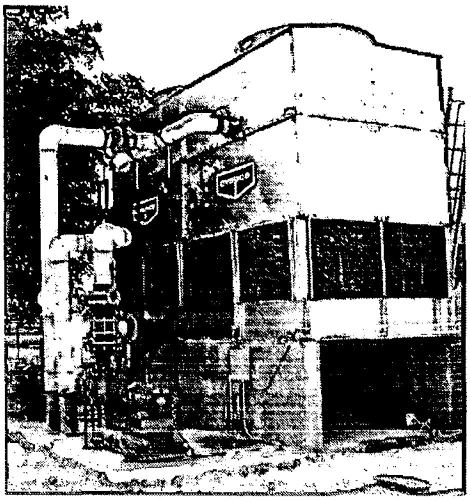


Fig 3.16 Cooling tower installed outside building envelope
Source: http://tropicac.com/industrial_service.htm

3.4.2 Cooling and Heating Distribution Components

Central systems produce a heating and/or cooling effect in a single location. This effect must then be transmitted to the various spaces in a building that require conditioning. Three transmission media are commonly used in central systems: air, water, and steam. Hot air can be used as a heating medium, cold air as a cooling medium. Hot water and steam can be used as heating media, while cold water is a common cooling medium. A central system will always require distribution components to convey the heating or cooling effect from the source to the conditioned locations.

In a water-based central system, pipes are used to convey water from the source to the final delivery components. A minimum of two pipes is necessary, one for supply water and one for return water, to establish a distribution loop. Closed circuit loops are universally employed as it is more economical to heat or cool water in a closed loop than in an open system. When both heating and cooling are required in a building, 3-pipe and 4-pipe distribution systems may be used to increase system flexibility. A 2-pipe system can only heat or cool, simultaneous heating and cooling -- not an uncommon requirement in large buildings -- is not possible with a 2-pipe system. A 3-pipe system has two supply pipes (hot and cold water) and a single return. The mixing of heating and cooling water in a single return is not energy efficient and is not recommended. A 4-pipe distribution system has two supply pipes and two separate return pipes (hot and cold). The 4-pipe arrangement provides the greatest control flexibility in the most energy-efficient manner.

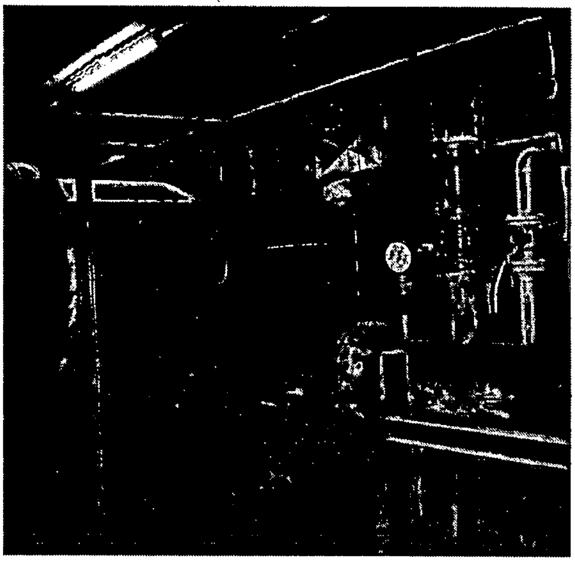


Fig 3.17 Duct running in a building

Source: Author

Hot and cold (chilled) water pipes in HVAC distribution systems are normally insulated. Minimum insulation requirements are prescribed in energy codes and standards. Numerous accessories will be found in typical HVAC piping systems. Valves are used to control water flow as a means of adjusting system heating or cooling capacity to the demands of the building thermal zones. Valves are also used to shut off water flow so that equipment may be maintained. A range of gauges, are used to balance system flows and verify temperature and pressure conditions. Such instrumentation provides a means to check the vital signs of an operating system and becomes increasingly important if systems are to be commissioned.

Water will not normally flow through a complex distribution system without the assistance of some driving force -- friction losses through the piping, accessories, and equipment are simply too extensive. A pump is used to provide the energy input required to overcome friction losses and circulate water through a system. The typical central HVAC system may require the use of several pumps: for hot water, for chilled water, and often for condenser water. Pumps come in a variety of designs and capacities and can be driven by electric motors, combustion engines, or steam.

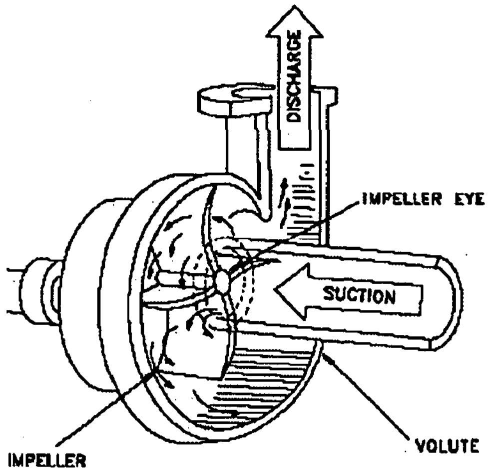


Fig 3.18 Centrifugal pump in an HVAC system

Source: http://www.betterbricks.com/detailPage.aspx?ID=546

Electric motor driven centrifugal pumps, Figure 3.18, are by far the most commonly used pumps for HVAC system applications.

In an air-based central system, ducts (ductwork) are used to convey air from a primary or secondary source to the final delivery components. Typically, two duct paths are necessary, one for supply air and one for return air. Air distribution loops often re-circulate as much indoor air as possible, as it is more economical to heat or cool return air than outdoor air. In practice, outside air should always be brought into the air circulation loop to assist in providing acceptable indoor air quality. The air that is displaced by such outdoor air is either allowed to leak out of the building envelope, is exhausted by bathroom and kitchen exhaust fans, or is exhausted to the outside by dedicated exhaust fans provided to maintain building pressure balances. Return air is often channeled back to the source through building voids. Using the building fabric itself as a return air path can provide economies of space and cost when properly done.

Duct shapes include square or rectangular, circular, and flat oval cross sections. A circular cross section is most economical with respect to material and friction losses. A rectangular cross section, however, is often more likely to fit in the types of spaces available for duct placement. Supply ducts are insulated to reduce heat gain from unconditioned spaces and warm plenums through which they may be routed (see Fig 3.19).

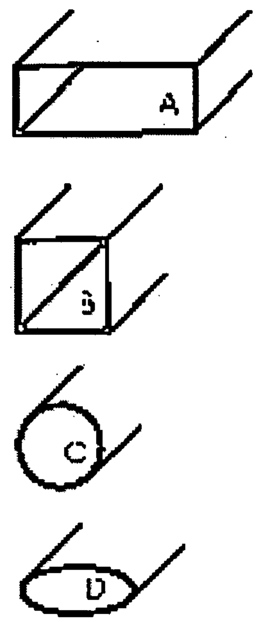


Fig 3.19 Typical Duct Shapes

Source: Author

Accessories found in many duct distribution systems include dampers, splitters, and turning vanes. Dampers are used to control air flow, either to balance flows throughout a system or to adjust air flow in response to changing building loads. Specialized fire dampers and smoke dampers are used to reduce the spread of fire and smoke through the building air distribution system. Splitters and turning vanes are used to reduce friction losses by reducing turbulence within the ductwork; they also can reduce noise generated within the ducts.

As with water, air flowing through a duct system will encounter friction losses through contact with the duct walls and in passing through devices such as dampers, diffusers, filters, and coils. A fan is used to provide the energy input required to overcome friction losses and circulate air through a system. The typical central HVAC system may require the use of several fans: for supply air, for return air, and for exhaust air.

3.4.3 Delivery Components

The heating or cooling effect produced at a source and distributed by a central system to spaces throughout a building needs to be properly delivered to each space to promote comfort. In air-based systems, heated or cooled air could theoretically just be dumped into each space. Such an approach, however, does not provide the control over air distribution required of an air-conditioning system. In water-based systems, the heated or cooled media (water or steam) can not just be dumped into a space. Some means of transferring the conditioning effect from the media to the space is required. Devices designed to provide the interface between occupied building spaces and distribution components are collectively termed delivery devices. A brief discussion of some common delivery devices is given below.

a) Diffuser: A diffuser is a device designed specifically to introduce supply air into a space, to provide good mixing of the supply air with the room air, to minimize drafts that would discomfort occupants, and to integrate with the ceiling system being used in the space in question. Diffusers are intended for ceiling installation and are available in many shapes, sizes, styles, finishes, and capacities (see Fig 3.20). In many buildings, the only portions of an HVAC system seen by occupants are the supply diffusers and return air registers or grilles. Diffusers should be selected with care as they are the point where the effect of an HVAC system is implemented. In addition, they are normally the HVAC system component with the most aesthetic impact.

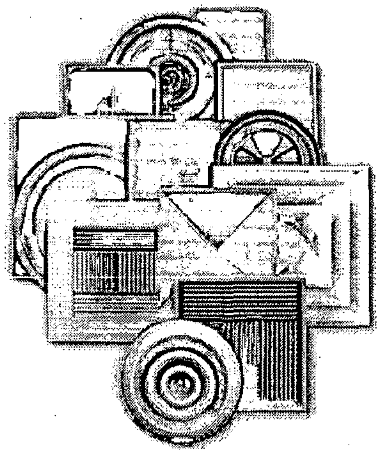


Fig 3.20 Different types of diffuser

Source: http://www.price-hvac.com/catalog/C_all/default.aspx

b) Register: Registers are similar to diffusers except that they are designed and used for floor or sidewall air supply applications or as return air inlets.

Fig 3.21 An example of Register in wall

Source: www.inspect-ny.com

c) Grille: Grilles are simply decorative covers for return air inlets; they are used to block sightlines so that occupants can not see directly into return air openings.

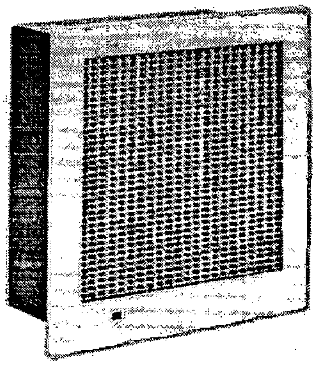


Fig 3.22 an example of grille

Source: http://americanhvacparts.com/Merchant2/graphics/00000001/f52f10_honeywell.jpg

d) Baseboard Radiator: Hydronic baseboard units are similar in general appearance to electric resistance baseboard units. Finned tube heat exchange elements transfer heat from the hot water distribution system to the room air.

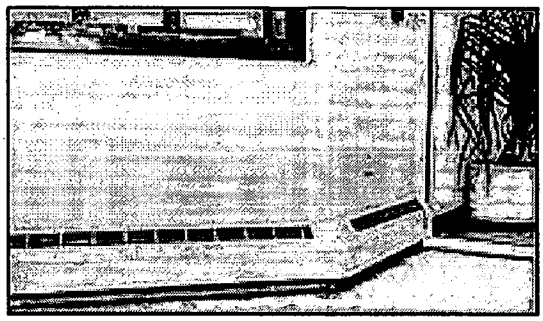


Fig 3.23 Baseboard Radiator used in a building

Source: http://www.sterlingheat.com/html/residential_heat.htm

e) Convector:

A convector is basically a high capacity heat exchange element consisting of one or more finned-tube heat exchange elements, housing, and possibly a fan. Convectors are used in steam or water (hydronic) central heating systems to provide high capacity heat delivery.

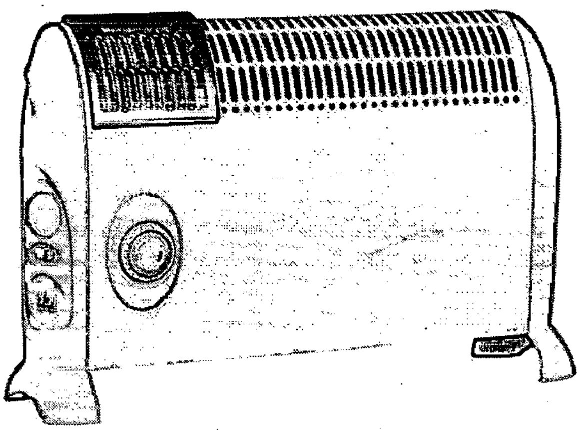


Fig 3.24 A Convector used in building

Source: http://www.turandogroup.com/hc/convector.htm

f) Radiant Panels

It is possible to embed pipes in wall or floor constructions to develop a radiant heat delivery approach for steam or water central heating systems. Radiant heat delivery is generally considered to provide an exceptionally comfortable environment. Packaged electric resistance radiant panels are also available; such units would normally be used to provide supplemental heating for a localized area of a building. Electric resistance cables can also be used with gypsum board construction to provide large-area radiant heating systems.

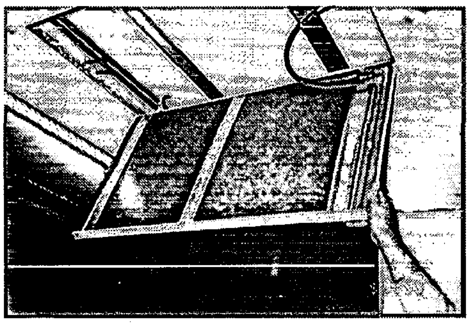


Fig 3.25 figure showing provision of Radiant Panel

Source: http://www.csemag.com/article/CA6499931.html

g) Workstation Personal Climate Control:

Rather than delivering conditioned air generally into a space or providing radiant surfaces at some distance from occupants, several manufacturers have developed workstation climate control systems that produce individualized micro-climates tailored to an individual's needs.

A personalized control approach allows very accurate control of the thermal environment at a particular area in a building (for example, at a particular desk). Such systems have a potential for increased energy efficiency through the delivery of climate control energy at a specific point of need. In addition, the ability to exercise more individual control over one's environment may improve perceptions of thermal comfort among occupants. Typically these workstation systems are similar to the delivery systems used in automobiles, with adjustable air supply louvers and easily reachable control settings.

h) Heat Recovery Devices:

A number of heat recovery approaches may be used to reduce energy consumption in buildings. Common heat recovery devices include heat wheels, run-around coils, and heat pipes. The purpose of a heat recovery device is to capture some of the energy contained in air about to be exhausted from a building -- normally so that the heat may be used to pre-heat incoming ventilation air. A similar approach may be used in hot climates to pre-cool ventilation air.

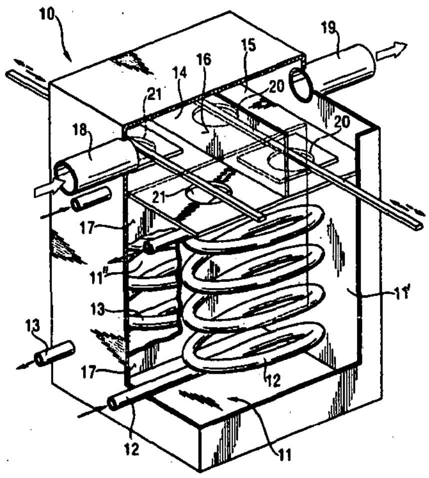


Fig 3.26 schematic diagram showing working of a Heat Recovery Device

Source: http://www.freepatentsonline.com/6626237.html

3.5 Types of HVAC systems

HVAC system can be classified on two parameters. Firstly it can be classified on the basis of type of conditioner used. Under this classification the most common types of air-conditioners are room air-conditioners, split-system central air-conditioners, packaged air-conditioners, and central air-conditioners. These different type of air conditioners are discussed below

3.5.1 Room and Split Air conditioners

Room conditioners cool rooms rather than the building. They provide cooling only when needed. Room air conditioners are less expensive to operate even if their efficiency is generally lower than that of central air conditioning system.

In a split-system central air-conditioner, an outdoor metal cabinet contains the condenser and compressor, and an indoor cabinet contains the evaporator. In many split-system air-conditioners, this indoor cabinet also contains a furnace or the indoor part of a heat pump

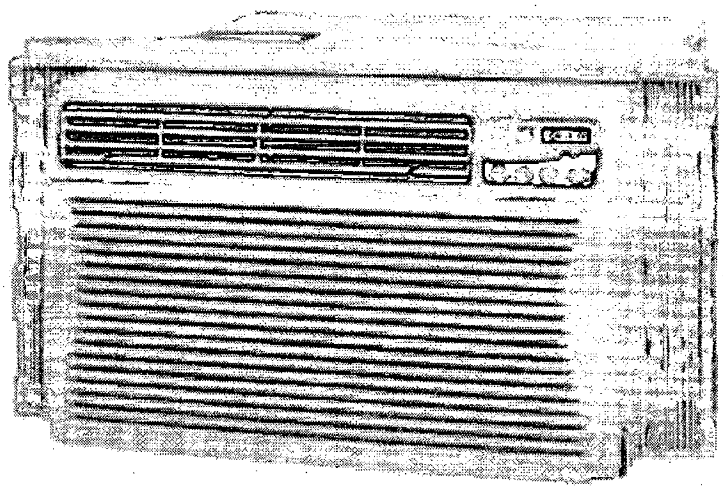


Fig 3.27 An example of Room Air Conditioner

Source: http://products.howstuffworks.com/kenmore-multi-room-air-conditioner-75151-review.htm

3.5.2 Packaged air-conditioner

In a packaged air-conditioner (fig 3.28), the evaporator, condenser, and compressor are all located in one cabinet, which usually is placed on a roof or on a concrete slab adjacent to the building. This type of air-conditioner is typical in small commercial buildings and also in residential buildings. Air supply and return ducts come from indoors through the building's exterior wall or roof to connect with the packaged air-conditioner, which is usually located outdoors. Packaged air-conditioners often include electric heating coils or a natural gas furnace. This combination of air-conditioner and central heater eliminates the need for a separate furnace indoors.

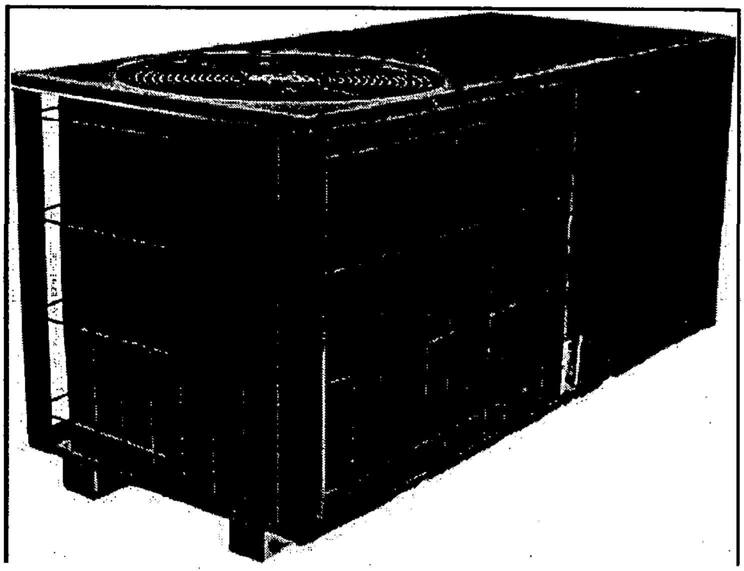


Fig 3.28 An example of Packaged Air Conditioner

Source: http://www.alibaba.com/offerdetail/14314100/Sell_Rooftop_Package_Air_Conditioner.html

3.5.3 Central Air conditioning

Central air conditioning is an air conditioning system which uses ducts to distribute cooled and/or dehumidified air to more than one room, or uses pipes to distribute chilled water to heat exchangers in more than one room, and which is not plugged into a standard electrical outlet.

With a typical *split system*, the condenser and compressor are located in an outdoor unit; the evaporator is mounted in the air handling unit (which is often a forced air furnace). With a *package system*, all components are located in a single outdoor unit that may be located on the ground or roof.

Central air conditioning performs like a regular air conditioner but has several added benefits:

a) When the air handling unit turns on, room air is drawn in from various parts of the building through return-air ducts. This air is pulled through a filter where airborne particles such as dust and lint are removed. Sophisticated filters may remove microscopic pollutants as well. The filtered air is routed to air supply ductwork that carries it back to rooms. Whenever the air conditioner is running, this cycle repeats continually.
b) Because the central air conditioning unit is located away from the activity areas of the building, it offers a lower level of noise indoors than a free-standing air conditioning unit.

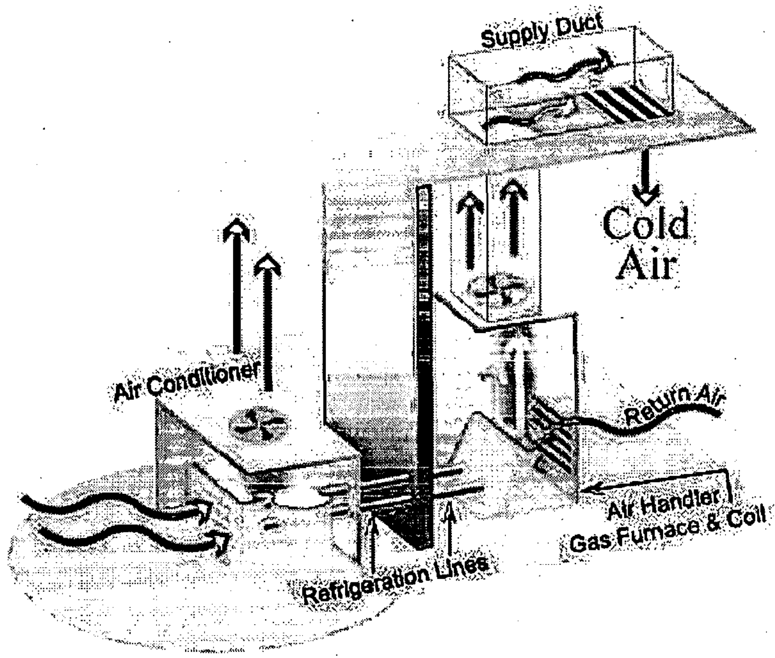


Fig 3.29 Working of Central Air conditioning System

Source: http://www.edszone.com/energy.htm

HVAC system can also be classified on the basis of mode of cooling or heating. On this basis it can be classified as air system, hydronic system and unitary system. All these systems are discussed in brief below.

3.5.4 Air Systems

Air type HVAC systems are systems that provide heating, ventilation, and cooling by circulating air through spaces, or rooms, to maintain the desired conditions in the space. A typical air system generally consists of a central air handling unit, with heating and/or cooling capabilities, and an air distribution system. The air distribution system generally consists of supply air ductwork to the space or room, return air ductwork from the space back to the air handling unit, and air distribution devices in the room, such as grilles and registers that provide desirable air patterns within the room. Heating of the air in the air handling unit (AHU) is usually accomplished with hot water coils, steam coils, gas furnaces, or electric heating coils. Cooling and dehumidification is generally accomplished by passing the air through direct expansion refrigerant coils, chilled water cooling coils, or by the introduction of outdoor air when conditions are favorable.

Air systems offer a number of advantages over other types of systems. These advantages include:

a) Central location of major equipment components.

b) Provide ventilation directly to the space.

c) Easy to use outdoor air for cooling when conditions are favorable.

d) Widely used for HVAC systems with many variations to choose from, i.e., multi-zone, variable air volume, dual duct, etc.

Air type systems also have a number of disadvantages when compared to other system types. These disadvantages include:

a. Central air handling unit (AHU) can require a large amount of space and ductwork can require large amounts of space above ceilings.

b. It is difficult to efficiently provide heating to one space while providing cooling to another space served by the same system.

c. Air flows into spaces need to be properly balanced to obtain the design air flow rates.

d. Air systems may tend to over cool and cause draftiness in the space.

e. Air systems can be quite noisy.

3.5.5 Hydronic and Steam Systems

Hydronic systems are systems that circulate water as a circulating medium for heating and/or cooling. Hydronic systems circulate hot water for heating and chilled water for cooling. Steam heating systems are similar to heating water systems, except steam is used as the heating medium instead of water.

Hydronic heating systems generally consist of a boiler, hot water circulating pumps, distribution piping, and a fan coil unit or a radiator located in the room or space. Steam heating systems are similar except no circulating pumps are required.

Hydronic cooling systems consist of a water chiller, circulating pumps, distribution piping, and a fan coil unit in the space or room. Chilled water systems usually require a cooling tower or some other device to reject heat to the outdoors.

Hydronic systems have several advantages over other types of systems. These include:

a. Individual room temperature control is easily achieved.

b. The same distribution piping system can sometimes be used for heating water and chilled water if simultaneous heating and cooling is not required.

c. The distribution piping requires considerably less space than ductwork.

d. System components have a long service life, between 15 to 20 years.

e. Heating is usually supplied at the perimeter of the building, where it is most needed.

Hydronic systems also have several disadvantages, which include:

a. It is difficult to provide adequate ventilation to rooms.

b. It is difficult to take advantage of outdoor air cooling when conditions are favorable (economizer).

c. Fan coil units in the occupied space can be noisy.

d. An elaborate condensate drainage system may be required for individual fan coil cooling units.

e. Hydronic cooling is usually not economical for smaller buildings.

f. Fan coil units take up space in the room.

g. It may be difficult to control humidity levels in the rooms.

h. Hydronic systems may be subject to freezing when used in air handling units with outdoor air.

3.5.6 Unitary Systems

Unitary systems consist of self-contained units that heat and/or cool a single space. Each space may have its own unitary system. The units are self contained and produce heating and/or cooling with the application of the proper energy source, usually electricity.

Cooling units are usually completely self contained, including cooling coils, compressors, refrigerant piping, condenser coils, and controls. Unitary cooling units need to be located near an outside wall or roof so the refrigeration system can reject heat to the outdoors.

Unitary heating is usually accomplished with electric heating coils or by a gas furnace within the unit. Occasionally, heating is accomplished with a heat pump cycle.

Examples of unitary equipment include window air conditioners, through-the-wall air conditioners and heat pumps, package rooftop air conditioners, electric baseboard radiators, and water source heat pumps.

Unitary systems have several advantages over other types of systems. These include:

a. Lower installation costs.

b. Individual control in each room.

c. Units installed on perimeter of building can easily bring ventilation air into building.

d. Simple, easy to use temperature controls.

e. Easy to service and maintain.

Unitary systems have several disadvantages which include:

a. Units with refrigeration compressors are usually quite noisy.

b. Precise temperature and humidity control is difficult, if not impossible.

b) Cooling units usually must be located near an outside wall or on the roof in order to reject heat to the atmosphere.

c) Units can be unsightly and aesthetically unpleasant. Condensate drainage can be a problem with some cooling units. Many units can be very time consuming to maintain. Compressors have a relatively short service life, between 5 to 10 years.

3.6 Criteria for selecting HVAC system

The decision of which type of system is best suited for a particular application is based upon several selection criteria. Some of the major considerations are discussed herein. No one type of system will be best suited for every application. Each application must be considered on an individual basis. Some of the major considerations are as follows:

a. The heating, cooling and ventilation loads, and requirements for the conditioned space.

b. Installation Cost: Some building owners are primarily concerned with initial installed costs. Some may have specialized operating requirements, such as a computer room, while others are more concerned about operating costs and are willing to pay for a higher performance system.

c. Operating Cost: Some systems are inherently more costly to operate than others.

d. Individual Temperature Control: Some systems can more readily provide individual room or zone temperature control than others.

e. Adequacy of Ventilation: Some systems, by their very nature, provide better ventilation than others.

f. Specialized Temperature and Humidity Control; Areas, such as computer rooms and special manufacturing processes, frequently require precise temperature and humidity control.

g. Maintenance Requirements: Consideration should be given to the capabilities of the owner's maintenance staff.

h. Aesthetics: Some owners are very conscious of the appearance of the building, both inside and outside thus require equipments accordingly.

i. Space requirements: Consideration must be, given to space requirements of the HVAC system, including space for maintenance, and how much space is likely to be available for the system.

j. Availability of Equipment: some Equipment may be readily available in the market whereas some equipment might be available in selected areas only or not being made any more.

k. Climate: Some systems, such as air source heat pumps, are better suited for one climate than another.

l. Availability of Energy Sources: Some fuel sources, such as natural gas, are not always available at the building site.

m. Acoustics: It is always important to consider the amount of noise and vibration generated by various HVAC system types. Some applications are more sensitive than others.

n. Complexity: A system should be selected that can adequately handle the requirements of the building, yet not be so overly complex that it is difficult to have the desired performance.

3.7 Concluding Remarks

1) HVAC system is a complex system with specialized component for each purpose. An idea of these components is useful for an architect to understand so as to know how they can be utilized.

2) It is essential to understand the working of HVAC system. It helps to decide the extent to which HVAC can be used in buildings.

3) Various deciding factors in the provision of HVAC system are essential to be known as they affect the design requirements and results.

4) Each type of HVAC system has its own merits and demerits. Prior to design it should be decided which system is to be used in the building.

CHAPTER 4

This chapter studies HVAC systems with respect to Acoustics and Structural concerns. In it we study various factors that create noise and vibration and also what are the various seismic considerations to be followed in a building while designing an HVAC system.

EFFECT OF HVAC ON DESIGN AND STRUCTURE OF BUILDING

4.1 Introduction to topic

HVAC systems affect the way our buildings are designed and the structural system that is used for construction. Its effectiveness is influenced by the way architects respond to the design proposal. HVAC system can be merged into the structural and floor plan layout so as to give the users a more effective system and more cleanly usable space. What type of HVAC system is used is also effected by the form of the building, surface treatment and whether it is a steel, wooden or concrete framework.

These effects could be due to the reason of laying out of ducts, working of different type of HVAC units, their functional effect and the earthquake and energy concerns.

4.2 Noise and HVAC system

Fans are a major source of noise in HVAC system. Most noise generated by fans is due to the high velocity of air passing through it. Fan noise can be either transmitted directly through the building structure, such as the wall of an equipment room, to an occupied space or transmitted by the supply air ductwork. Sound from it let of a fan can also be transmitted to an occupied space by the return air ductwork.

In packaged HVAC equipment, such as rooftop air conditioners and condensing units the compressors in the refrigeration system, as well as the fans, are a major source of noise and vibration.

Paths through which sound enters a space include the supply air ductwork, the return air ductwork, and through the building structure. The sound path through the ductwork include two components, duct breakout noise and duct borne noise. Duct breakout noise is sound that continues to travel in a straight line when the ductwork changes direction. Duct breakout noise typically occurs directly under a rooftop air conditioner at the first elbow in the ductwork. The sound simply continues in a straight line as the ductwork changes direction. Duct borne noise is sound that travels down the ductwork and enters the space through an air diffuser, or register, just as the air does. Finally, structure borne noise is sound that results from the vibration of the structure itself. Lightweight metal deck roofs are particularly vulnerable to this type of problem. The structure borne noise usually results tank vibration caused by the fans and/or compressors.

In an attempt to reduce sound caused by roof mounted equipment, such as roof top conditioners and compressors, there are several design procedure rules of thumb that should be considered. For maximum sound attenuation (reduction), roof mounted equipment should be located over non-critical, non-occupied spaces, such as storerooms and toilet rooms. Slightly higher sound levels can be tolerated in these areas. It is also advisable to install duct liner in the supply and return air ductwork, especially up to the first change intersection. Whenever possible, round distribution ductwork should be used because round ductwork tends to naturally resist sound breakout. Ductwork may also be enclosed with dry wall to reduce the sound transmitted from ductwork. In extreme cases, the ductwork may be enclosed, or encased, in lead lining.

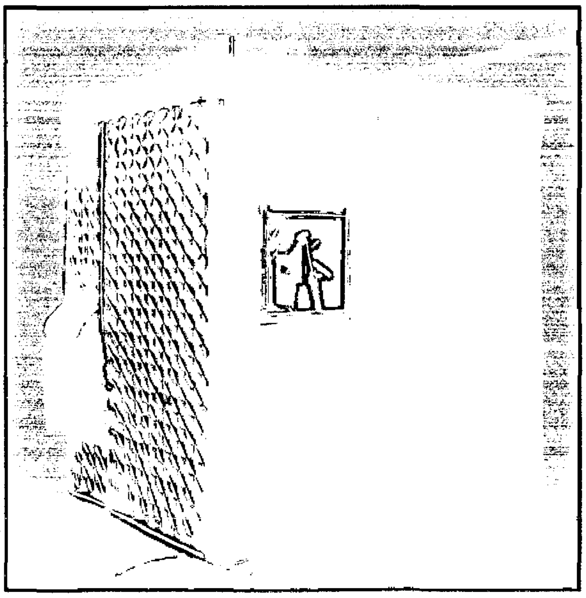


Fig 4.1 Damper used at source to reduce the noise

Source: Mull Thomas E., HVAC Principals and Application Manual

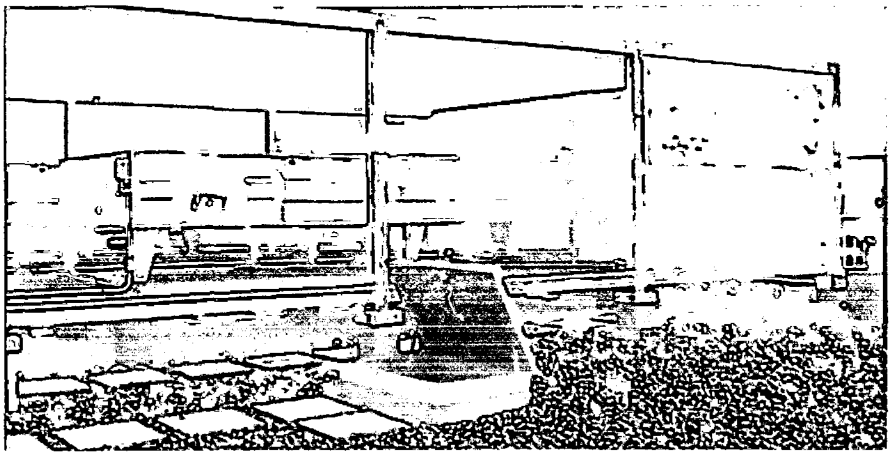


Fig 4.2 Noise protection for Roof top equipments

Source: http://www.avtinc.net/hvac/roof_top_equipment.html

Variable air volume (VAV) terminal units and fan terminal units can be a source of HVAC system noise. When selecting air terminals, it is important to consider the sound generated by these units. The noise generated within the terminal can be a result from two sources, the fan and from throttling of the primary air. If the unit is a fan terminal unit, noise can be generated by the fan much like noise generated by fans in air handling units. Noise can also be generated by the VAV throttling taper. As the damper closes, the velocity of the primary air passing through the terminal lends to increase, which may result in an increase in the generated noise.

Sound from a terminal unit may be either from the discharge of the unit or radiated mind. Discharge sound travels out the end of the unit and is transmitted to the space through the distribution ductwork, and out the air devices, such as air diffusers. To reduce the noise that a terminal may cause in a space, the terminal should be selected for the proper design air flow and with the sound power output in mind. As a general rule, terminal units should be looted over areas that are less sensitive to sound and noise, such as corridors, storerooms, etc. Finally ductwork and air devices such as diffusers, grilles, and registers can be a source of noise. In general, ductwork will tend to attenuate or reduce duct borne sound. The amount of attenuation is a function of the construction of the ductwork, the length of the ductwork, and whether the ductwork is lined (Reference: *Mull Thomas E., HVAC Principals and Application Manual, Tata McGraw Hill*).

4.3 Vibrations and HVAC system

In addition to creating objectionable noise in buildings, HVAC systems can also cause excessive and objectionable vibrations. All machines, including HVAC equipment, are inherently vibration generators. It is impossible to design a machine that is completely vibration free. It is therefore necessary to provide support systems for HVAC equipment that minimize the transmission of the vibration to the base structure or building.

A large percentage of the vibrations to the base structure can be eliminated by the proper selection of vibration equipment and materials. Vibration isolators are resilient supports on which equipment is mounted to isolate them from the base structure. These supports may be made of some resilient material, such as neoprene, or, more frequently, they are springs. The effectiveness of vibration isolators is measured in terms of efficiency. Efficiency is a measure of percentage of vibrations absorbed as opposed to the percentage that it transmits.

There are basically three types of vibration isolators used for HVAC equipment. Pad type isolators are relatively inexpensive and are usually made of rubber neoprene or other such resilient material. They are suitable for small vibrations from high speed equipment in which deflections are relatively small (as shown in Fig 4.3).

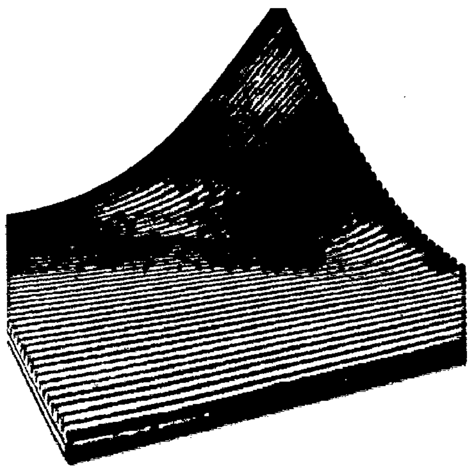


Fig 4.3 Rubber Pad isolator

Source: Mull Thomas E., HVAC Principals and Application Manual

Steel spring type isolators (see Fig 3.33) are the most common type of isolator used for HVAC equipment. Restrained spring vibration isolators are used for roof mounted equipment. The restraints provide safety stops in the event of high wind loads. Restrained isolators are also beneficial as seismic equipment units, to reduce equipment movement in the event of an earthquake.

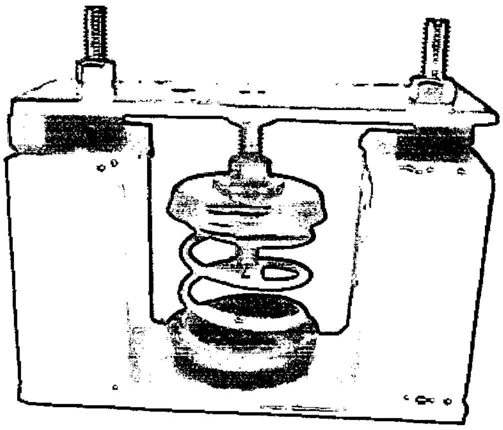


Fig 4.4 Steel Spring Isolator

Source: Mull Thomas E., HVAC Principals and Application Manual

Vibration isolation bases are essentially floating base pads, mounted on vibration isolation springs. Vibration isolation bases are used to add mass to the equipment support. The additional mass lends to dampen and absorb vibrations. The base can be made of structural steel or it can be made of concrete. These types of isolators are frequently used to support equipment, such as pumps, although they may also be used to support rooftop air conditioners.

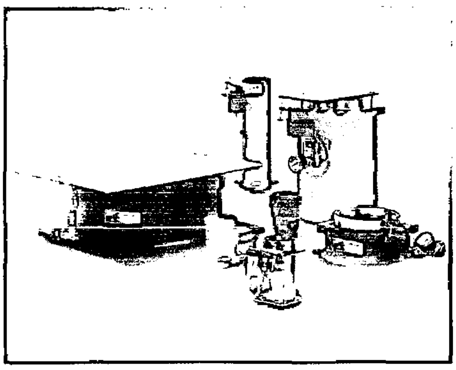


Fig 4.5 Different Type of Vibration Isolation Bases

Source: Mull Thomas E., HVAC Principals and Application Manual

4.4 Seismic Design consideration for HVAC System

The main intent of seismic restraints is to prevent non-structural items in a building, such as HVAC equipment, from becoming lethal missiles in the event of an earthquake. Earthquakes can cause equipment to break loose and fall from a ceiling or slide across a floor when the ground shakes a building and its contents. In addition to the lethal missile problem, it is also important to keep building mechanical systems in operation during and after an earthquake. The attachment (or seismic restraint) of equipment must have sufficient to transmit the forces during an earthquake, or it must provide sufficient isolation allow for the induced motion of the equipment. In order to properly select suitable seismic restraints for HVAC equipment, it is first necessary lo determine the seismic zone in which the building is located. These zones give some measure of the severity of earthquakes that can be expected.

There are two general methods for restraining equipment, such as HVAC and other mechanical equipment. The first method is to rigidly attach the equipment to the building structure to prevent any movement. In such an arrangement, the supporting members used "attach the equipment to the building structure must be strong enough to withstand the forces that would be expected in the event of an earthquake. Rigidly attaching equipment to the building structure has some disadvantages.

The second method is the isolation approach, in which equipment is provided with sufficient space and the support has sufficient flexibility to reduce the possibility of excessive motion of the equipment. This method usually employs restraints to limit the travel of the equipment. Past experience with mechanical equipment systems in earthquakes has provided an indication of how equipment supported by both methods will react and the type of damage that can by expected.

When designing and selecting seismic restraints for HVAC equipment it is important to consult the appropriate codes, the manufacturer of the restraints (if any), and an engineer experienced in seismic design.

However, there are some guidelines which should be followed when designing HVAC systems that will reduce the problems caused by earthquakes. These guidelines are as under.

1. Heavy mechanical equipment should not be mounted on the upper floors of tall buildings, unless the mounts are carefully selected and analyzed for earthquake resistance.
2. Floor mounted equipment, with vibration isolation devices, should be bolted to the equipment base and to the structural slab.
3. Lateral and vertical restraints should be provided for all isolated floor mounted equipment to restrain displacement.
4. Resilient material should be provided on the contact surfaces of the restraining devices to reduce impact loads.
5. Horizontal ductwork should be supported as close as possible to the structural member.
6. Long hangers and support for ductwork should have lateral sway bracing.
7. Supports for tanks and heavy equipment must be designed with sufficient strength to withstand earthquake forces. Support should be anchored to the floor or otherwise secured.
8. Support for elevated tanks or equipment should be sway braced and anchored to the structural slabs or walls.
9. Piping should be anchored to only one structural system. Where structural systems change, and relative deflections might occur, flexible or moveable joints should be provided to allow for movement.
10. Whenever possible, pipes should not cross the seismic joints of the building. If they must cross, it should be at the lowest floor possible and seismic piping joints should be provided.

CHAPTER 5

This chapter deals with the case studies done in this dissertation. How the provision of HVAC components has affected the design quality in different buildings have been studied and based upon it some inferences have been deduced out of it.

CASE-STUDIES

5.1 Literature Study

The following literature studies have been humbly borrowed from Mechanical and Electrical Equipment for Building by W.J. McGuinnes. These studies are aimed to study only the positive aspects of HVAC system in these building and do not cover the study of whole building with respect to design and other services.

5.1.1 Luz Electricia Building, Caracas, Venezuela.

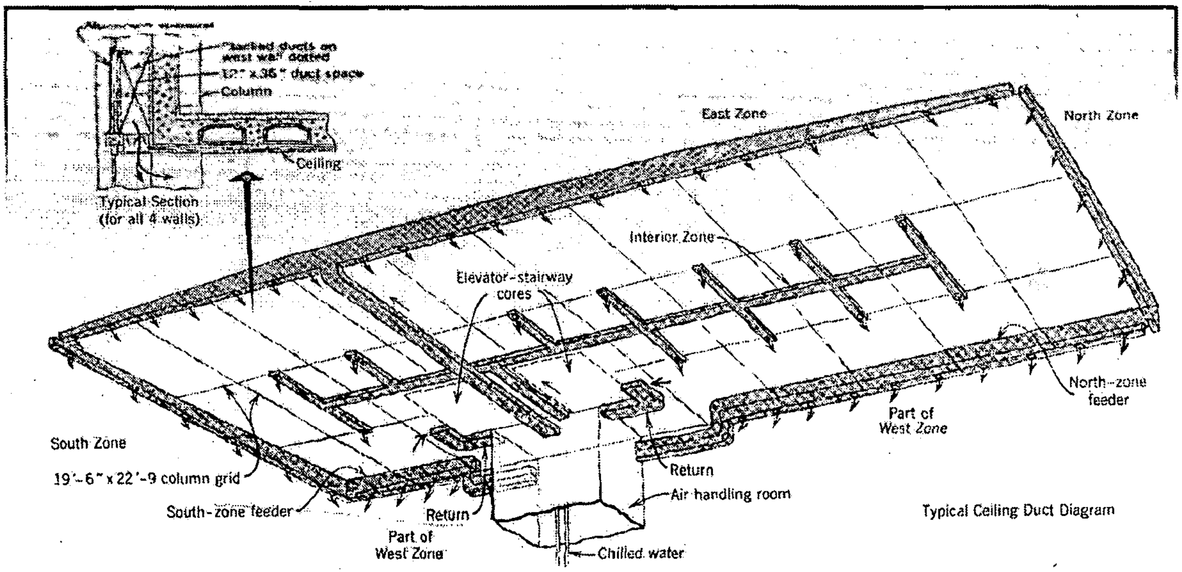


Fig 5.1Reflected ceiling plan for Luz Electricia Building

Source: McGuinnes W.J., Mechanical and Electrical Equipment for Building

Basic idea in this building was to eliminate the need of vertical feeders by placing air handling at each floor. A four zone perimeter distribution of conditioned air is achieved by ducts entirely outside the structural spandrels and above the structural soffit of each ceiling. In a space between the upturned spandrel beam and an exterior skin of insulated aluminum, the duct distributes air laterally. The windows are blanketed by a down flow from grills that are flushed with the ceiling. A careful design has made only one supply duct needed in eastern zone. Thus an uncluttered ceiling has been achieved which has improved the aesthetic appearance of the surface.

An added benefit is that it reduces the structural complexity that arises due to the overlapping of beams and supply ducts. This case study emphasizes the importance of service ducts in office building and how they reduce the network of supply ducts.

A simple step taken while designing has reduced the need of providing more supply duct than necessary which also has economic benefits.

5.1.2 International Building, San Francisco, California.

In this building the dual-duct feeders are enclosed in nonstructural vertical towers at diagonally opposite corners of the building. At the alternate corners, air is returned through matching vertical elements. Pressure reducing and mixing boxes at the perimeter ceiling serve, not individual diffusers, but a continuous strip ceiling outlet that down feeds air directly in the plane of the glass. Interior spaces are supplied and exhausted by concealed lateral ducts connected to vertical low-velocity ducts in the core.

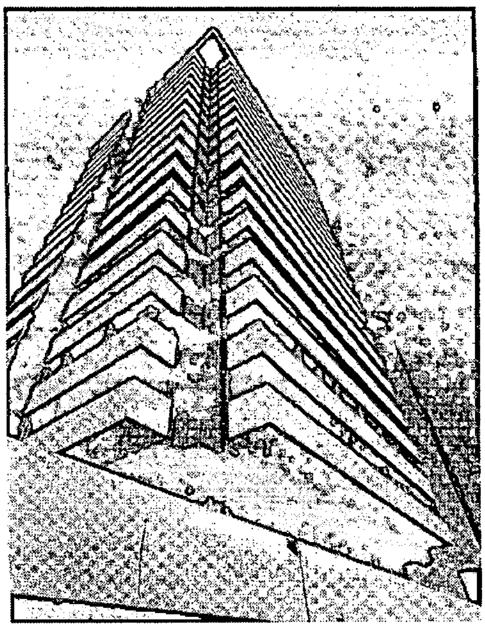


Fig 5.2 Arteries supporting HVAC, International Building San Francisco

Source: McGuinnes W.J., Mechanical and Electrical Equipment for Building

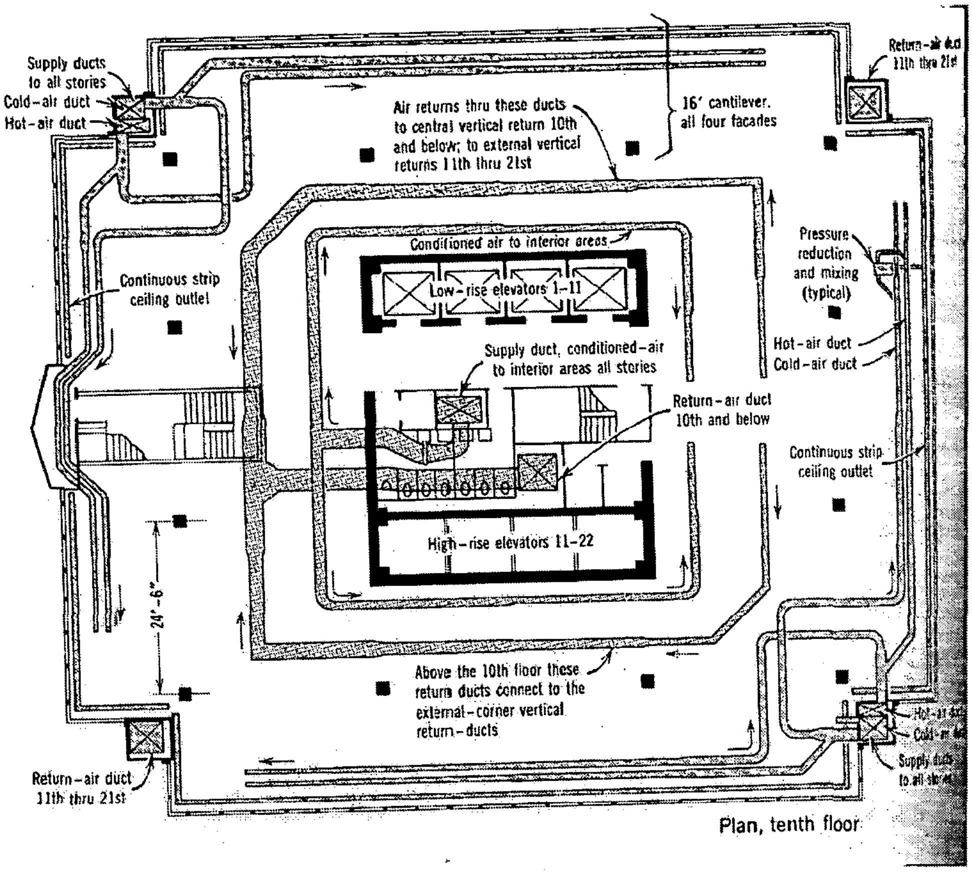


Fig 5.3 Floor plan, International Building San Francisco

Source: McGuinnes W.J., Mechanical and Electrical Equipment for Building

In this scheme, the ply arteries for conditioned air have been located in alternate corners. In diagonally opposite locations, supply risers are placed in large square enclosures. Though nonstructural, each enclosure is emphasized as a distinct vertical design element. Each encloses both hot- and cold-air ducts which supply two separately controlled orientations on all of the 21 stories. Conditioned air originates at an intermediate floor, the third. In the opposite two corners, similar ducts return much of the air to the equipment story. The balance is returned through duct risers in the core

Benefit of this type of planning was that it not only enhanced the aesthetic appearance of the building but the need for inner ducts required for circulation is also not needed. Since ducts are at periphery, need for noise control is also minimal.

5.1.3 Blue Cross-Blue Shield Building, Boston Massachusetts

This office building was designed by Architect Paul Rudolph in 1960. Noticeable feature of HVAC system in this building is that all of the ducts that supply the perimeter are overlaid in a vertical pattern on the outside of the structure. It bears some resemblance in principle to the Luz Uectnca solution, except that, instead of a horizontal pattern of exterior low velocity supply ducts, it present a vertical pattern of exterior high velocity (hot and cold) supply ducts as well low velocity return ducts. Each column and mullion is utilized.

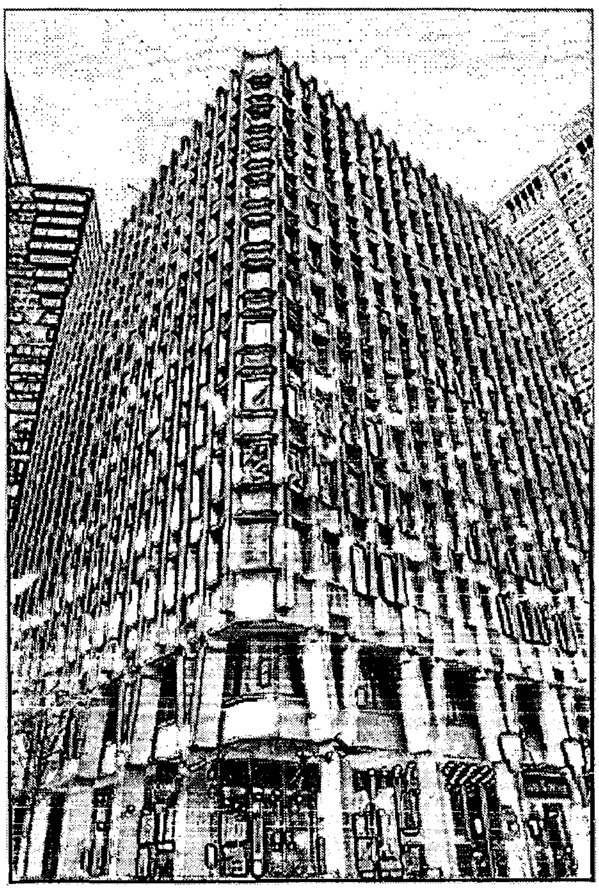


Fig 5.4 A view of Blue Cross-Blue Shield Building, Boston

Source: http://www.grammarpolice.net/archives/cat_architecture.php

The two story Y-shaped forms are structural columns which divide at mezzanine level and continue to in pairs to form the exterior skeleton frame. Hollow I channels on the exterior of each pair enclose, individually, a hot-air supply duct and a cold-air supply duct. This round, high-velocity ducts join for mixing and velocity reduction in attenuation boxes, located between columns at each floor. Conditioned air is discharged upward from a window-sill grill above the box. A mullion between each pair of structural columns originates at the second-floor level and extends to the mechanical story at the roof. This mullion encloses a return-air duct which draws air through grills in the sills of the two adjacent windows on each story. Thus the air is delivered at the exterior, accomplishes its mission at that surface, and returns in the same vertical plane to the suction side of fans on the roof.

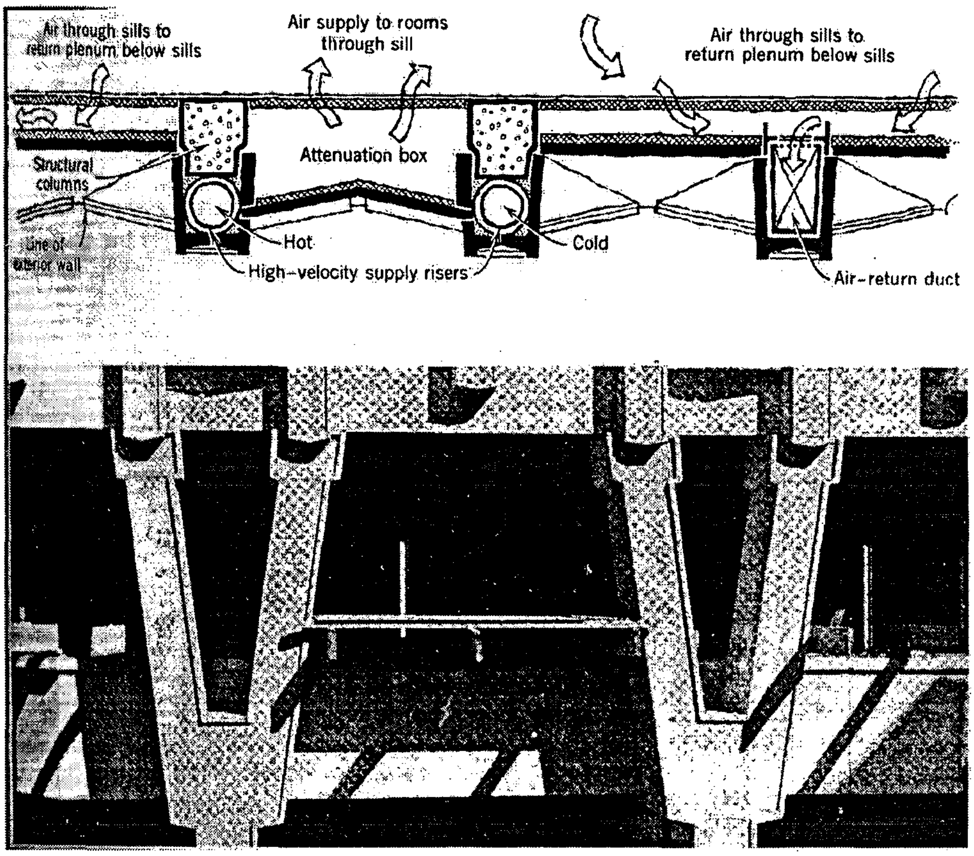


Fig 5.5 Mullion and Columns used for laying out Ducts

Source: McGuinnes W.J., Mechanical and Electrical Equipment for Building

5.2 Analytical study of DLF office complex

DLF is one of the countries biggest commercial sector real estate players. It is one of the major players that have turned Gurgaon from a mere village adjoining Delhi to one of the most happening Global business activity centre in India. DLF has 32 million square feet of developed/ under development office area. Currently it has 26 million sqft of rentable commercial space.

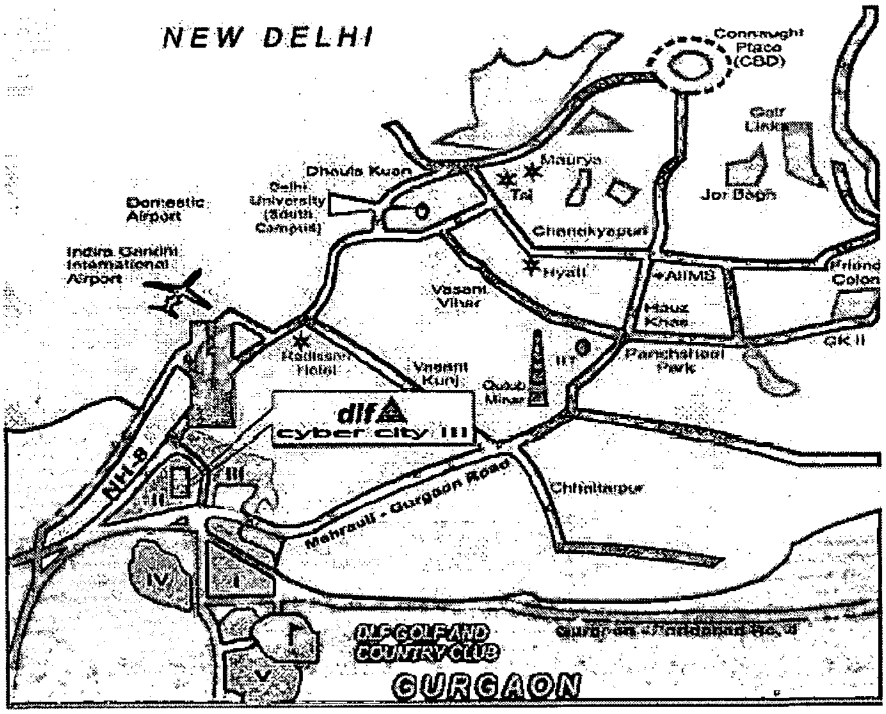


Fig 5.6 Location map to DLF Cyber city III
Source: http://www.dlf.in/

In addition to Gurgaon DLF has IT Parks developed/under development at Noida, Chandigarh, Kolkata, Bangalore, Hyderabad, Chennai, Pune, Bhuvneshwar and Nagpur.

Two buildings have been studied in the complex namely Infinity tower and Tower 8(B) both being a part of the DLF Cyber City Phase III office complex.

5.2.1 Introduction to Infinity Tower

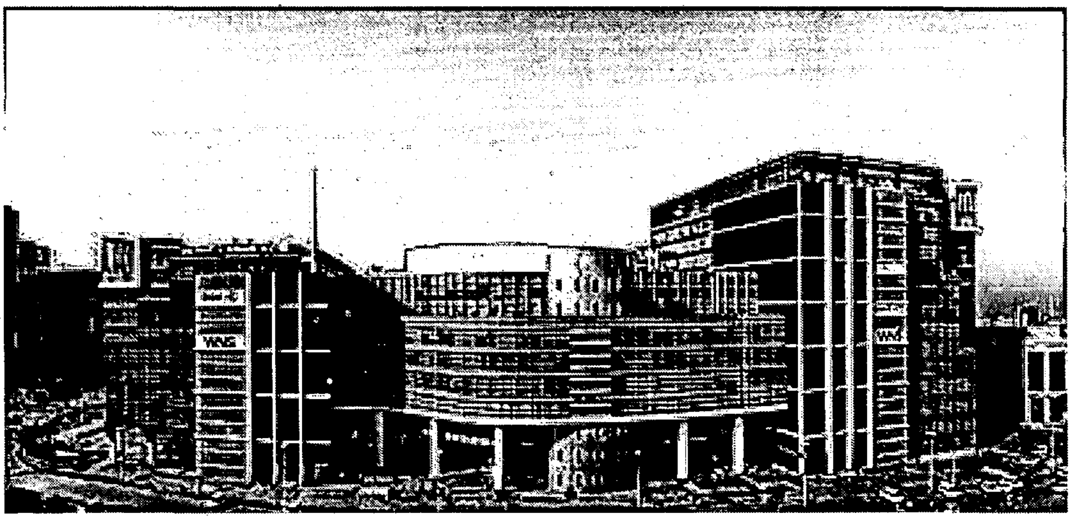


Fig 5.8 DLF Infinity tower
Source: http://www.dlf.in/

Location: Cyber city III, Gurgaon.

Launch of the Project - October, 2004

Year of completion: 2006

Owner: DLF Limited.

Architect: Hafeez Contractor.

Infinity Towers is located just off National Highway-8 at the entrance of Gurgaon. Designed by renowned architect Hafeez Contractor the complex constitutes three interconnected towers (A, B, C) scaling between 10-12 storeys. Spread across 1.2 million sqft of space, the complex is designed to provide with various option ranging from 38,000 sqft to 52,000 sqft providing for contiguous space of up to 1,35,000 sqft on each individual floor. Well connected to domestic and international airport and south, central, and west Delhi it provides for easy connectivity.

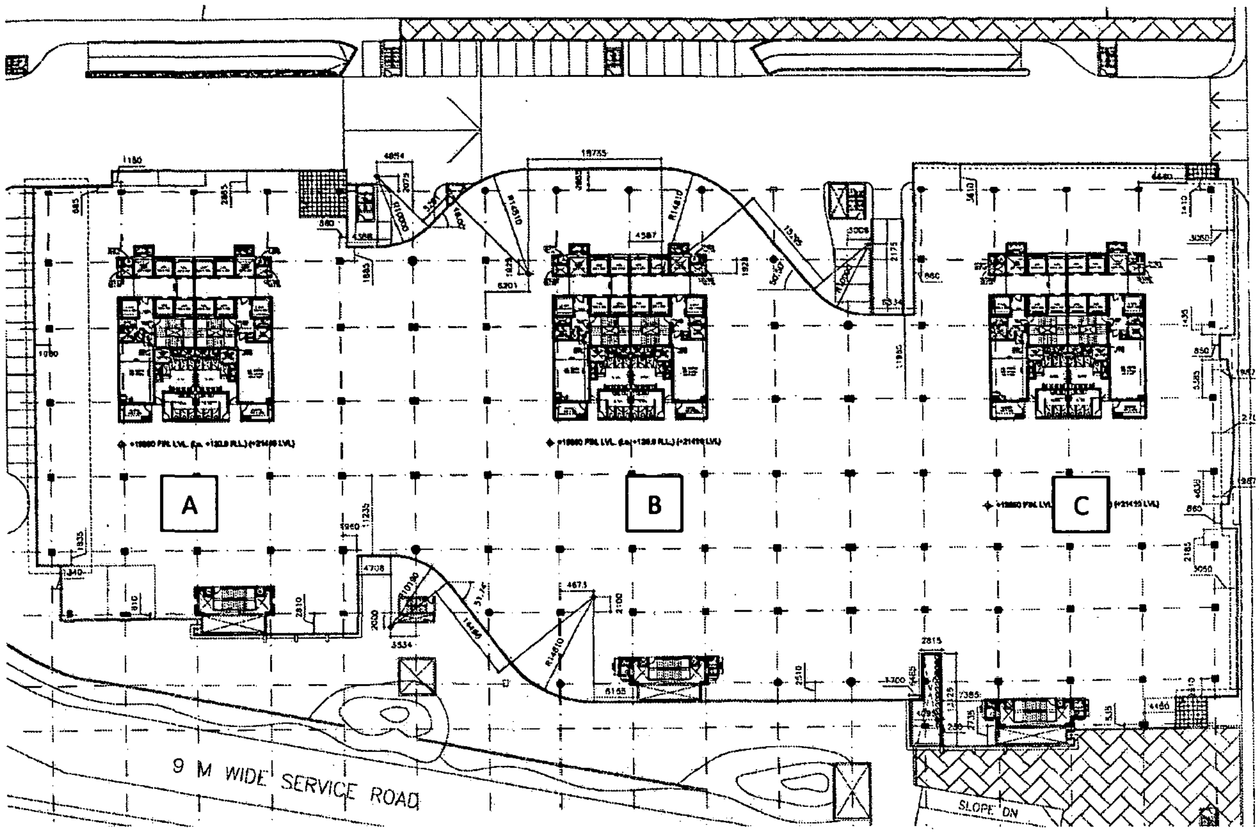


Fig 5.9 DLF Infinity tower, Floor plan
Source: DLF Architectural Section

Table 5.1 Area and Number of Floor for each Block-Infinity Tower

Block	No. of Floors	Typical Floor Area (sqft.)	Total Super Area (sqft.)
Tower A	Ground plus 9 floors	38,000 sqft. (approx.)	3, 15,500 sqft. (approx.)
Tower B	Ground plus 8 floors	52,000 sqft. (approx.)	3, 85,000 sqft. (approx.)
Tower C	Ground plus 12 floors	50,000 sqft. (approx.)	5, 87, 000 sqft. (approx.)

Source: Author

5.2.2 Introduction to Tower 8

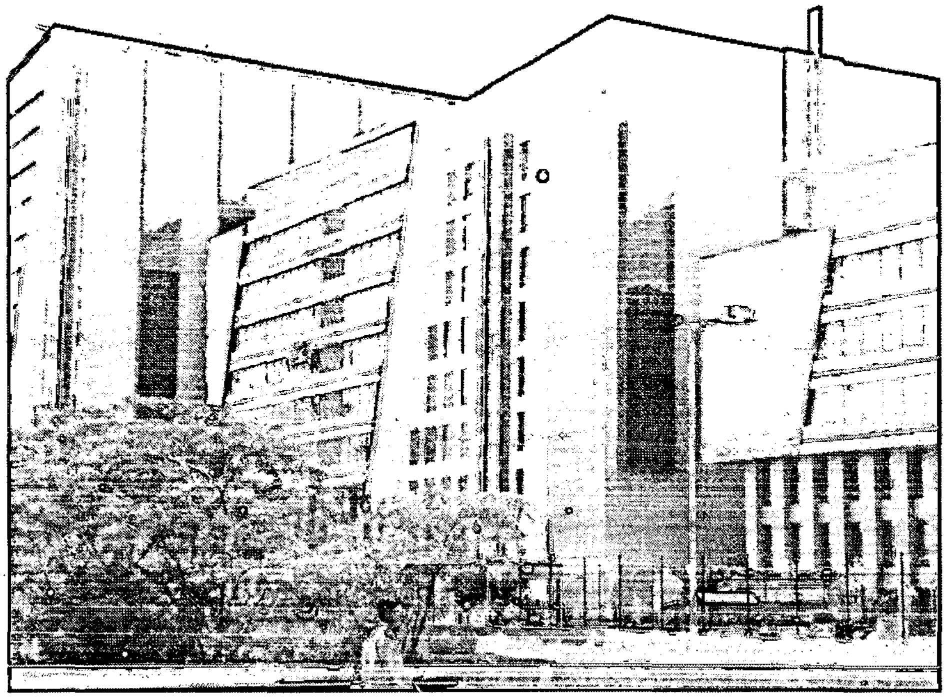


Fig 5.10 A view of Tower8
Source: DLF Architectural Section

Location: Cyber city III, Gurgaon.

Launch of the Project - October, 2005

Year of completion: 2008

Owner: DLF Limited.

Architect: Hafeez Contractor.

Located just off the national Highway-8 in DLF Cyber City Gurgaon Building 8 is spread across an area of approx 1.4 million sqft. It is divided in to 3 blocks (8A, 8B & 8C), with a range of 4-9 floors. Tower 8 is not its actual name but name given as a reference. Actual naming of tower will be done at later stages.

Conforming to modern work environment, facilities like food court, ATM and retail outlets, forms an integral part of the complex.

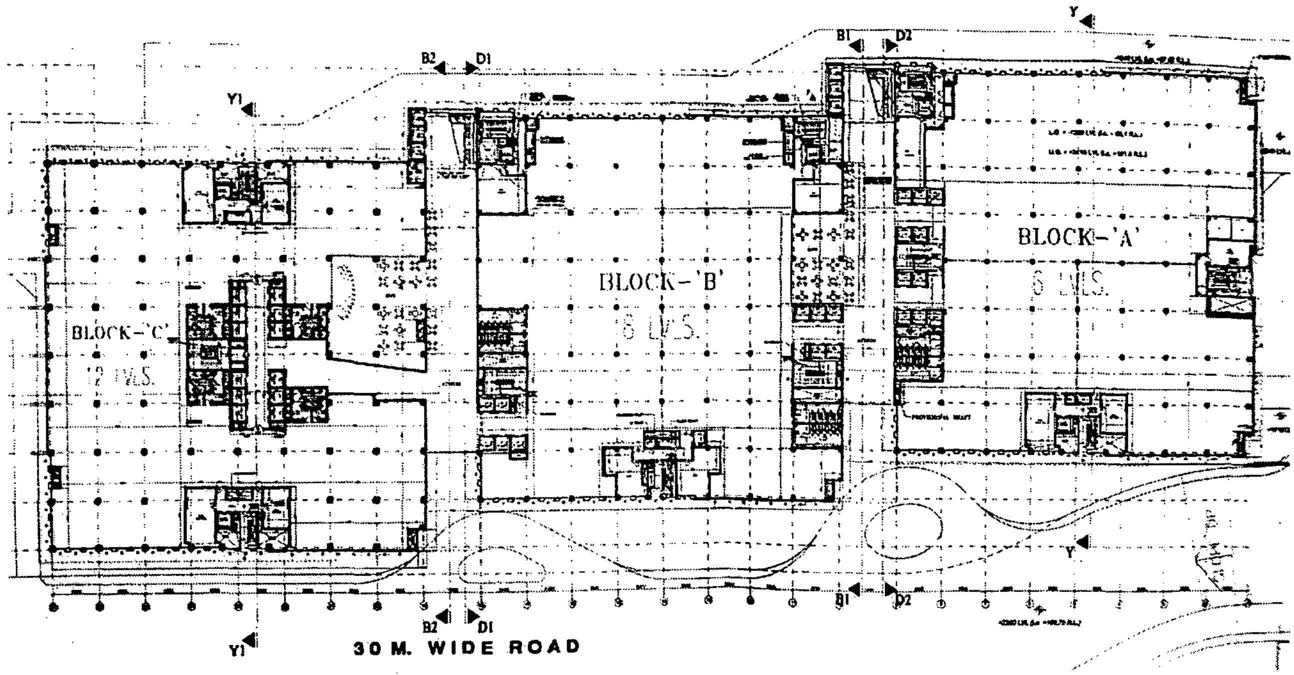


Fig 5.11 Ground floor plan of Tower 8
Source: DLF Architectural Section

Table 5.2 Area and Number of Floor for each Block- Tower 8

Block	**No. of Floors**	**Tentative Floor Area**
Block A	Ground plus 5 floors	Typical Floor Area= 54,000 sqft. (approx.) Total Super Area = 324,500 sqft. (approx.)
Block B	Ground plus 8 floors	Typical Floor Area= 53,000 sqft. (approx.) Total Super Area = 477,000 sqft. (approx.)
Block C	Ground plus 14 floors	Typical Floor Area= 53,000 sqft. (approx.) Total Super Area = 795,000 sqft. (approx.)

Source: Author

5.2.3 Provision of HVAC system in the complex

All the HVAC components have been provided in the second basement below the covered central court. Central air conditioning has been used in the complex with a plant of a capacity of 750 tons. Total number of chiller plants that are used is five with six consisting of five operational units and one standby unit. Two boilers are being used for heating purpose. Air type system is used for the purpose of air conditioning in the complex.

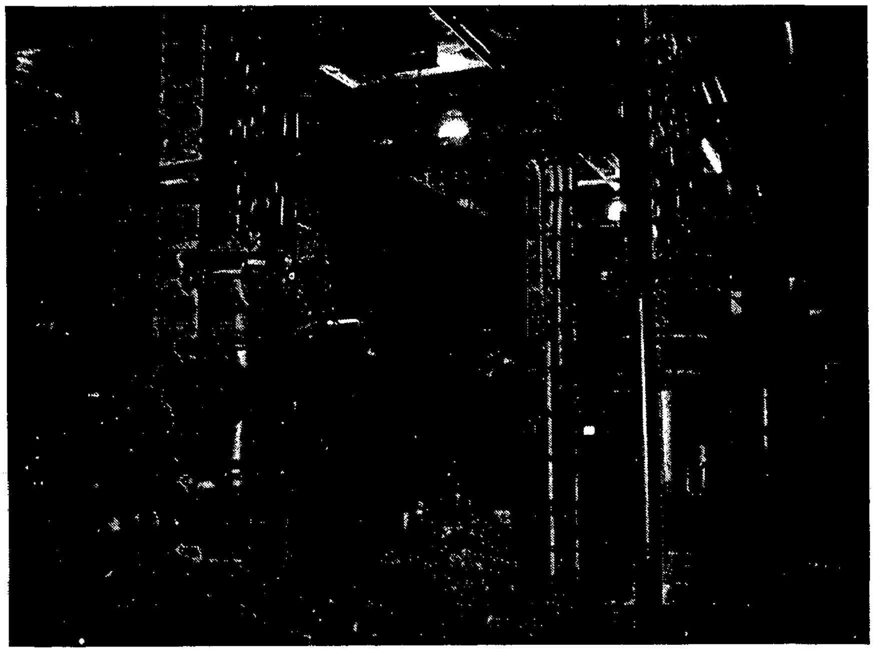


Fig 5.12 Main plant room for HVAC
Source: Author

Two maintain the temperature of public areas; external units based on evaporative cooling (as shown in Fig 3.8) are used at some places (for example parking areas). HVAC system has been made fully automated by use of programmable logic circuits thus reducing the need to manually operate the system and keep a watch over it. This leads to a higher level of comfort and more efficient HVAC system. Piping that is used has been colour coded and insulated to for better performance.

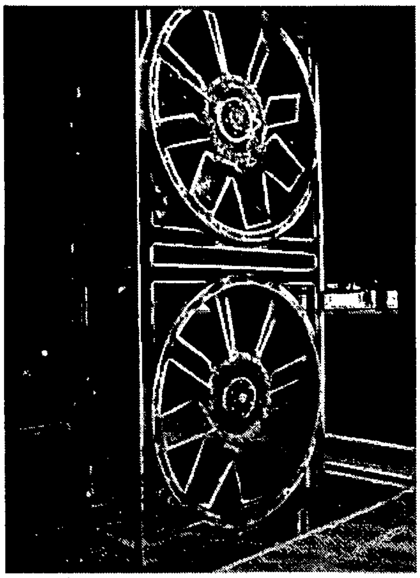


Fig 5.13 Evaporative cooling unit in basement parking area
Source: Author

Maintenance entry for the main plant room has been provided from central court which not only disturbs the circulation pattern of office complex occupants but also causes a lot of noise problem. Condition of noise and vibration further worsens in the parking area where it is high above the comfortable audible range of sound.

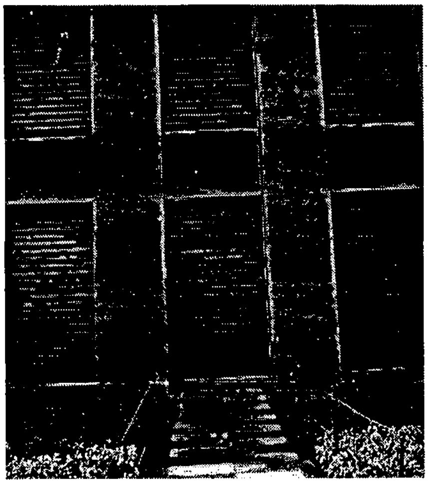


Fig 5.14 Maintenance entry opening into central court
Source: Author

5.2.4 Different services in the buildings

Infinity tower and Tower 8 provides all the basic services that are required in an office building i.e. lighting/electrical, plumbing, and mechanical, communication, safety and security along with maintenance and parking. Organization of these services has been done in the two basements that have been provided below the entire complex.

For the purpose of distribution of services in both the buildings, a set of shaft has been provided in each of the block for each type of service that requires service runs. These ducts run on either side of core (as shown in fig 6.15, 6.16).

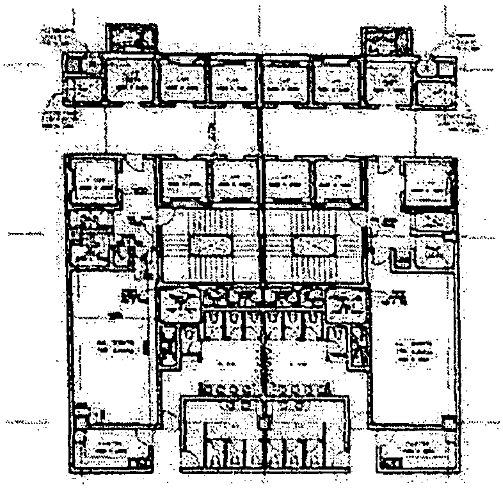


Fig 5.15 Detail of service core for Infinity tower
Source: DLF Architectural Section

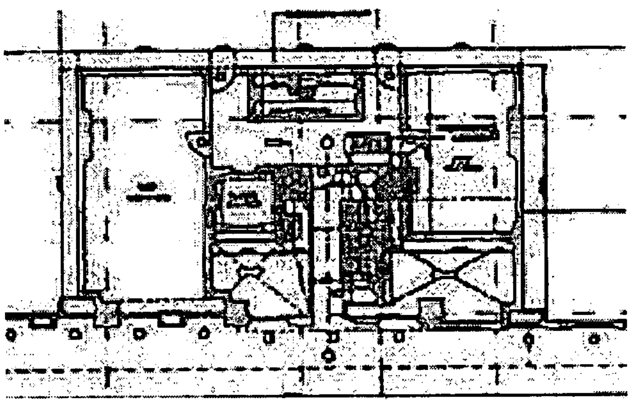


Fig 5.16 Detail of service core for Tower 8
Source: DLF Architectural Section

5.2.5 HVAC in the buildings

Six AHU's two for each block of the building has been provided in the Infinity Tower (see Fig 6.9 and 6.15). Fresh air shafts that have been provided are adjoining the toilet ventilation ducts. AHU's are located on the either side of core thus dividing the block into two HVAC zone from the centre of the core.

For Tower 8 there are four AHU units in each block (see fig 6.11and 6.16) thus a total of 12 units serving at each floor of the building, making HVAC a costly component in it. In all the blocks position of AHU keeps on changing but broadly they divide each block into four zones.

Building's structural system affects the layout of supply ducts. A considerable number a bends are provided from the AHU till the end of duct thus making the system perform more than could have been achieved by some alternative arrangement so that layout of ducts have minimum interruption by building's structural system.

Diffusers have been provided at distances for the purpose of air – conditioning. Presence of Workstation Personal Climate Control system is absent which otherwise could have been really effective method of cooling considering the type of organization of space in both of the buildings. Also no heat retention system has been used. Supply ducts are completely insulated but are not braced. Therefore structural integrity of HVAC system in the building is not ensured.

There is no provision for natural ventilation in both of the buildings. In both the building façade is made up of glass and Aluminum cobalt panels. Both of the buildings are designed in form of sealed boxes where natural flow of air is not permitted. Thus it is totally dependent upon artificial systems of heating and cooling for its comfort.

5.3 Inferences from Case-studies

Various inferences have been drawn from the literature study and the personal visit done which can be summarized as under:

a) Supply ducts can perform smoothly if they are integrated into the structural system like Blue cross Blue Shield building. This is not only saves space but also helps with the seismic precautions.

b) Optimal use of glass is necessary. In western countries where most of the time temperature is below normal, extensive use of glass is advised. But in Indian context glass must be chosen wisely. In DLF extensive use of glass has caused a drastic increase in the HVAC load.

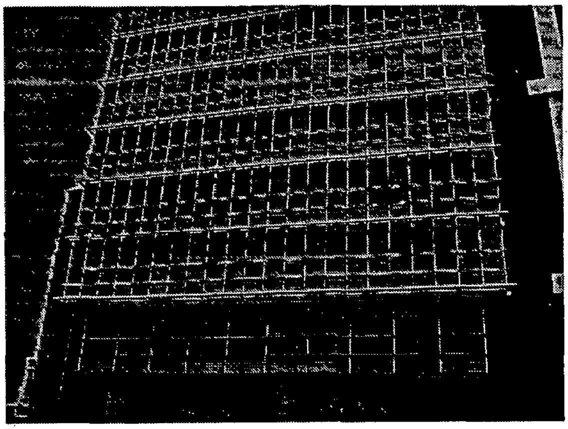


Fig 5.17 Extensive use of glass in building facade
Source: Author

c) Surrounding also affects the HVAC condition. In DLF complex all the area that surrounds the building is formed of hard landscaping with minimal vegetation. This increases the heat gain from the reflected component of solar radiation.

d) In all the literature studies it was found that the location of supply ducts and distribution system is of high importance. It is evident that it not only affects the load and layout of supply duct, but also affects the aesthetics of the building both exterior and from the inside.

e) It was viewed in DLF that the noise source is affecting the condition of occupants of the building. Thus it is always suggested that the noise sources need to be kept away from the activity area as far as possible and if the same can not be done due to some unavoidable conditions then some soundproofing measures should be taken into consideration.

f) Methods of energy conservation are absent in the studies which is an undesirable practice. For example in Indian conditions where solar radiation is high, solar thermal collector can be used.

g) There is no control over individual comfort in HVAC performance. Devices that control the HVAC area over smaller areas (to be particular for individual occupants) are not seen in the studies.

h) No use of heat recovery devices is seen in the case-studies.

i) Only diffusers are used in the building where as depending upon the area it might not be necessary that cooling be provided from ceiling only. So if required other delivery components can also be used.

j) In all the buildings studied ducts were rectangular in shape. However the same shape has maximum friction loses but most compatible with structure. Wherever possible circular or oval ducts should be used.

k) Seismic safety of supply ducts was not present in DLF which is a must for any building to have especially when it is in zone 5 of earthquake prone area.

CHAPTER 6

This chapter states all the findings that have been done in this complete dissertation and how can they be used to affect the design for its betterment.

FINDINGS AND SUGGESTIONS

From all the literature and case studies done in this dissertation, some problems with respect to the provision of HVAC system and certain architectural aspects to be considered while designing the system have been concluded. Keeping these aspects in mind will help to develop a better HVAC system.

Findings and suggestions from the dissertation study are as under

1) *Saving in Energy consumption*:

As HVAC is a major energy consumer in any type of building it is essential to reduce the consumption as far it is possible. If half of the electricity is saved by efficient systems it would be equal to 3% flexibility on the rent for the developer. This economic factor turns out to be a huge saving in big projects.

This could be done by following measures:

a) Reduce the load of heat gain/ loss by controlling the heat transfer. External heat gains could be reduced by certain modifications in architectural form, material treatment, providing vegetation inside and outside. Internal heat gain can be reduced by use of efficient building equipment and HVAC equipment. These points are further elaborated as under.

- Extensive use of glass in the office buildings is the first thing that needs to be taken care of. Unlike western countries where heating is needed for most of the period in a year so that they make their building facades out of glass, Indian climatic condition requires cooling for most of the time. With complete glass façade it is hard to control the amount of solar radiation that enters into the building. Also the glass that is used is not of the appropriate specification which further creates problem. To solve this problem glass use of glass should be intelligently thought of so as to have a balance in permissible light and heat gain. Also wherever glass is used it should be double skin or heat resistant glass.
- Vegetation is also one aspect of the HVAC that is sometimes neglected while designing the HVAC system. It is neither necessary nor possible to always provide natural ventilation into the building.

But the vegetation can be used in other ways also. A planned landscape not only reduces the reflected component of solar radiation that heats up the building but also maintain a suitable level of humidity in its surrounding. Similarly indoor landscaping will also maintain the temperature and humidity of indoor environment.

- Form and orientation of the building also affects the buildings' HVAC system. It is always preferable to have minimum area of wall on the face having maximum sunlight. It is preferable to have circular form as the solar radiation absorbed/ transferred in case of circular form are lower as compared to heat gain from a flat surface.

b) The comfort envelop can be expanded by reducing radiant heat load, increased air flow, proper furniture and change in dressing where appropriate. These measures are less employed but can save significant amount of energy. By switching to casual dressing instead of business suit can give a 3 degree Celsius saving in comfort envelop which give a significant saving in cost by allowing a large zone of comfort and also smaller equipments are needed.

c) The delivery component of HVAC system can be optimized by reducing velocity pressure and friction losses in ducts and piping. High efficiency fans and diffusers should be used.

d) Non vapor compression cooling techniques should be used wherever possible. They require 20-30% as much energy per unit of cooling as required by a conventional system and can serve much or the entire load that remains after the cooling load is reduced. These alternatives include natural ventilation with cool outside air, ground coupled cooling, night sky cooling, evaporative cooling, absorption cooling, and desiccant systems fueled by natural gas, waste heat, or solar energy. All these features need to be developed at the time of conceptualization of design of the building.

e) More efficient refrigerative cooling system should be employed. These include use of efficient chillers, pumps, fans, multiplexed chillers (to minimize part-load operation penalties), large heat exchangers, low-friction duct layout and sizing, low pressure drops in air-handling and piping components, and overall optimization of the entire HVAC system.

2) *Selection of Equipments*

The HVAC equipment that is used in a building should match to the cooling and heating loads of the building. In addition to reducing energy consumption and costs, proper equipment will also

a) Reduce the acoustical problems that arise from the equipment.

b) Increase overall saving in installation and operation

c) Reduce installation/working area required by the equipments.

d) Control moisture and improve indoor air quality.

3) *Location of AHU* is significant in designing the HVAC system. If properly it reduces the supply ducts to be laid out. It also affects the activities that can be placed into surrounding area. It is always preferable to keep it to the perimeter of the building so that it can take fresh air which is required for ventilation.

Location of AHU is also important as it defines the zoning of the building. Zoning is directly related to comfort level of the occupants. Better the zone is defined better will be the comfort level. So prior to deciding the location of AHU it must be kept in mind what would be the various activities that are to be organized in the space. If a space has more number of occupant to serve or more heat generating equipment than it might need more than one AHU. Deciding this factor gives an idea of how much floor space will be occupied by HVAC system at a floor. This knowledge is needed when the sellable area to be offered needs to be calculated.

Need to determine the location of AHU is also important while developing the interior space. Since AHU houses a lot of equipment that might be source of noise or vibration they could affect the activities that are provided. It is advisable that AHU should be surrounded by those areas which have a low occupancy. Such areas could be toilets, store rooms staircases or any such area where presence of people is generally kept low.

4) *HVAC duct layout* must have a good design that is planned early in the construction process and understood by the designer and HVAC contractor. Every joint and bend in the duct system affects the efficiency of the system. The duct system must be properly installed with the correct amount of airflow. The duct system must be air sealed, insulated and appropriately sized.

    a) Building core and AHU should be such designed such the duct layout is minimum possible. More the volume of supply duct is laid out less effective the HVAC system becomes and it also increases the cost of installation as well as the running cost. It also affects the ceiling quality where mostly HVAC ducts run.

    b) Ducts can be used with structural members. When we talk of multi-storied construction of buildings RCC has a limit because of its structural and load aspects, whereas steel construction can be used in such cases. When steel sections are used they provide as a flexibility to use them to carry out ducting with creating additional shafts. For example if a C-section is used in a building then it is quite easy to integrate the duct in building structure.

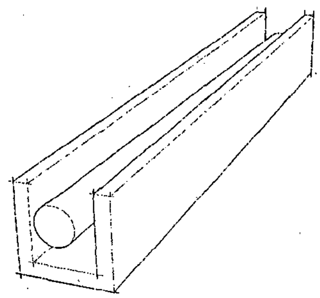


Fig 6.1Illustration showing a Supply duct running through a C-section.

Source: Author

There are a number of possibilities of arranging the supply ducts with different components of structure and design used in the building. All that needs to be done is to identify those components and find out various possible ways in which it can be used.

c) Shape and form of duct is also important in HVAC system. They effect the ease with they can be fixed (as discussed earlier circular duct have lower friction losses but more difficult in fixing whereas rectangular/square ducts are easy to install but have higher friction losses).

5) *Effect of HVAC on Structure*

As discussed earlier the structural members of a building can be integrated with supply ducts to make the HVAC system more efficient. In addition to it there are also other affects of HVAC on structure which could be the effect of acoustics and seismic consideration (*Details already discussed in chapter 4*). Wherever such concern arises structure must be carefully designed so that the negative effects of the HVAC system are not carried on to other parts of the building.

It should be kept in mind that under no case structural safety should be compromised on the behalf of HVAC system.

In short it can summarize that an understanding and careful planning of the HVAC system will make office buildings more efficient, both functionally and aesthetically.

APPENDIX 1

Concept of Shared Tenant Services:

While shared tenant services are a relatively new idea, it has great potential. Such a concept could dramatically affect the long-awaited move toward the automated office by making sophisticated technology--advanced data and voice communications--available to them at a fraction of what it would cost to buy their own systems. All the companies in the same building complex share the overall expense.

Basically under this concept it is supposed that various features like elevators, ample parking, coffee shop, air conditioning and convenient access to major roads and public transportation are not generated by individuals / tenants of a building but a third party does the same.

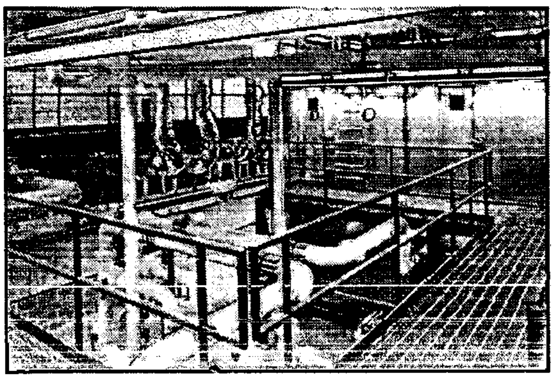
Other method for provision of services in such type of buildings would be when all the tenants get their services on individual basis. However if this method is employed gross cost of services tends to be very high, thus many users may be unable to use many of the services which otherwise would be available.

Thus if services are offered by a third party to all the users it would be more effective use of the resource and higher quality of service as compared to individual efforts.

APPENDIX 2

Mechanical floor in a building

A mechanical floor, mechanical penthouse, or mechanical level is a floor of a high-rise building that is dedicated to mechanical and electronics equipment. "Mechanical" is the most commonly-used term, but words such as *utility, technical, service*, and *plant* are also used. They are present in all tall buildings including the world's tallest skyscrapers with significant structural, mechanical and aesthetics concerns.



Mechanical Floor in a building

Source: http://dels.nas.edu/ilar_n/ilarjournal/46_1/graphics/46_1_25f1.jpg

While most buildings have mechanical rooms, typically in the basement, tall buildings require dedicated floors throughout the structure for this purpose, for a variety of reasons discussed below. Because they use up valuable floor area (just like elevator shafts), engineers try to minimize the number of mechanical floors while allowing for sufficient redundancy in the services they provide. As a rule of thumb, skyscrapers require a mechanical floor for every 10 tenant floors (10%) although this percentage can vary widely (see examples below). In some buildings they are clustered in groups that divide the building into blocks, in others they are spread evenly through the structure, in others still they are mostly concentrated at the top.

Mechanical floors are generally counted in the building's floor numbering (this is required by some building codes) but are accessed only by service elevators. In some legislation they have been excluded from maximum floor area calculations, leading to significant increases in building sizes.

APPENDIX 3

Major terms in HVAC

1) **Air Change per Hour (ACH)**

   The number of times per hour that the volume of a specific room or building is supplied or removed from that space by mechanical and natural ventilation.

2) **Air handler, or air handling unit (AHU)**

   Central unit consisting of a blower, heating and cooling elements, filter racks or chamber, dampers, humidifier, and other central equipment in direct contact with the airflow. This does not include the ductwork through the building.

3) **British thermal unit (BTU)**

   Any of several units of energy (heat) in the HVAC industry, each slightly more than 1 kJ. One BTU is the energy required to raise one pound of water one degree Fahrenheit, but the many different types of BTU are based on different interpretations of this "definition". In the United States the power of HVAC systems (the rate of cooling and dehumidifying or heating) is sometimes expressed in BTU/hour instead of watts.

4) **Coil**

   Equipment that performs heat transfer when mounted inside an Air Handling unit or ductwork. It is heated or cooled by electrical means or by circulating liquid or steam within it. Air flowing across it is heated or cooled.

5) **Controller**

   A device that controls the operation of part or all of a system. It may simply turn a device on and off, or it may more subtly modulate burners, compressors, pumps, valves, fans, dampers, and the like. Most controllers are automatic but have user input such as temperature set points, e.g. a thermostat. Controls may be analog, or digital, or pneumatic, or a combination of these.

6) Delta T

Delta T is a reference to a temperature difference. It is used to describe the difference in temperature of a heating or cooling fluid as it enters and as it leaves a heat transfer device. This term is used in the calculation of coil efficiency.

7) Fan-coil unit (FCU)

A small terminal unit that is often composed of only a blower and a heating and/or cooling coil (heat exchanger), as is often used in hotels, condominiums, or apartments. One type of fan coil unit is a unit ventilator.

8) Condenser

A component in the basic refrigeration cycle that ejects or removes heat from the system. The condenser is the hot side of an air conditioner or heat pump. Condensers are heat exchangers, and can transfer heat to air or to an intermediate fluid (such as water or an aqueous solution of ethylene glycol) to carry heat to a distant sink, such as ground (earth sink), a body of water, or air (as with cooling towers).

9) Constant air volume (CAV)

A system designed to provide a constant air volume per unit time. This term is applied to HVAC systems that have variable supply-air temperature but constant air flow rates. Most residential forced-air systems are small CAV systems with on/off control.

10) Variable Air Volume (VAV) System

A space conditioning system that maintains comfort levels by varying the volume of conditioned air. This system delivers conditioned air to one or more zones. The duct serving each zone is provided with a motorized damper that is modulated by a signal from the zone thermostat.

11)Damper

A plate or gate placed in a duct to control air flow by introducing a constriction in the duct.

12)Evaporator

A component in the basic refrigeration cycle that absorbs or adds heat to the system. Evaporators can be used to absorb heat from air (by reducing temperature and by removing water) or from a liquid. The evaporator is the cold side of an air conditioner or heat pump.

13)Fresh air intake (FAI)

An opening through which outside air is drawn into the building. This may be to replace air in the building that has been exhausted by the ventilation system, or to provide fresh air for combustion of fuel.

14)Heat load, heat loss, or heat gain

Terms for the amount of heating (heat loss) or cooling (heat gain) needed to maintain desired temperatures and humidity in controlled air. Regardless of how well-insulated and sealed a building is, buildings gain heat from warm air or sunlight or lose heat to cold air and by radiation. Engineers use a heat load calculation to determine the HVAC needs of the space being cooled or heated.

15)Packaged terminal air conditioner (PTAC)

An air conditioner and heater combined into a single, electrically-powered unit, typically installed through a wall and often found in hotels.

16)Louvers

Blades, sometimes adjustable, placed in ducts or duct entries to control the volume of air flow. The term may also refer to blades in a rectangular frame placed in doors or walls to permit the movement of air.

17)Makeup air unit (MAU)

- An air handler that conditions 100% outside air. MAUs are typically used in industrial or commercial settings, or in **once- through** (blower sections that only blow air one-way into the building), **low flow** (air handling systems that blow air at a low flow rate), or **primary-secondary** (air handling systems that have an air handler or rooftop unit connected to an add-on makeup unit or hood) commercial HVAC systems.

18)Roof-top unit (RTU)

An air-handling unit, defined as either "recirculating" or "once-through" design, made specifically for outdoor installation. They most often include, internally, their own heating and cooling devices. RTUs are very common in some regions, particularly in single-story commercial buildings.

19)Variable air volume (VAV) system

An HVAC system that has a stable supply-air temperature, and varies the air flow rate to meet the temperature requirements. Compared to CAV systems, these systems waste less energy through unnecessarily-high fan speeds. Most new commercial buildings have VAV systems.

20)Thermal zone

A single or group of neighboring indoor spaces that the HVAC designer expects will have similar thermal loads. Building codes may require zoning to save energy in commercial buildings. Zones are defined in the building to reduce the number of HVAC subsystems, and thus initial cost. For example, for perimeter offices, rather than one zone for each office, all offices facing west can be combined into one zone. Small residences typically have only one conditioned thermal zone, plus unconditioned spaces such as unconditioned garages, attics, and crawlspaces, and unconditioned basements.

21)Air System Balancing

Adjusting airflow rates through air distribution system devices, such as fans and diffusers, by manually adjusting the position of dampers, splitter vanes, extractors, etc., or by using automatic control devices, such as constant air volume or variable air volume boxes.

22)Coefficient of Performance (COP)

Chiller efficiency measured in Btu output (cooling) divided by Btu input (electric power). Multiplying the COP by 3.412 yields the energy-efficiency ratio.

23)Constant Volume System

A space-conditioning system that delivers a fixed amount of air to each space. The volume of air is set during the system commissioning.

24)Economizer, Water-side

A system by which the supply air of a cooling system is cooled indirectly with water that is itself cooled by heat or mass transfer to the environment with the use of mechanical cooling.

25)Economizer, Air-side:

A duct and damper arrangement and automatic control system that together allow a cooling system to supply outdoor air to reduce the need for mechanical cooling during mild or cold weather.

26)Tons

One ton of cooling is the amount of heat absorbed by one ton of ice melting in one day, which is equivalent to 12,000 Btu/h or 3.516 thermal kW.

27)Energy-Efficiency Ratio (EER)

Performance of smaller chillers and rooftop units is frequently measured in EER rather than kW/ton. EER is calculated by dividing a chiller's cooling capacity (in Btu/h) by its power input (in watts) at full-load conditions. The higher the EER, the more efficient the unit.

28) ***Hydronic System Balancing***

Adjusting water flow rates through hydronic distribution system devices, such as pumps and coils, by manually adjusting the position of valves, or by using automatic control devices, such as flow control valves.

29) ***kW/ton Rating***

Commonly referred to as efficiency, but actually power input to compressor motor divided by tons of cooling produced, or kilowatts per ton (kW/ton). Lower kW/ton indicates higher efficiency.

30) Integrated Part-Load Value (IPLV)

This value attempts to capture more representative "average" chiller efficiency over a representative operating range. It is the efficiency of the chiller, measured in kW/ton, averaged over four operating points, according to a standard formula.

31) Return Air

Air from the conditioned area that is returned to the conditioning equipment for reconditioning. The air may return to the system through a series of ducts, plenums, and airshafts.

32) Seasonal Energy Efficiency Ratio (SEER)

SEER is a measure of equipment energy efficiency over the cooling season. It represents the total cooling of a central air-conditioner or heat pump (in kWh) during the normal cooling season as compared to the total electric energy input consumed during the same period.

33) Zone

A space or group of spaces within a building with heating and cooling requirements that are sufficiently similar so that desired conditions (e.g., temperature) can be maintained throughout using a single sensor (e.g., thermostat or temperature sensor).

BIBLIOGRAPHY

Books:

- Bahamon, Alejandro; Offices for Small Spaces; Harper Design International.
- Barton, Paul K.- Building services integration
- Cotroneo, Domenico-Object-oriented Design of an Intelligent Building Management System
- Chadderton, David V. - Building Service Engineering-4th Edition, Spon Press
- Edwards, Sandra; Office Systems; PBC International Inc.
- Grondzik, Walter; Vital Signs- HVAC Components and Systems
- Gupton, Guy W., HVAC control: operation and Maintenance, Lilmont; Fairmont Press, 1987.
- Haive R.W., HVAC System Design Handbook, McGraw Hill, 1997
- Hascher, Rainen –Office Building Design Manual
- Mull Thomas E., HVAC Principals and Application Manual, Tata McGraw Hill.
- McGuinnes W.J., Mechanical and Electrical Equipment for Building

Journals

- Energy Conservation Building Code tip sheet HVAC system, Version 1.0- March 2008.
- Langdon, F.J.; Modern Offices: a user survey, National Building Studies, Research Paper 41; London/HER MAJSTY'S STATIONARY OFFICE.
- Proceedings from the international conference on high-tech buildings held in London 1988, online publications.
- Satish Dhar; Gurgaon- a model city for the new India, A+D Nov 2007.

Websites:

- http://en.wikipedia.org
- www.sciencedirect.com
- http://www.tcil-india.com/new/html/intelbldg.htm
- http://propertybytes.com/?p=188
- www.lonix.org
- http://www.hvachome.net/
- http://epaper.timesofindia.com/

REFERENCES

- Barton, Paul K.- Building services integration
- Energy Conservation Building Code tip sheet HVAC system, Version 1.0- March 2008
- Grondzik, Walter; Vital Signs- HVAC Components and Systems
- Mull Thomas E., HVAC Principals and Application Manual, Tata McGraw Hill.
- McGuinnes W.J., Mechanical and Electrical Equipment for Building
- http://en.wikipedia.org