Indian Institute of Corporate Affairs at Manesar, Gurgaon is a high performance building

An Overview of Low Energy HVAC Systems for High Performance Buildings

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Introduction

The residential and commercial sector consumes approximately 25~35% of the total electricity usage of the country. Typically in a building:

- 57% of the building load is consumed by air conditioning equipment,
- 22% of the building load is consumed by area lights,
- 16% of the building load is consumed by miscellaneous equipment,
- 5% of the building load is consumed by ventilation equipment.

Today, the designing of energy efficient HVAC systems is more technologically challenging than ever before. While design innovations and product improvements promise sleeker, more versatile, more powerful and more energy efficient HVAC systems, the challenge today lies in identifying the most appropriate energy efficient product, or mix of products, for the application at hand to reduce Global Warming.

Vehicles and Buildings

When we buy a vehicle, generally we look for speed, acceleration, appearance, interior design, low maintenance cost, and fuel consumption (mileage).

About the Author

Syed Moazzam Ali is an M.Tech. (Mechanical Design) and IGBC-AP, with fifteen years of national and international experience in designing MEP services for residential, commercial and industrial buildings. He started his career as a lecturer in mechanical engineering, and then worked as a Senior HVAC Design Engineer in Jeddah, Saudi Arabia, where he was the MEP Project Leader. He is a Ph.D. Research scholar at JNTU, Hyderabad. He has conducted national and international training programs for various companies, engineering institutes, ISHRAE, FSAI and IEF (Indian Engineers Forum – Saudi Arabia). He has presented papers in national and international journals on energy efficient HVAC Systems, chilled beams, etc.

Dr. B. Balu Naik completed his Ph.D. in Energy Systems from JNTUH and is presently Deputy Director, UGC Academic Staff College, JNTUH. He has seventeen years of research and teaching experience, and has published fourteen papers. He was vice-president of JNTU College of Engineering Teachers Association, and is a governing body member of self-financed engineering colleges. He has worked in various capacities, including Head of the Centre for Nano Science & Technology.

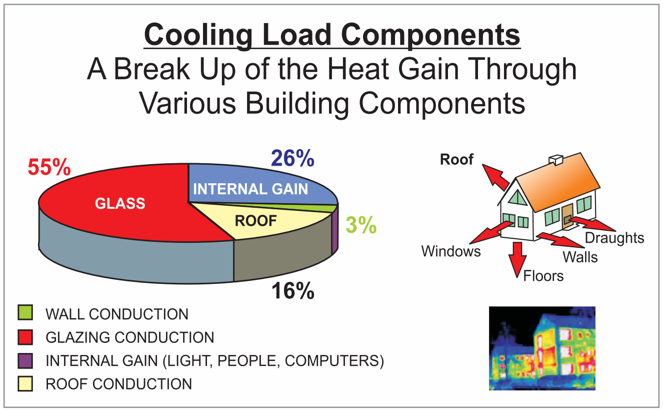

Figure 1: Cooling load components

We build or design buildings keeping in mind aesthetics, creativity, safety and security, quality of life, human comfort, indoor air quality, etc. Energy performance kWh/sqft of the building is an important parameter. It can be calculated by dividing the annual energy consumption by the total carpet area of the building.

Just as a car that gives a mileage above 25km/lit is considered fuel efficient, a building with energy consumption between 10 and 25 kWh/sqft is considered a high performance building. To predict the energy consumption value of a building, there are several energy simulation software such as HAP and eQUEST, which can calculate kWh/sqft by evaluating the overall energy consumed by the building for 8,760 hours (one year).

Building Performance

For evaluating a building's performance, we need to check kWh/sqft and sqft/TR values, which would be in the following ranges:

- Annual energy consumption per unit area:10 to 25 kWh/sqft – the lower, the better.
- Carpet area per unit AC load: 150 to 300 sqft per TR – the higher, the better.

Cooling Load Estimation

For HVAC design, the first step is to decide how much cooling is required in the zone. To estimate the cooling load we can use HAP (Hourly Analysis Program) software. This gives us the tonnage and air quantity in cfm.

There are tools like eQUEST which can be used to compare energy used and operating cost of alternate system design in order to choose the optimal design. Software energy modeling using eQUEST can be done for various shapes of the building.

Cooling Load Components

Heat gain in a building comprises of sensible heat and latent heat. Heat gain can be through people, building envelope construction like wall, glass and roof, and because of lighting or electrical appliances. It is observed that most of the heat is gained through glass (about 55%), followed by internal gain through electrical appliances, occupants, lighting etc. (about 26%), roof (about 16%), and walls (about 3%).

In heat load calculation, orientation of building and envelope measures such as glazing, shading, sky lighting and wall, play important roles in determining the kWh/sqft value of the building.

Outdoor Design Conditions

Outside DBT and WBT affect heat load calculation. We get the data for city temperature from ISHRAE or NBC Part 8/ Section 3.

Indoor Design Conditions

Indoor DBT and RH recommended values can be selected from ISHRAE for residential buildings, commercial buildings and factories. We can design the system to maintain these conditions.

Fresh Air

Fresh air supply is required to maintain an acceptably non-odorous atmosphere and to dilute the carbon dioxide exhaled. To calculate the fresh air quantity, we can follow ASHRAE 62.1-2004 guidelines for cfm/ft^2 and cfm/person requirements.

Improving Air Side Efficiency

The air side system can be made more efficient by using:

a) Outside Air Economiser

Return air from a zone is taken back to the AHU, where it is cooled and mixed with fresh air and supplied to the zone. But, if outside air is cooler than the return air, outside air economizer relieves all return air and takes in 100% fresh air. It reduces the load on cooling coils and improves the efficiency of the system.

b) Variable Air Volume (VAV)

Using VAV boxes instead of the conventional constant air volume system results in more energy-efficient air conditioning.

c) Demand Controlled Ventilation (DCV)

The CO_2 sensor senses the CO_2 level in the zone and signals the control panel, which in turn directs the fresh air damper to supply fresh air to dilute CO_2

d) Heat Recovery Wheel (HRW)

In Air Handling Units, the return air from the room is cool compared to the outside fresh air. The cool return air can be used to pre cool the ambient hot fresh air. This process is called heat recovery and it can be achieved by using a Heat Recovery Wheel.

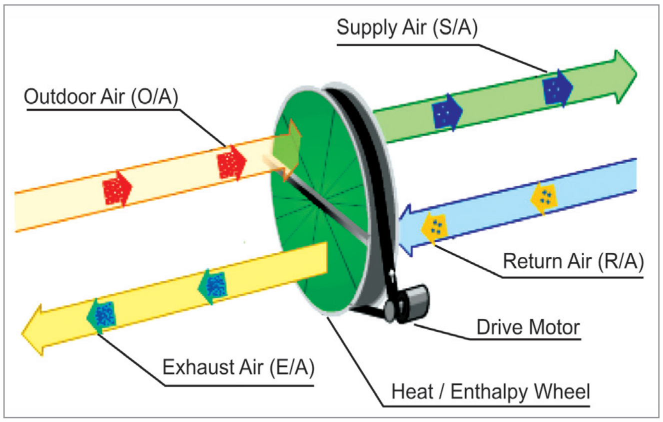

Figure 2: Heat recovery wheel

An HRW has two sections. One part of the wheel receives ambient hot fresh air and the other part receives cool return air from the room; this causes one part of the wheel to become cool and the other part to become hot. After a time period, the wheel is rotated and the cool part starts pre cooling the incoming fresh air; this reduces the load on the cooling coil.

In a hospital operation theater where 100% fresh air is supplied, we can use a glycol run around cycle, where only glycol would circulate and the chances of return air bypass are reduced.

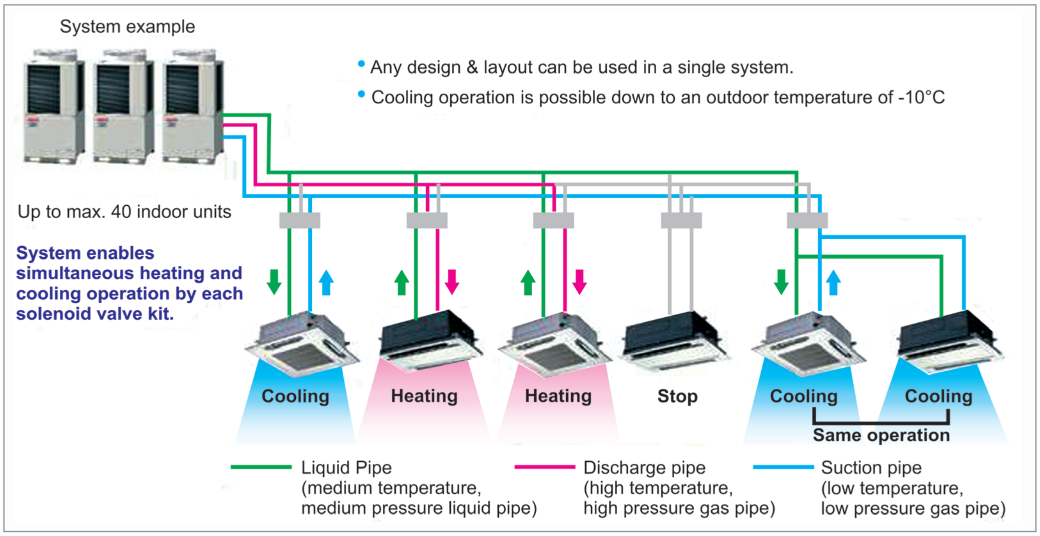

Figure 3: Variable refrigerant flow

The advantages of an HRW are that it reduces cooling and heating loads, downsizes equipment and ductwork, and enables increase in ventilation.

The disadvantages are that its first cost is high, fan energy consumption increases due to static pressure, and it requires air filtration.

e) Indoor Fan – Variable Speed Drive (VSD)

Indoor supply fans can be connected to VSD to match the demand of the supply air in the room, resulting in energy savings.

Improving High Side Efficiency

a) Variable Refrigerant Flow (VRF)

By using a VRF system, we can connect multiple indoor units to one outdoor unit to ensure design flexibility, space conservation and energy efficiency with modular switching.

b) Water Side Economizer

If the outlet temperature of cooling tower water is chilled because of low ambient temperature that happens at night time or during winter, we can directly supply cooling tower water to FCUs and AHUs using water side economizer, which results in energy efficiency.

c) Cooling Tower with Variable Air Flow

Cooling towers with variable air flow give power saving of the order of 15 to 20%.

d) Cold Air System: Glycol

In cold air system, glycol is used as the refrigerant. The chiller operates at 3°C and 12°C. Air supply is at 13°C. This arrangement gives better humidity control, requires less pumping and fan energy, and conserves energy.

e) Thermal Storage System

Thermal energy storage is a method to store thermal energy in reservoirs for later use. It works by creating ice at night when the electricity is less expensive, and then using the ice to cool the building air during daytime. This system is good for demand side management, and may reduce HVAC capital cost and energy consumption.

f) Primary-Secondary Distribution (Variable Flow)

ASHRAE/IES Standard 90.1-1989 – *Energy Efficient Design of New Buildings Except Low-Rise Residential Buildings* requires that "all HVAC hydronic systems having a total pump system power exceeding 10hp must be capable to flow at 50% of design value or less." This standard highly recommends the use of primary-secondary system for large complexes.

A primary-secondary pumping scheme divides the chilled water system into two distinct circuits (loops) that are hydraulically separated by a neutral bridge (de-coupler).

i. Primary circuit is the place where chilled water is produced, and its principal components are the chiller and pumps. The primary pumps are typically constant volume, low head pumps intended to provide a constant flow through the evaporator of the chiller. These are usually placed in tandem with each chiller, though they can also be arranged in a common header.

ii. The secondary circuit is responsible for the distribution of the chilled water to the terminal units. Among the components of the secondary circuit are pumps, terminal units such as fan-coils and AHUs, and control valves. The secondary pumps can be constant speed or variable speed, and are sized to move the flow rate and overcome the pressure drop of secondary circuit only.

iii. The neutral bridge consists of two tees that are typically located at the suction header of the secondary pumps and at the suction header of the primary pumps and connected by a de-coupling pipe. This de-coupler separates the primary and secondary loops. This common pipe is designed for negligible pressure drop at design flow. A well designed, low pressure-drop common pipe is the heart of primary-secondary pumping, allowing the two pumps to operate independently.

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Innovative Technologies

Earth Air Tunnel

A ground-coupled heat exchanger is an underground heat exchanger loop that can capture or dissipate heat to or from the ground. It uses the earth's near constant subterranean temperature to warm or cool air or other fluids for residential, agricultural or industrial uses. If building air is blown through the heat exchanger for heat recovery ventilation, it is called an earth tube (also known as earth cooling tube or earth warming tube) in Europe, and earth-air heat exchangers (EAHE or EAHX) in North America. These systems are known by several other names, including air-to-soil heat exchanger, earth channels, earth canals, earth-air tunnel systems, ground tube heat exchanger, hypocausts, subsoil heat exchangers, underground air pipes, etc.

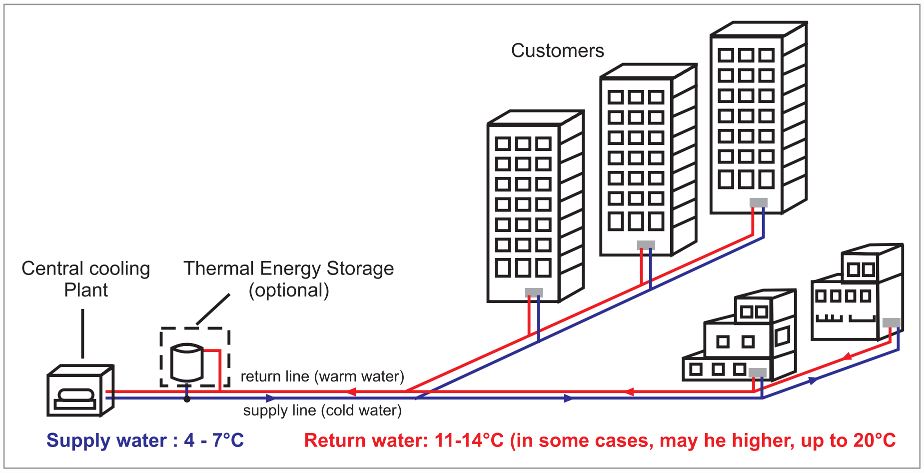

Figure 4: Schematic of a district cooling system

Geothermal Energy System

Geothermal energy is thermal energy generated and stored in the earth. Thermal energy determines the temperature of matter. Earth's geothermal energy originates from the original formation of the planet (20%) and from radioactive decay of minerals (80%). The geothermal gradient, which is the difference in temperature between the core of the planet and its surface, drives a continuous conduction of thermal energy in the form of heat from the core to the surface. The adjective geothermal originates from the Greek roots *geo*, meaning earth, and *thermos*, meaning heat.

The heat that is used for geothermal energy can be stored deep within the earth, all the way down to the earth's core – 4,000 miles down. At the core, temperatures may reach over 9,000 degrees Fahrenheit. Heat conducts from the core to the surrounding rock. Extremely high temperature and pressure cause some rock to melt into what is commonly known as magma. Magma convects upward since it is lighter than solid rock. It heats rock and water in the crust, sometimes up to 700 degrees Fahrenheit.

From hot springs, geothermal energy has been used for bathing since Paleolithic times and for space heating since ancient Roman times, but it is now better known for electricity generation. Worldwide, about 10,715 megawatts (MW) of geothermal power is online in 24 countries. An additional 28 gigawatts of direct geothermal heating capacity is installed for district heating, space heating, spas, industrial processes, desalination and agricultural applications.

Geothermal power is cost effective, reliable, sustainable, and environmental friendly, but has historically been limited to areas near tectonic plate boundaries. Recent technological advances have dramatically expanded the range and size of viable resources, especially for applications such as home heating, opening a potential for widespread exploitation. Geothermal wells release greenhouse gases trapped deep within the earth, but these emissions are much lower per energy unit than those of fossil fuels. As a result, geothermal power has the potential to help mitigate global warming if widely deployed in place of fossil fuels.

The Earth's geothermal resources are theoretically more than adequate to supply humanity's energy needs, but only a very small fraction may be profitably exploited. Drilling and exploration for deep resources is very expensive. Forecasts for the future of geothermal power depend on assumptions about technology, energy prices, subsidies, and interest rates.

Thermal Mass Storage System

Thermal mass is a concept in building design which describes how the mass of the building provides 'inertia' against temperature fluctuations, sometimes known as the thermal flywheel effect. For example, when outside temperatures are fluctuating throughout the day, a large thermal mass within the insulated portion of a house can serve to 'flatten out' the daily temperature fluctuations, since the thermal mass will absorb thermal energy when the surroundings are higher in temperature than the mass, and give thermal energy back when the surroundings are cooler, without reaching thermal equilibrium. This is distinct from a material's insulation value, which reduces a building's thermal conductivity, allowing it to be heated or cooled relatively separate from the outside, or even just retain the occupants' thermal energy longer.

Scientifically, thermal mass is equivalent to thermal capacitance or heat capacity, the ability of a body to store thermal energy. It is typically referred to by the symbol C_{th} and measured in units of J/°C or J/°K (which are equivalent). Thermal mass may also be used for bodies of water, machines or machine parts, living things, or any other structure or body in engineering or biology. In those contexts, the term 'heat capacity' is typically used instead.

District Cooling System

District cooling is a utility which provides chilled water to customer buildings *via* a metered and controlled process. The cooling (actually heat rejection) is usually provided from a dedicated cooling plant.

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District cooling has its roots in early nineteenth-century schemes to distribute clean, cool air to houses through underground pipes. Many early systems supplied ammonia and brine for refrigeration of meat, as well as cooling restaurants, theatres and other public buildings. Large district cooling systems are now widely used in countries like the UAE, Qatar etc.

The benefits of district cooling system include better building design – a step towards more efficient green buildings, improving the city's overall look, better environment – less CO_2 production, less refrigerant leakage and less noise, and lower government spending – reduced electrical infrastructure. District cooling is for the benefit of urbanization and green buildings.

Radiant Cooling

A radiant cooling system refers to a temperature-controlled surface that cools indoor temperatures by removing sensible heat, and where more than half of heat transfer occurs through thermal radiation. Heat will flow from objects, occupants, equipment and lights in a space to a cooled surface as long as their temperatures are warmer than the cooled surface and they are within the line of sight. The process of radiant exchange has negligible effect on air temperature, but through the process of convection, the air temperature is lowered when air comes in contact with the cooled surface. Radiant cooling systems use the opposite effect of radiant heating systems, which rely on the process of heat flow from a heated surface to objects and occupants.

Chilled Beam

A chilled beam is a type of convection HVAC system designed to heat or cool large buildings. Water through pipes is passed through a 'beam' (a heat exchanger) suspended a short distance from the ceiling of a room. As the beam chills the air around it, the air becomes denser and falls to the floor. It is replaced by warmer air moving up from below, causing a constant flow of convection and cooling the room. Heating works in much the same fashion, similar to a steam radiator. There are two types of chilled beams – active and passive.

Some passive types rely solely on convection, while there is a radiant-convective passive type that cools through a combination of radiant exchange (35%) and convection (65%) which can provide higher thermal comfort levels. The active type (also called an 'induction diffuser') uses ducts to push ('induce') air toward the unit (increasing its heating and cooling capacity).

The disadvantages of chilled beams are high cost, condensation, and difficulty in lighting coordination.

Under Floor Air Distribution (UFAD)

UFAD systems rely on the natural stratification that occurs when warm air rises due to thermal buoyancy. In a UFAD design, conditioned air stays in the lower, occupied part of the room, while heat sources such as occupants and equipment generate thermal plumes, which carry the warm air and heat source generated pollutants towards the ceiling where they are exhausted through the return air ducts. The temperature stratification created by the UFAD system has implication for space set points. Most of an occupant's body is in an area that is colder than the temperature at thermostat height; therefore, current practice recommends raising thermostat set points compared to traditional overhead systems. The optimal ventilation strategy controls the supply outlets to limit the mixing of supply air with room air to just below the breathing height of the space. Above this height, stratified and more polluted air is allowed to exist. The air that the occupant breathes will have a lower concentration of contaminants compared to conventional uniformly mixed systems.

Many factors, including ceiling height, diffuser characteristics, number of diffusers, supply air temperature, total flow rate, cooling load and conditioning mode affect the ventilation efficiency of UFAD systems. Swirl diffusers and perforated floor-panel diffusers have been shown to create a low air velocity in the occupied zone, while linear diffusers create the highest velocity in the occupied zone, disturbing thermal stratification and posing a potential draft risk. Additionally, floor diffusers add an element of personal control within the reach of the occupant, as users can adjust the amount of air that is delivered by the diffuser by rotating the diffuser top.

White Roof Coating

A white coating consists of a polymeric binder blended with pigments and other additives to provide two main benefits: (i) protection of roof membranes for longer roof life cycles; and (ii) reflectivity of solar radiation for lower air conditioning costs.

White roof coatings are applied on a variety of roof substrates or membranes because they provide protection against water, chemicals or physical damage. Additionally, they protect a roof against excessive temperatures and UV radiation by reflecting visible light and stopping ultraviolet radiation.

White roof coatings provide three key attributes as part of a roofing system: (i) the ability to help shed water and keep interiors dry; (ii) the ability to help reduce cooling costs for buildings with AC units, and to help reduce interior temperatures on buildings with no cooling units; and (iii) the ability to protect and prolong the roof system life cycle by reducing the 'thermal shock' stress associated with large temperature changes.

Conclusion

Indeed, today the emphasis is no more on understanding air conditioning 'products' but on creating 'solutions' – and not just solutions, but 'customized low energy solutions' that suit specific cooling needs of specific businesses and establishments. The consultant or designer who understands the dynamics of the client's business is more likely to offer better long term cooling solutions than one who does not.

It is a truism that man works effectively in conductive environments. The emergence of HVAC made it possible for man to maintain himself in a comfort zone irrespective of seasonal variations within his surroundings. It is the cost and degree of comfort that determine to what extent the function of air conditioning is needed. ❖