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Kolmetz Handbook Of Process Equipment Design

HVAC (HEATING, VENTILATING, AND AIR CONDITIONING) SYSTEM SELECTION, SIZING AND TROUBLESHOOTING

(ENGINEERING DESIGN GUIDELINES)

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INTRODUCTION

Scope

Heating, Ventilating and Air Conditioning, HVAC is a huge field. HVAC Systems include a range from the simplest hand – stoked stove, used for comfort heating, to extremely reliable total air – conditioning system found in submarines and space shuttles. Cooling equipment varies from the small domestic unit to refrigeration machines that are 10000 times the size, which are used in industrial processes.

HVAC evolved based on technological discoveries, such as refrigeration, that were quickly adopted for food storage; economic pressures, such as the reduction in ventilation rates after the 1973 energy crisis; computerization and networking, used for sophisticated control of large complex systems serving numerous buildings; medical discoveries, such as the effect of second hand smoke on people, which influenced ventilation methods.

Modern air conditioning is critical to almost every facet of advancing human activity. Although there have been great advances in HVAC, there are several areas where active research and debate continue. Depending on the complexity of the requirements, the HVAC designer must consider many more issues than simply keeping temperatures comfortable. This guideline will introduce the fundamental concepts that are used by designers to make decisions about system design HVAC.

HVAC

HVAC (Heating, Ventilating and Air Conditioning) is the technology of indoor and vehicular environmental comfort. Its goal is to provide thermal comfort and acceptable indoor air quality. HVAC System design is a subdiscipline of mechanical engineering, based on the principles of the thermodynamics, fluids mechanics and heat transfer. Refrigeration is sometimes added to the field's abbreviation as HVAC&R or HVACR, or ventilating is dropped as in HVACR (Such as the designation of HCAR-rated circuit breakers).

HVAC is important in the design of medium to large industrial and office buildings such as skyscrapers and in marine environments such as aquariums, where safe and healthy building conditions are regulated with respect to temperature and humidity, using fresh air from outdoors.

Ventilating or ventilation (the V in HVAC) is the process of "changing" or replacing air in any space to provide high indoor air quality which involves temperature control, oxygen replenishment, and removal of moisture, odors, smoke, heat, dust, airborne bacteria and carbon dioxide. Ventilation removes unpleasant smells and excessive moisture, introduces outside air, keeps interior building air circulating, and prevents stagnation of the interior air.

Ventilation includes both the exchange of air to outside as well as circulation of air within the building. It is one of the most important factors for maintaining acceptable mechanical/fored and natural types.

The purpose of an HVAC system is to provide the heating, cooling, and ventilation requirements of a building over a range of ambient conditions specific to the building location. A system must be designed to cope with the maximum value of each of these requirements. The degree to which an HVAC system fails to match the requirements and overheats, overcools or overventilates the building space determines the amount of energy being wasted.

A Particular system may have one or more purposes.

- To maintain comfort by controlling temperature and humidity within acceptable limits.
- To maintain air quality within acceptable limits of carbon dioxide, oxygen and odor content.
- To remove airbornerne contaminants produced by processes and occupants.
- To remove internal heat gain produced by processes, building services and occupants.
- To provide special environments control for equipment and processes.

The processes by which effective control of parameters in an air conditioned space is maintained are as follows:

1. Heating
2. Cooling
3. Humidifying
4. Dehumidifying
5. Cleaning
6. Ventilating
7. Air movement

Energy consumption in HVAC systems is affected by the following:

- Building enclosure heat loss and heat gain.
- Heat loss and gain owing to infiltration of outdoor air and exfiltration of indoor air.
- Heating and cooling of ventilating air.
- Amount of heat produced by internal sources.

- Fan energy for circulation of conditioning air.
- Pump energy for circulation of heating and cooling liquid.
- Distribution system loss.

Heat exchange in building system is normally defined under two categories.

- Sensible heat which is the heat required to raise or lower the temperature of a substance such as air or water.
- Latent heat which is the heat required to cause a change of state of a substance such as the conversion of water to ice (latent heat of fusion), or water to vapor (latent heat of vaporization).

The HVAC designer must be skilled and experienced to work on facilities. He/she should be sensitive to the threats posed and should be able to address and incorporate the appropriate detail following appraisal of the various design parameters. He/she should have:

1. Knowledge of Area Classification
   - Potential hazardous gases and their likely sources
   - Segregation of hazardous and non-hazardous areas
   - Pressure differential between segregated areas

2. Knowledge of Fire Safety
   - Fire protection design and its integration with HVAC systems
   - Passive fire protection measures such as compartmentation, zoning, fire proofing, right classification of fire rating materials and pressurization.
   - Smoke and gas control philosophy (i.e. prevention of ingress of smoke or gas into accommodation spaces, control stations, enclosed escape routes or enclosed muster areas).

3. Knowledge of HVAC System & Equipment
   - Equipment selection appropriate to operating conditions (corrosive and saline environment)

- Orientation of a fixed platform in order to maximize benefit from natural ventilation
- Standardization of components used in HVAC systems in order to provide interchangeability between systems
- Equipment redundancy and standby philosophy

4. Knowledge of Control Philosophy
    - Emergency shutdown and emergency power philosophies
    - DCS
    - Field Instrumentation

HVAC History

For millennia, people have used fire for heating, initially, the air required to keep the fire going ensured adequate ventilation for the occupants. However, as central furnaces with piped steam or hot water became available for heating, the need for separate ventilation became apparent. By the late 1880s, rules of thumb for ventilation design were developed and used in many countries.

In 1851 Dr. John Gorrie was granted U.S patent 8080 for a refrigeration machine. By the 1880s, refrigeration became available for industrial purposes. Initially, the two main uses were freezing meat for transport and making ice. However, in the early 1900s there was a new initiative to keep buildings cool for comfort. Cooling the New York Stock Exchange, in 1902, was one of the first comfort cooling systems. Comfort cooling was called "air conditioning".

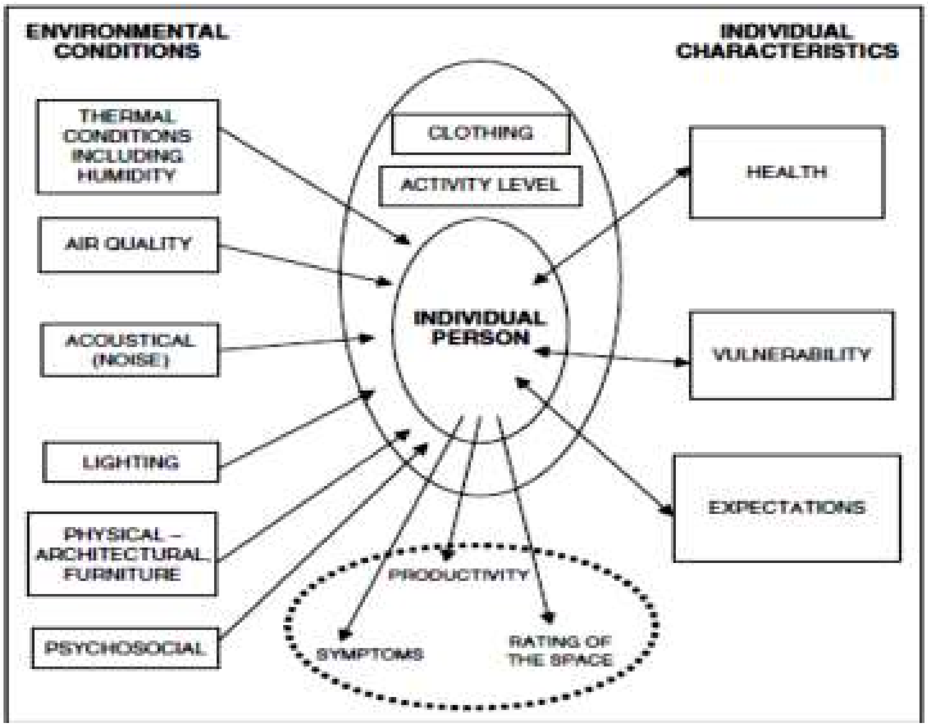

Figure 1: Personal Environment Model ("The construct of comfort a framework for research" by W.S. Cain)

Figure 1 is a simplified diagram of the three main groups of factors that affect comfort.

1) Attributes of the space influencing comfort

There are six attributes of the space influence comfort: thermal, air quality, acoustical, lighting, physical, and psychosocial. Of these only the thermal condition and air quality can be directly controlled by the HVAC system. The acoustical (noise) environment may be influence how the HVAC is perceived. The psychosocial environment in the space is largely dependent on the occupants, rather than the design of the space.

1. Thermal conditions include more than simply the air temperature. If the air speed is very high, the space will be considered drafty. If there is no air movement, occupants may consider the space ‘stuffy’. The air velocity in a mechanically conditioned space is largely controlled by the design of the system.

   On the other hand, suppose the occupants are seated by a large unshaded window. If the air temperature stays constant, they will feel very warm when the sun is shining on them and cooler when clouds hide the sun. This is a situation where the architectural design of the space affects the thermal comfort of the occupant, independently of the temperature of the space.

2. The air quality in a space is affected by pollution from the occupants and other occupants and other contents of the space. This pollution is, to a greater or lesser extent, reduced by the amount of outside air brought into the space to dilute the pollutants. Typically, densely occupied spaces, like movie theatres, and heavy polluting activities, such as cooking, require a much higher amount of outside air than an office building or a residence.
3. The acoustical environment may be affected by outside traffic noise, other occupants, equipment, and the HVAC system. Design requirements are dictated by the space. A designer may have to be very careful to design a virtually silent system for a recording studio. On the other hand, the design for a noisy foundry may not require any acoustical design consideration.
4. The lighting influences the HVAC design, since all lights give off heat. The lighting also influences the occupant’s perception of comfort. If the lights are much too bright, the occupants may feel uncomfortable.
5. The physical aspects of the space that have an influence on the occupants include both the architectural design aspects of the space, and the interior design. Issues like chair comfort, the height of computer keyboards, or reflections off computer screens have no relation to the HVAC design, however they may affect how occupants perceive the overall comfort of the space.
6. The psychosocial situation, the interaction between people in the space, is not a design issue but can create strong feelings about the comfort of the space.

2) Characteristic of the individual that influence comfort

All people bring with them health, vulnerabilities and expectations. Their health may be excellent, and they may not even notice the draft from the air conditioning. On the other hand, if the occupants are patients in a doctor's waiting room, they could perceive a cold draft as very uncomfortable and distressing. The occupants can also vary in vulnerability. For example, cool floors will likely not affect an active adult who is wearing shoes. The same floor may be uncomfortably cold for the baby who is crawling around on it. Lastly the occupants bring their expectations. When we enter a prestigious hotel, we expect it to be comfortable. When we enter an air – conditioned building in summer, we expect it to be cool. The expectations may be based on previous experience in the space or based on the visual perception of the space.

3) Clothing and Activity as a function of individual Comfort

The third group of factors influencing comfort is the amount of clothing and the activity level of the individual. If we are wearing light clothing, the space needs to be warmer for comfort than if we are heavily clothed. Similarly, when we are involved in strenuous activity, we generate considerable body heat and are comfortable with a lower space temperature. In the summer, in many business offices, managers wear suits with shirts and jackets while staff members may have bare arms, and light clothing. The same space may be thermally comfortable to one group and uncomfortable to the other. There is much more to comfort than most people realize. These various aspects of comfort will be covered in more detail in later chapters.

HVAC Design Criteria

1) Design Criteteria – 1

The control system :

- Must meet the needs of the process
- Should control the process as directly as possible
- Must be designed to work with the HVAC system and vice versa

2) Design Criteria – 2

The control system :

- Should minimize energy consumption while meeting process goals
- Must meet the budget
- Must be designed for maximum simplicity
- Must be easy to understand and maintain

General Design Considerations

1) Pre-design Phase

Before a mechanical engineer can design a HVAC system, a building program must be created. This is usually prepared by the client or his/her consultants. The program establishes space needs and develops a project budget. The building program should include, but need not be limited to, the following:

- The client's objectives and strategies for the initial and future functional use of the building, whether it be a single or multiple – family dwelling or a commercial, industrial, athletic, or other facility.
- A clear description of function for each discrete are within the building.
- The number, distribution, and usage patterns of owner – provided heat – producing equipment.
- The geographic site location, access means, and applicable building and zoning codes.
- The proposed building area, height, number of stories, and mechanized circulation requirements.
- The owner's capital cost and operating cost budgets.
- A clear statement of anticipated project schedule and or time constrains.
- A clear statement of required or expected project quality.

Although some of this information may not be available before the mechanical designer start to work, it must be obtained as soon as possible to ensure that only those HVAC&R systems that are compatible with the building program are considered.

While the architect prepares the general buildings program, the mechanical engineers have the responsibility of developing a discipline – specific program even though some of this information may be provided by the architect or owner. The building program and use profile provided by the owner or architect and the HVAC&R system program developed by the engineer in response to the building functional program should be explicitly documented for future reference. This documentation is termed the Owner's Project Requirements, and it provides the context for all design decisions. All changes made to the program during the design process should be recorded so that the documentation is always up to date.

The information that should be contained in the HVAC&R system program includes:

- Design outdoor dry-bulb and wet-bulb temperatures (absolute and coincident)
- Heating and cooling degree – days/hours
- Design wind velocity (and direction) for winter and summer,
- Applicable zoning, building, mechanical, fire, and energy codes, and
- Rate structure, capacity, and characteristic of available utilities and fuels.

Additional information regarding solar radiation availability and subsurface conditions would be included if use of a solar thermal system or ground – source heat pump was anticipated.

The environmental conditions to be maintained for each building space should be defined by:

- Dry-bulb and wet-bulb temperatures during daytime occupied hours, nighttime occupied hours, and occupied hours.
- Ventilation and indoor air quality requirements.

- Any special conditions, such as heavy internal equipment loads, unusual lighting requirements, noise-and-vibration-free areas, humidity limits, and redundancy for life safety and security and
- Acceptable range of conditions for each of the above.

An understanding of the functional use for each area is essential to select appropriate HVAC&R systems and suitable control approaches because the capabilities of Proposed systems must be evaluated and compared to the indoor environmental requirements.

2) Design Phase

In conventional (business as usual) building projects, serious work on HVAC&R system design typically occurs in the later stages of the design phase. Projects where energy efficiency and/or green building design are part of the intent or building types where HVAC&R systems are absolutely integral to building design (laboratories, hospitals, and etc.), will see HVAC&R design begin earlier and play a more integrated role in design decision making.

The design phase is often broken down into three sub-phases: conceptual design, schematic design and design development. The terms schematic design, design development, and construction documents are also commonly used to describe design process sub phases. The purpose of conceptual/schematic design efforts is to develop an outline solution to the OPR that captures the owner’s attention, gets his/her buy-in for further design efforts, and meets budget. Schematic (or early design development) design efforts should serve as proof of concept for the earliest design ideas as elements of the solution are further development/construction documents, the final drawings and specifications are prepared as all design decisions are finalized and a complete analysis of system performance is undertaken.

The schematic/early design development stage should involve the preliminary selection and comparison of appropriate HVAC&R systems. All proposed systems must be able to maintain the environmental conditions for each space as defined in the OPR. The ability to provide adequate thermal zoning is a critical aspect of such capability. For each system considered during this phase, evaluate the relative space (and volume) requirements for equipment, duct, and piping, fuel and/or electrical use and thermal storage requirements and capabilities, compatibility with the building plan and the structural system, and the effects on indoor air quality, illumination, and aesthetics. Also consider energy code compliance and green design implications (as appropriate). Early in the design phase, the HVAC&R designer may be asked to provide an evaluation of the impact of building envelope design options, heavy lighting loads, and other unusual internal loads on HVAC system performance and requirements.

Questions should also be expected regarding the optimum location of major mechanical equipment–considering spatial efficiency, system effectiveness, aesthetics and acoustical criteria. Depending upon the level of information available, the designer may be asked to prepare preliminary HVAC system sizing or performance estimates based upon patterns developed through experience or based upon results from similar, previously designed projects.

If envelope and internal loads are reasonably well defined, peak load and rough energy calculations for alternative HVAC systems may be prepared at this time using appropriate methods for presentation to the architect and/or owner. Although they are preliminary and will change as the building design proceeds, such preliminary load is usually definitive enough to compare the performance of alternative systems because these systems will be sized to meet the same loads. As you gain experience, you will be able to estimate the likely magnitude of the loads for each area in a building with a little calculation effort.

Resources useful during this phase of design include design manuals, textbooks, equipment literature, and data from existing installations. Frequently, this type of early system evaluation eliminates all but a few systems that are capable of providing the environmental requirements and are compatible with the building structure.

If the client request it, if architectural details have been sufficiently developed, and if the mechanical engineers fee has been sent at a level to warrant it, comparisons between construction (first) cost and operating (life-cycle) cost and the performance of different HVAC&R systems can be made in greater detail. Typically, one system is set as a reference (or base) and other proposed system is compared to this base system. Such an analysis would proceed according to the following steps:

1. Estimate the probable capital costs of each system using unit area allowances, a rough selection of equipment, sketches of system layouts and such tools as:
   - Cost – estimating manuals
   - Recently completed similar projects (many technical journals contain case studies that provide such information)
   - Local HVAC&R contractors
   - Professional cost estimators
   - Design office files
   - Experienced design engineers.

2. Identify the energy source or sources available and their cost per a convenient unit of energy (million Btu, kWh, and therm), considering both present and anticipated costs. Determine local utility tariffs, energy charges, demand charges, and off-peak rates, as appropriate.

3. Calculate the number of operating hours and hourly operating costs for each subsystem of each candidate HVAC system. This can be done manually or by computer using a simplified energy analysis method or proprietary programs offered by equipment manufacturers and software developers.

4. Using the local utility tariffs, calculate monthly utility cost and sum them for the year.

5. If required by the owner or design team, perform comparative life – cycle (or other) cost analyses.

It is important to note that the seasonal or annual in-use efficiency of equipment is not the same as the equipment's full-load efficiency. Consider efficiency at part-load conditions (the number of hours at 100%, 90%, 80%, 60% of full load, etc.) when calculating building energy requirements. As an annual average, cooling equipment operates at 50% to 85% of capacity; fans and pumps operate at 60% to 100% of capacity.

3) Construction Phase

During construction, HVAC&R engineer generally:

- Check shop drawings to verify that equipment, piping, and other items submitted by manufacturers and contractors have been selected and will be installed to conform to the project plans and specifications.
- Make periodic visits to the building under construction to observe and maintain a log of the work being installed by the contractors.
- Provide interpretation of the construction documents when questions arise at the project site.
- Witness tests for system performance, such as airflow volume and temperature, equipment efficiency, control sequence strategies, and indoor air quality, if called for in the professional agreement and provided for in the fee. These activities may or may not be part of a formal commissioning process
- Ascertain proper workmanship and extent of completion to ensure that contractor invoices for work completed during each billing period are correct.

DEFINITIONS

Adiabatic Process – A process in which there is neither loss nor gain of total heat. The heat merly changes from sensible to latent or latent to sensible.

Air Cleaner – a device used to remove airborne impurities.

Air movement – the process of circulating and mixing air through conditioned spaces in the building for the purposes of achieving the proper ventilation and facilitating the thermal energy transfer.

Cleaning – the process of the removing particulates (dust, etc.) and biological contaminants (insect, pollen, etc.) from the air delivered to the conditioned space for the purpose of improving or maintaining the air quality.

Condensate – liquid formed by the condensation of a vapor.

Condensation – process of changing a vapor into liquid by extracting heat.

Convection – heat transfer by the movement of air or a liquid.

Cooling – the process of removing thermal energy (heat) from the conditioned space for the purposes of lowering or maintaining the temperature of the space.

Dehumidifying – the process of removing water vapor (moisture) from the air the conditioned space for the purposes of lowering or maintaining the moisture content of the air.

Density – the mass of air per unit volume.

Dew point temperature – The temperature at which water vapor from the air begins to form droplets and settles or condenses on surfaces that are colder than the dew point of the air.

Direct Expansion – The evaporation of a refrigerant liquid in an air-cooling coil.

Direct-fired gas heater – The gas burns in the air supplied to the space.

Dry Bulb Temperature – The temperature of air measured with a dry sensing device in such a way as to avoid the effects of radiation and evaporative cooling.

Exfiltration – air flow cut ward through a building enclosure.

Heating – the process of adding thermal energy (heat) to the conditioned space for the purposes of raising or maintaining the temperature of the space.

Humidifying – the process of adding water vapor (moisture) to the air in the conditioned space for the purposes of raising or maintaining the moisture content of the air.

Latent Heat – The transfer of heat energy required to produce a change of state in a substance from a solid to a liquid or from a liquid to a gas (vapor).

Latent Heat of Vaporization – The amount of heat required to change one kilogram of boiling water to steam at a given pressure.

Mechanical ventilation – can be achieved by using fans to draw air in from outside or by fans that exhaust air from the space to outside.

Moisture content (humidity ratio) – The amount of water contained in a unit mass of dry air.

Natural ventilation – is driven by natural draft. Like when you open a window.

Psychrometric Chart – a chart which illustrates the relationship of air – water – vapor mixtures with regard to dry and wet bulb temperature, relative humidity, humidity factor, sensible heat, latent heat, total heat and other properties.

Radiation – the transfer of energy in the form of low frequency light rays. The energy is transferred directly from the emitting surface to the receiving surfaces and can be transmitted through a vacuum.

Radiant Heat – Heat transferred by radiation.

Relative humidity – The ration of the measured amount of moisture in the air to the maximum amount of moisture the air can hold at the same temperature and pressure.

Saturation – A condition at which the air is unable to hold any more moisture at a given temperature.

Saturated Air – Air containing maximum amount of water vapor that can exist in gaseous form at the particular temperature and pressure.

Saturated steam – Steam at the saturation temperature for the existing pressure.

Saturation Temperature (of a Gas) – The temperature at which further loss of heat energy will cause condensation of a gas to a liquid at the existing pressure.

Saturation Temperature (of a Liquid) – The temperature at which further gain of heat energy will cause evaporation of a liquid to a gas at the existing temperature.

Sensible Heat – The heat required to produce a change in temperature in a substance without creating a change of state.

Stack Effect – the buoyant effect of air at a higher temperature and lower density and the air it is displacing.

Thermodynamics – the science of heat energy and its transformation.

Total pressure – the sum of velocity and static pressure.

Ventilation – The process of supplying and removing air by natural or mechanical means to and from a building space.

Ventilating – the process of exchanging air between the outdoors and the conditioned space for the purposes of diluting the gaseous contaminants in the air and improving or maintaining air quality, composition and freshness.

Wet bulb temperature – The temperature measured by a thermometer whose sensing bulb is covered with a wet cloth and exposed to a moving air stream. The value is affected by the moisture content of the air stream. It is used in conjunction with a psychrometric chart to determine the air stream relative humidity.

NOMENCLATURE

C_p : Specific Heat at Constant Pressure
h_a : enthalpy of dry air
h_w : specific enthalpy of water vapor
HTC : Heat transfer coeff
m : mass of gas
m_a : mass of dry air
m_w : mass of vapor
n : number of moles
n_a : number of moles of dry air
n_w : number of moles of water vapor in moist air sample
n_{ws} : number of moles of water vapor in saturated moist air sample
M : molecular weight
P : pressure of gas
P_{at} : atmospheric pressue of the moist air
P_a : partial pressure of dry air
P_w : partial pressure of water vapor
Q : Energy
R : gas constant
R_o : universal gas constant
T : Temperature of dry air
T_{IN} : Indoor temperature icient
T_{OUT} : Outdoor temperature
T_R : absolute temperature of gas
v : specific volume of gas
V : total volume of gas
w : humidity ratio of moist air

X_w : mole fraction of water vapor
X_{ws} : mole fraction of water vapor in saturated moist air

Greek Letters

φ : Relative humidity of moist air