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Energy-Efficiency in Air Conditioned Buildings: The Green Buildings Dream

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Abstract

To design an optimum HVAC airside system that provides comfort and air quality in the air-conditioned spaces with efficient energy consumption is a great challenge. This paper evaluates recent progresses of HVAC airside design for the air-conditioned spaces. The present evaluation study defines the current status, future requirements, and expectations. It has been found that, the experimental investigations should be considered in the new trend of studies, not to validate the numerical tools only, but also to provide a complete database of the airflow characteristics in the air-conditioned spaces. Based on this analysis and the vast progress of computers and associated software, the artificial intelligent technique will be a competitor candidate to the experimental and numerical techniques. Finally, the researches that relate between the different designs of the HVAC systems and energy consumption should concern with the optimization of airside design as the expected target to enhance the indoor environment.

Keywords *HVAC Design, Energy Efficiency, Air Quality, Comfort*

1. Introduction

To design an optimum HVAC airside system that provides comfort and air quality in the air-conditioned spaces with efficient energy consumption is a great challenge. Air conditioning identifies the conditioning of air for maintaining specific conditions of temperature, humidity, and dust level inside an enclosed space. The conditions to be maintained are dictated by the need for which the conditioned space is intended and comfort of users. So, the air conditioning embraces more than cooling or heating. The comfort air conditioning is defined as “the process of treating air to control simultaneously its temperature, humidity, cleanliness, and distribution to meet the comfort requirements of the occupants of the conditioned space” [1]. Air conditioning, therefore, includes the entire heat exchange operation as well as the regulation of velocity, thermal radiation and quality of air, as well as the removal of foreign particles and vapours [2].

Achieving occupant comfort and health is the result of a collaborative effort of environmental conditions, such as:

- Indoor air temperature;
- Relative humidity;
- Airflow velocity;
- Pressure relationship;
- air movement efficiency;
- Contaminant concentration;
- Illumination and visual comfort;
- Sound and noise; and other factors.

Proper understanding of these factors and their respective effects on human comfort and health leads to develop a proper HVAC airside design. Those parameters were previously investigated to define the acceptable design and operating ranges to obtain the comfort and hygiene in the air-conditioned spaces. So, this paper evaluates the above parameters and the recent progresses of HVAC airside design for the air-conditioned spaces. The present evaluation study aims to define the current status, future requirements, and expectations.

Indeed, the human spends great part of his life in the enveloped spaces, which can be artificially conditioned. The air-conditioned applications vary according to the functionality and the sensitivity degree of the application. These applications can be divided into residential, commercial, and healthcare applications. The healthcare applications and some sort of the commercial applications have so critical influence on the human health. The following sections evaluate the environmental conditions in these applications and review the methods of control and monitoring.

2.Comfort Levels

Proper comfort level can be achieved by reaching the optimum conditions of the indoor air temperature, relative humidity, and airflow velocity. Indoor air temperature is one of the most important conditions to provide the optimum comfort. The temperature regulatory center in the brain is about 36.8 °C at rest in comfort and increases to about 37.4 °C when walking

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and 37.9 °C when jogging. An internal temperature less than about 27.8 °C can lead to serious cardiac arrhythmia and death and temperatures greater than 46.1 °C can cause irreversible brain damage. Therefore, the careful regulation of body temperature is critical to comfort and health [1]. This condition can inhibit or promote the growth of bacteria and activate or deactivate viruses, in healthcare facilities. Some of codes and guidelines specify the temperature (only) as a measure of comfort and healthy. Local temperature distributions greatly affect occupant comfort and perception of the environment. Furthermore, high temperatures may cause increased out gassing of toxins from furnishings, finishes, building materials, etc. Alternatively, ambient temperatures that are too cool can cause occupant discomfort such as shivering, inattentiveness, and muscular and joint tension. Relative humidity plays an important role in the comfort feeling, which affects the comfort feeling directly or indirectly by its influence on the temperature. Improper relative humidity conditions may cause a thermal sensation, skin moisture, discomfort, and tactile sensation of fabrics, health and perception of air quality.

Elevated humidity levels are known to reduce comfort. At lower levels of humidity, thermal sensation is a good indicator of overall thermal comfort and acceptability. Most of guidelines specify the range (35% to 50%) as the optimum conditions for the relative humidity. Few codes raise the upper limit to 60% as accepted range, but this is not recommended according to the practice. The airflow velocity plays an important role in the comfort sensation and also in the scavenging of the hazards and airborne particles. According to the results of researches and the standards specifications, the optimum airflow velocity falls in the range of (0.2 m/s to 0.25 m/s) in the occupied zone. Many of the HVAC applications suffer from the poor distribution of the indoor air temperature and relative humidity as well as the incorrect airflow velocities. This poor distribution arises from the poor airflow distribution and the presence of the thermal drift due to the buoyancy effect.

2.1. Status Quo

In the present time, most of researches recommend the experimental and numerical simulation as the perfect tools to obtain the optimum design. The optimization procedure of the HVAC airside design depends on the predictions of the air temperature distribution based on the simulation of different parametric designs using experimentally verified numerical tools. The influence of various ventilation strategies and vapour generation rate on the characteristics of temperature and moisture distribution is investigated [3]. It was found the significance of the ventilation strategies on the temperature and moisture distributions even with the same ventilation rate. It was found also the importance of the airside design and room furnishing in order to ensure a comfortable environment, especially in the displacement ventilation configuration [4].

The airflow velocity influence was investigated, and it was found that the velocity could be accepted to be as high as 0.35 m/s in the occupied zone [5], especially in the mixing ventilation, because this value will cause 20% of dissatisfaction among occupancy only. Still, there is no specific method or formula that can be followed to assess the comfort level in the ventilated and air-conditioned spaces. Also, comparisons of comfort between the two different ventilation situations are not general and depend on the configuration of the spaces and the HVAC airside designs [5]. Obviously, the airside design and the configuration of the conditioned space affect the comfort level as well as the space applications, such as the healthcare facilities, which are so complex [6]. The correct specifications of outdoor ambient conditions affect thermal loads, as shown in Figure 1, and consequently the comfort level [7]. Some researches recommend changing the focus on the effect of building envelope to reduce the thermal load to enhance the thermal comfort [8].

2.2. Closure

The comfort conditions depend on many factors beyond the indoor air temperature, relative humidity, and airflow velocity. Comfort conditions depend also on the air distribution pattern and the air movement, but the effect of these factors can be considered close to the air quality more than the comfort level. Indeed, the comfort criteria affect the air quality and the energy conservation in the ventilated and conditioned spaces, as shown in the following sections. The relation between the comfort and air quality is an interchange or mutual relation.

3. Air Quality

Most of guidelines consider the air quality is the result of a collaborative effort of environmental conditions those presented in the introduction section. Indeed, in the present literature the air quality is specified by the result of a collaborative effort of the pressure relationship, air movement efficiency, and contaminant concentration. These conditions play an important role to achieve the optimum air quality. Simply, design of ventilation system must, as much as possible, provide air movement from the clean to the less-clean areas. This rule requires a great careful to design the airside system and to select the design of airside system of the neighbourhoods. There are relative interactions between the conditioned neighbouring spaces. This criterion is very critical in the critical spaces such as the hospitals, which affects the comfort, asepsis, and odour control and then directly affects the patient hygiene and healing. In critical care areas, constant volume systems should be employed to assure proper pressure relationships and ventilation, except in unoccupied rooms.

The air distribution and movement efficiency can be considered as the indicator of the comfort and air quality simultaneously. There are several important considerations that characterize the air distribution in air-conditioned spaces, namely first, the flow is generally turbulent and buoyancy effects are often significant. Then the transverse transport effects are of particular interest in the flows. The boundary conditions are complicated due to the presence of free surfaces, with or without wind shear of openings, such as, doors in the rooms through which inflow and outflow may occur and of time-varying heat losses at the boundaries. Combined heat and mass transfer processes prevail in that case and coupled transport mechanisms are generally present. Finally, the inflow conditions, particularly temperature, may be coupled with the outflow conditions. There are many alternative approaches to control and direct the air distribution to achieve the desired quality. Factors affecting the air distribution in air-conditioned spaces should be analyzed to give a better understanding of the nature of the process.

In critical applications, such as the hospital facilities, the air movement takes an extra important role in the controlling of the healthy criteria. Undesirable airflow between rooms and floors is often difficult to control because of open doors, movement of staff and patients, temperature differentials, and stack effect. While some of these factors are beyond practical control, the effect of others may be minimized by terminating shaft openings in enclosed rooms and by designing and balancing air systems to create positive or negative air pressure within certain rooms and certain areas [9].

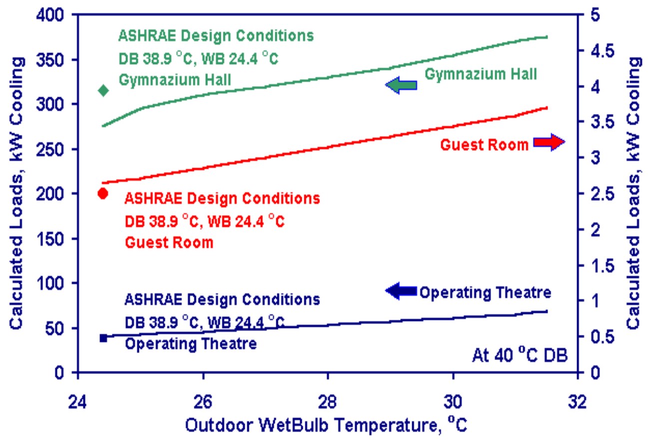

Figure 1: Outdoor Conditions and Thermal Loads

Contaminants can be classified in four broad headings, each of which represents a wide variety of pollutants; Organic & Inorganic Compounds; Particulate Matter; and Biological Contaminants.

It should be understood that these classifications are intended to facilitate the categorization of contaminants. Although the pollutants are classified into these categories, certain contaminants may belong to two or more classifications, depending upon their nature [10]. The classification of organic compounds represents chemical compounds that contain carbon-hydrogen bonds in their basic molecular structure. Their sources can be either natural products or synthetics; especially those derived from oil, gas, and coal. Organic contaminants may exist in the form of gas (vapour), liquid or as solid particles in the atmosphere, food and/or water [11]. Inorganic compounds are those which do not contain carbon-hydrogen bonds in their molecular structure. They include carbon dioxide, sulphur dioxide, nitrogen oxides, carbon monoxide, ozone, lead, sand, metal, ammonia and some particulate matter. A complex mixture of organic and inorganic substances formulates particulate matter, each with diverse physical and chemical properties. Furthermore, they represent a wide variety of substances ranging in size from 0.005mm to 100 µm (microns) in aerodynamic diameter, including asbestos, dust, mould, pollen, and dander.

The danger of particulate matter is their ability to become contaminated by other ambient sources, increasing health risks to individuals who are exposed to Respirable Suspended Particles (RSP). Particles following into this category are, usually, less than 10 mm in aerodynamic diameter. As mentioned previously, particles smaller than 5 mm are capable of bypassing the respiratory defences. Biological contaminants are generally referred to as microbes or micro organisms. Biological contaminants are minute particles of living matter produced from a variety of sources. For the most part, sources of biological contaminants are found outdoors; however, many may occur both in outdoor and indoor environments. The variety of biological compounds that may be present in the ambient environment is immense. Therefore, exposure to an increased concentration creates a potential health risk to susceptible individuals. Contaminants of this source may come in one of the following three main forms:

Bacteria* - *Virus* - *Fungi

At extremes of the exposure range for light, heat, cold, and sound, organ dysfunction in measurable, and disease, such as frostbite, burns, and noise-induced hearing loss occur. Some transitions between healthy and disease states are more difficult to delineate. Pain from bright light, erythema from heat, and nausea from vibration represent reversible effects but are interpreted by health professionals as abnormal. Air quality must also be maintained to provide a healthy, comfortable indoor environment. Sources of pollution exist in both the internal and external environment. The air quality is controlled by removal of the contaminant or by dilution [2]. ASHRAE standard 2010 [12] prescribes both necessary quantities of ventilation for various types of occupancies and methods of determining the proportions of outside air and recirculated air. If the level of contaminants in outdoor air exceeds that for minimum air quality standards, extraordinary measures must be used. The ASHRAE standard provides the necessary recommendations for the residential, commercial, and industrial applications. Although proper air conditioning designs are helpful in the prevention and treatment of diseases, the application of air conditioning to health facilities presents many specific problems. Those are not encountered in the conventional comfort conditioning design.

3.1. Problem Identification

The contaminant concentration mainly depends on the two factors, air pressure relationship, and the air movement efficiency. So the optimum design of these two factors leads to accepted concentration and safe distribution of the contaminant. Actually, most of guidelines, known to date, don't restrict any airside design for each application. This gives a large tolerance and many designs alternatives, which are not totally perfect.

3.2. Status quo

The comfort and air quality is investigated with the aid of experimental and numerical techniques, to represent the relation between the thermal conditions and the air quality [13]. It was found that thermal conditions affect the air quality and therefore any recommended the numerical models should account for balanced thermal conditions. This would affect the discrepancies between measured and simulated results and consequently create a more generalized numerical formula of the air characteristics.
The effect of thermal loads and cooling strategies on the airflow pattern in an office was investigated by applying mixing ventilation, [14] as well as those results indicating the effect of supply conditions on the airflow pattern [6]. The ventilation performance takes a great place in the last decades, which represents the capabilities of the airside design on providing a clean space. The effect of the heat and contaminant source location on the ventilation performance was also considered. It was found that the optimum ventilation

performance is achieved when these sources are located near the exhaust opening [15]. The air quality is generally influenced by airborne and contaminant generation in the healthcare applications, especially in the critical sites such as the isolation and surgery rooms. Several researches investigated the airborne particle control in the operating rooms using the numerical techniques [16-19]. These researches indicated that the particle distribution depends on the particle source location, airside design, and furniture and equipment distribution. The airflow turbulence has also strong influence on the contaminant concentration.

3.3. Closure

Air movement efficiency is mainly based on two factors, which are; the air pressure relationship with the other neighbourhood spaces, and the airside design.

Differential air pressure can be maintained only in an entirely sealed room. Therefore, it is important to obtain a reasonably close fit of all doors and seal all walls and floor penetrations between pressurized areas. This is best accomplished by using weather stripping and drop bottoms on doors. The opening of a door between two areas instantaneously reduces any existing pressure differential between them to such a degree that its effectiveness is nullified. When such openings occur, a natural interchange of air takes place between the two rooms due to turbulence created by the door opening and closing combined with personal ingress/egress. For critical areas requiring both maintenance of pressure differentials to adjacent spaces and personnel movement between the critical area and adjacent spaces, the use of appropriate air locks or anterooms is indicated. In general, outlets supplying air to sensitive ultraclean areas should be located on the ceiling, and perimeter or several exhaust outlets should be near the floor. This arrangement provides a downward movement of clean air through the breathing and working zones to the floor area for exhaust. Infectious isolation rooms should have supply air above and near the doorway and exhaust air from near the floor, behind the patient's bed. This arrangement is such that clean air first flows to parts of room where workers or visitors are likely to be, and then flows across the infectious source and into the exhaust. Thus, non-infected persons are not positioned between the infectious source and the exhaust location. The bottom of the return or exhaust openings should be at least 75 mm above the floor.

4. Energy Efficient Buildings Design

Energy crisis in the early 1970s forced the development of energy conserving strategies in a variety of industries. Sustainability and energy efficiency continue to be strong issues in this time of limited resources. Therefore, the implementation of energy conserving strategies in the HVAC systems must be balanced with occupant comfort and health. Few guidelines gave specific recommendations about the energy saving in the HVAC systems, but these recommendations don't meet all requirements and design varieties. Indeed, in the hot and humid climate the outdoor conditions play important role in the energy consumption. Also the utilization strategies of the conditioned air in the conditioned space play an important role to save the energy consumption.

4.1. Pyramid Concept

Till now, the guidelines and design standards don't provide restricted utilization strategies of the conditioned air in the spaces. Indeed, this situation creates several inefficient systems and consequently expensive energy invoice. In some critical facilities, such as hospitals, HVAC designers face the problem of balancing between the healthy conditions and the energy utilization. The assessment of the overall energy performance of a particular building, including the technical building systems, comprises a number of successive steps, which can be schematically visualized as a pyramid. Figure 2 indicated the various items into energy performance of buildings.

4.2. Status Quo

The relation between the HVAC system designs and the optimum conditions and optimum energy utilization is still under investigation up today. In recent researches [20, 21], the effect of ventilation design on the comfort and energy utilization is investigated. The effect of the displacement ventilation on humidity gradient in a factory located in the hot and humid region was illustrated [20]. It was found the strong dependence relation between the correct supplying conditions and comfort. Indeed, the displacement ventilation is recommended as an energy efficient system, however, the created humidity and temperature gradient, because this system gives the designers the suitable tolerance to select more economize supply conditions [20].In recent years, new design traditions of the ventilation systems, such as the under-floor ventilation systems are growing to overcome the problems of the current systems. The under-floor air supply is recommended as an alternative to the ceiling air supply in the office buildings to overcome the lack of flexibility in the ceiling systems and to improve the comfort conditions [21]. It is noticeable that those who advised the under-floor system recommend it due to its capability to reduce the energy consumption due to the operational characteristics of supplied air.

4.3. Closure

As the optimization of the energy consumption is new trend, the achievement of this level needs new investigation trend in the scientific researches. Actually, the energy utilization mainly depends on the optimum utilization of the conditioned air in the conditioned spaces. Sets of common terms, definitions and symbols are essential for all segments from top to bottom. These cover terms such as energy needs, technical building systems, auxiliary energy use, recoverable system losses, primary energy and renewable energy shown here in Figure 3.

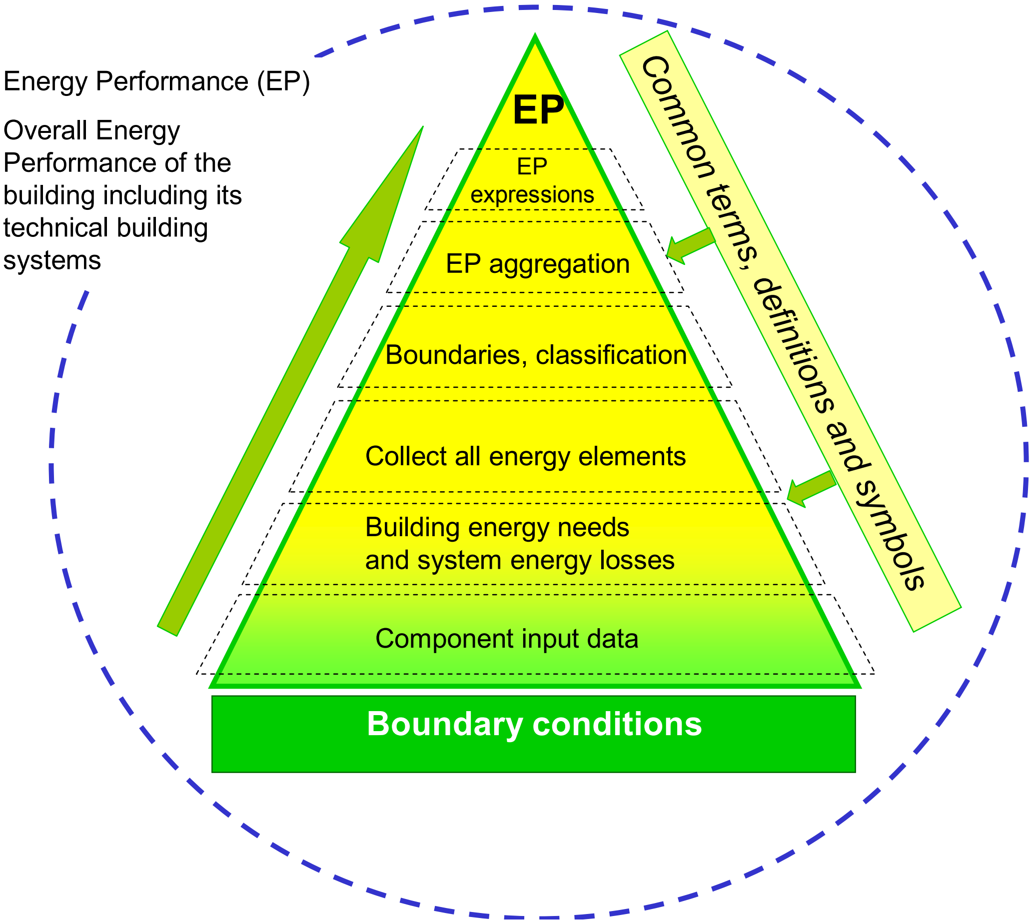

Figure 2: Overall building energy performance Indications

Fig. 3 – Harmonization of energy terms in building technology

5. Air Conditioning System Design of Commercial Buildings

In theory, if properly applied, every system can be successful in any building. However, in practice, such factors as initial and operating costs, space allocation, architectural design, location, and the engineer's evaluation and experience limit the proper choices for a given building type.

Heating and air-conditioning systems should be:

- Simple in design and
- Of proper size for a given building
- Of generally fairly low maintenance
- Of low operating costs.
- Of optimum inherent thermal control as is economically possible.
- Such control might include materials with high thermal properties, insulation, and multiple or special glazing and shading devices.

For buildings the following parameters are to be considered:

1. Load Characteristics
2. Design Concepts
3. Design Factors
4. Comfort Level
5. Costs
6. Local Conditions
7. Automatic Temperature Control
8. Fire, Smoke, and Odour Control

An example of Commercial buildings applications is provided here for libraries and museums.
In general, libraries have storage areas, working and office areas, a main circulation desk, reading rooms, rare book vaults, and small study rooms. Some libraries also contain seminar and conference rooms, audiovisual rooms, special exhibit areas, computer and internet rooms, and perhaps an auditorium. Such large diversity of functions requires careful analysis to provide proper environmental conditions.

On the other hand museums fall into several categories such as; art museums and galleries, natural and social history , Science museums, and special topical museums. In general, museums would have exhibit areas, work areas, back offices, and storage areas. Some larger museums may have souvenir shops, a restaurant or cafeterias, etc. Many of the art museums and galleries, and some natural history museums, have their exhibits exposed within the viewing area while others have exhibits kept in enclosed cases, cubicles, or rooms when special conditions that differ markedly from human comfort are required.

5.1. Load Characteristics

Many libraries, especially college libraries, operate up to 16 h per day and may run the air conditioning equipment about 5000 h per year. Such constant usage requires the selection of heavy duty, long-life equipment, which requires little maintenance. Museums are generally open about 8 to 10 h per day, 5 to 7 days per week. The ambient conditions should not vary in temperature or relative humidity. The conditions should remain constant 24 h per day, year-round. Cold or hot walls and windows, and hot steam or water pipes should be avoided. Object humidity may be destructive, even if the ambient relative humidity is under control. An example is shown in Figure 4.

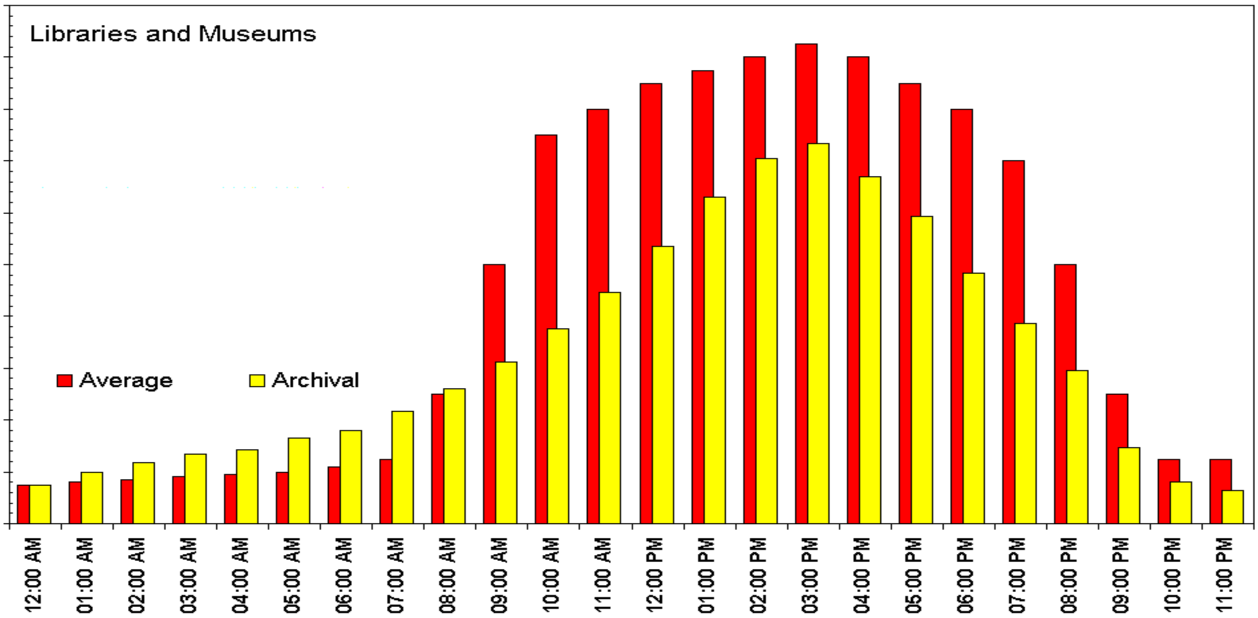

Figure 4: Load schedule on Libraries and Museums

Sun Gain.
Libraries and museums usually have windows, sometimes of stained glass, and skylights—more in traffic areas, than in book stacks or storage areas. Care must be taken to minimize the effects of the sun; shortwave (actinic) rays are particularly injurious. Heat gain from skylights, often over artificially lighted frosted glass ceilings, can be reduced by a separate forced ventilation system.

Transmission.
In winter, effects on objects located close to outside walls and possible condensation of moisture on the objects and the surface of outside walls must be evaluated. In summer, possible radiant effects from exposure should be considered.

People.
Some areas may have concentrations as high as 1.0 m^2 per person, while office space will have closer to 10 or 15 m^2 per person, and book stack areas up to 100 m^2 per person. When smoking is permitted, return air should be contained, and the recirculated part of the air should be deodorized with activated charcoal and similar odour-removal devices or exhausted.

Lights.
Careful analyses of the required lighting intensity should be made in various rooms and in view of daylighting availability.

Stratification. In reading rooms, large entrance halls, and large art galleries with high natural or false ceilings, air temperature may stratify.

Design **Concepts**

All-air ducted systems are preferred in library public areas, careful evaluation of relative humidity is essential. This is also true for museums, because exhibit items are generally irreplaceable. In museums, people loads vary, depending on whether there is a new exhibit, the time of day, weather, and other factors. Thus, individually controlled zones are required to maintain optimal environmental conditions. Due to the nature of museums exhibits, partitioned areas may be radically altered depending on exhibit. Attempts to establish a modular system for partitions have been only partially successful because of the wide range of sizes of items in the exhibits. In art museums, particularly, partitions may create local pockets with hot air supply or exhaust; transfer grilles may be placed in the partitions to obtain some air flow movement. Another problem is the location of room thermostats and humidistats

Special Considerations

Many old manuscripts, books, museum exhibits, and works of art have been damaged or destroyed because they were not kept in a properly air-conditioned environment. The need for better preservation of such valuable materials, together with a rising popular interest in the use of libraries and museums, requires that most of them, whether new or existing, be air-conditioned. Air-conditioning problems for museums and libraries are generally similar, but differ in design concept and application. The temperature and humidity ranges that are best for books, museum exhibits, and works of art do not usually fall within the human comfort range.

Design Criteria

In an average library or museum, less stringent design criteria are usually provided than for archives, because the value of the books and collections does not justify the higher initial and operating costs. Low-efficiency air filters are often provided. Relative humidity is held below 55%. Room temperatures are held within the 20 to 21.5°C range. Archival libraries and museums should have 85% or better air filtration, a relative humidity of 35% for books, and temperatures of 16°C in book stacks and 20°C in reading rooms.

Building Contents

Museums contents and collections reaction to room conditions should be carefully considered and critically examined. For example, paper used in books and manuscripts prior to the eighteenth century is very stable and is not significantly affected by the room environment. For archival preservation, this paper should be stored at very low temperatures. It is estimated that for each 5°C dry bulb the room temperature is lowered, the life of the paper will double, and that any humidity reduction will also lengthen the life of paper.

Effect of Ambient Atmosphere

The temperature and, particularly, the relative humidity of the air have a marked influence on the appearance, behaviour, and general quality of hygroscopic materials such as paper, textiles, wood, and leather, because the moisture content of these substances comes into equilibrium with the moisture content of the surrounding air. The object humidity is usually defined as the relative humidity of the thin film of air in close contact with the surface of an object and at a temperature cooler or warmer than the ambient dry bulb. If objects in a museum are permitted to cool overnight, the next day they will be enveloped by layers of air having progressively higher relative humidities. These may range from the ambient of 45 to 60% to 97% immediately next to the object surface, thus effecting a change in material regain or even condensation. This, combined with the hygroscopic or salty dust often found on objects recovered from excavations, can be destructive. If the particular material is warmed, however, the object's humidity will be lower than the humidity of the surrounding space. This warming may be caused by spotlights or any hot, radiating surface.

Sound and Vibration

Air-conditioning equipment should be treated with sound and vibration isolation to ensure quiet comfort for visitors and staff as per the ASHRAE standards and local environmental laws.

6. Evaluation Indices

The evaluation indices of the comfort, air quality, and energy utilization efficiency can be divided to two main categories, empirical indices based on the experimental techniques, and numerical indices based on the numerical techniques. The most common indices provide the required evaluation of the air characteristics at individual positions (or in other scope, at individual points) in the indoor environment.

6.1. Problem Identification

Until now, the evaluation of the comfort, air quality, and energy utilization efficiency performed only at individual position (locally evaluation). Still there is no general global evaluation index for several characteristics such as the airflow movement and the contaminant concentration and its influence on the occupancy health. Actually, the air flow distribution pattern plays the role of global evaluation index up today. On the other hand, there is no global evaluation index capable of evaluating comfort, air quality, and energy utilization efficiency simultaneously. Actually, this global index will aid the HVAC designers to achieve the optimum design according to the optimum indoor air quality levels.

6.2. Status Quo

The experimental techniques play an important role to yield complete view of air characteristic pattern in air-conditioned spaces. The most famous experimental indices are the PMV, MTS, ET^*, and DR [4]. These indices can not express the real assessment of the indoor environment in critical areas. The numerical techniques play an important role in the dealing with the parametric designs. This tool is a very powerful tool to predict the indoor air quality of any space with the complex configurations and sensitive functionality. But in contrast, this technique is not capable to introduce a global evaluation of the conditioned space by itself only [8, 22-28]. There is a new trend in recent years that is based on the integration of the artificial intelligent tools with the numerical tools to replace the human being in the decision taking. The genetic algorithm is the one of the artificial intelligent techniques that is usually integrated with the numerical tool, and is found to be highly suitable for exploring alternatives from different areas of the design spaces to enhance and evaluate the HVAC performance

[28]. Indeed, this attempt does not create a flexible evolution index. Indeed, the analytical method needs massive effort to obtain the results. In some situations, the performance of the analytical method is less than the expected. The Neuro-Fuzzy technique is integrated also with the numerical method [17] to evaluate the ventilation performance, depending on the conclusion, which is "The evaluation action is a mental process".

6.3. Closure

Present evaluation indices don't introduce the complete evaluation for the simulated ventilation design or for the air-conditioned spaces. The individual evaluation indices can perform the duty partially, waiting the progress in this field. Indeed, the future of these indices is guided by the capabilities of the hardware and software.

7. OBSERVATIONS

7.1. Technical Observations

- In general, the best investigation technique of the status in the air-conditioned spaces is the technique that based on the experimental and numerical investigations. Currently, the ultimate goal of the experimental investigations is to create a validated numerical tool for the prediction of the characteristics of the indoor environment, Figure 5. So the experimental work plays a remarkable role to obtain the airflow characteristics of the ventilation and air-conditioning systems.
- There are many trials to create global or general quantitative indices to evaluate the comfort, air quality, and energy utilization efficiency resulted from the airside design parameters changing with no significant progress. This arisen from the complex nature of the indoor environment and the complex nature of each target (comfort, air quality, energy utilization efficiency) in the global index and the conflict among them in the many situations.

7.2. Environmental Observations

1. Actually, the dependence on supply conditions only to save the energy is not valuable. This trend leads the researches to unrealistic results. One should investigate the roots of the energy-wasting problem in the air-conditioned spaces due to the HVAC systems, Figure 6. Indeed, the optimum airside configuration design can save the energy directly.

2. Airflow characteristics especially the humidity ratio and the contaminant concentration is the main comfort and air quality factors, respectively, in the global indoor air quality.
3. The airflow distribution pattern needs new development to increase the performance of the ventilation systems. For example, still up today, there is no final solution to deal with the recirculation zones and dead zones in the air-conditioned spaces, just only some recommendations about the airside designs.
4. Actually, the new traditions in the HVAC and airside designs are required to enable the designers to select the optimum design from a variety. But this new trend will add new responsibilities to assess these new designs and their suitability with the required internal conditions.

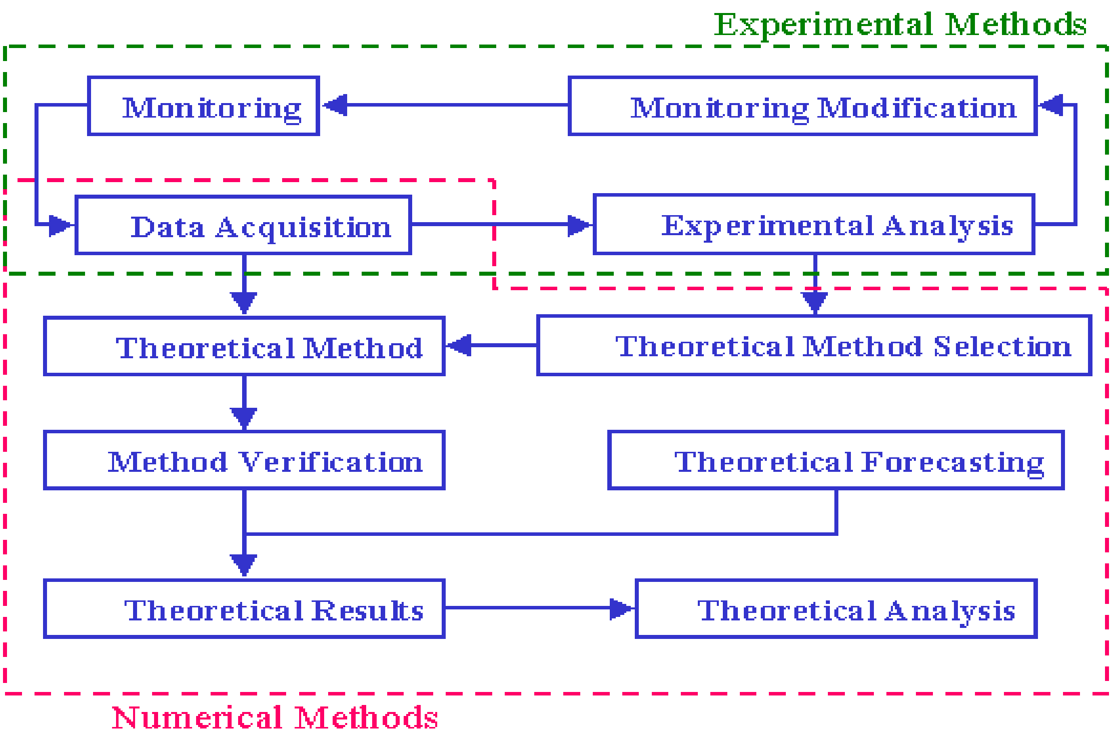

Figure 5: Experimental and Numerical Techniques

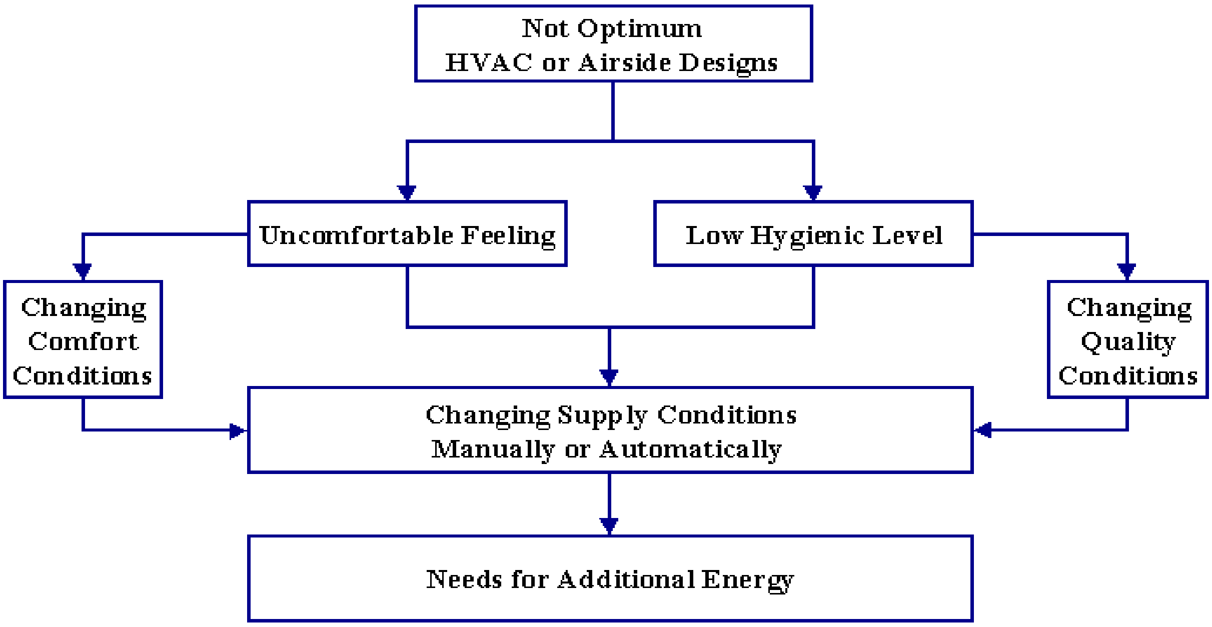

Figure 6: Causes of Energy Waste

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