THE HISTORY OF VENTILATION AND AIR CONDITIONING: IS CERN UP TO DATE WITH THE LATEST TECHNOLOGICAL DEVELOPMENTS?

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Abstract

The invention of ventilation cannot be ascribed to a certain date. It started with simple aeration when man brought fire into his abode and continued through different stages including air cooling using ice to finally arrive at the time when ventilation and air conditioning has become an essential part of our life and plays an important role in human evolution. This paper presents the history of ventilation and air conditioning, explains the key constraints over the centuries, and shows its influence on everyday life. Some examples of previous air-conditioning plants are described and different approaches to the way of calculation of ventilation systems discussed. It gives an overview of the Heating, Ventilation and Air Conditioning (HVAC) installations at CERN and points out their particularities. It also compares them with the latest technological developments in the field as well as showing the new trends that are being applied at CERN.

1 INTRODUCTION

Why did people start to look for control of indoor air quality? What were the stages in the evolution of ventilation and air conditioning and how did it affect man? Where can we situate CERN's Heating, Ventilation and Air Conditioning (HVAC) installations in the history of science? We will try to answer these questions in the present document.

2 THE HISTORY OF VENTILATION AND AIR CONDITIONING

2.1 Ventilation

The invention of ventilation cannot be ascribed to a certain date. The first attempt was probably made when man brought fire into his abode and discovered the need to have an opening in the roof to let out the smoke as well as to supply air to keep the fire burning [1]. Because the fire warmed the space to a more comfortable temperature, thermal comfort was initially linked to ventilation.

Also the need for appropriate air cleanness in ancient Egypt let man discover the beneficial aspects of ventilation. The Egyptians observed that stone carvers working indoors had a higher incidence of respiratory distress than those working outdoors. They attributed this to a higher level of dust in the indoor workspaces. These observations resulted in the improvement of air circulation within the work areas by the provision of additional openings in the walls.

The need for indoor fires disappeared temporarily with the Romans' invention of underfloor heating where hot combustion products were ducted from 'stoves' around the periphery of the buildings, through the floor tiles to a smokestack. There are still remains of the baths with the fragments of floors under which there are hot air ducts. Such technical solutions for central heating were signs of wealth and the higher status of the owner and were often present in the bawdy houses of the 1st century B.C. [2].

In the Middle Ages, people began to realize that air in a building could somehow transmit disease among people in crowded rooms. Homes and small buildings were heated with open fires in fireplaces. Smoke often spilled into the room and poisoned the air. King Charles I of England in 1600 decreed that no building should be built with a ceiling height of less than 10 ft (3 m), and that windows had to be higher than they were wide. The objective was to improve smoke removal.

Research began to address the question, What constitutes bad air? In the 17th century, experiments were started on small animals, which were placed in a confined bottle with a burning candle. The candle flame was extinguished before the animal was asphyxiated. An animal survived about half as long again without the candle. The conclusion was that the 'unknown particles of the air' were the cause of the demise.

One hundred years later in 1775, the French chemist, Antoine Lavoisier, identified the 'unknown particles' as carbon dioxide – CO_2. Lavoisier began his study of oxygen and carbon dioxide in the air of crowded rooms in 1777. He concluded that excess CO_2 rather than a reduction of oxygen caused the sensations of stuffiness and bad air. This hypothesis opened a long discussion over two centuries about the minimum amount of fresh air per occupant needed to maintain comfortable indoor conditions.

For a long time there were two schools of thought with respect to ventilation. Architects and engineers were concerned with providing comfort and freedom from noxious odours and debilitating effects of oxygen depletion and/or carbon dioxide accumulation. Physicians, on the other hand, were concerned with minimizing the spread of disease. Different approaches resulted in various recommendations for fresh air rates.

In 1836 a Cornish mining engineer, Thomas Tredgold, published the first estimate of the minimum required quantity of ventilated air which was 7.2 m^3/h per occupant. Tredgold's estimate was intended to satisfy metabolic needs, but it didn't take into consideration the needs for ventilation for comfort. Different studies were carried out on both sides of the Atlantic. During the Crimean War (1853–1855) and a few years later in the US Civil War, it was observed that there was a greater and faster spread of disease among wounded soldiers in crowded hospitals with poor ventilation. Based on this observation, physicians recommended 50 m^3/h per occupant of fresh air as adequate for comfort. This value was accepted and proposed as a model law in 1914 by the American Society of Heating and Ventilation Engineers (ASHVE).

As a consequence of the energy crisis, half a century later this law was reviewed in order to minimize the indoor air rate. New studies carried out independently in the US and Denmark confirmed that 27 m^3/h per occupant was the minimum accepted volume of fresh air. The comfort chart was modified to reflect the response due to clothing, heating/cooling system design and living habits (i.e. smoking) and finally published in 1989 as ASHRAE/ANSI Standard 621989 which is now the accepted norm in most countries. This agreement put an end to the long discussion on the required fresh air rates for comfort, however, it didn't stop research into the environmental aspects of ventilation.

It was one thing to find out the minimum volume of fresh air needed to maintain comfortable indoor conditions, but quite another to find how to deliver it to the ventilated areas. This required mechanical ventilation and placed responsibility for system design and construction on the engineers. Although the first fan was built in circa 1500 by Leonardo Da Vinci as a water-driven fan to ventilate the boudoir of his patron's wife, the real development of this industry did not start until the 19th century. Before that, ventilation was natural and controlled by the building's orientation and placement of windows to catch the prevailing breezes. High ceilings and large open central staircases with ventilated domes provided some assistance to gravity and Mother Nature.

Ventilation didn't truly take off until the mid-1880s, when the use of steam and electricity had spread. The first steam-driven fans were quite powerful, but they weighed several tons. The electrical industry was growing rapidly. In the competition between direct current (DC) and alternating current (AC), the first was for a long time recognized as better adapted for ventilation (the speed of a motor could be controlled by varying the voltage). However, from 1887 after Tesla's inventions for AC electrical designs, the second became more popular in the HVAC&R industry thanks to multiphase motors. That's how ventilation and air conditioning entered everyday life.

2.2 Air conditioning

"Man is a funny creature.
When it's hot he wants it cold.
When it's cold he wants it hot.
Always wanting what is not.
Man is a funny creature."

As pioneer of cooling and air conditioning Willis Carrier (1876–1950) noted "Development of air conditioning is the natural outgrowth of busy, intelligent minds aiming towards improvement." We already know that the driving force for the development of ventilation was the fact that indoor air quality affects both comfort and health. People realized that not only fresh air volume has an influence on their comfort. They started to look for different ways of controlling other factors in order to become independent of the external environment. That's how air conditioning was born as a science. Its principle is to control temperature, humidity, purity and motion of air in an enclosed space independently of outdoor conditions.

The quest for comfort is probably as old as the human race. Fire was used for warmth at least 100 000 years ago and perhaps before that. But what of comfort cooling? The beginning of comfort cooling is buried in obscurity; we have to rely on written records for the history of cooling. Since there was no mechanical refrigeration before the 19th century, any attempts to artificially cool the air would have used ice, snow, cold water or evaporative cooling.

One of the earliest records, the Bible, mentions "The coolness of snow in the heat of the harvest." There are other sporadic accounts of ancient peoples using ice or snow for cooling. For example, the Roman Emperor Various Avitus ordered that mountain snow be brought and formed in mounds in his garden so that the natural breezes might be cooled. An early method of cooling air in India was to hang wet grass mats over windows where they cooled incoming air by evaporation.

Other examples, most unrecorded, are scattered across the centuries. However, not much was done in the comfort cooling field until the 1800s.

Tesla's invention of the electric fan in 1882 was considered a major innovation in helping people feel more comfortable during hot weather. However, it obviously had limitations on effective cooling. At most, an electric fan makes the air feel 7–8 degrees cooler by increasing convective heat transfer from the body. It was a logical step for many people to place ice in front of the fan to provide additional cooling. Indeed, physicians used steam-powered fans and over 20 tons of ice to cool American President James A. Garfield's bedroom during the summer months of 1881.

The development of air conditioning, as we know it today, started with the birth of refrigeration. Early refrigeration plants often were used to make ice as an alternative to naturally harvested ice from frozen lakes. Their machinery was driven by steam engines, hence used mostly in industrial installations. One of the earliest successful vapour compression refrigeration machines was developed by Charles Tellier in France [3]. In the 1870s, important advances were made by David Boyle who developed an ice machine using ammonia, and Raoul Pictet who developed one using sulfur dioxide.

While comfort cooling was rarely applied to individual homes in the US before 1920, it was a steadily growing industry serving commercial, cultural, and industrial markets. By 1911, air conditioning proved itself to be of great economic value in "lithography, the manufacture of candy, bread, high explosives and photographic films, and drying and preparing of delicate hygroscopic materials such as macaroni and tabacco" according to Willis Carrier's experience [4]. At that time control of indoor humidity started to be of major concern to several branches of industry, thus resulting in the expansion of this science as a part of air conditioning engineering. Air conditioning was used not only because of technological constraints, but it was also observed that workers in such plants were often more comfortable, more productive, and less prone to absenteeism. The first exposure to air conditioning for most Americans was in cinemas and theatres during the 1920s and 1930s. Without air conditioning, most theatres were closed during summer months. Theatre operators found that they were able to recover the cost of their air conditioning equipment in just one summer.

After World War II, comfort air conditioning became increasingly popular and affordable to the growing middle class. Advertising of air conditioning systems moved from engineering and architectural trade journals to popular magazines. Air conditioning was gaining wide acceptance and was on the path to becoming a common appliance and not only a luxury [5]. The first console coolers appeared as a fine piece of furniture like a radio in the mid-1930s (Fig. 1).

Figure 1: The first room cooler.

The oil embargo of 1974 in the US brought attention to energy use. Air conditioning systems had to be designed and operated to achieve a proper balance among thermal comfort, air quality and energy consumption. The low operation cost installations started to be a major concern of the engineers. New ways of recovering thermal energy were invented at that time, and there was a renewed interest in off-peak storage. Some systems were designed and installed using ice banks, in which ice was manufactured during the night, and then used during the day for cooling. Another improvement was the use of heat pumps using cheap low-temperature energy sources to heat up conditioned areas. All these achievements allowed air conditioning to become more promising and interesting for investors than ever before.

The mid-1970s brought attention to environmental matters. It was pointed out that use of certain refrigerants like CFCs and H-CFCs might seriously endanger the ozone layer. Therefore, several international actions were undertaken in order to reduce the emission of these chemicals into the atmosphere. This resulted in new research for the replacement of the refrigerants concerned in air conditioning equipment and is still under study by many engineers [6].

Recent developments in electronics have made a major improvement in the control of air conditioning systems. Its exploitation can nowadays be programmed and executed according to the user's needs. Several zones can be served using only one control that may be accessed remotely via a phone line (i.e. Internet).

Air conditioning has been a significant shaping influence in our homes and cities. Like most other modern technologies it has had its share of supporters and detractors. Nevertheless, air conditioning is taken for granted in many countries these days. Europe, however, still seems to be slightly behind in this field compared to Japan or the US where the energy demand for cooling is higher than for heating. Many people now can afford to sleep comfortably on the hottest summer night and feel refreshed throughout the day by being in air-conditioned homes, cars, aeroplanes or offices, thanks to the effort of countless people working in the air conditioning and related industries.

3 HVAC INSTALLATIONS AT CERN

From the very beginning of CERN, the systems of heating, ventilation and air conditioning have been present on all sites of the laboratory. Their principal role is to assure appropriate indoor conditions for equipment in the experimental areas; however, comfort applications can also be found. The size and importance of installations at CERN requires huge investment and complex studies of these auxiliary systems. In most cases they have an industrial character assuring good conditions for the machinery rather than for people working in the experiments.

Starting from the birth of the PS, through the construction of the SPS until the LEP machine, we have observed how the state of the art in HVAC engineering has developed at CERN. Obviously, the most obsolete and sometimes 'archaic' (by today's standard) installations can be found on the Meyrin site - in the PS complex, which is the oldest part of the laboratory. They therefore require much more maintenance and attention than elsewhere. That's why these systems are being permanently modernized and improved. Since the installations exist and are operated almost non-stop, their renovation is very difficult and delicate. In addition to technical constraints, limitations in the budget put all the improvements in question.

The structure of CERN's civil engineering property can be divided into three main parts: underground sites related to the experimental activities (caverns, tunnels, shafts, etc.), surface experimental buildings (halls), and finally so-called non-experimental buildings situated on both sites of CERN. This functional division is reflected in different requirements for ventilation and air conditioning. The first group, apart from temperature control, also requires low indoor absolute humidity in order to avoid any risk of condensation on the equipment installed. An important effort is made for all security aspects with particular attention being paid to smoke extraction and final filtration of the exhaust air (radioactivity protection). The second group of buildings is characterized by the large volume of ambient air to be treated. Cooling and dehumidification is of minor concern, whereas heating and ventilation must be carefully studied. Because of the nature of the work carried out in these halls, security aspects are of secondary importance, but they cannot be neglected. The final group of buildings consists of offices, laboratories, computer centres, restaurants, and other auxiliary buildings. Their ventilation and air conditioning is mainly used to maintain acceptable conditions for people working inside.

4 TECHNOLOGICAL DEVELOPMENTS IN VENTILATION AND AIR CONDITIONING AT CERN

As already mentioned, ventilation and air conditioning started to grow as an industry in the beginning of the 20th century. Since then, remarkable expansion has been observed in all branches of these sciences and therefore it is difficult to judge clearly whether a complete system is up to date with the latest technological developments in all HVAC fields. The best way to analyse CERN's installations is to take into account the three main axes of evolution in ventilation and air conditioning engineering: indoor air quality, energy use, and environmental protection.

4.1 Indoor air quality at CERN

Regarding air cleanness, CERN's ventilation systems are well adapted to the user's needs. The latest achievements in air filtration allowed CERN's engineers to design and construct several clean rooms with cleanness classes reaching 1000 according to the American Standard FS209D equivalent to ISO 6 (e.g. Bldg 14). On the other hand, there are still installations using old filtration systems with wet oil filters on the supply line (e.g. ventilation of the PS tunnel). This, however, does not affect indoor air quality.

Building 154, with its flexible ventilation ducts (see Fig. 2), represents the example of the latest achievements in indoor air distribution. Not only main ducts, but also displacement diffusers classify that installation as modern. The case of Bldg 154 can be compared to the old air distribution system in the West Hall area where several 'dead zones' are present.

Figure 2: Flexible ventilation duct in Bldg 154.

The supply air is treated by using modern equipment (direct expansion cooling coils, chilled water coils) and no 'archaic' ice/snow methods for cooling have been applied to CERN's installations.

4.2 Energy use at CERN

The nature of CERN with its large number of different, independent users (budgets) creates the situation where almost each of them has his own local air-conditioning system. This has been observed from the beginning of CERN and unfortunately the problem still remains unsolved. This trend must obviously have an impact on the energy consumption for HVAC installations. Instead of having a centralized cooling system, hundreds of small air conditioners are being installed.

Also the fact that CERN's installations are spread over 190 hectares within a radius of 9 km makes it difficult to have a global hot/chilled water distribution network. As a consequence, electricity is very often used for heating purposes. This situation led CERN's engineers to design systems where heat recovery/recycling could be possible. As examples we can note building BA7 of the SPS with its heat pump recovering the wasted heat for the condensers, or ISOLDE having a sophisticated recirculation system. However, there are still a lot of installations where energy could be used in a more rational way (e.g. Bldg 893 with electric heaters to heat the primary water used in the air conditioning unit).

Energy use in not limited only to pure energy consumption. Primary sources of cooling also have a big impact on the exploitation costs of the installations. Medium- and large-sized HVAC installations (above 500 kW of cooling power) are more and more often cooled by air – directly or via cooling towers. This allows important savings in raw water consumption, which is nowadays used for cooling in small installations.

Recent developments in control and regulation systems widely present at CERN contribute to better energy use for HVAC installations. Building 376, equipped with a variable air volume air-conditioning system, is a good example.

4.3 Environmental protection at CERN

CERN, being a European Laboratory, applies the strictest environmental protection standards from all the member states. This policy imposes very high protection requirements for HVAC installations.

All air exhausts from experimental areas are equipped with active carbon terminal filters to eliminate the rejection of radiated particles into the atmosphere. These systems are permanently monitored and regularly checked for efficiency (LEP rejection points).

Regarding noise emission from different installations, CERN is also up to date with the latest inventions in this field. Specially designed sound attenuators reduce noise emission to acceptable levels (e.g. ventilation of the co-generation plant in Bldg 238).

Finally, the respect of all international agreements vis-à-vis CFC and H-CFC refrigerants confirms the high level of knowledge and competence regarding environmental protection at CERN (all CFCs have been replaced or suppressed and other machines working on H-CFCs are being progressively retrofitted).

5 CONCLUSIONS

Ventilation and air conditioning as a science has developed over the centuries. Starting from very primitive systems through different evolutionary stages we have arrived at a time when they play an important role in human life and have become an essential part. People have always wanted to assure the most comfortable indoor conditions according to their knowledge, thus they were looking for the best adapted solutions.

A similar tendency can be observed at CERN, where old installations, often obsolete, are mixed with modern applications using the most recent technological developments. Few need immediate renewal or replacement. Energy concerns at CERN are of lower importance on account of the nature of the Organization, where the needs of diverse communities are very difficult to predict and centralize. Also the fact that the investment and exploitation costs are usually paid from different budgets results in the tendency to minimize initial costs of an installation without regard to rational use of energy.

In all other aspects of ventilation and air-conditioning engineering, CERN’s achievements can be considered as fully satisfactory and conform to the recent developments in these sciences.

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