THE ART OF VENTILATION IN BARCELONA IN THE SECOND HALF OF THE XIX CENTURY

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The needs of ventilation

Ventilation has been associated with two human needs: comfort and health. Despite not being acquainted with the nature and properties of air, the ancients understood that fire caused air to circulate, since flow was produced by the flame. Hippocrates is said to have recommended lighting large fires in public squares during a plague in Athens.

Comfort concerned the architects much more than health with the result that balconies, windows, open stairs were incorporated to provide ventilation and improve comfort. Only dramatic events such as the death by asphyxiation of miners or of prisoners in confined spaces without ventilation demonstrated that if air was not renewed it could be lethal. Between the XVI and the XVIII centuries, ventilation was only considered under extreme conditions such as in mines. Giorgio Agricola devised some methods to ventilate mines using manpower or horse power in the *De re metallica.*

This period saw important advances in our understanding of the nature and properties of air. Torricelli determined atmospheric pressure; Pascal and Boyle developed the early theory of gases. Even Newton discovered a law of thermal transfer. In 1713, cardinal Melchior Polignac under the pseudonym of Nicolas Gauger published a book entitled *Le Mechanique du Feu* in which he discussed at the same time the construction of chimneys for heating and its application to ventilation. Despite having no notion of the composition of the air, Gauger described two of its properties: 1) air heats rapidly, 2) hot air rises and cold air descends. Both properties were confirmed by two experiments. In the case of the former property, he used a curved tube, and for the latter he distributed a number of thermometers in a room. This book constitutes a pioneering work that focuses jointly on heating and ventilation. This close link was broken only when mechanical ventilation systems were adopted. Gauger's book was translated into English by Theophile Desaguliers, who designed a fan for the House of Commons in 1736.

Notable advances in science concerning the composition of air and the changes caused by respiration in the air took place between the mid XVIII and mid XIX centuries. A tragic event, known as the black hole of Calcutta, focused attention on ventilation. In 1756, a garrison numbering 146 British and Anglo-Indian soldiers and civilians were imprisoned by Nawab of Bengal in a very confined space (5 by 6 m). Of these, 123 prisoners died from suffocation the following day. This tragedy contributed to the idea that CO_2 in the air is increased by respiration and combustion, making the air unbreathable.

In the XIX century, industrial development and large increases in urban concentrations demanded more heating and ventilation especially in factories.

In 1814 the French aristocrat, soldier and writer, Jean Frederic, Marquis de Chabannes, developed a heating and ventilation system by means of a stream of air passing through pipes and the chimney using a mechanical process. Between 1815 and 1818, Chabannes lived in exile in England, where he was engaged in two activities: political agitation and the business of heating and ventilation. It was in London where Chabannes obtained a patent for "furnace fan calorífer fumívor".

However, in 1824 the self taught engineer Thomas Tregold published his *Principles of Warming and Ventilating Public Buildings, Dwelling Houses, Manufactories,* *Hospitals, Hot Houses*. In this work, which was one of the most influential treatises on heating and ventilation in de XIX century, Tregold stressed the importance of ventilation for health reasons, i.e. he set out to determine the degree of air pollution caused by both respiration and perspiration. To ensure safety he recommended that the air be renewed in 4 cubic feet per minute and per person (6.8 m^3/h). In private houses Tregold opted for a heating system that combined the use of steam to preheat halls and corridors with fireplaces in rooms. Nevertheless, for hospital he preferred the use of steam to fireplaces. The illustration shows a siphon shaped duct for ventilating a room heated by a fireplace. This system eliminated smoke.

If Tregold laid the foundations of ventilation, David Boswell Reid was responsible for its development and consolidation. Reid was professor of physics at the University of Edinburgh and in 1834 was commissioned to heat and ventilate the new Houses of Parliament in London. The destruction of these buildings by fire and their subsequent reconstruction demanded a new system of heating and ventilation. Reid opted for the use of steam. Air was conveyed to the plenum where it was heated by a battery of steam heaters. Reid took into account humidification and purification using filters and additives to eliminate foul air. Ventilation was provided by a large chimney with a fire at the base to produce the necessary draught. Subsequently, between 1851 and 1854, he used the same system to heat and ventilate the market in Liverpool, known as St. George’s Hall.

Tregold and Reid helped to establish the theory of ventilation in the first half of the XIX century before new sources of energy emerged and gave it a new character.

In 1844 Reid published *Illustrations of the theory and practice of ventilation with remarks on warming, exclusive lighting, and the communication of sound*. This work was crucial for understanding the change that occurred in the first half of the century. Health in homes and cities became a major concern of technicians. Reid believed that, contrary to what had happened previously, the architect had to take into account ventilation from the very start of the design of the building. He contended that ventilation should be taken into account from the outset and that the cost of the construction and the health of the inhabitants should be considered simultaneously. He believed that both factors should be complementary.

The work of Reid had repercussions not only in Europe but also in the USA. After 1842 the techniques described by Reid were widely implemented in hospitals, theatres and other venues in different countries of Europe, and in the USA. They were implemented in the exhibition halls of the Universal Exhibition of 1867 in Paris.

The second half of the XIX century was marked by significant advances in the techniques of heating and ventilation. The development of these techniques spread throughout England. Eugene Peclet and Arthur Morin contributed to the understanding of heating and ventilation in France. Their work had a considerable impact in Barcelona and played a major role in the introduction of techniques in the training of industrial engineers.

Peclet was one of the founders of the Ecole Centrale des Arts et Manufactures, where he taught general physics and industrial physics. He wrote a number of books including the *Traité de la chaleur*. Peclet was considerably influenced by Reid and Gay-Lussac as is shown by his analysis of the ventilation of the Paris Stock Exchange. In his book, Péclet provides some recommendations for heating and ventilation to improve health. There were two places, prisons and hospitals, where health needs were of paramount importance.

Péclet alludes to the ethical conflict concerning the health of prison inmates. Some people believed that prisoners did not merit conditions that were healthier than those undergone by honest workers. Péclet advocated the ventilation of prisons using powerful fans that were driven by prison inmates.

A commission was established in 1843 to evaluate the heating and ventilation projects for the Prison of Mazas (in Paris). They selected the project presented by Philippe Grouvelle, which consisted in warming air using hot water pipes. Heat was produced in steam generators located in basements and was transferred to water containers placed on each floor. Ventilation was achieved by the draught of a chimney (4 m^2 and 29 m high) placed at the centre of the building. The air was removed from each cell by the pipes used for the depositions of the inmates.

The need for hospital ventilation seemed self-evident. Péclet recognized that, in this regard, France was lagging behind England, in which country this problem had been studied in the early XIX century whereas France had no ventilated hospitals until 1840 (if we do not count opening windows). Architects did not regard ventilation as a priority. Nevertheless, it was well known that specific diseases existed in hospitals because of the lack of ventilation. Péclet made a distinction between large and small hospitals. In large hospitals he recommended ventilation by injecting air with a mechanical process that was more advantageous if a steam boiler existed. In small hospitals, metal or cast iron stoves were adequate for heating, and for ventilation he suggested a fireplace with a chimney to remove the hot air.

A contemporary of Péclet, Artur Jules Morin (1795-1880) challenged the work of his colleague. Before completing his studies in l'École Polytechnique, Morin had embarked upon a military carrier, reaching the rank of general. After leaving the army, he was appointed professor of mechanics at the Conservatoire d'Arts et Métiers, of which he became the director. Of his books, special mention should be made of *Études sur la ventilation*, which appeared after the death of Péclet and was inspired by the Universal Exhibition of 1862. As a result of this Exhibition, Morin realized the importance of Reid's work and of the advances in heating and ventilation in England. Nevertheless, in his books Morin incorporated several important innovations such as the volume of the air needed for renovation, values of which were ten times more than the ones proposed by Tregold and Reid.

Morin used the Lariboisière hospital in Paris as a reference. In this hospital, Morin carried out experiments that challenged the work of Péclet. Eugene Péclet considered that the introduction of air into a space would create a variation in internal pressure that could be used in hospitals to cure some diseases that necessitated variations of pressure. Morin disagreed with his contentions and had difficulty understanding how a physicist could hold such an opinion since variations in mm of mercury have no influence on health. Morin may have been defending the position of the practical engineer against that of the theoretical physicist.

The art of ventilation in Spain

The introduction of scientific ventilation in Spain is closely linked to heating. Ventilation was included in the physics syllabus of the technical schools. The first book in Spain to mention this subject was a manual of applied physics in industry written by the engineer Eduardo Rodriguez in 1858. This book contains a long chapter on heating and a shorter one on ventilation. Eduardo Rodriguez, who had been a student of the École Centrale de Paris, was professor at the Royal Industrial Institute of Madrid.

Rodriguez dedicated only 7 pages to ventilation and established a minimum of 6 m^3/h per person to renew the air although he recommended this value to be increased from 7 to 10 m^3/h per person. Rodriguez opted for methods of ventilation based on heat rather than on machines since these required maintenance. For example in theatres he proposed that air should be introduced under the seats and that this should be extracted through the roof where a chimney, in which there was a fire, would be installed.

Rodriguez devotes a few lines to fans powered by a steam engine or operated manually as was the practice in prisons. Nevertheless, he highlighted the need for ventilation. The book by Eduardo Rodriguez was used as a text book in the training of engineers in Madrid and had considerable influence on teachers at the School of Industrial Engineering of Barcelona. We now analyze the works of two disciples of Rodriguez, Francisco de P. Rojas and Josep Vallhonesta, who were among the first engineers to graduate in Spain.

Ventilation and heating by Rojas

Francisco de Paula Rojas y Caballero Infante (1834-1909) was professor of physics at the Industrial School of Valencia in 1856. As a result of the political and economic crisis of 1865, which led to the closure of all engineering schools in Spain except the one in Barcelona, Rojas was charged with teaching machine construction in Barcelona. He also taught industrial physics before moving to the newly created Escuela General Preparatoria in Madrid at 1886.

During his stay in Barcelona, Rojas focused his attention on heating and thermodynamics. He published a book entitled *Calentamiento y ventilación de edificios*, which received an award from the Real Academia de Ciencias Exactas, Físicas y Naturales de Madrid in 1867. Rojas was considered to be an eminent specialist in heating and ventilation in his time.

In the book *Calentamiento y ventilación de edificios,* Rojas compared the different views of Péclet and Morin and also contributed some of his own ideas. Like Morin and Péclet, Rojas also used the Lariboisière hospital as a reference for ventilation. Despite the fact that Péclet opted for air injection and Morin for air aspiration, Rojas recommended a combination of the two systems in order overcome the disadvantage of using only one system. References to Morin and Péclet are present throughout his book. For example, he challenged the view of Péclet that the air was much colder and cleaner at a higher altitude.

In his book, Rojas focused on different systems of heating and ventilation in a hypothetical military hospital to be located in Barcelona or Valencia. This hospital would cater for 144 patients who would be distributed over six rooms on three floors. The reason why a hospital was chosen was that this type of building required a regular supply of heating and ventilation. For heating, he made use of three systems: 1) heating by air with calorifers inside or outside, 2) heating by steam or combined with water, and 3) heating by circulation of hot water.

As for ventilation, Rojas uses four systems: 1) chimney by aspiration from below, 2) chimney by aspiration from above, 3) aspiration “a nivel” (from each floor), and 4) mechanical system. The combination of these systems of heating and ventilation provided him with seven options.

The different systems of ventilation prompted Rojas to make some comparisons. He compared the first three ventilation systems from the technical point of view and then he compared these with the remaining four from the economic point of view.

The three ventilation systems of aspiration were compared in terms of air velocity. This was applied to Barcelona. All conditions being equal, the best system was aspiration “a nivel” (from each floor). In this system, vitiated air was exhausted through ducts on each floor and as it ascended its temperature increased. These ducts played the role of chimneys. Nevertheless, the differences in air velocity of each system were not the determining factor in choosing one system or the other.

For this reason, he considered the cost of the four systems. The chimney by aspiration from below was the most suitable system for the simple reason that it consumed less fuel. Rojas believed that mechanical ventilation was not as economical as Peclet claimed because apart from the fuel cost, additional costs would include the boiler, chimney, installation and maintenance. Notwithstanding, if steam was used for heating it would be possible to use this steam to drive a fan. This solution would be of interest to hospitals and textile factories.

Ventilation and cooling of buildings according Vallhonesta

The second case concerns Josep Vallhonesta Vendrell (1835-1899), who qualified as an engineer in the same year as Rojas (1856). He obtained a grant to study textile dyeing and printing in Paris with Chevreul at the Gobelins Factory. In 1872, Vallhonesta published a book about a new system for combining ventilation and cooling entitled: *Nuevo sistema de ventilación para mantener frescos en el verano los edificios públicos y particulares*. In 1888, he was appointed professor of inorganic chemistry at the Escola d'Enginyers Industrials de Barcelona. Vallhonesta considered that more emphasis should be placed on cooling then on heating in Barcelona given its Mediterranean climate. Thus, he proposed a new approach that combined ventilation and cooling, i. e. a system that required no capital for installation or maintenance. The only condition was the design of the building.

In the absence of developed systems of refrigeration, Vallhonesta took advantage of the studies on ventilation and heating. Given that hot air rises and cold air descends, he proposed that ventilation could be obtained by making use of the sun's radiation to heat metal ducts. He opted for the Saussure box, which consisted of a black wooden box covered with two sheets of glass to heat the air and assist its circulation. This device bore a striking resemblance to a solar panel.

As regards cooling, Vallhonesta was aware that if a hole is made in the ground at a given depth, the temperature is unaffected by climatic conditions. To this end, he recommended the construction of an underground duct to circulate clean air before its introduction into a room. This device was very similar to geothermal uses today.

Vallhonesta designed a building that had a north facing garden with large trees and bushes and plants with thick foliage. The air would be extracted from these plants via ducts. This air would be kept cool and purified provided that the garden was watered regularly. The system would be feasible if the differences in temperature between the sun and the shade were sufficiently large. The fresh air would be conveyed by ducts installed underground at a level where temperature was unaffected by the weather and would then be introduced into a room through other ducts located inside the walls.

After use, the air would be collected in flat ducts on the roof, similar to the Saussure box, part of which was made of zinc, painted in black and covered with glass to be heated by the sun. The hot air was conveyed into a metallic chimney located in the middle of the roof.

The doors and windows had to be kept tightly closed to prevent the air from entering and interrupting the cooling process. The outside walls would have to be of a suitable thickness and would be made of a refractory material. In fact, Vallhonesta's method was not only a precursor of solar and geothermal uses but also of isolation.

Conclusions

The art of ventilation was introduced into Spain in the middle of the XIX century via the physics text books that were used in the schools of engineering.

These books were based on the technology developed at the Conservatoire d'Arts et Métiers in France.

Research into ventilation in Spain benefited from the work of Péclet and Morin.

Development was theoretical in the case of engineering because of the scarcity of applications.

The works of Rojas and Vallhonesta linked ventilation to heating or to cooling. As regards heating, Rojas compared the systems for a hypothetical military hospital in Barcelona from the technical and economic standpoints.

Vallhonesta, on the other hand, presented an innovative device that is a precursor of geothermal energy to provide clean air, and another device that is based on solar panels to exhaust vitiated air.

To our knowledge, these devices failed to arouse the interest of the architects and were not applied

Bibliography

GAUGER, Nicolas (1714) *Le Mechanique du Feu ou l'art d'en augmenter les effets, et d'en diminuer la dépense contenant le traité de nouvelles cheminées qui échauffent plus que les cheminées ordinaires, 6 qui ne sont point sujettes à fumer,& c.* Cosmopoli.

FIGUIER, Louis (1867) *Les merveilles de la science ou description populaire des inventions modernes.* París : Libraire Furne Jouvet et Cie, éditeurs.

GARRISSON, F. H., (1927). "The history of heating, ventilation and lighting" *The New York Academy of Medicine*. Vol. III, n. 2, February, p. 57-67.

DONALDSON, Barry; HAGENGAST, Bernard (1994), *Heat & Cold. Mastering the great indoors.* Atlanta: ASHRAE.

JOLY, V. CH. (1872) *Traité pratique du chauffage, de la ventilation et de la distribution des eaus dans les habitations particulières.* París: Librairie Polytechnique J. Baudry, livraire-editeur.

FERNÁNDEZ GALIANO, Luis (***) Fire & memory on architects and energy. MIT Press.

Tredgold, Thomas (1825) *Principes de l'art de chauffer et d'aérer les édifices publics, les maisons d'habitations, les manufactures, les hôpitaux, les serres, etc., et de construire les foyers, les chaudières, les appareils pour la vapeur, les grilles, les étuves, démontrés par le calcul et appliqués a la pratique; avec des remarques sur ma nature de la chaleur, er de la lumière, et plusieurs tables utiles dans la pratique*. Traduït de l'anglés per T. Duverne. París: Bachelier (Successeurs de Mme Ve. Courcier).

GALLO, "Emmanuelle (****) La Contribution du marquis de Chabannes (1762-1836) à la innovation en matière de construction, de chauffage et d'urbanisme". Dins:CARVAIS, Robert, GUILLERME, André, NEGRE, Valerie, SALAROVITCH, Jules(dir.). *Edifice et Artifice. Histories constructives*. 1117-1126.

CHABANNES, Jean Frederic, Marques de (1818) *On conducting air by forced ventilating ans regulating the temperature in dwelling.* Londres: The Patent Calorifere Fumivore Manufactory.

RODRÍGUEZ, Eduardo (1858) *Manual de Física General y Aplicada a la agricultura i a la industria.* Madrid: Imprenta, fundición y librería de Don Eusebio Aguado.

POHL VALERO, Stefan (2006) "La termodinamica comoelemento legitimador dela física teórica y aplicada en la España de la segunda mitad del siglo XIX". *Quaderns d'Història de l'Enginyeria.* Vol VII, 73-114.

ROJAS, Francisco de P. (1868) *Calentamiento y ventilación de edificios*. Memoria premiada por la Real Academia de Ciencias Exactas, Físicas y Naturales en el concurso público de 1867. Madrid: Imprenta de la viuda de Aguado e hijo.