From craft to building industry

in the aspect of development of ventilation systems

Krystyna Pietrzyk

The basic stimulator to find the technical solutions for the problems of ventilation has been the development of building technology which provides for the changing needs of certain groups of people as well as for the whole society. Until the sixteenth century the attempts to solve these problems were based on the experience of craftsmen gathered over centuries on trial and error basis. The discoveries of chemists, physicists, physiologists and others led to better understanding of the principles of air movement in the enclosed spaces and of the physiological requirements of health. The development of power supplies made arrangements of the effective mechanical ventilation systems possible. The scientifically-based innovations were often based on the solutions developed by

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Ventilation of a room can be considered from two aspects. The first one is the air flow through the envelope, the second one is the air movement inside the space[1]. Climatic phenomena which are involved in the process of air flow through the envelope are wind and external temperature causing pressure difference between outside and inside the building which forces air flow through the existing openings. The air movement inside the building is mostly generated by the gravitational forces of the air of different temperatures (free convection) but also by the air forced through the openings (forced convection).

craftsmen. The expert knowledge in the field has been codified in the form of handbooks. Common access to these books from the sixteenth century led later to popular copying of standardised solutions. It enabled manufacturing and engineering of ventilating equipment and systems. Nowadays it is still important to verify old practices in order to make new, improved applications. The whole scope of the subject "from craft to building industry in aspect of development of ventilation systems" is presented on the flow diagram in Figure 1.

In the ancient days the problem of insufficient air movement was recognised because of extreme discomfort when living in hot arid or warm humid zones, or working in mines. These extreme conditions required practical solutions to reduce the

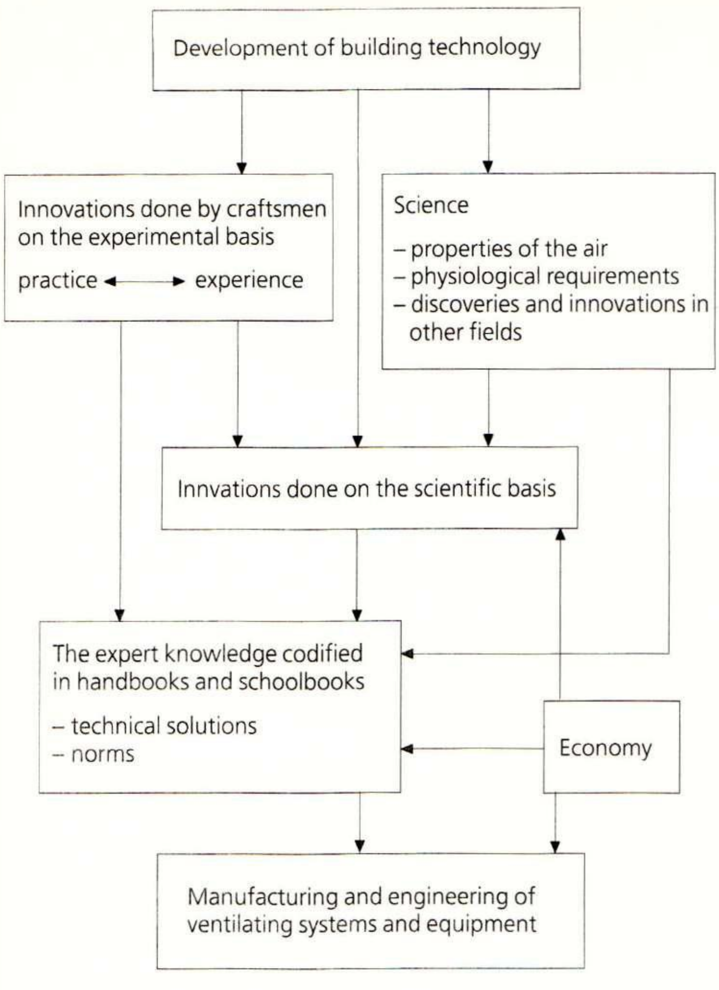


Figure 1. Flow diagram of the scope of subject "from craft to building industry in the aspect of development of ventilation systems".

degree of discomfort. Buildings of unusual shapes like, for example, the pyramids in Egypt, needed special technique for delivering fresh air to the interior. Figure 2[2] shows the system of two narrow shafts running obliquely through the masonry and reaching the exterior of the pyramid, which probably were meant for ventilation.

In hot arid climates special architectural solutions were developed to make living spaces cooler and better ventilated. To satisfy the need for ventilation wind towers were invented. When the wind blew through the top of the tower, which was slotted, the warm air inside the house was sucked up and the cool air was drawn upwards to cool the interior. The function of

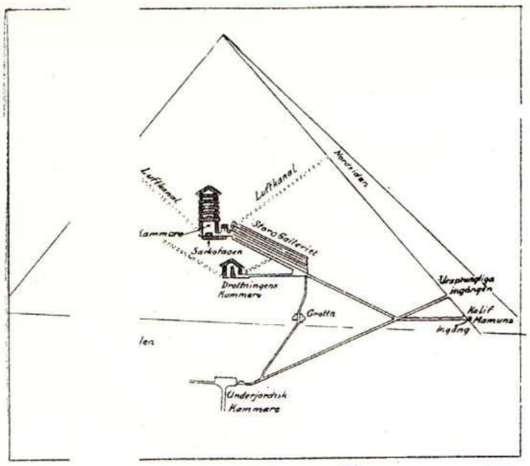
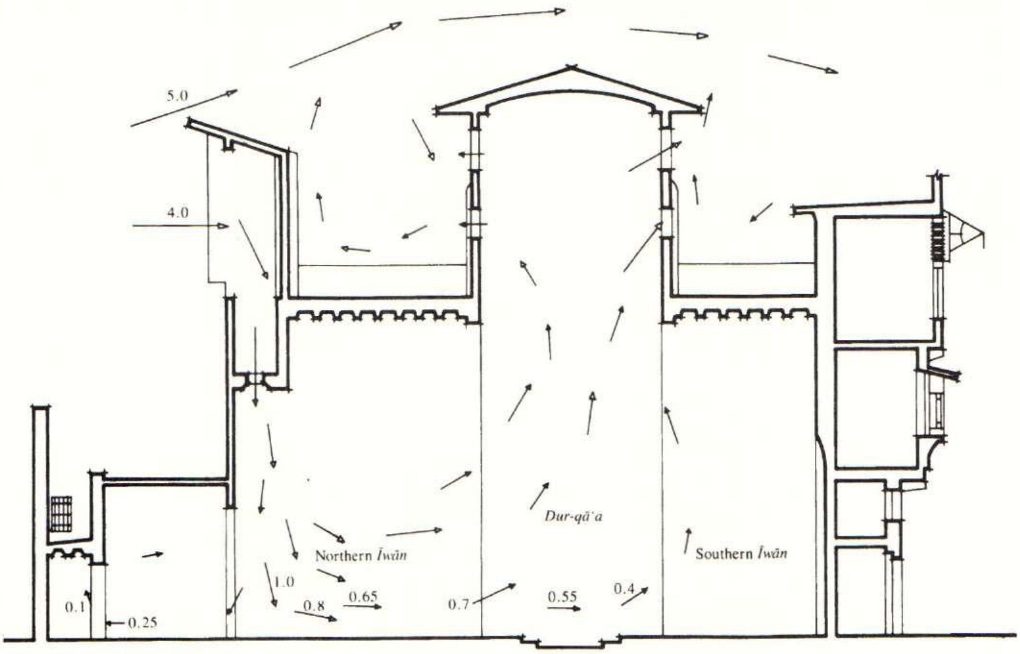


Figure 2. Section of the pyramid of Cheops

catching the wind, and the function of sucking the air from the space can be separated, so that wind-catch and wind-escape are distinguished. The opening of the top of wind-catch is facing the prevailing wind while the wind-escape opening is placed on the leeward side. The example of wind induced ventilation using wind-catch and wind-escape is shown in Figure 3[3]. The wind towers are of different shapes, heights, location, the number and the size of openings. An example is shown in Figure 4[4]. The idea of wind towers dates back to a very historical times. They were used already by ancient Egyptians and they are shown, for example, on the old paintings found on the tomb from 1300 BC.[5]

Architectural design in the tropical countries ensured natural air movement by placing the air vents adequately. To provide airflow into a room a special lattice wall called *mashrabiya* was used. It was composed of two parts: a lower section with a close mesh, and an upper section with a wide mesh as



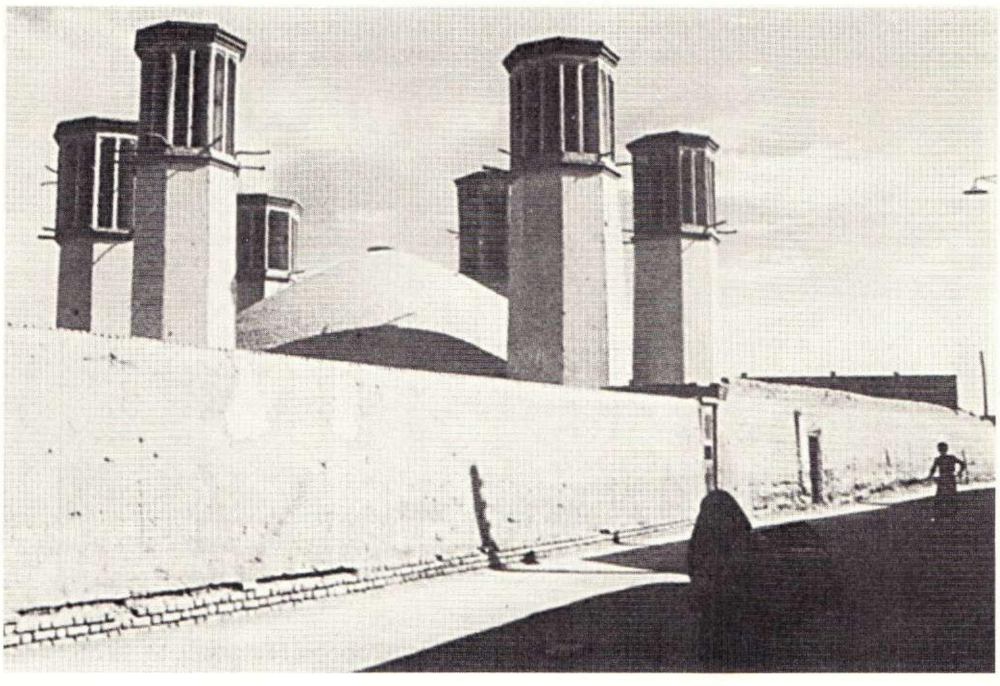


Figure 4. Wind catcher in Yzad (Iran).

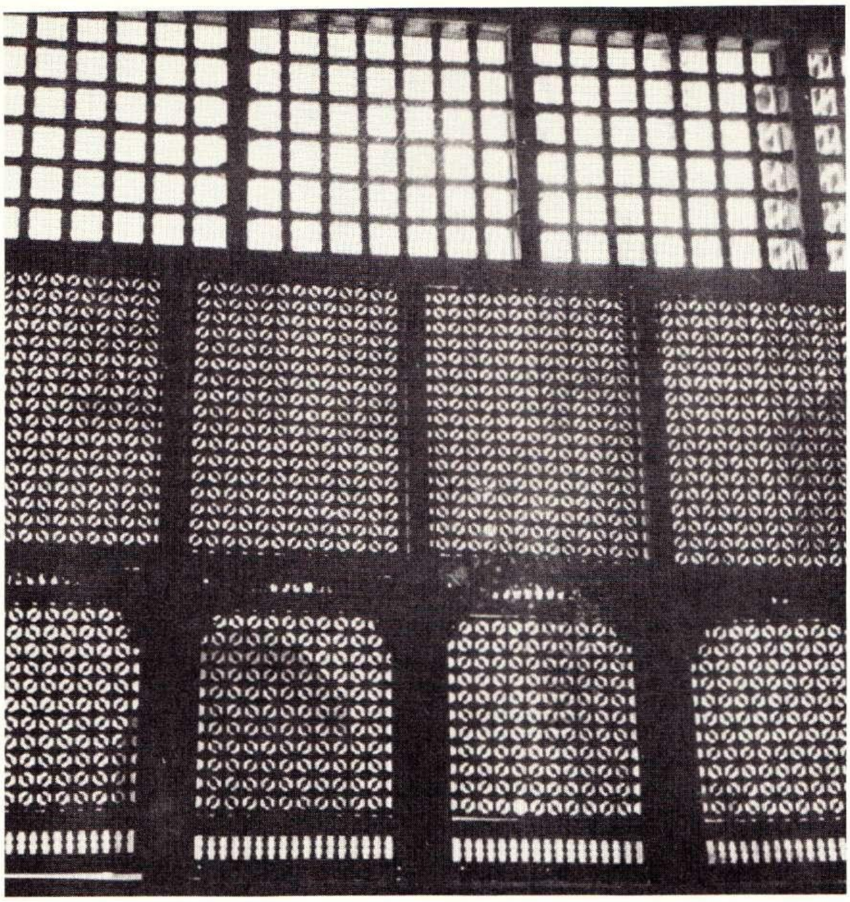


Figure 5. Special wall *mashrabiya* to provide air movement through a room.

shown in Figure 5 [6]. The dimensions were designed according to the local climatic conditions and the needs of ventilation. In some places that kind of wall was used indoors between rooms for cross-ventilation.

The presence of noxious and flammable gases caused miners to recognise the critical importance of ventilation in coal mines from the earliest days. In the period of 1600 to 800 BC one tried to solve the ventilation problems in mines by connecting the shafts in pairs, and building parallel tunnels (corridors) between the shafts. One could control the direction of the air flow by using doors with special openings mounted in these tunnels. To improve circulation of the air, fires were lit in the shafts. Another method was to pump the fresh air to the shafts by means of blankets. Figure 6 shows the reconstruction of a mine in Mitterberg in Tyrol [7].

Generally, the most reliable method, before the introduction of fans, was the use of a furnace at the shaft bottom or on the surface. "Despite the hazard of fire and explosion, there were still a large number of furnaces operating, at least in non gassy mines, in the early 20th century." [8] German mineralogist Georgius Agricola has applied ventilation by means of fans that move air mechanically for the first time. The system consisting of fans and bellows operated by human, animal or water power, has been described in edition *de re Metallica* (1556). Figure 7 (see page 78) shows the example of ventilation system where a bellow was used to pump air into the tunnel, and rotating fan wheels were used for ventilation of the horizontal shaft [9].

Technical solutions which induced and supported ventilation were developed and improved on the basis of experience by skilled workmen who practised a craft (craft-based technology). Their design lacked a theoretical basis. At that time there was no proper understanding of the properties of air and the physiological requirements of health.

During the seventeenth and eighteenth centuries scientific investigations led to fundamental discoveries, on the properties of air and the interrelations of pressure, volume, and temperature [10]. The invention of thermometer (Galileo, 1592) and barometer (Evangelista Torricielli, 1643) helped chemists to establish the empirical formulae of gas laws. Anglo-Irish chemist Robert Boyle demonstrated the physical characteristics of air and the necessary role of air in combustion and respiration. In 1662 he described the relation concerning the compression and expansion of a gas at constant temperature. French physicist Jacques Charles discovered, in 1787, that the volume occupied by a fixed amount of gas is directly proportional to its absolute temperature, if the pressure remains constant. These two gas laws were fundamental to understand the origin of convective flow, the natural source of air movement. The scientific research resulted in isolating of the air components carbon dioxide (Joseph Black, 1750) and nitrogen (Daniel Rutherford, 1770). Antoine Lavoisier is credited with the discovery of oxygen (1777). He also showed that respiration converts oxygen to carbon dioxide. Lavoisier gave a clear picture of the constituents of air, which was of great interest in the subject of ventilation. He belived that the principal source of contamination of the air is carbon dioxide, restproduct of respiration and combustion. The hazards of poor ventilation were not clearly understood until the early 20th century. Carbon dioxide accumulation has since been revealed to have minimal effect on human health under most circumstances. An English chemist John Dalton made important discoveries for later measurements of ventilation in terms of oxygen and carbon dioxide levels. In 1802 he formulated the law which claims that the total pressure of a gas is equal to the sum of the pressures of its constituents.

Measurements of the content of air were made by Sir Humphrey Davy and later (1862) by a German chemist Max von Pettenkoffer.

> Pettenkoffer's cooperation with a German physiologist Carl von Voit led to his most productive investigations. After building a "respiration chamber" capable of supporting human subjects, they proceeded to study animal metabolism during states of activity, rest and fasting, by measuring [...] the consumption of oxygen, and the production of carbon dioxide and heat" [11].

Figure 6. Reconstruction of a copper mine in Mitterberg in Tyrol.

These investigations gave background to formulate quantifiable basis for design.

The results of scientific investigations and scientific theories influenced and inspired engineers and scientist to make new science-based technological innovations, as well as to create new applications to old innovations. A good example is the introduction of the openable sash window to common use after 1700, while it had been invented since the 1300's. New application of mechanical ventilating fan wheels, were done after 200 years by John Theophile Desaguliers at the Royal Society of London in 1734 [12]. In the nineteenth century the increased scale and complexity of buildings led to the application of more sophisticated ventilation systems. The ventilation of St.George's Hall in Liverpool designed by dr David Boswell Reid and completed in 1854 involved the mechanical supply and distribution of air, as well as its removal and exhaust. The developments of steam and electric power provided effective power supply for mechanical means of ventilation.

Expert knowledge based on actual experience in the field was codified and formulated in the form of handbooks and schoolbooks. These books contained technical solutions and later the minimum standards for the design of ventilation systems. Already the Roman architect Vitruvius referred to the use of fire to induce ventilation in his handbook *On Architecture*[13]. The big contribution to the popularisation of that knowledge was the invention of the printing press in the 1500's. Georgius Agricola's *de re Metallica* which described the principles of fan-powered ventilation reached a wide audience in 1556[14]. One of the most influential handbooks in the field of ventilation is Thomas Tredgold's *Principles of Warming and Ventilating Public Buildings, Dwelling Houses, Manufactories, Hospitals, Hot Houses, Conservatories, etc.* published in 1824[15]. Thomas Tredgold, a self-taught engineer codified much of the engineering practice of his time. He recommended the minimum ventilation requirement for respiration and for use in ordinary space with artificial lighting. He understood that ventilation was needed, not only to deliver oxygen for respiration, but also to remove the contaminants. Minimum quantities of fresh air were proposed by numerous engineers and physicians like Charles Hood, dr Boswell Reid, Max Pettenkoffer, Eugene Peclet, Arthur Morin. They based theirs estimations on different experiments and assumptions concerning the air contents for personal comfort and the preservation of health. Odour, temperature, carbon dioxide, were estimated to be good measures also of the effect of ventilation[16]. It was first in the twentieth century (experiments of the German prof. C. Flugge and the English medical doctor Leonard Hill) that man realised that physical properties of the air, like temperature, humidity and air movement, are the most important in the evaluation of comfort and not primarily the chemical contents[17].

Manufacture of ventilation systems started in the nineteenth century. Companies transformed the new concepts of inventors to the serial products. Some of these companies developed their own technical innovations in the field of ventilating equipment. One of the good examples is Benjamin Franklin Sturtevant, who began as a craftsman (shoemaker) in 1850 and later built a centrifugal exhaust fan[18]. He started commercial manufacturing of these fans and also invented a pressure blower for heating system. His company was manufacturing fan blowers, ventilation systems, steam and electric fans. One can say that the end of the nineteenth century saw the birth of the heating and ventilation industry.

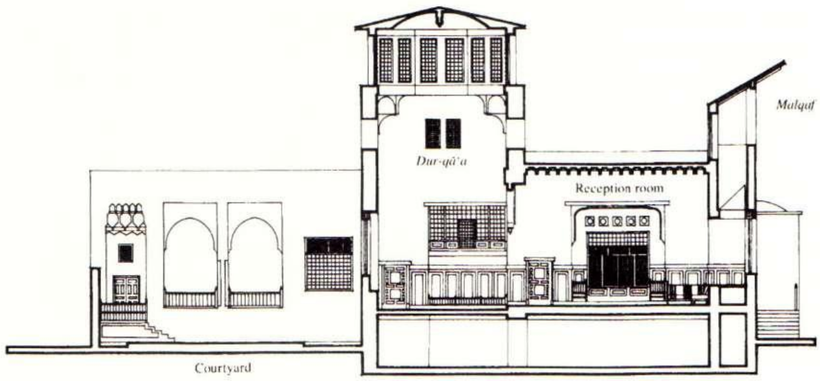


Figure 8. Section through a modern villa designed by Hassan Fathy.

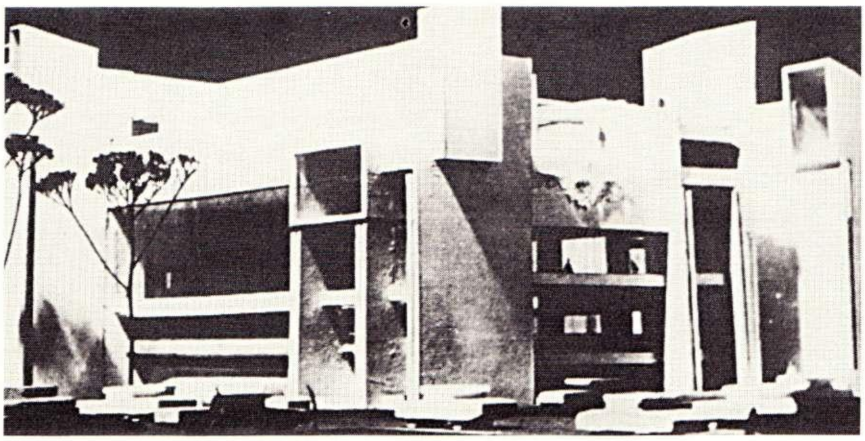


Figure 9. Design for the Yale University School of Architecture by Paul Rudolph.

The work to improve ventilation has become more and more the optimisation task, which answers the question how to provide the comfortable, healthy living conditions at the possibly lowest cost? The decrease of energy consumption is an actual problem throughout the world, though especially in the poor countries where the resources are much more limited.

Practical solutions dating from the craft-influenced period can still be applied in the original or improved form. A good example which applies the traditional ventilation solutions, is a modern villa designed by the Egyptian architect Hassan Fathy. Figure 8[19] shows a section through the reception room of that villa. One can see a complete climatic system including typical lattice wall and wind tower. Wind catchers have also been designed for the Yale University School of Architecture by Paul Rudolph, as shown in Figure 9[20], to show that they can be used in buildings of modern design.

The idea of natural ventilation based on natural sources of energy includes many such solutions. Nowadays, the design of naturally ventilated buildings can be facilitated by new methods enabling the prediction of air distribution pattern in an enclosure, which are generally known under the name of computational fluid dynamics (CFD). Air flow models can also predict the air temperature distribution in space. A good example of using this method is the ventilation analysis of a newly designed naturally ventilated music centre. The air velocity vectors along the vertical section through the centre of the auditorium are shown in Figure 10[21]. Computer simulations of different models, assuming different distributions of the main openings, help to find the optimal solution for designed comfort. The same project designed in the nineteenth century would probably have resulted in the application of mechanical ventilation system. In the ancient days the design would have been based on contemporary practice, but the solution would probably be less adequate than today's because of the lack of technical tools to predict the efficiency of the chosen system.

In order to save energy the use of the mechanical systems can be limited to a certain extent. The method of controlling the effect of mechanical exhaust systems accounting for the actual weather conditions has been analysed in ref.[22]

The flow diagram shown in Figure 1 is still valid. New ventilation tasks coming from the changes in building technology and limited by economical reasons inspire for looking for new ventilation solutions. They are based on existing ones (sometimes very old) and incorporate new achevements in technology, architecture and medicine.

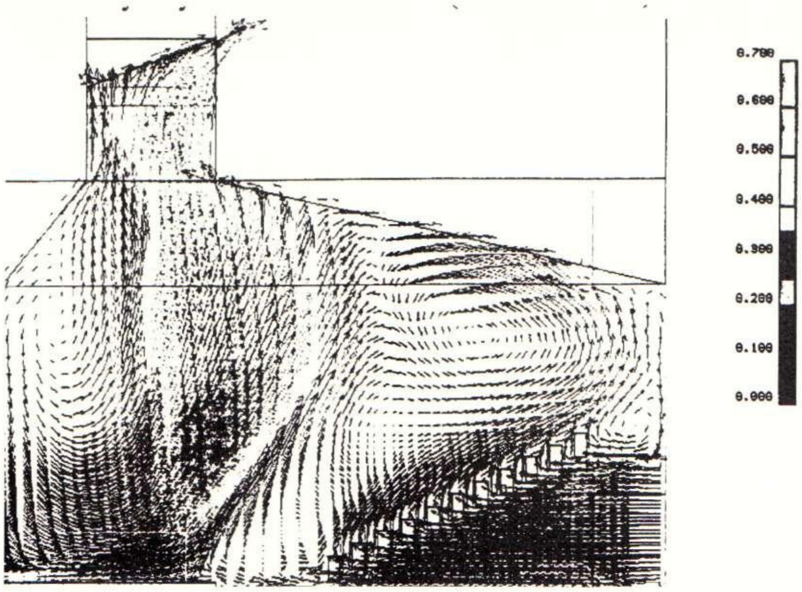


Figure 10. The example of application of CFD to predict air velocity distribution.

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10. All informations to the end of the paragraph have been taken from Donaldson 1994: p.21–24 and *Encyclopaedia Britannica* 1996:
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Krystyna Pietrzyk,
Building Aerodynamics,
Chalmers University of Technology.

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