VENTILATION TECHNOLOGIES IN URBAN AREAS

19TH ANNUAL AIVC CONFERENCE

OSLO, NORWAY, 28-30 SEPTEMBER, 1998

Title: On the Time-Dependent Efficiency of Building Ventilation on the Indoor Air Quality in a Medium Sized Urban Area in Greece

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ON THE TIME-DEPENDENT EFFICIENCY OF BUILDING VENTILATION ON THE INDOOR AIR QUALITY IN A MEDIUM SIZED URBAN AREA IN GREECE

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Synopsis

From an air pollution study in a medium-sized, seaside town in Central Greece (Volos) it was found that some common air pollutants (CO, NO, NOx, SO_2, O_3), whose emissions are connected to activities and conditions that reveal some characteristics of periodicity on a daily, weekly or yearly basis (e.g.: production activities, meteorological conditions), are monitored in the atmosphere in concentrations that reflect this periodicity. Additionally, characteristics of periodicity can also be found in the concentrations of indoor gas pollutants whose emissions are connected to some inhabitants' activities (e.g.: cooking) or are influenced by the microclimatic conditions in the building interior (e.g.: temperature, humidity). By processing this data, by statistical methods, periods were identified during the day, week or year when it is feasible to predict that indoor or outdoor air is more contaminated and harmful and, accordingly, to appreciate the relative contribution of building ventilation to the formation of indoor air quality. Corresponding findings, especially those related to periodicity on a daily basis, are used for the judgement and corroboration of the measures that are taken for the protection of indoor air quality during episodes of environmental air pollution and for the elaboration of proposals for the design of natural ventilation systems for the buildings in the area.

1. Introduction

Building ventilation makes the indoor air quality unavoidably associated with the environmental air quality. Nowadays, due to extensive and intensive pollution, there are areas on the planet where we encounter considerably increased concentrations of air pollutants. Such areas can be found in metropolitan city centres and in industrial zones. In such areas, ventilation can no longer correspond to its traditional role. In similar conditions, a more sophisticated and complex treatment of the building's air change systems is required, and possibly the implementation of additional measures that will guarantee more comfortable and hygienic conditions for the inhabitants. So, for example, in extreme conditions of environmental pollution, the installation of systems to remove the elements of pollution from the air is required. Such systems, beyond the cost of installation, operation and maintenance, also burden the building's energy balance as they presuppose the existence of mechanical ventilation systems. Instead, in moderate conditions of environmental pollution, it is possible that the natural ventilation systems are able, by themselves, to minimise the problem by the application of appropriate measures and techniques. A precondition for this is that the design of the system be made according to the actual climatic and environmental conditions of the area. Additionally, in order to make the applied measures and techniques more efficient, they should be considered and studied carefully during the design phase of the corresponding systems.

In Greece, there are areas where episodes of serious environmental pollution occur relatively frequently. They are mainly in the centres of large cities and in areas with intense industrial activity. However, a large proportion of the population lives and work in buildings which are located in areas with only moderate environmental problems. They are generally the non-central districts in large cities and medium and small-sized urban areas. A representative example of this category is the town of Volos, a medium-sized urban area, with a population of about 100,000, which extends to the cove of the Pagasitikos Gulf in the Eastern part of Central Greece.

In this paper, the conditions of environmental pollution in the area of Volos are examined, as a factor influencing the indoor air quality in the residential and commercial buildings of the area. The objective of the paper is the judgement and corroboration of the techniques and measures which are traditionally applied, or which could be applied for the ventilation of the buildings in the area in order to limit the adverse effects of environmental pollution in their interior.

2. The climatic and environmental conditions in the area

The climate in the area of Volos, like in the greater part of Greece, is Mediterranean type (Tselepidaki, 1994). More specifically, the annual period can, in general, be divided into the climatically cold and humid season (October - March) on the one hand, and the hot and dry season (April - September) on the other (Figure 1). From September to October there is a significant drop in temperature (~ 5° C) which continues gradually until January, which is the

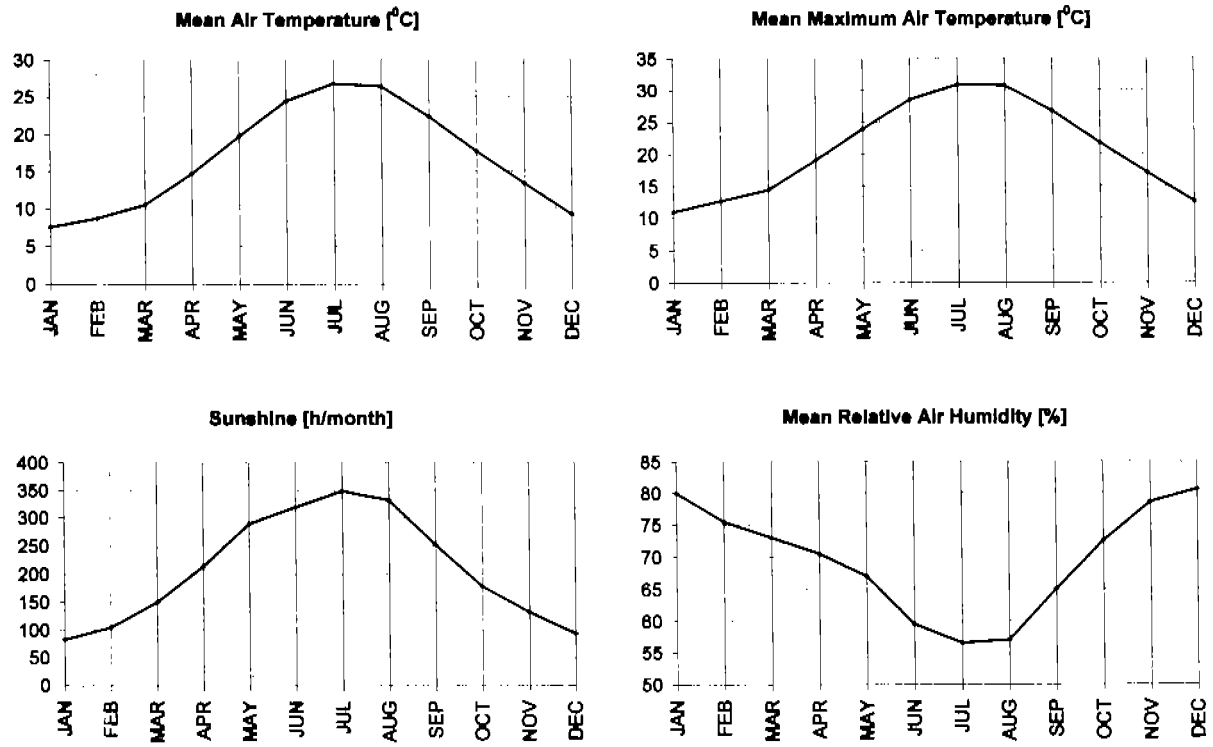

Figure 1: The mean monthly values of some basic climatic parameters in the area of Volos.

coldest month of the year (mean temperature: 7.6 °C). Starting from March, the temperature begins to increase until July and August, which are the hottest months of the year (mean temperatures: 26.8 °C and 26.4 °C, respectively). The intermediate seasons (autumn and spring) are quite clearly delineated and, in particular, the autumn is hotter than the spring by about 2 - 4 °C. Through the area passes the mean annual isotherm of 17.5°C. The mean extreme temperatures are approximately 3°C in winter and 31°C in summer. The mean annual Degree Days in the area is about 1506.

The wind's climatic characteristics, as determined by both the general atmospheric circulation and the prevailing synoptic systems in the wider area, contribute to the predominance of west and north components and moderate speeds (Zabakas, 1981). Nevertheless, in combination with these factors, the landscape, as a factor of canalisation and mid scale thermal circulation, plays a dominant role in the determination of the direction and speed of the prevailing wind in the area (Papamanolis *et al.*, 1996). On a smaller scale, the characteristics of the wind at every point in the city are influenced, in a complex way, by the street layout and the shape and dimensions of the surrounding natural and artificial obstacles (e.g.: trees, houses) (Kobysheva, 1992).

The area, due to the problems encountered in many Greek cities (lack of land planning, unplanned urban development) but also due to the increase in productive activities (industries of all sizes, transport, the port), has displayed problems of atmospheric pollution in recent years. Such problems, while they do not seem particularly serious, must not be overlooked. In a recent study which was based on the recordings from the local air pollution station of the concentration of basic pollutants for the period 1987-1994, their mean annual concentration values were calculated as follows: CO = 1.7 mg/m^3, O_3 = 73.3 ìg/m^3, NO_2 = 58.5 ìg/m^3, NO = 55.8 ìg/m^3, SO_2 = 63.5 ìg/m^3 (Dalezios *et al.*, 1995). From the same study, it becomes apparent that a large proportion of the responsibility for the air pollution in the area can be put down to traffic pollution. Moreover, a significant proportion seems to be the result of burning, both for the heating of buildings during the cold period and for productive activities (factories, industry). An influence on the environmental conditions of the area is exerted by the wind, which, depending on its direction and its speed, contributes either positively or negatively to the build-up of pollution (Papamanolis *et al.*, 1996), as does the sea breeze during the summer period (Papamanolis and Dalezios, 1997).

In some of the above studies, certain characteristics of periodicity in the concentrations of air pollution in the region have been identified. These features have been explained by the periodicity of human activities which are responsible for the emissions, and the meteorological phenomena which affect them. So, on a daily basis, higher levels of the accumulation of pollution can be observed (with the exception of O_3) during the hours where traffic circulation is heaviest due to rush-hour movement. Similarly, on a weekly basis, the accumulation of pollution is higher on the working days of the week and especially on days when shops and businesses are open both in the morning and in the evening. Periodicity was also detected on a yearly basis: the pollutants which are related to burning (CO, NO_X, SO_2) show high concentrations during the winter, when the heating requirements of buildings are at their highest. Ozone, as a product of photochemical reactions, was found to exhibit a special behaviour,

with clear indications of periodicity on a daily, weekly and yearly basis, but with extreme values, which are generally in contrast to those of the remaining air pollutants.

These findings concerning the periodicity of mean and extreme values of the concentration of pollutants which are derived using Descriptive Time Series Analysis methods, were verified by the Fourier Transformation processing of the hourly concentration values of the corresponding gas pollutants for the period 1991 - 1994. As a result of this process, the seasonal indices of the relative, to their mean annual, air pollutants concentrations, over the 24-hour period, are shown separately, for the hot and the cold periods of the year, in the diagrams in figure 2.

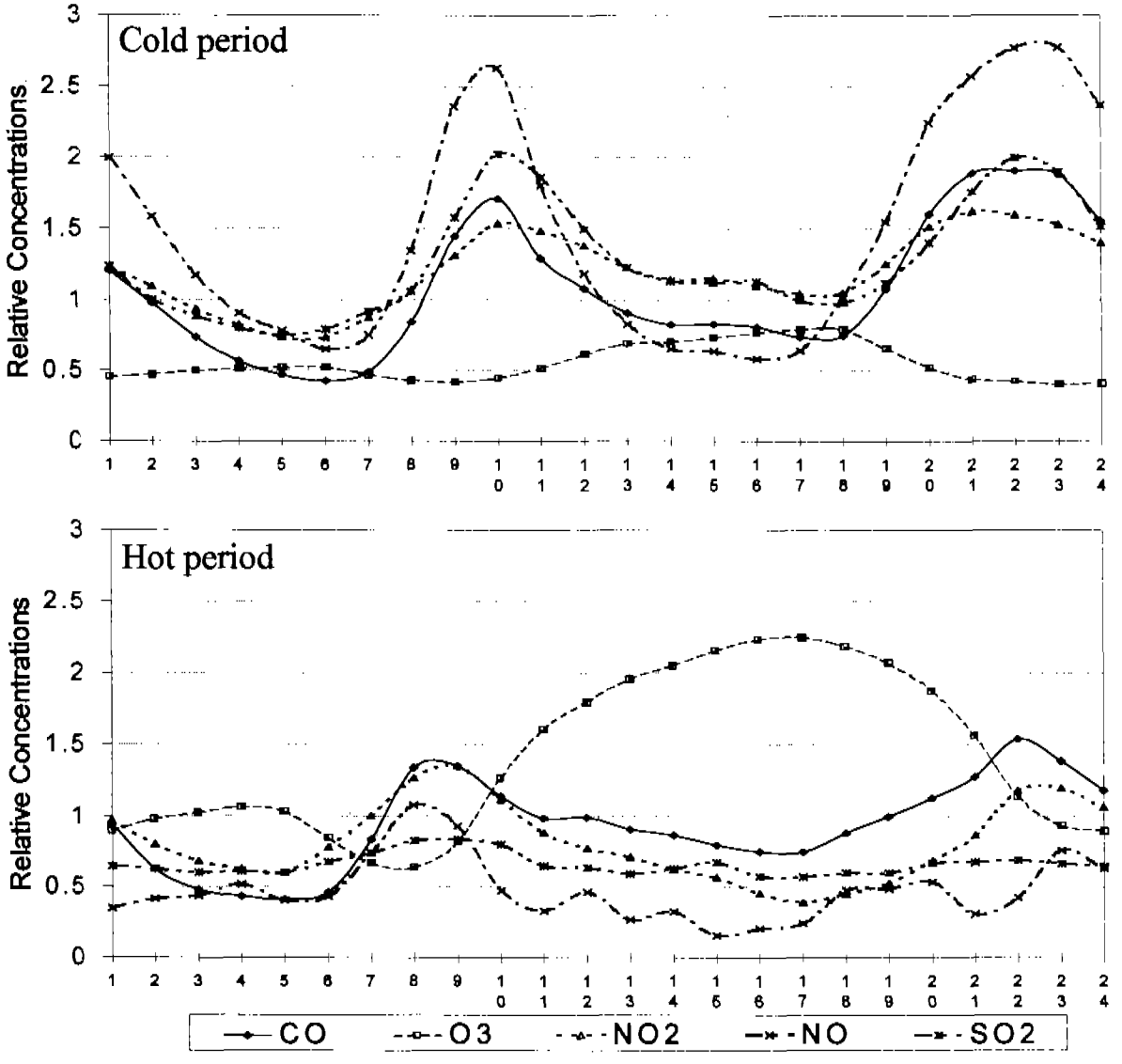

Figure 2: Seasonal indices of the relative, to their mean annual, air pollutants concentrations in the area of Volos, over the 24-hour period (based on hourly concentration values for the period 1991-94)

These diagrams show clearly the intervals during the 24-hour period when, with periodicity, increased concentrations of air pollutants can be observed. These particular pollutants, even when encountered in concentrations below their standard threshold values, have harmful effects on human health (Namiesnik *et al.*, 1992). Moreover, their presence in the atmosphere, and the fact that they were found to be largely due to traffic pollution, is unavoidably connected to the presence of other pollutants - which can not be measured with the equipment available - but also to high noise levels. Consequently, it is crucial over the corresponding periods to protect the internal environment of the buildings in the area from the influence imposed by the external environment primarily through ventilation processes. Buildings close to roads with heavy traffic are obviously more vulnerable. Especially, their lower floors, which are closer to the street level, are exposed to pollutant concentrations much higher than those recorded at the station located on the terrace of a five-store building.

3. The building ventilation conditions and the indoor pollutants in the area

In Greece, as in most countries in mild and moderate climates, the majority of residential and commercial buildings use natural ventilation systems. To a large extent, the air change takes place via infiltration and, when that is not sufficient, the residents open their windows. Furthermore, in certain spaces - the so-called 'wet' rooms (kitchen, bathroom, WC) - an exhaust fan is also often installed which, when required, is operated at the discretion of the residents.

A large number of the buildings in Volos, especially in the centre of the town, were built in the late 1950's within the framework of an extensive programme of rebuilding following a series of catastrophic earthquakes. As a consequence, there is a similarity in the architectural and constructional characteristics of these buildings. These characteristics, which include for example the method of construction, the building materials, the dimensions of the rooms, the dimensions and the type of openings, the roofing, etc. in the degree that are comparable to those prevailing in other urban centres in Greece, lead to similar conditions of natural ventilation in the buildings. From the studies which relate to the ventilation conditions of conventional building constructions in Greece, although not supported by statistically reliable samples of measurements under normal conditions, they can be classified (at least from a quantitative point of view) in the same group as corresponding buildings in a wide range of countries (mainly in Europe and North America) which offer richer bases of similar data (Papamanolis and Koinakis, 1996; Papamanolis, 1998). In other words, for an ordinary building, under meteorological conditions which are normal for its location, the range 0.5 to 1.0 ac/h constitutes a reasonable first approximation for its air change rate. Yet, such air change rates in residential and commercial buildings are frequently connected to indoor air quality problems (CEC, 1992).

The studies which refer to the quality of the internal environment in Greece are limited (e.g.: Lagoudi *et al.*, 1996). For the commercial and residential buildings in the area of Volos, as also in other urban centres in Greece, the fact that gas is not really used and that instead central heating systems and electrical appliances (for heating, cooking, etc.) are favoured, limits the range and the quantity of unavoidable pollutants inside them. Therefore, it is reasonable to assume that the main pollutants are those associated with metabolism (carbon dioxide and odour) as well as moisture (from cooking and washing) and odour (from cooking). Besides

these, there are always pollutants present which are emitted from building materials and furniture as well as from smoking, if applicable (Namiesnik *et al.*, 1992). Some of the pollutants which are the result of the activities of the residents can be monitored, showing characteristics of periodicity in the interior of many buildings. The most obvious pollutants in this category are those which are related to the presence of the residents themselves in the buildings and to cooking, which, as is reasonable, takes place prior to eating times. As far as the emissions which are not related directly to the activities of the residents are concerned, it is possible that, to the extent that they are influenced by the micro-climatic conditions inside the building (e.g.: temperature, humidity), they are also subject to periodicity (Namiesnik *et al.*, 1992). However, considering the complexity of the procedure concerned and the lack of relevant data, no clear predictions can be made.

4. The effect of building ventilation on the indoor air quality in the area

Indoor pollutants are derived from both indoor and outdoor sources. Each of these sources tends to impose different demands on the control strategies needed to secure good health and comfortable conditions. As regards the pollutants that are emitted in the interior of the buildings in the area, it seems that, based on the appreciation of their qualitative and quantitative characteristics, they do not cause any particular problem. The episodes of indoor pollution seem to be generally recognisable (part of the pollutants are odours) and easily solvable (by opening windows and with the operation of exhaust fans).

On the contrary, the assumed problems of indoor air quality in the area seem to be more closely related to environmental pollution. More specifically, during periods of increased concentrations of outdoor pollutants, the effectiveness of ventilation, as a process of supplying clean air into the building's interior, is devaluated or even reversed. This particular problem can not be confronted either by filtering the incoming air or by cleaning the indoor air, since natural ventilation systems, which prevail in the buildings in the area, are not compatible with the operation of corresponding systems. Therefore, the only way to confront this problem is by controlling the ventilation openings in the building shell. This involves closing windows (during the hot period) or keeping them closed (during the cold period) when high levels of pollution are recorded in the atmosphere. This measure, however, besides the possible limitations which are involved (e.g.: in ventilation cooling), also varies in effectiveness as the change in the quantity of ventilation provided depends on the intensity of the driving natural forces i.e.: wind and indoor/outdoor temperature difference as well as the dimensions, the type and the distribution of the remaining openings, including the infiltration openings. Moreover, this measure, which by nature is applicable for only a short period of time for inhabited places, is subject to further limitations of duration because of the generally small dimensions of the internal spaces in buildings in Greece, which means that they have only a limited ability to operate as fresh air reservoirs. The measure's applicability and effectiveness is very depended to indoor pollutant emissions (e.g.: cooking, smoking). Therefore, the reduction in the internal pollution for the corresponding period means an extension of the time it is applicable and beneficial.

According to this data, the identification of the main sources of emission of air pollutants and of the characteristics of periodicity in the build-up of air pollution in the area offers limited capability for the application of direct measures for the protection of the quality of the internal

air. This fact, however, to the extent where it is caused by the inherent weaknesses in the natural ventilation systems, is not enough to reverse the clear advantages of natural ventilation systems in favour of mechanical systems, which, under the climatic and environmental conditions of the area, are documented mainly in terms of energy cost (Liddament, 1996). A series of techniques of natural ventilation -if they are planned and implemented in the design of corresponding systems - can contribute through their implementation to the reversal of the disadvantages which were detected and, still further, contribute to the improvement of the ventilation efficiency and the building's energy balance. Similar techniques and corresponding design approaches are described in related technical notes (e.g.: Liddament, 1996). As an example, some of these, which are considered to be compatible with the architectural and constructional characteristics of the buildings in the area, concern:
- The increase in the airtightness of the building shell, so that the intervention of the residents by opening and closing large openings will be more effective.
- The elimination of spaces with high demands on air quality (e.g.: living rooms) from the sides of the building which are nearest to the external sources of pollution (e.g.: roads with heavy traffic)
- The facilitation of interzonal air circulation by locating openings on the sides of the building furthers away from the sources of pollution.
- The use and exploitation of the advantages of louvres and "top hung" windows as well as air vents and "trickle" ventilators. Automatic air inlets, even though those which are sensitive to air quality parameters are costly, can be proved useful in many cases.

5. Conclusions

The relatively high air pollution values which, according to the conclusions of relevant studies, were met in the area of this medium-sized town in central Greece (Volos), affect, through building ventilation, the indoor air quality. This is more perceptible in buildings close to the pollutant emission sources (e.g.: roads with heavy traffic). The resistance to their influence, concerning the natural ventilation systems that prevail in the residential and commercial buildings of the area, is achieved to some degree by the control of the large openings (windows, balcony doors) in their shells. For this measure, in counterbalance to its inherent disadvantages, the periodical characteristics that were discovered for the concentration of pollutants together with the identification of their major emission sources contribute to its better application. Additionally, provided that the climatic and environmental conditions in the area do not justify the use of mechanical ventilation systems, a series of disadvantages in the performance of the natural ventilation systems could be lessened by the application of proper design approaches

This study is an attempt to investigate the issue of influence of the environmental pollution on the indoor air quality as well as possible measures to confront it using building ventilation systems in a particular area, based on the available data for the real conditions that are valid there. The variations in these data (environmental, climatic, ventilation conditions, etc.) from country to country and from region to region obviously change the whole image and impose the need for different approaches in every case for the confrontation of this particular problem.

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