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Indoor environment quality: a new challenge for environmental education

J.E. Ramos*

Polytechnic Institute of Leiria,
Morro do Lena, Alto Vieiro, Leiria, 2401-951, Portugal
Fax: +035 244820310 E-mail: jramos@estg.ipleiria.pt
E-mail: jramos@estg.iplei.pt
*Corresponding author

R.A. Pitarma and M.E. Ferreira

Polytechnic Institute of Guarda,
Av. Francisco Sá Carneiro, No. 50, Guarda 6300, Portugal
E-mail: rpitarma@ipg.pt E-mail: eroque@ipg.pt

M.G. Carvalho

Technical University of Lisbon-IST,
Av. Rovisco Pais, Lisboa Codex 1096, Portugal
E-mail: maria@navier.ist.utl.pt

Abstract: Presently, most people are aware that pollution of the external air (atmospheric pollution) is prejudicial to health, but few know that the indoor environment can also have highly noxious effects in human beings. In certain cases indoor pollution even can reach levels higher than about ten times that of external pollution. All over the world there are more and more frequent unpleasant manifestations in relation to indoor Lisboa Codex environment quality. This domain is a new challenge for environmental education, which has a fundamental role in the increment of the quality of life. The main objective of this paper is the relationship among the different environmental parameters, the occupational health and the variety of sensations and states of mind in which satisfaction with the indoor environment is expressed. They are referred to as the several causes of an inadequate indoor environment.

Keywords: environmental education; indoor environment quality; indoor air pollutants; occupational health; ventilation.

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Biographical notes: Professor João Esteves Ramos has been a Coordinator and Professor at the Department of Mechanical Engineering of Instituto Politécnico de Leiria (Polytechnic Institute of Leiria) since 1999. In 1991 and 1998 he obtained, respectively, his MSc and PhD in Computer Simulation at the Technical University of Lisbon. He has several publications in international conference proceedings. His main field is mathematical modelling of energy and environment in buildings.

Professor Rui António Pitarma has been a Coordinator and Professor at the Department of Mechanical Engineering of Instituto Politécnico da Guarda (Polytechnic Institute of Guarda) since 1998. In 1992 and 1998 he obtained, respectively, his MSc and PhD in Computer Simulation at the Technical University of Lisbon. He has several publications in international conference proceedings. His main field is mathematical modelling of fluid flow, heat transfer and pollutant transport phenomena.

Professor Maria Eduarda Ferreira has been a Coordinator and Professor at the Department of Biology of Instituto Politécnico da Guarda (Polytechnic Institute of Guarda) since 1999. In 1998 she obtained her PhD in Applied Biology at the University of Aveiro. She has several publications in international conference proceedings. Her main field is biology and environmental education.

Professor Maria Graça Carvalho has been a Full Professor at the Department of Mechanical Engineering of Instituto Superior Técnico (Technical University of Lisbon) since June 1992. In 1983 she obtained her PhD in Computer Simulation of Glass Furnace at the Imperial College in London. She has participated in and coordinated a large number of international R&D Projects. She has over 300 publications in scientific journals, books and international conference proceedings to her credit. Her main field is mathematical modelling of combustion and heat transfer phenomena. One of her specialities has been the development of general numerical prediction methods for engineering combustion equipment. These methods encompass the phenomena of the turbulent reaction of gaseous, liquid and pulverised fuels, pollutant formation and thermal radiation.

1 Introduction

In modern technological society, the time people spent permanently in the indoor environment of buildings, associated with the climate of the country and the varied indoor pollutants sources, including the materials used to build and decorate, have been conditioning the quality of life and the health of the human occupants. They are relevant to introduce the 'ventilation of buildings' as a new challenge for environmental education.

As a result of the energy-saving measures, which started in the early 1970s, the artificially created 'indoor' environments have undergone radical changes, some being positive and others negative. On the positive side, increased levels of thermal comfort have been established, through improved thermal insulation, and more advanced air-conditioning or heating system design. On the negative side, a deterioration of the indoor air quality has been experienced particularly among air-conditioned buildings.

In this paper the term 'ventilation of buildings' is used, of a generic form, mentioning the general ventilation of indoor enclosures of buildings, is industrials, residential or of services, with or without climatisation of air. That is, even so ventilation is necessary to guarantee acceptable conditions of the quality of air that can equally be used for the transport of energy for heating and cooling of the environment, providing thermal comfort.

The essential necessities that lead to the installation of a system of general ventilation are the control of the distribution of gaseous contaminants in air, for dilution with insufflating new air with low levels of contaminants and the control of the environmental conditions of the air temperature, moisture, air velocity, turbulence and noise, through the climatisation of the spaces, as a fundamental role for the increment of the life quality.

All over the world there are more and more frequent unpleasant manifestations in relation to indoor environmental quality that is, instead of the building being dependent on human beings there seems to be a tendency for humans to submit to the buildings, risking their health, productivity and comfort.

In this paper a small introduction to the 'ventilation of buildings' and to its interface with the human being is made (Awbi, 1991; CEN Report, 1998; Goodfellow and Tahti, 2001; Ramos, 1998). The main objective of this paper is approached by the relationship among the different environmental parameters, the occupational health and the variety of sensations and states of mind in which satisfaction with the indoor environment is expressed.

2 Thermal comfort and ventilation

Thermal comfort is defined as "that condition of mind in which satisfaction with the thermal environment is expressed". Therefore, both thermal environment and personal variables influence thermal response and comfort.

The thermal sensation mainly is related with the thermal energy balance of the human body and the involving environment. The heat balance equation (1) for the human body relates, for unit of time, the rate of internal production of heat in the body with metabolism (M), the mechanical work performed by the human being (W) and the heat losses from the body to the environment due to the physical processes of evaporation (E), breath (B), thermal radiation (R), convection (C) and conduction through clothes (COND) (Fanger, 1972; *Ashrae Handbook of Fundamentals*, 2001).

$$Q = M + W - R - C - \mathrm{COND} - E - B \; [W] \tag{1}$$

Thus, the type of activity, clothes and the environmental parameters influence the transference of heat between the body and the environment. A positive value of Q (heat storage in the body) indicates a rising body temperature and when $Q = 0$ the body is in thermal equilibrium.

The physical quantities that affect the thermal comfort of the human body are the air velocity, the air temperature, the water vapour pressure in the air, the mean radiant temperature, the metabolism, the work and the thermal resistance of clothing.

The mean radiant temperature can be calculated in each point from the factors of form, the areas, the surface emissivity and the temperatures of the surfaces involved or measured using a thermometer with a black globe sensor, which integrates the effect of the radiation emitted for the surfaces involved.

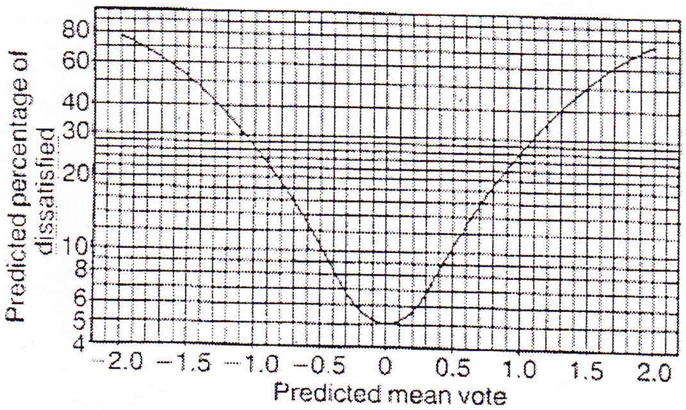
These values are combined to express the level of thermal sensation in various thermal comfort indices. The most widely used environmental indices in ventilation studies are the effective temperature, the operative temperature, the dry resultant temperature and the Fanger's thermal comfort criterion.

Results gotten by Fanger (1972) are used in standards and recommendations for design, as they are the ISO 7730 (1994) and Ashrae 55 (1992). ISO 7730 (1994), published for the first time in 1984, establishes an objective criterion for the evaluation of the thermal comfort in a perspective of evaluation of the thermal energy balance of the human body equation (1), function of the seven of the parameters cited above, three characteristics are of human beings and four characteristics of the environment.

ISO 7730 (1994) standardises the PMV – 'predicted mean vote' and the PPD – 'predicted percentage of dissatisfied' index as the method for evaluation of moderate thermal environments. To quantify the degree of comfort, the PMV index gives a value on the seven-point ASHRAE thermal sensation scale: +3 = hot, +2 = warm, +1 = slightly warm, 0 = neutral, –1 = slightly cool, –2 = cool and –3 = cold.

Even if a PMV value of zero is obtained (ideal environment), at least 5% of the occupants will be dissatisfied with the thermal environment. The predicted percentage of dissatisfied (PPD) index can be determined from the following equation (1), plotted in Figure 1.

Figure 1 Predicted percentage of the dissatisfied vs. predicted mean vote



Source: ISO 7730 (1994).

$$\text{PPD} = 100 - 95 \exp - (0.03353 \text{ PMV}^4 + 0.2179 \text{ PMV}^2) \quad (2)$$

The standard recommends a PPD limit of 10% corresponding to $-0.5 < \text{PMV} < 0.5$; PPD < 10%.

The Fanger's thermal comfort criterion produces good results for the standard conditions of sedentary activity and light clothing, but it is less satisfactory at more extreme conditions of activity and heavy clothing.

Besides the general thermal state of the body, although the body may be thermally neutral in a particular environment, a person may not be thermally comfortable if local influences on the body from asymmetric radiation, high air velocities, vertical air temperature gradient or contact with hot or cold surfaces are experienced.

Studies on the effect of draught, have found that persons with lower activity levels (sedentary or standing) are very sensitive to draughts, an undesired local cooling of the human body caused by air movement (Fanger and Christensen, 1986; Jones et al., 1986). Draught effect is probably the most frequent causes of complaints in air-conditioned spaces.

Occupants who are subjected to draughts in winter tend to elevate the room temperature to counteract the cooling sensation thereby increasing the energy consumption. In extreme cases ventilation systems are shut off or air supply outlets are blocked off with a consequent deterioration of the indoor air quality.

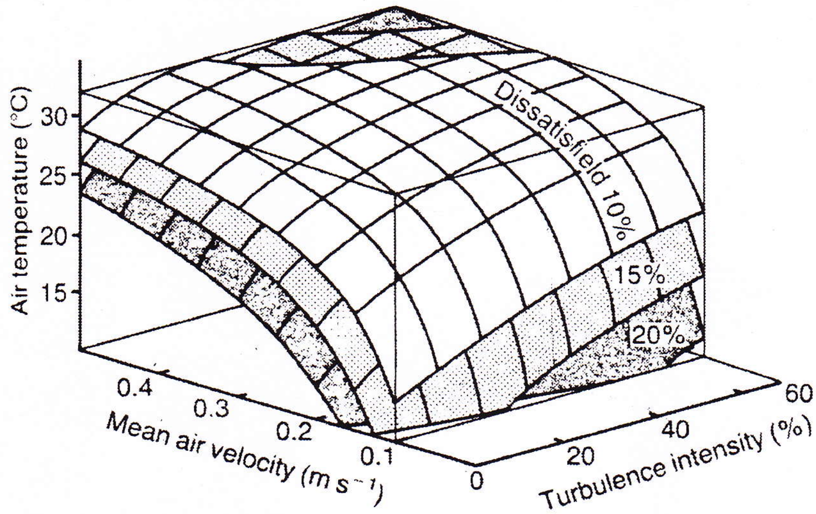
Fanger et al. (1988a) developed a mathematical model to quantify the draught risk in terms of the percentage of dissatisfied people. In this model, the percentage of dissatisfied people due to draughts, DR (%), is calculated, in the head region, from:

$$\begin{aligned} &DR\,(\%) = (34 - T)\,(v - 0.05)^{0.6223}\,(3.143 + 0.3696\,I\,v) && \text{para } v > 0.05 \text{ m/s} \\ &DR\,(\%) = 0\% && \text{para } v < 0.05 \text{ m/s} \qquad (3) \\ &DR\,(\%) = 100\% && \text{para DR} > 100\% \end{aligned}$$

where T is the local air temperature (°C), v the mean velocity (m/s) and I the turbulence intensity (%), which is defined as the velocity fluctuation over the mean velocity.

A three-dimensional representation of equation (3) is shown in Figure 2 for three surfaces of the percentage of dissatisfied, i.e. DR = 10, 15 and 20%.

Figure 2 Representation of the three parameters influencing the percentage of the dissatisfied due to draught at the head region



The model of the risk of the sensation of draft due to circulation of air equation (3) started to be enclosed in the reviewed version of ISO 7730 (1994). This standard, in its last version, recommends for design the values of the temperature, the air velocity and the intensity of the turbulence of the air flow of the air that, in set, take the values of DR lower than 15%, as the required degree of requirement.

The impact of turbulence intensity on sensation of draft was investigated by Fanger et al. (1988a) and Fanger and Pederson (1977) for different methods of air distribution. These studies have shown that a turbulent air velocity is less comfortable than a laminar air velocity of the same average. In occupied spaces the air movement is rather random and not well defined, which is a characteristic of turbulent flow.

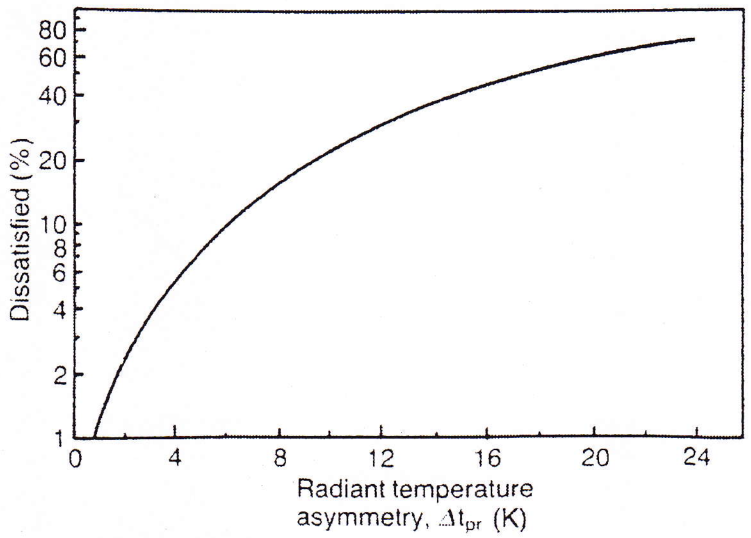
The asymmetry of the thermal radiation in rooms of residential buildings or services essentially may be caused by cold/hot windows, walls, ceilings and heating panels, while in environments of industrial buildings it is caused essentially by the thermal radiation emitted by the cold or hot surfaces of the machines.

This effect can be described by the parameter radiating temperature asymmetry (ΔT_{pr}), which is defined as the difference between the plane radiant temperatures of each one of the faces of a located small plane element in the interior of an enclosure. In this context, the plane radiant temperature T_{pr} corresponds to a fictitious uniform temperature for the one involved, for which the incident thermal radiation in the face of a plane element takes an identical value to the resultant of the real situation.

Olesen (1985) presents the results of a study of the effect of the asymmetry of the thermal radiation, with a group of people, in thermal balance, sedentary activity in a room, with light clothes (I_{cl} = 0,6 clo), submitted initially to the heated ceiling effect and later to the effect of a cold window, for different values of $\Delta\ T_{pr}$.

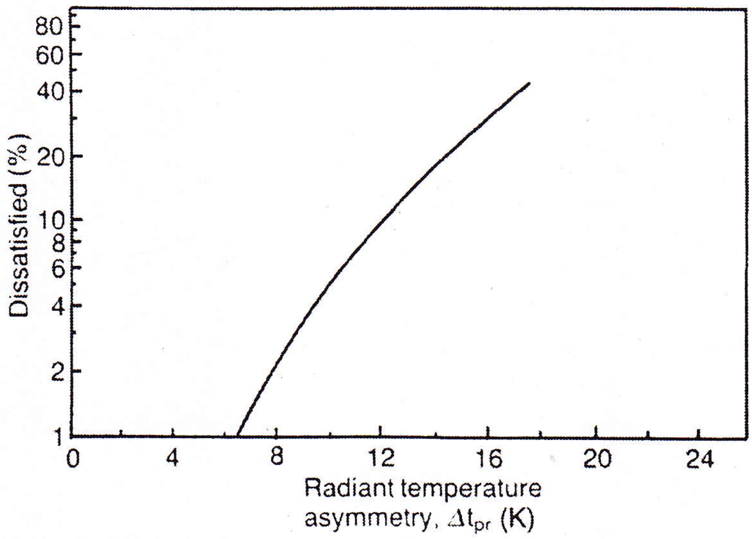
Figures 3(a) and (b) show the percentages of dissatisfaction gained in this study, respectively for the heated ceiling effect and for the cold window effect.

Figure 3(a) Effect of radiant temperature asymmetry due to a heated ceiling and the percentage of the dissatisfied



Source: Olesen (1985).

Figure 3(b) Effect of radiant temperature asymmetry due to a cold wall and the percentage of the dissatisfied

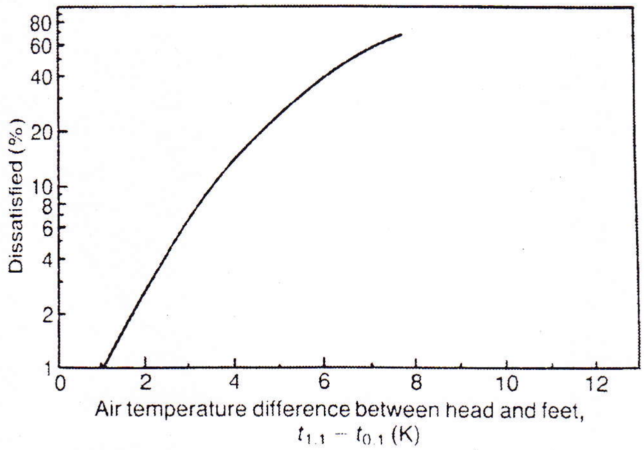


Source: Olesen (1985).

These results show that people are more sensible to the effect of the asymmetry of the radiation in the vertical direction than of that in the horizontal and the one standard ISO 7730 (1994) that they had taken recommends the limits of 10°K for the thermal radiation asymmetry between vertical cold surfaces and a vertical plain surface, located at 0.6 m of height, and 5°K for the thermal radiation asymmetry in the vertical direction.

The effect of the air temperature vertical gradient (Brohus and Ryberg, 1999) already had been studied by Olesen et al. (1979) in a climatised room, having concluded that, essentially for people seated or without significant activity, the differences of the temperature of air do not have to be greater than 3°K between the level of the head and the ankles, corresponding to a percentage of dissatisfaction of about 5% of the people (Figure 4). ISO 7730 (1994) recommends this limit.

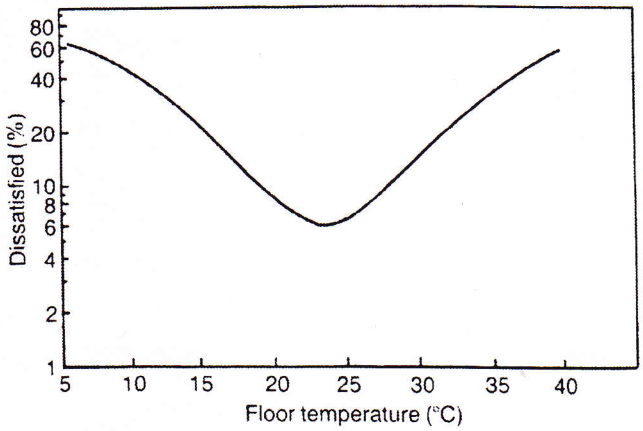
Figure 4 Effect of vertical air temperature difference on the percentage of the dissatisfied



Source: Olesen (1979).

In winter, for people in sedentary activity, the sensation of discomfort due to the cooling of the feet is common. The floor temperature of the room can induce this effect. Olesen (1977) extensively investigated this effect having concluded that the excellent temperature of the surface of the floor, in winter, is 25°C for a sedentary seated person and 23°C for a standing or walking person, being able, however, to vary in the range 19–29°C for values of the dissatisfaction lower than 10% (Figure 5).

Figure 5 Effect of floor temperature on the percentage of the dissatisfied



Source: Olesen (1979).

3 Air quality perception and ventilation

Today, everybody knows that atmospheric pollution, in general is associated with industrial processes and combustion, it harms the health but they do not know that indoor air pollution can also have a highly harmful effect on human beings, reaching levels higher than that on the outside.

The levels of pollution of indoor air are of particular interest to the health of human beings because it is predicted that 85% of human beings permanently spend time in the indoor spaces of buildings. Thus, beyond the thermal and acoustics characteristics (noise, temperature, moistness and air speed) the air quality in these spaces cannot be rejected.

In the last years, the detected problems of health in the occupants of residential buildings, hospitals and offices, the quality of indoor air have deserved particular attention on the part of the World Organization of Health, investigators, psychologists, engineers, medics, building designers, etc. This problematic one, still badly known, is related with psychological, physical and chemical aspects not obvious of the contamination levels that could be reached, the permissible time of exposition to the contaminants (dose) and what causes this contamination.

The evidence so far appears to point towards poorly ventilated and tight buildings and these are not necessarily buildings starved of outdoor air but rather the quality of the air supplied to them is poor. The deficient air quality essentially is associated to the modern buildings, with systems of AVAC, to low taxes of ventilation, to few openings for the exterior, to deficient maintenance of the systems or to the unacceptable quality of insufflating air.

The infectious illnesses provoked by biocontaminants can bring problems of health, as for example the 'illness of the legionary', caused for the 'legionella pneumophila'. In contrast of the old one estimated that the occupants were preferential or exclusively the polluting agents (odours and tobacco), studies in natural and mechanical ventilation have shown that more complaints related to building sickness (such as nasal blockage, dry throat, headache and rhinitis) were found among occupants of the mechanically ventilated buildings (Ashley, 1986; Robertson et al., 1985). It is believed that these complaints are caused more by pollutants emitted internally by building materials, furnishings, equipments and ventilation plants than by the occupants of the buildings themselves that does not contribute to more than 30% of the contamination (Bluyssen et al., 1995; Fanger et al., 1988b; Pejtersen et al., 1990).

This fact, strengthened by the fact that the complaints disappear or diminish outside of the work environment, lead to believe that the illnesses are caused by discomfort problems, as by the illumination, the noise, the vibrations, the radiations (for example 'radon'), the air temperature, the moistness, and essentially by several pollutants emitted internally.

The priority form for the resolution of the problem of the contamination of the environment in the buildings seems to be the prevention, through the adequate ventilation of the spaces, the hygiene and the control of the proper emitting sources.

Thus, in the last years, an increasing interest in the knowledge of the taxing effects of release of pollutants emitted from specific sources as they are the ammonia, chlorine, the formaldehydes, etc. (Bluyssen et al., 1995).

Thus the quality of air, as well as the thermal comfort and the hygiene, a question of environmental education a bigger information directed to the public will have to exist and, essentially, specific formation will have to be given to building designers and to the technician who follows the AVAC installations.

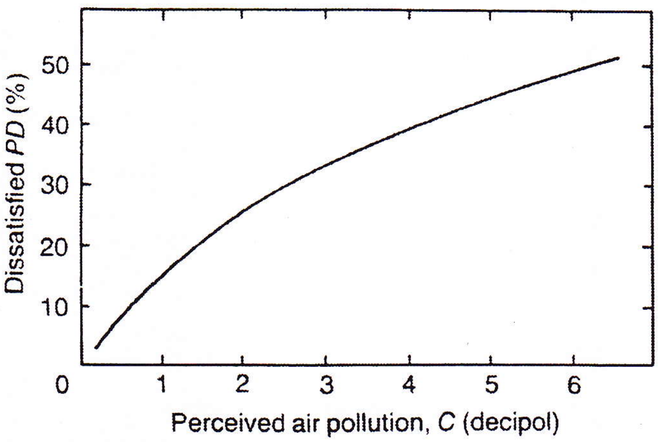
4 Ventilation requirements

Beyond the reduction and control of the intensity of the contamination sources, the indoor air quality will have to be promoted through the dilution of the contaminants with new air, until a level of acceptable concentration, either with forced, natural or mixing ventilation. The minimum values of this ventilation requirement in the buildings have been changing in the last years until the present (Brouns and Waters, 1991; Janssen, 1989).

The perception of air quality being a subjective parameter, Fanger et al. (1988b), using the results from previous studies on bioeffluents involving more than 1,000 sedentary men and women, obtained a correlation between the percentage of dissatisfied (PD_q) and the ventilation rate. Thus, it created two new units – 'olf' to quantify the value of the concentration emitted by the pollutant source and 'decipol' to quantify the level of the perception of the air quality detected by human beings. One olf is defined as the concentration of the pollutants emitted by a non-smoker occupant, in sedentary activity, while one decipol corresponds to the perception of the air quality in a space subject to a pollutant source of one olf, ventilated with a flow rate of 10 l/s of clean air (Fanger, 1988).

The air quality was judged (voting) by 168 men and women just after entering into a room where there had been more than 1,000 people, in sedentary activity (one met and one olf), Fanger et al. got correlation (4) between the percentage of people dissatisfied with the air quality PD_q and the perceived air quality C, for a pollutant source of one olf, represented in the graphical form in Figure 6.

Figure 6 Percentage of the dissatisfied as a function of the indoor air quality perception



Source: Fanger (1988).

$$PD_q\,(\%) = 395\exp(-3.25C^{-0.25}) \quad \text{para } C < 31.3 \text{ decipol}$$

$$PD_q\,(\%) = 100 \text{ para} \quad C > 31.3 \text{ decipol} \tag{4}$$

The work group no. 6 of the Commission of the European Communities, in the project 'Indoor Air Quality and its Impact on Man', defined a new methodology for the evaluation of the minimum requirements of ventilation that would be desirable in the buildings (CEC, 1992). This methodology is based on a new boarding of the evaluation of the ventilation requirements, which takes into consideration the contribution of all types of pollutants sources, the type of human occupation, the materials of construction and decoration, the quality of new air, etc. Thus, this boarding is a strong incentive for the use of weak pollutant materials sources. In contrast to the USA 'Ashrae Standard 62' (1989) this methodology does not fix a value for the minimum ventilation flow rate as a function of the use of the spaces and its taxes on human occupation. The value of the ventilation requirements is based on the total load of the pollutants, on the quality of new air to be inlet, on the level of the perception of the air quality desired and still on the efficiency of the ventilation system that will be selected.

With this methodology, by means of the type of use of the spaces, some levels of requirement of the perception of the air quality are assumed, that is, in some cases it will be enough to consider a modest quality (high *C*) while that in others we will need one high air quality (low *C*). These categories correspond to different levels of dissatisfaction in people (see Figure 6). This autonomy in the decision of the level of the indoor air quality desired allows defining a commitment with the rational management of the energy.

5 Conclusions

In a modern technological society, the time of permanence of the people in the indoor environment of buildings, associated with the climate of the country and the varied indoor pollutants sources, including the materials used to build and decorate, have been conditioning the quality of life and the health of the human occupants. All over the world there are more and more frequent unpleasant manifestations in relation to the indoor environmental quality, being excellent to introduce the 'ventilation of buildings' as a new challenge for the environmental education.

This paper approaches the relationship among the different environmental parameters, the occupational health and the variety of sensations and states of mind in which satisfaction with the indoor environment is expressed. The physical quantities that affect the thermal comfort of the human body are the air velocity, the air temperature, the water vapour pressure in the air, the mean radiant temperature, the metabolism, the work and the thermal resistance of clothing. These values are combined to express the level of thermal sensation in various thermal comfort indices.

Besides the general thermal state of the body, although the body may be thermally neutral in a particular environment, a person may not be thermally comfortable if local influences on the body from asymmetric radiation, high air velocities, vertical air temperature gradient or contact with hot or cold surfaces are experienced. Studies on the effect of draught, have found that persons with lower activity levels (sedentary or standing) are very sensitive to draughts. It is probably the most frequent causes of complaints in air-conditioned spaces.

Today, all the people know that the atmospheric pollution, in general is associated with the industrial processes and of combustion, it harms the health but they do not know that the pollution of indoor air can also have highly harmful effects on human beings, arriving to reach levels higher than in the outside. The deficient air quality essentially is associated with the modern buildings, with systems of AVAC, low taxes of ventilation, few openings for the exterior, deficient maintenance of the systems or the unacceptable quality of insufflating air. The priority form for the resolution of the problem of the contamination of the environment in the buildings seems to be the prevention, through the adequate ventilation of the spaces, the hygiene and the control of the proper emitting sources (occupation human, the materials of construction and decoration, the quality of new air, etc.).

Thus the indoor air quality, as well as the thermal comfort and the hygiene, a question of environmental education a bigger information directed to the public will have to exist and, essentially, specific formation will have to be given to building designers and to the technician who follow the AVAC installations.

References

Ashley, S.P. (1986) 'Sick buildings', *Build. Serv.*, February, pp.25–30.

Ashrae Handbook of Fundamentals (2001) *Thermal Comfort*, Ashrae, Atlanta, pp.8.1–8.13.

Ashrae Standard 55 (1992) *Thermal Environmental Conditions for Human Occupancy*, American Society of Heating, Refrigeration and Air-Conditioning Engineers, Atlanta.

Ashrae Standard 62 (1989) *Ventilation for Acceptable Indoor air Quality*, American Society of Heating, Refrigeration and Air-Conditioning Engineers, Atlanta.

Awbi, H.B. (1991) *Ventilation of Buildings*, Chapman and Hall, London.

Bluyssen, P.M. *et al.* (1995) 'European audit study in 56 office buildings. Conclusions and recommendations', *Healthy Buildings'95*, Milano, September, pp.1287–1292.

Brohus, H. and Ryberg, H. (1999) *The Kappa Model – a Simple Model for the Approximate Determination of Vertical Temperature Distribution in Rooms*, Aalborg University.

Brouns, C. and Waters, B. (1991) *A Guide to Contaminant Removal Effectiveness*, Technical note, AIVC, Vol. 28, No. 2.

CEC (1992) *Guidelines for Ventilation Requirements in Buildings, Report 11, European Concerted Action 'Indoor Air Quality and its Impact on Man'*, Office for Publications of the European Communities, Luxembourg.

CEN Report (1998) 'CR 1752 design criteria for indoor environment', in Etheridge, D. and Sandberg, M. (Eds.) (1996): *Building Ventilation – Theory and Measurement*, Wiley.

Fanger, P.O. (1972) *Thermal Comfort*, McGraw-Hill, New York.

Fanger, P.O. (1988) 'Introduction of the olf and the decipol units to quantify air pollution perceived by humans indoors and outdoors', *Energy and Buildings*, Vol. 12, pp.1–6.

Fanger, P.O. and Christensen, N. (1986) 'Perception of draught in ventilated spaces', *Ergonomics*, Vol. 29, pp.215–235.

Fanger, P.O. and Pederson, C.J.K. (1977) 'Discomfort due to air velocities in spaces', *Proc. Meet. of Commission B1, B2 and E1 of the International Institute of Refrigeration*, pp.271–278.

Fanger, P.O., Lauridsen, P. and Clausen, G. (1988b) 'Air pollution sources in offices and assembly halls, quantified by the olf unit', *Energy and Buildings*, Vol. 12, pp.7–19.

Fanger, P.O., Melikov, A., Hanzawa, H. and Ring, J. (1988a) 'Air turbulence and sensation of draught', *Energy and Build*, Vol. 12, pp.21–39.

Goodfellow, H. and Tahti, E. (2001) *Industrial Ventilation Design Guidebook*, Academic Press.

ISO 7730 (1994) *Moderate Thermal Environments – Determination of the PMV and PPD indices and Specification of the Conditions for Thermal Comfort*, International Organization for Standardization, Geneva.

Janssen, J.E. (1989) 'Ventilation for acceptable indoor air quality', *ASHRAE Journal*, October, pp.40–48.

Jones, B.W., Hsich, K. and Hashinage, M. (1986) 'The effect of air velocity on the thermal comfort at moderate activity levels', *ASHRAE Trans.*, Vol. 92, pp.761–769.

Olesen, B.W. (1977) 'Thermal comfort requirements for floors occupied by people with bare feet', *ASHRAE Trans.*, Vol. 83, pp.563–570.

Olesen, B.W. (1985) 'Local thermal discomfort', *Bruel and Kjaer Tech. Rev.*, Vol. 1.

Olesen, B.W., Scholer, M. and Fanger, P.O. (1979) *Vertical Air Temperature Differences and Comfort, in Indoor Climate*, Danish Building Research Institute, Copenhagen, pp.561–579.

Pejtersen, J. *et al.* (1990) 'A simple method to determine the olf load in a building', *Proc.* of *Indoor Air'90*, Toronto, pp.537–542.

Ramos, J. (1998) *Modelação do Comportamento Térmico e Ambiental de Edifícios*, PhD Thesis, Department of Mechanical Engineering, Technical University of Lisbon-IST, Lisboa.

Robertson, A.S. *et al.* (1985) 'Comparison of health problems related to work and environmental measurements in two office buildings with different ventilation systems', *Br. Med. J.*, Vol. 291, pp.373–376.