PERIODICA POLYTECHNICA SER. MECH. ENG. VOL. 44, NO. 2, PP. 249–264 (2000)

COMFORT IN CLOSED SPACES ACCORDING TO THERMAL COMFORT AND INDOOR AIR QUALITY

Levente HERCZEG, Tamás HRUSTINSZKY and László KAJTÁR

Department of Building Service
Budapest University of Technology and Economics
H–1521 Budapest, Hungary

Received: March 30, 2000

Abstract

In general the comfort of closed spaces means the thermal sensation, the air quality, the acoustic and lighting characteristics of the room. When designing the air-conditioning of a so called comfort room, the primary goal is to provide a pleasant microclimate for the people staying inside. Basically this means that the required thermal comfort of the people has to be satisfied. A person has pleasant thermal comfort if he/she feels that the temperature, the humidity and velocity of the surrounding air, as well as the mean radiating temperature is optimal. In this case the person staying in the room does not wish the surrounding air to be warmer, colder, more or less humid. Furthermore, considering the necessity of satisfying the thermal comfort, foreign regulations and standards take the quality of the air also into consideration. The good quality of the air inside the room can be maintained by letting in clean fresh air in a sufficient amount for the people staying inside. The technical regulations concerning this respect have not yet been properly prepared. The frequently heard complaints of people working in air- conditioned rooms are in connection with all this. They find that the air has an unpleasant smell, they feel a lack of air, or they might have a headache.

Keywords: thermal comfort, quality of air, computer simulation.

1. Heat Generation and Thermal Equilibrium of the Human Body

The factors influencing the thermal equilibrium of the human body are the basis of the dimensioning processes, so we give a brief summary of the equations describing the heat generation and heat equilibrium of the human body. The equations expanded by Fanger and used in the ISO 1984 standard are applied by the international technological practice.

The first basic definition concerning the temperature generation of the human body is the so called metabolism, which is the sum of those processes of the body, that are concerned with the intake, the transformation, the storage and the outlet of materials. The metabolic heat energy can be measured on the basis of the oxygen consumption, and can be calculated with the following function:

$$M = RQ \cdot 5.8 \cdot \frac{V_{O_2} \cdot 60}{F_{Du}} \qquad \text{[kcal/h]}. \tag{1}$$

The next basic definition, which is also part of the previous one, is the so called

DuBois surface. This is used for calculating the surface area of the human body:

$$F_{Du} = 0.203 \cdot G^{0.425} \cdot L^{0.725}. \qquad [\mathrm{m}^2]. \tag{2}$$

According to the thesis of Fanger the oxidation process taking place in the human body consists of two components: the outside mechanical work (W) and the required inner heat (H):

$$M = H + W \qquad [\mathrm{kcal/h}]. \tag{3}$$

The efficiency of the mechanical work can be expressed accordingly:

$$\eta = \frac{W}{M} \qquad [\%]. \tag{4}$$

Heat is generated inside the human body, which can be dissipated in four different ways. The optimal situation from the point of view of the human body is the one, in which the heat exchange process is in balance, that is the amount of the generated and the dissipated heat is identical. This condition is generally expressed by a very simple function (1):

$$Qw = M - W - E \pm S \pm C \qquad [\mathrm{kcal/h}]. \tag{5}$$

In case when the right side of the equation is positive, the temperature of the body is increasing, this means that the person feels warm. In case it is negative, the temperature of the body is decreasing, so the person feels cold. A thermal equilibrium can be reached, if $Qw = 0$. In this case the thermo sensation of the person is pleasant.

2. Fanger's Dimensioning Procedure on the Basis of the Thermal Equilibrium of the Human Body

The data and causalities concerning the method are also summarised in the ISO 7730, which came into effect in January 1983. According to the calculation method the thermal equilibrium of the human body is the function of the following factors:

$$f\left(\frac{H}{F_{Du}}, I_{cl}, t_{lb}, t_{ks}, p_{vg}, v\right) = 0. \tag{6}$$

The basic equation of thermal equilibrium is the following:

$$H - E_d - E_{SW} - E_{re} - L - K = S + C. \tag{7}$$

Substituting the elements of the equation with the suitable factors, we get the so called equation of thermal equilibrium:

$$\begin{aligned} &\frac{M}{F_{Du}}(1-\eta) - 0.35(1.92t_{ks} - 25.3 - p_{vg}) - \frac{E_{SW}}{F_{Du}} \\ &-0.0023\frac{M}{F_{Du}}(44 - p_{vg}) - 0.0014\frac{M}{F_{Du}}(34 - t_{lb})) = \frac{t_{ks} - t_{cl}}{0.18 I_{cl}} \\ &= 3.4 \cdot 10^{-8} f_{cl}[(t_{cl} + 273)^4 - (t_{ks} + 273)^4] + f_{cl}\alpha_c(t_{cl} - t_{lb}). \end{aligned} \tag{8}$$

Fanger expanded the following mathematical causalities concerning the level of activity, the temperature of the skin and sweating:

$$t_b = 35.7 - 0.032\frac{H}{F_{Du}} \qquad [°C], \tag{9}$$

$$E_{SW} = 0.49F_{Du}\left(\frac{H}{F_{Du}} - 50\right) \qquad [W]. \tag{10}$$

In case we substitute these equations into the basic equation of thermal equilibrium (8), we get the so called equation of comfort, which is concerned also with the change of skin temperature and sweating depending of the comfort feeling:

$$\begin{aligned} &\frac{M}{F_{Du}}(1-\eta) - 0.35\left[43 - 0.061\frac{M}{F_{Du}}(1-\eta) - p_{vg}\right] \\ &-0.42\left[\frac{M}{F_{Du}}(1-\eta) - 50\right] - 0.0023\frac{M}{F_{Du}}(44 - p_{vg}) - 0.0014\frac{M}{F_{Du}}(34 - t_{lb}) \\ &= \frac{35.7 - 0.032\frac{M}{F_{Du}}(1-\eta) - t_{cl}}{0.18 I_{cl}} \\ &= 3.4\cdot 10^{-8} f_{cl}[(t_{cl}+273)^4 - (t_{ks}+273)^4] + f_{cl}\alpha_c(t_{cl} - t_{lb}). \end{aligned} \tag{11}$$

Fanger expanded the so called comfort diagrams on the basis of the comfort equation. These comfort diagrams were designed on the basis of the previous equation. This was absolutely necessary, because the solution of the equation for practical usage is rather complicated, since it involves numerous iterations. 28 diagrams can be considered strictly as comfort diagrams.

Fanger also expanded a method of calculation on the basis of which the expected thermo sensation can be defined for given points of the closed room with the help of some known parameters. This is the so called PMV value, the value of the expected temperature sensation, and the PPD value is the expected percentage of those not satisfied with the temperature sensation.

The mathematical expression of the PMV value and exposition of the factors:

$$\begin{aligned} PMV &= 0.352e^{-0.042M/F_{Du}} + 0.032\left\{\frac{M}{F_{Du}}(1-\eta)\right. \\ &-0.35\left[43 - 0.061\frac{M}{F_{Du}}(1-\eta) - p_{vg}\right] - 0.42\left[\frac{M}{F_{Du}}(1-\eta) - 50\right] \\ &-0.0023\frac{M}{F_{Du}}(44 - p_{vg}) - 0.0014\frac{M}{F_{Du}}(34 - t_{lb}) \\ &\left. - 3.4\cdot 10^{-8} f_{cl}[(t_{cl}+273)^4 - (t_{ks}+273)^4] + f_{cl}\alpha_c(t_{cl} - t_{lb})\right\}. \end{aligned} \tag{12}$$

According to the PMV value, any number between −3 and +3, wherein the negative value corresponds to the cold and the positive value to the warm temperature sensation. The PPD value can be calculated in the function of the PMV value, and t expresses the percentage of those who are expected to be unsatisfied with the temperature sensation:

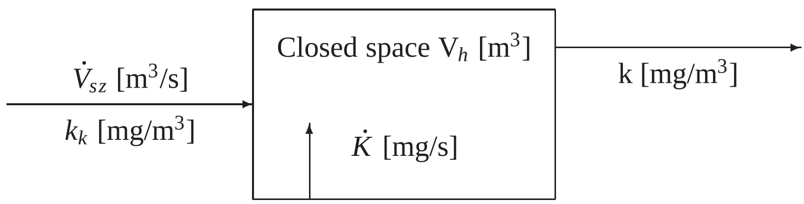
$$PPD = 100 - 95\exp(-0.0335 \cdot PMV^4 - 0.2179 \cdot PMV^2) \qquad [\%]. \qquad (13)$$

According to Fanger the 5% value can be considered as optimal, which is the minimum of the function. But this can only be achieved by air-conditioning, which needs to be automated on a high level, if we take Fanger's intervals of parameters into consideration. Building such a system is rather expensive.

3. Contaminant Concentration inside the Closed Room

The required fresh air flow volume and the number of air exchanges can be calculated from the contamination emission. It is also necessary to know the change in contaminant concentration inside the room within a given period of time, since this is an instationary process. The contamination of the closed room may be a constant process in time (e.g. human CO_2 production) or it may be an event, taking place at a special moment, when a given amount gets into the air.

a) The Contaminant Emission is a Constant Process in Time



Conditions:

1. $\dot{V}_{sz} = $ const.
2. $k_k = $ const.
3. $\dot{K} = $ const.
4. Perfect mixing is assumed.
5. There is no local outgoing contamination.

Balance equation concerning time τ:

$$\dot{V}_{sz} \cdot k_k \cdot \tau + \dot{K} \cdot \tau = \dot{V}_{sz} \cdot k \cdot \tau. \qquad (14)$$

- Contaminant concentration of a closed room in a constant situation:

$$k = k_k + \frac{\dot{K}}{\dot{V}_{sz}} \qquad [\text{mg/m}^3]. \qquad (15)$$

- The balance equation can be expanded for time $\mathrm{d}\tau$

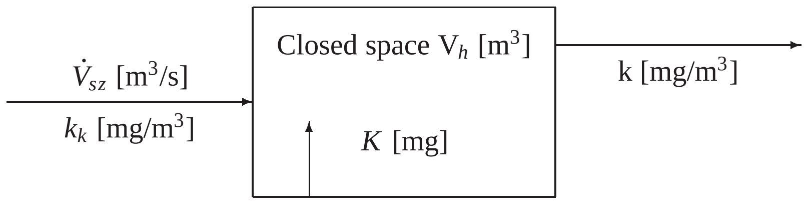
$$\dot{V}_{sz} \cdot k_k \cdot \mathrm{d}\tau + \dot{K} \cdot \mathrm{d}\tau - \dot{V}_{sz} \cdot k \cdot \mathrm{d}\tau = V_h \cdot \mathrm{d}k, \tag{16}$$

initial conditions: $\tau = 0$ time moment $k = k_k$.

- After solving the equation we get the following result for the change of concentration within a period of time:

$$k = k_k + \frac{\dot{K}}{\dot{V}_{sz}}(1 - e^{-n\tau}) \qquad [\mathrm{mg/m^3}]. \tag{17}$$

b) Emission of contaminants of a given mass in the moment of time $\tau = 0$



Conditions:

1. $\dot{V}_{sz} =$ const.
2. $k_k =$ const. $= 0$.
3. Perfect mixing is assumed.
4. There is no local outgoing contamination.

- Initial concentration assuming a perfect mixing: in $\tau = 0$ moment of time

$$k_0 = \frac{K}{V_h}. \qquad [\mathrm{mg/m^3}] \tag{18}$$

- The balance equation for $\mathrm{d}\tau$ time:

$$\dot{V}_{sz} \cdot k \cdot \mathrm{d}\tau = -V_h \cdot \mathrm{d}k, \tag{19}$$

initial conditions: $\tau = 0$ moment of time $k = k_k$.

By solving the equations we get the following result for the changing of concentration within a period of time:

$$k = k_0 \cdot e^{-n\tau} \qquad [\mathrm{mg/m^3}]. \tag{20}$$

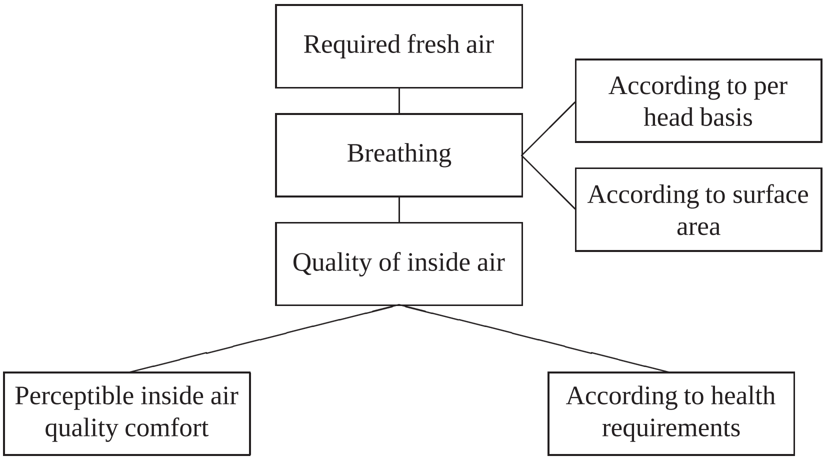


Fig. 1. Steps of defining the required fresh air [6]

4. Definition of Required Fresh Air

On the basis of the internationally accepted theoretical method, the main steps of defining the required fresh air can be found in *Fig. 1*. Contemporary Hungarian regulations only contain the required fresh air on a per head basis.

a) Fresh Air Required for Breathing

Breathing in a closed room maintains the CO_2 concentration on a given level. Human beings as a source of contamination emit CO_2 into the air of the closed room. The physical model of this phenomenon was illustrated in point 4.1. The required amount of air can be defined for the designing process on a per head basis or on the basis of the area. According to the Hungarian regulations the prescribed volume flow of fresh air for no smoking rooms is 20 m^3/h, person, and 30 m^3/h, person, if smoking is allowed. In the case of intellectual work the prescribed amount is also 30 m^3/h, person. We can find prescriptions on a per head basis as well as on an area basis in the German standard. The higher value has to be chosen from the calculated fresh air volume flow amounts.

b) Required Fresh Air According to the Perceptible Inside Air Quality Comfort

The quality of the inside air means all the thermal characteristics that have an impact on the general condition of people (e.g. gases, vapours, smelling materials). These are released from the furnishings of the rooms as well as the people staying inside the room.

The air pollution caused by smell effects and the numerical expression thereof has been examined for more than 50 years. It has been generally accepted that the smell contamination released by human beings should be considered as a reference value. Fanger has placed the theory of the inside air quality on a new basis. He introduced two new measuring units: the olf and the decipol. One olf is the amount of biological smell emission released by an average person. The polluting effect of all other contaminating sources equals as many olfs as the number of average people that emit the same amount of smell contamination as the source in question. One decipol is the amount of smell contamination (emission) caused by one person (source with an effect of one olf) in case ventilation takes place with the amount of air of 10 1/s. With the application of these two units a new method has been introduced for defining the required amount of fresh air.

The fresh air volume flow necessary from the point of view of the perceptible inside air quality requirement:

$$\dot{V} = 10 \cdot \frac{G}{(c_b - c_k)\varepsilon} \qquad [1/\mathrm{s}], \tag{21}$$

$$G = G_{\mathrm{person}} + G_{\mathrm{furnishing}} \qquad [\mathrm{olf}]. \tag{22}$$

The requirements of inside air quality were distributed into three categories, according to the percentage of those unsatisfied with the inside air. Category 'A' has the highest comfort level, with an expected percentage of 15% of those unsatisfied.

The quality of the inside air is not the same at each point of the room. The most important point is the zone of abode, where people move around and breathe. Lack of homogeneity, the quality of the air has an effect on the requirements of ventilation. This is expressed by the effectiveness of ventilation.

$$\varepsilon = \frac{k_t - k_{sz}}{k_b - k_{sz}}. \tag{23}$$

If the quality of air is better in the zone of abode than in the air extracted, then $\varepsilon > 1$, which means that a lower ventilation rate can be applied. The value of ε depends on the place of the air inlet, on the method of blowing in air, as well as from the thermal and humidity load of the room.

c) Required Fresh Air Calculated on the Basis of Health Regulations

There are several thousands of contaminants in the comfort room. The concentration of the individual pollutants (e.g. formaldehyde, VOC components, nitrogen oxides, etc.) can be measured by an instrument, in a selective way. The different international standards also contain limits arising from health regulations, on the basis of which the dimensioning can be arranged. The volume flow for the required ventilation prescribed by health regulations can be calculated in the following way:

$$\dot{V}_{\text{frisseg}} = \frac{\dot{K}}{k_b - k_k} \cdot \frac{1}{\varepsilon} \qquad \left[\frac{\text{m}^3}{\text{h}}\right]. \tag{24}$$

5. Computer Simulation Program for Defining the PMV and PPD Values

For defining the PMV and PPD values on the basis of the above mathematical model, several iterations are needed, that is why the solution of it is rather complicated. The aim of the preparation of the Comfort 1.0e program was mainly the elimination of these disadvantages and also the carrying out of different processes of investigation of effects.

The program is suitable for carrying out both individual investigations as well as investigations of effect. In the case of individual investigations the PPD value is calculated for only one point, one garment and one level of activity. In the case of an investigation of effect there is a possibility for investigating the change of the PPD value in the function of the air temperature, the medium temperature of radiation, the insulating capacity of the garment and the various values of metabolism. The mean radiant temperature can be calculated for points defined according to choice, but there is a possibility for defining the change along a given line of the room as well.

The results can be printed or saved, as it is needed. The simplified block version of the program can be seen in *Fig.* 2.

a) Case Study of Thermo Sensation in a Comfort Room

We have carried out the designing according to thermal sensation of the room shown in *Fig.* 3 with the help of the program. We have investigated the change of the PMV and PPD values along the illustrated dashed line, in function of the distance measured from the window. The surface area of the room is 4.4×6 m, the internal height is 2.7 m, the outside glass surface is 7.5 m^2. The heat transmission factors are the following: walls: 0.7 W/m^{2}K; ceiling: 0.4 W/m^{2}K, windows and doors: 2.9 W/m^{2}K. The heat dissipation of the built-in radiator is 1900 W. The temperature of the rooms next to it are given in *Fig.* 3.

The results of the investigation are relevant for different levels of activity and for garments with different insulating capacities. The change in the PMV and PPD values depending on the distance from the cooling down surface (window) is illustrated in *Fig.* 4 and 5.

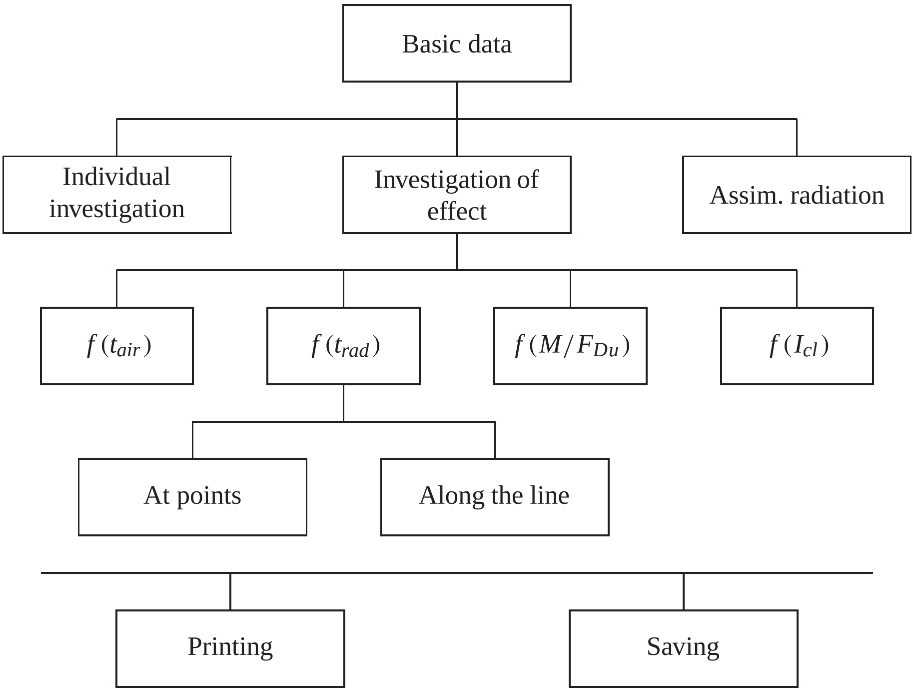


Fig. 2. The block diagram of the simulation program

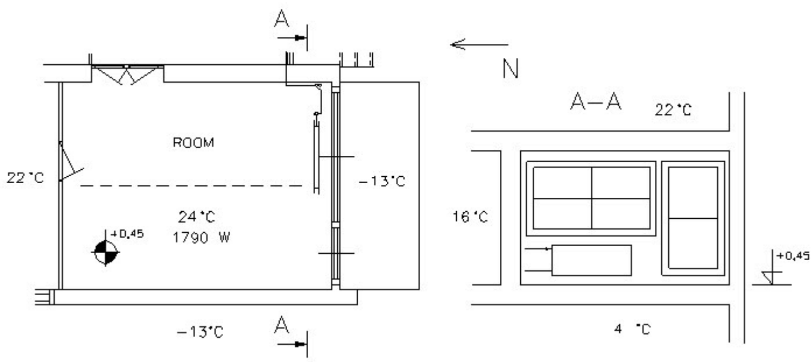


Fig. 3. Comfort room investigated

b) Summary of the Simulation of Temperature Sensation

According to the Hungarian regulations, taking the thermal sensation increase also into consideration, the designing value of the inside temperature of the room inves-

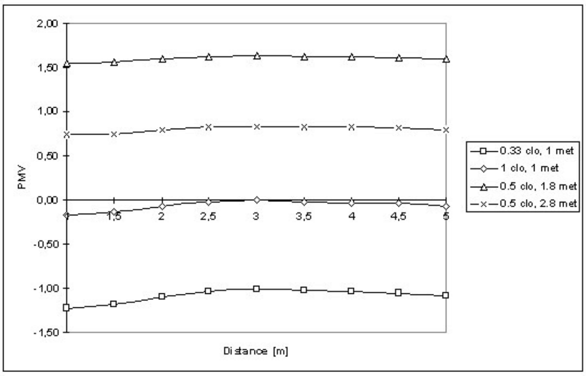


Fig. 4. Change of the PMV value

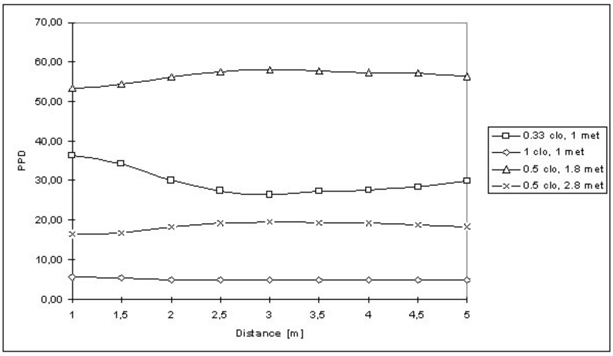


Fig. 5. Change of the PPD value

tigated should be 21 °C. The investigations of thermo sensation were carried out at an air temperature of 24 °C.

After summarising the results, it can be seen, that the indoor temperature of 24 °C guarantees a pleasant thermo sensation only in one case. In this case the activity is quiet sitting (1 met), and the garment is the typical suit of a businessman (1 clo). In the case of other activities and garments no pleasant thermal sensation can be felt.

6. Computer Simulation Program for Defining the Amount of Required Fresh Air

The program can be used for defining the fresh air volume flow required by the different regulations and standards, as well as for preparing comparative analyses. The change of some parameters can be investigated individually as well.

The input data of the program – besides the basic parameters of the room (surface, inside height) – are the following: the number of the people staying in the room, the type of the activity, the category according to the air quality prescribed inside, the quality of the outside air, the chosen type and the effectiveness of the ventilation. It can also be defined if smoking is allowed in the room.

The physical model used in the program is based on the calculation procedures and functions given in point 5. The database contains and also offers the regulations and recommendations to be found in foreign literature during the calculation process. Furthermore there is also a possibility for working with our own data, these can be saved as well.

The results – the required fresh air volume flow, the contaminants, the CO_2 concentration, the comparative diagrams can be printed, or saved for future application.

The simplified block diagram of the program is shown in *Fig. 6*.

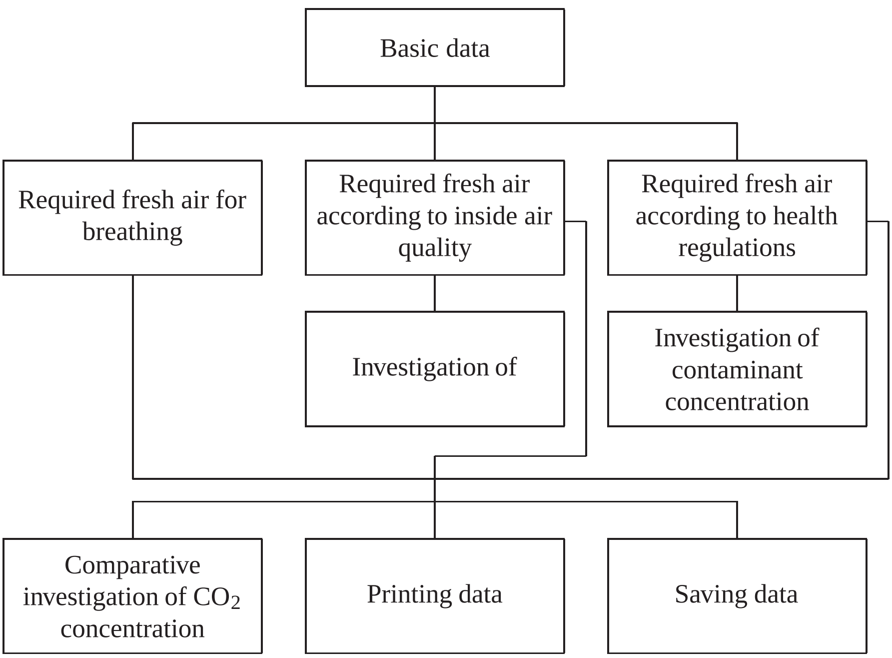


Fig. 6. Block diagram of the simulation program

a) Investigation of the Air Quality in Comfort Room

As an example, with the application of the program we investigate an office with an inner surface area of 10 m × 10 m and inner height of 2.7 m. There are 11 standard employees in the room, all of them are sitting and doing intellectual work. The inside air is of highest quality, which is category 'A'. Smoking is prohibited. The office is situated in the downtown, where the quality of outside air is medium. Mixed ventilation is used in the room. According to inside air quality, the bottom of the room is investigated for traditional as well as for PVC covering.

Results of the investigation:

- required fresh air according to the different regulations:

Chart 1. Calculated fresh air requirement [3]

Dimensioning principle		V_{fresh} [m^3/h]	n [1/h]
MSZ breathing	According to per head calculation	330	1.22
DIN breathing	According to surface area	600	2.22
	According to per head calculation	660	2.44
On basis of BLM	Average layout	2306	8.54
	PVC covering	8494	31.46

- influence of the outside and inside air quality on the volume flow of the ventilation air.

- Change in CO_2 concentration in the case of different ventilation air volume flows.

Limit values:

- ventilation air volume flow according to the Hungarian Standard: k_{MSZ} = 850 ppm,
- ventilation air volume flow according to the German standard: k_{DIN} = 600 ppm,
- according to the inside air quality comfort: k_{IAQ} = 442 ppm.

b) Simulation Summary of the Air Quality

Considering the values of *Chart 1*, it can be seen that the Hungarian Standard is quite obsolete compared to procedures of calculation and dimensioning applied

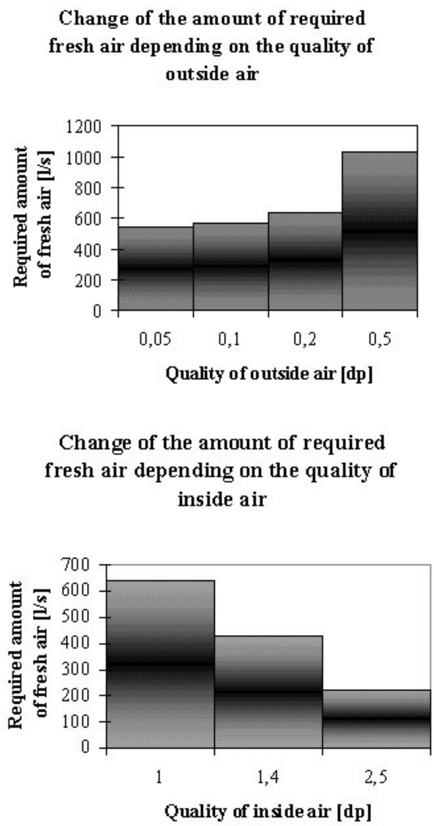


Fig. 7. Change of the amount of required fresh air [3]

internationally. The DIN Standard takes besides the larger per head values also the surface into consideration. In the case of climatized rooms the relative high percentage of those unsatisfied with the circumstances of comfort can basically be explained by this fact. Due to a smaller amount of prescribed fresh air the CO_2 concentration can be higher (*Fig. 8*). As a result, the employees are more tired by the end of the day, they complain about headaches. This is an especially great problem in the case of large office buildings, where the larger thermal and humidity load is absorbed by Fan-coil appliances and the network of air ventilation is only suitable for letting in the prescribed amount of fresh air. The modification of the system for larger volume flows would involve serious problems.

It is absolutely necessary to take the prescriptions for air quality already introduced in international practice also into consideration while revising the Hungarian technological prescriptions. The prospects of joining the European Union makes

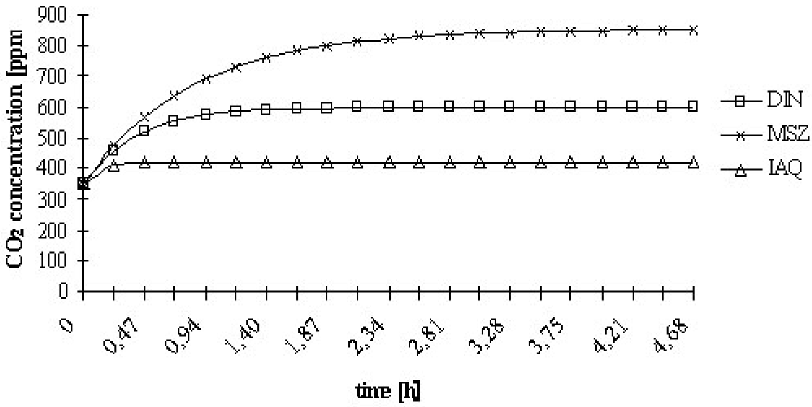


Fig. 8. CO_2 concentration in the case of different ventilation air volume flows [3] (350 ppm outside CO_2 concentration and 15 l/h, person human CO_2 production)

this an even more important and urgent task.

7. Summary

We have summarised the theoretical bases of thermal sensation and air quality comfort. We have provided the relevant physical models and descriptional equations. The dimensioning procedures applied in international practice are based on these, and different national and international standards have been prepared with their application. Using the simulation programs dimensioning can also be arranged.

The case studies of this treatise demonstrate the fact that the Hungarian practice differs significantly from the methods used abroad. This is the reason for the frequent complaints concerning thermo sensation and air quality. The numerical results also provide proof for the fact, that the currently applied methods of dimensioning according to thermal sensation need to be revised. Furthermore, the dimensioning of the inside air is also necessary.

Nomenclature

RQ	–	Ratio of the exhaled Co_2 (Vco) and the inhaled oxygen ($V0_2$), its value is between 0.83 (quiet situation) and 1.0 (hard physical work).
V_{02}	–	value of oxygen consumption in l/min, in case of 0 °C temperature and 1.0132 10^5 Pa air parameters [l/min]
G	–	weight of the person [kg]
L	–	height of the person [m]
Qw	–	heat storage of the human body, or temperature change within a given unit of time [kcal/h]
M	–	metabolic heat [kcal/h]
W	–	mechanical work [kcal/h]
E	–	total heat dissipation by sweating [kcal/h]
S	–	heat dissipation by radiation [kcal/h]
C	–	heat dissipation by convection [kcal/h]
$\frac{H}{F_{Du}}$	–	inner heat generation for one unit of body surface [kcal/h m^2]
I_{cl}	–	thermal resistance of the garment [clo]
t_{lb}	–	air temperature [°C]
t_{ks}	–	medium temperature of radiation [°C]
p_{vg}	–	partial pressure of water steam in quiet air [Pa]
v	–	relative air speed [m/s]
H	–	inside heat generation of the human body [kcal/h]
E_d	–	heat loss by vapour diffusion through the skin [kcal/h]
E_{sw}	–	heat loss evaporating from the skin surface by sweating [kcal/h]
E_{re}	–	heat loss caused by the hidden heat of exhalation [kcal/h] L – dry heat loss of exhalation [kcal/h]
K	–	heat transmission from the skin surface to the outside surface of dressed up human body (heat transmission through the garments [kcal/h]
S	–	radiation heat loss from the outer surface of the dressed up human body [kcal/h]
C	–	convectional heat loss from the outer surface of the dressed up human body [kcal/h]
G	–	total amount of contamination load in the space [olf]
C_b	–	quality of the inside air [decipol]
c_k	–	quality of the outside air [decipol]
ε	–	effectiveness of ventilation (-)
k_t	–	contaminant concentration in the outgoing air [mg/m^3]
k_{sz}	–	contaminant concentration in the ventilation air [mg/m^3]
k_b	–	contaminant concentration in the zone of abode [mg/m^3]
$\dot{K}$	–	force of the inner contamination source [mg/h]
k_k	–	concentration of the most dangerous contaminant in the outside air [mg/m^3]
t_b	–	temperature of the skin [°C]
V_{sz}	–	volume flow of the ventilation air [m^3/h]
k	–	contaminant concentration of the outgoing air [mg/m^3]
K	–	given amount of contaminant [mg]

References

[1] BÁNHIDI, L. (1976): Zárt terek hőérzeti méretezése. Műszaki Könyvkiadó, Budapest.
[2] BÁNHIDI, L. – KAJTÁR, L. – MAGYAR, T. (1996): Designing the Ventilation of Buildings with an Eye on the Regulations of the European Union.
[3] HRUSTINSZKY, T. (1998): Air Quality of Comfort Rooms, Investigation of Fresh Air Requirements.
[4] KAJTÁR, L. (1995): Providing High Quality Air in Climatized Rooms.
[5] ISO 7730-1984: Moderate Thermal Environments – Determination of the PMV and PPD Indices and Specification of the Condition for Thermal Comfort, International Standard, First edition.
[6] HERCZEG, L. (1998): Thermo Sensation Dimensioning of Comfort Rooms, Problems of Discomfort.
[7] MSZ 04-135/1-82: Légtechnikai Berendezések Általános Előírásai.
[8] 21875-2: Munkahelyek Fűtésének és Szellőztetésének Munkavédelmi Követelményei.
[9] DIN 1946 Teil 2: Raumlufttechnik, Gesundheitstechnische Anforderungen
[10] CR 1752:1998: Ventilation for Buildings – Design Criteria for the Indoor Enviroment.
[11] ERDŐSI, I. – KAJTÁR, L. – BÁNHIDI, L. (1997): Thermal Comfort in Climatized Office Buildings Washington. *Healthy Buildings/IAQ Conference*, **2** pp. 207–213.
[12] MSZ 04-140/3-87: Hőszükséglet számítás.
[13] FANGER, P. O. (1982): Thermal Comfort. Robert E. Krieger Publ. Co., Malabar, Florida.
[14] BÁNHIDI, L.– KAJTÁR, L.: Komfortelmélet, Műegyetemi Kiadó, Budapest, 2000.