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THERMAL AND AIR QUALITY COMFORT OF OFFICE BUILDINGS BASED ON NEW PRINCIPLES OF DIMENSIONING IN HUNGARY

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Abstract

The majority of climatized comfort spaces are located in office buildings. It is of particular importance to ensure an adequate heat and air quality comfort in such buildings as occupants usually spend their entire working day (8 hours) in their offices unlike in a theatre, restaurant or cinema. Furthermore, issues of comfort in office buildings must be addressed with special attention because the type of work performed requires extra intellectual concentration. In our research the theoretical issues of ensuring adequate thermal and air quality comfort were studied and in-situ measurements were carried out in office buildings. This paper proposes to present the results and the conclusions of the research, which will be the basis of the new principles of dimensioning.

Keywords: thermal comfort, indoor air quality, measurement, dimensioning methods.

1. Introduction

The comfort of people working in office spaces is fundamentally influenced by thermal and air quality comfort. In line with the prevailing architectural style office buildings are currently built with large outer glass surfaces. To achieve the maximum use of area, work stations are created near the windows and the outer walls as well. HVAC engineers must design air conditioning equipment and the network of air ducts to be fit in a minimal space therefore combined air conditioning equipment is often used. The primary task of the central air conditioning equipment is to supply fresh air and it is required only secondarily to compensate the thermal load, which is usually carried away by fan-coil units. The cooling energy supply naturally requires a cooling plant.

People working at work stations located in the outer zone of office spaces complain particularly of sensation of cold in winter. Due to the extensive network of air ducts, the central air conditioning system designed to supply the required volume of fresh air is not capable of providing the necessary amount of fresh air in many cases. Complaints of lack of fresh air are also quite frequent.

Complaints of thermal comfort and lack of fresh air also arise from the fact that the currently applied Hungarian dimensioning methods do not take appropriately into account cold surfaces (e.g. windows) and the limit of pollutants in indoor air.

In international practice, in dimensioning thermal comfort a higher air temperature (and operative temperature) and more specific fresh air are considered as a basis.

2. Methods

Thermal sensation of human beings can be evaluated in several ways. The most complex assessing method is the determination of PMV (predicted thermal sensation) and PPD (predicted percentage of dissatisfied with the thermal surrounding). Equation of PMV:

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

Being aware of the six parameters necessary for the calculation of PMV the surface temperature of the clothing has to be determined first with the help of iteration. The PPD values can be calculated from the PMV value by diagram

$$\begin{aligned} t_{cl} = {} & 35.7 - 0.032\frac{M}{F_{Du}}(1-\eta) - \\ & -0.18I_{cl}\left\{3.4 \cdot 10^{-8} f_{cl}\left[(t_{cl}+273)^4 - (t_{ks}+273)^4\right] + \right. \\ & \left. + 3.4 \cdot 10^{-8} f_{cl}\left[(t_{cl}+273)^4 - (t_{ks}+273)^4\right]\right\}. \qquad [°\mathrm{C}] \end{aligned} \tag{2}$$

The quality of the air of the office space is primarily determined by the volume flow of the fresh air and source strength of the contaminants. The method of determining the volume flow of the fresh air:

$$\dot{V} = 10 \cdot \frac{G}{(c_b - c_k)\,\varepsilon}. \qquad [1/\mathrm{s}] \tag{3}$$

Solving the differential equation of the change of contaminant concentration:

$$k = k_k + \frac{\dot{K}}{\dot{V}_{sz}}\left(1 - e^{-n\tau}\right), \qquad [\mathrm{mg/m^3}] \tag{4}$$

$$\lim_{\tau \to \inf} k(\tau) = k_k + \frac{\dot{K}}{\dot{V}_{sz}}. \qquad [\mathrm{mg/m^3}] \tag{5}$$

The fresh air volume flow determinable according to the above way is higher than the demand of fresh air concerning breathing. Beside the various parameters the demand for fresh air was also determined in respect of the offices. The results are shown in *Table 1*.

Table 1. The fresh air volume flow [2]

Human		Human only (0.1 person/m^2)			human + build. + HVAC system (build. + HVAC. = 0.2 olf/m^2)		
		$\dot{V}$, m^3/h, person					
Art of work	olf	$c_b = 0.7$, $\leq 10\%$	$c_b = 1.4$, $\leq 20\%$	$c_b = 2.5$, $\leq 30\%$	$c_b = 0.7$, $\leq 10\%$	$c_b = 1.4$, $\leq 20\%$	$c_b = 2.5$, $\leq 30\%$
Activity: 120 W	1	72	30	15.6	216	90	46.8
Activity: 150 W	1.5	108	45	23.5	252	105	54.8
20% smoking	2	144	60	31.3	288	120	62.6
40% smoking	3	216	90	47.0	360	150	78.3
smoking average	6	432	180	94	576	240	125.3

Remark: $c_k = 0.2$ dp, $\varepsilon = 1$.

The following parallel methods were applied in the examination of thermal comfort and air quality comfort in office buildings:

– objective evaluation of thermal comfort through the measurement of air temperature and relative humidity,
– objective evaluation of thermal comfort through the measurement of PMV and PPD,
– evaluation of air quality on the basis of the actual fresh air supply of different office spaces,
– subjective evaluation of thermal comfort on the basis of a questionnaire,
– subjective evaluation of air quality and fresh air supply on the basis of a questionnaire.

The in-situ measurements and the survey were conducted in January and February, 1996. The outdoor temperature varied between $-1,5°$C and $-2°$C at the time of the measurement of thermal and air quality comfort.

The basic area of the 9-storey office building is 45×65 m and the built-in volume is approximately 70 000 m^3. The building contains offices used by 1 or 2 persons as well as open-plan offices, located on five floors. The remaining floors are occupied by the garage and other service areas. The measurements of temperature, humidity and fresh air supply and the questionnaire covered all offices. Owing to time pressure, overall PMV and PPD measurements were only carried out on the 3rd floor.

Air temperature was measured by THERM 2246 and TESTO 610 thermometers and PMV and PPD values were determined using Thermal Comfort Meters (Type 1212). The questionnaire covered 422 persons working in the office building of which 84 persons work on the 3rd floor. The respondent rate was 67% on both the 3rd floor and in the entire building.

The following level of activity and clothing were used for the evaluation of thermal comfort:

– level of activity: 1 met (calm sitting)
1.2 met (office work, typing and using computer)

– clothing: $I_{clo} = 1.0$ (suits, dress typical of business people)
$I_{clo} = 0.8$ (business suit without coat)

In the questionnaire a five-grade scale was used regarding thermal comfort and a three-grade scale was applied with respect to fresh air supply.

The major results of measurements regarding the 3rd floor, which is considered representative of the entire building, are summarized as follows:

2.1. Air Temperature and Humidity

In the course of the measurements the temperature and relative moisture content of the air were determined. All office rooms were measured. *Table 2* contains the results of the evaluation carried out with mathematical statistical methods.

Table 2. Results of the measurement of air temperature and humidity

	Air temperature	Humidity
Average	23.1°C	53.9%
Dispersion	0.77°C	2.4%
Maximum value	24.7°C	58.0%
Minimum value	21.8°C	48.0%
Number of measuring points	32	32

2.2. Results of PMV and PPD Measurements

In the course of the on-the-spot measurements PMV and PPD values were measured at several points of the selected representative offices (12 rooms). As measurement points we defined working places close to and far away from the window in approximately equal proportion. There were 3–4 measurement points in the larger offices and 1–2 ones in the smaller rooms. *Table 3* shows the results of the evaluation carried out with mathematical statistical methods. The histograms of the PMV and PPD measurement values were also drawn, which are included in *Figs 1–2*.

The histogram of PMV and PPD results is shown in *Figs 1, 2*.

Table 3. Results of the measurement of thermal sensation

		Level of activity, clothes		
		1 met 0.8 clo	1 met 1 clo	1.2 met 1 clo
PMV	average	–1.13	–0.67	–0.17
	dispersion	0.38	0.31	0.25
	maximum	–0.39	–0.12	0.28
	minimum	–1.7	–1.2	–0.59
PPD	average	38.4	17.5	6.9
	dispersion	19.8	9.9	2.5
	maximum	72.0	38.0	12.4
	minimum	9.0	5.8	5.01

2.3. *Measurement of Fresh Air Supply*

The volume flow of actual fresh air was measured in all rooms of the office building. The specific volume of fresh air was determined as well. On the various floors climatized offices belonged to 5–6 zones. The actual specific volume flows of fresh air (m^3/h, person) were determined for all rooms, zones and floors as well as the entire building. Results on the representative 3rd floor are given in *Table 4.*

Table 4. Result of fresh air measurements

		Fresh air m^3/h, person
Zones	1	26
	2	30
	3	32
	4	28
	5	21
Average on 3rd floor		28
Average in building		29

2.4. *Results of the Questionnaire*

The results of the questionnaire on thermal comfort and air quality on the 3rd floor can be seen on *Figs 3, 4.*

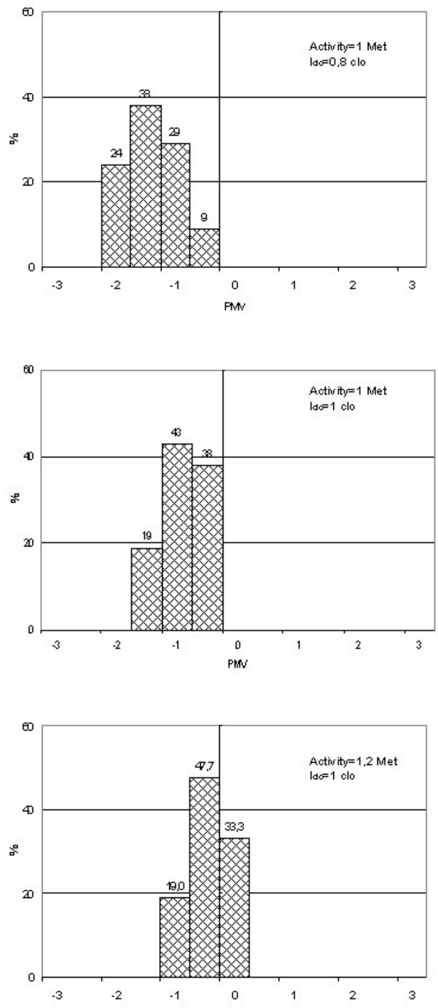

Fig. 1. Histogram of PMV results (3rd floor)

3. Concluding Remarks

The in-situ measurements and the questionnaire showed similar results. Occupants characteristically indicated a slight feeling of cold and lack of fresh air. The following conclusions were drawn on the basis of the evaluation:

3.1 A pleasant thermal comfort can be ensured by dimensioning for the resultant temperature and PMV and PPD requirements. Contrary to Hungarian and Eastern-European requirements (air temperature set at 20°C) current constructions

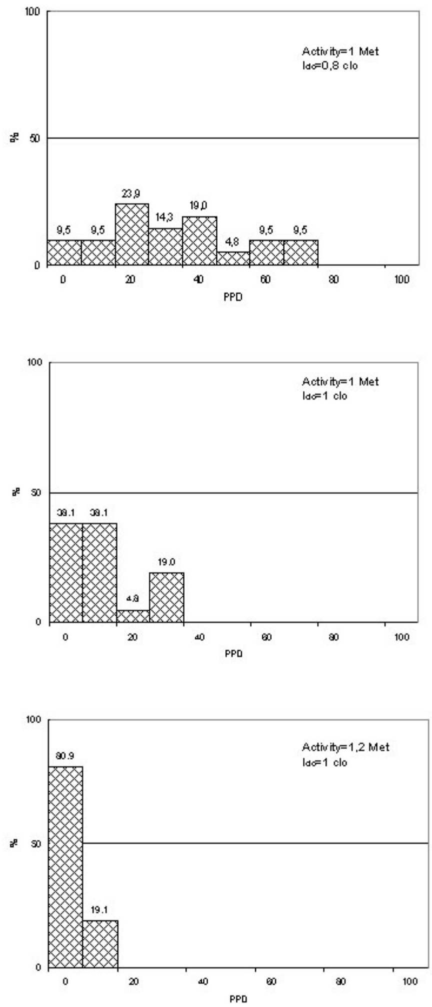

Fig. 2. Histogram of PPD results (3rd floor)

and plans make a higher air temperature necessary. This is very well demonstrated by the histograms of the PMV measurements (*Fig. 1*). All measurements resulted in a negative PMV value in case of a level of activity of 1 met and a clothing of 1.0 clo. The PMV results are only positive (more than zero) in case of a higher level of activity (1.2 met). This means that the workers are typically cold under the analysed conditions of comfort (temperature and moisture content). We can detect a small degree of feeling warm in respect of one third of the work places (33.3%) in case of a higher working intensity (e.g.: typing with a speed of 40–50 words/min).

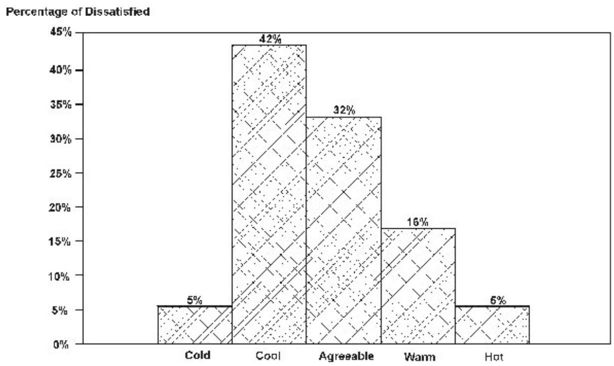

Fig. 3. Results of the Questionnaire on Thermal Comfort in the Percentage of Responses

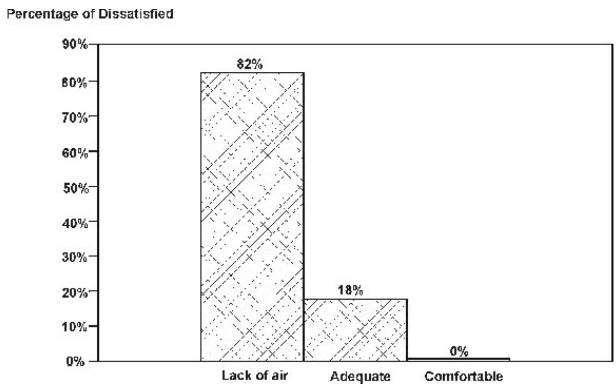

Fig. 4. Results of the Questionnaire on Fresh Air Supply

3.2 The examined building had an average window coverage rate of 45%, while in certain rooms (e.g. in corner rooms) it slightly exceeded 50%. Depending on the type of clothing, the impact of glass surfaces on thermal comfort is offset by an increase of temperature of 1.5 – 2.5 °C. This means that instead of the thermal sensation correction (increase) determined in the Hungarian Standard 04 – 140/3 a higher value has to be applied in order to assure pleasant thermo sensation. The recommended thermal sensation corrections based on the research work are shown in *Table 5.*

3.3 In offices covered by materials currently used by interior designers, the specific fresh air volume of 30 m^3/h, person should be increased. According to comparative calculations this is 60–80 m^3/h, person, depending on air quality requirements.

Table 5. Recommended thermo sensation correction

Cooling surface	Glazed out of this	Thermo sensation correction, if the proportion of glazed surface to the cooling surface $G < 50\%$
1	1	3 (0)
2,3	1	3 (1)
	2	4 (2)
	3	4 (3)

Note: values according to Hungarian Standard 04-140/3 are found in the brackets.

To sum up all the above remarks, it can be stated that using the current dimensioning basic data and principles and taking into account the construction technologies, it is not possible to ensure an agreeable thermal and air quality comfort.

4. Symbols

$\frac{M}{F_{Du}}$ – 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]
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]
V_{sz} – volume flow of the ventilation air [m^3/h]
τ – time [s]
n – air change number [1/h]

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