Subjective response to the thermal comfort in heated dwellings

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ABSTRACT
The main aim of a heating system is to provide the objective thermal comfort parameters. The subjective thermal sensation of users is a very important aspect.

The paper presents the results of experimental measurements on thermal comfort of indoor environment. The investigation was carried out in two blocks of flats. They were alike, but for the installed thermal valves. The main purpose was to analyse users' clothing ensembles, intensity and duration of ventilation as well as an opinion on the beginning and the end of the heating season.

The results show that there is only a little difference in the clothing habit between inhabitants of the two blocks of flats. There is a significant difference as far as the ventilation frequency and its duration are concerned.

INDEX TERMS
Dwellings; Thermal comfort; Subjective response

INTRODUCTION

The indoor climate has become one of the main determinants of the quality of human life. A question that might arise is: Why bring a human in a dwelling to the state of thermal comfort? The term 'comfort' sounds like luxury but it should be treated very carefully. In the middle of the 1970s, in the last posthumously presented publication, Nevis said: '…Environmental control has caused human progress, not resulted from it. It has become a necessity rather than a luxury'; Nevis (1975).

People are not alike. They react differently to the same environment and it is difficult to design and operate buildings that will satisfy all occupants. When we want to provide the optimal indoor thermal environment within our climatic conditions we need a lot of energy to operate the HVAC systems.

The greater part of this energy consumption is used for heating in dwellings, which presumably are the only one sector of the world's energy consumption where the largest potential possibilities for energy conservation exist. However, the question is: 'Should heating system in dwellings be operated according to the human physiological requirements and subjective sensations including the user's habits as well?'.

THERMAL COMFORT CONDITIONS

The thermal comfort criteria in heated dwellings from the point of buildings construction must be provided by the following thermo-technical properties:

(a) thermal resistance of structure,
(b) thermal capacity of structure,
(c) thermal accumulation of floors,
(d) thermal stability of rooms,

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(e) water condensation on structures,
(f) air infiltration through structures.

The prior building constructions are designed under the assumption of quasi-stationary state, where the indoor air temperature is being considered as 20°C. Then thermo-technical properties of engineering structures must guarantee the basic thermal state of heated interiors, which in our conditions is expressed by the following values:

(a) indoor surface temperature is higher than 16°C (vertical) and 17.8°C (horizontal) compared to the outside structure,
(b) temperature amplitude on indoor surface of envelope structures must be lower than 0.6 K during the heating season,
(c) floor temperature is 17°C and more,
(d) the so-called total temperature of rooms (sum of indoor air temperature and mean surface temperature) must be higher than 38°C in the heating season, and by intermittent heating cannot drop lower than 32°C,
(e) indoor surface temperature of outside structures must be always higher than the dew-point temperature, i.e. under assumption of indoor air temperature 20°C and at relative air humidity 64% cannot be lower than 12°C,
(f) air infiltration through structures cannot cause drop of temperature higher 0.2 K in the crevices.

The heating systems are secondary to the design. The globe temperature is used for the design of a thermal condition. These values are different for different rooms in dwellings. To provide the proper thermal regime under non-stationary run of outdoor climatic parameters, the continuous flow change of the heating medium is needed. This should satisfy the condition that temperature difference of the same two randomly chosen rooms situated among the bottom and top floors should not be greater than 3 K.

From the point of energy conservation by heating of dwellings the globe temperature must be controlled according to the following values during the day:

(a) required mean globe temperature from 8 a.m. to 9 p.m. should be 18°C,
(b) globe temperature between 10 p.m. and 6 a.m. cannot drop by about 3°C but not to lower than 16°C in occupied rooms, and by about 5°C in other spaces,
(c) temperature difference of the same two randomly chosen rooms situated among the bottom and top floors must not be more than 3 K.

ENERGY CONSUMPTION DUE TO HEATING

The majority of industrially developed countries consume about 30% of the total energy consumption in buildings. Heating plays the key role in energy consumption as it represents approximately 70–80% of the total operational consumption in dwellings.

An obvious step in energy conservation strategy is to lower the winter indoor temperature to raise the summer one. A decrease of 1°C in winter would save 4–6% in heating costs (presuming an average outdoor temperature of 0–8°C in the heating season). A human's preferred ambient temperature depends on his/her clothing, activity, air velocity and humidity.

An alteration in clothing can give quite considerable potential possibilities for conservation. Thus air temperature can drop by 1°C by increasing usual clothing (0.8–0.9 clo) by 15–20% (sedentary activity). In theory, it is possible to avoid heating of building altogether and instead increase the clothing.

Energy consumption profiles are now available. However, comparable values of the energy consumed in terms of the indoor environmental quality maintained is not well documented: for example, are today's building achieving the optimal balance between decreased energy consumption as by reduced ventilation rates and acceptable indoor air quality? Are the variable rates at air volume systems of the 1980s providing indoor air quality comparable to that provided by the constant volume/reheat systems of the 1960s? Research on indoor air quality infiltration and ventilation performance in buildings addresses these questions. Therefore, energy may be conserved by tight buildings with controlled ventilation. The application of air quality sensors to control the ventilation systems is an interesting possibility.

The choice of heating system is determined by:

- heating source and fuel type selected,
- the distribution network selected,
- the type of heat transfer used in the heated buildings.

Most of all, the heat supply control is remarkably influenced by the operation of the heating system under so-called transient regime, e.g. by the changes of heat conductivity coefficient depending on water flow, on the pressure losses due to friction, on flow speed and water kinetic viscosity, etc. It is therefore obvious that when performing control of heat supply to heated interiors with the aim to lower its energy consumption, the ratio of temperature and real outdoor air calculated temperature difference becomes the most important factor. It is obvious that the real heat requirements, and therefore, the energy consumption are inversely proportional to the temperature gradient of the heating medium.

CASE STUDY ON SUBJECTIVE RESPONSE TO THE THERMAL CLIMATE

The Indoor Comfort Investigation Based on the Questionnaire Method

Aim

The influence of thermostatic control valves on the decrease of the building energy consumption together with the habits of the users has been studied in two typologically, construction-wise and materially identical buildings. In one building, called Hrebienok, thermostatic valves have been installed, whereas in the other, called KAMZIK, they are not.

The construction projects of the Hrebienok and Kamzik blocks of flats started in 1962 and these were completed in 1963, within the Poprad locality. These are stand-alone buildings with 10 floor depicting the building facade. As for construction materials composition, the buildings are identical. Therefore, they are also identical with regards to their thermo-technical properties. They are situated within one district, in fact one beside the other, and their orientations is the same as well. With regard to the heating energy consumption, the buildings are well comparable.

Methods and results

The questionnaire for occupants has been made in a harmony with the aims stated earlier. Its main purpose has been to investigate the subjective feelings of occupants as well as to verify their habits.

Question 1: Express the thermal condition of the heated rooms in your flat using the 7-point psycho-thermal scale.

Answer 1: –3, cold; –2, cool; –1, slightly cool; 0, neutral; +1, slightly warm; +2, warm; +3, hot.

Table1 Thermal sensation of occupants in buildings with and without controlled heating system with respect to flat category (number of rooms) and orientation

Flats	Percentage							Average
	–3	–2	–1	0	+1	+2	+3	
HREBIENOK—with thermostatic valves								
1-room flats	0	21	21	0	29	29	0	0.21
2-room flats	0	22	3	8	28	39	0	0.58
3-room flats	0	10	7	11	33	35	4	0.84
								Average: 0.54
KAMZIK—without the thermostatic valves								
1-room flats	0	17	9	0	52	22	0	0.53
2-room flats	0	8	7	3	29	49	4	1.16
3-room flats	7	20	13	9	24	27	0	0.04
								Average: 0.71

Question 2: Express the thermal condition of the heated rooms in your flat using the 7-point psycho-thermal scale (according to the floor).

Answer 2: –3, cold; –2, cool; –1, slightly cool; 0, neutral; +1, slightly warm; +2, warm; +3, hot.

Table 2 Thermal sensation of occupants based on the floor level

HREBIENOK—with the thermostatic valves		KAMZIK—without the thermostatic valves	
Floor no.	Average value	Floor no.	Average value
1	–0.50	1	–1.12
2	–0.33	2	1.25
3	0.60	3	1.56
4	1.30	4	1.65
5	0.50	5	1.00
6	1.00	6	0.95
7	1.23	7	–1.38
8	1.05	8	0.98
9	0.62	9	1.20
10	–0.20	10	–0.18
Total average value: 0.58		Total average value: 0.60	

Note: orientation of flats is as follows: 1-room flats, north-eastern; 2-room flats, south-eastern; 4-room flats, south-western/north-eastern.

Question 3: How do you dress at home?

Answer 3: 1, light clothing (short-sleeved shirt); 2, slightly warm dress (long-sleeved shirt); 3, warm clothing (pullover).

Table 3 Average values of users' clothing ensembles

Flat	Percentage of clothing ensemble			Average clothing ensemble
	1	2	3	
HREBIENOK—with the thermostatic valves				
1-room flat	14	17	14	Slightly warm clothing

3-room flat	0	100	0	Slightly warm clothing
4-room flat	10	80	10	Slightly warm clothing
Total average value: slightly warm clothing				
KAMZIK—without thermostatic valves				
1-room flat	20	60	20	Slightly warm clothing
3-room flat	56	33	11	Light, slightly warm clothing
4-room flat	10	80	10	Light, slightly warm clothing
Total average value: light/slightly warm clothing				

DISCUSSION

Our investigation originally started as part of a thermal comfort research. In accordance with the answers in the questionnaire, the discussion about the occupants' thermal habits in dwellings Hrebienok and Kamzik (without the thermostatic valves) is as follows:

- The *total average values of thermal condition* according to the average value of different floors are 0.57 (Hrebienok) and 0.60 (Kamzik). In Hrebienok, the coldest floor is the first one defined between slightly cool and neutral. In Kamzik, it is the 7th floor. Its thermal condition is defined as between cool and slightly cool. The warmest floors are the 7th in Hrebienok and 4th in Kamzik, both defined between being slightly warm and warm.
- The *total average values of the clothing ensembles* are 2 and 1.75. These are almost the same and include significantly warm clothing with long sleeves during the heating season. Comparing 3- and 4-room flats of Kamzik and Hrebienok, the people of Kamzik dress a little bit warmer. The proportion among light, slightly warm and warm clothing of people living in 4-room flats are the same in both buildings, but it is different in 3-room flats.
- The *total average of the intensity of air exchange* rates are twice a day (Hrebienok) and 2.8 times a day (Kamzik). There is more significant difference in average intensity of ventilation between 3-room flats in Kamzik and Hrebienok.
- Majority of the occupants of 1-room flats of Hrebienok would appreciate if heating period would be longer, whereas in Kamzik people are satisfied with the heating period. About one-third of occupants living in Hrebienok 3-room flats are satisfied with the heating but another one-third of the people would like an extended period. In 4-room flats (Hrebienok) people are satisfied with the heating season. One-half of people living in 4-room flats in Kamzik are also satisfied but if possible, in both cases they would like that it started sooner.

CONCLUSION

The results of our case-study aimed at a comparison of users of dwellings with controlled and uncontrolled heating systems have shown the following:

1. Only minimum difference in subjective thermal sensation among users of both buildings.
2. Moderate difference in type of clothing.
3. Significant difference in ventilation frequency and its duration.

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