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Thermal performance of typical residental buildings

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Abstract. This paper describes indoor temperature forming in typical panel apartment buildings. Using average free heat gain data, balance temperatures in different months of the heating period are determined. Based on average external temperatures of the years 1971–2000 in Tallinn and balance temperatures, the number of corrected heating degree-days in different months is obtained.

Key words: free heat gains, heat losses, balance temperature, corrected heating degree-days.

1. INTRODUCTION

For increasing energy efficiency, it is important to know thermal performance and indoor temperature forming of buildings. Sometimes simple cumulative degree-day method with the base temperature of 18 °C is used for energy consumption calculation [1–3].

In this investigation, the minimum calculation period is a month; for thermal performance analysis of typical apartment buildings the steady-state method is used. Factual heat consumption data for space heating and calculated free heat values enable us to determine balance temperatures. Variable-base balance temperature [1,4] permits more precise energy consumption analysis on the monthly basis. The investigation is based on 28 typical panel apartment buildings, type 1-464A [5], in the Mustamäe district of Tallinn. All buildings are 5-storey 60-apartment buildings with 4 staircases. Half of the buildings have N–S orientation and the other half W–E orientation. The heating period lasts more than 7 months with the average external temperature approximately 0.4 °C.

All the buildings are connected to the district heating network. The heat substations have heating and domestic hot water controllers and heat and hot water meters. Heating systems are balanced. As a rule, buildings have one-pipe heating systems and central domestic hot water systems with circulation network and with towel-dryers in bathrooms. Ventilation is natural. In the investigation factual heat energy consumption data of 1999 were used.

2. SPECIFIC HEAT LOSSES

Specific heat losses H are calculated as

$$H = \sum_{i=1}^{n} H_{\mathrm{T}_i} + H_{\mathrm{V}}, \tag{1}$$

where H_{T_i} is specific transmission heat loss of the building envelope element i and H_{V} is specific ventilation loss.

Specific transmission heat losses and specific ventilation losses are calculated as

$$H_{\mathrm{T}_i} = U_i A_i, \tag{2}$$

$$H_{\mathrm{V}} = L c \rho, \tag{3}$$

where U_i and A_i are thermal transmittance and area of the envelope element i, respectively, L is the volume air flow rate, c is specific heat capacity of air, and ρ is density of the indoor air.

The investigated buildings have about the same gross floor area, in the average 2678 m^2 and the average heated volume of the buildings is 10 155 m^3. Thermal transmittance of the building envelope elements is calculated on the basis of their construction. Wall panels have 3 layers: 55 mm of concrete, 125 mm of thermal insulation (TEP-plate), and 70 mm of concrete. Cold bridges reduce the thermal resistance of insulation for 23%. Calculated U of the outdoor panel is 1.03 that is very close to the value, given in [5]. In this reference the layout of a typical apartment building 1-464A is depicted. The ratio of the building volume and outdoor walls is 7.0 and the volume and windows ratio is 23.7. Average gross floor area per occupant is 19.4 m^2 and the average area of an apartment is 44.6 m^2. The calculated thermal transmittance values of the envelope elements of the investigated buildings and average specific transmission heat losses are presented in Table 1.

Specific ventilation losses are influenced by the volume airflow rate. Average air change rate of winter months is 0.35. In apartment buildings with natural ventilation, the airflow rate depends on the external air temperature, wind velocity, air tightness of the windows, height of canals, opening of windows, and on other factors. Taking into consideration external air temperature and average monthly wind velocity data [6], and interpolating air change measurement results for this type of apartment buildings, specific ventilation loss and average specific heat loss of the investigated building during the heating period of 1999 were determined (Table 2).

Specific heat loss per gross floor area for winter months is 1.6 W/(K m^2).

Table 1. Thermal transmittance and average specific transmission heat losses of the envelope elements of the investigated buildings

Envelope element of the building	Thermal transmittance, W/(m^2 K)	Average specific transmission heat losses, W/K
Window	2.70	1157
External wall	1.03	1491
External door	1.70	64
Roof	0.91	611
Floor	1.19	271
Total		3594

Table 2. Specific ventilation losses and specific average heat losses of investigated buildings in 1999

Month	External temperature, °C	Specific ventilation losses, W/K	Specific heat losses, W/K
January	–3.4	789	4383
February	–4.8	789	4383
March	0.1	677	4271
April	6.4	789	4383
May	7.8	338	3928
September	13.4	113	3707
October	7.4	451	4045
November	2.8	564	4158
December	–0.8	677	4271

3. HEAT USE FOR SPACE HEATING

Indoor temperature forming in typical apartment buildings is influenced, besides the heating system, also by free heat, i.e., by the internal and solar heat gain. In residential buildings the internal heat sources are mainly occupants, electrical appliances, and lighting.

Free heat gain Q_F is calculated as

$$Q_F = Q_e + Q_p + Q_s, \tag{4}$$

where Q_e is heat gain from lighting devices and other electric appliances, Q_p is metabolic gain from occupants, and Q_s is the solar heat gain.

Average useful heat flow from lighting devices and other electric appliances is 4.3 kW and the average heat flow from occupants 4.0 kW. The average useful heat flow from occupants is 67 W, from lighting devices 20 W, and from other electric appliances 52 W per apartment.

Solar heat gain calculation is based on measured solar radiation data for different months in Tallinn [6]. Useful solar heat gain is determined monthly by the prEN calculation method for residential buildings [7]. In addition, influence of the intensive solar radiation on heat losses is taken into account. Influence of the solar radiation is sometimes taken into account as outdoor temperature rise [8]. In calculations it is determined as $0.014q$, where q is the average total solar radiation intensity, W/m^2. In free heat calculations this component is added to useful solar radiation from February to October. Average solar heat gain in investigated apartment buildings in different months are given in Table 3.

Table 3. Average specific solar heat gain in investigated apartment buildings in different months

Month	Specific solar heat gain in month, kWh/m^2
January	0.3
February	0.7
March	3.2
April	3.4
May	4.1
September	2.3
October	0.8
November	0.3
December	0.2

Building heat losses, kWh/month are calculated as

$$Q_L = \tau H (T_s - T_e) \times 10^3 , \tag{5}$$

where Q_L is building heat losses in a month, τ is the number of hours in the month, T_s is the indoor set-point temperature, and T_e is external temperature.

Considering useful free heat, building heat losses are covered by heat gain from the heating system and free heat

$$Q_L = Q_H + Q_F , \tag{6}$$

where Q_H is heat gain from the heating system.

In the investigated apartment buildings heat consumption was measured and domestic hot water part in it was calculated on the basis of the measured hot water consumption and water temperatures. Heat consumption for heating (heat energy from the heating system and domestic hot water system pipes and towel-dryers) in different months in investigated buildings is calculated as

$$Q_H = Q - Q_{hw} , \tag{7}$$

where Q is the measured heat consumption in investigated buildings and Q_{hw} is the calculated heat consumption for domestic hot water heating.

Average free heat, heat consumption for heating, calculated heat losses, and external temperature values on the basis of the 1999 data in different months of the heating period are shown in Table 4.

Table 4. Average free heat, heat consumption for heating, heat loss, and external temperatures in different months of the heating period in 1999

Month	External temperature, °C	Free heat, kWh/m²	Heat consumption for heating, kWh/m²	Heat losses, kWh/m²
January	−3.4	2.6	26.2	29.7
February	−4.8	3.3	24.8	28.4
March	0.1	5.4	20.0	24.8
April	6.4	5.5	13.5	17.2
May	7.8	6.3	8.8	14.4
September	13.4	4.5	2.0	7.6
October	7.4	3.6	11.9	15.3
November	2.8	2.5	17.0	20.4
December	−0.8	2.5	22.5	25.9

The free heat on average is 17% of the heating period heat losses (January – 9%, May – 39%, September – 59%).

The indoor temperature in apartment buildings is influenced from one side by heat losses and from the other side by free heat and heat consumption for heating.

Indoor temperature rise, influenced by heat consumption for heating, is calculated as

$$\Delta T_{\mathrm{H}} = Q_{\mathrm{H}} / (\tau H). \tag{8}$$

Indoor temperature rise, influenced by useful free heat gain, is

$$\Delta T_{\mathrm{F}} = Q_{\mathrm{F}} / (\tau H), \tag{9}$$

and the indoor temperature is formed as

$$T_{\mathrm{s}} = T_{\mathrm{e}} + \Delta T_{\mathrm{H}} + \Delta T_{\mathrm{F}}. \tag{10}$$

The balance temperature T_{B} of a building is the value of the external temperature T_{e} when, for a specified value of the indoor temperature T_{s} the total heat loss is equal to the free heat gain. Heating is needed only when external temperature drops below the balance temperature. Balance temperature is the sum of the external temperature and indoor temperature rise, influenced by heat energy consumption for heating

$$T_{\mathrm{B}} = T_{\mathrm{e}} + \Delta T_{\mathrm{H}}. \tag{11}$$

Variation of different temperatures during the year 1999 is shown in Fig. 1. Table 5 presents average data about the indoor temperature forming in 60 apartment buildings in 1999 during the heating period.

Calculated indoor temperatures are close to actual indoor temperatures in investigated buildings.

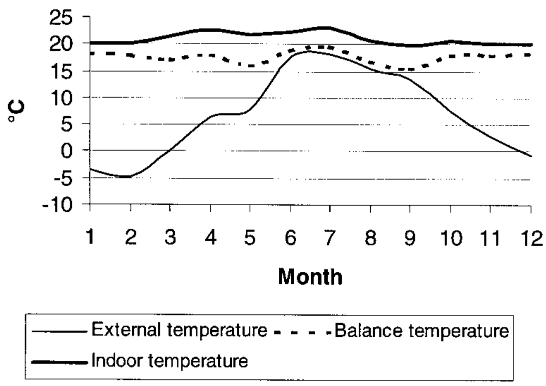

Fig. 1. Variation of various temperatures through the year.

Table 5. Average data about the indoor temperature forming in 60 apartment buildings in 1999

Month	External temperature, °C	Temperature rise by heat consumption, °C	Balance temperature, °C	Temperature rise by free heat, °C	Indoor temperature, °C
January	−3.4	21.5	18.1	2.1	20.2
February	−4.8	22.6	17.8	3.0	20.8
March	0.1	16.9	17.0	4.5	21.5
April	6.4	11.5	17.9	4.7	22.6
May	7.8	8.1	15.9	5.8	21.7
September	13.4	2.0	15.4	4.5	19.9
October	7.4	10.6	18.0	3.2	21.2
November	2.8	15.2	18.0	2.2	20.2
December	−0.8	18.9	18.1	2.1	20.2

Balance temperatures and external temperatures of different months permit calculation of the number of the corrected heating degree-days for heat calculation in different months

$$S = \tau(T_B - T_e)/24. \tag{12}$$

Here S is the number of heating degree-days in a month.

In Table 6 the balance temperatures and corrected numbers of the degree-days of different months for typical apartment buildings with thermostat valves on the basis of 21 °C indoor set-point temperature are presented. For comparison, simple degree-day calculation results S_{18} are also given. In calculations, 30 year (1971–2000) average external month temperatures in Tallinn were used. It is interesting to notice that due to changes in the climate, the degree-day calculations based on the last 20–30 years give a decrease of about 5–8% [9].

The difference between the variable-based and S_{18} degree-days is up to 50% (in May). The difference in total heating degree-days is 4%.

Table 6. Balance temperatures and numbers of the degree-days in different months on the basis of 21 °C indoor set-point temperature for a normal year

Month	Designed external temperature, °C	Balance temperature, °C	Number of corrected degree-days	Number of S_{18} degree-days
January	−3.8	18.9	704	676
February	−4.6	18.0	633	633
March	−1.3	16.5	552	598
April	3.9	16.3	372	423
May	9.8	15.2	167	254
September	10.7	16.6	177	219
October	6.2	17.8	360	366
November	1.2	18.8	528	504
December	−2.1	18.9	651	623
Total			4144	4296

4. CONCLUSIONS

The part of the free heat by covering heat losses in typical apartment buildings in a system with thermostat valves is on average 17% during the heating period. The average indoor temperature rise caused by the free heat is 3 °C. By thermal performance analysis of typical apartment buildings, the balance temperature in different months has been determined and the corrected number of the degree-days has been calculated.

REFERENCES

1. McQuiston, F. C., Parker, J. D., and Spitler, J. D. *Heating, Ventilation and Air Conditioning*. J. Wiley, New York, 2000.
2. Krarti, M. *Energy Audit of Building Systems*. CRC Press, New York, 2000.
3. Braumbaug, J. E. *Heating, Ventilating and Air Conditioning Library*. Vol. 1. Macmillan, New York, 1986.
4. Kreider, J. F., Curtiss, P. S., and Rabl, A. *Heating and Cooling of Buildings*. McGraw-Hill, New York, 2002.
5. Kurnitski, J. *Tyyppikerrostalojen LVI-tekniset laiteet ja järjestelmät Virossa LVI-viennin kannalta*. Helsinki University of Technology, Otaniemi, 1995.
6. Prilipko, G. *Climate of Tallinn*. Meteoizdat, Leningrad, 1982 (in Russian).
7. *European Standard prEN 832:1998. Thermal perfomance of buildings – calculation of energy use for heating – Residential buildings*. European Committee for Standardization, Central Secretariat, Brussels, 1998.
8. *ASHRAE Handbook. Fundamentals*. American Society of Heating, Refrigerating and Air-conditioning Engineers, Inc., Atlanta, 1985.
9. Skaugen, T. E. and Tveito, O. E. Changes in the heating season and degree-days due to climate changes. In *Proc. XXII Nordic Hydrological Conference*. Røros, Norway, 2002, **2**, 631–639.

Tüüpelamute soojuslik käitumine

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On kirjeldatud siseõhu temperatuuri formeerumist paneelelamutes. Arvestades keskmiste vabasoojuse väärtustega, on määratud tasakaalutemperatuurid kütteperioodi erinevatel kuudel. Tallinna keskmiste (1971–2000) välisõhutemperatuuride ja tasakaalutemperatuuride alusel on leitud erinevate kuude korrigeeritud kütte kraadpäevade arv.