Thesis of PhD dissertation

THERMAL COMFORT ANALYSIS OF LOW EXERGY HEATING-VENTILATION SYSTEMS DURING VARIABLE OPERATION MODES

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Debrecen, 2013

1. Introduction

In the field of building energy the 91/200/EC Directive of European Parliament and Council (hereafter EPBD) established that: "*The residential and tertiary sector, the major part of which is buildings, accounts for more than 40 % of final energy consumption in the Community and is expanding, a trend which is bound to increase its energy consumption and hence also its carbon dioxide emissions.*" *Furthermore the Directive lays down that "Buildings will have an impact on long-term energy consumption and new buildings should therefore meet minimum energy performance requirements tailored to the local climate. Best practice should in this respect be geared to the optimum use of factors relevant to enhancing energy performance. As the application of alternative energy supply systems is generally not explored to its full potential, the technical, environmental and economic feasibility of alternative energy supply systems should be considered; this can be carried out once, by the Member State, through a study which produces a list of energy conservation measures, for average local market conditions, meeting cost-effectiveness criteria. Before construction starts, specific studies may be requested if the measure, or measures, are deemed feasible.*" Since the Directive get into force in Hungary and other European countries new regulations had been developed according to which the energy performance of buildings can be determined or the energy certification can be elaborated. At the same time these regulations contain the requirements which must be met by new buildings or under certain conditions even by refurbished buildings. The 91/2002/EC Directive was modified in 2010. The EPBD 31/2010/EU laid down that "*Member States shall ensure that by 31 December 2020, all new buildings are nearly zero- energy buildings; and after 31 December 2018, new buildings occupied and owned by public authorities are nearly zero-energy buildings.*"

According to these enouncements it can be seen that the European Parliament and Council expects continuous reduction of energy consumption in the building sector. On the other hand building, depending on their function, must assure the comfort conditions to occupants in order to obtain maximal efficiency of work or proper health or regeneration conditions.

2. **Purposes of research work**

The original version of EPBD and modified version either contain the statement the energy saving cannot be done in a way which can lead to improper thermal comfort conditions, the refurbishment cannot lead to risk of occupants health.
My research is done taking into account the future thermal and energy conditions in buildings. This future is not so far, taking into account the enouncements of EPBD from 2010. The European Union expects from member states to introduce new national regulations in two steps related to zero energy buildings (2019 for state property building, 2021 for residential buildings).

Although when the research work starts this was not predictable but the tendency was clear, the national regulations getting stricter and more and more passive houses are built. So, the question was only the scheduling of tightening.

The introduction in two steps of new requirements given by EPBD suggests to made comfort related research for buildings with different functions.

Consequently I have made comfort related research for both residential buildings and office buildings. The precondition of a nearly zero energy building, the high energy performance" can be translated as high performance insulation materials, airtight envelope and appropriate shadowing. These boundary conditions will lead to low energy need for heating and cooling if the protection against heat gains during summer period is assured.

Related to analysis of energy savings, I extended my research besides quantitative questions also with qualitative questions. The quality of energy, called exergy, is given by its capacity to do mechanical work. Related analysis of building performance exergy is a proper factor taking into account that renewable energy sources can be efficiently used in low energy buildings.

The very well insulated airtight building envelope raises several problems which are not characteristic for current building stock.

The low heat demand of a building, which is comparable with the heat released by one or two persons or an electric device, can lead to indoor temperature variations if the heating system output is not properly controlled. In case of residential buildings the continuous, the intermittent and random utilization of rooms are equally possible. In case of office buildings the intermittent operation is a consequence of building function. During the periods of time, when there are no occupants in the rooms, the indoor temperature is not kept at its set point value. If the utilization of a room has a defined schedule the heating up can be easily programmed, but it is not indifferent the energy consumption during this process. The length of utilization time is an important question, it must be analysed from thermal comfort and energy point of view if the heating up period can have a part which can be considered as utilization time.

I analysed the following:

- The variable internal and external gains can lead to variable indoor temperatures, which can be kept in acceptable intervals only in case of flexible, well controlled heating systems. As the flexibility, obviously the air heating systems are the most advantageous. In this case if the air flow is reduced to fresh air only, the energy consumption of fans will be low, but the temperature of introduced air must be high. If the temperature of the introduced air is reduced, then the airflow will be higher, consequently the energy consumption of fans will increase. From exergy point of view both options are disadvantageous, so I have analysed from exergy and thermal comfort point of view the intermittent operation of heating systems with low operation temperatures and higher thermal inertia.
- In case of residential buildings the airtight envelope raises the question of indoor air quality and mould. In this case I have analysed the interrelation between heating system type and natural ventilation, in case of air inlet and evacuation elements placed in the windows frame.
- Related to office buildings, where usually ventilation systems are installed I have analysed the energy consumption and obtained thermal comfort assuming simultaneous operation of heating and ventilation systems.
- The highly efficient insulation of buildings envelope raises the risk of overheating during summer period. The summer thermal comfort is a problem even in case of existing buildings and the need of air conditioning systems can lead to important energy and exergy consumption. My research related to summer thermal comfort was done analysing the possibilities to assure proper thermal comfort only with ventilation systems (without cooling equipments).

During my research started in 2007 I tried to find answers to question raised. After the analysis of national and international references in this field between 2007 and 2011 I performed a series of measurements. I used the boxplot diagrams to represent the measured data in case of high number of subjects involved. The age of involved subjects was between

22 and 28 years and I tried to involve in equal number women and man in each measurement. The selection process of subjects was done taking into account the prescriptions fixed by Wyon and Bánhidi in paper entitled: "*The question of sample size in the comfort research*". The measurements had been done in the Building Physics Laboratory of University of Debrecen. I published the results of my research work in national and international Journals and in proceedings of national and international Conferences.

NEW RESULTS

1st thesis

In case of analysed buildings, after thermal refurbishment and installation of heat pumps with surface heating systems, the energy savings reach 60-70%. The rationality of energy conscious building refurbishment solutions usually is decided based on energy savings. This quantitative approach does not taken into account the quality of energy. Because in general the renewable energy sources have low temperatures, the exergy approach of refurbishment solutions gives better solutions.

Analysing different refurbishment solutions on a representative number of residential buildings I have established that the exergy saving exceeds considerably the energy saving (the exergy saving can reach even 90%, but in every analysed case the exergy saving exceeds the energy saving).

2nd thesis

Usually during the renovation of buildings the air tightness is raised using new airtight windows. The change of windows can have negative influence on the indoor air quality and the accumulation of vapour in the internal air can lead to mould on the weak points of the external building elements if a controlled ventilation system is not installed. There are cases when air gaps are installed in the windows frame. A series of measurements had been done to analyse the effects of installed heating system on the air change rate when the air inlet and evacuation elements are placed in the window frame.

In case of air inlet and air evacuation elements placed in windows frame, when the air change is realized only because of the indoor-outdoor temperatures, if the temperature difference exceeds 20 K, the lowest air change rate is obtained in case of radiator heating (the radiator placed under the window) compared with floor or ceiling heating.

3rd thesis

The interrelation between geometrical characteristics of the closed space and obtained mean radiant temperature was analysed. The following boundary conditions were assumed:

- the closed space has one external element (wall);
- the window of the closed space is placed on the external wall and its length is equal to the length of the wall;
- the radiators are placed under the window occupying the whole length of the external wall;
- in case of floor heating the whole floor area is assumed to be a heating surface;
- the heat delivered by radiators or floor is equal to the heat demand of the room.

3a. I have developed a relation between mean radiant temperature, the internal height of the room and the length of the closed space (the length of external wall). I have established that in the closed space centre the mean radiant temperature variation depending on the height of the space is parabolic. The variation of the mean radiant temperature with the length of the closed space is parabolic too.

3b. After thermal refurbishment of buildings, the mean radiant temperature in a closed space will be lower than before refurbishment. I have established that the mean radiant temperatures in case of floor heating is lower than in case of radiator heating if the external building elements have similar thermal characteristics.

4th thesis

I have developed a series of measurements combining ceiling- and floor heating in intermittent operation mode. The ceiling heating was switched on when measurements starts, then the floor heating was switched on. The energy consumption was measured and at the same time the thermal comfort was evaluated by subjects.

Comparing different intermittent operation mode for ceiling- and floor heating up I identified an operation mode according to which the thermal comfort was acceptable for subjects and 27% of energy saving was obtained.

5th thesis

I have analysed the intermittent operation of floor- and ceiling heating system from energy and thermal comfort point of view assuming different air change rates for ventilation. It was not possible to use similar operation mode since the thermal inertia and the surface temperatures of these heating systems are quite different. The duration of measurements was four hours. The floor heating was switched on when the measurement begins and switched off after three hours. The ceiling heating starts after one hour after measurements begins and the heating was switched odd after two hours of operation. The surface temperatures, the air velocities and the turbulence intensity in the occupancy zone were measured. The percent of dissatisfied with draught was determined. The operative temperatures vary in case of floor heating between 19-21 ^{o}C and in case of ceiling heating between 19-22 ^{o}C. The thermal comfort was analysed based on the answers given by 32 subjects. The data had been assessed using the boxplot diagram. ***I have established that for analysed operative temperature intervals 80% of the subjects accept the obtained thermal comfort for three hours from the total duration of four hours measurement. The energy saving for developed operation modes was 10.4% in case of ceiling heating and 6.2% in case of floor heating in comparison with the full time operation.***

6th thesis

I analysed the energy consumption to assure the required microclimate parameters for different building comfort categories (MSZ CR 1752).

6a. ***I have established that the primary energy consumptions for heating or cooling can be even three times higher in case of different comfort categories of buildings.***

6b. ***I have established that after thermal refurbishment of a building, if the mean radiant temperature decreases from 28 ^{o}C to 24 ^{o}C, the same operative temperature can be assured with an air having its temperature higher with 2.5 K than it was before refurbishment. This temperature difference leads to 26% exergy saving in case of traditional cooling systems (with compressors).***

7th thesis

Because the traditional cooling systems using compressors have high power consumption which can influence the energy category of the low energy building I developed a series of measurements to analyse if the thermal comfort can be assured at high ambient temperatures using only ventilation systems with high velocity of the internal air. I had the possibility to compare three different traditional ventilation systems: air introduced under the ceiling and evacuated under the ceiling, air introduced under the ceiling and evacuated above the floor, air introduced above the floor and evacuated under the ceiling. ***I have established that if the ambient temperature is 26 ^{o}C the neutral comfort condition (PMV=0) in the occupancy zone cannot be obtained even if ACH=8 h^{-1}.***

8th thesis

After it was proven that at 26 ^{o}C the required thermal comfort conditions cannot be assured using traditional ventilation systems a new personalized ventilation equipment was developed (ALTAIR). Based on the conception I have developed the experimental equipment. The equipment and the conception were forwarded to Hungarian Intellectual Property Office in the name of University of Debrecen (18th of June 2012).

8a. ***Using this new equipment I had developed and performed a series of measurements comparing the obtained thermal comfort with traditional ventilation modes. I established that the subjective thermal comfort at 30 ^{o}C ambient temperature is lower in case of new equipment with 0.1-0.4. In case of 28 ^{o}C ambient temperatures there were subjects who reported the environment as too cold which makes possible the cooling/ventilation power savings.***

8b. ***I have measured the carbon dioxide concentration in the occupation zone in both traditional and new alternative personalized ventilation mode. Based on the measured data I have established that while in case of traditional ventilation mode the carbon dioxide concentration rises, in case of new alternative personalised ventilation mode the carbon dioxide concentration remain constant during measurements.***

LIST OF PUBLICATIONS

1. Publications in Journals

1.1 International Journals with impact factor

[1] **KALMÁR T.**, ZÖLD A.: *Human components of low energy buildings*, Environmental Engineering and Management Journal, Vol 10, No. 9 September 2011, ISSN: 1582-9596 (**Lektorált és referált**) (**IF=1.004**) (*SCOPUS*, Web of Science)

[2] KALMÁR F, **KALMÁR T.**: *Analysis of floor and ceiling heating with intermittent operation* Environmental Engineering andManagement Journal, Vol 10, No. 9 September 2011, ISSN: 1582-9596, (**Lektorált és referált**) (**IF=1.004**) (*SCOPUS*, Web of Science)

[3] KALMÁR F., **KALMÁR T.** *Interrelation between room geometry and mean radiant temperature*, Energy and Buildings 37. Kalmár F., Kalmár T. Interrelation between room geometry and mean radiant temperature, Energy and Buildings Volume 55, December 2012, Pages 414-421, (ISSN: 0378-7788, **IF: 2.386**), (**Lektorált és referált**) (*SCOPUS*, Web of Science)

1.2 Referred international Journals

[1] KALMÁR F.**, KALMÁR T.** *Energy class, building structure and solar gains*, Journal of Harbin Institute of Technology (New Series) 14 (SUPPL.), 2007, p. 81-84 (*SCOPUS*) (ISSN 100 59113) (**Lektorált és referált**)

[2] **KALMÁR T.** HUSI G., SAHIN Y., KALMÁR F., IKBAL E. *Neural network predictor for thermal comfort conditions*, Journal of Computer sciences and Control systems, Academy of Romanian Scientists, University of Oradea, vol. 2. no. 2, 2009, p. 97-102. (ISSN 1844-6043) (**Lektorált és referált**)

[3] **KALMÁR, T**. KALMÁR, F**.** *Comfort and energy analysis of heating up*, Int. Rev. of Applied Sciences and Engineering, 1 (2010), 1-2, p. 35-43 (DOI: 10.1556/IRASE 1.2010.1-2.6) (ISSN 2062-0810) (**Lektorált és referált**)

1.3 National Journals

[1] HALÁSZ, GY-NÉ. **KALMÁR, T.** Különböző hőtermelővel ellátott fűtési rendszerek exergetikai összehasonlítása, I. rész, Magyar Épületgépészet LVI. évf. 2007/12 (lektorált).

[2] HALÁSZ, GY-NÉ. **KALMÁR, T.** *Különböző hőtermelővel ellátott fűtési rendszerek exergetikai összehasonlítása*, II. rész, Magyar Épületgépészet LVII. évf. 2008/1-2 (**lektorált**)

[3] **KALMÁR, T.** *Sugárzó fűtések elemzése szakaszos üzemeltetés esetén*, GÉP, A Gépipari Tudományos Egyesület Műszaki Folyóirata LIX.évfolyam 2008/8 (**lektorált**)

[4] KALMÁR F**. KALMÁR T**. *A komfortkövetelmények, az épületek primer energia fogyasztása és az exergiaszemlélet*, Magyar Építőipar, 4. sz., 2011, p. 131-136 (**Lektorált**)

[5] **KALMÁR T.** Családi házak fűtési exergiaigényének elemzése, Magyar Épületgépészet, LVIII. évfolyam, 2009/9. szám (**lektorált**)

2. Publications in proceedings of international conferences

[1] **KALMÁR, T.** *Utilization time at intermittent heating*, Int.conf. Instalatii pentru Constructii si Confortul Ambiental, 29-30 Martie, Timisoara, Romania, 2007.

[2] KALMÁR, F. **KALMÁR, T.** *Interrelation between ACH, PMV and heating system type*, ROOMVENT 2007, 13-15 June, Helsinki, Finland, 2007.

[3] **KALMÁR, T.** *Physical Aspects of Infiltration at Closing Elements of Buildings*, Conferinta tehnico-stintifica. Instalatii pentru constructii si economia de energie, 5-6 Iulie, Iasi, Romania, 2007

[4] HALÁSZ GY-NÉ, **KALMÁR, T.** *Spatial optimization of heating seatback*, International Conference. Indoor Air Quality, 28-31 October., Sendai, Japan, 2007 (*SCOPUS*)

[5] KALMÁR, F. **KALMÁR, T.** *Exergy Consumption for Heating in Retrofitted Detached Houses*, Nordic Symposium on Building Phisics, 15-18 June, Denmark, 2008.

[6] KALMÁR, F. **KALMÁR, T** *Thermal comfort conditions having surface heating and fresh air introduced directly in the room*, Indoor Air, 17-22 August Copenhagen, Denmark, 2008

[7] KALMÁR, F. **KALMÁR, T.** *Balance point temperture of buildings*, Int.conf. Instalatii pentru Constructii si Confortul Ambiental, 17-18 Martie, Timisoara, Romania, 2008.

[8] **KALMÁR, T** *Thermal comfort feeling during the heathing–up and cooling down period of surface heathing systems*, 14th „Building Services, Mechanical and Building Industry days" Int. Conference, 30-31 October, Debrecen, Hungary, 2008

[9] KALMÁR, F. **KALMÁR, T** VARGA, E KOCSIS, I JENEI, T CSOMÓS,GY *Energy and comfort aspects of infiltration at closing elemens of buildings*, The 29th AIVC Conference, „Advanced building ventilation and environmental technology for addressing climate change issues" 14-16 October, Kyoto, Japan, 2008

[10] KALMÁR, F. **KALMÁR, T** CSÁKI, I HUSI, G *Interrelation between ACH and air temperature distribution in a room*, ROOMVENT 2009, The 11th International Conference on Air Distribution in Room, 24-27 May, Busan, Korea, 2009

[11] GULYÁS, L FÓRIÁN, S **KALMÁR, T** *Fluidum áramlási energiaveszteségeinek egységes értelmezése*, Fiatal Műszakiak Tudományos Ülésszaka XIV, Műszaki Tudományos Füzetek, 26-27 március, Kolozsvár, Romania, 2009

[12] KALMÁR, F., **KALMÁR, T.**, VARGA, E., CSÁKI, I., JENEI, T., Effects of building refurbishment on the operative temperature and ACH, 9th International Conference and Exhibition - Healthy Buildings 2009, 7 September 2009; Code94942, (SCOPUS).

[13] **KALMÁR, T.** ZÖLD, A. *Thermal comfort in low energy houses*, „Design technology refurbishment of buildings", 37 th IAHS World Congress on Housing Science, 26-29 October, Santander, Spain, 2010

[14] KALMÁR, F. **KALMÁR, T** CSÁKI, I. *Certification of Residential Buildings Using the Detailed and the Simplified Method*, 15th International Conference on Civil Engineering and Architecture, ÉPKO 2011, 2-5 June, Csíksomlyó, Romania, 2011, ISSN1843-21