IMPACT OF INDOOR TEMPERATURE ON ENERGY EFFICIENCY IN OFFICE BUILDINGS

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Abstract
Since most of energy in buildings is used for creation of healthy and comfortable indoor environment, lately an increased attention has been directed towards the optimization of operation of heating, ventilation and air conditioning (HVAC) systems. This paper presents graphic-analytical approach to investigate the impact of indoor temperature and relative humidity on energy efficiency. Thermodynamic analysis is performed using statistical data for outdoor air conditions in Latvia and recommended values of indoor air parameters for office buildings, prescribed by European standards in the field of indoor climate. The study shows that it is not economically viable to maintain optimal indoor air condition throughout the entire year, thus the allowance for deviation of temperature and humidity should be considered during certain periods, especially in summer. Results of this study could be further used for the improvement of building norms and regulations regarding the design and operation of HVAC systems.
Key words: energy efficiency, HVAC systems, temperature and humidity.

Introduction

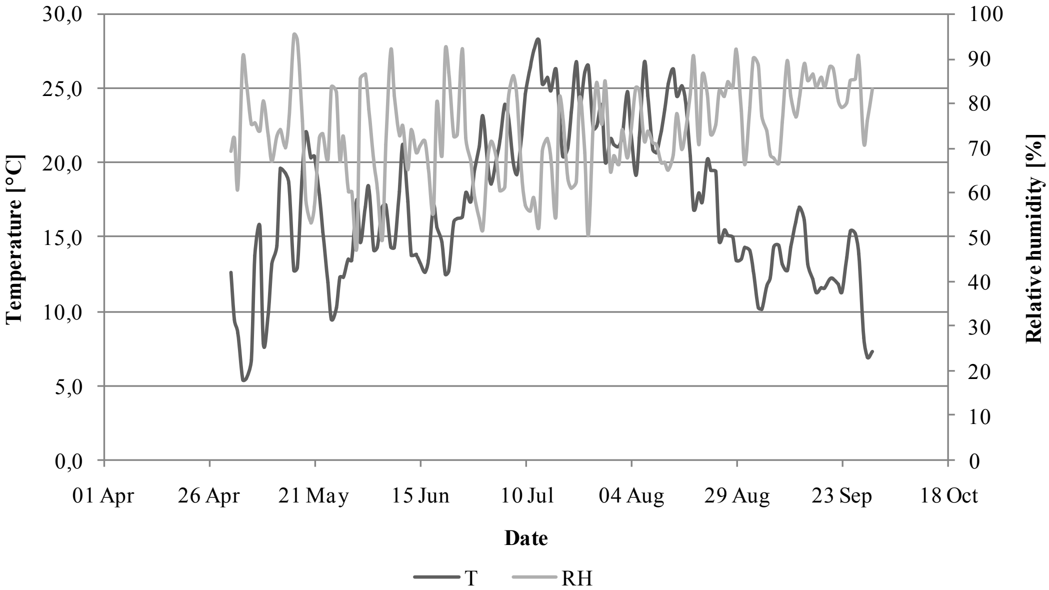
Nowadays most people in urbanized countries spend about 90% of their lifetime indoors, from which many spend their working hours in office environment. Therefore, it is important to establish a healthy, comfortable and productive work environment that the majority of building occupants will find pleasant and stimulating to stay and work in. ASHRAE standard (ASHRAE, 2004) recommends keeping temperature in the range of 23-26.0°C and relative humidity between 30% and 60% in office buildings. European standard 15251 (CEN, 2005) provides values of indoor temperature for different categories of indoor environment (I to IV). For office premises, the recommended operative temperature set-points are consequently 21.0°C, 20.0°C, 19.0°C during winter (heating) season, and 25.5°C, 26.0°C, 27.0°C during summer (cooling) season for categories I to III, respectively. Yamtraipat (Yamtraipat et al., 2006) investigated indoor temperature increase to 26.0°C and reported up to 36% electricity savings achieved by an increase of room temperature from 20.0°C to 26.0°C.

Outdoor climatic conditions itself are not sufficient to ensure the desired thermal comfort all year round; it is necessary to adjust to outdoor climate by using heating, ventilating and air conditioning (HVAC) systems for space heating and/or cooling. The type of HVAC system chosen will directly affect the airflow pattern within the building and consequently the indoor air quality and thermal conditions. Today one of the most commonly used air distribution methods in office buildings is conventional overhead mixing ventilation, where air is conditioned at the air handling unit (AHU), having a pre-heating coil, a cooling coil, and a secondary heating coil. Usually no humidifier is installed, that in its turn does not allow keeping optimal humidity throughout entire year. The combined effects of chosen air conditioning system and indoor temperature were studied by Fong (Fong et al., 2010) who found that variable air volume (VAV) system has energy saving potential from 5% for room temperature of 25.0°C to 33.2% for 30.0°C, and as opposed to VAV, constant air volume (CAV) system is not feasible when the room air temperature is above 27.0°C.

The following paper presents methodology for thermal energy calculations using graphic-analytical approach, and an example of its application analyzing statistical outdoor parameter data for Latvian outdoor conditions. The similar approach has been already used by Borodinecs (Borodinecs et al., 2007), investigating different ventilation operation regimes for dwellings. However, the paper was limited to graphical representation and no mathematical model was developed.

Materials and Methods

A mathematical model for thermal energy calculation is performed for the AHU having a pre-heating coil, a cooling coil, and a secondary heating coil. The AHU configuration considered in this paper has no humidifier and neither a heat exchanger. Power necessary to condition (heat or cool) outdoor air was calculated using most common psychrometrics equations and a h-x diagram. Only transmission heat losses were considered, thus infiltration and ventilation heat losses were not included in calculations. Effects of wind speed and solar radiation were also disregarded.



Source: Latvian Environment, Geology and Meteorology Centre (LEGMC, 2011)

Figure 1. **Outdoor temperature and relative humidity during the period May-September 2010**

The thermodynamic analysis is performed using statistical data for hourly outdoor air conditions (temperature and relative humidity), measured at a meteorological station in Riga (Latvia) during the period of May-August 2010, when both heating and cooling of air would be required. The Microsoft Office work package Excel was used to process statistical data of outdoor conditions. It has been decided to round up temperature by 0.5°C and humidity by 10% to find out the frequencies of particular temperature and relative humidity, expressed in hours.

Normally, in office buildings people work between 08:00-17:00 and thus in this example it was assumed that an office building is conditioned 12 hours daily, i.e. from 07:00 to 19:00.

Results and Discussion

Mathematical model development

Heat flow in a heating or cooling coil at the AHU is expressed as the total transmission heat loss subtracted with heating or cooling capacity to be covered by buildings' main heating/cooling system, as shown in equation (1).

$$H_t = \sum_i U_i \cdot A_i + \sum_k \psi_l \cdot l_k - H_{heat(cool)} \quad (1)$$

where H_t is the specific transmission heat loss (WK^{-1}), U_i is the heat transfer coefficient (Wm^{-2}K^{-1}), A_i is the surface area (m^2), Ψ_k is the linear thermal transmittance (Wm^{-1}K^{-1}), l is the length of thermal bridge (m), and $H_{heat(cool)}$ is the heating or cooling capacity to be covered by buildings' main heating/cooling system other than ventilation (WK^{-1}).

Supply air temperature (equation 3) can be found from equation (2).

$$H_t = m_a \cdot c_p \cdot (t_r - t_s) \quad (2)$$

where m_a is the mass flow rate of air (kgs^{-1}), c_p is the specific heat capacity of air (Jkg^{-1}K^{-1}), t_r is the desired room temperature (K) and t_s is the supply air temperature (K).

$$t_s = t_r - \frac{\sum_i U_i \cdot A_i + \sum_k \psi_l \cdot l_k - H_{heat(cool)}}{m_a \cdot c_p} \quad (3)$$

The specific thermal (heat) energy for conditioning of air can be then expressed as in equation (4).

$$E = \sum_i m_a \cdot (h_{2,i} - h_{1,i}) \cdot \sum_{t=-30}^{40} \sum_{\varphi=0}^{100} n_{t,\varphi} \quad (4)$$

where E is the specific heat energy necessary to condition the air (kWh), h_2 and h_1 is the enthalpy before and after a coil, respectively (kJ/kg); h=f(t,φ) and is found from the h-x diagram, n is the hours (h) with specific outdoor temperature and relative humidity.

Outdoor air conditions

Outdoor air conditions (temperature and relative humidity) in Latvia, calculated as daily averages for the period May-September 2010, are presented in Figure 1.

The outdoor temperature varied between 5°C and 30°C, reaching its highest values of about 27-28°C in mid-July. May and September months

Table 1

Frequencies of outdoor temperature and relative humidity combinations, expressed in hours

Relative humidity [%] \ Temperature [°C]	4,0	4,5	5,0	5,5	6,0	6,5	7,0	7,5	8,0	8,5	9,0	9,5	10,0	10,5	11,0	11,5	12,0	12,5	13,0	13,5	14,0	14,5	15,0	15,5	16,0	16,5	17,0	17,5	18,0
0-10	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
10-20	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
20-30	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	1	-	-	-	-	-	-	-	-	-	1
30-40	-	-	-	-		-	-	-	-	-	-	-	-	1	-	-	2	-	1	3	1	3	1	9	4	4	6	3	10
40-50	-	-	-	-	1	-	-	-	-	-	1	2	5	3	3	1	5	-	-	6	3	9	8	11	9	15	22	16	9
50-60	-	-	-	-	-	-	2	-	2	2	2	3	3	2	3	3	7	3	5	13	14	29	14	17	13	11	9	9	8
60-70	-	-	-	-	-	2	-	4	1	-	5	8	3	1	2	7	7	11	15	15	21	18	17	22	7	5	7	14	14
70-80	-	1	1	2	6	7	3	2	3	6	-	1	-	2	5	5	15	17	14	27	18	8	25	14	6	8	12	4	13
80-90	1	1	6	5	1	1	-	2	1	8	2	5	8	7	10	15	14	25	6	15	17	19	15	8	5	12	4	4	6
90-100	-	-	-	-	-	-	-	-	-	-	2	3	-	-	-	1	8	4	3	4	2	-	1	-	3	1	5	1	1

Cont. Relative humidity [%]	18,5	19,0	19,5	20,0	20,5	21,0	21,5	22,0	22,5	23,0	23,5	24,0	24,5	25,0	25,5	26,0	26,5	27,0	27,5	28,0	28,5	29,0	29,5	30,0	30,5	31,0	31,5	32,0
0-10	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
10-20	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
20-30	1	1	1	-	-	-	-	-	-	-	2	1	1	1	-	-	1	-	-	-	-	-	-	-	1	2	1	-
30-40	1	3	4	5	6	5	12	5	1	3	3	9	9	11	8	3	3	5	5	2	1	7	11	7	6	4	6	1
40-50	4	3	6	9	9	5	9	9	8	12	11	14	17	12	11	5	9	8	8	5	7	8	4	8	4	5	7	3
50-60	12	9	4	11	21	18	16	22	21	15	9	9	5	5	5	10	8	14	11	5	7	6	2	4	2	2	-	-
60-70	18	15	30	14	10	18	10	11	8	6	15	9	9	10	13	11	10	10	7	7	1	2	1	-	1	-	1	-
70-80	9	13	10	12	11	12	8	6	6	10	5	9	9	9	2	1	1	2	-	-	1	-	-	-	-	-	-	-
80-90	3	3	3	3	6	3	5	4	3	11	2	2	1	1	1	-	1	-	2	1	2	1	-	1	1	-	4	-
90-100	1	2	4	3	4	1	-	-	-	1	-	1	-	-	2	-	-	1	1	1	1	-	-	-	-	-	-	-

0-5 | 5-10 | 10-20 | 20-30

Source: Latvian Environment, Geology and Meteorology Centre (LEGMC, 2011)

were rather cold, with a temperature decrease of up to 5°C. According to Figure 1, there was a need to cool outdoor air in July and August months, when the temperatures were consequently the highest.

The average relative humidity was 75% ± 10%. It was the most humid in May, with a relative humidity reaching 95%. Combinations of temperature and relative humidity, expressed in hours, calculated for 07:00-19:00 regime and corresponding to the duration of particular conditions, are given in Table 1.

During the period May-September 2010, most of time the temperature was between 12.5°C and 23.0°C, and the relative humidity 40-80%. The most frequent (30 hours) combination of humidity and temperature was the temperature about 19.5° and the humidity between 60-70%. There has rarely been a need to humidify the outdoor air. Data provided in Table 1 could be further used for economic evaluations regarding the necessity of conditioning the outdoor air. For example, when making decisions whether to keep a desired room set-point or allow it to deviate during certain 'extreme' outdoor conditions, which last just a couple of hours.

The most frequent combinations of temperature and relative humidity in Latvia during the investigated period May-September 2010, as well as possible working regimes of ventilation system, presented on the h-x diagram are shown in Figure 2.

For AHU configurations studied in this paper, one can generally distinguish between three main regimes of operation of ventilation system. When an outdoor temperature is below 20.0°C (Zone 1), through the process of air heating it is possible to achieve a desired supply air set-point, while the desired humidity levels cannot be controlled. In Zone 2, an outdoor temperature is above 20.0°C and a relative humidity is below 50% and once again, it is possible to achieve a required temperature set-point, but not the relative humidity. If the outdoor air conditions correspond to Zone 3, the desired set-points can be achieved, first by cooling of air, and consequent heating after the condensation process.

Using the previously developed mathematical model, as for an example, thermal energy consumption was calculated for a space of 100 m^2, with the fresh air supply of 3.6 kgs^{-1} per m^2 conditioned area. Three different supply air temperatures were

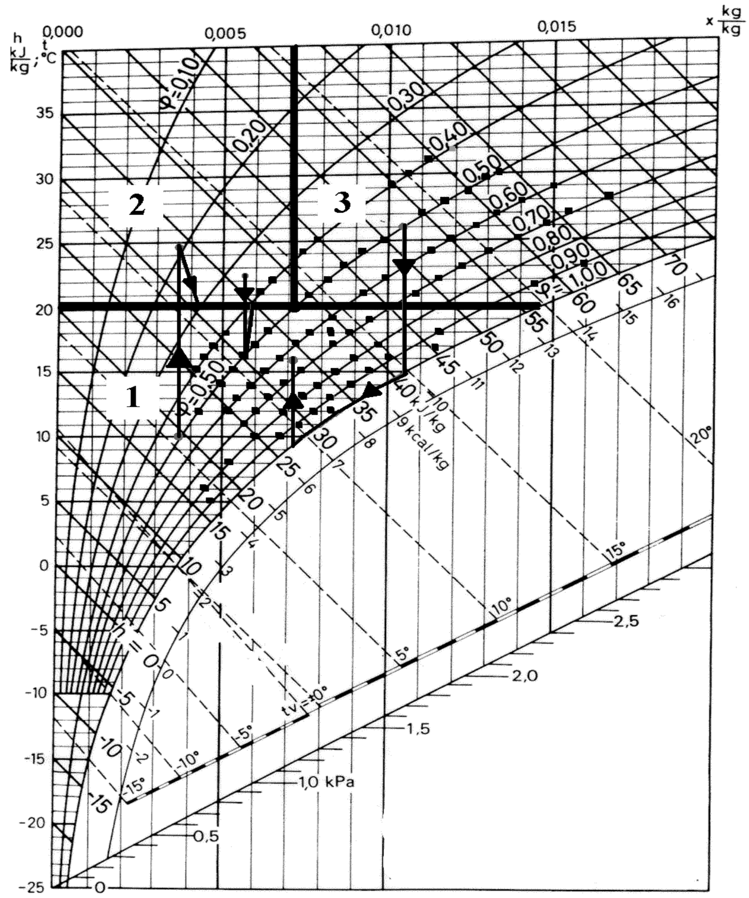


Figure 2. **Latvian climate parameters and ventilation system operation regimes in the h-x diagram**

investigated, i.e. 19.0°C, 20.0°C and 21.0°C (during the cooling period). It was found that thermal energy required to condition air to 19.0°C compared with 21.0°C was about 7% lower.

Conclusions

This paper presents graphic-analytical approach to investigate the impact of indoor temperature and relative humidity on energy efficiency. By use of an h-x diagram and statistical outdoor condition data, it is then possible to identify the air conditioning process zones, with the highest and lowest energy requirement to condition outdoor air. The most frequent AHUs used in office buildings do not have a humidifier, and the proposed method then enables investigation of, e.g. how many hours relative humidity is outside the desired comfortable range. For the cooling period, three different supply air temperature levels were studied, i.e.19.0°C, 20.0°C and 21.0°C. It was found that by increasing a temperature of supply air by 2°C (from 19 to 21°C), the energy consumption for cooling of outdoor air reduced by 7%. In addition, greater attention should be directed towards allowance of temperature fluctuations during certain periods of 'extreme' outdoor conditions that in its turn would lead to greater energy savings. The future improvements of the proposed model should be done, e.g. by inclusion of solar radiation data, infiltration and transmission losses, statistical data for outdoor conditions during longer periods.

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