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Trends in Cooling Degree Days for Building Energy Estimation in Latvia

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Abstract. **Calculation of cooling degree days (CDDs) and hours (CDHs) is one of the simplest methods to describe the effect of outside air temperature on building cooling energy consumption. Calculations of CDD numbers and analysis of trends were performed using 10-year data of outdoor temperature, measured at the meteorological station in Riga (Latvia). Values of CDDs and CDHs for seven base temperatures (from 19.0°C to 26.0°C) are provided in a tabular form. Results showed an increase in CDDs by the year 2020. Findings of this study could be further used for energy management in Riga region.**

Keywords: **cooling degree days, energy consumption, HVAC systems, temperature**

I. INTRODUCTION

Nowadays the building sector in member states of the European Union accounts for about 40% of final energy consumption and about a third of greenhouse gas emissions, of which about two-thirds are ascribed to residential and one-third to commercial buildings [1]. Even though most of energy in eastern European buildings is used for space heating, e.g., about 70% in Latvian households [2], special attention should also be directed towards space cooling, since the energy consumption it accounts for (mostly electrical energy) is growing rapidly. It is expected that energy demand for cooling will increase even more in the future due to global warming, higher demands for quality of life and comfort, an increased use of glazing in architecture, increased number of electric appliances etc. and generally due to economic growth [3].

Heating and cooling energy consumption in buildings is mostly affected by outdoor temperature changes [4; 5], where spatial and temporal considerations also play an important role. Several methods are available for energy analysis and estimation of energy demands. These methods differ in complexity, in amount of ambient condition data that needs to be taken into account, time increment used for calculations, detail of description of the building geometry and its characteristics etc. [6]. Degree day method is currently the simplest and well-established technique for energy analysis, providing adequate results for simple systems and applications. It is appropriate in cases when the use of building, efficiency of HVAC equipment, indoor temperature and internal gains are relatively constant. Degree day method allows for the comparison of building current and past energy performance, as well as the comparison of buildings in different climate zones. In [7] cooling degree day data for 171 countries was summarized, where Mali and Nigeria were ranked 1st and 2nd for having the highest number of cooling degree days per year, i.e., 4064 and 4033, respectively. This is about 5–7 times higher compared to the warmest EU countries (Greece, Spain and Italy), and almost 70 times higher than in Latvia, were 58 CDDs were calculated.

In developed countries, advanced building simulation programs are often used by heating, ventilating and air conditioning (HVAC) engineers to determine the cooling demand. These programs provide very accurate results since rather extensive input data on building characteristics and outdoor climatic conditions is used. In many countries, HVAC designers estimate capacities of cooling equipment (e.g., cooling coils at the air handling unit) by using outdoor design temperature (summer and winter) for the building specific location. This method provides reasonable results, however, often leads to the oversizing of HVAC equipment, which results in higher capital and running (energy) costs. Degree day method provides adequate results on the estimation of cooling requirements for simple cases, e.g., when choosing a split type air conditioner for the apartment. This helps to size the air conditioning unit more accurately, avoiding long-term problems that involve inefficient comfort levels and high energy consumption.

Regulations of the Cabinet of Ministers No. 39 [8] on methodology for building energy performance calculation provide equations for the estimation of building heating and cooling energy demand. These regulations also state the need to correct heating and cooling energy consumption according to outdoor climatic conditions based on degree day method. However, all further explanations and calculations on the topic of degree days are provided explicitly for a heating period. In addition, Regulations of the Cabinet of Ministers No. 39 [8] refer to Latvian building norms No. 003-01 [9] on climatology that specify the length of a heating period (expressed in days) and no information is provided regarding a cooling season. Since very limited data is available regarding cooling energy consumption and trends of degree days and hours for Latvia, the aim of this study is to fill in this gap of information.

II. DEGREE DAY HISTORY

Since ancient times humans have tried to ensure comfortable indoor conditions at their surroundings, e.g. at their living and working environments. Very actual topics such as energy efficiency, thermal performance of building envelope and indoor air quality, have been investigated already since the end of 19th century. This is also the period when energetics became a separate and definable discipline. Development of the energetics industry in its turn enhanced development of other important disciplines for human society, including building heat and electricity supply. Citizens of industrial countries take electricity as for granted, while about 31% of the world's population do not have access to electricity at all [10].

The history of modern heat supply began at the beginning of 20th century, when the first district heating projects were realized. Industrial development at the end of 19th century and early 20th century, stimulated emergence of the energy sector and its further development. At that time availability of electricity made also possible the realization of first district heating projects with forced water circulation [11].

The growth of cities was accompanied with supply of required energy resources that consequently led to increased use of electricity and district heating both in industrial and residential sectors. Increase in heating energy consumption resulted in increased demand for primary energy resources, e.g. fuel wood, coal, oil and its products.

When determining the primary energy requirement for heating, seasonal nature of heating should be taken into account. In order to predict duration of the heating period, meteorological data (e.g. mean and critical temperatures) for a minimum of 30 years are used, with respect to particular geographical location. This metrological data enables estimation of the normative numbers of heating degree days for one season, taking into account an outdoor temperature, at which heating period should consequently start and finish.

During the 1920s, in the United States it was found that fuel consumption varies proportionally to changes in a number of degree days at the outdoor air temperature lower than 18.3°C, which is considered as the base or reference temperature. Degree-day theory facilitates determination of the energy resource consumption required for space heating and this method is widely used in several countries. Degree-day theory is also used for calculations regarding building thermal performance. This methodology has been in force in UK since 1939, with the base temperature set to 15.5°C for heating calculations.

The origin of degree-day theory can be actually found in non-energy sector. Its founder is an English natural scientist and politician Richard Strachey [1817-1908], who introduced degree days to describe the vegetative phase of plant development, initiating at the base temperature of 5.6°C. The theory of degree days is still used in biology and agriculture for this reason, as well as for determination of potential geographical distribution of plants [12].

In Russia and other former Soviet countries, including Latvia, the mean values of meteorological data for specific period are more often used to describe the heating period. In these countries degree days are rarely used for thermal calculations with respect to building envelope. The building climatology is based on a meteorological data for certain period, with declared heating season start and end temperature of +8°C. This is also the temperature which can be partly considered as a base temperature in theory of degree days, since requirement of indoor temperature equilibrium is not met, when considering thermal resistance of the building envelope. Russia (Soviet Union) can be considered as a pioneering country for building thermal physics science, where many publications were published, including one of the first fundamentals book called "Heating techniques fundamentals for civil engineering“, written by Professor V.D.Macinska in 1923. Relation towards base temperature changes here is just as conservative as in many other countries around the world. During extensive period of time, numerous publications have been written in Great Britain, indicting necessity to change the base temperature of 15.5°C, due to changes of building thermal performance norms. M.C.Vickers

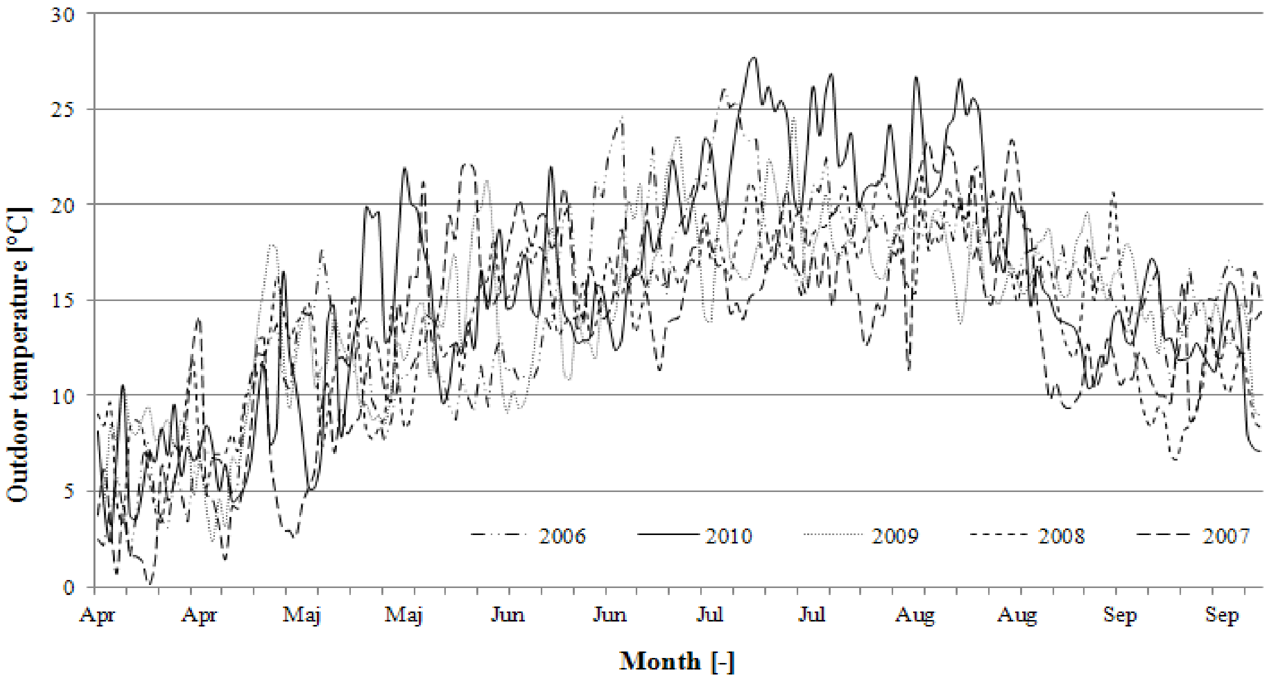

Fig. 1. Outdoor temperature from April to September for the period of 2006–2010 in Riga, Latvia [16].

in Great Britain, had already proposed introduction of two base temperatures for daytime and night-time calculations respectively, in early 1946 [13]. N.S.Billington in 1960s had also tried to introduce flexible base temperature. He suggested that base temperature should be corrected with the adjustment coefficients describing building thermal performance properties [14]. This method made building heating calculations more complicated and inaccurate determination of coefficients led to significant calculation errors. All this prevented further use of Billingtons method. In the U.S. a similar approach for calculation of flexible base temperature was proposed by H.C.S.Thom in 1950s [15]. Discussion on the determination of specific base temperature for each individual building or group of buildings has become a very actual topic. This is particularly important when carrying out building energy audit, considering the real condition of building envelope that can be the basis for determination of the specific base temperature both for space heating and cooling.

III. Methodology

A. Ambient Data Collection

Accurate and reliable ambient data is very important for building energy analysis and simulations, determining accuracy and characteristics of the results. The outdoor temperature data for this study was obtained from the Latvian Environment, Geology and Meteorology Centre [16] that measured temperature during an interval of three hours. Therefore, hourly values were further determined by an interpolation principle. The numbers of CDDs and CDHs in this paper were calculated using outdoor air temperature, measured at the meteorological station in Riga (geographic coordinates of 56°57'N latitude and 24°6'E longitude) during the period of 10 years, from 2001 to 2010.

The mean outdoor temperature during summer months in Riga given as normative values in Latvian building norms No. 003-01 [9] are 15.4°C, 16.9°C and 16.2°C for June, July and August, respectively. The outdoor air temperature levels measured during the period April–September from 2006 to 2010 are presented in Fig. 1.

The mean outdoor temperature values during the period of recent 10 years (2001 to 2010), calculated in this study, are as follows: 15.8°C, 19.3°C and 18.2°C for June, July and August, respectively. Thus, the latest tendencies indicate generally higher mean temperatures in Riga, especially in July and August. This leads to the necessity to reconsider and update the existing climatology norms developed for building engineers.

B. The Degree Days

Calculation of cooling degree days is currently one of the most commonly used steady-state methods in the HVAC industry to describe the effect of outside air temperature on building cooling energy consumption. Generally, in the degree day method it is assumed that energy demand for a building is proportional to the difference between the mean daily temperature and a base or reference temperature. The base temperature is usually defined as the temperature below or above which heating or cooling is needed. Cooling degree days can be calculated using equation (1):

$$CDD = \sum_{days} (T_m - T_b)^+ \tag{1}$$

where: T_b is the base temperature (°C); T_m is the daily mean outdoor temperature (°C) calculated as average between day minimum and maximum values. The plus sign in equation (1) indicates that only positive values are summed.

Traditionally, CDDs are determined using 22°C as a base temperature, corresponding to un-insulated building case. However, the base temperature varies from building to building due to the differences in building characteristics (insulation, glazing type etc.), thermostat set-points and other factors. In this study, CDDs and CDHs are calculated for the base temperatures between 19°C and 25°C with 1°C temperature increment.

Total number of cooling degree hours for a month can be expressed as follows:

$$CDH = \sum_{j=1}^{N} (\overline{T_m} - T_b)^+ \tag{2}$$

where: T_m is the hourly mean outdoor air temperature (°C); N is the number of hours of the month (h). The plus sign indicates that only positive values are summed.

Several statistical methods can be used for trend detection, each having its own strengths and weaknesses. In this study, the linear regression technique was used to detect trends. Linear regression analysis indicates the tendency rate (slope) by using least square method with the 0.05 significance level.

IV. Results and Discussion

The calculated cooling degree days as averages for the entire period from 2001 to 2010 with base temperatures of 19–25°C are presented in Table I.

According to the obtained results, there is no cooling demand in April and September. The highest energy consumption for cooling is expected during the warmest summer months, i.e., July, followed by August and June.

The calculated cooling degree hours as averages for the entire period from 2001 to 2010 with base temperatures of 19–25°C are listed in Table II.

TABLE I

COOLING DEGREE DAYS WITH VARIOUS BASE TEMPERATURES FOR RIGA, LATVIA

Month	Base temperature (°C)						
	19	20	21	22	23	24	25
April	0	0	0	0	0	0	0
May	5	2	1	0	0	0	0
June	7	4	2	1	0	0	0
July	43	29	20	13	9	5	2
August	26	17	10	6	4	2	1
September	0	0	0	0	0	0	0
Total	81	53	33	21	13	7	3

TABLE II

COOLING DEGREE HOURS WITH VARIOUS BASE TEMPERATURES FOR RIGA, LATVIA

Month	Base temperature (°C)						
	19	20	21	22	23	24	25
April	23	14	8	4	2	1	0
May	204	136	87	52	28	13	5
June	368	251	165	106	66	38	19
July	1361	1040	774	563	399	275	185
August	799	581	409	279	185	120	75
September	70	38	18	7	2	1	0
Total	2825	2060	1461	1012	683	448	284

Calculation of cooling degree hours provides more accurate results. Comparison of CDD and CDH expressed as days is shown in Fig. 2.

When using cooling degree hour method in calculations, some cooling would be required also from April to September. The total number of cooling degree days is almost 50% higher compared to calculations using a cooling degree hour approach. This might lead to significant inaccuracies when estimating energy consumption for cooling with a CDD approach.

The CDD numbers for a particular year, using base temperatures of 22°C, 21°C and 19°C are given in Fig. 3.

The highest number of CDDs was calculated for the year 2010, followed by 2001 and 2002, when there were

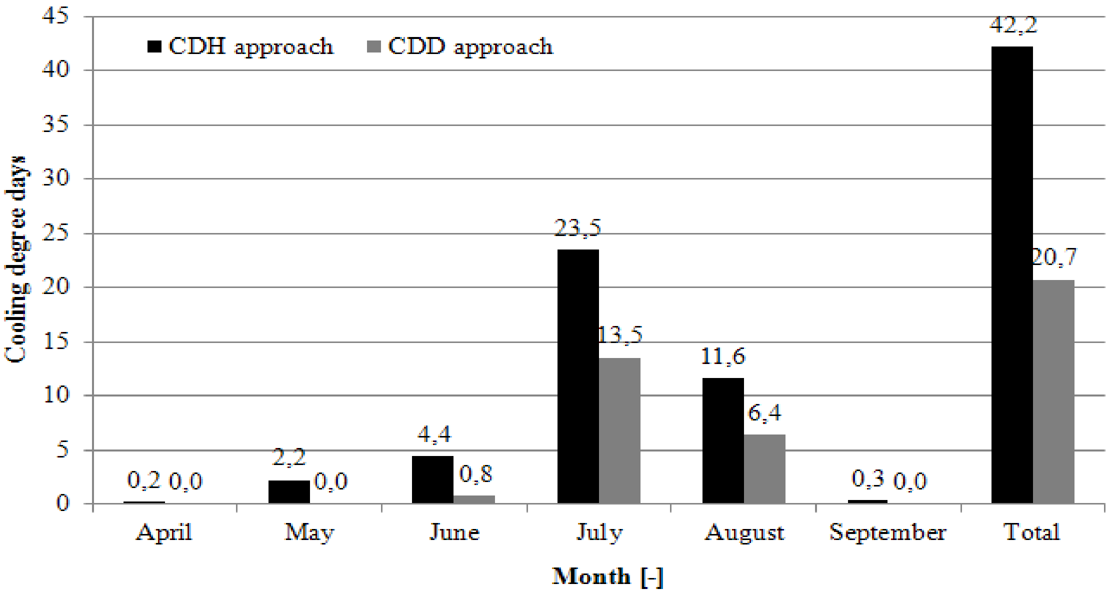

Fig. 2. Calculated cooling degree days and hours expressed as days for the base temperature of 22°C.

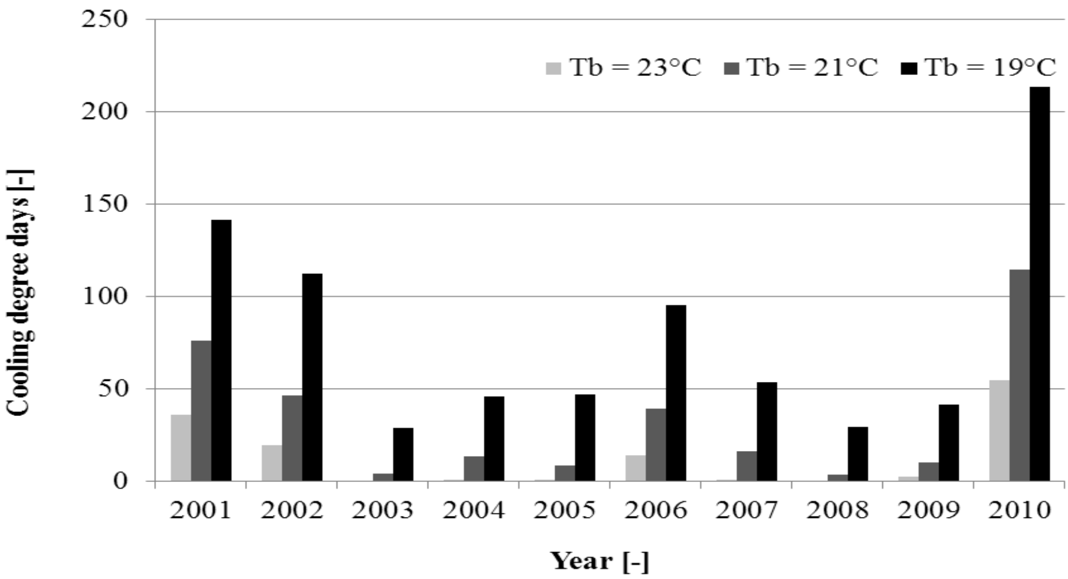

Fig. 3. Yearly cooling degree days in Riga, Latvia.

consequently higher outdoor air temperatures, as indicated in Fig. 1. The difference of 1°C between base temperatures of 22°C and 21°C, results in almost double difference in a number of CDDs.

Linear trends over the period from 2001 to 2010 were determined on the annual basis. Even though Fig. 4 shows a continuous trend of increase in a number of cooling degree days, statistical significance of the trends should be further tested using, e.g., the non-parametric Mann-Kendal test.

The increasing tendency of cooling degree numbers was also obtained in locations other than Latvia [17]. It should also be mentioned that Fig. 4 was actually constructed for indicative and methodological purposes only, since 10-year data is too little for accurate forecasting. The future research should therefore be directed towards further examination of outdoor climatic data for longer periods and energy consumption for HVAC system operation, as well as towards the development of a contour map of yearly cooling degree days for the entire territory of Latvia.

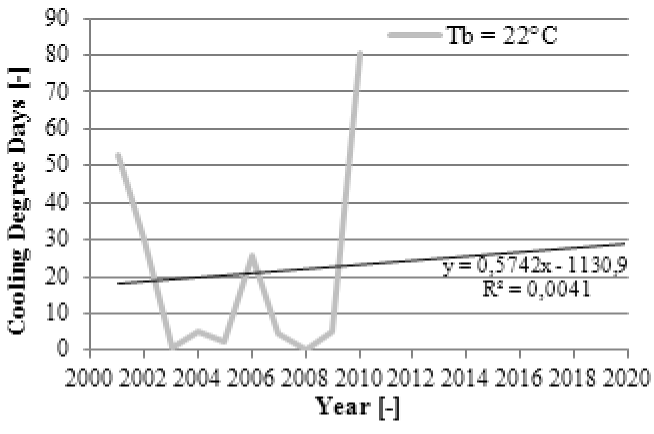

Fig. 4. Trend in cooling degree days.

V. Conclusions

The following paper presents the study on trends of cooling degree days to investigate the extent to which temperature variability affects energy consumption for cooling of buildings in Riga region, Latvia. The cooling degree day and hour data calculated with various base temperatures and using outdoor air temperature data for the last 10 years is presented in a tabular form. The actual mean outdoor temperature measured during the last 10 years was significantly higher (e.g., about 2°C for July and August) compared to the normative values given in the local climatology norms, indicating some necessity for their update. Total cooling degree number was about 50% higher when using a degree hour approach, providing more accurate data for future energy consumption estimations. Even though some continuous trend of increase in a number of cooling degree days was obtained, further investigation of statistical significance of the trends is necessary, as well as procession of outdoor temperature data for longer time periods.

The findings of this study could be useful for energy management in Riga region under global warming trends. In addition, the obtained data could further complement the local building norms and regulations regarding the design of HVAC systems and energy efficiency, filling in the gap of missing information for methodology of simplified energy calculations in Latvian buildings. However, further validation of the calculated cooling degree hours and days would be necessary using real object data (cooling energy) from numerous office buildings in Riga.

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