P2.2 HEATING AND COOLING DEGREE DAYS AS AN INDICATOR OF CLIMATE CHANGE IN FREIBURG

Andreas Matzarakis, Finn Thomsen
University of Freiburg, Germany

1. INTRODUCTION

Heating degree day (HDD) and cooling degree day (CDD) are quantitative indices being designed to reflect the demand for energy requirements to heat or cool a home, business or other issues. These indices are derived from daily air temperature observations. Generally, a degree-day fixes the value that expresses the adding temperature of the environment. It gives the value of quantity and duration when the air temperature becomes lower or higher than a determined threshold value, which is known as the basic temperature (Hitchen, 1981, Martinaitis, 1998, McMaster and Wilhelm, 1987). In order to estimate heating costs, this value is given as the total deficit of outdoor air temperature in relation to the basic temperature.

The heating (or cooling) requirements for a given structure at a specific location are considered to be directly proportional to the number of heating degree days at that location. For Freiburg (Fig. 1 and 2), the city with a long tradition in urban climatology in the southwest of Germany, the expected climate conditions for the future indicate an increase in air temperature and therefore a change in the demand of cooling and heating requirements.

Concerning urban climate and urban planning purposes it is not only of interest to have the increase of air temperature in an annual mean but also in form of frequencies of thresholds and number of days. The question is how to quantify the heating and cooling energy demands. This can be carried out by the use of degree days and annual amount of them. The advantage of them is that they are based only on air temperature and the final results are given in °C.

Corresponding author address:
Andreas Matzarakis, Meteorological Institute, University of Freiburg, Werthmannstr. 10 D-79085 Freiburg, Germany; e-mail: andreas.matzarakis@meteo.uni-freiburg.de

Fig. 1: Map of Europe with the location of Freiburg (Picture: NASA World Wind 1.4; www.worldwind.arc.nasa.gov).

Fig. 2: Freiburger Münster (Freiburg Cathedral), the town's landmark (Picture: F. Thomsen).

The costs and effects of climate change for settlements and society can be very different. The effects become altogether tendentiously more negative ever greater the climate change will be. The projected climate change for Northern and Central Europe will be at first different (IPCC, 2007).

However there can be of course for some regions both disadvantages like the increase in cooling and advantages such as the reduction of heating.

2. METHODS

Based on daily values of mean, maximum and minimum air temperature (Ta) heating and cooling degree days have been calculated. For heating degree days, the thresholds of 15 °C, 14 °C, 13 °C and 12 °C have been used. 15 °C is the standard heating value for Freiburg. For cooling degree days, the thresholds of 18 °C, 18.3 °C, 20 °C and 22 °C have been applied. Recommended is the 18.3 °C threshold. Three different periods and two different kinds of data have been analysed. The period 1961-2007 corresponds to the measured period of the German Weather Service data (DWD).

Based on existing climate station of the German Weather Service (DWD) and regional climate simulations (REMO) for two different scenarios (A1B, B1) the heating and cooling conditions have been analysed.

Following formulas have been used to calculate the heating degree days and cooling degree days.

$$\boxed{HDD_{ht} = \sum_{1}^{z} (t_{ht} - t_a)} \quad (1)$$

HDD_{ht}: heating degree day for one month (K*d/a)
z: number of heating days of one month
t_{ht}: heating threshold
t_a: mean air temperature of a heat day

$$\boxed{CDD_{ct} = \sum_{1}^{z} (t_a - t_{ct})} \quad (2)$$

CDD_{ct}: cooling degree days for one month (K*d/a)
z: number of cooling days of one month
t_{ct}: cooling threshold
t_a: mean air temperature of a cooling day

According to the German VDI-guideline 2067 the heating degree day (Gradtagszahl; GTZ) is a measure for the heat demand of buildings during the heating period (VDI, 1991). The GTZ is counted when the outdoor air temperature (heating threshold) is less than 15 °C. The GTZ is the sum of the difference from the room ambient temperature of 20 °C and the respective daily mean temperature. The degree day numbers can be used to calculate the heating energy consumption (Heizenergie-verbrauch; HEV).

$$\boxed{GTZ_{20/ht} = \sum_{1}^{z} (t_r - t_a)} \quad (3)$$

$GTZ_{20/ht}$: degree day numbers for one month at the threshold value (K*d/a)
z: number of heating days of one month
t_r: mean room ambient temperature (20 °C)
t_a: mean air temperature of a heat day

$$\boxed{HEV_{future} = HEV_{mean} * \frac{GTZ_{future}}{GTZ_{mean}}} \quad (4)$$

HEV_{future}: heating energy consumption (kWh/a) that should be calculated
HEV_{mean}: known heating energy consumption for a certain period (here 1997 – 2007)
GTZ_{future}: degree day numbers that were calculated for a certain period
GTZ_{mean}: known degree day numbers for a certain period (here 1997 – 2007)

3. RESULTS

REMO data for the area of Freiburg (9 grid points have been used in order to get the mean conditions for the area of Freiburg) have been processed for the A1B-scenario and the period 1961-2100 and for B1 for 2001-2100 (Jacob, 2001, Jacob et al., 2007). Fig. 3 and 4 show the heating and cooling days for A1B. The period 1961 – 2000 is the control period for REMO data. The heating degree days and cooling degree days for DWD, A1B, and B1 are shown in Fig. 5 and 6, the heating and cooling days in Fig. 6 and 8 respectively.

Fig. 3 shows the heating days of the A1B-scenario based on the threshold values 12 °C, 13 °C, 14 °C and 15 °C. Generally there exists a decreasing trend over the decades of 1961 to 2100. In each case, the coefficient of determination shows a high statistical relation to linear regression of the different thresholds, in which the scenario with the threshold value of 15 °C forms the highest statistical relation with R^2 = 0.92.

Fig. 4 shows the cooling days of the A1B-scenario based on the threshold values 18 °C, 18.3 °C, 20 °C, and 22 °C. Discernible is the increasing trend of cooling days in the period from 1961 to 2100. In Fig. 5, the coefficient of determination of all curves shows a high statistical relation to the linear regressions, whereas the scenario with a threshold value of 18 °C forms the strongest relation with R^2 = 0.92.

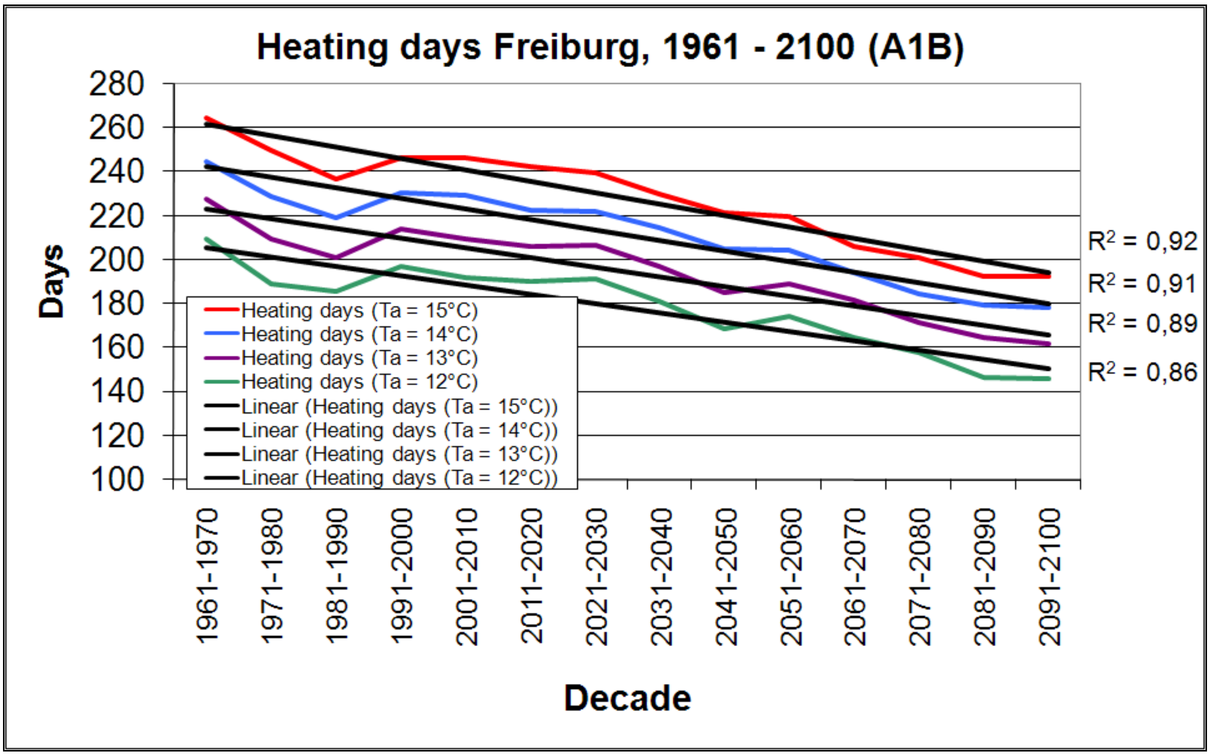

Fig. 3: Heating days in Freiburg for the A1B-scenario (REMO) (based on Ta: 12 °C, 13 °C, 14 °C, and 15 °C) for 1961 – 2100.

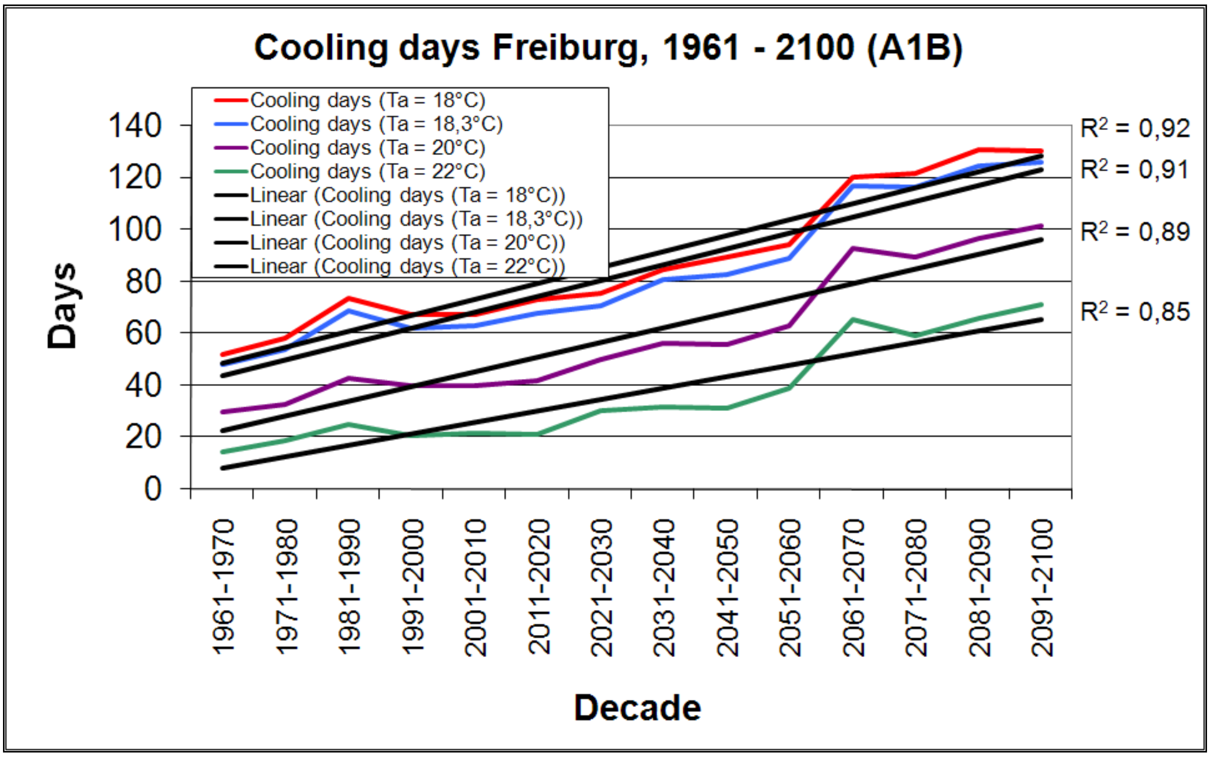

Fig. 4: Cooling days in Freiburg for the A1B-scenario (REMO) (based on Ta: 18 °C, 18.3 °C, 20 °C, and 22 °C) for 1961 – 2100.

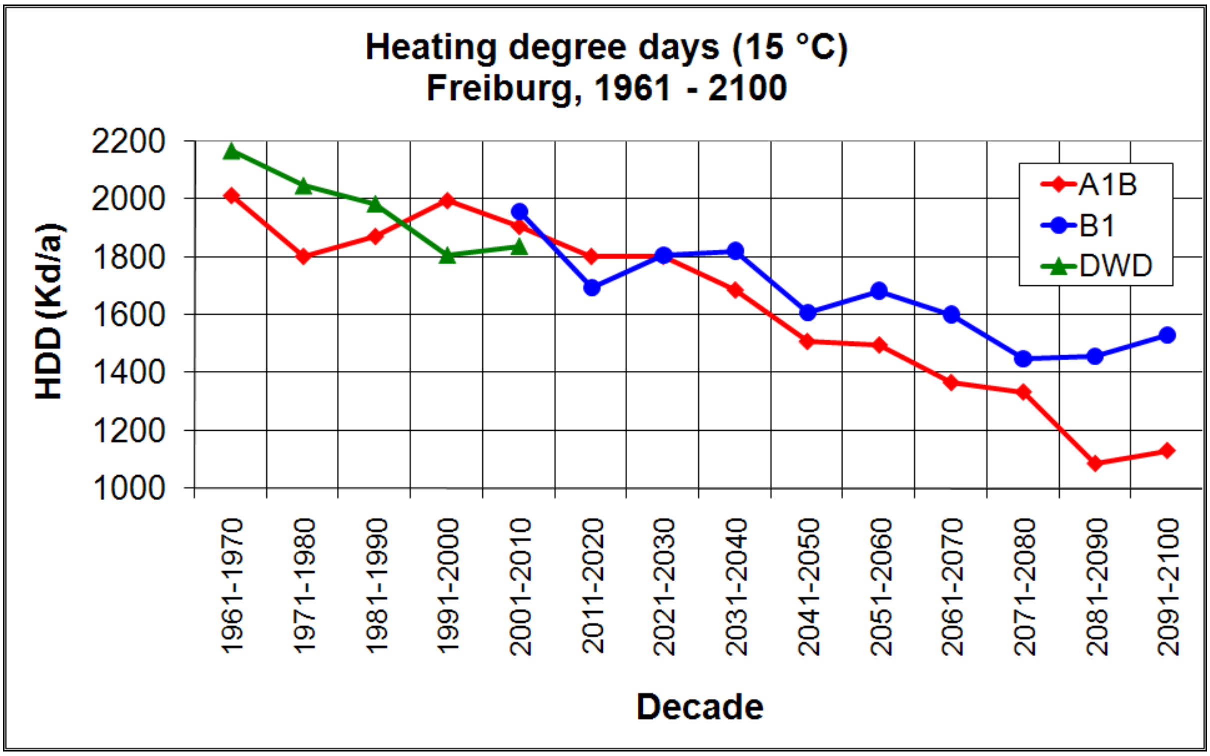

Fig. 5: Heating degree days in Freiburg for DWD, REMO A1B and B1 (based on Ta: 15 °C) for 1961 – 2100.

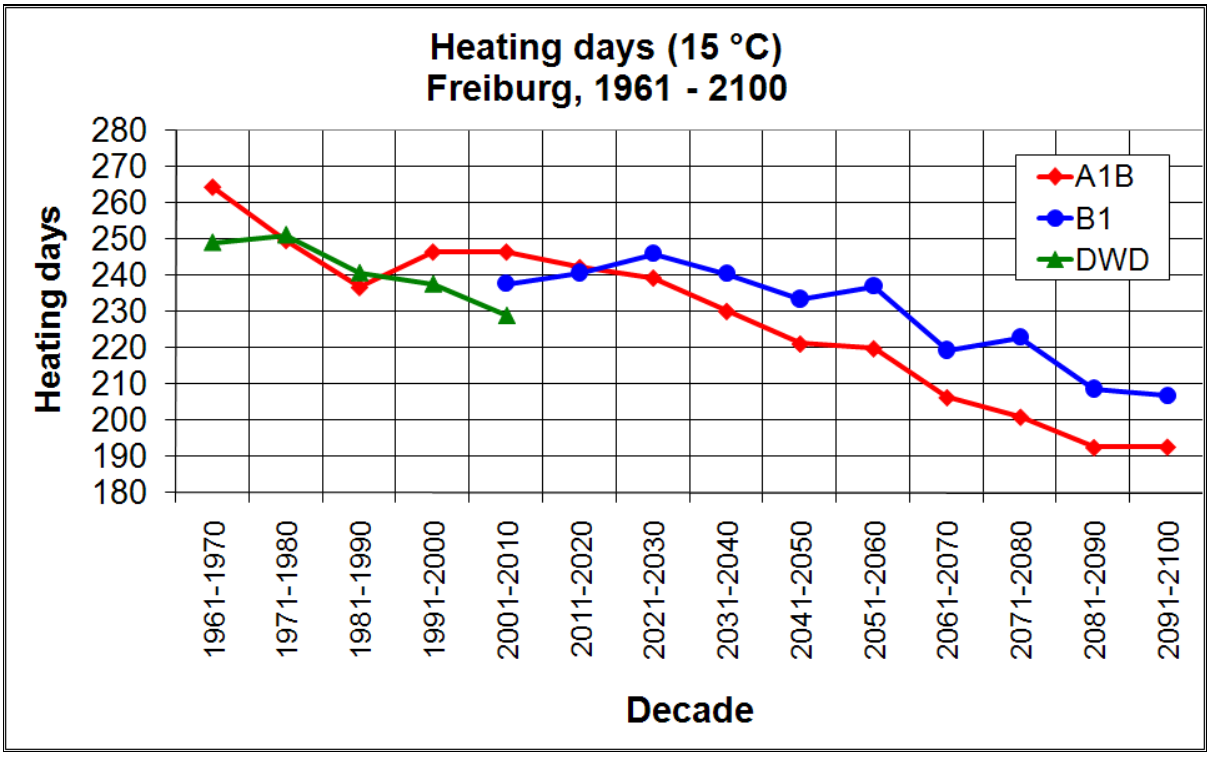

Fig. 6: Heating days in Freiburg for DWD, REMO A1B and B1 (based on Ta: 15 °C) for 1961 – 2100.

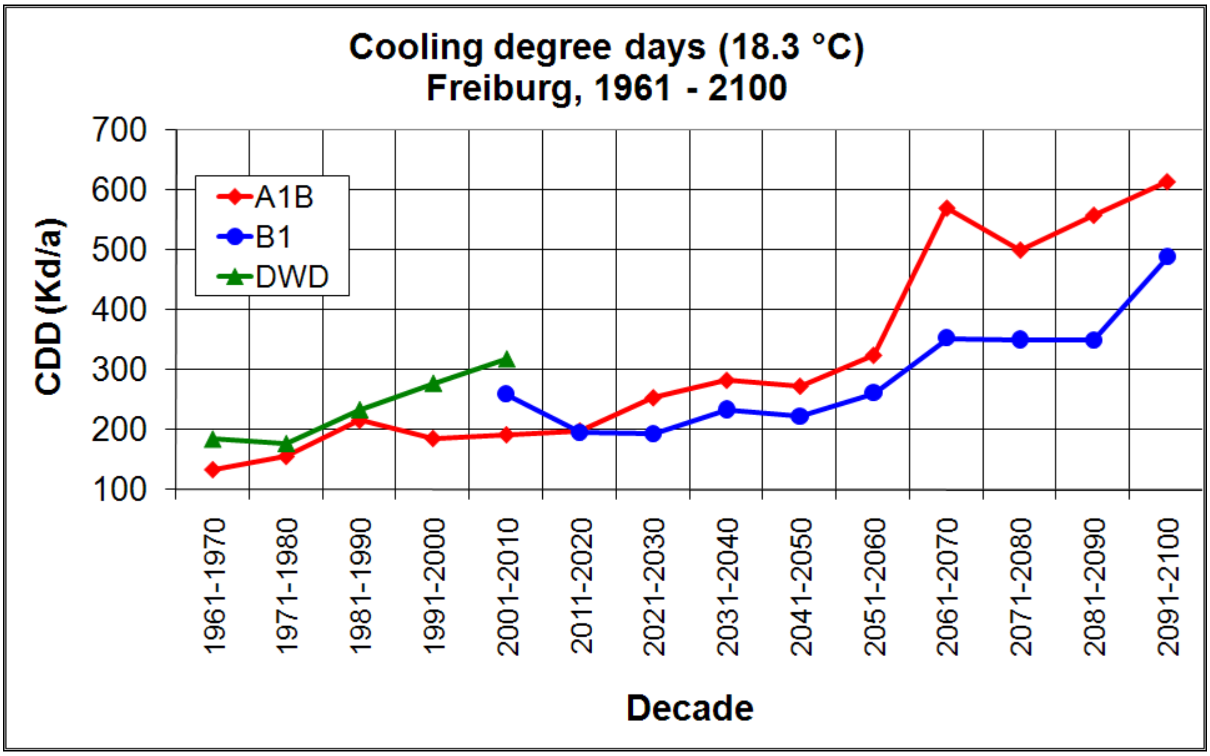

Fig. 7: Cooling degree days in Freiburg for DWD, REMO A1B and B1 (based on Ta: 18.3 °C) for 1961 – 2100.

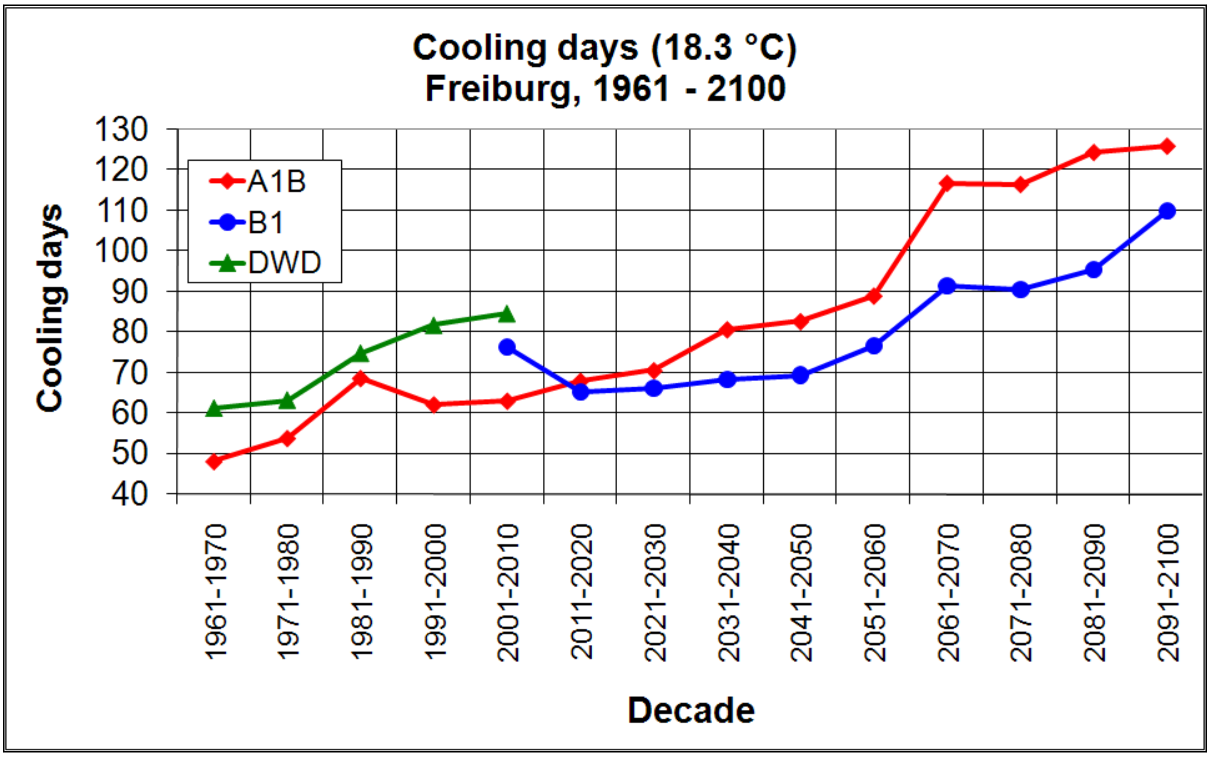

Fig. 8: Cooling days in Freiburg for DWD, REMO A1B and B1 (based on Ta: 18.3 °C) for 1961 – 2100.

The heating degree days based on air temperature of DWD as well as the A1B- and B1-scenarios (with a threshold value of 15 °C) are shown in Fig. 5. All graphs have a decreasing trend. In the second half of the 21st century, the A1B-scenario features much less heating degree days than the B1-scenario. This is also similar for heating days (shown in Fig. 6). These results are not surprising, because the A1B-scenario runs on the assumption that there will be an increase in air temperature of maximal 4.4 °C until the end of 21st century, whereas the B1-scenario only calculates with a maximum increase of 2.9 °C.

Fig. 7 shows the cooling degree days, Fig. 8 the cooling days based on DWD data as well as A1B- and B1-scenario at the threshold value of 18.3 °C. All curves show an increasing trend. From 2020 on, the A1B-scenario reveals higher cooling- and cooling degree days than the B1-scenario. This is as previously mentioned caused by the air temperature, which increases much higher in the case of A1B, compared to B1.

In the 1990s and the beginning of the 21st century, the measured values of Ta were generally higher than the Ta simulated in the A1B-scenario. In the decades of 1991 – 2000 and 2001 – 2010, the amount of observed heating- and heating degree days was clearly under the expected values of the A1B-scenario. Likewise there existed more observed cooling- and cooling degree days as expected by the scenario.

The discrepancy between the simulated and the observed values was the result of mild winters and hot summers in this period of time (Schönwiese et al., 2005).

The degree day numbers (shown in Fig. 9) of DWD, A1B and B1 are decreasing likewise the heating degree days.

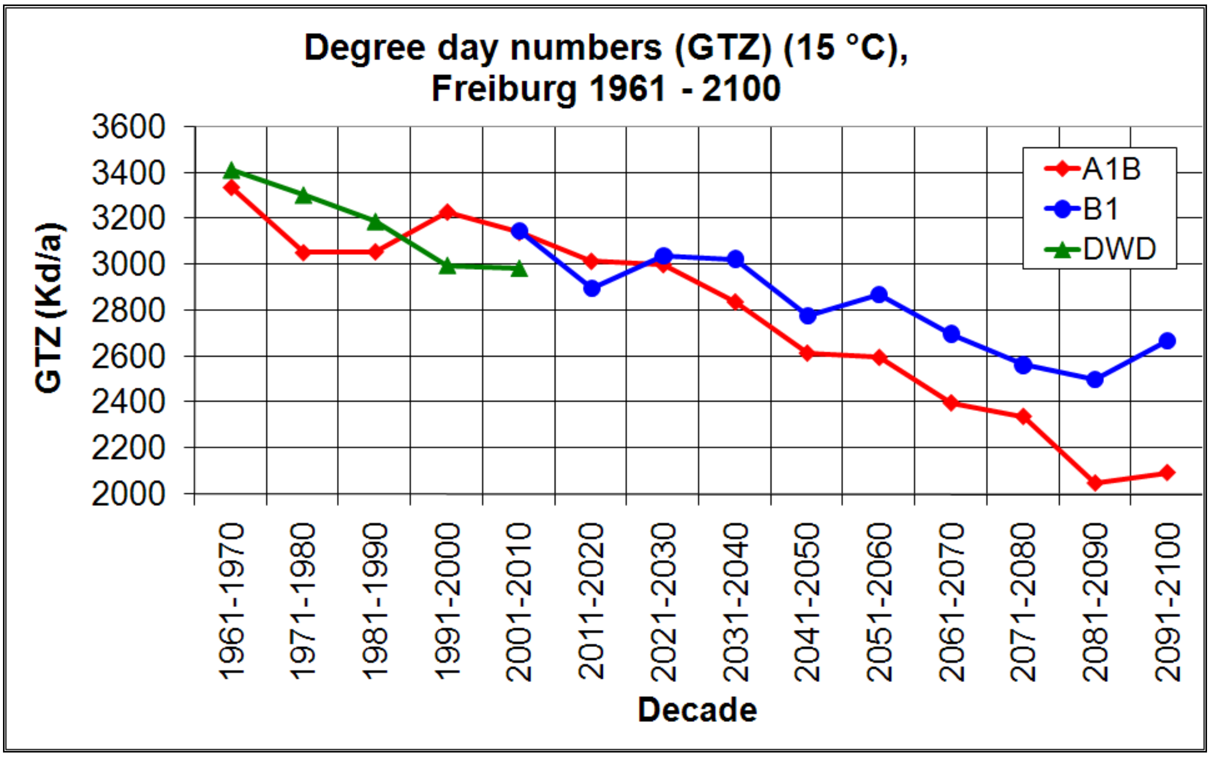

Fig. 9: Degree day numbers in Freiburg for DWD, REMO A1B and B1 (based on Ta: 15 °C) for 1961 – 2100.

More than 25.000 residential buildings exist in Freiburg. The mean building of this town could be an apartment house with three till six apartments in a building class from 1949 till 1960. It has an effective surface of 350 m² and an annual heating energy consumption of 61.950 kWh/a. The total heating energy consumption in the period of 1997 – 2007 was 1442 GWh/a (Fitz, 2008).

The following Fig. 10 shows the heating energy consumption of Freiburg. The mean HEV from 1997 – 2007 is displayed as bar and the HEV of the A1B-scenario as red curve, B1 in blue. The annual heating energy consumption in the decade 2091 – 2100 is approx. 1050 GWh/a for the A1B-scenario and about 1200 GWh/a for the B1-scenario, respectively.

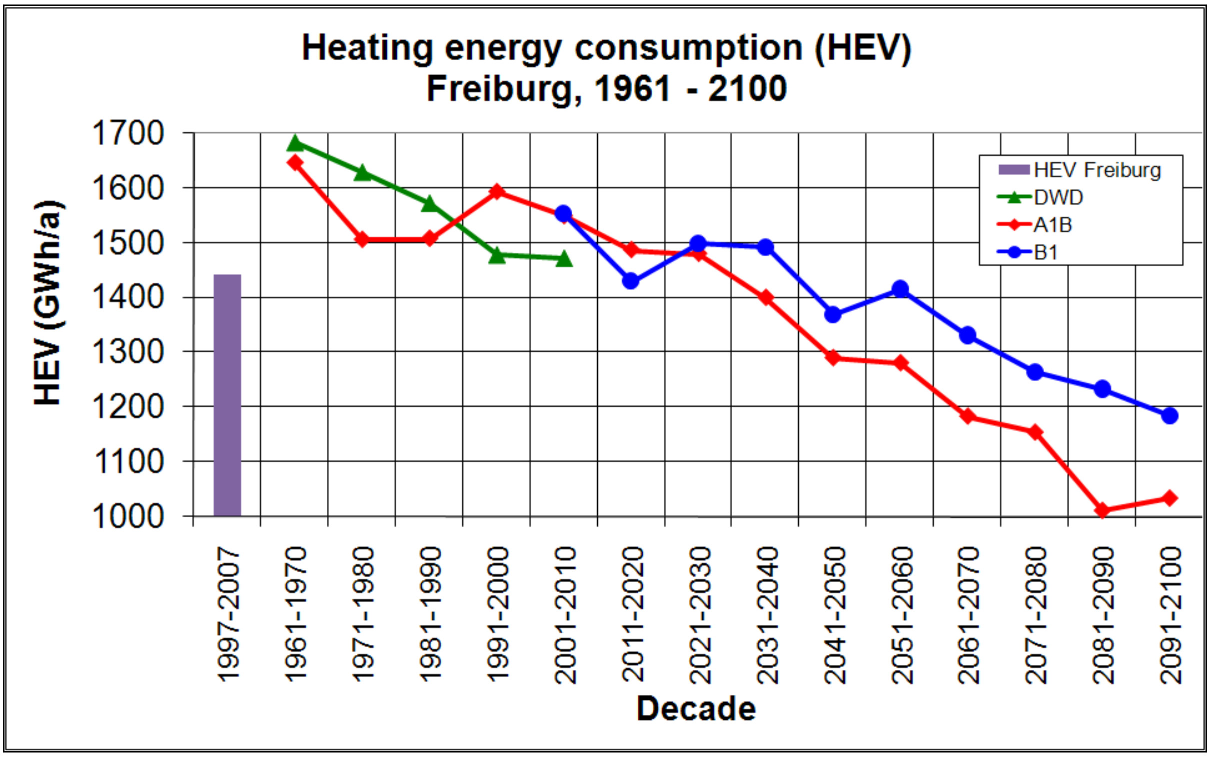

Fig. 10: Heating energy consumption in Freiburg for DWD (purple bar) for 1997 – 2007, REMO A1B for 1961 – 2100 and B1 for 2001 – 2100.

4. CONCLUSIONS

The analysis based on measured DWD data shows a decrease of heating of more than 20 days for the period 1961 – 2007. The cooling days rose up from 60 to 85 days. For the REMO simulated data the A1B-simulation shows a decrease from 240 to 190 days and to 220 days for B1 for the period 2001 – 2100. The cooling days increase from 90 to 130 days for A1B and to more than 100 days for B1 for 2001-2100, respectively. If the heating threshold of 12 °C is selected (that is the standard heating value of Switzerland) in comparison to the German threshold of 15 °C the heating degree days decreased about 620 and if the cooling threshold of 22 °C compared to 18.3 °C is selected the cooling degree days decreased about 200 per year. By the increase in air temperature to the year 2100 and the resultant milder winter with a lower number of heating days and degree day numbers, the heating energy consumption may be reduced between 18 % (B1) and 28 % (A1B).

The examined conditions by the use of heating and cooling days for a city in a moderate climate and the expected climate conditions to the end of the 21st century build valuable information about the regional and local climate.

Based on the present calculations and analysis the energy as well as heating and cooling demand for future climate conditions can be quantified. There are of course open questions for future heating or cooling degree days, if human beings will have an adaptation to higher air temperatures in winter, resulting to lower heating requirements. For summer, residents will accept higher thermal loads and avoid cooling devices e.g. air conditioning.

The climate change shows, according to each climate element and season, different structures of time and space, so there should be detailed regional studies based on observations compared with the global overview (Schönwiese et al., 2005).

It is difficult to calculate energy costs exactly because the compilation is very heterogenic. Heating energy is produced out of many energy sources for example heating oil, gas, biomass, and electricity. Air-conditioning plants need electricity to run. The electricity is produced out of many different energy sources for example coal, oil, gas, nuclear-, wind- and water plants as well as solar installations. An ascent of energy consumption for cooling can effect the built of more new power plants (Hadley et al., 2004).

For urban areas the knowledge of heating and cooling requirements for present and future climate conditions play a significant role and not only for the formation and influence on urban heat island but also for thermal perception or comfort conditions as well as thermal adaptation of humans in a future climate.

Climate change is one of the greatest challenges the mankind be faced with. Many climate experts state that there will be aggravating consequences for people and environment (Mahrenholz et al., 2005).

Finally it is established that the behaviour of the society in the case of heating and cooling, can caused lower or higher energy consumption.

REFERENCES

Fitz, S., 2008: GIS-gestützte Klimaschutz- und Energieverbrauchsanalyse der Gebäude-typologie der Stadt Freiburg im Breisgau. Magisterarbeit am Institut der physischen Geographie der Albert-Ludwigs Universität Freiburg.

Hadley, S. W.; Erickson III, D. J.; Hernandez, J. L.; Thompson S. L., 2004: Future U.S. Energy Use for 2000-2025 as Computed with Temperatures from a Global Climate Prediction Model and Energy Demand Model. http://www.csm.ornl.gov/~fj7/USAEE_paper.pdf

Hitchen, E.R., 1981: Degree days in Britain. Build. Serv. Eng. Des. Tech. 2, 73-82.

IPCC, 2007: Vierter Sachstandsbericht des IPCC (AR4). Klimaänderung 2007: Zusammenfassungen für politische Entscheidungsträger. (http://www.de-ipcc.de/).

Jacob, D., 2001: A note on the simulation of the annual and inter-annual variability of the water budget over the Baltic Sea drainage basin. Meteorol. Atmos. Phys. 77, 61–73.

Jacob, D.; Bärring L.; Christensen O. B.; Christensen J. H.; Hagemann S.; Hirschi M.; Kjellström E.; Lenderink G.; Rockel B.; Schär C.; Seneviratne S. I.; Somot S.; Van Ulden A.; Van Den Hurk B., 2007: An inter-comparison of regional climate models for Europe: Design of the experiments and model performance. Climatic Change 81, 31-52.

Mahrenholz, P.; Munz, N.; Hasse, C., 2005: Klimafolgen und Anpassung an den Klimawandel in Deutschland: Was wir in Deutschland darüber wissen und was wir tun müssen. Klimastatusbericht 2005. http://www.dwd.de/

Martinaitis, V., 1998: Analytic calculation of degree-days for the regulated heating season. Energy and Buildings. 28, 185-189.

Matzarakis, A.; Balafoutis, C., 2004: Heating degree days as an index of energy consumption. Int. J. Climatol. 24, 1817-1828.

McMaster, G. S.; Wilhelm, W. W., 1987: Growing degree-days. One equation, two interpretations. Agricultural and Forest Meteorology. 87, 291-300.

Schönwiese, C.-D.; Staeger, T.; Trömel, S., 2005: Klimawandel und Extremereignisse in Deutschland. Klimastatusbericht 2005. http://www.dwd.de/

Thomsen, F.: 2008: Langzeitliche Entwicklung der Heiz- und Kühlgradtage in Freiburg auf der Grundlage von Messungen und REMO-Modellierungen. B.Sc. Arbeit. Fakultät für Forst- und Umweltwissenschaften. Albert-Ludwigs-Universität Freiburg.

VDI, 1991: VDI-Richtlinie 2067: Berechnung der Kosten von Wärmeversorgungsanlagen, Raumheizung. Blatt 2. Verein Deutscher Ingenieure. VDI-Gesellschaft Technische Gebäudeausrüstung. VDI-Verlag, Düsseldorf.