Impact of Climate Change on the Design of Air Handling Units

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Abstract. Air Handling units (AHU) are designed to guarantee a high indoor air quality for any time and outdoor condition all over the year. To do so, the AHU removes particle matter like dust or pollen and adapts the thermophysical properties of air to the desired, seasonal indoor comfort conditions. AHU have a robust design and thus operate for more than fifteen years, sometimes even for decades. An AHU designed today must consider and anticipate the change of user needs as well as outdoor air conditions for the next twenty years. To anticipate the outdoor air condition of coming decades, scientific models exist, which allow the design of peak performance and capacities of the air treatment components. It is most likely, that the ongoing climate change will lead to higher temperatures as well as higher humidity, while the comfort zone of human beings will remain at today's values. Next to the impact of global warming with average rise of mean air temperature local effects will influence the operation of AHU. On effect investigated here is the steep temperature increase in city centres called *urban heat islands*. Heating and cooling capacities as well as water consumption for humidification are investigated for a reference AHU for fifteen regional locations in Germany. These regions represent all climate zones within the country. Additionally, the urban heat island effect was investigated for Berlin Alexanderplatz compared a rural area close by. The AHU was chosen to operate in an intensive care unit of a hospital. The set-up leads to 24/7 operation with 8760 hours per year. The article presents the modelling of current and future weather data as well as the unit set up. The calculated hourly performance and capacity parameters for current (reference year 2012) and future weather data (reference year 2045) yield energy consumption and peak loads of the unit for heating, cooling and humidification. The results are displayed by relative comparisons of each performance value.

Keywords. Air handling unit, climate change, urban heat island, future capacity needs.
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1. Introduction

Air Handling units (AHU) are designed to guarantee a high indoor air quality for any time and outdoor condition all over the year. To do so, the AHU removes particle matter like dust or pollen and adapt the thermophysical properties of air to the desired, seasonal comfort conditions by heating, cooling, humidification and dehumidification.

Further, a heat recovery system is uses the energy content of the extract air. AHU have a robust design and thus operate for more than fifteen years, considering refurbishment of components like fans, often more than twenty years.

The design of air conditioning of a building under construction means to consider and anticipate the change of user needs as well as outdoor air conditions for the next twenty years.

To anticipate the outdoor air condition of coming decades, scientific models exist, which allow the design of peak performance and capacities of the air treatment components. It is most likely, that the ongoing climate change will lead to higher temperatures as well as higher humidity, while the comfort zone of human beings will remain at today's values (e. g. 20 – 24 °C, 40 – 60 % r.h.).

Next to the impact of global warming with average rise of mean air temperature local effects will influence the operation of AHU. On effect investigated here is the steep temperature increase in city centres called urban heat islands.

Heating and cooling capacities as well as water consumption for humidification are investigated for a reference AHU for fifteen regional locations in Germany. These regions represent all climate zones within the country. The AHU was chosen to operate in an intensive care unit of an hospital. The set-up leads to 24/7 operation with 8760 hours per year.

In a first step the generation of weather data for historic and future years is explained. This includes the reginal modelling and the extension to micro climate for urban heat islands. Second, the AHU and its operating and boundary conditions are shown.

In a next step the procedure to calculate the design loads for given weather data is explained and results are presented for test reference years (regional weather) and urban heat islands (urban micro climate), respectively.

Finally, the results for one particular region (Berlin, TRY-region 4) are summarised and evaluated with respect to current and future AHU design rules. Berlin was chosen as the urban heat island effect is well investigated here.

2. Modelling of climate data

Representative weather data for almost any location worldwide is given by test reference years (TRY). These TRY data include hourly values for temperature, humidity, wind speed and direction, rain etc. In Germany, TRY data come from historical weather recordings between 1995 and 2012 (TRY 2012), where representative parts of real weather recordings are used [1]. Further, extreme summer or winter conditions are available. For the investigations here, “summer” TRY data was chosen.

Although, fifteen weather stations in Germany were tested, only the Berlin region will be discussed in this paper, because for Berlin detailed data of urban heat island effects are available. Berlin is located within region 4, Fig. 1. This region is one of the largest in Germany.

The same data structure is available for the weather in 2045. To get these future values, 24 climate models were used to extrapolate the local weather including effects of urbanisation. TRY 2045 is based on projections of global warming with a global radiation increase of 6.0 W/m²K for the years 2021 until 2060. The time path is called representative concentrations path (RCP) and is explained in the fifth Assessment Report of the Intergovernmental Panel on Climate Change, IPCC [3]. Radiation will increase due to higher concentration of greenhouse gases (GHG). RCP range from 2.0 W/m²K up to 8.5 W/m²K with projections of global warming from 1750 until 2100, Fig. 2.

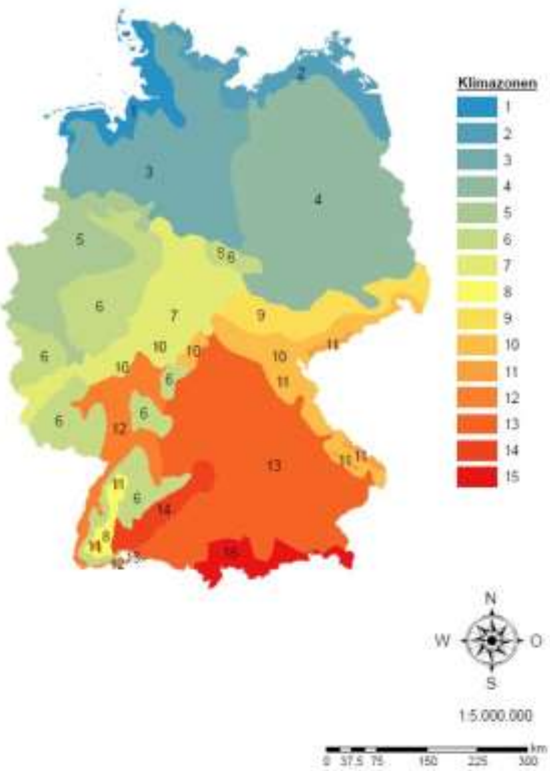

Fig. 1 - Weather (TRY) regions in Germany according to [2]. Berlin = region 4.

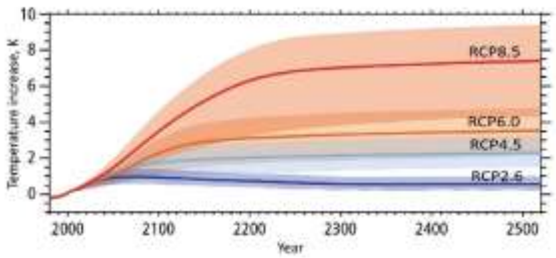

Fig. 2 - Global temperature rise based on RCPs with ±5 % confidence interval according to [4].

Global warming results from higher concentration of GHG like CO_2. According to RCP6 CO_2 concentration will reach a level of 850 ppm compared to 413 ppm today. More pessimistic scenarios like RCP8.5 even end up with a CO_2 concentration of 1370 ppm. In any case, higher CO_2 concentration in the outdoor air will increase minimum air flow rates to keep indoor air quality constant compared to current regulations.

2.1 Weather data overview

As one might expect the mean temperatures and humidity will increase with global warming. The impact for 2045 compared to 2012 is shown for summer (August) and winter (January) for TRY region 4 (weather station Potsdam) including Berlin area in Fig. 3.

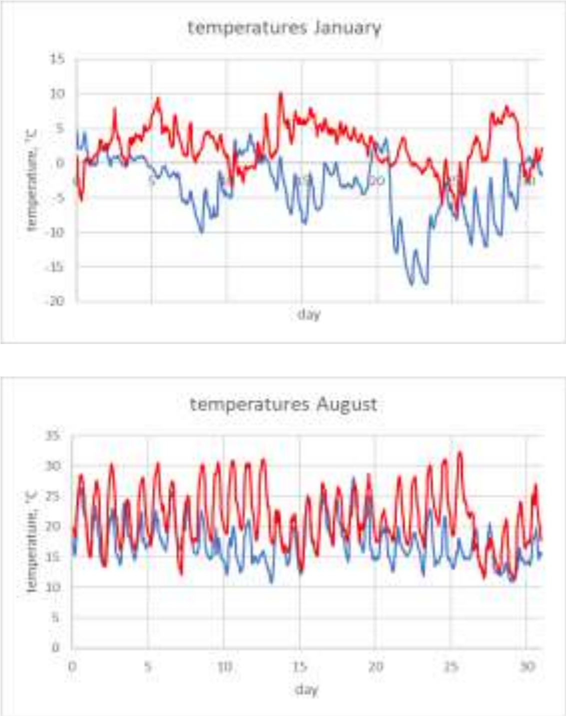

Fig. 3 – Hourly temperatures for region 4 (Potsdam) in January (top) and August (bottom). Blue lines = TRY 2012, red lines = TR 2045.

The average temperature differences between TRY 2012 and TRY 2045 are +4.4 K in August and +6.0 K in January. Both values are extreme. For the complete year the temperature increase in region 4 is only 1.2 K. In general the temperatures increase with TRY 2045, but also have a larger bandwidth within comparable time period (e.g. months).

2.2 Urban heat islands

Additional to the temperature increase due to global warming local effects of urbanisation will modify micro climates in larger cities. Even today, we see a temperature difference of five Kelvin between city and neighbouring, rural areas. As an example, Fig. 4 shows the temperature of one week in July 2020 with up to 4 K higher temperatures in the city centre.

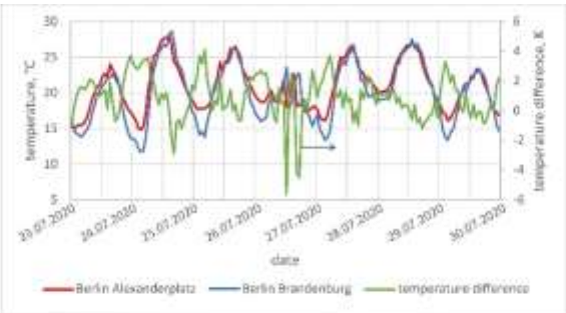

Fig. 4 – Temperatures of one week in Berlin Alexanderplatz and Berlin-Brandenburg (July 23rd – 30th 2020).

Urban heat islands lead to more summer days with temperatures above 30 °C as well as so called tropical nights with temperatures above 20 °C. The frequency is not yet predictable as current summer days and tropical nights are still rare [5]. The impact of climate change will be similar for both urban heat islands and rural areas [6].

Through the day solar radiation heats up the buildings and pavement, where the concrete serves as a heat storage. During the night, the heat is released to warm the outdoor air and thus yields higher air temperatures mainly in early morning hours compared to rural areas.

For Berlin Alexanderplatz in the centre of Berlin the weather data from June 2020 until end of December 2020 were investigated and compared to a rural weather station at Berlin-Brandenburg. The distance between both weather stations is 17.6 km. The weather data is available through the homepage of German Weather Service [7].

The number of hours with a temperature difference of more than four Kelvin is displayed in Fig. 5 where also the time frequency is shown. It is obvious that urban heat island effects are mainly present during the evening and night from 19:00 h until 5:00 h. That means the urban heat island effect is strongest when most building operate with reduced cooling capacity outside of business hours.

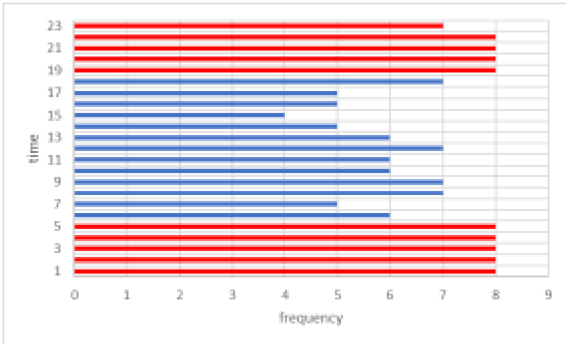

Fig. 5 – Time dependent probability of temperature differences (> 4K) between Berlin Alexanderplatz and Berlin-Brandenburg.

3. Design and operation of a representative air handling unit

A planned air handling unit for an intensive care unit in a hospital in southwest Germany serves as a role model for the performed simulations. The unit model was fed with weather data of fifteen representative weather stations with TRY 2012 and TRY 2045, respectively.

The AHU is designed to supply conditioned air for 20 patient rooms with up to 27 patients and five persons of medical staff. The unit is in operation all the time (24/7) and adapts supply air (SUP) depending on outdoor conditions, Fig. 6. Extract air temperature

(ETA) ranges from 20 °C up to 26 °C in winter and summer, respectively. In any case, the supply air humidity is between 6 g/kg ≤ x_{SUP} ≤ 10.5 g/kg.

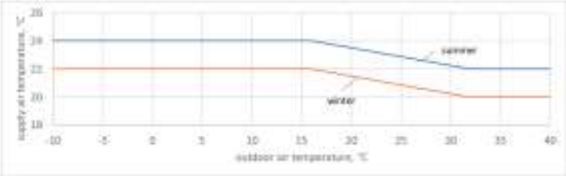

Fig. 6 – Supply air temperatures depending on ODA conditions.

The AHU displayed in Fig. 7 is able to heat, cool humidify and dehumidify outdoor air to the desired conditions. To fulfil current energy requirements a heat recovery system (run-around coil) is used with a heat recovery rate of 72 %.

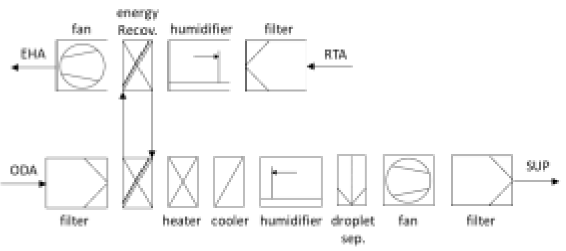

Fig. 7 – AHU set up.

Maximum airflow rate is 6.7 m^3/s with a nominal flow rate of 4.7 m^3/s used in the simulations.

4. Simulation of performance parameters

To gain the actual capacities to achieve the SUP conditions an Excel tool is used which calculates performance and operating hours of all components for each hour of the year. The following flow chart explains the procedure, Fig. 8.

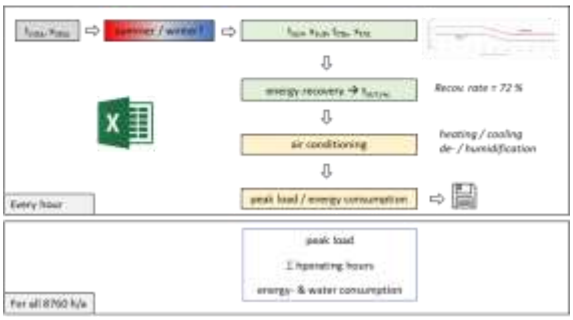

Fig. 8 – Calculation procedure for hourly performance values.

For each hour of the year, the SUP and ETA air condition is determined and the needed energy and capacity to reach the values are calculated. The components of the AHU are not limited performance-wise. Indeed, the max. capacity yields the design size of the heater and cooler as well as water demand for humidification. For full load and part load, the same efficiency parameters are applied. After the hourly calculations maximum and minimum values as well as total energy consumption for the year are calculated

4.1 Validation of the results

TRY weather data files contain a large amount of information and may blur potential errors during processing of the Excel tool. Several quality checks help eliminating potential errors.

Displaying the data in graphs gives a quick overview of the consistency of the input and output data. To do so temperatures and performance data for all components are plotted in a time line as well as in a Mollier h-x diagram. Further, a correlation between outdoor air temperature and performance values show clear trends following the designed boundaries. Finally, thermal balance is displayed for each month.

The following figures show an example of the validation details for TRY 2012 in region 4.

Fig. 9 shows the hourly heating and cooling demand with annual peak load (dotted lines). Cooling and heating curves do not overlap (simultaneous heating and cooling) and correspond to the expected seasonal distribution of the demands.

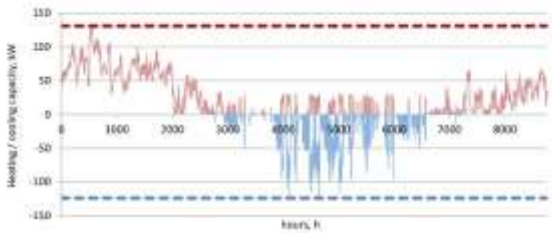

Fig. 9 – Validation of capacity data (Redline = heater, blue line = cooler, dotted lines = maximum capacity).

Fig. 10 shows the energy and water demand as a function of outdoor air temperature. Heating for ODA temperatures above 22 °C results from reheating due to dehumidification.

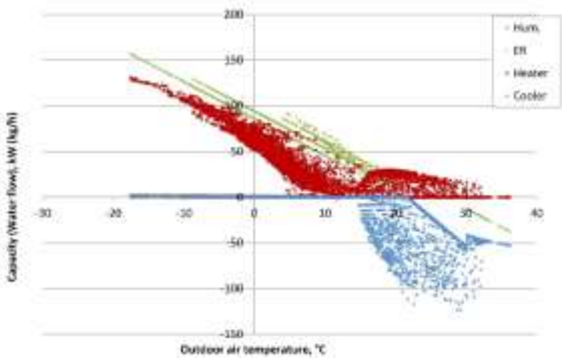

Fig. 10 – Validation of Design parameters vs. ODA.

Fig. 11 sums up the monthly energy and water demands. Electrical power for the fans are constant due to the fixed flow rate. Cooling demand is relevant only for the summer months from June until September.

Fig. 11 – Validation of monthly energy balance.

Testing the tool with constant temperature and humidity values allows a direct comparison with theoretical calculations of temperatures and enthalpies of the system. An addition, sample data for individual hours were calculated manually and checked with the Excel calculations.

5. Results

5.1 Results for TRY 2012 and TRY 2045 in Potsdam region 4

As one example of the absolute results Tab. 1 displays the parameters from region 4 with weather station located in Potsdam.

Tab. 1 - Performance values for region 4 for TRY 2012 and TRY 2045.

Parameter	TRY 2012	TRY 2045
Heating capacity	131 kW	96 kW
Heating energy	216340 kWh	184328 kWh
Heating hours	5625 h	5619 h
Cooling capacity	124 kW	125 kW
Cooling energy	59047 kWh	59423 kWh
Cooling hours	1542 h	1660 h
Water flow rate	109 kg/h	83 kg/h
Water demand	188 m^3	153 m^3
Operating hours	4043 h	4128 h

Potsdam and Berlin are strongly influenced by continental climate with east wind directions from Russia. Thus, the predicted mean climate change towards hotter summers is not clearly seen here.

The following two figures Fig. 12 and Fig. 13 show the changes from TRY 2012 to TRY 2045.

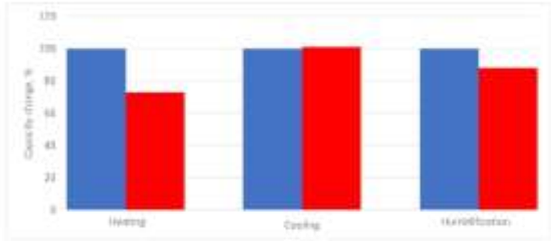

Fig. 12 – Difference in capacity (Blue = TRY 2012, red = TRY 2045).

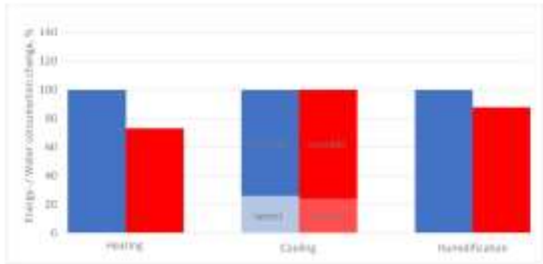

Fig. 13 – Difference in energy and water demand (Blue = TRY 2012, red = TRY 2045).

For the Potsdam region, reduced heating demand is visible, but cooling is not affected at all. As mentioned above, this is a specific result of the climate influence, which keeps summer temperatures at moderate levels. Nevertheless, the average temperature is rising and thus humidity, too. Humidification demand is decreasing accordingly.

5.2 Artificial German weather simulation

In addition to the regional TRY evaluation an area, weighted average weather was created from all fifteen weather stations correlated to the region size. Fig. 14 shows the share of surface area for all fifteen German weather stations according to Fig. 1.

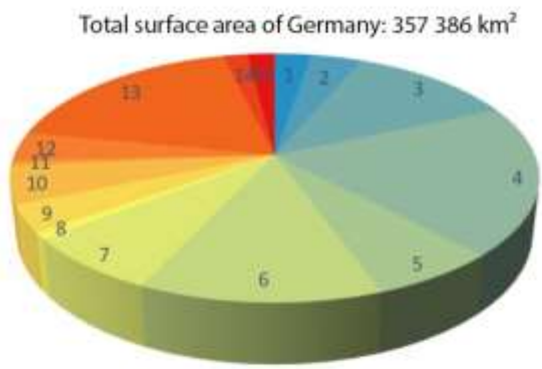

Fig. 14 – Share of surface area for all German TRY-regions

Weighting the TRY data by surface area share of each station, an artificial German weather data set was created and also tested. The following table shows the relative changes from TRY 2012 to TRY 2045 for Germany as a total.

Tab. 2 - Comparison of changes for area-weighted average TRY data (weather stations 1 – 15).

Air conditioning	Performance parameter	Change from 2012 to 2045
Heating	Heating capacity	-16 %
	Heating energy	-17 %
	Heating hours	+5 %
Cooling	Cooling capacity	+2 %
	Cooling energy	+67 %
	Cooling hours	+42 %
Humidifier	Water flow rate	-19 %
	Water demand	-31 %
	Operating hours	-4 %

From Tab. 2 a reduction of heating capacity and demand is obvious as we expect an average temperature increase for the next decades. For cooling, the capacity is almost constant, but the hours, where part load cooling is needed increases by 42 % and thus the overall energy demand. Humidification decreases as higher air temperatures allow higher relative humidity and thus a higher water vapour load.

5.3 Range of German weather simulation

The range of the differences is wide for the fifteen regions including mountain areas as well as seaside locations. Tab. 3 shows the range of changes for all TRY weather regions.

Tab. 3 – Range of changes from TRY 2012 to TRY 2045 for all fifteen regions

Air conditioning	Performance parameter	Deviation range
Heating	Heating capacity	-28 % ... + 2 %
	Heating energy	-28 % ... -8 %
	Heating hours	-5 % ... +8 %
Cooling	Cooling capacity	-29 % ... +93 %
	Cooling energy	-9 % ... +58 %
	Cooling hours	+4 % ... +40 %
Humidifier	Water flow rate	-25 % ... +2 %
	Water demand	-38 % ... -9 %
	Operating hours	-23 % ... +9 %

The changes for all German weather regions show clear trends towards higher temperatures and humidity in TRY 2045. That results in less heating demand and capacity while cooling needs become more important. In some regions the effects leads to almost doubled cooling capacity (+93 %). The number of cooling hours increases, too. The reduction of heating hours due to cool outdoor air temperatures is partly compensated by reheating during dehumidification during warmer und humid air conditions.

5.3 Results for urban heat islands

In contrast to the TRY simulations, we used measured data from two weather stations at Berlin Alexanderplatz and Berlin-Brandenburg from June 14th 2020 until December 2nd 2020, where the summer months July and August are most important for the UHI effect. As the investigation of urban heat islands is quite new, available comparable data with hourly resolution is still limited.

Similar to the TRY results, the diagrams just display differences, but no actual absolute values. Focus is on the differences and not on quantitative performance data.

In case of cooling capacity, no difference is seen which means the same cooler dimension fits for both locations. The heater for Berlin Alexanderplatz needs 5 % less in capacity. Humidification is not needed in the displayed time period and thus not displayed, Fig. 15.

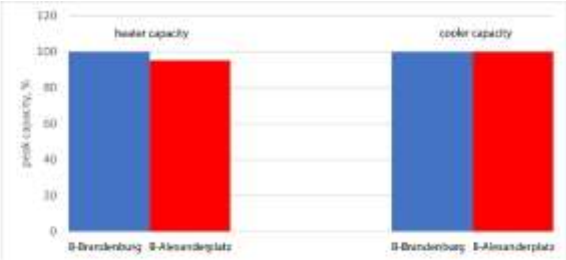

Fig. 15 – Peak capacity for second half of 2020.

As the temperature difference between city centre and rural areas is greatest at night where ODA temperatures are moderate, the effect on cooling capacity is negligible. Peak temperatures are similar for both locations during day time and storage effects of urban structures vanish during the night and early morning hours.

Looking at the energy needed as well as the operating hours, the difference becomes clearer. Here, cooling energy demand as well as operating hours increase by 20 % and 22 %, respectively, Fig. 16.

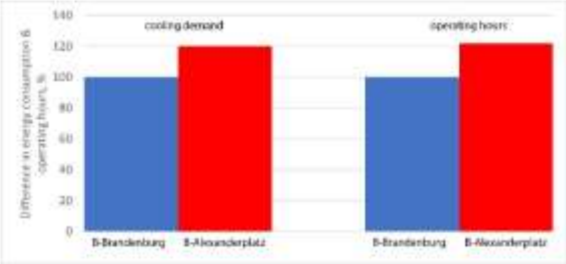

Fig. 16 – Cooling energy difference and difference in operating hours.

Although the database is limited, urban heat islands do not increase peak cooling capacity. Nevertheless, for the AHU of an intensive care unit an increase of operating hours is most likely as cooling demand at night increases.

6. Conclusion and outlook

The predicted climate change and its effects on local weather conditions were introduced and explained for Berlin / Potsdam region in Germany. The influence of urban heat islands on local temperatures was shown for recent weather data.

To make the effects more tangible, an air handling unit for an intensive care unit of a hospital was simulated with TRY-weather data from 2012 and 2045. The results were characterised by heating, cooling and humidification parameters.

The effect of global warming should be part of local climate boundary conditions for the design phase of AHUs. While the maximum cooling capacity just increases by 10 – 15 %, the operating hours will increase stronger. Thus, planers should not only consider additional buffer capacity, but should be aware of higher operating costs due to more operating hours. Although heating capacity is decreasing in the coming years, the effect on current AHUs would lead to a gap in heating capacity in winter. Humidification demand will decrease due to higher humidity in winter and transition periods.

Urban heat islands may not lead to higher cooling capacity, but surely to more cooling hours. As the effect is strongest at night, the impact will mostly affect buildings with a high share of annual operating hours. Office buildings closing at night might only be affected by their cooling strategy of potentially using free cooling during night time. The local effects of urban heat islands are not present yet in the TRY data of the regional weather stations used in this investigation. Nevertheless, DWD has finished a project to calculate local TRY weather data with a resolution of one km^2. Here, UHI is already included in the TRY data [8] and an extension to future TRY data will be soon available.

The results are based on a unit with 24/7 operating hours. Some effects will be similar for office buildings with reduced air conditioning at night, other building types will deviate. Thus, a variety of building and air conditioning types should be further simulated to get the full picture of climate change impact.

7. Acknowledgement

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8. References

[1] Deutscher Wetterdienst. Test Reference Years. https://www.dwd.de/DE/leistungen/testreferenzjahre/testreferenzjahre.html?nn=507312. Retrieved on 2.08.2021.

[2] VDI 4710-3:2011-03. Meteorological data for the building services.

[3] Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.): IPCC: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA. 2013.

[4] Pachauri, R.K., Meyer, L.A. (eds.):IPCC: Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. IPCC, Geneva, Switzerland. 2014.

[5] Früh, B., Koßmann, M., Roos, M. Berichte des Deutschen Wetterdienstes: 237: Frankfurt am Main im Klimawandel – Eine Untersuchung zur städtischen Wärmebelastung. 2011.

[6] Schau-Noppel, H., Koßmann, M., Buchholz, S. Meteorological information for climate-proof urban planning – The example of KLIMPRAX. Urban Climate. 2020; 32.

[7] Deutscher Wetterdienst. Urban Heat Islands. https://www.dwd.de/DE/leistungen/waermeinsel/waermeinsel.html. Retrieved on 3.01.2022.

[8] Krähenmann, S., Walter, A., Brienen, S. et al. Theoretical and Applied Climatology. High-resolution grids of hourly meteorological variables for Germany. 2018 (131): 899–926.

The datasets analysed during the current study are available in the DWD-Klimaberatungsmodul repository, https://kunden.dwd.de/obt/