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PASSIVE COOLING BY NIGHT-TIME VENTILATION USING CLIMATE RESPONSIVE ELEMENTS

Annual report 2006

Autor und Koautoren	Nikolai Artmann und Heinrich Manz
beauftragte Institution	Empa, Abt. Gebäudetechnologien
Adresse	Ueberlandstrasse 129, CH-8600 Duebendorf
Telefon, E-mail, Internetadresse	044 823 5511, nikolai.artmann@empa.ch, www.empa.ch
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SUMMARY

Due to an overall trend towards less heating and more cooling demand in buildings in many European countries over the last couple of decades, passive cooling by night-time ventilation is seen as a promising technique particularly for low-energy buildings. The basic concept involves cooling the building structure overnight in order to provide a heat sink that is available during the occupied period. However, as it requires a sufficiently high temperature difference between ambient air and the building structure during the night to achieve efficient convective cooling of the building mass, this concept is highly dependent on climatic conditions.

Therefore in the first part of the project, the climatic potential for the passive cooling of buildings by night-time ventilation was evaluated. An approach for calculating degree-hours based on a variable building temperature — within a standardized range of thermal comfort — was developed and applied to climatic data from 259 stations throughout Europe. To estimate the impact of climate change, the method was applied to future temperature projections for 8 selected locations representing different climatic zones of Europe.

The results show a very high potential for night-time ventilative cooling over the whole of Northern Europe and a still significant potential in Central, Eastern and even some regions of Southern Europe. However, given the inherent stochastic properties of weather patterns, series of warmer nights can occur at some locations, where passive cooling by night-time ventilation alone might not suffice to guarantee thermal comfort. Furthermore a significant reduction in the potential for night cooling was found due to climate change.

Even if the potential might not always be sufficient to assure thermal comfort, night-time ventilation can still be used to reduce the cooling energy demand in buildings using hybrid systems.

Projektziele

During the last decades, a trend towards increasing cooling demand in buildings can be observed in Europe [1], [2]. This is especially true in commercial buildings, where high internal loads in combination with high solar gains through extensive glazing systems lead to considerable cooling loads, even in moderate and cold climates like in Central or Northern Europe. An additional rise of the cooling demand is caused by the global climate warming, which is expected to increase summertime temperatures significantly. While the heating demand can be effectively reduced by installing thermal insulation, cooling plays a more significant role in the overall energy demand of buildings.

Particularly in moderate and cold climates with relatively low night-time temperatures, night-time ventilation seems to be a promising technique to reduce the cooling energy demand of buildings. The basic concept involves cooling the building structure overnight in order to provide a heat sink that is available during occupancy periods. The ventilation with cold air during the night can be driven by thermal buoyancy and wind forces (natural ventilation), or be supported by a mechanical fan (hybrid/mechanical ventilation). As naturally driven systems are highly sensitive to ambient conditions, reliable planning tools are needed to encourage a widespread application of this method.

The goals of the project are:

- To evaluate possibilities and limitations of passive cooling by night-time ventilation in present and future climates
- To improve the building design knowledge in the field of passive cooling
- To understand the impact of geometrical and physical parameters etc. on air exchange and cooling effect
- To develop an engineering model to be implemented in Building Energy Simulation tools
- To demonstrate the application potential of climate responsive elements

Durchgeführte Arbeiten und erreichte Ergebnisse

Evaluation of possibilities and limitations of passive cooling by night-time ventilation in present and future climates

Particularly in moderate and cold climates with relatively low night-time temperatures even in summer, passive cooling of buildings by night-time ventilation appears to hold considerable potential to guarantee the daytime thermal comfort of building occupants without mechanical cooling or, at least, with a lower daytime cooling energy requirement. However, as it requires a sufficiently high temperature difference between ambient air and the building structure, this technique is highly sensitive to climatic conditions. Therefore the climatic potential for the passive cooling of buildings by night-time ventilation in present and future climates in Europe was evaluated.

A method to assess the potential for passive cooling of buildings by night-time ventilation was developed, verified and applied to present [3] and future [4] climatic data. The climatic cooling potential CCP, was defined as the sum of degree-hours for the difference between building and external air temperature (Fig 1). It was assumed that night-time ventilation starts at 7 pm and ends at 7 am. Because a certain temperature difference is needed for effective convection, night ventilation is only applied if the difference between building temperature, T_b and external temperature, T_e is greater than $\Delta T_{crit} = 3K$.

An example for the practical significance of the defined potential showed [3] that a CCP of about 80 K h per night is needed to discharge heat gains of 50 W/m^2 during 8 h. However, as building parameters as well as heat gains can vary significantly, this value should be seen only as a rough indication.

For the evaluation of the potential for night-time ventilation in present climates of Europe, the degree-hours method was applied to semi-synthetic hourly temperature data from the commercial database *Meteonorm* [5]. Two hundred fiftynine locations in densely populated locations all over Europe were selected to map the climatic cooling potential (Fig 2). As expected, a clear gradation from north to south emerged. Even in the hottest month of the year, Northern Europe (including the British Isles) exhibits a very high cooling potential of between 120 to 180 K h. In not only Central and Eastern Europe, but also in the northern parts of Portugal, Spain, Greece and Turkey, the cooling potential is still 60 to 140 K h.

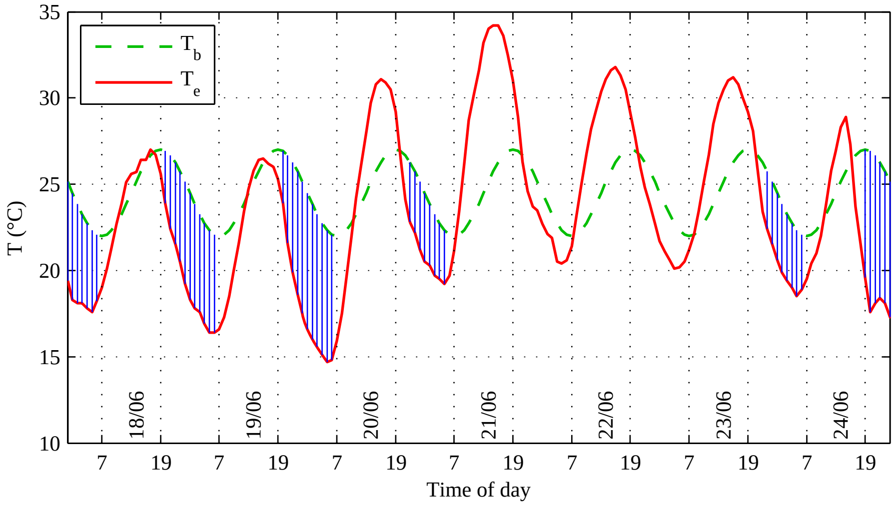

Fig 1 Shaded areas illustrate graphically the climatic cooling potential during one exceptionally hot week in summer 2003 for Zurich SMA (ANETZ data).

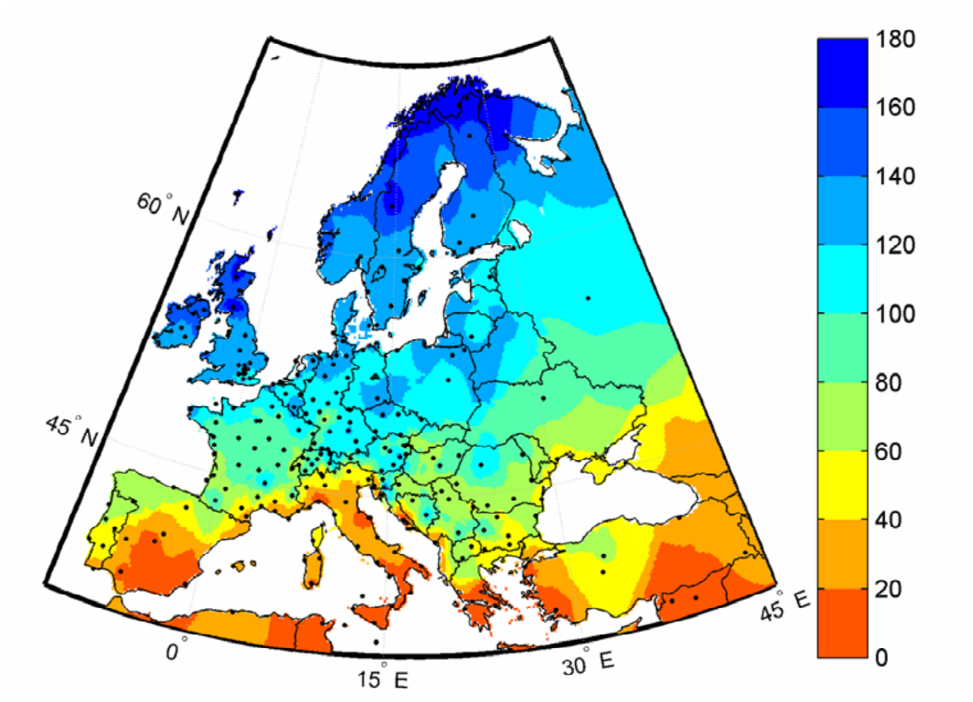

Fig 2 Map of mean climatic cooling potential (K h / night) in July based on Meteonorm data.

In order to quantify the impact of climate warming on the night-time ventilative cooling potential in Europe, site-specific regression models were developed to estimate the climatic cooling potential (CCP) from minimum daily air temperature, T_{min} (Fig 3). CPP was computed for present conditions (1961 – 1990) using measured T_{min} data from the *European Climate Assessment* (ECA) database. Possible future changes in *CPP* were assessed for the period 2071 - 2100 under the *Intergovernmental Panel on Climate Change* (IPCC) “A2” and “B2” scenarios for future emissions of greenhouse gases and aerosols. Considered were 30 local T_{min} scenarios constructed from data sets obtained from the European *PRUDENCE* project.

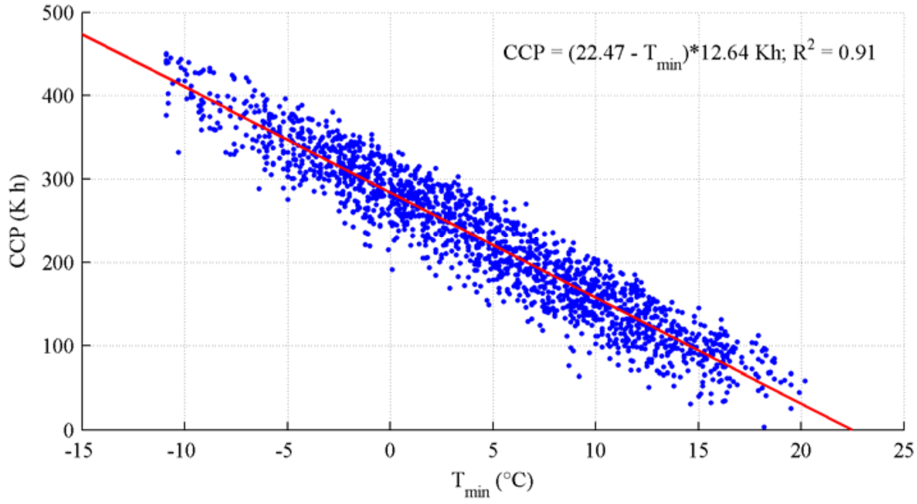

Fig 3 Correlation between CCP per night and daily minimum temperature, based on Meteonorm data for Zurich SMA.

Fig 4 shows the absolute values of CCP per season at different locations sorted by latitude. Not surprisingly, the potential is highest in winter and lowest in summer; it also clearly increases from South to North. A significant reduction of the potential for cooling by night time ventilation is displayed for all locations, seasons and both forcing scenarios. As expected, the scenario “A2” with higher concentrations of radioactively active gases results in lower CCP values than scenario “B2”.

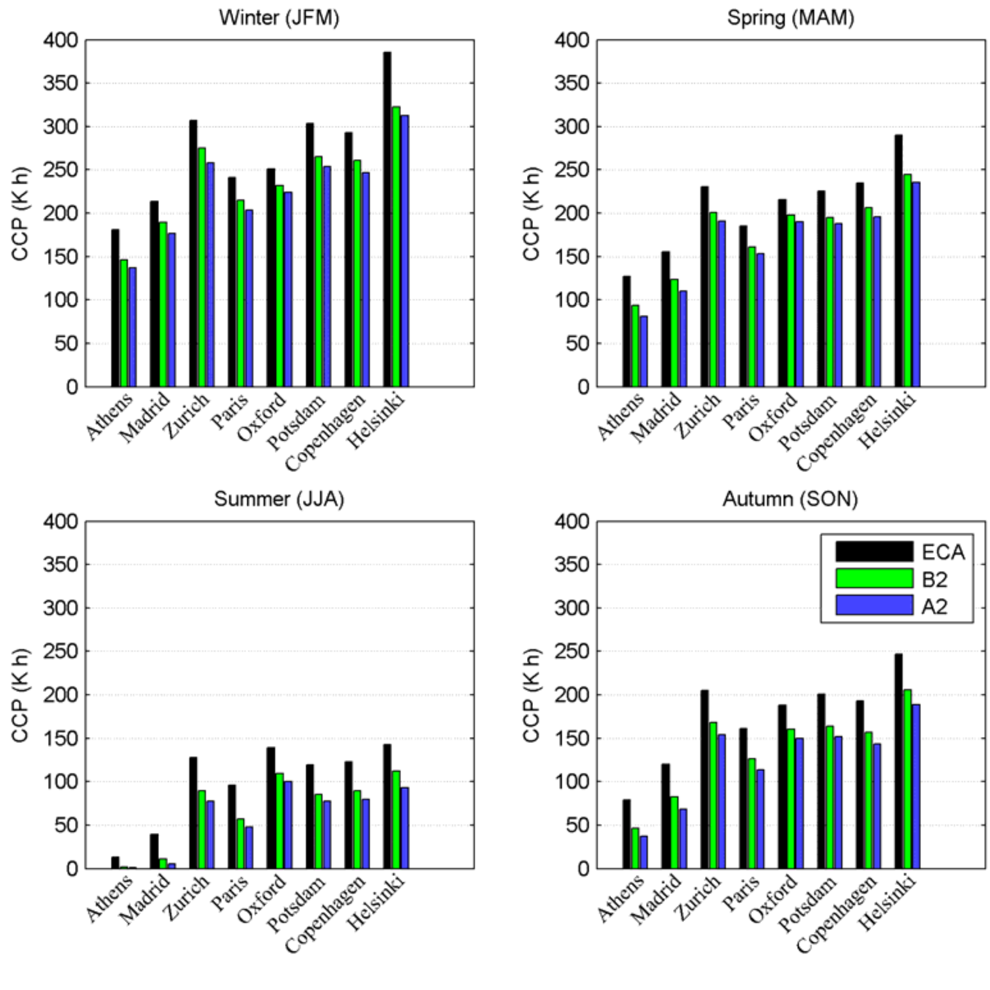

Fig 4 Estimated mean climatic cooling potential (CCP) per season under current (1961-1990, ECA data) and future (2071-2100, scenarios “A2” and “B2”) climatic conditions.

For a more detailed analysis the seasonal cumulative distributions of the cooling potential were plotted. These charts give the relative number of nights per season, when the cooling potential exceeds a certain value. Fig 5 shows the averages of selected simulation runs based on the forcing scenarios “A2” and “B2” for Zurich and Madrid. The curves calculated from ECA data represent the cooling potential in present climate. Additional charts for other case study locations are presented in the Appendix (Fig A1).

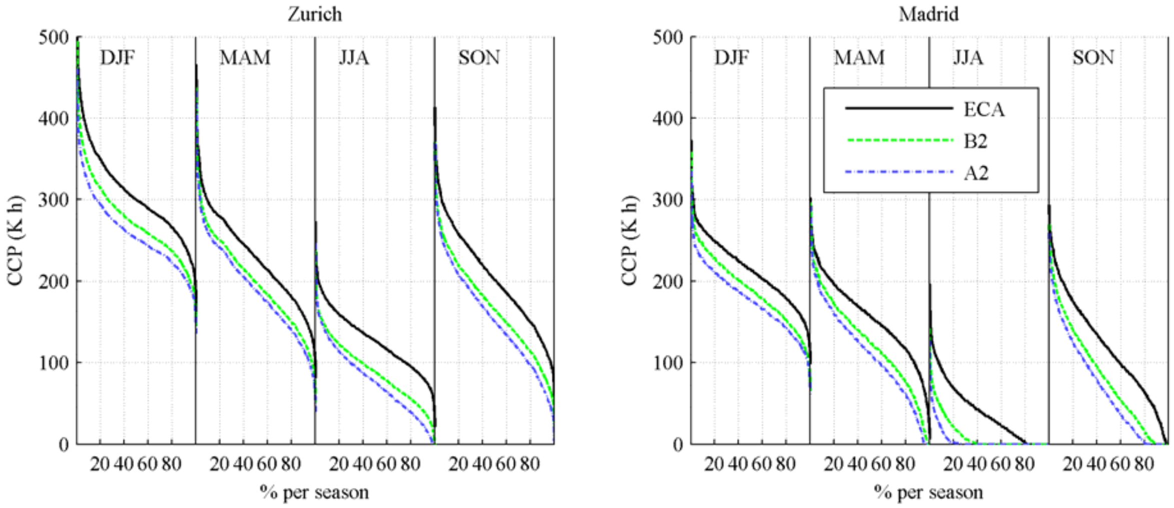

Fig 5 Seasonal cumulative distributions of CCP in Zurich (left) and Madrid (right) for current climate (ECA) and averages for forcing scenarios “A2” and “B2”.

Until the end of the 21st century, a decrease in CCP per night of about 20 to 60 K h was found depending on season, location and forcing scenarios (“A2” and “B2”). Compared to 80 K h – roughly necessary to remove heat gains of 50 W/m^2 – this shows a notable impact of climate change on the climatic potential of night cooling.

In some cases, as in summer in Zurich or also in spring and autumn in Madrid, the increased variability in future climate causes a non-parallel shift in CCP (i.e. the decrease in cooling potential is highest for the warmest periods). Therefore extended periods with very low night cooling potential, where thermal comfort cannot be assured based on night-time ventilation only, are expected in Central Europe. Even in Northern Europe, where the potential is currently sufficient throughout the year, some days with a risk of thermal discomfort might occur. However, considering an increasing cooling demand in spring and autumn, there will still be a notable potential for cooling by night-time ventilation in Central and Northern Europe at least for hybrid systems.

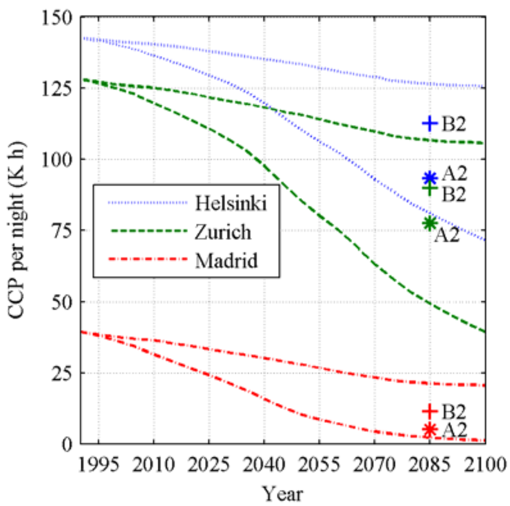

Fig 6 Time-dependent change in mean climatic cooling potential during summer (JJA); upper and lower scenario based on mean global temperature scenarios ([6] Figure 9.14, “several models, all SRES envelope”) and mean values of selected PRUDENCE models for “A2” and “B2”; absolute values (left) and relative to 1990 (right).

In Southern Europe, a temperature increase leads to a shift of the night cooling period towards earlier spring and later autumn. Additionally, a period of very low cooling potential is extended significantly. In order to prevent a serious increase in energy consumption of mechanical cooling systems – also in hybrid systems – the possible application of other passive cooling techniques should be considered whenever the potential for cooling by night-time ventilation is not sufficient.

A transient CCP scenario based on a wide range of forcing scenarios showed that the main changes occur during the second half of the 21st century (Fig 6). Therefore in Central and Northern Europe useful potential for night-time ventilation is likely to remain until 2050. Despite the decreasing climatic cooling potential available found in this study, it should be stressed that building design should be based on energy-efficient passive cooling techniques whenever possible.

Nationale Zusammenarbeit

The evaluation of future climate scenarios has been performed in collaboration with D. Gyalistras, Institute for Integrative Biology, ETH Zurich.

Internationale Zusammenarbeit

Within the frame of this BFE-project a PhD-thesis (N. Artmann) will be written. The major professor is P. Heiselberg from the Hybrid Ventilation Centre, Department of Civil Engineering, Aalborg University, Denmark.

N. Artmann participates in the IEA Annex 44 Integrating Environmentally Responsive Elements in Buildings which is led by P. Heiselberg. Two meetings were held in 2006: Torino, March 29th to 31st and Graz, September 11th to 13th.

Bewertung 2006 und Ausblick 2007

A new method for the quantification of the climatic potential for passive cooling of buildings by night-time ventilation was developed and applied to assess the potential in present and future climates. The presented method is valuable to discuss the cooling potential for a given climate and might mainly be helpful in the first design phase of a building at a given location.

However, it has to be stressed that a more thorough analysis of the summertime transient thermal behaviour of a building has to be based on results from building energy simulation, taking into account all building-specific parameters such as time-dependent internal and solar gains, active building thermal mass, air flow patterns and air flow rates. In order to identify most important physical parameters for the passive cooling technique, a parametric study employing a transient model will be undertaken. As air flow patterns are not modelled in detail in currently used building energy simulation codes, new models need to be developed for an improved predictions of the night-ventilation efficiency. Computational fluid dynamic (CFD) simulations and full scale experiments will be performed to develop an engineering model to be implemented in building energy simulation tools until the project is completed.

Referenzen

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[3] Artmann N, Manz H, Heiselberg P. Climatic potential for passive cooling of buildings by night-time ventilation in Europe, Applied Energy (In Press, available online 24 August 2006 at www.science.direct.com)

[4] Artmann N, Gyalistras D, Manz H and Heiselberg P. Impact of climate warming on the potential for passive building cooling by night-time ventilation in Europe (in preparation)

[5] Meteonorm, Global meteorological database for engineers, planners and education. Version 5.1 – Edition 2005, Software incl. Manual (www.meteonorm.com)

[6] Cubasch U, Meehl GA, Boer GJ, Stouffer RJ, Dix M, Noda A, Senior CA, Raper S, Yap KS et al. Projections of Future Climate Change. In: Houghton JT, Ding Y, Griggs DJ, Noguer M, van der Linden PJ, Dai X D, Maskell K, Johnson CA, editors. Climate Change 2001: The Scientific Basis. Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change (IPCC), Cambridge UK and New York USA: Cambridge University Press; pp 525-582, 2001.

Anhang

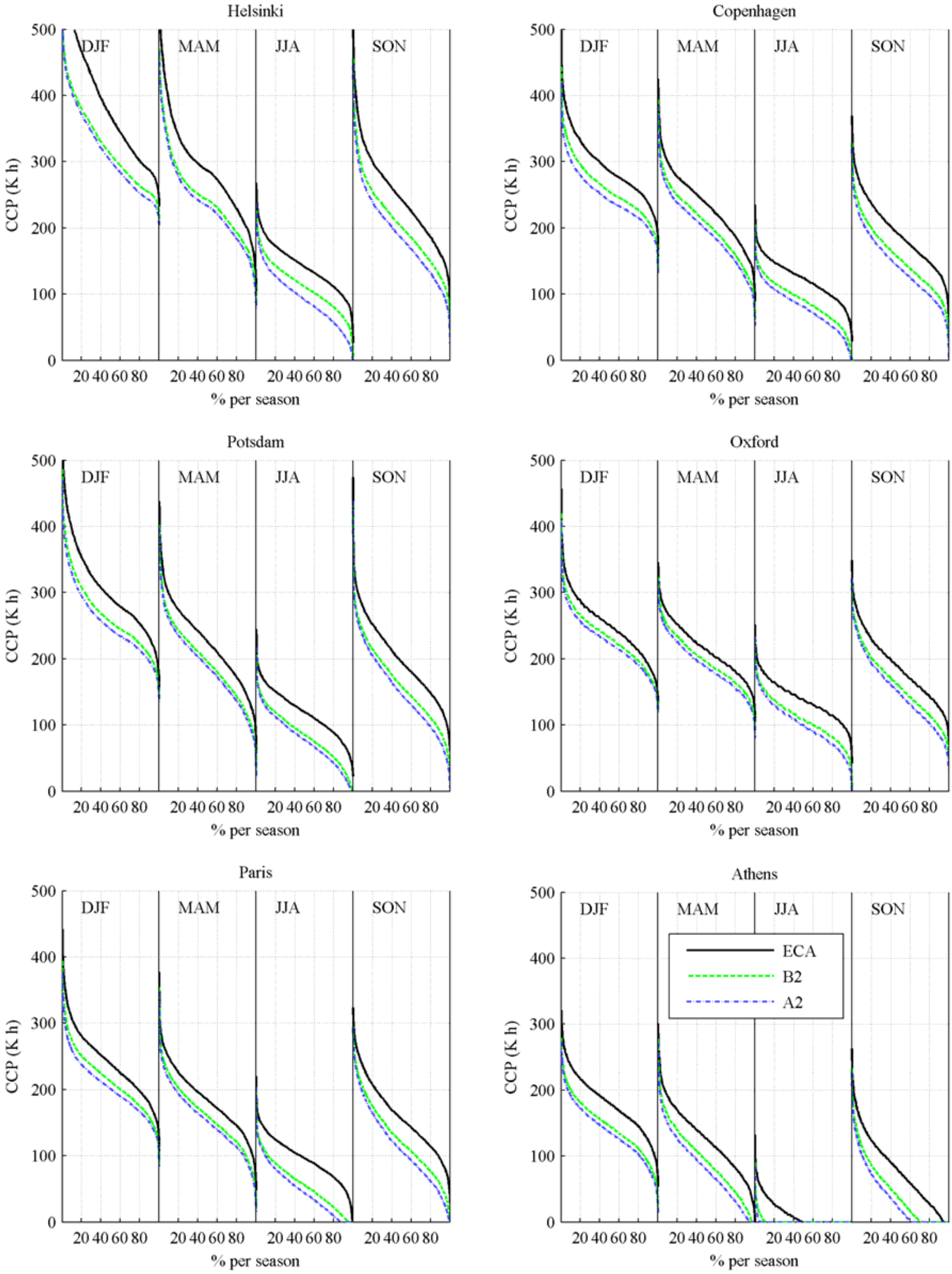

Fig A1: Seasonal cumulative distributions of CCP at different locations under current climatic conditions (ECA data) and projections based on forcing scenarios A2 and B2.