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Climate change impacts on building heating and cooling energy demand in Switzerland

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Abstract

The potential impacts of climate change on heating and cooling energy demand were investigated by means of transient building energy simulations and hourly weather data scenarios for the Zurich–Kloten location, which is representative for the climatic situation in the Swiss Central Plateau. A multistory building with varying thermal insulation levels and internal heat gains, and a fixed window area fraction of 30% was considered. For the time horizon 2050–2100, a climatic warm reference year scenario was used that foresees a 4.4 °C rise in mean annual air temperature relative to the 1961–1990 climatological normals and is thereby roughly in line with the climate change predictions made by the Intergovernmental Panel on Climate Change (IPCC). The calculation results show a 33–44% decrease in the annual heating energy demand for Swiss residential buildings for the period 2050–2100. The annual cooling energy demand for office buildings with internal heat gains of 20–30 W/m^2 will increase by 223–1050% while the heating energy demand will fall by 36–58%. A shortening of the heating season by up to 53 days can be observed. The study shows that efficient solar protection and night ventilation strategies capable of keeping indoor air temperatures within an acceptable comfort range and obviating the need for cooling plant are set to become a crucial building design issue.

Keywords: Building; Climate change; Heating energy; Cooling energy; Overheating; Modeling

1. Introduction

The year 2003 saw Europe experience the most intense summer heatwave on record. Global warming and climate change scenarios came to dominate the agenda worldwide. The third assessment report of the Intergovernmental Panel on Climate Change (IPCC) [1] predicts an increase in surface temperature of 1.4–5.8 °C over the period 1990–2100 together with an increase in climate variability and extreme events. The key findings point to changes in the frequency, intensity and duration of extreme events, such as hot days, heatwaves and heavy precipitation, along with a lower incidence of cold days. Moreover, a wide band of uncertainty exists regarding the amount of warming. The different climate scenarios for 2100 relative to 2000 show a temperature rise of 3.5 °C with an uncertainty band of ±2 °C. Recent research results from the Hadley Centre in UK [5] suggest that a doubling of atmospheric carbon dioxide concentrations in Europe over the next 50–100 years will, with a 90% probability, spell an average global temperature rise of between 2.4 and 5.4 °C. Extreme heatwave events such as those witnessed in summer 2003 will become more frequent in future and over half of all European summers are likely to be warmer than in 2003.

A wide range of future climate change scenarios [4–6,16–18] and their potential implications for the built environment [14] have been investigated and published within the UK Climate Impacts Programme (UKCIP). A recent study published by the European Environment Agency (EEA) [3] describes trends in and projections for 22 climate change state and impact indicators. In Switzerland, a National Research Programme and National Center of Competence in Research (NCCR) on climate variability, predictability and climate risks [10] were established in 2001. An advisory board on climate change risks (OcCC), which focuses on issues related to the implementation of the Kyoto Protocol, acts as a liaison point between science and politics in Switzerland. Detailed reports [9,11] have been published which outline the potential impacts of climate change on

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vegetation, water resources, glaciers, human health and economy and describe the associated trends and indicators. Luterbach et al. [7] investigated European seasonal and annual temperature variability, trends and extremes since 1500, identifying 1708–1709 as the coldest European winter and 2003 as hottest summer. An analysis of the exceptional year 2003 by Bader [8] pinpointed another extreme behavior besides the summer heatwave: a sudden, sharp drop from high summer to low winter temperatures brought about extremely cold weather in October. Schär et al. [12] advanced the idea that, alongside the rise in mean temperature, a regime with an increased variability by up to 100% may be able to account for the summer heatwaves of 2003. A study performed in New Zealand [2] concluded that provision for climate change risks is required in future revisions of building codes and that rating tools should be developed to aid assessment. Climate change is expected to impact on many aspects of building performance. While various studies on energy demand have been performed to date, most of these have adopted the heating and cooling degree–day approach [13,19,20] with only a few based on detailed numerical building simulation modeling [15]. All studies forecast a sharp fall in heating energy demand, though these reductions are offset by a large increase in cooling energy demand.

Buildings with different thermal insulation levels and solar or internal heat gains will have different base temperatures, which need to be factored into the simplified degree–day method for the determination of energy demand. This paper focuses on building heating and cooling energy demand and the overheating problem using a dynamic building simulation model based on the thermal balance method with hourly time steps. As hourly weather data series are needed for this purpose, this study made use of long-term measured data to generate different reference years.

2. Methodology

2.1. Climatic data

ANETZ is a Swiss network of 72 automatic weather stations operated by MeteoSwiss, the Federal Office of Meteorology and Climatology, since 1981. To facilitate energy simulation applications for buildings, EMPA developed a software tool [23] to provide direct access to the database of ANETZ and to supplement the basic measured data (air temperature, humidity, wind velocity and direction, cloud cover fraction, global solar radiation on a horizontal plane) with computed values for the solar radiation components (diffuse and direct beam, global horizontal and vertical for all main directions) and the long-wave downward irradiance from the sky, using the dewpoint-correlation model given in [22]. The weather data are finally converted into the input format required by different building simulation codes (HELIOS, DOE-2, TARP, SERIRES, DEROB or SUNCODE).

Weather data for Zurich–Kloten (47.29 N/8.32 E/436 m), representative of typical climatic conditions in the Swiss Central Plateau, were chosen for this study. Hourly weather data during the period from 1981 to 2003 were used and analyzed. Annex A shows the mean monthly air temperatures (based on hourly mean) and the minimum and maximum monthly values for the last 20 years (1984–2003). The coldest winter was 1985 with an hourly temperature minimum of $-23.7\,^{\circ}$C in January and a mean monthly value of $-6.0\,^{\circ}$C, while the warmest summer was 2003 with an hourly temperature maximum of 36.7 °C in August and a mean monthly value of 22.3 °C. Extreme hourly temperature variations were observed in January 1987 with $\Delta\theta = 33.4\,^{\circ}$C and in October 1997 with $\Delta\theta = 30.9\,^{\circ}$C. Table 1 gives a summary of all mean monthly air temperatures and the mean seasonal and annual values. The winter season is defined as the period from October to April, while the summer season runs from May to September. The table shows that 1994 was the warmest year due to a warm winter, while 2003 had the warmest summer. The year 2003 saw an extreme temperature drop from 14.3 to 6.4 °C in the mean monthly values for September and October. Witnessing the warmest June and August and the coldest October in the last 23 years, 2003 also displayed the highest temperature variability during this period. Linear trends for the different annual or seasonal climatic parameters over the 23-year period are given in Figs. 1–3. Both the mean annual and (winter/summer) seasonal air temperatures were shown to rise by approximately +0.5 °C per decade ($r^2 = 0.31$). No significant increase in the mean annual solar radiation on a horizontal plane can be observed. Air moisture content in summer is up by +0.38 g/m^3 per decade ($r^2 = 0.33$), while the equivalent rise in the winter period is only half this figure.

Table 2 summarizes the mean air temperatures for the different reference year scenarios considered in this study. Scenario A represents the climatological normals for the WMO reference period of 1961–1990 (see [21] for data source). Scenario B is the Design Reference Year (DRY) for the period 1981–1990, developed as part of Task 9 [25–27] of the IEA Solar Heating and Cooling Programme. In this project, EMPA participated in the group led by Hans Lund from the Technical University of Denmark, producing and publishing DRY weather data sets for 22 locations covering all climatic zones in Switzerland [24,28]. Scenario C and D represent an average as well as a warm reference year selected on a monthly basis from the period 1984–2003 in such a way, that the mean monthly air temperatures meet the values given in Table 2. The four climate scenarios were used for the numerical study of heating and cooling energy demand; these foresee a rise in mean annual air temperature of +0.7, +1.0 and +4.4 °C relative to scenario A, which is the WMO reference climatic data set. Table 3 summarizes the mean solar radiation on a horizontal surface for the different climate scenarios. The mean yearly solar data for the

Table 1
Mean monthly and seasonal air temperatures at Zurich–Kloten in °C from 1981 to 2003 (ANETZ)

	January	February	March	April	May	June	July	August	September	October	November	December	Year	Winter	Summer
1981	−2.2	−1.1	7.4	9.6	12.1	15.7	16.5	17.4	14.2	9.0	4.3	0.2	8.6	3.9	15.2
1982	−0.7	0.1	4.1	7.4	12.8	16.9	19.0	16.6	15.6	9.3	5.2	2.9	9.1	4.1	16.2
1983	2.6	−1.5	5.5	9.0	10.8	17.2	21.7	18.5	14.5	9.6	3.0	0.7	9.3	4.1	16.5
1984	1.0	0.0	2.5	7.4	10.2	15.5	18.3	17.3	13.2	10.2	5.4	1.6	8.5	4.0	14.9
1985	−6.0	−0.6	3.4	8.5	13.0	14.7	19.5	17.6	15.5	9.4	1.3	2.7	8.2	2.7	16.1
1986	0.9	−5.1	3.3	6.6	14.6	16.6	18.0	17.3	13.8	10.5	4.7	1.3	8.6	3.2	16.1
1987	−4.1	0.7	1.4	10.0	10.2	14.6	18.6	17.3	16.9	10.4	5.5	2.2	8.7	3.7	15.5
1988	3.3	1.9	3.8	9.3	14.4	15.8	18.0	17.9	14.0	10.7	2.8	2.8	9.6	4.9	16.1
1989	1.1	2.6	8.0	7.5	14.5	15.6	18.6	17.9	14.2	9.9	2.2	2.2	9.5	4.8	16.2
1990	0.6	5.8	7.4	7.4	15.1	15.6	18.7	19.0	13.5	11.0	4.6	0.4	9.9	5.3	16.4
1991	1.3	−1.9	6.9	7.7	10.1	15.0	19.9	19.8	16.4	8.5	4.0	−0.3	8.9	3.7	16.2
1992	−0.9	1.4	5.9	8.4	14.9	16.2	19.2	20.8	14.4	8.0	6.7	0.8	9.6	4.3	17.1
1993	3.3	−0.3	4.4	10.7	14.7	17.2	17.3	17.8	13.3	8.2	1.4	4.2	9.4	4.6	16.1
1994	2.8	2.1	9.2	7.7	13.4	17.2	21.6	19.3	13.8	9.0	7.9	3.6	10.6	6.0	17.1
1995	−0.4	5.1	3.5	9.0	12.8	14.9	20.9	17.8	11.9	12.3	3.4	0.1	9.3	4.7	15.7
1996	−0.4	−1.0	3.0	9.2	12.5	17.3	17.4	16.9	10.9	9.2	4.5	−0.8	8.2	3.4	15.0
1997	−2.2	3.9	7.2	7.7	13.4	16.0	17.1	19.4	14.6	8.8	4.1	2.4	9.4	4.5	16.1
1998	1.4	2.6	5.4	8.6	14.7	17.2	18.6	18.3	13.5	10.0	2.0	0.7	9.4	4.4	16.5
1999	1.2	−0.7	6.0	9.1	15.1	15.3	19.0	18.0	16.4	9.2	2.0	2.0	9.4	4.1	16.8
2000	0.2	3.8	6.1	10.0	15.1	18.0	16.2	18.8	14.7	10.3	5.5	3.4	10.2	5.6	16.5
2001	1.2	3.0	6.9	7.2	15.5	15.2	18.9	19.1	11.7	12.6	2.9	0.2	9.5	4.9	16.1
2002	0.3	5.4	6.7	9.0	13.0	19.1	18.4	17.7	13.0	9.6	6.3	3.8	10.2	5.9	16.2
2003	0.2	−2.1	7.0	9.4	14.7	22.6	20.1	22.3	14.3	6.4	4.8	0.8	10.0	3.8	18.8

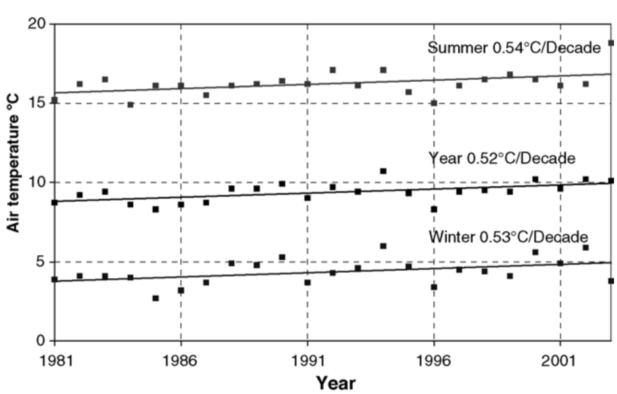

Fig. 1. Trends for mean annual and seasonal air temperature at Zurich–Kloten from 1981 to 2003.

scenarios A–C lie very close together while the value of scenario D shows a slight increase of 13% compared to scenario A.

2.2. Building description

The built stock in Switzerland consists of some 1.5 million buildings, three-quarters of which date from before 1980. A 30 m long, 12 m wide and 10 m tall heavyweight multistory building was chosen for the study presented in this paper. The facade areas and the thermal insulation levels used to represent the varying building code framework between 1970 and 2003 are given in Tables 4 and 5. The internal sensible heat gains considered are set out in Table 6. A heating set point of 20 °C and a cooling set point of 26 °C were chosen for all buildings. The air change rate selected

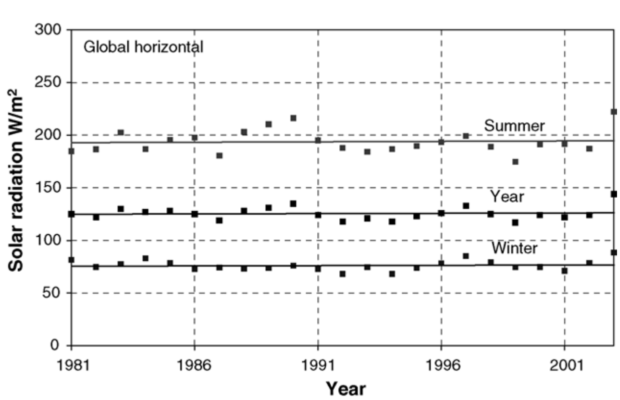

Fig. 2. Trends for mean annual and seasonal mean solar radiation at Zurich–Kloten from 1981 to 2003.

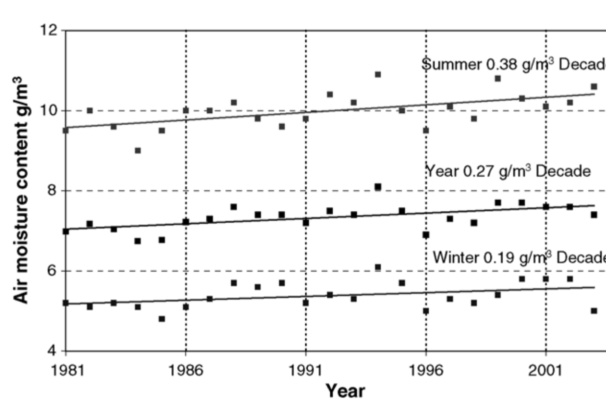

Fig. 3. Trends for mean annual and seasonal air moisture content at Zurich–Kloten from 1981 to 2003.

Table 2
Mean monthly and seasonal air temperatures at Zurich–Kloten in °C according to different climate scenarios

	Scenario			
	A WMO normals (1961–1990)[a]	B IEA Design Reference Year (1981–1990)[a]	C Average reference year (1984–2003)[a]	D Warm reference year (1984–2003)[a]
January	−1.0	−0.4	0.3	3.3
February	0.4	0.3	1.3	5.8
March	3.9	4.7	5.4	9.2
April	7.8	8.3	8.5	10.7
May	12.2	12.8	13.4	15.5
June	15.5	15.8	16.6	22.6
July	17.6	18.7	18.7	21.6
August	16.8	17.7	18.3	22.3
September	13.8	14.5	14.0	16.9
October	8.9	10.0	9.6	12.6
November	3.5	3.9	4.1	7.9
December	0.2	1.7	1.6	4.2
Year	8.3	9.0	9.3	12.7
Winter	3.4	4.1	4.4	7.7
Summer	15.2	15.9	16.2	19.8

[a] Period.

Table 3
Mean monthly and seasonal solar radiation on a horizontal surface at Zurich–Kloten in W/m^2

	Scenario			
	A WMO normals (1961–1990)[a]	B IEA Design Reference Year (1981–1990)[a]	C Average reference year (1984–2003)[a]	D Warm reference year (1984–2003)[a]
January	43	38	43	35
February	70	68	73	75
March	91	114	118	108
April	174	160	164	172
May	189	199	169	213
June	232	221	236	285
July	234	229	258	240
August	184	193	187	228
September	110	139	137	157
October	76	81	82	91
November	43	43	43	31
December	31	30	29	30
Year	123	127	128	139
Winter	75	76	79	77
Summer	190	196	197	225

[a] Period.

for the residential building was 0.3–0.5 h^{-1}, with night ventilation by window airing commencing as soon as the indoor air temperature exceeded 24 °C. Air change rate values are shown in Fig. 4 as a function of the air temperature difference between indoors and outdoors. The office buildings were assumed to be ventilated mechanically

Table 4
Building facade areas

	A_{tot} (m^2)	A_{wall} (m^2)	A_{window} (m^2)
East	300	210	90
South	120	102	18
West	300	210	90
North	120	102	18

Table 5
Thermal values of building components

Thermal insulation level	$U_{wall/roof}$ (W/(m^2 K))	U_{floor} (W/(m^2 K))	U_{window} (W/(m^2 K))
1	0.8	0.8	2.7
2	0.4	0.4	1.9
3	0.2	0.2	1.4

Table 6
Internal heat gains (sensible)

Residential building	Office building 1	Office building 2
96 Wh/(m^2 day)	240 Wh/(m^2 day)	360 Wh/(m^2 day)
4 W/m^2	20 W/m^2	30 W/m^2

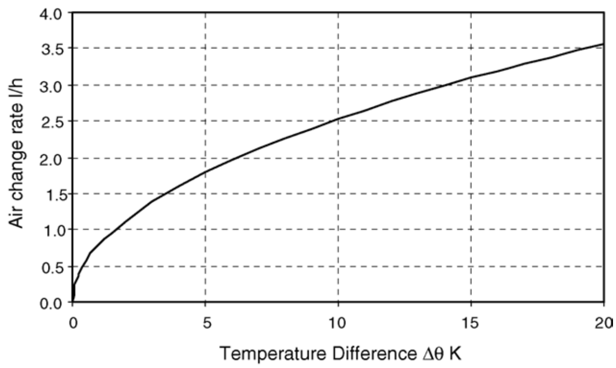

Fig. 4. Air changes due to natural ventilation by window airing.

during working hours at a volume rate of 2.7 m^3/h outdoor supply air per m^2 floor area. For all buildings, an external shading device with a total solar energy transmittance for the whole window of 0.1–0.2 (lower value for low e-coated glazing, higher value for normal clear glazing) was applied where the incident solar irradiance on the facade exceeded 200 W/m^2.

2.3. Simulation model

HELIOS [29], the building energy simulation program used in the study, is based on a detailed thermal balance model for a single zone with a 1-h time step. Building envelope elements are divided into opaque, transparent and internal components as illustrated in Fig. 5.

The zone thermal system is described by the heat balance equations for the zone air (1) and for all internal (2) and external (3) envelope surfaces:

$$\sum_{j=1}^{N}(A \cdot q_c)_j + \Phi_V + \Phi_{int} + \Phi_s + \Phi_H = c_a \cdot M_a \cdot \frac{\partial \theta_i}{\partial t} \qquad (1)$$

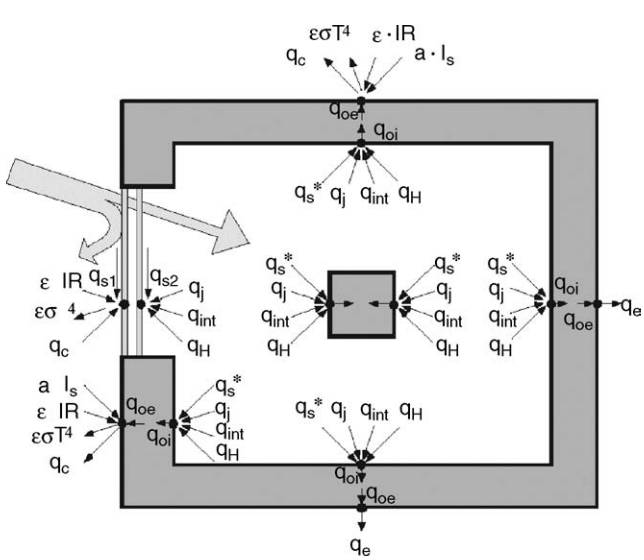

Fig. 5. Heat balance model HELIOS.

where N is the number of internal surfaces in contact with the internal air, A the area of each envelope element, q_c the density of the heat flow rate by indoor convection, Φ_V the heat flow rate by ventilation and infiltration, Φ_{int} the heat flow rate due to convective internal sources, Φ_s the solar to air heat flow rate, Φ_H the heat flow rate due to heating or cooling supplied to the zone air, c_a the specific heat capacity of air, M_a the mass of the internal air, θ_i the temperature of the internal air and t is the time.

$$q_s + q_i + q_{int} + q_H - q_{oi} = 0 \qquad (2)$$

where q_s is the density of heat flow rate due to the absorbed short-wave radiation, q_i the density of heat flow rate by convection and radiation, q_{int} the heat flow rate due to the radiative component of internal gains, q_H the heat flow rate due to radiative heating or cooling devices and q_{oi} is the the density of heat flow rate by conduction:

$$a_s \cdot I_s + \varepsilon \cdot \mathrm{IR} - \varepsilon \cdot \sigma \cdot T^4 - q_c + q_{oe} = 0 \qquad (3)$$

where $a_s \cdot I_s$ is the absorbed solar radiation $\varepsilon \cdot$IR the absorbed incoming long-wave radiation (sky and surroundings), $\varepsilon \cdot \sigma \cdot T^4$ the long-wave radiation emitted from the surface, q_c the density of heat flow rate by convection and q_{oe} is the density of heat flow rate by conduction.

The simplified Eq. (4) from EN 13465 [34] and the specifications for the discharge coefficient C_d given by Favarolo [31] were used for natural single-sided ventilation through windows (see also Fig. 4):

$$\dot{V}_{nat}(t) = \frac{1}{3} \cdot C_d \cdot A \cdot \sqrt{g \cdot H \cdot \frac{T_i(t) - T_e(t)}{T_i(t)}} \qquad (4)$$

where $\dot{V}$ is the airing flow rate (m^3/h), t the time (s), A the opening area (m^2), H the height of the opening (m), C_d the discharge coefficient (–), g the gravity constant (9.81 m/s^2), T_i the indoor air temperature (K) and T_e is the outdoor air temperature (K).

The conduction heat transfer through opaque building elements is solved by the response factor method, which relates the heat flux at one surface of an element to a series of temperature histories at both sides and the heat flux of the last time step [30].

The set of heat balance equations can be represented by the following matrix equation:

$$\begin{pmatrix} A_{1,1} & A_{1,2} & A_{1,N} & A_{1,N+1} \\ \cdots & \cdots & \cdots & \cdots \\ A_{N,1} & A_{N,2} & A_{N,N} & A_{N,N+1} \\ A_{N+1,1} & A_{N+1,2} & A_{N+1,N} & A_{N+1,N+,1} \end{pmatrix} \cdot \begin{pmatrix} \theta_{s,1} \\ \cdots \\ \theta_{s,N} \\ \theta_a \end{pmatrix} = \begin{pmatrix} B_1 \\ \cdots \\ B_N \\ B_{N+1} \end{pmatrix} \qquad (5)$$

where $A_{i,j}$ are the coefficients of the unknown surface temperatures (θ) (from 1 to N relating to the external and internal surfaces, $N+1$ relating to the internal air or to the heating or cooling load at a given set point temperature), $\theta_{i,j}$ the unknown temperatures (external, internal surfaces and internal air), B_i the coefficients of the known terms.

The solution of the equation system for the unknown temperature vector $[\theta]$ can be obtained by matrix inversion:

$$[\theta_{i,j}] = [A_{i,j}]^{-1} \cdot [B_i] \quad (6)$$

3. Results

3.1. Overheating risks

Global warming trends in the last 23 years are characterized by longer, more intense heatwave periods, as witnessed in extreme by the summer 2003. Overheating risks are illustrated in the following for climate scenario C with 8 heatdays (maximum outdoor air temperature $\theta_{e,max} > 30\,^{\circ}C$) and climate scenario D with 29 heatdays. Simulation results for the residential building case with thermal insulation level 3 show that, in climate scenario C, heatwaves lasting 3–9 days with moderate amplitudes fail to cause overheating problems (see Fig. 6) as the building is able to cool down by natural night ventilation. The heatwaves in summer of climate scenario D are generally up to 3–5 °C higher in amplitude with a longer duration of 5–15 days. Where night ventilation is provided, the indoor air temperatures remain within an acceptable range of 25–29 °C (see Fig. 7). In buildings without night ventilation, on the other hand, indoor air temperatures steadily rise to a level outside the comfort range (see Fig. 8).

3.2. Impacts on heating and cooling energy demand

The calculated annual heating energy demands for the residential building, subject to the different climatic change scenarios, are given in Fig. 9 for three levels of thermal insulation. An 8–13% heating energy reduction was determined for climate scenario C (+1.0 °C temperature rise) and a 33–44% drop for scenario D (+4.4 °C temperature rise). For the building with the lowest thermal insulation level 1, the heating season is shortened from 262 to 210 heating days; the building with insulation level 2 experiences a similar fall from 222 to 189 days and the building with the highest level 3 a reduction from 185 to 154 days. The calculated annual heating and cooling energy demands for the office buildings are given in Figs. 10 and 11.

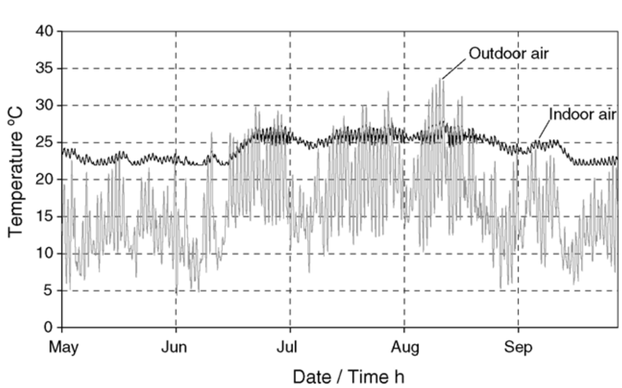

Fig. 6. Air temperatures for residential building level 3 with night ventilation (climate scenario C).

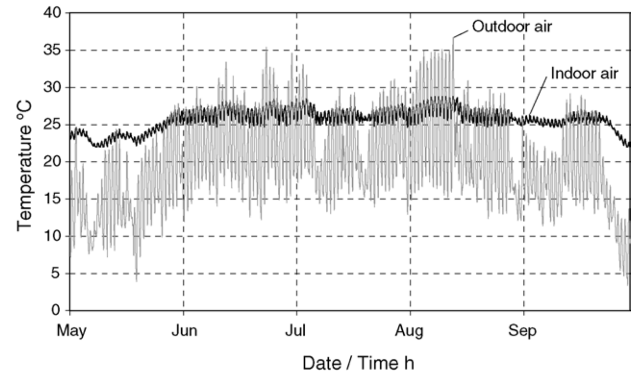

Fig. 7. Air temperatures for residential building level 3 with night ventilation (climate scenario D).

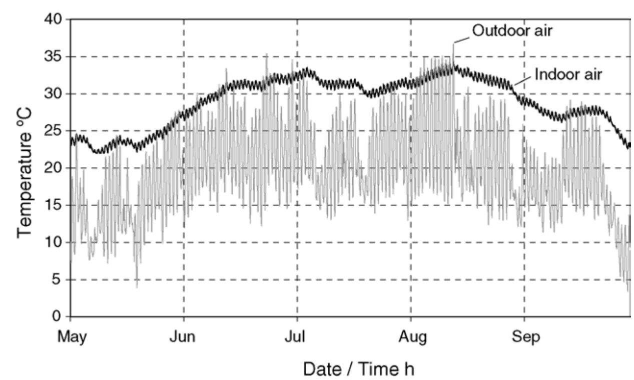

Fig. 8. Air temperatures for residential building level 3 without night ventilation (climate scenario D).

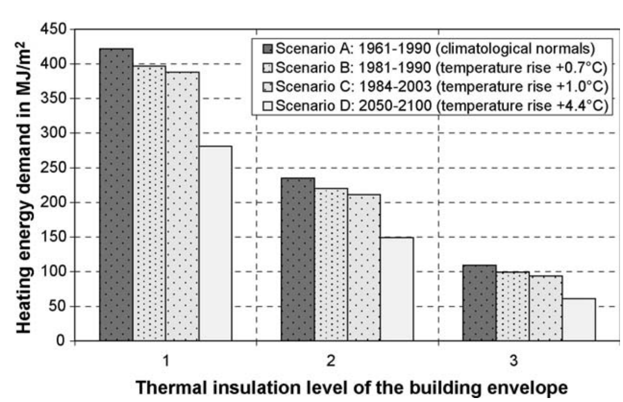

Fig. 9. Annual heating energy demand of residential buildings for three levels of thermal insulation.

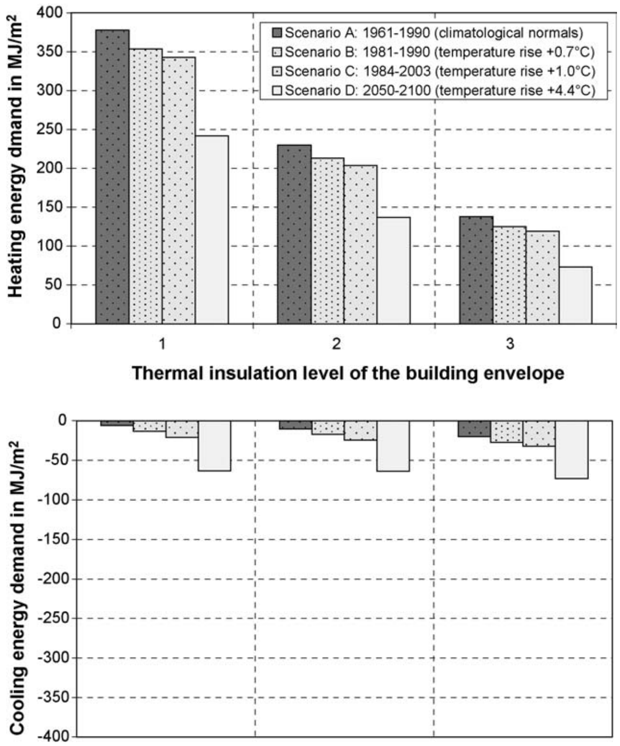

Fig. 10. Annual heating and cooling energy demand of office building 1 for three levels of thermal insulation.

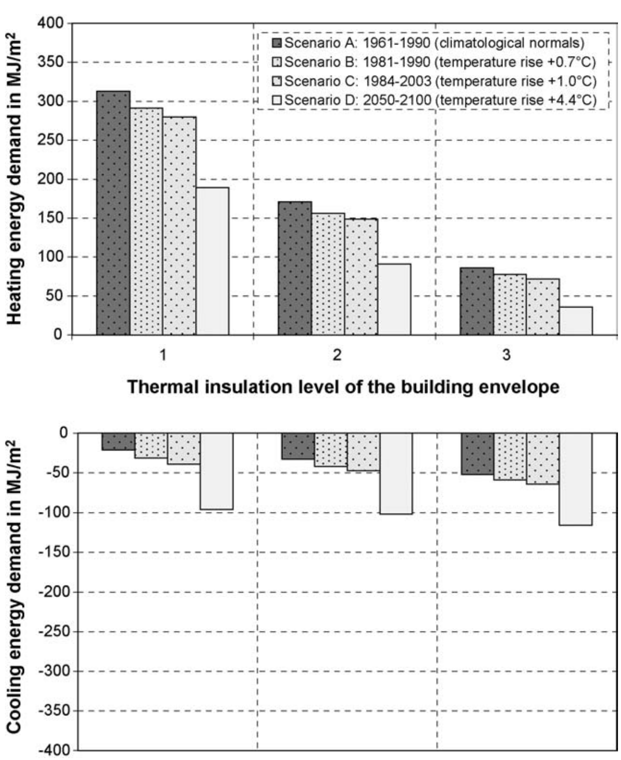

Fig. 11. Annual heating and cooling energy demand of office building 2 for three levels of thermal insulation.

The upper section of the graphs shows the heating energy demands as positive values, the lower part the cooling energy demands as negative values. Office buildings 1 and 2 differ only by their internal heat gain level of 20 and 30 W/m^2, respectively. The reduction in heating energy demand for climate scenario C (+1.0 °C temperature rise) is 9–14% for office building 1 and 11–16% for office building 2. The corresponding drop for climate scenario D (+4.4 °C temperature rise) is 36–47% for office building 1 and 40–58% for office building 2. The heating periods are shortened by 30–60 days. For climate scenarios A to C, the cooling energy demands for office building 1 are quite low and, here, the installation of cooling plant would not be allowed by the present Swiss National Standard SIA 382 [33]. The requirement specified in the standard that the aggregate indoor air temperatures over the whole summer period exceed a threshold of at least 30 K h above the limit temperature of 28 °C would not be met. The cooling energy demands for climate change scenario D (+4.4 °C temperature rise) increase dramatically, being 365–1050% up on the figures for reference climate scenario A in the case of office building 1 and lying 223–457% higher for office building 2. The cooling periods are extended by 49–72 days a year.

4. Discussion and conclusions

Hourly weather data measured at the Zurich–Kloten location over the past 23 years (1981–2003) were used to define various climate scenarios representing the past, the present and possible future situations. The investigations into climate change impacts on energy demand focused on a typical multistory heavyweight building with different thermal insulation levels and internal heat gain situations. Four climate scenarios were considered in calculating the heating and cooling energy demand:

- WMO climatological normals based on the period 1961–1990 (scenario A);
- IEA Design Reference Year based on the period 1981–1990, showing a mean annual temperature rise of +0.7 °C (scenario B);
- mean annual temperature rise of +1.0 °C, representing the climate change ascertained for the period 1981–2003 (scenario C);
- mean annual temperature rise of +4.4 °C, reflecting a likely trend for the time horizon 2050–2100 (scenario D).

Scenarios B and C are shown by the study to have a moderate and scenario D a substantial impact on heating and cooling energy demand. Heating energy demand will fall by up to 44% in residential buildings and by up to 58% in office buildings. These findings generally concur with those presented in the study by Christenson [19], which is based on the heating degree–day method.

Mechanical cooling is avoided in residential buildings by the use of natural night ventilation. This strategy limits the indoor air temperature to a maximum of 29 °C—an acceptable value for a short-term period with a high outdoor air temperature maximum of 36.7 °C. For office buildings, the calculations reveal an up to 1050% increase in cooling energy demand. The number of cooling days grows substantially while the number of heating days declines. Given the key role of internal heat gain levels, concerted efforts are required to minimize these. The calculations show, that the thermal insulation level has an important impact on the heating energy demand of the buildings for all climate scenarios. For the thermal insulation level 2 (reflecting building code 1980) a reduction of 39–52% and for level 3 (reflecting building code 2000) a reduction of 63–81% in heating energy demand can be observed relative to the thermal insulation level 1 (building code 1970).

This study makes no claim to completeness since only a few building parameters and boundary conditions were systematically analyzed. Further topics of major importance, which have to be addressed to gain a fuller picture include:

- Excessive use of glazed facade areas (window area fraction >60%) and the appropriate solar shading concept and operation, including disturbance to occupants.
- Thermal mass of buildings and optimum use of thermal inertia in conjunction with the ventilation and cooling strategy.
- Moisture balance of the building and its impact on the indoor environment.
- Heat island effects in cities, which lead to more severe outdoor temperature conditions.

Buildings in Switzerland have a long lifespan of about 50–100 years. The building designer has traditionally assumed an unchanging outdoor climate based on statistical values collected over a period of 10–30 years. This approach, which still underlies the Swiss SIA Standards [32,33], has to be revisited. Confronted with a changing climate, we have to re-examine the weather design criteria for buildings, mainly for summer conditions. The presented paper aims to initiate a discussion of this issue.

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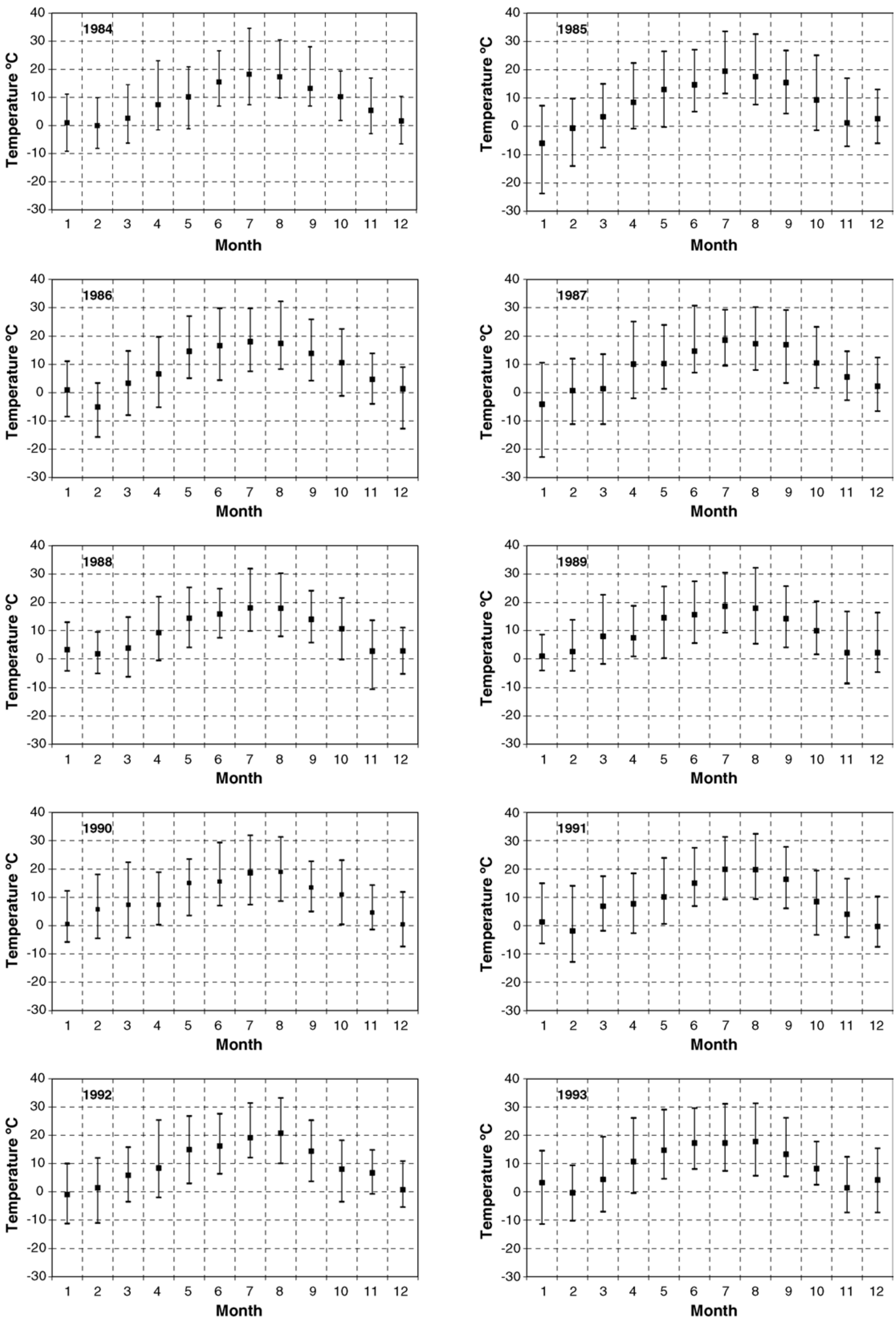
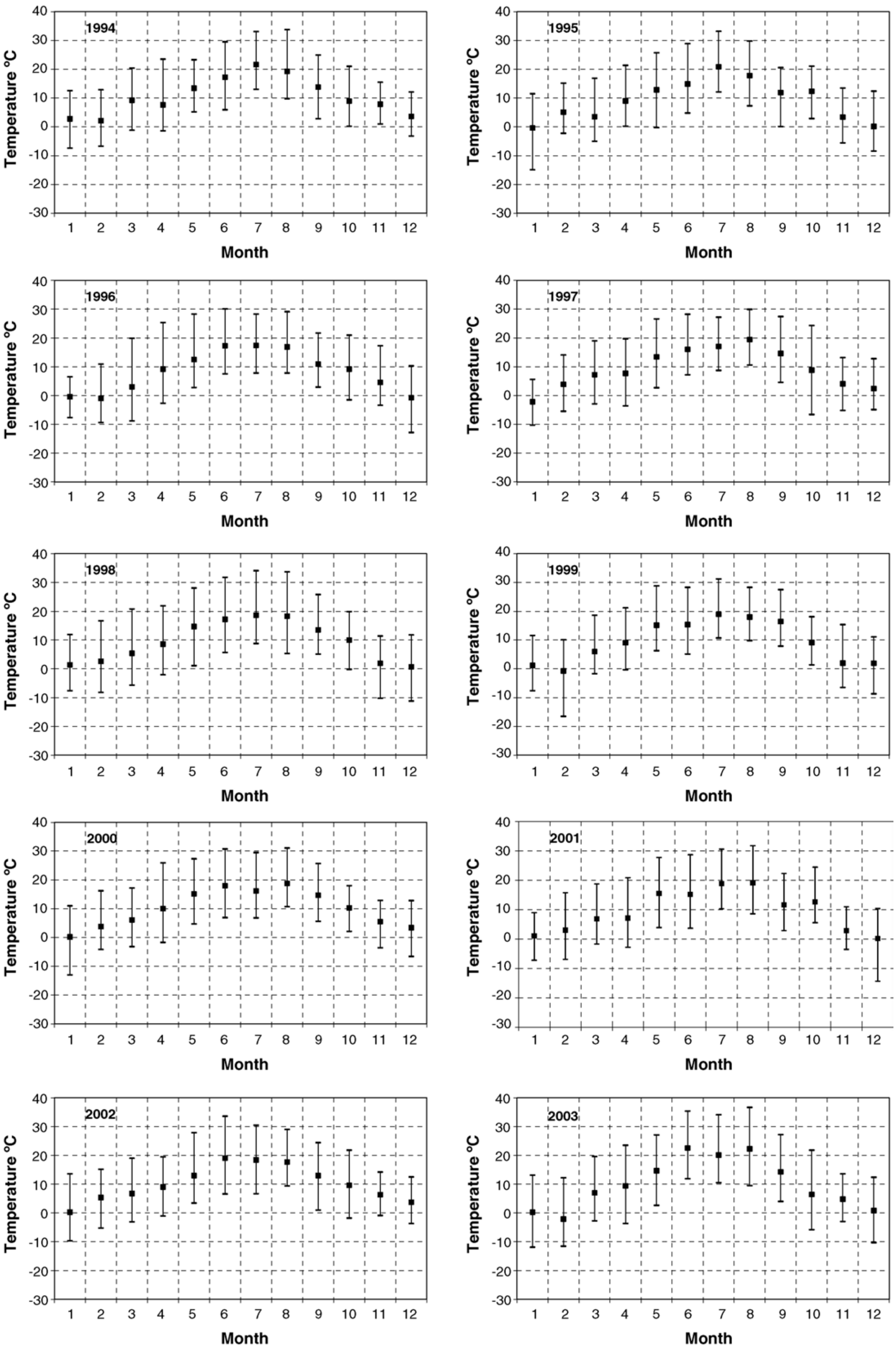
Appendix A

Monthly air temperatures (hourly mean, maximum and minimum values) at Zurich–Kloten (ANETZ)



Appendix A (*Continued*)



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