Urban climate scenario data for European cities

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Abstract. Climate change and the urban heat effect are expected to have a large influence on the energy consumption and thermal comfort of buildings. However, using meteorological data which incorporates effects of climate change and characteristics of cities is not currently a standard practice in building simulation. By default, data of nearby meteorological stations often outside cities are used. This may lead to important discrepancies between simulation results and actual energy consumption and/or indoor climate data for buildings in urban areas. These effects are analysed within building energy part of H2020 climate-fit.city project. First, adapted urban and future meteorological data modelled using the UrbClim model and standard meteorological data were compared. Second, these data were included within the Meteonorm software (version 7.3.2). This was carried out for current climates as well as for future scenarios (RCP 4.5 and 8.5, 2050) for the cities of Barcelona, Bern, Berlin, Bremen, Prague, Rome and Vienna. Like this Meteonorm includes a combination of urban and future climates accessible in a user friendly tool.

In a third step the urbanized TMY data sets generated by Meteonorm were used to simulate energy consumption, peak loads and indoor climate conditions with models of several typical buildings. In this comparison we show a simulation for a multi-family house for current and future climates. The whole-year simulation runs were compared to the reference scenario – the standard TMY (available in Bern and Vienna).

For current climates heating energy consumption is 10-25% lower within cities and cooling energy up to 60% higher (Barcelona). Even bigger changes are seen for future climates: Heating loads drop by up to 30% and cooling loads rise more than 100% (they are 2-3 times higher than heating loads in Barcelona by 2050).

Introduction

The purpose of the Building Energy service of the project climate-fit.city is to develop services to provide building design engineers with more accurate and adequate climate data for simulating buildings located in cities. The objective is to construct or refurbish buildings with better indoor quality and less energy demand.

For the Building Energy service, Meteotest enhances its Meteonorm desktop software and web service (www.meteonorm.com) to account for urban climate conditions, in particular the urban heat island effect, using high resolution climate data of Urbclim model [1]. Concretely, this enables the stochastic generation of time series of a so-called Typical Meteorological Year (TMY), for diverse urban conditions both for the current situation and under future climate conditions.

In a first phase Pronoó employs urbanized Meteonorm data (MN 7.3) to simulate building cooling and heating loads and thermal comfort levels using the IDA-ICE building simulation software (www.equa.se/de/idacv-ice). The results are compared to simulation results based on standard TMYs.
The objective of the first phase is to show low deviations at sites with met stations used to produce standard TMY (the data used historically for building design) and to prove the working hypothesis that for sites within cities, significant deviations are seen compared to the standard meteo stations (and therefore urban adaptation is needed).

In the second ongoing phase, more cities in Meteonorm are upgraded with urbanized data. The final target is to include urbanized Meteonorm data for all bigger urban areas in Europe and in other continents and like this to enable more accurate building performance simulations for urban locations.

**Data & method**

VITO (www.vito.be) – the coordinator and main climate data producer of the H2020 climate-fit.city project – delivered ERA-Interim (1987-2016) based UrbClim files in hourly time resolution. ERA-Interim is a re-analysis dataset of the European Center for Medium Range Weather Forecast (ECMWF) (https://climate.copernicus.eu/climate-reanalysis). It includes gridded fields of meteorological parameters for historical periods. UrbClim [1] is a fast urban boundary layer climate model. Additionally RCP scenarios 4.5 and 8.5 for the period 2046-55 were delivered by Vito based on Cordex (www.cordex.org) and Urbclim.

Parameters used were temperature, wind speed, relative humidity, global radiation (this parameter was directly taken from ERA-Interim and climate change scenarios).

In the first phase the cities of Bern, Rome, Barcelona and Prague were included. In the ongoing 2nd phase Berlin and Bremen data was added. More cities will follow.

Based on the input values Meteotest calculated TMY based on Sandia method [2] and condensed the temperature information into Meteonorm. The results of Meteonorm were TMY datasets in hourly input format for IDA-ICE. This includes the parameters air temperature, relative humidity, wind speed, wind direction, direct horizontal radiation and diffuse horizontal radiation. In Figure 1, the data flow of the production of the TMY’s is shown.

![Data flow of TMY production](image)

**Figure 1**: Data flow of TMY production.

Measurements were used to compare the results and for debiasing. The stations are from MeteoSwiss for Switzerland and Zentralanstalt für Meteorologie und Geodynamik (ZAMG) for Austria. For
Switzerland additionally the station Bern/Bollwerk from Swiss National Air Pollution Monitoring Network as used.

**Validation of urban climate data**

A first test based on urbanized Meteonorm (MN 7.3) was done by comparing the climate datasets with measurements at meteo stations. TMY directly made of ERA/UrbClim time series, SIA 2028 (http://www.energytools.ch/index.php, period 1984-2003), the default TMY in Switzerland for building design, Meteonorm MN 7.2 (preceding version) and 7.3 (current version) and measurements were compared.

All datasets aside SIA 2028 have been adapted (bias corrected) to Bern/Zollikofen. SIA 2028 data show somewhat lower temperature values due to the older period (1984-2003).

The urban effect between Bollwerk, Von Roll and Zollikofen is about 1°C (measured as well as modelled). ERA-Interim underestimate the urban heat effect, whereas MN shows the same magnitude. For Vienna ERA and MN overestimate the urban effect somewhat (measured: 1.1°C, ERA: 1.7°C, MN: 1.9°C).

Also, different temperature thresholds have been checked (like tropical nights, hot days and maximum temperatures). In Table 1, the number of hot days (daily maximum above 30°C) are listed as an example of temperature threshold values.

| Model                        | Bern/Bollwerk | Bern/Zollikofen | Bern/Von Roll | Vienna/City | Vienna/Hohe Warte | Vienna/Unterlaa |
|------------------------------|---------------|-----------------|---------------|-------------|-------------------|----------------|
| Land type                    | urban         | land            | semi-urban    | urban       | land              | semi-urban     |
| ERA-Interim / UrbClim        | 3             | 1               | 5             | 16          | 11                | 12             |
| Official TMY                 | 0             | 3               | 3             | 13          | 7                 | 9              |
| MN 7.2                       | 4             | 3               | 3             | 13          | 7                 | 9              |
| MN 7.3                       | 5             | 5               | 3             | 19          | 12                | 16             |
| Measurement                  | 12            | 9               | 14            | 30          | 24                | 23             |

A second test based on urbanized Meteonorm (MN 7.3) was done by comparing MN datasets for climate change scenarios. This test includes the cities of Bern, Rome, Barcelona and Prague. Differences between centre and land (heat island effect) are not very high concerning average temperatures (in the range of 0.8 – 1.5°C). Changes concerning climate change are higher (1.8-2.2°C for RCP 4.5 and 2.5-2.8°C for RCP 8.5). The combination of both effects can reach more than 4°C.

Maximum temperatures do differ only slightly between centres and land (Table 2). On average, they are even lower in the centres as in the surrounding. An exception is Barcelona, where the airport station is located also nearby the sea (which has a lowering effect for maximum temperatures). Differences regarding climate change are much higher (4.7-7.4°C). They are also more than twice as high as for average temperatures. The models show bigger trends of maximum temperatures in the cities.

In most cities (aside Rome) there are clearly more tropical nights in the city centre (5-57 days). Again, in Barcelona the sea has a clear influence on the Airport. Climate change has a slightly higher effect than the built environment. By 2050, in the northern sites outside city centres tropical nights will occur regularly (up to now they were seldom). Differences between city centres and surrounding are getting smaller in the future.

Hot days do not show big differences between city and land (with exception of Barcelona, which includes sea/land effects), whereas climate change has a big influence (13-47 more hot days) – especially in the South (Barcelona and Rome), where hot days may be doubled in the future.
Table 2: Average maximum temperatures in Prague, Vienna, Rome and Barcelona in °C

| Model                      | Centre | Airport | Differences heat island | Differences CC (centre) |
|----------------------------|--------|---------|-------------------------|-------------------------|
|                            | Prague | Prague  | (Centre-Airport)        | (Future-current)        |
| MN 7.3 (2000-2009)         | 32.9   | 33.1    | -0.2                    |                         |
| MN 7.3 / RCP 4.5 (2046-55)| 38.8   | 38.6    | 0.2                     | 5.9                     |
| MN 7.3 / RCP 8.5 (2046-55)| 39.9   | 39.7    | 0.2                     | 7.0                     |
|                            | Vienna | Vienna  |                          |                         |
|                            | Centre | Airport | (Centre-Airport)        | (Future-current)        |
| MN 7.3 (2000-2009)         | 33.9   | 35.0    | -2.1                    |                         |
| MN 7.3 / RCP 4.5 (2046-55)| 38.6   | 38.6    | 0.0                     | 4.7                     |
| MN 7.3 / RCP 8.5 (2046-55)| 40.7   | 40.7    | 0.0                     | 6.8                     |
|                            | Rome   | Rome    |                          |                         |
|                            | Centre | Urbe Airp. |                          |                         |
| MN 7.3 (2000-2009)         | 37.8   | 37.6    | 0.2                     |                         |
| MN 7.3 / RCP 4.5 (2046-55)| 43.3   | 43.8    | -0.5                    | 5.5                     |
| MN 7.3 / RCP 8.5 (2046-55)| 44.2   | 44.8    | -0.6                    | 6.4                     |
|                            | Barcelona | Barcelona |                          |                         |
| MN 7.3 (2000-2009)         | 34.7   | 32.5    | 2.2                     |                         |
| MN 7.3 / RCP 4.5 (2046-55)| 39.8   | 36.7    | 3.1                     | 5.1                     |
| MN 7.3 / RCP 8.5 (2046-55)| 42.1   | 39.2    | 1.9                     | 7.4                     |

It is clearly visible that future climate changes are immense – much more significant than differences within the city or compared to the surrounding land. Climate change until 2050 (2046-75) will be 1.5°C for RCP 4.5 and 2.5°C for RCP 8.5. The difference between urban and land is getting somewhat lower in the future (the reason for this is not known).

Building simulation
Pronoó defined one type of building (multi-family house), using two building standards (historic of 1960-79 and current of >2006). In series of full years simulations, the energy consumption (heating and cooling) and the indoor climate (EN-15251: typical hours per year in four comfort classes) for the different buildings and climate files were compared for Bern, Vienna, Prague, Barcelona and Rome.

A simple standard-building body with typical urban shading situation has been defined. According to the typical local situation, the constructions and window parameters were then exchanged or adapted. The descriptions of the typical constructions were taken from data sheets from the TABULA project [3].

The computed results are limited to yearly energy consumption (useful energy), peak loads (max. hour values for heating and cooling) and the indoor climate comfort definition according to the standard EN-15251. This evaluation method contains four comfort levels with adaptive boundaries and is therefore convenient for this purpose in different European climate zones.

Building simulation results
In Barcelona, the urban effect reduces the heating energy demand by 25% for current climate (Figure 2). Applying the RCP scenario 4.5, this reduction rises to approximately 50% for the year 2050.
The cooling energy demand lies in the city centre about 60 to 70% higher than in the surroundings. In the future the cooling energy demand will be more than doubled in the surroundings and almost tripled in the city centre. Of course, these results assume that the indoor comfort level is not affected, and that the standard of the building stays maintained.

![Figure 2](image_url)

**Figure 2:** Analyses for the local differences per climate data and building type.: Example for old multifamily house in Barcelona. Circle: Heating energy consumption in comparison to standard TMY; Triangle: Cooling energy consumption in comparison to standard TMY; Quadrat: Number of occupation hours per year outside the comfort zone boundaries in the most exposed zone; left: urbanized Meteonorm 7.3; right: future climate according IPCC scenario RCP 4.5.

The heating peak load is affected similarly as the energy demand for the current urban effect. Future climate scenarios do not change much. In other words, also in the future, there will be cold periods. The situation is different for the cooling loads; the actual urban effect is not very important but in the future the peak load will be about 50 to 70% higher. This finding corresponds with the important number of tropical nights in the future; the warm nights do not support the cooling and for the following day the thermal mass of the building cannot absorb the additional heat load of the day. In general, the climate change will reinforce the urban effect.

All these results suppose the existence of a cooling system with enough power, which is not defined in detail. Therefore, the comfort level is not significantly affected.

In absolute values, the heating energy demand for an old residential building in Barcelona is today, according to standard TMY, about twice as high as the cooling energy demand. However taking the current urban effect into account the heating and cooling energy demand are almost the same. In the future this will change completely, and the heating energy demand will be lower than the cooling energy demand also in the non-urban conditions. In the city centre, the cooling energy demand will be two times higher than the heating energy demand.

The heating energy demand is in the city centre of Bern, due to the current urban climate effect, about 10 to 20% lower. With climate scenario RCP 4.5 (2050) this difference doesn't change much.

Looking at the indoor climate comfort, the current urban effect has an important influence on the number of occupancy hours in the best category but no significant change in the unacceptable category. This will change in the future, where hundreds of occupancy hours will be outside the comfort limits.
without cooling system almost independent of the location in or around the city. In general, the urban effect in Bern shows lower impact in comparison to Barcelona.

Climate-fit.city shows that the use of urban climate data has a significant impact on energy consumption and thermal indoor comfort. This simple fact might not be very surprising, but it is probably the first time that this aspect has been studied in a way to quantify the effect in high temporal and spatial resolution.

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