Simulating and mapping future energy demands for European museums

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Simulating and Mapping Future Energy Demands for European Museums

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Abstract

In this paper we present a new method for simulating and mapping energy demands for European museums for recent past (RP), near future 2020-2050 (NF) and far future 2070-2100 (FF). It is new combination of three recent developments: Firstly, the simulation and mapping of building performance indicators based on European weather stations. Secondly, a multi zone energy model, representing a wide range of museums. The latter consists of 16 different museum zone types equal to all combinations of 4 levels of building construction and 4 levels of climate control. Thirdly, the availability of hourly based, EU wide, external future A1B climate files from the EU FP7 Climate for Culture project. We used 7 performance indicators: (1) mean indoor temperature; (2) mean indoor relative humidity; (3) mean heating demand; (4) mean cooling demand; (5) mean humidification demand; (6) mean dehumidification demand; (7) total energy demand, to produce EU maps for 16 museum types and five 30 year time periods: RP, NF, FF, NF-RP and FF-RP. This gives in total 560 maps. The most important mapping results are included and discussed in this paper.

Keywords: Map; museum; EU; energy; simulation; future; climate

1. Introduction

Due to the climate change debate, a lot of research and maps of external climate parameters are available. However, maps of indoor climate performance parameters are still lacking. This paper presents a methodology for obtaining maps of performances of similar buildings that are virtually spread over whole Europe. The produced maps are useful for analyzing regional climate influence on building performance indicators such as energy use and indoor climate. Our approach visualized in Fig.1, is a new combination of three recent developments.
Firstly, the simulation and mapping of building performance indicators based on European weather stations. Secondly, a multi zone energy model, representing a wide range of buildings. Thirdly, the availability of hourly based, EU wide, external future A1B climate files from the EU FP7 Climate for Culture project.

(I) The simulation and mapping of building performance indicators based on European weather stations [1]. This paper presents a methodology and results for obtaining maps of performances of similar buildings that are virtually spread over whole Europe. The whole building model used for the simulations, originates from the thermal indoor climate model ELAN which was already published in 1987 [2]. The current hourly-based model HAMBase, is part of the Heat, Air and Moisture Laboratory [3,4], and is capable of simulating the indoor temperature, the indoor air humidity and energy use for heating and cooling of a multi-zone building. The physics of this model is extensively described by de Wit [5]. An overview of the validation results of the whole building model HAMBase are recently presented in [6].

(II) A multi zone indoor climate and energy model, representing a wide range of museums. In [7], Martens describes the input for the existing simulation model HAMBase that allows studying all 16 combinations of quality of envelope (QoE) and level of control (LoC) of a typical exhibition room layout. To be able to assess the influence of Quality of Envelope (QoE) and Level of Control (LoC), this room layout is put into the simulation model. The layout is based on common museum exhibition room specifications as encountered in several researched museums [7]. This room is located at a corner of a building. The room consists of a single zone, 10m long, 10m wide and with a height of 3.5m. The ceiling, floor, north and east wall are adiabatic, which means that the zone is connected to other zones, identical in behavior, that are not part of the simulation. The south and west wall are external walls and have a window of 5 m² each. In [7] a full description of the input for the model is provided. This single zone is put into the model 16 times; for each zone some parameters are changed according to QoE and LoC. These parameters are displayed in Table 1 and 2.

Table 1. Definition of Quality of Envelope (QoE) by different building parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>QoE 1</th>
<th>QoE 2</th>
<th>QoE 3</th>
<th>QoE 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Exterior wall</td>
<td>Solid brick wall 400 mm, plastered</td>
<td>Solid brick wall 400 mm, plastered</td>
<td>Solid brick wall 400 mm, insulation on the inside 100 mm, plastered</td>
<td>Brick wall 100 mm, cavity, insulation 150 mm, brick 100 mm, plastered</td>
</tr>
<tr>
<td>Glazing</td>
<td>Single</td>
<td>Double</td>
<td>Double low-e</td>
<td>Double low-e</td>
</tr>
<tr>
<td>Infiltration rate</td>
<td>1 h⁻¹</td>
<td>0.4 h⁻¹</td>
<td>0.2 h⁻¹</td>
<td>0.1 h⁻¹</td>
</tr>
</tbody>
</table>
The construction of the building depends on QoE: walls, glazing and infiltration rate (caused by leakages in the envelope) all change when improving the thermal quality of the envelope. Set points depend on LoC. The available capacity for heating, cooling, humidification and dehumidification is set to an unrealistically high value to make sure set points are actually achieved; this is deliberately chosen to stress the influence on energy use. All 16 types were implemented into one single multi-zone HAMBase model, thus providing a very efficient way of simulating all variants simultaneously. A year with hourly based external climate values takes less than 10 seconds to run on a 4GB, 2.6GHz computer.

(III) Hourly based, EU wide, external future A1B climate files. During the Climate for Culture project [8], external climate files were developed especially for building simulation purposes using the REMO model [9,10]. The geographical locations are shown in Fig.1. left hand side.

2. Methodology

In this paper we present simulated results for recent past (RP), near future 2020-2050 (NF) and far future 2070-2100 (FF) energy demands for European museums and monumental buildings. A multi zone energy model, representing a wide range of museums and monumental buildings. The latter consists of different 16 building zone types as all combinations of 4 levels of buildings construction and 4 levels of climate control. The different building type 1 through 16 with the corresponding Level of Control (LoC) and Level of Envelope (LoE) are shown in Fig 2. (Left) together with a typical result from Martens [7] (Fig2. Right).

![Fig. 2](image-url)

**Fig. 2.** Left: Classification matrix of museums [7]. Right: The different building types 1 through 16 with the corresponding Level of Control (LoC) and Level of Envelope (LoE) using the museum classification matrix[7]

We used 7 performance indicators: (p1) mean indoor temperature; (p2) mean indoor relative humidity; (p3) mean heating demand; (p4) mean cooling demand; (p5) mean humidification demand; (p6) mean dehumidification demand; (p7) total energy demand to produce EU maps for 16 building types and five 30 year time periods: RP, NF, FF, NF-RP and FF-RP. This gives in total 560 maps. Interpretation of mean demand is the mean power (W) over a period of 30 years (and thus regardless of the seasons). Please note that in all our models the building volume is 350
m³. So 1W also represents 31MJ. For example 100W and a building volume of 500m³ equals about 100 liter/year. Furthermore, for all power calculations related with the indoor climate, we assumed perfectly (100% efficiency) air-conditioned HVAC system. The reader should notice that in practical HVAC systems a lot more energy may be required for cooling and dehumidification. For example for dehumidification most systems cool first below dew point and afterwards heat the air to a certain value. Therefore, it is clear, that a lot more energy may be required than just looking at air-sided part of the balance.

3. Results

In this Section we present simulated results for recent past (RP), near future 2020-2050 (NF) and far future 2070-2100 (FF) energy demands for European museums and monumental buildings. As already discussed, we produced 560 maps. These maps will become public available at the website of Climate for Culture (2014)

3.1. Exemplarily performance maps

We use building type 16 i.e. both the highest quality of envelope as well as the highest quality of control and the external climate of the recent past (RP). We start with explaining the seven different types of maps. The reader should notice that each map has its own colorscale.

![Fig. 3](image1.png)

Fig. 3. Left: The mean indoor temperature of building type 16 from 1960-1990 (RP); Middle: The mean relative humidity; Right: The mean heating demand.

![Fig. 4](image2.png)

Fig. 4. Left: The mean cooling demand of building type 16 from 1960-1990 (RP); Middle: The mean humidification demand; Right: The mean dehumidification demand.

Fig. 3. left, shows the mean indoor temperature. Due to the high level of control, the mean indoor temperature (p1) is within a small band around 20 °C. Fig. 3, middle, presents the mean indoor relative humidity (p2). Again, due to the high level of control the mean relative humidity is within a small band around 50%. The reader should notice that the results on the top left (part of Greenland) and bottom right (near Iraq) are artifacts that are created by
extrapolation errors. Fig. 3, right provides the mean heating demand (p3). We see as expected the highest heating power at the north part of Europe and the Alps. Again the negative values (see bottom left) are not physical and are created by extrapolation errors. Fig. 4, left, shows the mean cooling demand (p4). As expected the most cooling is needed at the south of Europe. Fig. 4, middle, presents the mean humidification demand (p5). The highest values are located where heating is also needed but also at relative dry external climates. Fig. 4, right, presents the mean dehumidification demand (p6). North Italy seems to have quite high values. Finally the mean total energy demand, i.e. the sum the four energy demands (see Fig. 3, right and Fig. 4 left, middle and right), is presented in Fig. 5 upper right.

3.2. Overview using the museum classification matrix

Fig. 5 presents one of the main results, regarding the total energy use in far future (FF) minus the recent past (RP), i.e. FF-RP using the classification of Fig 2, right hand side.

![Fig. 5. The total energy use in far future (FF) minus the recent past (RP) using the corresponding Level of Control (LoC) and Level of Envelope (LoE) using the classification of Fig. 2. right hand side. The blue color represents less expected energy needed in the future, the red color represents more expected energy needed in the future. The brighter the color the higher the value.](image)

We refer to Table I and II for the meaning of all different combinations of LoC and QoE. From Figure 5 it can be seen that the first column is zero, because LoC1 corresponds with a free floating building without any systems. The second column LoC2 corresponds with heated buildings systems. What we see in this column (i.e. LoC2) going from low quality of the envelope QoE1 to a high quality QoE4, a decrease of the total energy use in far future (FF) minus the recent past (RP). This can interpreted that the future climate change has less effect on the heating demand in case of a building with high quality of envelopes. The third column LoC3 represents a heated building with basic humidity control. Comparing with column 2, it can be concluded that basic humidity control has just a small effect compared to heating. Summarizing: Columns 2 and 3 (LoC2 and LoC3) show that in future less energy use is
expected in heated buildings. However if a strict climate control is required, as represented by column 4 (i.e. LoC4),
the results are quite different compared to the other columns. This is mainly caused because LoC4 includes cooling.
The expected future energy use is now very dependent on the location of the building in Europe. For example, South
Europe may expect an increase of the total energy use, due to an increasing cooling demand, as North Europe still
may expect a decrease of the total energy use, because cooling is no issue here. Also in this column, going from low
quality of the envelope QoE1 to a high quality QoE4, a decrease of the total energy use in far future (FF) minus the
recent past (RP) is observed. LoC4, QoE1 represents a poor insulated building with a high performance system.
Here the highest differences between expected energy gains and losses can be expected in future.

4. Conclusions

We presented a new method for simulating and mapping energy demands for European buildings for the recent
past (RP), near future 2020-2050 (NF) and far future 2070-2100 (FF). It is new combination of three recent
developments: Firstly, the simulation and mapping of building performance indicators based on European weather
stations. Secondly, a multi zone energy model, representing a wide range of buildings. The latter consists of 16
different building zone types equal to all combinations of 4 levels of buildings construction and 4 levels of climate
control. Thirdly, the availability of hourly based, EU wide, external future A1B climate files from the EU FP7
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relative humidity; (3) mean heating demand; (4) mean cooling demand; (5) mean humidification demand; (6) mean
dehumidification demand; (7) total energy demand to produce EU maps for 16 building types and five 30 year time
periods: RP, NF, FF, NF-RP and FF-RP. This gives in total 560 maps. By using a classification of monumental
buildings and museums, the influence of level of control and level of envelope on the performance indicators can be
visualized.

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References

Frontiers of Architectural Research; 2013; 2, p.121-133.
Technology; 2006.
[9] Jacob, D. and Podzun, R. Sensitivity studies with the Regional Climate Model REMO. Meteorology and Atmospheric Physics; 1997; 63, pp
119-129.
[10] Larsen X.G., Mann, J., Berg, J., Gottel, H., Jacob, D. Wind climate from the regional climate model REMO. Wind Energy; 2010; 13, pp
279-206