Expected Changes in the Demand for Electrical Energy in Buildings due to Climate Change and its Economic Impact: Madrid Case Study

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Abstract. It analyses the impact of global climate change on electricity demand and its respective economic cost in buildings covering an area of 1 km by 1 km in the city of Madrid. In order to know the energy demand, meteorological information has been produced with a spatial resolution of 50 meters, taking into account the three-dimensional structure of the buildings and the land use properties around the buildings. Climate variables are dynamically downscaled from 1° to 50 m using a nesting approach. Energy simulations of buildings are implemented with the EnergyPlus model. To determine the cost of impacts, the future distribution of energy sources in the two climate scenarios analysed and the corresponding 2012 prices of the Spanish Energy Commission are taken into account. Impacts on the area's energy demand are calculated for 2030, 2050 and 2100 versus 2011 under two IPCC global climate projections: RCP 4.5 (emission stabilization scenario) and RCP 8.5 (little effort to reduce emissions). The expected changes in electricity consumption in the year 2100 are very important. RCP 8.5 shows a strong increase in electricity demand for cooling buildings. In RCP 4.5 decreases in electricity consumption are observed (-14.37%) due to very important decreases in temperature. On average, the global climate for the year 2100 will have an impact on a typical building block in Madrid of 117918 euros per year according to scenario RCP 8.5 while in scenario RCP 4.5 110537 euros per year would be saved.

1. Introduction

The energy consumption of buildings is susceptible to the effects of climate change. Previous studies [1] and [2] have found that climate change has significant implications for energy consumption in buildings for heating and cooling. These changes may lead to different patterns of energy consumption. Analyzing the energy demand of buildings is a difficult task because it requires consideration of the detailed interactions between the building, the HVAC system and the building environment (climate). Climate change will have a major impact on the energy use of buildings for heating and cooling due to changing outdoor conditions [3]. The impact of climate change on the use of energy for heating and cooling in different locations varies due to their different climates [4]. Urban areas are the areas where the local response to global change is most pronounced [5]; recent studies have suggested that global climate change will have a significant impact on the local climate [6]. Previous studies examining the consequences of climate change for energy demand tend to quantify the impacts at a relatively coarse spatial resolution. However, average responses have little value [7]; therefore, they should be made on a fine scale, taking into account the three-dimensional shape of buildings and local urban conditions.
The atmospheric flow and the special microclimate of cities are influenced by the characteristics of the urban surface [8]. Global climate models (GCMs) have a spatial resolution of about one degree, so it is necessary to use numerical models of higher horizontal resolution to obtain accurate data on the urban microclimate, taking into account all its special characteristics [9], so it should be done at fine scale, as this study in which the climate is calculated at 50 meters spatial resolution, taking into account the shape of buildings, modeled as three-dimensional structures, their effects on ventilation. In the case of urban areas with building blocks, this resolution is not sufficient and we need to do Computational Fluid Dynamics (CFD) simulations with spatial resolution meters. It is computationally very demanding but is based on physical laws and produces a complete set of climate production and air pollution variables.

2. Material and methods
In this study the climate (dry bulb temperature, wet bulb temperature, global solar radiation, wind speed, wind direction, humidity, and pressure) is calculated at 50 meters of spatial resolution, taking into account the 3D shape of the buildings. Energy consumption of buildings is influenced by outdoor meteorological conditions and in case of urban buildings, specific urban meteorological phenomena (urban microclimate), as urban heat island (air temperatures are higher than rural areas) and building effects in the wind, have to be taken into account. We have run Computational Fluid Dynamics (CFD) simulations with 50 meters of spatial resolution, called the MICROSYS, using the best boundary and initial conditions from a regional climate model, Weather Research and Forecasting Chemical model (WRF/Chem). The dynamical downscaling process begins from IPCC (Intergovernmental Panel on Climate Change) scenarios based on the Fifth Assessment Report (AR5) and on the Representative Concentration Pathways (RCP). We have only simulated climate projections using the RCP 4.5 and 8.5 scenarios. We have used the program for the Department of Energy’s called Energy Plus program. It is well-known and accepted tool in community building energy analysis worldwide [10] and the model is highly validated. EnergyPlus is a simulation program of building thermal load with very high level of detail that is based on detailed user inputs. Building energy demand was estimated for the 94 building blocks by simulating prototypical buildings differentiated by the building use, area and number of floors. By each building block we have simulated with a mount of building floor area represented by each prototype based on the use of the buildings. This strategy give us a reasonable assessment of energy demand characteristics of the entire building stock in the 1 km by 1km Madrid area selected. The building blocks have been modeled combining four ASHRAE 90.1 prototype buildings: Apartment, Medium Office, Mid-Rise Apartment, Warehouse and Strip mall. The prototypes have been tuned with local information about area (m2) and number of floors. The local information has been extracted from observation of the Google Earth and querying the Madrid municipality GIS (Open layer: Uses and Activities). Outdoor ventilation air requirements and schedules are defined following the ASHRAE 90.1 Prototype Building Modeling Specifications [11]. We have run a simulation for each building block (94 in this area) using eight hourly weather data as results of combine four years (2011, 2030, 2050 and 2100) and two possible climate scenarios (RCP 4.5 and RCP 8.5). The meteorological data are calculated as the spatial average of the 50 meters grid cells which are around of the building block. In total we have ran and analyzed 752 simulations using the following simulation tool.

3. Results
Relative (%) spatial differences (50m of spatial resolution) of annual mean temperature changes between (the future) 2100 and 2011 (present) for RCP 4.5 and RCP 8.5 in a Madrid area of 2 km by 2km are showed in figure 1. Figure 1 shows than with the scenario 4.5 we can observe a decrease in temperature for the year 2100 up to 16% compared to 2011. The climate scenario 8.5 results in an increase of the temperature for the year 2100 up to 10.9% compared to 2011 in this area of Madrid where the energy consumption of buildings will be analysed in the next paragraph. It is interesting to observe, that between two very close points can be differences up to 0.5%, so the location of the buildings is very important from a meteorological and energy points of view. The temperature has been calculated using the dynamical downscaling approach which was explained in the past sections.
Now we are going to show the main findings after the energy simulations. It is assumed that the buildings don’t change for the future simulations to isolate effects of the global climate on the energy demand of the buildings. The table 1 presents the variations of the annual total electricity, fans electricity, cooling electricity and outdoor temperature average of the 94 simulated building blocks between 2030, 2050, 2100 versus 2011 with two climate scenarios RCP 4.5 and RCP 8.5. The electrical consumption changes in the 2100 are very important. In the RCP 8.5 we can observe a very strong increment on the electricity demand for cooling the buildings (21.55 %). It is interesting to notice that increased future local temperatures translate in higher energy consumption for cooling. In the RCP 4.5 decreases of electrical consumption (-14.37 %) are observed because due to very important decreases of the temperature.

Table 1. Variations on energy demand for 2030, 2050 and 2100 versus 2011.

| SIMULATIONS vs 2011 | 2030  | 2050  | 2100  |
|---------------------|-------|-------|-------|
| Δ Total Electricity (%) | -3.05 | 2.7   | 5.74  | 8.89  | -14.37 | 14.32 |
| Δ Fans Electricity (%)   | -1.09 | 1     | 0.35  | 1.39  | -0.05  | 2.55  |
| Δ Cooling Electricity (%) | -4.25 | 3.71  | 9.04  | 13.37 | -23.14 | 21.55 |
| Δ Outdoor Temperature (%) | -1.16 | 1.91  | 4.43  | 6.72  | -16.41 | 10.43 |

Figure 2 shows the monthly changes (%) in electricity demand for the total, cooling and fans for a Madrid building by the 2100 as compared to the 2011 under climate scenarios 4.5 and 8.5 plus changes in the monthly average outdoor temperature. The total electricity will increase up to 40 % for July and under the RCP 8.5 climate scenario. The main reason is a high increase of the electricity for cooling (45%) because 2100 will be hotter than 2011, in July 2100 the temperature could be 20 % higher than in 2011.

In order to determinate a cost of impacts the following table has been applied. Table 2 includes future distribution of the energy source in the two climate scenarios [12] and the corresponding 2012 prices from the Spanish Commission of the Energy. The calculated electricity consumption data for the years 2100-2011 were multiplied by the 2012 energy prices taking into account the energy sources distribution for each climate scenario. A “mean” cost for each climate scenario has been obtained to
simplify the final cost analysis. On average the global climate for year 2100 will have an impact on a typical Madrid buildings block of 117918 euros per year following the RCP 8.5 and the RCP 4.5 will save 110537 euros per year.

Figure 2. Change 2100-2011 (%) in monthly electricity demand (total, fans and cooling) and outdoor temperature under two climate scenarios for a “mean” Madrid building block.

Table 2. 2100 energy sources and 2012 price of the kWh.

| Energy Source   | 2010 RCP 4.5 | 2100 RCP 8.5 | €/kWh (2012) |
|----------------|--------------|--------------|--------------|
| Renewable      | 33.43%       | 21.7%        | 0.071        |
| Natural Gas    | 20.72%       | 15.83%       | 0.069        |
| Coal           | 17.98%       | 48.3%        | 0.058        |
| Nuclear        | 27.87%       | 14.17%       | 0.018        |

4. Conclusions

Results indicate that building electricity demand in Madrid is very sensitive to the climate. The most serious impacts occur with the RCP 8.5 climate scenario for year 2100. The scenario RCP 4.5 for 2100 project to decrease electricity demand. The RCP 8.5 will produce climate conditions that are worse from a building electricity demand point of view because it is characterized by temperature increments. Results show than electric energy consumption for cooling is 21.55 % more in 2100 in comparison to 2011. Madrid urban buildings are likely to experience an increasing degree of summer overheating for the RCP 8.5 climate scenario. The increase of a particular building varies according to the location, so it is very import to get very high spatial resolution climate data. The severe impacts under the RCP 8.5 scenarios with the rising temperature, the increased cooling demand may require buildings with traditional air condition systems to retrofit and expand their cooling capacity. The established methodology is of interest for its results and that can be applied to other buildings in other cities. The prediction of electricity use change lies on the reliability of the urban climate model prediction. Our dynamical downscaling tool used in this study predicts the pattern change reasonably accurate, but not the exact energy consumption change. These types of impacts assessments help to identify solutions that will both enhance the resilience of buildings to future climate changes. The large variations found in the relationship between climate change and building energy consumption highlight the importance of assessing climate change impacts at local scales.

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