World Academy of Science, Engineering and Technology
International Journal of Environmental and Ecological Engineering
Vol:9, No:7, 2015

Energy Performance of Buildings Due to Downscaled Seasonal Models

Anastasia K. Eleftheriadou, Athanasios Sfetsos, Nikolaos Gounaris

Abstract**—**The current paper presents an extensive bottom-up framework for assessing building sector-specific vulnerability to climate change: energy supply and demand. The research focuses on the application of downscaled seasonal models for estimating energy performance of buildings in Greece. The ARW-WRF model has been set-up and suitably parameterized to produce downscaled climatological fields for Greece, forced by the output of the CFSv2 model. The outer domain, D01/Europe, included 345 x 345 cells of horizontal resolution 20 x 20 km^2 and the inner domain, D02/Greece, comprised 180 x 180 cells of 5 x 5 km^2 horizontal resolution. The model run has been setup for a period with a forecast horizon of 6 months, storing outputs on a six hourly basis.

Keywords**—**Urban environment, vulnerability, climate change, energy performance, seasonal forecast models.

I. INTRODUCTION

THE present work examines the suitability of a seasonal forecasting model downscaled with a very high spatial resolution in order to assess the energy performance and requirements of buildings. The application of the developed model is applied on Greece for a period and with a forecast horizon of 6 months in the future.

Greece, as a country in the middle of a financial crisis and facing serious societal challenges, is also very sensitive to climate changes. The commonly used method for the correlation of climate change with the buildings energy consumption is the concept of Degree Days (DD). This method can be applied to heating and cooling systems for a better management of environmental, economic and energy crisis, and can be used as medium (3-6 months) planning tools in order to predict the building needs and country's requirements for residential energy use.

II. HDDS & CDDS ESTIMATION

The current paper presents an extensive bottom-up framework for assessing building sector-specific vulnerability to climate change: energy supply and demand. The research focuses on the application of downscaled seasonal models for estimating energy performance of buildings in Greece. The ARW-WRF model has been set-up and suitably parameterized to produce downscaled climatological fields for Greece, forced by the output of the CFSv2 model. The outer domain, D01/Europe, included 345 x 345 cells of horizontal resolution 20 x 20 km^2 and the inner domain, D02/Greece, comprised 180 x 180 cells of 5 x 5 km^2 horizontal resolutions. The model run has been setup for a period of 6 months, storing outputs on a six hourly basis due to memory limitations.

Based on the existing bibliography [1]–[6] and the four climatic zones for energy performance assessment of buildings (KENAK) [1] the suggested base temperatures for HDD and CDD are presented in Table I. According to the bin method and having available hourly data the energy performance assessment of buildings are defined. For each month of the year the daily values are summed giving the monthly values of HDD and CDD. In the same way, the monthly values are summed giving the annual values, respectively.

TABLE I
SUGGESTED BASE TEMPERATURES ^{o}C OF HDDS AND CDDS

Climate Zones KENAK	Base Temperature ^{o}C	
	Heating	Cooling
Zone A	15	26
Zone B	14	25.5
Zone	13	25
Zone D	12	23.5

$$HDD = \frac{\sum_{i=1}^{24}(\mathrm{T}_b - T_i)}{24} \tag{1}$$

$$CDD = \frac{\sum_{i=1}^{24}(\mathrm{T}_i - T_b)}{24} \tag{2}$$

Having available hourly database the energy performance assessment of buildings is defined according to the bin method. Equations (1) and (2) show the calculation of the daily values (in 24 hourly bins) of HDD and CDD using hourly values of air temperature.

T$_\mathbf{b}$:The base temperature.

T$_\mathbf{i}$: The model estimated air temperature at 2m above ground level.

According to KENAK regions with elevation over 500m are immediately categorized in an upper level. Values of HDDs and CDDS obtained from these relations were used for the construction of maps presenting the geographic distribution of

---

Anastasia K. Eleftheriadou is Post-doctoral Researcher, Inrastes, Dhmokritos National Center for Scientific Research, P. Grigoriou & Neapoleos 27 Str., 15310 AgiaParaskevi, Athens Greece (corresponding author: e-mail: aelefthe@ipta.demokritos.gr)

Athanasios Sfetsos is Research Scientist, Inrastes, Dhmokritos National Center for Scientific Research, P. Grigoriou&Neapoleos 27 Str., 15310 AgiaParaskevi, Athens, Greece (e-mail: ts@ipta.demokritos.gr)

Nikolaos Gounaris is Special Scientific Personnel INRASTES, Dhmokritos National Center for Scientific Research, 15310 Agia Paraskevi, Athens, Greece (*e-mail:* gounaris@ipta.demokritos.gr)

the HDDs over the entire Greek area taking into consideration the region elevation. By using the method of regression with the data of a topographic model of the Greek area was solved the problem of how to fit special statistical models in order to transfer specific information from point to point. The regional climate characteristics along with the climate zone have been taken into consideration for the applied base temperatures.

III. SEASONAL MODELS

Fig. 1 Downscaled Seasonal Models

The ARW-WRF model (version 3.5) has been set-up and suitably parameterized to produce downscaled climatological simulations for Greece [7]. The downscaling has been determined in two successive nested domains as shown in Fig. 3. The outer domain, D01/Europe, included cells of horizontal resolution 20 x 20 km^2 and the inner domain, D02/Greece, comprised of cells of 5 x 5 km^2 horizontal resolution. In the vertical, 27 levels were used with the maximum resolution dz of 1500 m at the top of the model (at ~50 mb). The estimation of the heating and cooling degree days has been estimated for two different simulation periods starting on the 2nd of January (ending on 31st of June regarding the Heating Degree Days) and 5th of February (ending on 31st of July regarding the Cooling Degree Days) 2015 respectively and covering a simulation period of six months. The initial and boundary conditions for the WRF model simulations were determined by 12-hourly operational analyses obtained from the National Center for Environmental Prediction (NCEP) Climate Forecasting System [8] valid at 00, 12 UTC for the referenced period. After initialization of the model run, these data were only applied at the boundaries.

The outer domain has been set to contain all the main climatology patterns that affect Greece, and thus the WRF/CHEM model fully coupled atmospheric phenomena with dust transport from the Sahara desert was deemed more appropriate. For Greece the normal WRF was found from many different validation studies [7] to provide optimal representation of many local scale features that do appear over Greece due to its complex topographical characteristics (Fig. 2).

The model run has been setup for a period of 6 months, computational time steps of 180 and 30 seconds respectively for the two domains. It was run on a HPC cluster of 12 CPUs with a total processing time of approximately 10 full days for both domains. Due to the large storage requirements, data were recorded every 6hours.

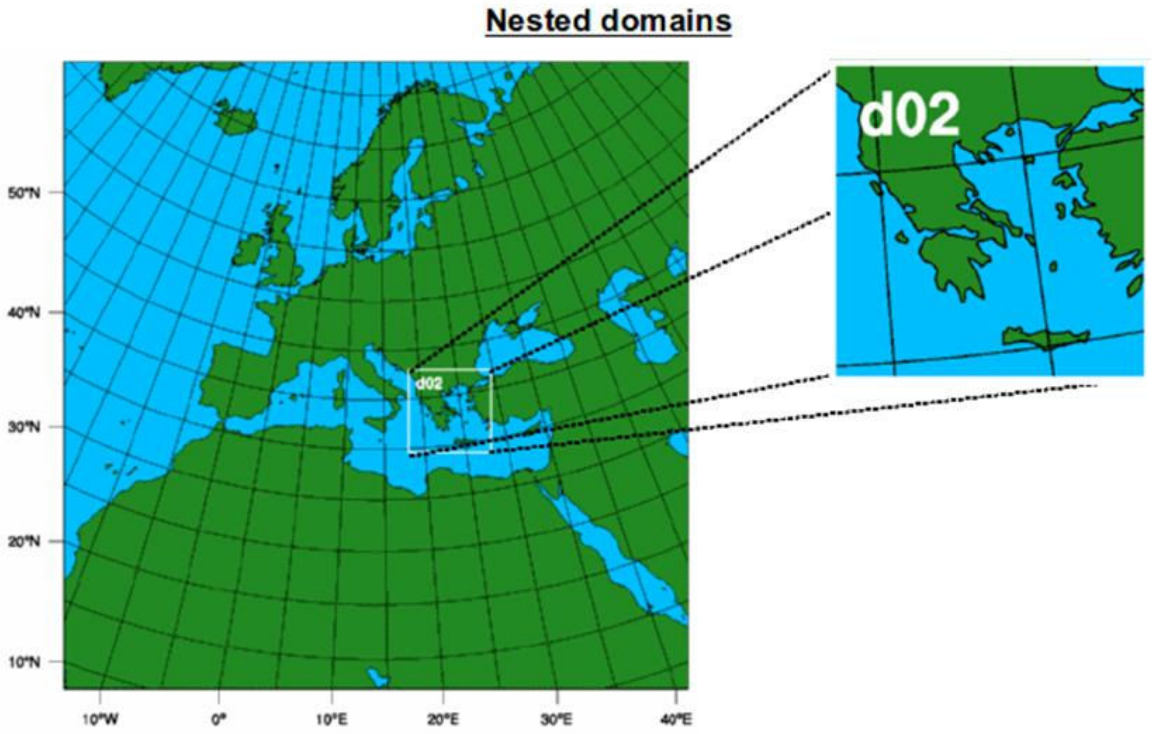

Fig. 2 Nested domains

IV. RESULTS

After the discrimination of the entire region of Greece in four climatic zones for energy performance assessment of buildings according to KENAK. categorization and having assigned in each zone suggested base temperatures, HDD and CDD are estimated [9]. The estimation is based on the bin method for interpolated hourly data which came from initial 6-hourly data. For each month of the year the daily values are summed giving the monthly values of HDD and CDD. Spatial maps have been constructed presenting the geographical distribution of HDDs for each month over entire Greece (Fig. 3). Similar maps have been constructed presenting the geographical distribution of CDDs over entire Greece (Fig. 4).

V. CONCLUSIONS

The analysis has been established through a series of indices for estimating Heating (HDD) and Cooling Degree Days (CDD) for 6-hourly data. The data, that covered all Greek regions and climatology zones according to the existing building regulations code present a very reasonable correlation with data published in previous studies. The low biasing terms is also an indication that predictions do not have a consistent over- or under- prediction which will be transferred into the estimation of the HDD and CDD.

Analyzing the calculated data, we establish that values of Degree Days (especially HDDs) vary considerably from region to region (Table II). The large difference in HDD values indicates the intense contrast in the climatic characteristics, energy and consequently economic demands between these two geographic points. Higher fuel consumption is required in northern and mountainous Greece, with high elevation, where much higher HDD amounts are estimated and for a longer period of time. Declining from north to south and from the mainland to the islands the HDD amounts, and subsequently the energy demand, decreases. The geographical distribution of the HDDs represented on the maps, show a significant statistical relation, as the estimated values are very close to the real, verifying the reliability of the models applied.

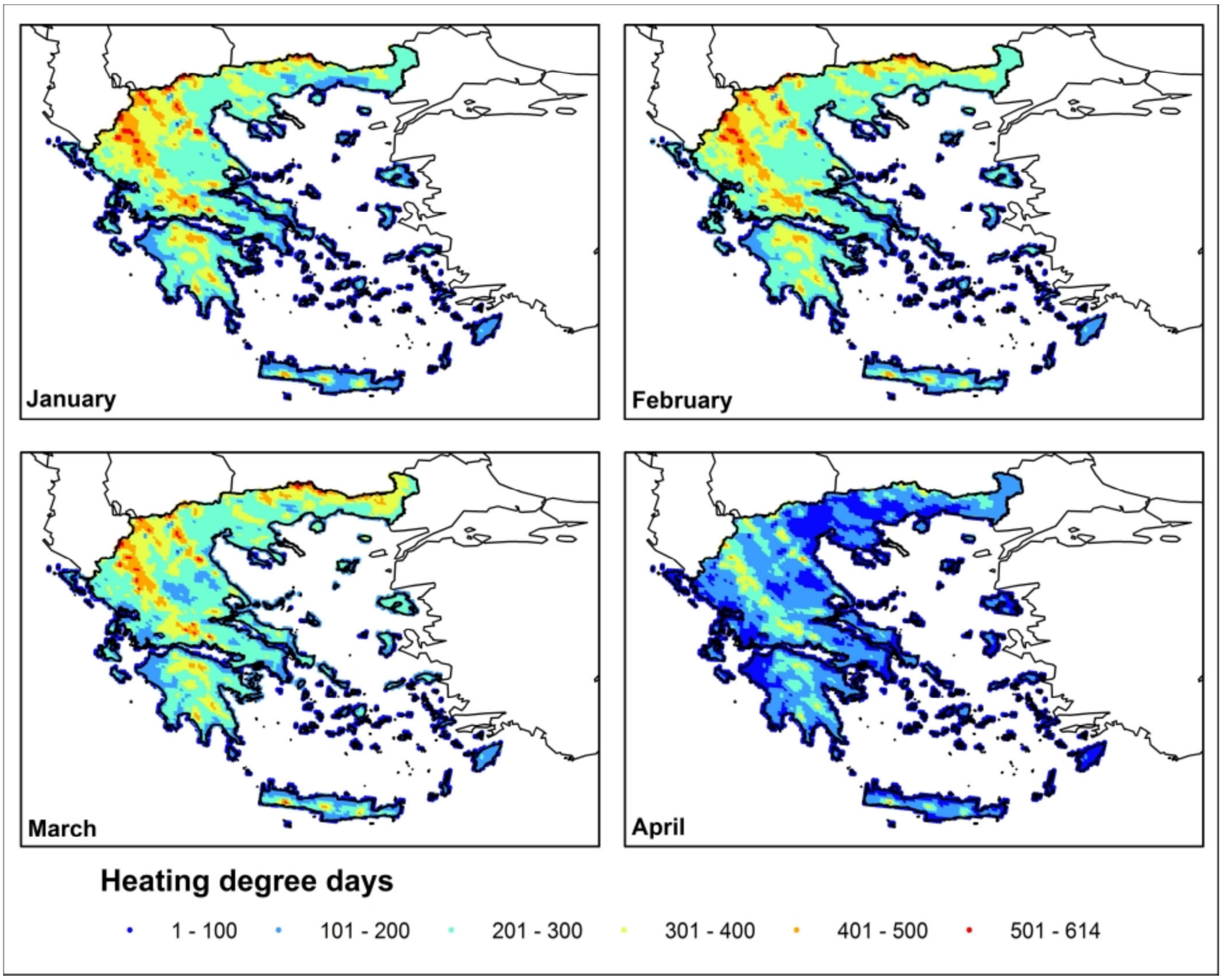

Fig. 3 Spatial maps presenting the geographical distribution of HDDs

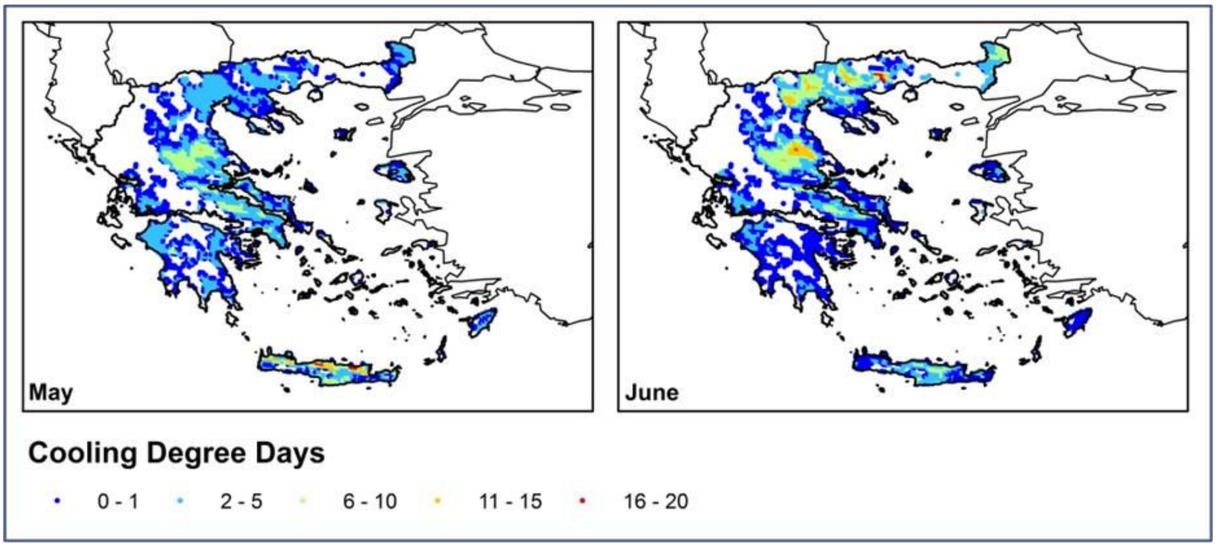

Fig. 4 Spatial maps presenting the geographical distribution of CDDs

TABLE II
RANGE VALUES OF HDDS AND CDDS ACCORDING TO CLIMATE ZONES

ZONE	Min HDD1	Max HDD1	Min HDD2	Max HDD2	Min HDD3	Max HDD3	Min HDD4	Max HDD4	Min HDD5	Max HDD5	Min HDD6	Max HDD6
1	0	46	12	202	78	258	0	37	0	23	0	0
2	0	56	37	262	85	308	0	41	0	18	0	0
3	5	44	72	265	154	315	2	38	0	8	0	0
4	20	97	206	395	223	455	9	112	0	10	0	2

ZONE	Min CDD2	Max CDD2	Min CDD3	Max CDD3	Min CDD4	Max CDD4	Min CDD5	Max CDD5	Min CDD6	Max CDD6	Min CDD7	Max CDD7
1	0	0	0	0	0	0	0	9	0	4	0	34
2	0	0	0	0	0	0	0	9	0	10	0	52
3	0	0	0	0	0	0	0	12	0	16	0	61
4	0	0	0	0	0	0	0	3	0	6	0	49

A consistent and extensive bottom-up framework has been established for assessing building sector-specific vulnerability to climate change: energy supply and demand is estimated determining correspondingly the economic demand. Downscaled seasonal climatic forecasting models are applied for estimating energy performance of buildings in Greece. The derived conclusions could serve in the better planning (exact period and demand) of fuel consumption by the authorities. The detailed analysis of the climate impact costs and benefits of adaptation can be an extremely useful decision support tool in deriving timely and accurate actions. Taking into consideration risk parameters, such as density population of buildings, DDs could be also used as a useful tool in conducting a risk assessment research.

ACKNOWLEDGMENTS

This work has been partially funded by FP7-316173 ENTEC project.

REFERENCES

[1] Ministry of Environment, Energy and Climatic Change (YPEKA), *Regulation on Energy Performance in the Building Sector – KENAK*, FEK 407/B/9.4.2010, Athens, Greece, 2010.

[2] SATE, *Energy and Environment in Building Sector – A Challenge for the Present and the Future*, Athens, 2008.

[3] K. Papakostas, G. Tsilingiridis, N. Kyriakis, "Heating Degree-days for 50 Greek Cities" *Technica Chronic,Scientific Journal,* Technical Champer of GreeceC, IV, No 1-2, 2005.

[4] K. Papakostas, G. Tsilingiridis, N. Kyriakis, "Cooling Degree-days for 50 Greek Cities" *TechnicaChronica, Scientific Journal,* Technical Champer of GreeceC, IV, No 1, 2010.

[5] TABULA, *D6.2: National Scientific Report – GREECE*, National Observatory of Athens – NOA, Athens, Greece, 2012.

[6] S. P. Bingulac, "On the compatibility of adaptive controllers (Published Conference Proceedings style)," in *Proceeding of the 4th Annu. Allerton Conf. Circuits and Systems Theory*, New York, 1994, pp. 8–16.

[7] A.Sfetsos,D. Vlahogianni, N. Politi, A. Demertzi, N. Gounaris, A. Papadopoulos, S. Karozis, G. Emmanouil, A. Eleftheriadou, N. Moustakidis, "Assessing climate change impacts in Greece through localized impact assessment models", *17th International Symposium on Environmental Pollution and its Impact on Life in the Mediterranean – MESAEP 2013*, Istanbul, Turkey, 2013.

[8] S. Saha et *al*., "The NCEP Climate Forecast System Reanalysis. Bull. *Amer. Meteor. Soc.*, 91, 1015.1057". doi: 10.1175/2010BAMS3001.1, 2010.

[9] A. Eleftheriadou, A. Sfetsos, N.Gounaris, A. Demertzi, "The Application of High Resolution Seasonal Downscaled Models for the Energy Performance of Buildings", *Proceedings of the European Climate Change Adaptation Conference*, Copenhagen - Denmark,12th - 14th May 2015.