2 – 5 November 2014

Athens

Greece

Med Power 2014

CONFERENCE PROGRAMME

IET Hellas

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In cooperation with

National Technical University of Athens

and

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CONFERENCE

Med Power 2014

**9th Mediterranean Conference
on Power Generation, Transmission, Distribution
and Energy Conversion**

**2 – 5 November 2014
Athens, Greece**

WEDNESDAY 5th NOVEMBER

09.00 – 11.00 **Parallel Sessions**

NEW AMPHITHEATRE: ***Demand Response and Load Flexibility***
CONFERENCE ROOM I: ***Planning***
CONFERENCE ROOM II: ***Storage***

11.00 – 11.30 Coffee Break

11.30 – 13.30 **Parallel Sessions**

NEW AMPHITHEATRE: ***Forecasting***
CONFERENCE ROOM I: ***Protection***
CONFERENCE ROOM II: ***High Voltage Engineering***

13.30 – 14.30 Lunch

14.30 – 17.00 **Parallel Sessions**

NEW AMPHITHEATRE: ***Load Identification and Energy Efficiency***
CONFERENCE ROOM I: ***Electric Machines***
CONFERENCE ROOM II: ***Cables and Insulating materials***

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Technological Educational Institute of Piraeus, Greece,

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11.30 – 13.30 Parallel Sessions

—NEW AMPHITHEATRE—

Forecasting

Chair: **A. Braunstein**, Tel Aviv University, Israel

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FOSS Research Centre for Sustainable Energy, Cyprus Energy Regulatory Authority, Electricity Authority of Cyprus, Cyprus

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Technological Educational Institute of Piraeus, Greece

Prediction of Electricity Load Demand in a Mediterranean Island Environment Based on the Physiologically Equivalent Temperature and Artificial Neural Networks Modeling

Konstantinos P. Moustris, Dimitrios Zafirakis, Apostolos I. Kokkosis, Athanasios G. Paliatsos and John K. Kaldellis

***Abstract*-- The goal of this work is to examine the potential for electricity load demand (ELD) hourly prediction with the use of artificial neural networks (ANNs), based on the Physiologically Equivalent Temperature (PET) index. The current research work investigates the relation between the PET index and electricity demand patterns in Mediterranean island regions and the Aegean Sea in specific. PET is based on the Munich Energy balance Model for Individuals, which describes the thermal conditions of the human body in a physiologically relevant way. Results obtained show that ANNs give an adequate prediction of hourly electricity load demand for Amorgos island (central Aegean Sea) at a statistical significant level of p<0.01.**

***Index Terms*--Artificial neural networks, electricity load demand, Amorgos Island, Greece.**

I. Introduction

URGENCY to achieve large-scale integration of the variable or even stochastic power generation from renewable energy sources (RES) calls among others for the employment of novel solutions including energy storage, upgrade of electricity grids and application of effective demand side management strategies. To this end, the problem of limited RES integration becomes even more severe in isolated island regions, such as those encountered in the Aegean Sea area, owed to the weak character of local electricity grids as well as to the technical minima of thermal-based power stations used to cover the greatest part of the local electricity needs. Furthermore, since industrial activities in small and medium scale islands are extremely limited, electricity demand in these regions is mainly configured by the local residential sector. At the same time, owed to the mild, Mediterranean conditions determining the Aegean islands' climate, the local residential sector is usually equipped with air conditioning units that cover both heating and cooling needs of the islanders, much influencing in this way the local electricity demand patterns. In this context, it may be concluded that human thermal comfort conditions comprise a critical driver of the local electricity demand [1]-[6].

Considering this argument, the goal of this work is to examine the potential for electricity load demand (ELD) hourly prediction with the application of artificial neural networks (ANNs), using the Physiologically Equivalent Temperature (PET) index.

II. Data and Methodology

Acknowledging the above, the current research work investigates the ability of ANNs to predict ELD using past data of the PET index in Mediterranean island regions and the Aegean Sea in specific. The PET is based on the Munich Energy balance Model for Individuals (MEMI), which describes the thermal conditions of the human body in a physiologically relevant way [6]. PET is defined as the air temperature at which, in a typical indoor setting (without wind and solar radiation), the heat budget of the human body is balanced with the same core and skin temperature under the complex outdoor conditions to be assessed [7], [8].

In order to estimate PET values, the RayMan model [9], [10] is currently used together with hourly values of air temperature (^{o}C), wind speed (m/s), relative humidity (%), and global solar irradiation (W/m^2) for a representative, medium-scale island region of the Aegean Sea, i.e. the Amorgos Island, for one year period (2012). Detailed PET results are then used in order to inform the development of an electricity demand forecasting model with the use of ANNs and the respective detailed time series of electricity demand in Amorgos Island (see also Fig. 1).

According to Fig. 1, is obvious that during the summer period and especially during July and August the electricity

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K. P. Moustris is in the Department of Mechanical Engineering, Technological Education Institute of Piraeus, 250 Thivon and P. Ralli Str., 122 44 Athens, Greece (e-mail: kmoustris@teipir.gr).

D. Zafirakis is in the Department of Mechanical Engineering, Technological Education Institute of Piraeus, 250 Thivon and P. Ralli Str., 122 44 Athens, Greece (e-mail: dzaf@teipir.gr).

A. I. Kokkosis is in the Department of Electronics Engineering, Technological Education Institute of Piraeus, 250 Thivon and P. Ralli Str., 122 44 Athens, Greece (e-mail: akokkos@teipr.gr).

A. G. Paliatsos is in the Department of Electronic-Computer Systems Engineering, Technological Education Institute of Piraeus, 250 Thivon and P. Ralli Str., 122 44 Athens, Greece (e-mail: agpal@in.teipir.gr).

J. K. Kaldellis is in the Department of Mechanical Engineering, Technological Education Institute of Piraeus, 250 Thivon and P. Ralli Str., 122 44 Athens, Greece (e-mail: jkald@teipir.gr)

demand in Amorgos Island is higher, almost double, than the rest of the year. This is due to the population increase, since July and August are the main touristic months for Amorgos Island as well as for the whole Aegean Sea. It is also during the same period that electricity needs skyrocket; owed to the increased cooling needs and the use of air conditioning units (see also Fig. 2).

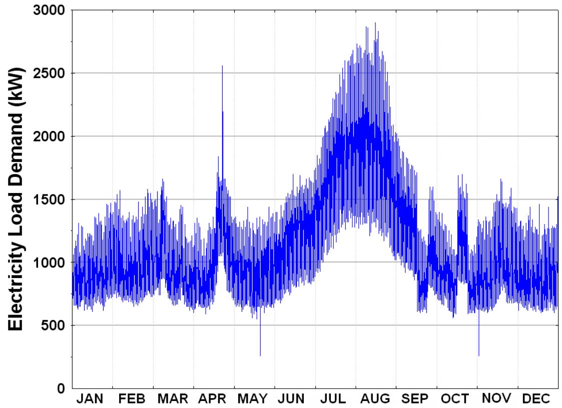


Fig. 1. Variation in hourly electricity load demand for Amorgos Island during the year 2012.

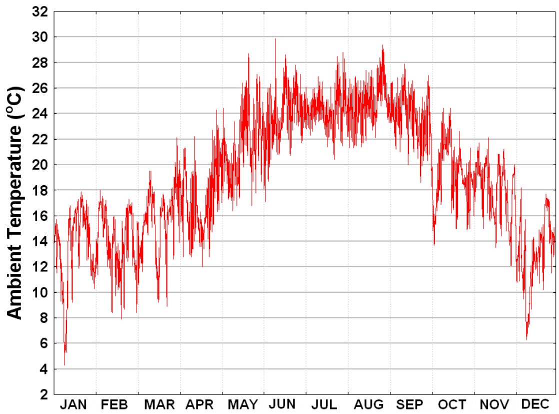


Fig. 2. Variation in hourly ambient temperature for Amorgos Island during the year 2012.

ANNs are a branch of artificial intelligence developed in the 1950s aiming at imitating the biological brain architecture. They are an approach to the description of functioning of the human nervous system through mathematical functions. Typical ANNs use very simple models of neurons. These artificial neurons models retain only very rough characteristics of biological neurons of the human brain [11]. ANNs are parallel distributed systems made of many interconnected nonlinear processing elements (PEs), called artificial neurons [12].

A renewal of scientific interest has grown exponentially since the last decade, mainly due to the availability of appropriate hardware that has made them convenient for fast data analysis and information processing. During the last two decades more and more scientists around the world have applied ANN models in many different scientific fields [13].

In this work, a special and well known kind of ANN models, the Multi-Layer Perceptron (MLP) is applied in order to predict, on an hourly basis, the load demand in Amorgos Island, during the year 2012. The MLP is the most commonly used type of ANNs [14]. Its structure consists of PEs, which are arranged in layers, and connections.

The first layer is the input layer, one or more hidden layers follow and the final layer is the output layer. An input layer serves as buffer that distributes input signals to the next layer, which is a hidden layer. Each neuron of the hidden layer communicates with all the neurons of the next hidden layer, if any, having in each connection a typical weight factor. So, each unit-artificial neuron in the hidden layer sums its input, processes it with a transfer function and distributes the result to the output layer.

It is also possible that there are several hidden layers connected in the same fashion. The units-artificial neurons in the output layer compute their output in a similar manner. Finally, the signal reaches the output layer, where the output value from the ANN model is compared to the target value and an error is estimated. Thus, the values of weight factors are amended appropriately and the training cycle is repeated until the error is acceptable, depending on the application. Since data flow within the artificial neural network from a layer to the next one without any return path, such kind of ANN models are defined as feed-forward ANN models [12].

Concerning our methodology, initially the hourly values of PET are calculated applying the RayMan model, for the whole year 2012 using data including hourly values of air temperature (^{o}C), wind speed (m/s), relative humidity (%), and global solar irradiation (W/m^2) (see also Figs. 2-5).

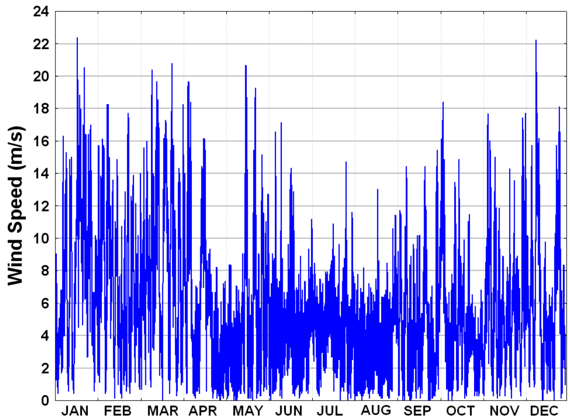


Fig. 3. Variation in hourly wind speed at 1.1m above sea level for Amorgos Island during the year 2012.

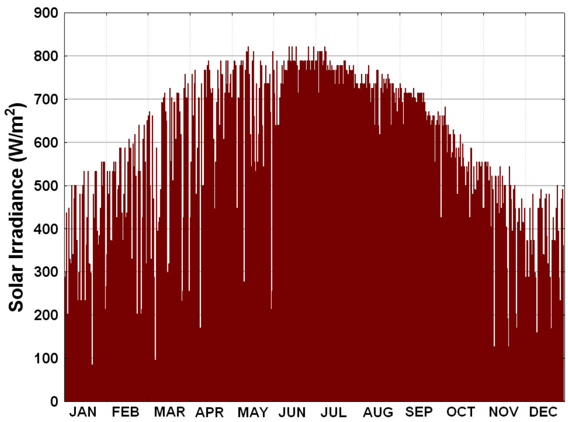


Fig. 4. Variation in hourly solar irradiance for Amorgos Island during the year 2012.

Then, the year is divided into two seasons, the cold season of the year (October-April) and the warm season of the year (May-September). Fig. 6 presents the mean hourly variation of PET values vs the mean hourly ELD for both the cold and the warm season of the year 2012. It seems that during sunlight, the ELD and PET values have a similar behavior for both the cold and the warm period of the year. During the night, the ELD presents a maximum due to the use of artificial lighting. The ELD is higher during the warm period of the year, as it was expected, due to the great number of tourists visiting the Amorgos Island.

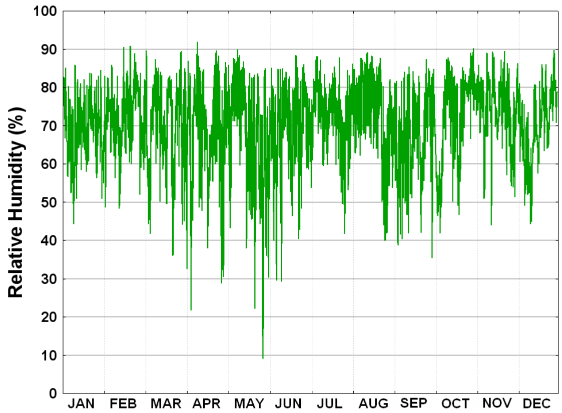


Fig. 5. Variation in hourly relative humidity for Amorgos Island during the year 2012.

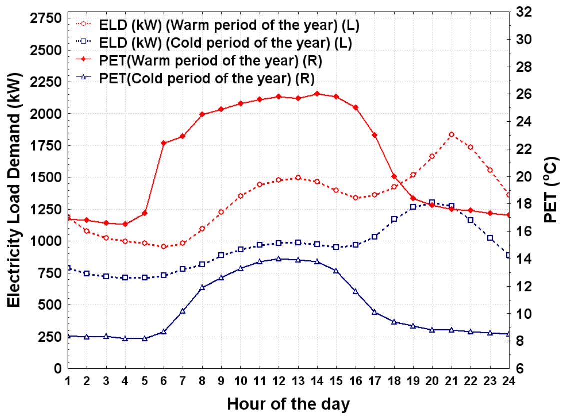


Fig. 6. Intraday variation of ELD and PET values for Amorgos Island during the year 2012.

Then, two separate ANNs models were developed. ANN1 was trained in order to predict the hourly values of ELD during the cold period of the year. ANN2 was trained in order to predict the hourly values of ELD during the warm period of the year. In both cases, as input nodes (input layer) the number of the month (1, 2, 3… 12), the number of the hour (1, 2, 3 …, 24), the ELD from the three previous hours (ELD_{t-3}, ELD_{t-2}, ELD_{t-1}) and the PET value (PET_t) of the t-hour, were used. The target value (output layer) was the ELD of the t-hour (ELD_t). Both ANN1 and ANN2 consist of one hidden layer. For the appropriate training of ANN1, the cold period of the year was divided into two subsets.

The first contains all the months of the cold period of the year (training data set) except January and was used for ANN1 training. The second subset which contains only the month January, was totally unknown to the trained ANN1 model and was used as the testing set. Similarly, for the appropriate training of ANN2, the warm period of the year divided into two subsets.

The first contains all the months of the warm period of the year (training data set) except July and used for ANN2 training. The second subset which contains only the month July, was totally unknown to the trained ANN1 model and used as the testing set.

III. Results and Discussion

For an effective evaluation of the predictive ability of the developed ANN1 and ANN2 models, a number of well-known statistical indices such as, the Mean Bias Error (MBE), the Root Mean Square Error (RMSE), the coefficient of determination (R^2) and the Index of Agreement (IA) were calculated [15]. Table 1 presents the values of the aforementioned evaluation statistical indices.

TABLE I
Samples of Times Roman Type Sizes and Styles Used for Formatting a PES Technical Work

	MBE (kW)	RMSE (kW)	R^2	IA
ANN1 (January 2012)	+8.7	61.6	0.901	0.972
ANN2 (July 2012)	+2.1	106.8	0.915	0.977

To this end, Fig. 7 depicts the observed versus the predicted ELD values using the prediction of ANN1 and ANN2 models, respectively, both demonstrating quite increased values for the resulting coefficient of determination, exceeding in both cases 0.9.

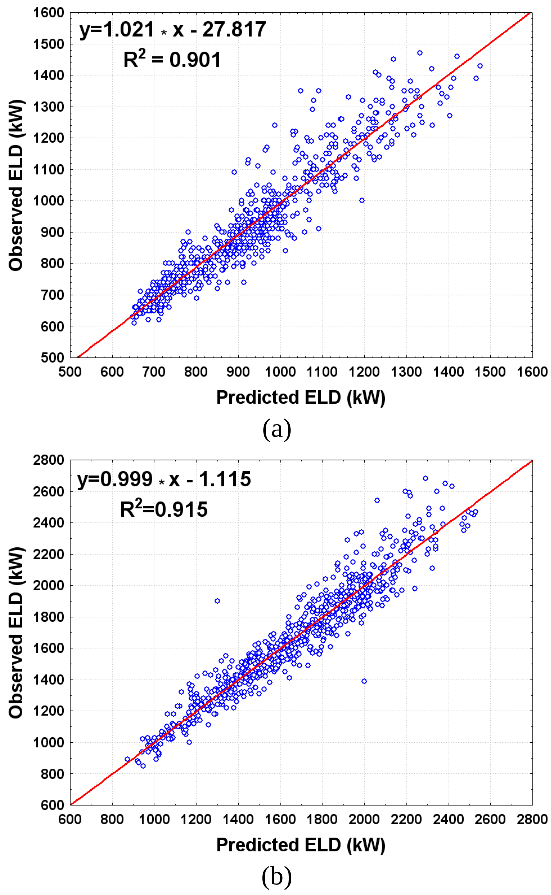
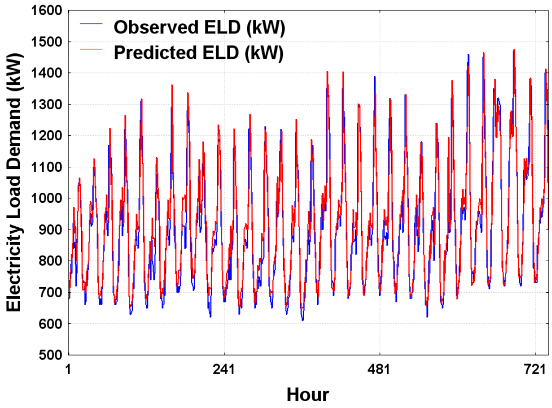
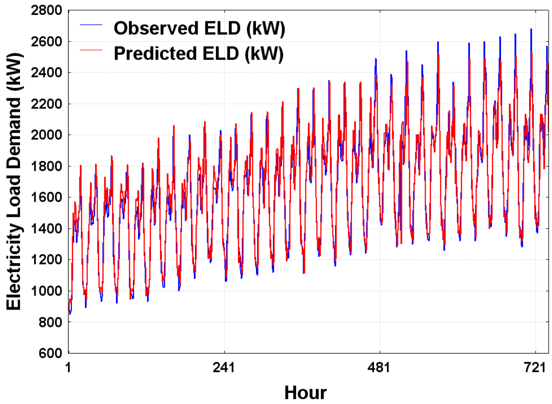


Fig. 7. Scatter plots of hourly observed versus predicted ELD values for Amorgos Island during January (a) and July (b) 2012.

Accordingly, Fig. 8 shows the results for January (Fig. 8a) and for July (Fig. 8b) prediction of hourly ELD for Amorgos Island. The blue line represents the ELD values recorded in 2012 and the red line represents the ELD values that the ANN models predicted for the year 2012 in each case.



(a)



(b)

Fig. 8. The January (a) and the July (b) prediction of hourly ELD values for Amorgos Island (year 2012).

IV. Conclusions

According to the preliminary results obtained by the development of the prognostic models, there is strong evidence of high correlation between PET and the local electricity demand in Amorgos Island, which allows for the sufficiently reliable short-term prediction of electricity demand. To this end, the development of appropriate signals for the application of demand side management strategies that also take into account the prognostic input of RES power generation becomes possible.

Besides that, by considering also previous research results of the authors concerning estimation of the PET index in urban Mediterranean areas (i.e. Athens area), differences noted in island (rural) regions are illustrated, highlighting at the same time the critical role that human thermal comfort conditions hold in the configuration of electricity demand patterns in the small and medium scale islands of the Aegean Sea.

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VI. Biographies

Konstantinos P. Moustris graduated from the National and Kapodistrian University of Athens where he studied at the Physics Department, Faculty of Sciences (B.Sc. degree in Physics).

He holds a M.Sc. in Atmospheric Physics and Meteorology from the National and Kapodistrian University of Athens, Greece. He also holds a Doctorate of the School of Chemical Engineering, National Technical University of Athens, Greece. His employment experience includes some private research companies and educational institutions of Athens city, Greece. His special fields of interest included applications of artificial neural networks in environmental protection and management. He is a member of the Board of the Greek Meteorological Society as well as member of the Balkan Environmental Association (BENA).

Nowadays, Konstantinos is Asst. Professor at the Department of Mechanical Engineering of Technological Education Institute of Piraeus, Greece.

Dimitrios Zafirakis received his Diploma in Mechanical Engineering (TEI of Piraeus, Greece) in 2005 and his M.Sc. in Energy (TEI of Piraeus, Greece in collaboration with Heriot Watt University, UK) in 2008.
Dimitrios is an early-career researcher specializing in energy systems modelling and energy storage. He has also worked on large-scale renewable energy integration and hybrid energy systems optimisation. He has published over 30 journal papers and has contributed in several research projects.

Apostolos I. Kokkosis (EurIng, BSc., PhD, CEng., FIET) is in the Department of Electronics Engineering, Technological Education Institute of Piraeus, Athens, Greece. His current research interests include Project Management and System Electronic Design. He is membership in many professional and technical societies.

He is President of Academic Staff Association of Technological Education Institutes (TEIs) of Greece (OSEP-TEI) and Chairman of IET Network in Greece.

Athanasios G. Paliatsos received the B.Sc. degree in Mathematics from the National and Kapodistrian University of Athens and the Ph.D. degree in Environmental Physics from the Aristotle University of Thessalonica, in 1983 and 1990, respectively. He is in currently Professor, at the Department of Electronic-Computer Systems Engineering of Technological Education Institute Piraeus, Athens, Greece.

His research interests include precipitation statistics, air pollution statistics, prediction of environmental and meteorological parameters, UV-B radiation variation, air quality assessment, environmental impacts from the electricity generation sector, adverse health effects from bioclimatic /environmental factors and artificial neural network models. He is a board member of the Hellenic Meteorological Society as well as member of Mediterranean Scientific Association of Environmental Protection (MESAEP) and Balkan Environmental Association (BENA).

John K. Kaldellis received his Diploma in Mechanical Engineering (National Technical University of Athens, Greece) in 1983, his Diploma in Business Administration (University of Piraeus, Greece) in 1988 and his Ph.D. at the National Technical University of Athens, Department of Mechanical Engineering, Fluid Sector, in collaboration with Ecole Centrale de Lyon, in 1988.

Nowadays, he is Professor at the Department of Mechanical Engineering of the Technological Education Institute (TEI) of Piraeus, Greece. Concretely, he is the Director of the Soft Energy Applications and Environmental Protection Laboratory of the TEI of Piraeus. He is also the Scientific Director of the MSc in Energy program organized by Heriot Watt University and TEI of Piraeus.

Professor Kaldellis scientific expertise is in the fields of energy and environment. His research interests include feasibility analysis of energy sector applications, technological progress in wind, hydro and solar energy market, hybrid energy systems, energy storage issues, social attitude towards renewable energy applications and environmental technology-atmospheric pollution.

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