WHY SHOULD CYPRUS EXPLOIT THE SOLAR POWER TO MATCH ITS PEAK DEMAND?

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***Abstract-* Cyprus lies in a sunny belt. The amount of global solar radiation received on a horizontal surface with average weather conditions is 1725 kWh/m^2 per year. The amount and duration of sunshine is among the highest in the world and it has given birth to mass extended utilization of passive solar water heaters. Cypriot manufacturers produces more than 30,000m^2 of collectors per year and mora than 9% of the total electricity consumption has been replaced by solar energy.**

Despite the sunshine duration and the proof of concept by using passive solar heaters, Cyprus's electricity generation continues to be reliant on an imported oil. There are efforts put forward by the Cyprus goverments such as enabling users to sell their electrcity to the grid and the feed in tariffs. However, due high levelized costs of the renewable energy systems, utilization of these systems are not gaining momentum.

Various studies have identified electricity consumption is multivariate. It is affected by variables such as relative humidity, cloudiness, solar radiation, wind speed, electricity price, gross domestic product growth etc.

Nevertheless, Cyprus's solar irradiation and ambient air temperature has been found to play the most important role in controlling the electricity load demand. This paper presents the characteristic of the electricity demand of Cyprus and explores its relationship with ambient air temperature and solar irradiance. Thermal comfort levels for Cyprus have been identified. By demonstrating the correlation between the solar irradiance and the mean ambient temperature of Cyprus, this study provides reasons to exploit the solar power to match Cyprus's peak demand.

***Index Terms*—Cyprus, Electricity Demand, Weather dependant demand, Renewable Energy, Solar Energy**

I. INTRODUCTION

Energy is an essential building block of an economic development. With increasing population and living standards, the global energy demand continues to increase [1]. According to the scenario published at the latest (2009) World Energy Outlook by International Energy Agency (IEA), the world's electricity demand is projected to grow an annual rate of 2.5% to 2030 [2].

In meeting this demand, the energy exploitation and utilization should be based on the sustainable development in order to tackle a major concern of the consequential production of green house gas that this growth will cause.

Renewable energy sources, which emit no or little greenhouse gasses, can help in reducing the dependency on finite fossil fuels and lower overall green house gas emissions. Following on successes in addressing other threats to the atmosphere and in order to achieve stabilized emissions against a background of growth in energy use, governments generally have set out policies and goals for efficient and renewable energy [3].

All parts of Cyprus enjoy a very sunny climate. In the central plain and eastern lowlands, the average number of hours of bright sunshine for the whole year is 75% of the time that the sun is above the horizon. Over the whole summer six months there is an average of 11.5 hours of bright sunshine per day whilst in winter this is reduced only to 5.5 hours in the cloudiest months, December and January [6]. This value is among the highest in the world and is mainly due to the long daily sunshine duration.

Despite these sunshine duration facts, Cyprus's electricity generation is isolated and currently almost fully reliant on imported oil [4, 5].

II. CYPRUS'S CURRENT ELECTRICITY GENERATION AND DEMAND

The island Cyprus is divided into two regions known as North and South. North is governed by Turkish Republic of Northern Cyprus and South is by Republic of Cyprus. These two separated sides currently work as isolated and self-sustaining networks from each other and from the other countries.

Electrical energy production in South is operated by Cyprus Transmission System Operator (TSO). The South area's available generation capacity is 1222 MW [4]. On the other hand, in the North, electricity production is owned and controlled by the governmental body which is called Electricity Authority of Northern Cyprus (KIBTEK). The North area's available generation capacity is 347.5 MW [5].

Electricity demand is affected by variables such as relative humidity, cloudiness, solar radiation, wind speed, electricity price, gross domestic product growth etc. In the most of the electricity systems, the residential sector is one of the main contributors to the load peaks [8]. In the residential sector, the energy consumption depends on features of the building envelope and the occupant behaviour as well. The latter is subject to many factors including householders' subjective comfort preferences and their socio-demographic and socio-economic characteristics [9].

In South Cyprus domestic demand represents 35% of total consumption [7] whereas this figure is 31% in the North [5]. Over the last decade the electric energy consumption in the residential sector has significantly increased especially in the summer season, because of the increasing use of air-conditioning (AC) systems, that has drastically changed the thermal comfort needs of urban population in the developed countries. The strong penetration of the AC systems on the market was also quickened by the sudden and rapid reduction of their cost and because of the "urban heat island" effect [10,11,12]. The "urban heat island" effect is the vicious circle in terms of cooling and power demand. The extended use of air conditioners, mainly of split-unit devices, increases the heat island in densely built urban areas. The heat rejected by the compressor units contributes to warm up the outdoor air in the narrow streets, thus increasing even more the cooling demand of the buildings and further reducing the coefficient of performance of the air conditioners [12, 13].

Daily demand data of Cyprus are gathered from the TSO [4] and the KIBTEK [5] websites and are illustrated in Figure 1. The data belongs to year 2007 and a typical day in summer (July) and winter (December). From Figure 1, it is explicit that the North and South consumer demand is showing very similar behavioural patterns. The correlation of the two curves and cardinal points such as summer morning peak, summer noontime plateau and winter darkness peak should be noted.

Many studies has considered use of temperature data combined with data on humidity, wind speed, cloudiness, rainfall, solar radiation as well as data electricity price, gross domestic product growth to draw up a single formula to represent the demand of electricity [17]. When the differential between outdoor and indoor temperatures increases, the starting up of the corresponding heating or cooling equipment immediately raises the demand for energy [15].

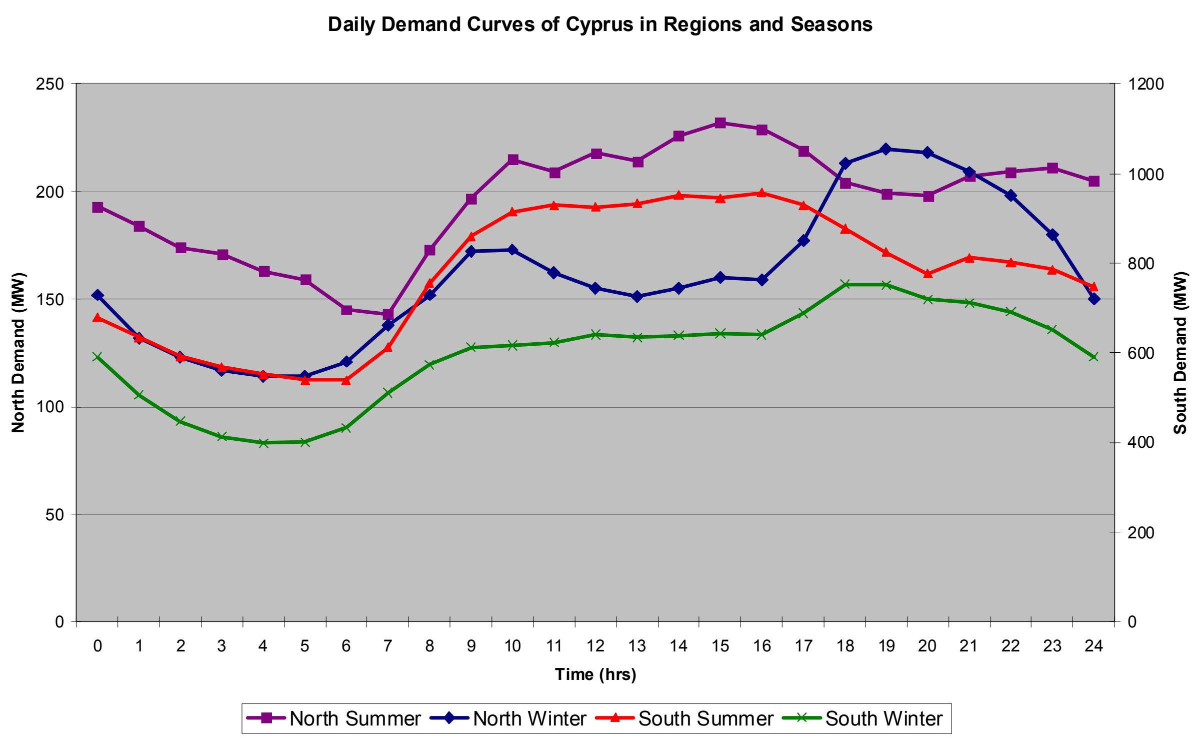

Fig. 1. Daily demand curves of Cyprus according to Regions and Seasons [4, 5]

In fact, especially in the Mediterranean countries, peaks in the electricity demand occur more frequently during the summer period than during the winter. This growing demand is being strengthened by the urban heat island effect, which results in higher air temperatures in densely built towns, thus enhancing the cooling load in commercial and residential buildings [12, 14].

On this basis along with the urban heat island effect, temperature stands out among the meteorological and other factors that affect electricity demand [16, 17].

III. Solar potential of Cyprus

The amount of global solar radiation received on a horizontal surface with average weather conditions is 1725 kWh/m^2 per year. Of this amount, 69% reaches the surface as direct solar radiation (1188 kWh/m^2) and 31% as diffuse radiation (537 kW/m^2) [22]. However, for Cyprus conditions, using solar thermal technology for power generation, the annual solar potential is estimated between 1950 kWh/m^2 and 2050 kWh/m^2 per year [23].

In the central plain and eastern lowlands, the average number of hours of bright sunshine for the whole year is 75% of the time that the sun is above the horizon. Over the whole summer six months there is an average of 11.5 hours of bright sunshine per day whilst in winter this is reduced only to 5.5 hours in the cloudiest months, December and January [6].

Map of yearly sum of global irradiation received by optimally inclined PV modules [18] is shown at Figure 2.

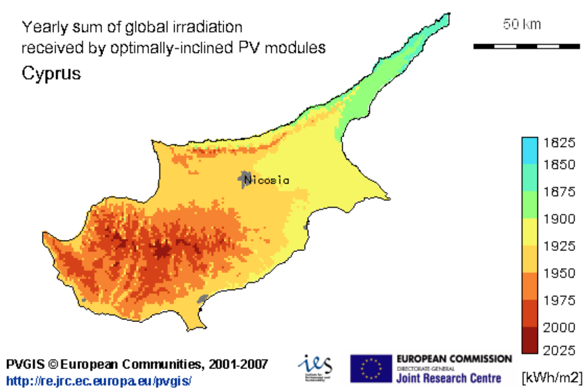

Fig. 2. Map of sum of global irradiation of Cyprus [18].

The availability of solar irradiation gave birth to mass-extended utilization of a renewable source of energy in the early sixties. This concentrated on the use of as solar water heaters. Cypriot manufacturer's produces more than 30,000 m2 of collectors per year and around 9% of the total electricity consumption has been replaced by solar energy [19].

Table 1 at below illustrates the manufacturing and sales trend of solar water heaters from 1975 to 1994 [20].

TABLE I

Solar collector production and sales in Cyprus

Year	National production (m2)
1975-1983	246,000
1984	25,570
1985	32,450
1986	33,050
1987	33,000
1988	31,000
1989	30,000
1990	30,000
1991	29,500
1992	28,500
1993	28,600
1994	28,600
TOTAL	576,270

In comparison to other European countries, European Solar Thermal Industry Federation ranked Cyprus at first place with approximately 1m^2 of installed solar per capita [21]. Figure 3 illustrates the difference between Cyprus and other European countries based on installed capacity and produced energy of the installed solar collectors. From the Figure 3, Cyprus has more than 900,000 m^2 of installed solar collectors with potentially producing almost 700,000 kWth of energy. However, the country ranked at second place, Austria, has little more than 400,000 m2 of installed solar collectors with production capacity of little more than 300,000 kWth. The difference is more than double compared on installed collectors as well as energy production.

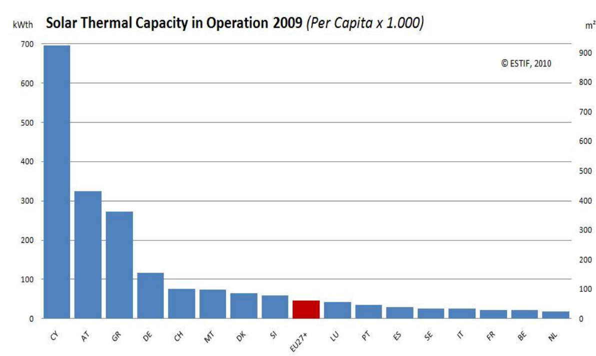

Fig. 3. ESTIF ranks Cyprus first with approximately 1m² of installed solar collector per capita [21].

IV. RELATIONSHIP BETWEEN AIR TEMPERATURE, SOLAR INSOLATION AND ELECTRICITY DEMAND OF CYPRUS

A.TEMPERATURE VS ELECTRICITY DEMAND

The experience of many utilities worldwide has illustrated the influence of weather in energy consumption and especially in electrical demand. In the electricity markets, it is important to understand and be able to predict the effects of natural variables on electricity demand in order to effectively manage the generation and supply of electricity [17]. Temperature stands out among the meteorological factors that affect the electricity demand. The principal studies indicate that the relationship between electricity demand and temperature is clearly non-linear. This non-linearity refers to the fact that both increases and decreases of temperature, linked to the passing of "threshold" temperatures, increase the demand for electricity [16]. This response is caused by the difference between the ambient or outdoor temperature and the comfort or indoor temperature. When the differential between outdoor and indoor temperatures increases, the starting-up of the corresponding heating and cooling equipment immediately raises the demand for energy [15, 16].

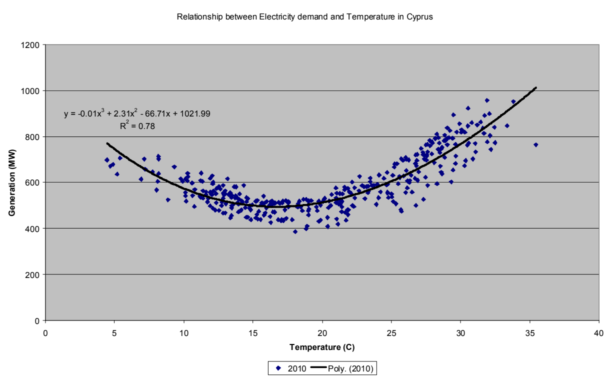

Fig. 4. Relationship between electricity demand and temperature for Cyprus.

Figure 4 illustrates the relationship between electricity demand and mean daily temperatures of year 2010 for Cyprus. The raw demand and temperature data is publicly accessible and obtained from TSO of Cyprus's website [4]. The variations of electricity demand with temperature is non-linear, increasing both for decreasing and increasing temperatures which reflects mainly use of electric or others means of heating appliances in winter and air conditioners in summer. For example, from figure 4 for year 2010, a rise in average daily temperature of 1°C from 24 °C to 25 °C would result in an increase of about 4.2% in electricity consumption. However, the demand seems to be less sensitive to temperature fluctuations in winter, since a fall in mean daily temperature of 1°C from 14 °C to 13 °C would result in an increase of about 2.1% in electricity consumption. This is mainly attributed to the fact that final consumers can use a variety of energy sources for heating for example gas, diesel oil etc. and practically only electricity for cooling. Nevertheless, at approximately 16.7 °C, the influence of temperature is minimal and electricity demand is inelastic to temperature changes at this temperature for year 2010.

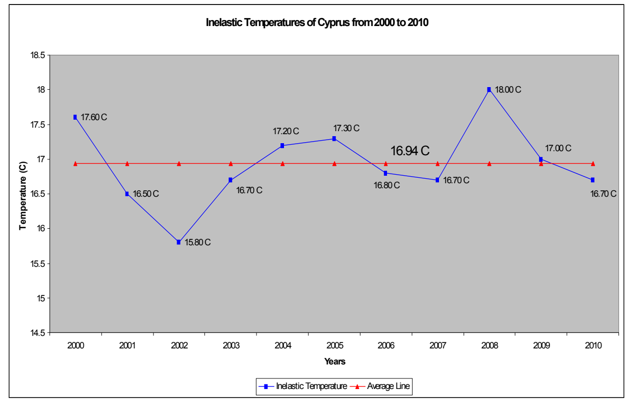

Fig. 5. Inelastic temperature trend of Cyprus from years 2000 to 2010

Figure 5 represents the calculated inelastic temperatures of Cyprus from 200 to 2010. The raw demand and temperature data, which is publicly accessible, obtained from TSO of Cyprus's website for years from 2000 to 2010 [4]. Each year's data is represented as done in Figure 4 and each year's minima or inelastic temperature is identified accordingly. There are fluctuations of the inelastic temperature of Cyprus throughout these years. Nevertheless, the average inelastic temperature throughout these years is 16.9 °C. This value is 16 °C for Athens [24] and 18.7 °C for Italy [12].

B.TEMPERATURE VS SOLAR INSOLATION

The amount of insolation at any particular location varies both throughout the year (annually) and throughout the day (diurnally). Annual fluctuations are associated with the sun's changing declination and hence with the seasons. Diurnal changes are related to the rotation of Earth about its axis [25].

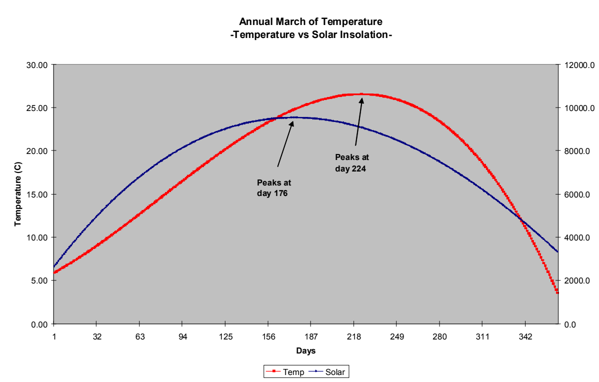

Fig. 6. Annual March of Temperature of Cyprus for year 2005

The temperature data obtained from TSO of Cyprus's website [4] of year 2005 and solar irradiation data obtained from SODA solar radiation data website [26] of year 2005 are used to create Figure 6 and 7. Figure 6 illustrates the relationship between solar insolation versus the air temperature. The temperature curve peaks at around day 224 whereas; solar insolation is at its maximum at around day 176 of year 2005. Therefore, there is a lag or delay of around 48 days between the maximum insolation and maximum temperature. This annual lag of temperature behind insolation is known a phenomenon called annual march of temperature. It is a result of the changing relationship between incoming solar radiation and outgoing Earth radiation [25]. In this case, temperatures continue to rise for a month or more after the summer solstice because insolation continues to exceed Earth's radiation loss. Temperatures continue to fall after the winter solstice until the increase in insolation finally matches Earth's radiation. Therefore, the lag exists because it takes time for Earth to heat or cool and for those temperature changes to be transferred to the atmosphere.

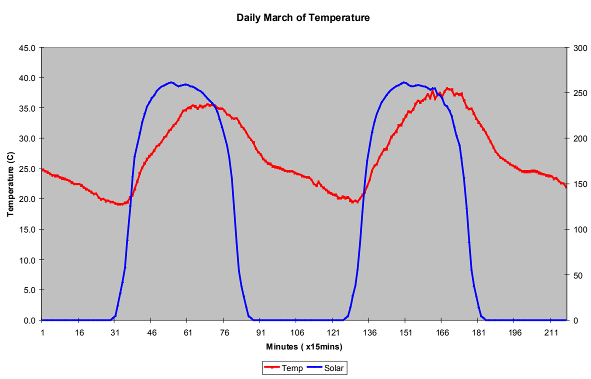

Fig. 7. Daily March of Temperature of Cyprus for year 2005 on days 185 and 186 (June)

Each day, insolation receipt beings at sunrise, reaches its maximum at noon and return to zero at sunset. Although insolation is greatest at noon, from Figure 7, it is noticeable that the mean temperature does not reach its maximum until 2 pm. This is because the insolation received by Earth from sunrise until the afternoon hours exceeds the energy being lost through Earth radiation. Hence, during that period, as Earth and atmosphere continue to gain energy, temperatures normally show a gradual increase. In the afternoon, when outgoing Earth radiation begins to exceed insolation, temperatures start to fall. The daily lag of Earth radiation and temperature behind insolation is accounted for by the time takes for Earth's surface to be heated to its maximum and for this energy to be radiated to the atmosphere. From figure 7, it is also observed that there is slower decay in temperature once the insolation is declined rapidly. Again, this is due to energy that has been stored in Earth's surface layer during the day which continues to be lost throughout the night and the ability to heat the atmosphere decreases. The lowest temperatures occur around dawn, when the maximum amount of energy has been emitted and before replenish from the su can occur. This phenomenon is also known as the daily march of temperature [25]. From figure 7, on this basis the daily march of temperature phenomenon, there is a gentle decline from mid-afternoon until dawn and a rapid increase in the 8 hours or so from dawn until the next maximum is reached.

V. Conclusions

The amount of global solar radiation received on a horizontal surface with average weather conditions is 1725 kWh/m^2 per year. However, for Cyprus conditions, using solar thermal technology for power generation, the annual solar potential is estimated between 1950 kWh/m^2 and 2050 kWh/m^2 per year. The availability of solar irradiation gave birth to mass-extended utilization of a renewable source of energy started from the early sixties. Therefore, today Cyprus has more than 900,000 m^2 of installed solar collectors with potentially producing almost 700,000 kWth of energy every year from the sun already.

The principal studies indicated that the relationship between electricity demand and temperature is clearly non-linear. The relationship between electricity demand and mean daily temperatures of year 2010 for Cyprus is illustrated and a rise in average daily temperature of 1^{o}C from 24 ^{o}C to 25 ^{o}C would result in an increase of about 4.2% in electricity consumption. However, the demand seemed to be less sensitive to temperature fluctuations in winter, since a fall in mean daily temperature of 1^{o}C from 14 ^{o}C to 13 ^{o}C would result in an increase of about 2.1% in electricity consumption. In addition, from the demand and temperature data for years from 2000 to 2010, the average inelastic temperature throughout these years is observed to be around 16.9 ^{o}C.

For year 2005, in Cyprus, the annual lag of temperature behind insolation, annual march of temperature, is found to be around 48 days. The diurnal relationship between solar insolation and temperature has also been explained and demonstrated.

As a result, the relationship between air temperature and electricity demand and the relationship between air temperature and solar irradiation hence the indirect relationship between solar irradiation and electricity demand has been identified. Therefore, the predictability of solar insolation and its indirect relationship with the electricity demand enables the system or grid operator to predict their peak demand which is cause of the solar insolation in the first place.

On the basis, that electricity demand is linked to air temperature and air temperature is linked to solar insolation, then solar energy is one of the best options that is to be exploited to provide power to the grid system in matching peak demands in Cyprus.

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