The Role of Weather Indicators in Energy Consumption

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***Abstract*—This paper presents a method for predicting the consumption of energy. The prediction is realized for the energy used for heating, where the thermal comfort has an important role. The equations that define the thermal comfort in function of the weather indicators are also mandatory for the research.**

***Index Terms*—energy consumption, polynomial regression, indoor comfort, prediction**

I. INTRODUCTION

As the field of energy management matures, the knowledge gained from thousands of energy efficiency projects is driving a transition from traditional tactical practices (one-time "build-and-forget" projects) to more comprehensive best practices (involving active management throughout the lifetime of the project). [1]

The main steps of a good energy management involve data acquisition, graphic representation of the data and prediction of energy consumption during a certain period of time. Each step has its importance into the whole process as: data collecting is the basis of the energy management, graphic representation is helpfully for the user to make a better analysis of data and the prediction of energy consumption is useful to improve the budget of a company by choosing the cheaper source of energy in a certain moment (for example gas or electricity) used for a certain purpose.

Modeling energy consumption is a critical step on the path of constructing performance metrics that accurately reflect the impact of actions taken to manage energy. Modeling building or process energy usage normally involves determining the relationship between energy consumption data and some variable (such as temperature or production activity) that represents the primary driver of that energy consumption. For buildings, there is normally a direct relationship between the energy consumed by a building and the indoor comfort for the human beings there are in that building. The indoor comfort's dependences will be presented in the next sections. The main parameter is the outside temperature.

In this paper, the analysis of the energy consumption is done for the heating of a building.

The historical data collected are presented in the fig. 1. To obtain the most accurate model possible, the length of this baseline period should encompass the time period required for the load being studied to cycle through its entire operating range. In the case of a building, the baseline period will normally be at least one year in length to capture the energy consuming behavior of the building across all seasons. In this paper we consider just the cold season (1st October – 1st March) because just during this season it's used energy for heating. Gas is the source of energy taken into account here.

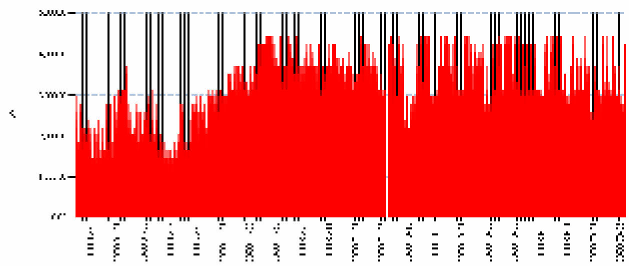

Figure 1. The data collected for the energy consumption

As it can be seen in the graphic, there are differences between day and night consumption. During the night, the consumption is less because there are not human activities. Based on this data acquisition it will be determinate the mathematical model of the energy consumption. The model is obtained through polynomial regression.

II. THE PARAMETERS USED FOR THE ANALYSIS OF ENERGY CONSUMPTION IN BUIDING

Energy used in buildings accounts almost half of the total amount of energy consumed in the European Community today. Almost 85% of the energy used in buildings is for low temperature applications such as space and water heating. [2]

Buildings are inherently linked to their usage and surroundings and hence their indoor environment is the result of a range of interactions affected by seasonal and daily changes in climate and by the requirements of occupants varying in time and space.

The design of buildings in the mid-late twentieth century has sought to eliminate the effect of outdoor daily and seasonal changes through the use of extensive heating, cooling, lighting and ventilation equipment, resulting in spiraling energy consumption and environmental impact.

Energy consumption in buildings is required mainly for the following uses: heating, cooling, ventilation, lighting, equipment and machinery, domestic hot water.

Every use has its own features and therefore it is study apart.

The indoor comfort has three components: thermal comfort, visual comfort and indoor air quality.

The thermal comfort

The comfort is defined as the sensation of complete physical and mental well being. A necessary condition for thermal comfort is the thermal neutrality, where there is an individual desire for neither a warmer nor a colder environment. The factors affecting comfort are divided into personal variables and environmental variables:

Personal variables

- ***Activity*** - The metabolic rate is the amount of energy produced per unit of time by the conversion of food. It is influenced by activity level and is expressed in mets (1 met = seated relaxing person).
- ***Clothing*** - describes the occupant's thermal insulation against the environment. This thermal insulation is expressed in *clo* units.

Environmental variables

- ***air temperature*** - the average air temperature from the floor at a height of 1 m.
- ***mean radiant temperature*** - the average temperature of the surrounding surfaces, which includes the effect of the incident solar radiation
- ***air velocity*** - which affects convective heat losses from the body, i.e. air at a greater velocity will seem cooler
- ***air humidity*** - which affects the latent heat losses and has a particularly important impact in warm and humid environments

Although the four parameters (air temperature, mean radiant temperature, air humidity and air movement) are generally recognized as the main thermal comfort parameters. Indoor environmental conditions in terms of thermal comfort can generally be assessed through three classes of environmental indices, namely: direct indices, rationally derived indices, empirical indices.

The direct indices are: dry-bulb temperature, dew-point temperature, wet-bulb temperature, relative humidity and air movement.

The rationally derived indices are: mean radiant temperature, operative temperature, heat stress and thermal stress.

The visual comfort

Visual comfort is the main determinant of lighting requirements. Good lighting provides a suitable intensity and direction of illumination on the task area, appropriate color rendering, the absence of discomfort and, in addition, a satisfying variety in lighting quality and intensity from place to place and over time. People's lighting preferences vary with age, gender, time and season. Also, the activity to be performed is critically important.

A luminous environment should be appropriate to the function of the room: there should be enough light for reading, writing, or filing documents. Illumination of 300 to 400 lux on a desk is often considered as minimum required levels for most of office tasks. Hallways might require lower levels, 100 lux, and commercial centers higher levels, 700 lux. The building technologies have to take into account all these factors.

The *daylight factor* is a measure of the daylight level at any position indoors as a percentage of the illumination levels outdoors. The daylight factor at any point on a working plane is calculated in terms of light coming directly from the sky (the sky component), light reflected from outdoor surfaces (the externally reflected component) and light reflected from surfaces within the room. The average daylight factor in a space can be calculated from the next equation:

$$DF = \frac{E_{in}}{E_{out}} * 100\% \tag{1}$$

If a predominately daylight appearance is required, then the daylight factor should be 5% or more if there is to be no supplementary artificial lighting, or 2% if supplementary lighting is provided. Discomfort is caused when the eye has to cope with, simultaneously, great differences in light levels, and the phenomenon is known as glare.

The indoor air quality

A conflict has always existed between adequate ventilation and energy costs. During the last three decades, decreased ventilation rates for energy conservation, along with increased use of synthetic materials in buildings have resulted in increased health complaints from building occupants. However, energy efficiency and good indoor air quality in buildings need not be mutually exclusive.

Good indoor air quality is a function of a number of parameters including: the initial design and continuous maintenance of HVAC systems; use of low toxic emissions building materials; and consideration of all sources of indoor air pollution. In fact, in 1986 the WHO (World Health Organization) reported that "energy-efficient but sick buildings often cost society far more than it gains by energy savings". The result of the reductions in ventilation rates in buildings have led to the so called "Sick Building Syndrome" (SBS) and "Building Related Illness" (BRI).

Few indicators that measure the quality of the air are the percent of O_2, the degree of humidity, the quantity of microorganisms.

The climate

The following climatic parameters have direct influence on indoor thermal comfort and energy consumption in buildings: the air temperature, the humidity, the prevailing wind direction and speed, the amount of solar radiation and the solar path, long wave radiation between other buildings and the surrounding environment and sky also plays a major role in building performance

The outdoor air temperature has a significant effect on building thermal losses due to conduction through the walls and roof of the building, as well as affecting ventilation and infiltration losses due to either desirable or undesirable air changes.

Prevailing wind speed and direction affect significantly the building thermal losses during the heating season, increasing both convection at exposed surfaces and hence encouraging envelope losses and also by increasing the air change rate due to natural ventilation and infiltration. During the cooling season, the knowledge of both the direction and wind speed permits the design of the building to facilitate passive cooling.

The sun-path and the cloud cover determine the amount of solar radiation impinging on differently inclined surfaces and since the sun-path changes from season to season, so does the amount of direct solar radiation impinging on these different surfaces.

One method of assessing the thermal comfort is to use the equations for predicted mean vote (PMV) and predicted percentage dissatisfied (PPD) produced by Fanger and given in the ASHRAE Handbook (ASHRAE 1997). These equations are based on an empirical investigation of how people react to differing environments. It is well known that different people will have a different perception of the climate produced in a building, and that any given climate is unlikely to be considered satisfactory by all. In fact, it is considered that satisfying 80% of occupants is good, so a PPD of less that 20% is good. PMV and PPD provide a measure of the likely response of people. The predicted mean vote is an index from - 3 (representing a response of very cold) through 0 (representing a thermally neutral response) to +3 (representing a response of very hot). The predicted percentage dissatisfied is directly related to the predicted mean vote, and so some people suggest that one is redundant. However, from an engineering stance, it is useful to have both immediately available. While PPD provides the information as to whether the environment is likely to be acceptable, PMV tells us what the problem is — whether it is too hot or too cold when the number dissatisfied is too large [3].

The equations implemented in the analysis [3] shown here are taken from Fanger's equations for PMV (ecuation 2) and PPD (ecuation 6) as given in BS EN ISO 7730: 1995.

$$PMV = (0.303\,e^{-0.036M} + 0.028)\{(M - W) - 3.05*10^{-3}[5733 - 6.99(M - W) - p_a] - 0.42[(M - W) - 58.15]\; 1.7*10^{-5}M(5867 - p_a) - 0.0014M(34 - t_a) - 3.96*10^{-8} f_{cl}[(t_{cl} + 273)^4 - (t_r + 273)^4] + f_{cl}h_c(t_{cl} \pm t_a)\} \quad (2)$$

where:

$$t_{cl} = 35.7 - 0.028(M - W) - I_{cl}\{(3.96 * 10^{-8} f_{cl}[(t_{cl} + 273)^4 - (t_r + 273)^4] + f_{cl}h_c(t_{cl} - t_a)\} \quad (3)$$

$$h_c = 2.38(t_{cl} - t_a)^{0.25}\_or$$
$$h_c = 12.1v^{0.5} \quad (4)$$

whichever is greater.

$$f_{cl} = 1.00 + 1.29 I_{cl}\_for$$
$$I_{cl} < 0.078\, m^2 kW^{-1}\_or$$
$$f_{cl} = 1.05 + 0.645 I_{cl}\_for$$
$$I_{cl} > 0.078\, m^2 kW^{-1} \quad (5)$$

$$PPD = 100 - 95e^{-n} \quad (6)$$

where

$$n = 0.03353 PMV^4 + 0.2179 PMV^2 \quad (7)$$

The other variables are:

- PMV – predicted mean vote
- PPD – predicted percentage dissatisfied
- M – metabolic rate (W/m^2 of the body area)
- W - external work (W/m^2 of the body area, = 0 in most cases)
- I_{cl} = thermal resistance of clothing (m^2*kW^{-1})
- $f_c l$ = ratio of clothed surface area to nude surface area
- t_a = air temperature (°C)
- t_r = mean radiant temperature (°C)
- v = air velocity relative to the body (m/s-1)
- p_a = partial water vapor pressure (Pa)
- h_c = convective heat transfer coefficient (W*m^2*K)
- $t_c l$ = clothing surface temperature (°C)

The number of parameters used to produce these measures begins to show how complex the human response is to the environment. PMV and PPD include air temperature, mean radiant temperature, air velocity, vapor pressure, clothing level, metabolic rate, and external work rate.

III. MODELING OF DATA COLLECTED

The historical data look like in the fig. 1. But not all data are useful for modeling, especially if the period of acquisition is very large. We make an average for each day, as it's presented in fig. 2 and we used this data for modeling.

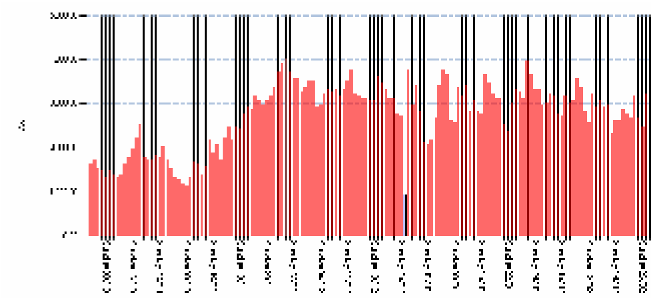

Figure 2. The average of energy consumption for each day

As it can be seen comparing the two types of data – historical and statistical - there are similar. This means that if we consider just the statistical data, the approximation is good enough for all data collected.

They can be defined two models. first takes into account the temperature and second the humidity. This data are presented in the fig. 3 (the temperature) and fig. 4 (the humidity).

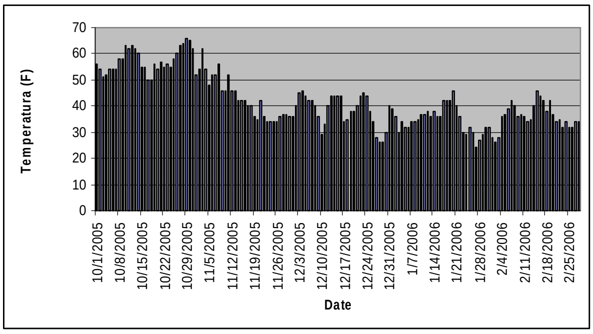

Figure 3. The average of temperature for each day

It can be easily observed from the graphics that the consumption of gas increases when the temperature decreases, as it's well know. In the same time, the role of the humidity is more difficult to be determinated, because the effect of humidity over the human sensitivity depends of dry-bulb temperature, parameter for witch we don't have data.

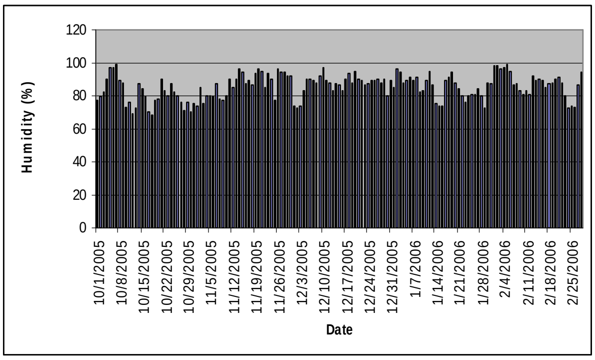

Figure 4. The average of humidity for each day

Regression model building

Regression analysis is one of the most popular techniques for predictive modeling. A multiple regression model [5] with more than one explanatory variable may be written as

$$y = b_0 + b_1 x_1 + b_2 x_2 + .. + b_p x_p + e \quad (8)$$

where

- y is the output variable
- b_i the regression parameters (i=1,2,…,p)
- X_i the input variables (i=1,2,…,p)
- e the random error term.

In our case, the input variable are temperature and humidity. The random error term is 0.

The least-squares method is generally used for estimation purposes in the multiple-regression model. Once regression coefficients are obtained, a prediction equation can then be used to predict the value of a continuous output (target) as a linear function of one or more independent inputs. The popularity of the regression models may be attributed to the interpretability of model parameters and ease of use. However, the major conceptual limitation of all regression techniques is that one can only ascertain relationship but can never be sure about underlying causal mechanism.

In our application for the prediction of gas consumption, polynomial regression [6] model is used, that fits data to the following equation:

$$y(x) = b_0 + b_1 x + b_2 x^2 + ... + b_p x^p \quad (9)$$

for some integer p ≥ 1 and unknown parameters β0, β1, . . ., βp. In our case, the variable *x* represents the temperature.

For the collected data, a good conditioned polynomial has as parameter the temperature and is less or equal then 4 degrees. The coefficients of the polynomial of degree 2 are [-0.0312 1.5150 53.3039], the coefficients of the polynomial of degree 3 are [0.0010 -0.1608 7.0970 -23.9061] and the coefficients of the polynomial of degree 4 are [0.0002 -0.0390 2.4573 -66.7531 732.5477]

These results were obtained with a simulation in Matlab. The function *polyfit* is used for the polynomial regression and an algorithm is implemented for multiple regression.

We compare the simulated results with the data collected one year later through the coefficient of determination of the regression (R^2). The model is better if coefficient of determination of the regression is closer by 1.

- for the 4 degrees polynomial R^2 = 0.7324
- for the 3 degrees polynomial R^2 = 0.7029
- for the 2 degrees polynomial R^2 = 0.6979
- for the multiple regression model R^2 = 0.6520

As it can be observed the model that fits the best is the polynomial regression model, where the degree of the polynomial is 4. The humidity parameter doesn't play a significant role because the building is well isolated and the ventilation is also good.

IV. CONCLUSION

Regression models are mainly adopted to predict energy consumption. The use of alternative analytical methods has not been popular in the energy consumption literature. While the regression analysis method is supported by statistical theories as producing good estimates according to certain statistical properties, for instance, being the best linear unbiased estimator, other approaches are found useful in developing predictive models in other fields.

The future steps in our work is to obtain a better model that takes into account as many parameters as possible from the parameters presented in the section II.

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