Exploring On-Line Meteorological Resources in Engineering

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***Abstract*—Meteorological stations are now-a-days used worldwide in many different fields: agriculture, civil engineering, thermal comfort, architecture, renewable energy, etc.**

The Laboratory of the Building Physics (FEUP) in collaboration with mechanical department, has been, supporting on-line delivery of the data from a meteorological station. This system has been used since nineties with great success in teaching and researching activities support both, in Civil and Mechanical Departments and also shared internationally for wide use.

The numerous activities performed based on this on-line experiment motivated the authors to share some case studies currently used in Engineering curricula.

***Index Terms*—on-line experiment, meteorological station, atmospheric sensors.**

I. INTRODUCTION

In the 1990s the Laboratory of Building Physics (LFC) was the first lab at FEUP to deliver online data related with meteorological physical quantities from the station available in the former FEUP location, at Porto town center, Figure 1.

In 2000 the FEUP moved to the present campus and so did the station. Later, since the middle of the last decade, there has been a joint effort between Mechanical and Civil Engineering staff, and in 2007 a new webpage was launched at FEUP making the station data available online as in the previous decade, Figure 2.

In 2008 the malfunction of the old meteorological station forced its replacement by a new one. The new station had to be set and the software interface reformulated in order to get on-line information of urban type climate at FEUP. Data from different sensors have been collected and used for students' work either at undergraduate or postgraduate levels. Meanwhile, in 2009, a cooperation project with the Budapest University brought an extension of the language interface (from English) to Hungarian and Portuguese [1]. Later, some links and other information were also included, namely related with the station instrumentation and some dissemination of museum equipment type, Figure 3 [2]. Additionally, a night vision outdoor IP camera was mounted and connected to the webpage as to reinforce the feeling of a real lab. The camera is enclosed in a protected house with a heater resistance and fan to keep the images clean under all weather conditions.

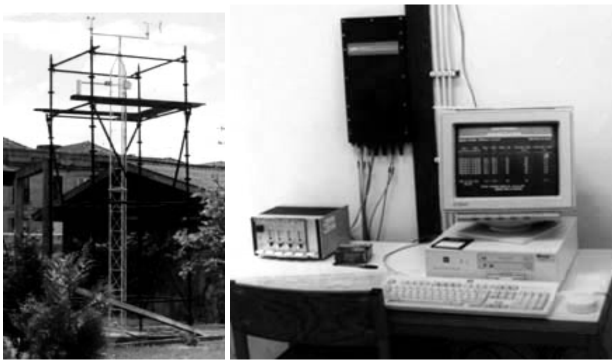
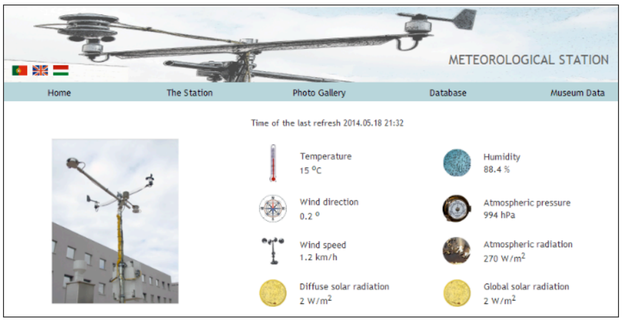


Figure 1. LFC weather station in the 1990s



Time of the last refresh 2014.05.18 21:32

Temperature
15 °C

Humidity
88.4 %

Wind direction
0.2 °

Atmospheric pressure
994 hPa

Wind speed
1.2 km/h

Atmospheric radiation
270 W/m^2

Diffuse solar radiation
2 W/m^2

Global solar radiation
2 W/m^2

Figure 2. Webpage delivering online meteorological data (2007)

This station has been very popular and some educational institutions were permanently connected to it, e.g. Labvirtual [3] and Mocho [4]. Its use has also been enlarged by the international cooperation which contributes to promote Engineering Education and training in the present scenario of "global engineering", [5-10]. This resource not only increases student awareness and motivation in using real data, but also exposes them to other education systems, curricula and learning tools. Moreover, access to remote and virtual resources should be looked as important as the access to any other type of learning objects which presently attract special attention from institutions everywhere [11].

Remote labs based in Meteorological Stations are usually oriented for contributing to a global world network on environmental data and knowledge, looking mainly to get as much data as possible on climate. In fact, many have been appearing everywhere and they can contribute for a huge "Global Meteorological Virtual Institute". More than providing real data from environment measurements, their analysis can assume relevance to identify representative environmental indicators, contributing for evaluating trends and to prevent potential environmental risks [12].

In the recent past the interest in evaluating the energy power available from renewable energy resources increased the number of solutions for measuring meteorological quantities in extended areas before the implementation of “huge energy farms”.

Weather models and forecast are based in experimental meteorological data and are especially important for agriculture to plan most of the tasks, like irrigation or harvesting [13-15].

However, the main goal of this remote lab is to provide real data of the urban climate at FEUP Campus to be used in R&D and training activities. The scope of the present work is to share some examples and case studies offering the bases of training activities either at civil or mechanical fields.

A description of the system sensors/transducers will be also included as well as the system architecture.

II. TECHNICAL FEATURES

The meteorological station is equipped with a data logger (Micromec Logbox) with serial and Ethernet communication ability. However, since its software didn’t allow a periodic automatic data retrieval, it was developed an application in LabVIEW 8.5. This application collects the sensors’ data (temperature, wind velocity and direction, ambient air pressure, relative humidity, global and diffuse solar radiation incident on a horizontal surface, normal rain and atmospheric radiation incident on a horizontal surface) from the station data logger and send it every day to a predefined set of emails. In addition, it sends the data to a *MySQL* database installed in a local server, running *Apache*.

The database can be query through the webpage, (http://experimenta.fe.up.pt/estacaometeorologica/index.php?lang=en), using a *PHP 5.0* application, Figure 5.

III. CASE STUDIES

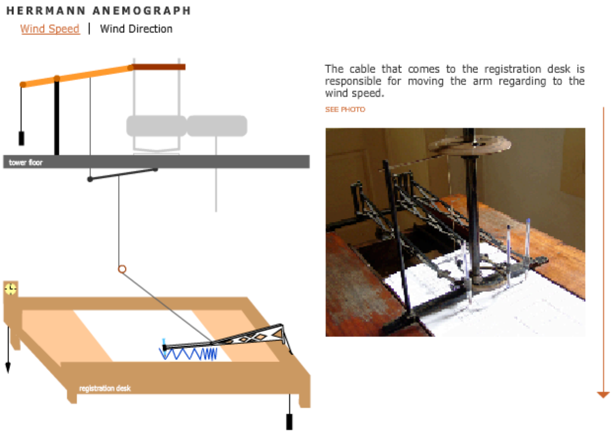
A. *Usefulness in the civil engineering field*

The data of the weather station is often used by civil engineering students to assess the hygrothermal behavior of the buildings. In this chapter two examples are presented, both analyzing the behavior of the buildings façades in FEUP. One of the examples shows how the climatic data, namely temperature and relative humidity, influence external surface condensation on an external thermal insulation system and the other points the relevance of the climatic data, namely temperature, relative humidity, solar radiation and wind driven rain in the water content of the same façade.

1) *Surface condensation on external thermal insulation composite systems*

External Thermal Insulation Composite Systems – ETICS are often used in Europe since the 70’s. ETICS are systems comprising prefabricated insulation panels, bonded and/or mechanically fixed onto the wall. Normally, in the Portuguese market, the insulation panels are expanded polystyrene (EPS), adhesively attached to the substrate and covered with a coat base reinforced with fibreglass mesh with a finish coat of thin acrylic-based rendering.

Despite its thermal advantages, low cost and ease of application, ETICS is facing a very serious problem: defacement caused by microbiological growth. Microbiological growth is due to high values of surface moisture content in a certain period of time, which depends mostly on exterior surface condensation.



The cable that comes to the registration desk is responsible for moving the arm regarding to the wind speed.

Figure 3. Meteorology museum apparatus (animation in the left and the picture in the right)

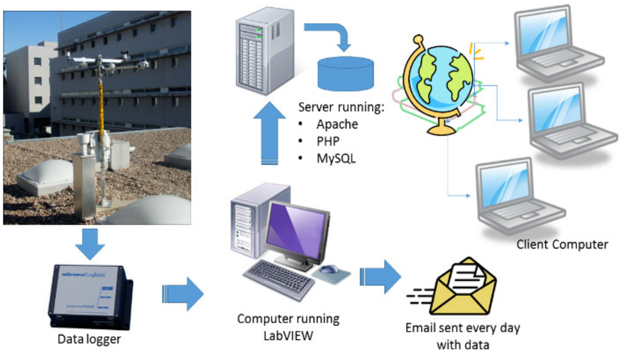
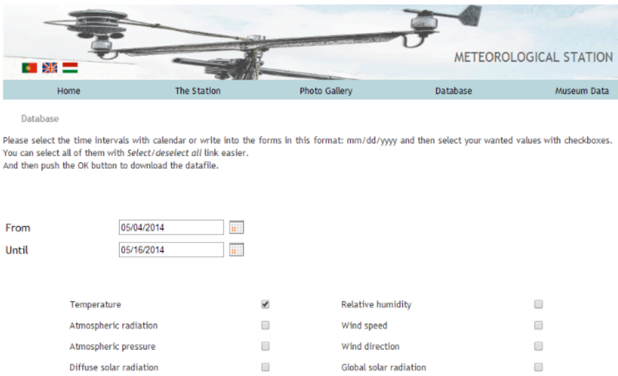


Figure 4. System architecture



Database

Please select the time intervals with calendar or write into the forms in this format: mm/dd/yyyy and then select your wanted values with checkboxes.
You can select all of them with *Select/deselect all* link easier.
And then push the OK button to download the datafile.

From 05/04/2014
Until 05/16/2014

Temperature ☑ Relative humidity ☐
Atmospheric radiation ☐ Wind speed ☐
Atmospheric pressure ☐ Wind direction ☐
Diffuse solar radiation ☐ Global solar radiation ☐

Figure 5. Online meteorological data available in the Station webpage

Although no statistical studies are available for the Portuguese case, it is assumed that there is a relatively high percentage of buildings covered with ETICS that present defacement due to microbiological growth. Especially when located in the coastal zones, like the case studied. One of the main causes for this problem is the Portuguese climate, particularly in the west coast which has mild temperatures and very high relative humidity year-round [16].

Exterior surface condensation can be analyzed using psychrometry principles. When water vapor partial pressure of the air is greater than the water vapor saturation pressure at the surface, condensation will occur. According to [17], the difference between the water vapor partial pressure in the air and the water vapor saturation pressure on the surface may be called Condensation Potential (CP), which implies condensation for positive values:

$$CP=P_v\,(air)-P_{sat}(surface) \qquad (1)$$

where $P_v(air)$ is the water vapor partial pressure in the air, and $P_{sat}(surface)$ is the water vapor saturation pressure on the surface. The accumulated value of positive Condensation Potential [$(CP > 0)_{accum}$] during a certain period of time allows the estimation of the amount of water vapor that is available to condensate in that period of time [17].

An experimental campaign was carried out to assess, among other topics, where in a façade condensation is more severe: near the corners, or in the middle of the wall. The tests were performed on one of the buildings of FEUP campus. The equipment was set up on the envelope of a technical body, located on the roof of the classes building. This technical building was chosen because it is close to the weather station, which collects the necessary climate data for this study. T-type thermocouples were used to assess surface temperature and placed in a square grid of 0.7 m (Figure 6).

The façade under study has the configuration indicated in Figure 7 and is facing North.

The average values of the outdoor climate variables, for the test period, are presented in Table I.

Although there was no significant variation between the temperatures measured by each thermocouple, when assessing the accumulated positive *CP* the differences become clearer. Surface condensation is higher at a distance of 1.4 m from the ground and from the left edge of the façade (Figure 8). These results are confirmed if positive *PC* is accumulated considering the average temperatures by each line and row (Figure 9). Higher surface condensation occurs for the line at 1.4 m from the ground and for the row at a distance of 1.4 m from the left edge of the façade, corresponding to the middle of the façade.

Surface temperature during the night depends on the heat transfer on the surface, which consists of two components: convective heat transfer and radiative heat transfer. Assuming that for the façade under study the incident long wave radiation is constant, the variation on the surface temperature is due to the convective heat transfer.

The convective heat transfer depends on the wind, which has different effect on the façade (higher in the corners and lower in the middle). For that reason, heat transfer by convection from the air to the surface is higher in the corners, which increases surface temperature and decreases condensation. Studying the current area of a façade is therefore a conservative approach of the reality.

TABLE I.
OUTDOOR CLIMATE (AVERAGE FOR THE TEST PERIOD – 14/01/2009 TO 25/01/2009)

Climatic parameter	Transducer	Average value
Temperature	Pt100 sensor	9.9 ºC
Relative humidity	Hygrometer sensor	88 %
Global radiation emitted by the sun	Pyranometer	117 W/m^2
Radiation emitted by the sky	Pyrgeometer	345 W/m^2
Wind velocity	Anemometer	1.8 m/s
Wind direction	Vane	158 º
Rain (accumulated)	Rain gauge	144 mm

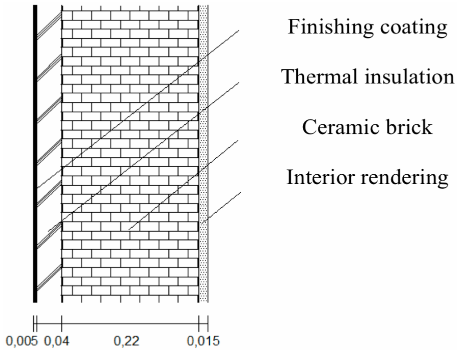


Figure 6. Wall under study

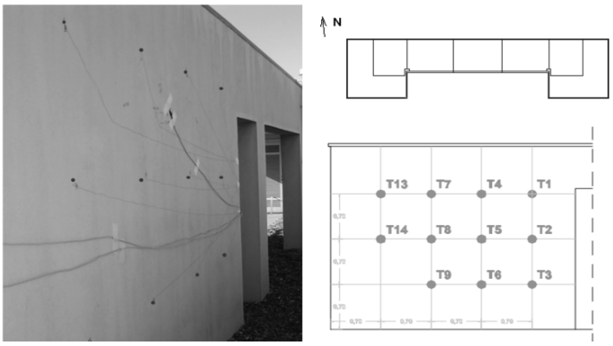


Figure 7. Thermocouples location on the North façade of the building

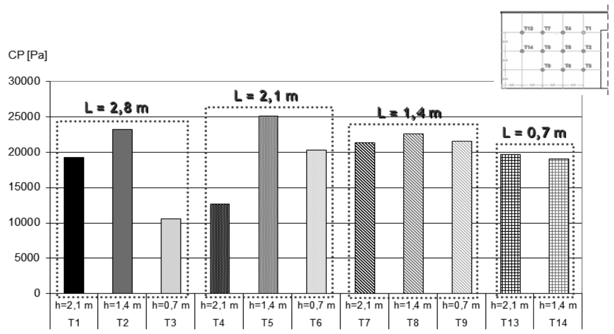


Figure 8. Accumulated positive CP for each thermocouple for the period under study (14/01/2009 to 25/01/2009)

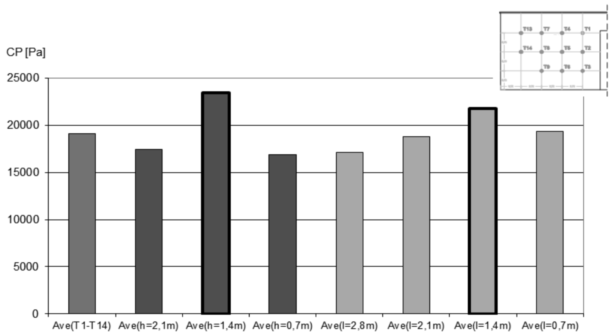


Figure 9. Accumulated positive CP by line and row for the period under study (14/01/2009 to 25/01/2009)

2) *Water contents variation of façades due climatic conditions*

Building pathologies originated by moisture are frequently responsible for the degradation of building components and can affect users' health and comfort. The solutions for treating moisture related pathologies are complex and, many times, of difficult implementation.

Several of these pathologies are due to innovative techniques combined with new materials of poorly predicted performance. The knowledge of the physical processes that define hygrothermal behavior allows for the prediction of a building response to climatic solicitation and for the selection of envelope solutions that will lead to required feasibility.

Using the climatic data measured by the LFC weather station, it was possible to simulate the hygrothermal behavior of façades covered with ETICS located in FEUP. The simulation was performed for a 30 days period, from 11th March to 10th April 2011. The climatic parameters of the air temperature, relative humidity, wind direction and velocity, normal rain, barometric pressure, diffuse and global solar radiation were hourly averages. The averages, for the test period, are presented in Table II.

Figure 10 shows the variation of the total water content of the façade from Figure 1 facing North and South, during the simulated period. It is possible to see that wind driven rain (rain water incident on the façade due to the wind influence) affects the water content of the façades in different way as the amount of rain reaching each façade is also different (Figure 11). The amount of rain is higher on the South façade, and when it rains the water content increases considerably regarding the North façade.

During the day, solar gains inside the room with the façade facing South are much higher than in the North façade because the incident radiation is also higher (Figure 12). Due to thermal inertia of the building, during the night the temperature inside the South' room remains higher, which induces higher interior surface temperatures. The effect of solar radiation is possible to be assessed, even during the night. As an example, Figure 13 shows the profiles of the façades facing North and South, at midnight of 19th May. It is possible to see that the interior surface temperature (right side) on the South façade is more than 1 ºC higher than on the North.

B. *Usefulness in the mechanical engineering field – Combustion of Fossil Fuels*

In a course of the mechanical engineering degree, graduate students need to become familiar with calculations involving energy production systems efficiency and its relation with fossil fuels combustion within different applications and geographical locations.

The present methodology can either be integrated in a course assignment or, as a part of an in-class learning activity. It aims at promoting critical thinking and involving students with real world problems that will better prepare them for the global workplace [18-19].

TABLE II.
OUTDOOR CLIMATE (AVERAGE FOR THE TEST PERIOD – 11/03/2011 TO 10/04/2011)

Climatic parameter	Average
Temperature	19.5 ºC
Relative humidity	0.50
Global radiation emitted by the sun	279 W/m^2
Diffuse radiation emitted by the sun	103 W/m^2
Wind velocity	1.02 m/s
Wind direction	170 º
Rain (accumulated)	75 mm

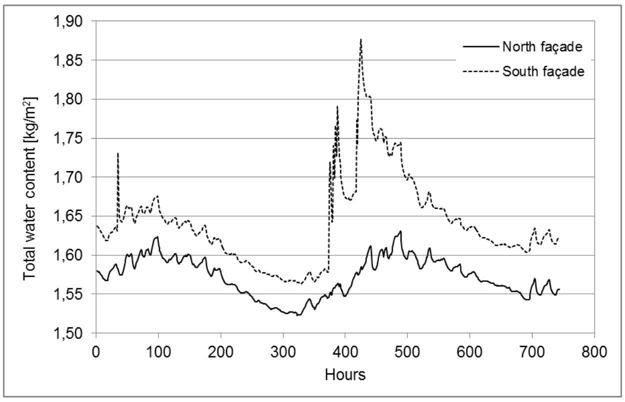


Figure 10. Total water content of the North and South façades

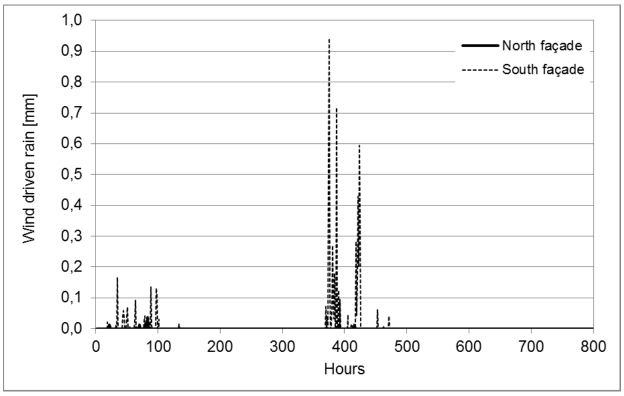


Figure 11. Incident rain on the façades facing North and South

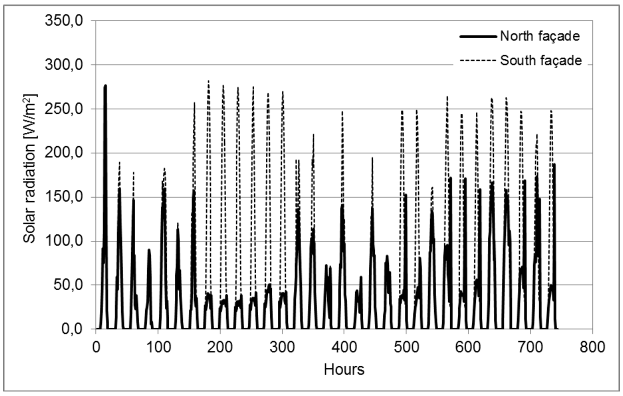


Figure 12. Solar radiation incident on the façades facing North and South

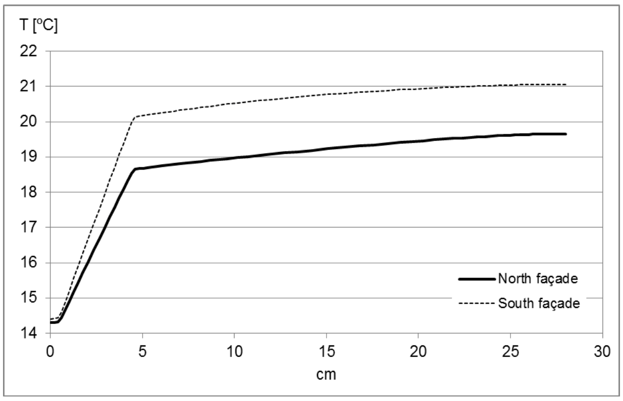


Figure 13. Temperature profiles of the North and South façades at midnight of May 19.

The specific objective is also to integrate previous acquired knowledge in other related courses of thermodynamic cycles and combustion (e.g., Thermodynamics and Heat Transfer) in a way that allows students to look at different conditions, conduct parametric studies and collaborate in an overall analysis of a specific power generation system [20-21]. The "What if?" questions that may rise are usually object of study of another student / group.

In this case data collected from the meteorological station is used to get students engaged in information research and build their own case study. Students choose the characteristics of the combustion air (temperature, pressure and relative humidity) from the meteorological station data on a specific day. Winter and summer day's series are available, as shown in Figure 14.

In order to apply the mass and energy balances to power cycles (gas and vapor power cycles or combined power cycles) students start by relating the combustion process and its characteristics with the thermal efficiency of a power plant. The first step includes the calculation of the theoretical combustion (stoichiometric) of methane (no unburned fuel and no free oxygen in the products) in dry air. For example:

$$CH_4 + 2\,(O_2 + 3.76\,N_2) \;\rightarrow\; CO_2 + 2\,H_2O + 7.52\,N_2$$

To make this a real problem, students choose the fuel (Natural Gas, NG) they want to work according with [22]. The first step comprises the choice of stoichiometric combustion conditions and dry combustion air, as shown in the diagram in Figure 15.

Then excess air (dry) is considered followed by the use of real atmospheric air conditions collected from the meteorological station (and /or data from stored month series).

Instead of passively receiving the information, students get actively involved in searching and choosing the necessary input data for their own case, namely, composition of the fuel and characteristics of the combustion air. In the latter case, they have to calculate for a specific fuel and air-fuel ratio, the influence of the atmospheric air moisture content based on the data collected from the meteorological station for a summer and a winter days. For these calculations, students need to know temperature, pressure and relative humidity (moisture content) of the atmospheric air, i.e., they need to consider the geographic location and the climate characteristics. In this context working with real data gives more flexible and reliable calculations, rather than working only with theoretical provided values. In fact, the data recorded in the database makes it possible to consider the weather in the respective area along a year, a month, and a day.

In stage one, reported here, one of the objectives is to understand how the atmospheric air characteristics in terms of water vapor content (moisture) influence the combustion itself, the exhaust gas composition and the overall system efficiency due to the dependence on the dew-point temperature (T_{dew}). One way of determining the combustion gas dew point temperature is by knowing the combustion air characteristics (including the relative humidity) and the water formed as a result of a combustion reaction.

The students need to integrate the knowledge of fundamental concepts as $T_{dew} = T_{sat\,@\,P_V}$ (where T dew is the saturation temperature of water corresponding to the vapor pressure P_V), and to understand that the temperature of the combustion gases is not to drop below (or even equal) the dew-point temperature.

They need to determine the air-to-fuel ratio (A/F), the exhaust gas composition as well as the dew point temperature (T_{dew}), as shown in Table III, and relate it with combustion efficiency and the overall system efficiency.

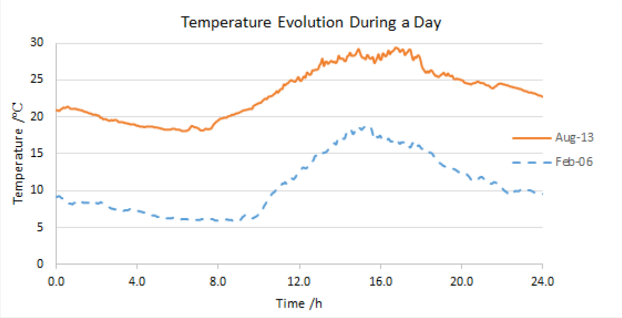


Figure 14. Temperature evolution along two days representative of summer and winter time (August 13, February 6)

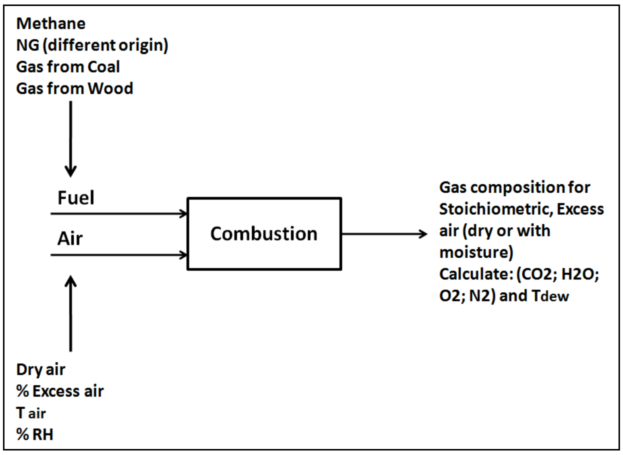


Figure 15. Schematic diagram of the initial proposed combustion process and variables

TABLE III.
SAMPLE VALUES FOR THE INITIAL PROPOSED COMBUSTION PROCESS

FUEL	AIR	Ex air (%)	(A/F) vol	Exhaust Gas (%)	T dew (ºC)
CH4	DRY	0%	9,52	CO_2 = 9,5 H_2O = 19,0 N_2 = 71,5	58,85
	DRY	30%	9,52	CO_2 = 7,6 H_2O = 15,3 O_2 = 2,3 N_2 = 74,8	54,33
ALGERIA NG	DRY	0%	10,8	CO_2 = 9,4 H_2O = 18,8 N_2 = 71,8	58,01
	DRY	30%	14,1	CO_2 = 7,8 H_2O = 14,4 O_2 = 4,5 N_2 = 73,3	52,99
	WINTER	0%	10,8	CO_2 = 9,8 H_2O = 19,0 N_2 = 71,2	58,85
	SUMMER	0%	10,8	CO_2 = 9,8 H_2O = 19,0 N_2 = 71,2	58,85
	WINTER	30%	14,1	CO_2 = 7,9 H_2O = 15,5 O_2 = 2,0 N_2 = 74,5	54,64
	SUMMER	30%	14,1	CO_2 = 7,9 H_2O = 15,6 O_2 = 2,0 N_2 = 74,5	54,64

The chosen application is related with the influence of ambient air conditions on energy production systems efficiency and to relate it with fossil fuels combustion as well as pollutant emission. The parameters considered most relevant are the air inlet temperature, the air humidity and pressure, as in the case of a gas turbine and in power cycles (gas and vapor power cycles or combined power cycles). The analysis will continue by evaluating the heat losses due to flue gas and by choosing another fuel (e.g., coal). Then, other parameters are considered as evaporation of water formed due to the H_2 in the fuel, unburned fuel in fly ash, etc. Ultimately the air inlet temperature (its density and therefore mass flow rate) as well as the air moisture content are related with turbine power output and NOx emission control.

IV. FINAL REMARKS

This work presents a remote meteorological lab of sensitive type. It is briefly described the history of the meteorological station, the system architecture, as well as different case studies based in the station recorded data along years, both of interest for Civil and Mechanical Engineering fields. This experiment has been relevant to contributing to support R&D and teaching activities worldwide, to promote engineering education and to foster teachers' and students' networking. It also contributes to make possible the concept of “Global Meteorological Virtual Institute” as a huge diversity of meteorological data which can be available in the world. The present work also pretends to share the case studies with all those interested in the topics.

This meteorological station has been collecting data since 1998 with some interruptions to maintenance and equipment update. Even so, a huge database has been recorded which allowed a considerable number of research either at Master or Ph.D. levels: Ph.D. theses 2 finished and 2 on-going and 8 Master dissertations plus supporting other projects and works.

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