

# DESIGN, CONSTRUCTION AND STUDY OF THE EFFICIENCY OF GREEN PANELS WITH A MONITORING SYSTEM FOR PHYSICAL VARIABLES

Oscar González Woge\*, Carlos Omar González Morán\*, Juan Carlos Baltazar Escalona\*, Gabriela Gaviño Ortiz\*, Héctor Herrera Hernández\*

Laboratorio de desarrollo de materiales y procesos inteligentes, Universidad Autónoma del Estado de México, Centro Universitario UAEM Valle de México, Blvd. Universitario s/n, Predio San Javier Atizapán de Zaragoza, C.P. 54500, Edo. de Méx., MÉXICO.

## ABSTRACT

The present work had some challenges such as to design and then construct an electronic system for monitoring the values of a select group of physical variables in a prototype of a green panel, the selected variables were temperature, relative humidity, soil humidity, mechanic and telluric vibrations and quantity of light, then study their behaviors of these variables mentioned before. To get the system ready for data acquisition and saving the data, it became necessary the construction of an electronically arrangement that understands; Open Source code, diverse types of electronic sensors and a free hardware device named "Arduino Uno board". The prototype of a green panel in which we installed the electronic system with sensors that recorded the changes in an automatic way, then they were sent to a computer connected to the system with an USB wire for capturing data in Microsoft Excel, with an interval defined by Open Source Code, constructing a database, after 44 days of monitoring, for processing the data we occupied the software "R studio" of Open Source for continuing the study with a statistical analysis giving the central tendency measures, graphs, histograms, density curves and proving the correlation between variables with correlation coefficient (R) obtained by "Pearson" methodology. The study of time series and for developing linear and non-linear equations were done with the least squares' methodology and GARCH method, running a simple regression, that included: logarithmic terms, quadratic terms, first differences, "dummies" and constants, in this case the statistical suites of choice were primarily E views, secondarily Minitab, SPSS, SAS and STATA. At the end of the regression, the results were in favor for the implementation of green panels in buildings, because they can bring several benefits to the environment. The conclusion was that the experiment generated atmospheric conditions that reduced in 8 °C of atmospheric temperature and the relative humidity in air is augmented in 15% and reduces carbon dioxide and carbon monoxide and the diminution of the "Urban Heat Island" effect in weather for a determined green area.

**KEYWORDS:** Open Source Code, Arduino, Green Panels, Monitoring.

**MSC:** 68U99

## RESUMEN

Para el presente proyecto se realizó la tarea de diseñar y luego construir un sistema electrónico para monitorizar, los valores de un grupo de variables dentro de un prototipo a escala de un panel verde, las variables seleccionadas fueron; temperatura, humedad relativa, humedad del sustrato, cantidad de luz, vibraciones mecánicas y telúricas, para luego estudiar el comportamiento de las variables mencionadas anteriormente. Para preparar el sistema para capturar y adquirir los datos y almacenarlos, se construyó un complejo electrónico que comprende diversos sensores electrónicos acoplados a una tarjeta de hardware libre para elaborar prototipos denominada "Arduino Uno" y que mandara los datos a un ordenador vía alámbrica (cable USB) y creaba hojas de cálculo en Microsoft Excel, con un intervalo de tiempo definido por código abierto, creando inmensas bases de datos, después de 44 días de monitorización, para posteriormente, sus cifras fueran procesadas mediante software "R studio" de código de fuentes abiertas, obteniendo las medidas de tendencia central, gráficas, histogramas, curvas de densidad y se demostraron las relaciones entre variables con el coeficiente (R) de correlación se obtuvo mediante el método "Pearson". El estudio de series de tiempo se logró desarrollar mediante ecuaciones lineales y no lineales; y se efectuó mediante el método de mínimos cuadrados y el método GARCH, corriendo una regresión simple que incluyó términos cuadráticos, logarítmicos, primeras diferencias, variables "dummy" o falsas y constantes, en este caso el software de elección fue E views, secundariamente Minitab, SPSS, SAS y STATA. Al terminar el análisis de regresión lineal, se obtuvieron resultados que confirmaron la eficiencia de los paneles verdes en el prototipo que se construyó, dando resultados que reforzaban la hipótesis del experimento, demostrando que las cubiertas vegetales instaladas en edificios reducen hasta en 8 °C la temperatura atmosférica y la humedad relativa del viento se potencializa hasta en 15 % más que en un edificio común y la disminución del efecto "Isla de Calor Urbana" por área verde determinada.

**PALABRAS CLAVE:** Arduino, código de fuentes abiertas, paneles verdes y monitorización.

## 1. INTRODUCTION

Currently the cities with high population density, show characteristics that make them places where is no longer possible to have the amenities that homes use to give to their owners, in part this is due to the Urban Heat Island effect, which is, an invisible dome forming in areas most densely populated, because exposure to surfaces or roofs of buildings absorb light and heat from the Sun during the day and release it at night, generating changes in the microclimate of the city.

On the other hand, a problem of this nature can be solved with a vegetal cover, known as green roofs, green walls, which have the virtue of providing thermal insulation, and does not absorb the heat of the Sun, but dissipates it with the same vegetable rug that is in contact with the Sun's rays and the building. As well the surface of materials such as concrete keep very high temperatures at certain times of the day, in comparison, the temperature of a surface covered with grass or plants is much lower. Also, the expansion and contraction of the material or surface covering the houses tends to wear out quickly, while the green roofs and green walls reduce wear by the stabilization of cooling and heating of the materials, acting as a protective layer of heat and cold during the hottest hours of the day and vice versa, during the cooler hours of the night.

For the implementation of the prototype, turned to engineering systems applied to the conservation of thermal comfort and insulation of the variations of the external climate, thus, we analyze data detected by sensors of physical variables in regular time intervals, to create a huge database (around 900,000 data): which allowed us to answer the hypotheses on the increase or decrease of temperature and relative humidity that exists between a common building and one with green panels, either in the ceiling or walls, as well as other variables such as soil humidity, Lux, telluric and mechanic vibrations. These data were collected during the period August to December. Allowing us to observe by means of linear and non-linear regression models and time series analysis changes to the thermal comfort, thermic efficiency and insulation of external factors that increase or they potentialize the desired characteristics of a house or building.

## 2. JUSTIFICATION

The living or green walls and ceilings are walls and/or roofs that are completely or partially covered with vegetation, distributed in the form of rectangles (green panels) and they are joined to each other to cover areas either solitary or integrated to a building or enclosure. Green roofs do not refer to synthetic green grass on roofs, or to roofs with plants in pots, but to roofs and/or walls with special adaptations that have the function of structural support for rugs of grass, plants and other types of vegetation. Green covers, green panels, vegetal rugs, vertical gardens and green gardens on roofs and walls, are some of the names that describe the system for installation of green areas in the walls and roofs of the buildings. One of the characteristics are the following: they can improve biodiversity, they also reduce the risk of inundation (retaining rain water): improve the thermal performance and efficiency of a building, they reduce the expense in electrical energy that supply for example: heating devices or air conditioners, they help with sustainable development and improve the aspect of a building, they also reduce the Urban Heat Island Effect, is the hot air dome that is created by the effect of the sunrays impacting against the concrete and paved surfaces, which have substituted the green areas, resulting in an increment of the temperature caused by the nocturne liberation of the caloric energy absorbed during the day by the constructed surfaces, generating micro-climatic changes in the weather of the city. The World Health Organization (WHO): establishes that it is recommended that large cities have at least of 10 m<sup>2</sup> to 15 m<sup>2</sup> of green area per inhabitant. In Mexico City, it is known that there is an average of 15.1 m<sup>2</sup> of green areas per habitant. Although it seems that the data is not so bad, the distribution of these green areas is not equitable. There are small delegations with high population density and few green areas. And delegations with lower population density and large green areas (Meza A., 2010 [1]). Therefore, it is a necessity to increase green areas of the city with green panels to achieve a better distribution of the green areas and which can be accomplished by reducing some of the negative effects of construction on the environment. Therefore, it is necessary to augment the green areas with green panels in buildings for distributing the green areas more evenly and to accomplish the diminution of some of the negative effects of the constructions over the environment.

In terms of sustainability in big cities, which have many problems, like; polluted air and environmental degradation, it is a good measure with a very positive impact in the search for a sustainable development. They are also useful as urban orchards, which encourages self-consumption of vegetables and/or fruits

and reduces expenses at the market. In the rural field they are also used as temperature regulators, they reduce the air pollution, they reduce the sanitary expenses derived from all pollutants and they improve the air quality, they absorb up to 80% of rain water thereby, they avoid possible flooding, they improve the appearance of a building and they augment the property's value (Mayor of London 2001 [2]).

**Framework:** The parameters of the physical variables that we will be registering are as follows: for the atmospheric temperature in a room in winter is 17-18 ° C, in summer is 26-27 ° C. For relative humidity in winter humidity it must not exceed 30%, in summer the relative humidity must be minimum of 40% and up to 70%. The variable amount of light measured in lux must be not less than 500 lux for an average room according to the NOM-025-STPS-2008 (Secretaría del Trabajo y Previsión Social 2008 [3]). Substrate humidity was measured with the physical scale known as capacitance and its units are Picofarads, which must not be less than 0.16 pF and the maximum is 2479.82 pF. For the variable telluric and mechanical vibrations measured in percentage its minimum should be an average of 4.61%. The parameters for the experiment. The interest in this issue lies in the fact that the green panels can also have beneficial results for the inhabitants of the place where they live, in this study it's intended to assess the performance of a prototype of a green panel on the monitoring of physical variables with sensors as: thermometers, hygrometers, mechanical and telluric vibration sensors, light meters. With his deployment of systems of monitoring on a prototype of a green panel, the temperature reduction will be achieved up to 8° C in the roof and 2 to 4° C in immediate downstairs of the property in the warmer months and will retain heat in the winter months. Increasing the relative humidity of 15 to 80% instead, thus becoming a comfort zone for people who are in it (Barahona S., 2011 [4]). Natural water cycle: from 50 to 60% of rain water returned to the atmosphere via evapotranspiration and avoids it to go to the drain. Assumes that the telluric vibration is reduced, and we are checking them, if it is true. Verification of the amount of light entering the building.

### 3. HYPOTHESIS

The actual investigation work has for objective to demonstrate, the main differences of ambient temperature, relative atmospheric humidity, substrate humidity in the green panel or green rug, the quantity of vibrations that will be monitored inside the prototype supplied with the engineering system of green roofs, and a room or office not supplied with green roof system, to monitor the variables, study and analyze the samples that were taken in both experiments; the sample from the prototype (green roof) and the sample from the office (flat roof) during the interval of 44 days, in typical weather conditions and with an even rate of monitoring during all the experiment. The monitoring of variables will seek to join a statistical population comprised of 3 samples of 3 experiments and samples will be analyzed with packages for statistical analysis, analysis of linear/non-linear regression and time series, to conclude with findings that support the real estate developments of the future, whereas the system of green panels for homes, buildings, etc.

#### Objectives

**General objective:** The objective of quantitative research is to acquire fundamental knowledge and the choice of the most appropriate models that allow us to know the reality in a more impartial way, which collected and analyzed the data through the concepts and variables. Therefore, for the present research project, will be putting into practice concepts and variables acquired by means of the methodology presented in the following pages, based on the concepts of the generation of statistical models that show us the performance of green panels, by means of data acquisition from sensors that measure the variables mentioned before: temperature, relative humidity, soil humidity, quantity of light and mechanic and telluric vibrations. To demonstrate the parameters in the green panel it's necessary to realize a quantitative statistical analysis, for developing the correct prediction models of the behavior of the correlated variables and they can bring a precise estimation of the real behaviors through time with the best possible reliability.

#### Specific Objectives:

- Design and construct a green panel for studying its performance.
- Design the sensor system.
- Develop a data acquisition system that is synchronized with the sensor system.
- Analyze the monitored information for demonstrating the system efficiency.

#### 4. DESCRIPTION OF THE MONITORING SYSTEM

It was a task to design a system for monitoring physical variables such as: air temperature, relative humidity of the atmosphere, telluric and mechanic vibrations, quantity of light and humidity of the substrate, which have the statistical sampling to produce a linear regression analysis using the method of least squares shall be fundamental to be able to describe the characteristics desired in the comfort of a room. Sensors are electronic components that work with voltages no greater than 5 volts and consume not more than 100 mA.

To complete the design of the system of monitoring that was mounted in the prototype (green panel): the sensors were organized in a printed circuit board that served as an assembly named “Shield” that was coupled to a free hardware card named Arduino. For the creation of the printed circuit board with software Fritzing. The variables were captured by a USB wire to a personal computer using Excel 2016 software in conjunction with an application called PLX-DAQ. This program can acquire data in real time, where it permits the setting of the mode of acquisition such as: header, number notation, sampling, time and date, and size of the sample interval.

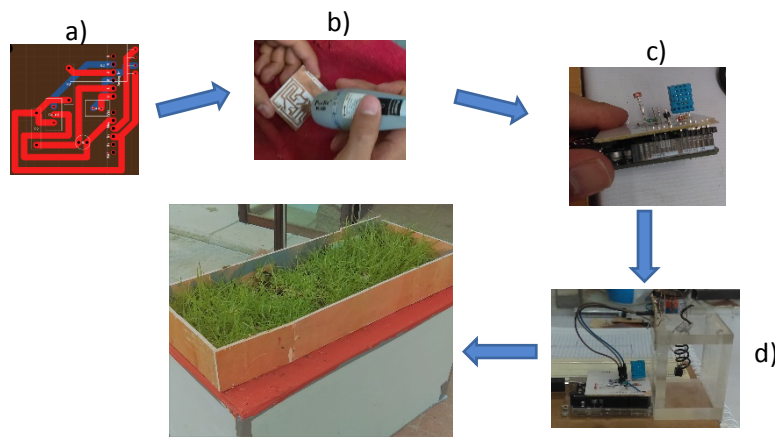


Figure 1. Design and construction of the monitoring system of physical variables for the prototype (green panel): a) PCB, b) printed circuit c) adaptation of the Shield to the Arduino, d) monitoring system.

**Sensors for the monitoring system:** For the monitoring of the prototype, the system has 4 electronic sensors, the first of them is DHT 11 sensor that measures air temperature and air relative humidity, a LDR photoresistor which give us an electric quantity relative to the darkness or maximum light intensity, CNY 70 sensor that measures the proximity of objects, a capacitive sensor of parallel plates which gave a relationship of capacitive quantity (pF) with respect to the degree of humidity of the substrate, all of them were arranged so that it registers data in Excel spreadsheet for further analysis and management, the data was applied with various mathematical techniques and statistical functions such as: the average, standard deviation and normal distribution, as well as obtaining its graphics. Both systems (external and internal) are activated at the same time to generate a quantitative sample. On average, the internal system, capturing 11,000 numerical data in Excel distributed in 5 columns (one for each variable): and in the case of the external monitoring system, capturing 11,000 data a day with 3 columns (one for each variable): generating several 88000-daily data for 44 days.

**Construction of the Green panel for simulation:** To build the prototype, we deal with common materials in the industry of construction, for the walls; panels of Sheetrock, for the structure; wood for the base and the roof beams; plywood and to isolate the complex; asphalt mats that protect it from moisture; acting as impermeabilization for the grass rug, with all of these elements the prototype was complete, in order to simulate the conditions of a house that implements the technology of green roofs. Next proceeded to place the plant mat of grass on the roof of our Green panel and surround it with a wooden frame which prevents the soil from overflowing with irrigation. The population of our database was completed when performing a total of observations showing greater reliability for a precise statistical analysis. We divide them into samples for each experiment to analyze separately each sample, then describes the analysis for each sample and the number of observations per sample and by variable.

Finally, install the monitoring systems inside the and outside of the prototype to start measuring, storing and ordering the observations and then analyze them.

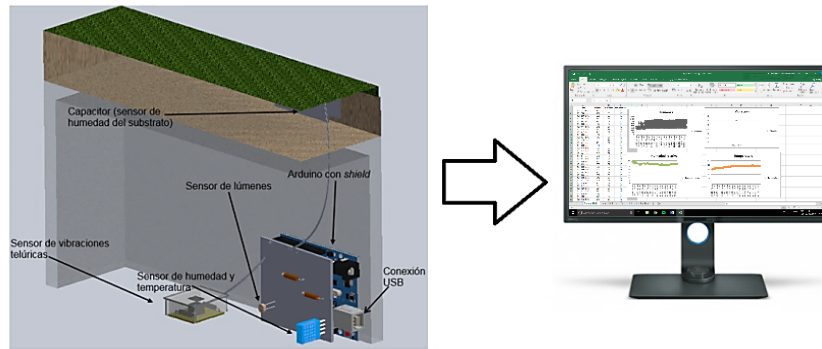


Figure 2. Installation and display the Green panel with the system of monitoring of physical variables.

When the monitoring experiment is finished, is then realized the statistical analysis of the physical variables by means of descriptive statistics with software suites such as R studio, E views, Stata, SPSS, SAS and Minitab, in which allowed to realize the linear and non-linear regression and further graphing and analysis of the equations, then estimating the behavior of the variables. The R studio software was mainly applied to develop scatterplots and correlation matrixes to visualize the data. The other software of choice was E views, which provided the time series analysis of our database, the equations were developed by assigning dependent and independent variables as the correlation analysis considered which were appropriate for every group of variables, also the equations needed quadratic terms, logarithmic terms, constants and “dummy” variables to adjust the regression. When the time series analysis was done results were reported as equations that summarized the behavior and forecast for those variables. Stata, SPSS, SAS and Minitab were barely applied but this doesn’t mean that they weren’t helpful.

**Results:** This quantitative statistical analysis is based on concepts of descriptive statistics (Levine et al., 2006 [5]): since the observations were acquired by monitoring systems.

In addition to summarize them in sets described as populations and samples. Subsequently to be able to present these results we focus on obtaining continuous numeric variables, since they were measured by numeric scales and described in acquisition and monitoring systems as positive amounts of percentages of atmospheric humidity, Celsius degrees of ambient temperature, pico-Faradays correlated to the humidity of the subsoil (González, C., 2013 [6]): amount of light outdoors in proportion and percentages of telluric vibration. To generate a statistical population, we put together Excel spreadsheets in the SPSS software, which allowed us to have a huge database, in total amounted to a population of 866,042 observations. See Table (1).

Table 1. Summary of the data of each experiment.

| <u>Sample to acquire</u>      | <u>Observations</u> | <u>Variables</u> |
|-------------------------------|---------------------|------------------|
| <b>Prototype (Interior)</b>   | 384,046             | 4                |
| <b>Building (work office)</b> | 141,734             | 3                |
| <b>Prototype (Exterior)</b>   | 340,262             | 3                |

Depending on the experiment, some variables like: temperature, relative humidity, soil moisture and telluric and mechanic vibrations were applied for the prototype, but the quantity of light variable was not applicable. On the other hand, the experiment of monitoring on the outside of the prototype and inside of the building (flat roof): had the following selection of variables: quantity of light, air temperature and relative humidity. See Table (2).

Table 2. Variables sampled on each experiment.

|                      | Database prototype (interiors) | Database building (work office) | Database prototype (exteriors) |
|----------------------|--------------------------------|---------------------------------|--------------------------------|
| Name of the variable |                                |                                 |                                |
| Temperature          | ✓                              | ✓                               | ✓                              |
| Relative Humidity    | ✓                              | ✓                               | ✓                              |
| Lux                  |                                | ✓                               | ✓                              |
| Vibrations           | ✓                              |                                 |                                |
| Substrate humidity   | ✓                              |                                 |                                |

**Results of the prototype of a Green panel:** Measures of central tendency each of the physical variables, averages, minimum, and maximum amplitudes are to be found in the following table (3).  
 Table 3. Measures of central tendency for remarks on the prototype (green panel).

| Vibrations      |       | Relative Humidity | Temperature   | Soil Humidity     |        |
|-----------------|-------|-------------------|---------------|-------------------|--------|
| Acquired Data   | (%)   | Acquired Data     | Acquired Data | Acquired Data     | (%)    |
| Min.: 0.4888    | 0.25% | Min.: 7 %         | Min.: 4°C     | Min.: 0.16pF      | 0.006% |
| 1st Qu.: 7.3314 | 3.82% | 1st Qu.: 24 %     | 1st Qu.: 13°C | 1st Qu.: 29.84pF  | 1.20%  |
| Mean: 8.8436    | 4.61% | Mean: 36.57 %     | Mean: 15.35°C | Mean: 160.30pF    | 6.46%  |
| 3rd Qu.: 8.7977 | 4.59% | 3rd Qu.: 49 %     | 3rd Qu.: 17°C | 3rd Qu.: 209.56pF | 8.45%  |
| Max.:191.5933   | 100%  | Max.: 88 %        | Max.: 30 °C   | Max.: 2479.82pF   | 100%   |

For visualizing the data, it became necessary to use scatterplot matrix in R, which showed the following graphic, see Figure (3).

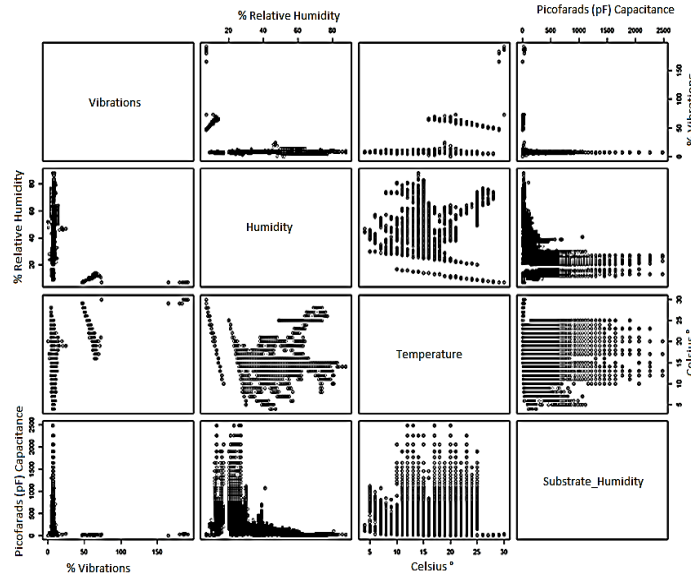


Figure 3. Scatterplot matrix for the variables sampled during the prototype experiment (green roof). The scatterplot showed before allowed to state the inference that the strongest relation would be, between air temperature and air relative humidity, then, the Correlation analysis by Pearson method was applied for more certainty, with code “corrplot” matrix in R. R packages for this task were: correllplot, corrgram,

corr, corrplot, matrix correlation, after deploying the libraries, and coding; the chart showed the next graphic, see Figure (4).

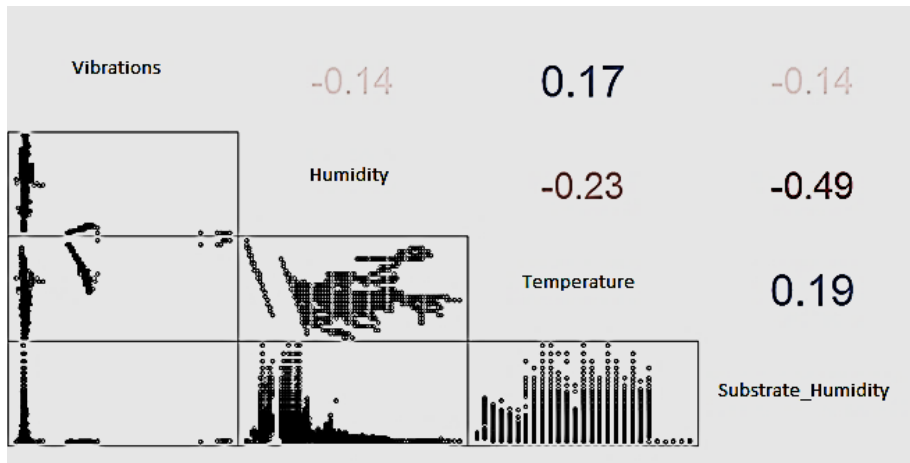


Figure 4. Correlation matrix made with the Pearson method.

Although the absolute value of the correlation coefficient between air humidity and soil humidity was bigger (-0.49); the regression showed no significance on its coefficients.

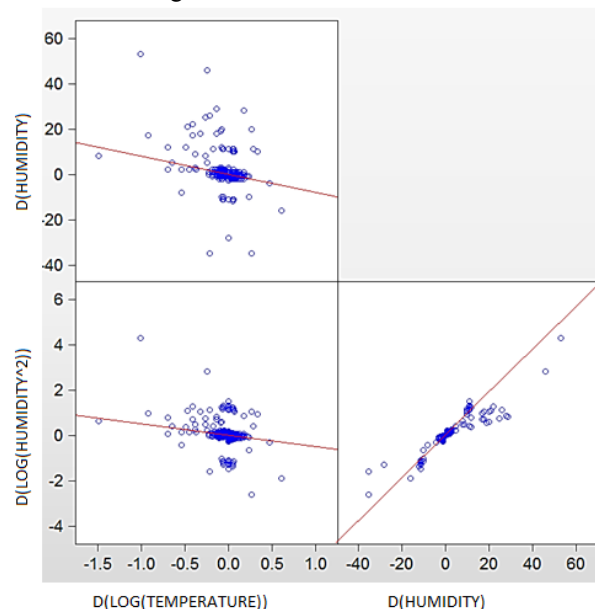


Figure 5. Scatterplot with slope for equation 1.

Relative humidity and temperature were assigned as variable in response; temperature, and as explanatory; variable humidity, since their regression coefficients were statistically high and in the scatterplot matrix showed the correlation between the two variables, also the correlation coefficient ( $R = -0.23$ ). After running the regression showing, the following equation (1) of non-linear regression model, as a result.

$$\begin{aligned} \Delta(\log(\text{Temperature})) &= -0.0144 * \Delta(\text{Humidity}) + 0.1151(\Delta(\log(\text{Humidity}^2))) + 0.0369 \\ &* \text{Dummy}_{8316} - 0.3492 * \text{Dummy}_{45119} - 0.7283 * \text{Dummy}_{189798} + [MA(1) \\ &= -0.6299, MA(2) = 0.0054] \end{aligned}$$

T-statistic, for coefficients,  $\beta_1, \beta_2, \beta_3, \beta_4, \beta_5$ :

$$(-1120.2847)***(477.3974)***(188.4744)***(-12.8486)***(-16.4321)***$$

Where:

$\Delta$ =first differences

log=base 10 logarithm  
 MA=Moving Average of first order and second order

The equation shows that the temperature varies negatively 1.4%, while the humidity is zero. This means that when the humidity increases, the temperature decreases, meaning that they have a proportionally inverse relation, which is manifested by the straight line with a slope of negative tilt to the right, describing the behavior of the variables with their coefficients  $\beta_1$  and  $(\beta_2)^2$ , which shows the statistical significance of the slope to the equation. See Figure (5). The results are displayed in short form, see Table (4).

Table 4. Results of the regression by least squares method.

| Variable                   | Coefficient  | Standard Error             | T-statistic | Probability |
|----------------------------|--------------|----------------------------|-------------|-------------|
| $\Delta(Humidity)$         | -0.0144      | 1.2918e-05                 | -1120.2847  | 0.0000      |
| $\Delta(\log(Humidity^2))$ | 0.1151       | 0.0002                     | 477.3974    | 0.0000      |
| D 8316                     | 0.0369       | 0.0001                     | 188.4744    | 0.0000      |
| D 45119                    | -0.3492      | 0.0271                     | -12.8486    | 8.9151e-38  |
| D 189798                   | -0.7283      | 0.0443                     | -16.4321    | 1.1811e-60  |
| MA(1)                      | -0.6299      | 8.2715e-05                 | -7576.5734  | 0.0000      |
| SIGMASQ                    | 0.0002       | 2.5884e-08                 | 6322.2594   | 0.0000      |
| R <sup>2</sup>             | 0.3355       | Mean of dependent variable |             | -1.6848E-07 |
| R <sup>2</sup>             | 0.3355       | Standar deviation          |             | 0.0156      |
| Standar error              | 0.0127       | Info. Akaike               |             | -5.8798     |
| Sum of squares resids      | 62.8480      | Schwarz Criterium          |             | -5.8796     |
| Log likelihood             | 1129069.0631 | Hannan-Quinn Criterium     |             | -5.8798     |
| Durbin-Watson stat         | 2.0066       |                            |             |             |

**Results of the office (flat roof):** The results of the measures of central tendency by means of descriptive statistics are summarized in the following Table (5).

Table 5. Central tendency measures for variables inside the office.

| Quantity of light |         | Humidity (%)  |  | Temperature (°C) |  |
|-------------------|---------|---------------|--|------------------|--|
| Acquired data     | (%)     | Acquired data |  | Acquired data    |  |
| Min.: 0           | 0 %     | Min.: 9 %     |  | Min.: 8 °C       |  |
| 1st Qu.: 655      | 36.85 % | 1st Qu.: 23 % |  | 1st Qu.: 15 °C   |  |
| Mean: 1193        | 67.13 % | Mean: 34.71 % |  | Mean: 18.46 °C   |  |
| 3rd Qu.: 1772     | 99.71 % | 3rd Qu.: 51 % |  | 3rd Qu.: 21 °C   |  |
| Max.: 1777        | 100 %   | Max.: 73 %    |  | Max.: 27 °C      |  |

Data from this sample was graphed with R, showing the next scatterplot matrix, providing information for the analysis. See Figure (6).

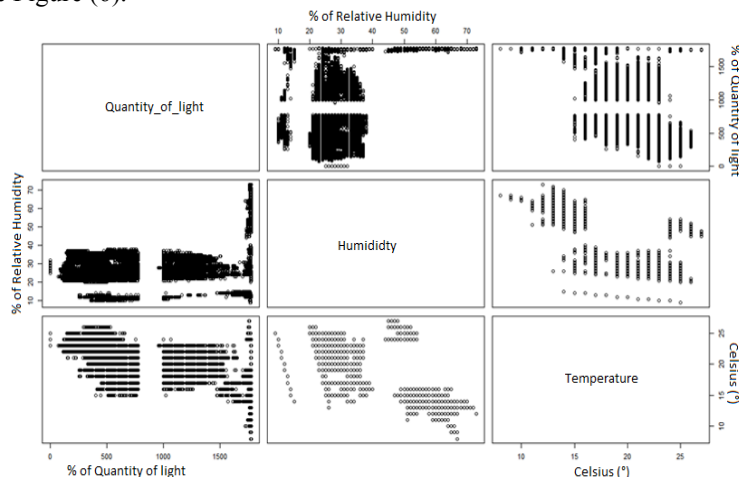


Figure 6. Scatterplot chart from the variables of the monitored data from the second experiment. The graphic shows that the relation of the variables: temperature and humidity is alike as the experiment from the prototype (green panel): this made possible to establish a relation between them. To see the correlation matrix, see Figure (7).



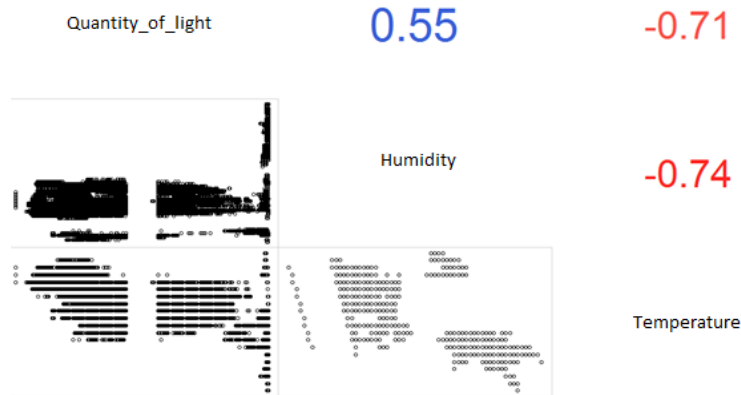


Figure 7. Correlation matrix of the physical variables, done with the data monitored during the office experiment.

As the evidence shows that the highest absolute value for the R coefficient or correlation coefficient was  $R=-0.74$ , between variables temperature and humidity, so the procedure was to define an independent variable (relative humidity) and a dependent variable (temperature): but due to the high volatility of the data, the regression coefficient was not correspondent to the correlation coefficient, until the regression was done with model GARCH (Box, G., 2015 [7]) (Generalized Autoregressive Conditional Heteroscedastic): the regression coefficient ( $\beta_1$ ) showed the same sign as the correlation coefficient (R): making the regression to generate a second equation (2) for the remarks of relative humidity and temperature registered by the system inside the office (flat roof).

$$\Delta(\text{Temperature}) = -1.8978 * \Delta(\log(\text{Humidity})) + 0.0001 * \Delta(\text{Humidity})^2 + 1.9557 * \text{Dummy}_{132732} + 3.9391 * \text{Dummy}_{79613} - 10.0166 * \text{Dummy}_{81513} - 1.9408 * \text{Dummy}_{87248} + [MA(1) = -0.7439]$$

Z-statistic, for the coefficients  $\beta_1, \beta_2, \beta_3, \beta_4, \beta_5, \beta_6$ :

$$(-1264.09)*** (115.3766)*** (68.4684)*** (1038.059)*** (-2791.554)*** (-35.57716)***$$

Variance equation:

$$\text{GARCH} = 0.0003 + 0.0671 * \text{RESIDUALS}(-1)^2 + 0.9284 * \text{GARCH}(-1)$$

$$(879.2257)*** \quad (242.9743)*** \quad (11259.75)***$$

Where:

$\Delta$ =first differences

log=base 10 logarithm

MA=Moving Average of first order

GARCH= Generalized Autoregressive Conditional Heteroscedastic

As the results of this second regression shows that it's evident that a minimal change in humidity makes huge impacts on temperature as the coefficient indicates:  $\beta_1=-1.89782$ , as the experiment took place inside an office with a flat roof, and no air conditioner nor heating devices, clearly, the variability in terms of atmospheric conditions studied by this analysis are totally volatile, due to the minimum control of the variation on air temperature and air relative humidity variables.

Then showed a graph with the dispersion is displayed to show the fitting between the data and the regression line, see figure (7).

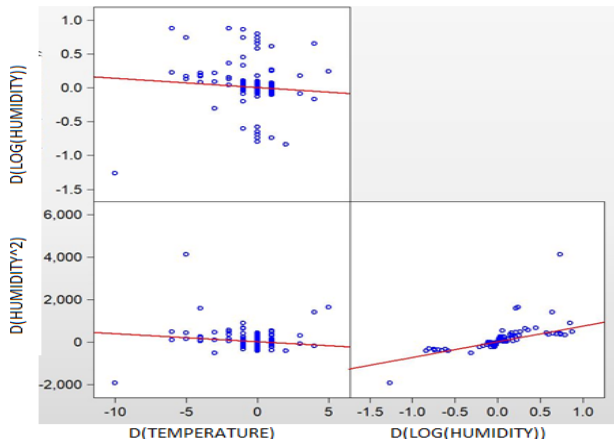


Figure 7. Remarks on the regression between humidity and temperature.

For the summary of the results on the second regression see table (6).

Based on the results and statistical summaries, it can be said, with very high reliability that estimations of the temperature and humidity, of the second experiment are truly accurate, if it is relying on the model, which is explained by the equation (2).

Table 6. Results of the regression of variables: air temperature and humidity.

| Variable                 | Coefficient | Standard Error             | Z-statistic | Probability |
|--------------------------|-------------|----------------------------|-------------|-------------|
| $\Delta(\log(Humidity))$ | -1.89782    | 0.001501                   | -1264.049   | 0.0000      |
| $\Delta(Humidity^2)$     | 0.000174    | 1.51e-06                   | 115.3766    | 0.0000      |
| D 132732                 | 1.955702    | 0.028564                   | 68.46840    | 0.0000      |
| D 79613                  | 3.939071    | 0.003795                   | 1038.059    | 0.0000      |
| D 81513                  | -10.01668   | 0.003588                   | -2791.554   | 0.0000      |
| D 87248                  | -1.940835   | 0.054553                   | -35.57716   | 0.0000      |
| MA(1)                    | -0.743944   | 0.002071                   | -359.2208   | 0.0000      |
| Variance Equation        |             |                            |             |             |
| C                        | 0.000348    | 3.96e-07                   | 879.2257    | 0.0000      |
| RESID(-1)                | 0.067114    | 0.000276                   | 242.9743    | 0.0000      |
| GARCH(-1)                | 0.928397    | 8.25e-05                   | 11259.75    | 0.0000      |
| R <sup>2</sup>           | 0.209601    | Mean of dependent variable |             | -7.76e-05   |
| R <sup>2</sup>           | 0.209601    | Standar deviation          |             | 0.215777    |
| Standar error            | 0.191839    | Info. Akaike               |             | -1.882341   |
| Sum of squares resid     | 5215.845    | Schwarz Criterium          |             | -1.881645   |
| Log likelihood           | 1333404.9   | Hannan-Quinn Criterium     |             | -1.882133   |
| Durbin-Watson stat       | 1.702067    |                            |             |             |

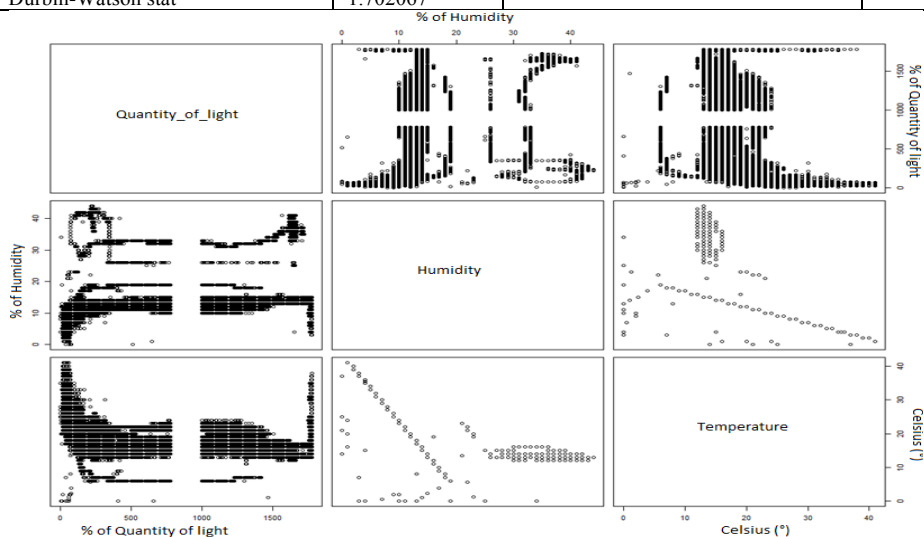


Figure 8. Scatterplot matrix of the database with the variables for the last experiment on the outside of the prototype.

**Results of the prototype (exteriors):** Conclusion of the statistical analysis, the following table with the measures of central tendency, which resulted, after running for all observations in total 340262, the calculations were made by R Studio, code “summary” for the last database, which gives the following, see table (7).

Table 7. Central tendency measures for the data acquired by the system on the exteriors of the prototype.

| Quantity of light |         | Humidity         |                   | Temperature       |                   |
|-------------------|---------|------------------|-------------------|-------------------|-------------------|
| Acquired data     | (%)     | Acquired data    | Acquired data     | Acquired data     | Acquired data     |
| Min. : 0.0        | 0 %     | Min. : 0.00 %    | Min. : 0.00 °C    | Min. : 0.00 °C    | Min. : 0.00 °C    |
| 1st Cu.: 54.0     | 3.04 %  | 1st Cu.: 9.00 %  | 1st Cu.: 17.00 °C | 1st Cu.: 17.00 °C | 1st Cu.: 17.00 °C |
| Mean : 374.6      | 21.08 % | Mean : 11.82 %   | Mean : 21.34 °C   | Mean : 21.34 °C   | Mean : 21.34 °C   |
| 3rd Cu.: 275.0    | 15.48 % | 3rd Cu.: 13.00 % | 3rd Cu.: 25.0 °C  | 3rd Cu.: 25.0 °C  | 3rd Cu.: 25.0 °C  |
| Max. : 1777.0     | 100 %   | Max. : 44.00 %   | Max. : 41.00 °C   | Max. : 41.00 °C   | Max. : 41.00 °C   |

To display the correlations between variables, was carried out the same procedure for samples and for the former variables, see next Figure (8): matrix with scatterplot charts.

The last chart shows the relations made by the scatterplots which indicates the same pattern in both variables: temperature and humidity, the following chart shows the scatterplot obtained with R command “corrgram” following the “Pearson” method for showing correlation between variables, helping in the assignation of variables for the regression. See Figure (9).

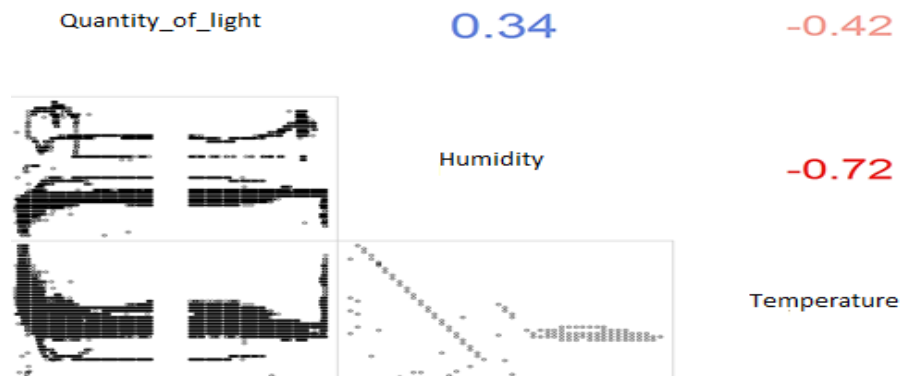


Figure 9. Correlation matrix from the variables captured by the system installed on the exteriors.

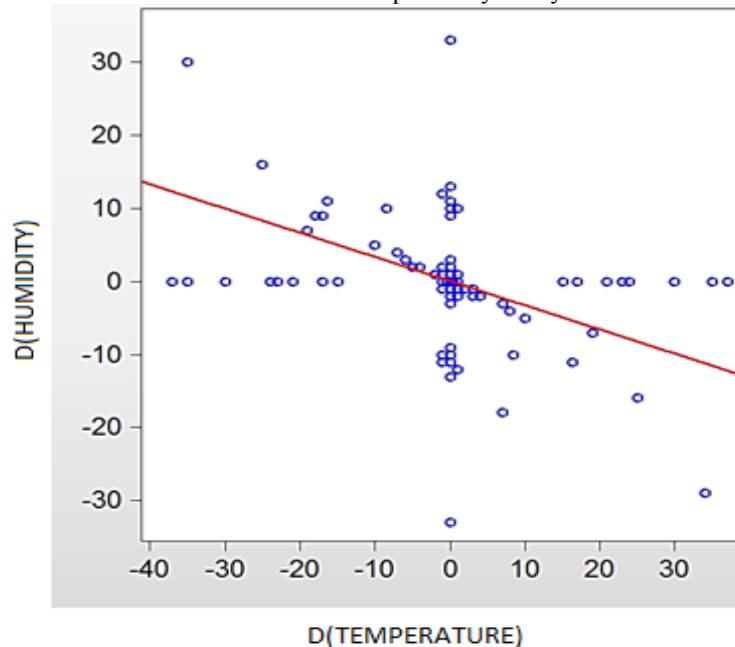


Figure 10. Slope for the equation 3.

The chart is showing that the strongest coefficient is  $R=-0.72$  showing that humidity and temperature are repeating the same pattern as the other two experiments.

Sixth equation of linear regression for the variables observed on the outside, first differences were deployed, moving averages of first order and “dummies” variables. The relative humidity is the independent variable, and the temperature is the dependent variable.

(Temperature)

$$= -0.2595 * \Delta(Humidity) + 1.3447 * Dummy_{96325} + 0.7644 * Dummy_{96249} + 1.3883 * Dummy_{96081} + 1.9636 * Dummy_{96141} + [MA(1) = -0.0614]$$

T-statistic for  $\beta_1, \beta_2, \beta_3, \beta_4, \beta_5$  coefficients of the regression:

$(-2308.335)^{***}(515.9337)^{***}(215.6713)^{***}(541.0939)^{***}(428.6994)^{***}$

Where:

$\Delta$ =first differences

MA=Moving Average of first order 1.

The equation has a coefficient  $\beta_1=-0.2595$ , meaning that when humidity increases or decreases the temperature reflects those changes inversely, depending on the value: (+/-) 0.2595 for each percentage in augmenting or reducing the humidity.

The chart for the slope found at the regression, shows the changes on the humidity along with temperature changes as well, see Figure (10).

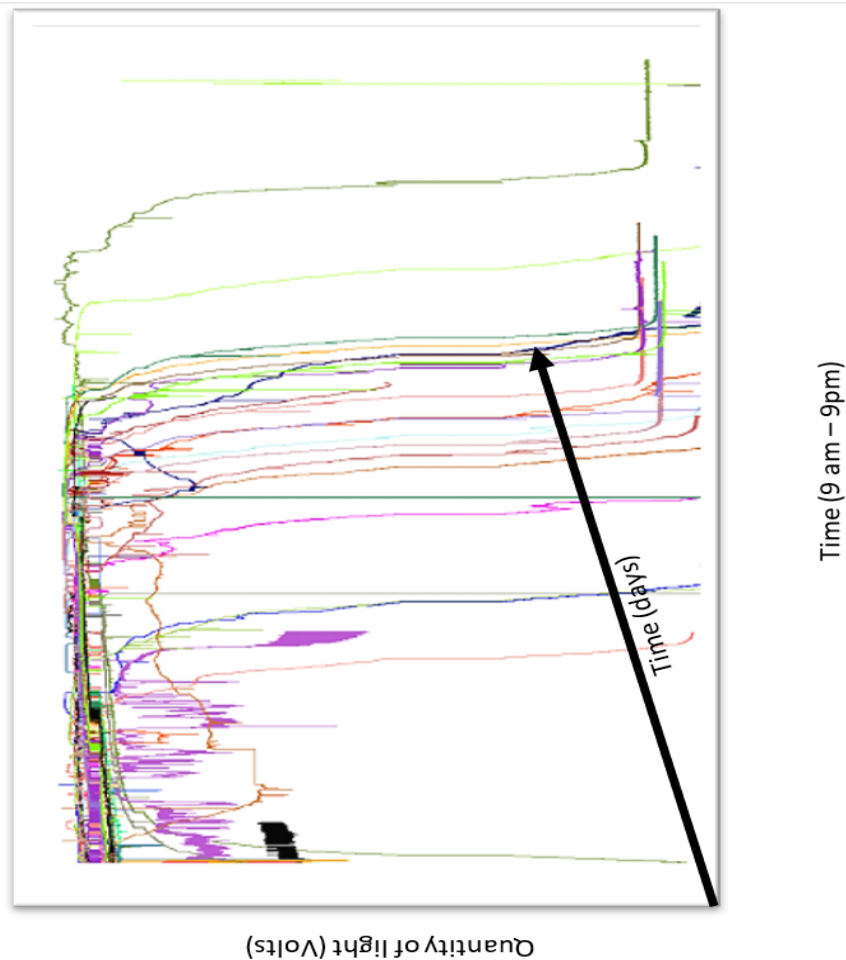


Figure 11. Light quantity on the exteriors.

Table 8. Summary for the results of running the regression.

| Variable                 | Coefficient | Standard Error             | Z-statistic | Probability |
|--------------------------|-------------|----------------------------|-------------|-------------|
| $\Delta(\text{Humedad})$ | -0.2595     | 0.0001                     | -2308.3350  | 0.0000      |
| D 96325                  | 1.3447      | 0.0026                     | 515.9337    | 0.0000      |
| D 96249                  | 0.7644      | 0.0035                     | 215.6713    | 0.0000      |
| D 96081                  | 1.3686      | 0.0025                     | 541.0939    | 0.0000      |
| D 96141                  | 1.1852      | 0.0027                     | 428.6994    | 0.0000      |
| MA(1)                    | -0.6149     | 0.0001                     | -5495.4047  | 0.0000      |
| SIGMASQ                  | 0.0867      | 9.0379e-06                 | 9597.6610   | 0.0000      |
| $R^2$                    | 0.3294      | Mean of dependent variable |             | 4.8435e-05  |
| $R^2$                    | 0.3294      | Standar deviation          |             | 0.3596      |
| Standar error            | 0.2945      | Info. Akaike               |             | 0.3932      |
| Sum of squares resid     | 19699.8449  | Schwarz Criterium          |             | 0.3935      |
| Log likelihood           | -44642.3128 | Hannan-Quinn Criterium     |             | 0.3932      |
| Durbin-Watson stat       | 2.0341      |                            |             |             |

Table (8).shows the summary for the regression.

Finishing the analysis and graphing with R, the light quantity variable and displayed it in form of a chart, see Figure (11).

## 5. CONCLUSIONS

The electronic system for monitoring present stability during the 44 days of monitoring. The purpose of the system of monitoring of physical variables was to demonstrate the physical conditions of the roofs and green walls, which was made through the analysis of the method of least squares regression (Montgomery, D., 2006 [8]) it's certain that the experiment in the prototype, with the equation, had a coefficient  $\beta_1 = -0.0144$ , which shows that the relative humidity in the air strikes in temperature in an inversely proportion. It's also true that the temperature is reduced to  $6^\circ\text{C}$ , with a roof covered with grass or plants, but increasing mulches to the walls of the model, the reducing effect of temperature is increased up to  $8^\circ\text{C}$ .

The comparison of physical conditions (temperature and relative humidity atmospheric) among statistical samples of the different experiments where the values of the variables were recorded, analyzed by the method of least squares: indicates that the coefficient  $\beta_1$  of the prototype (green roof) and the same coefficient  $\beta_1$  from office building with flat roof, were  $-0.0144$  and  $-1.8978$  respectively, which explains, that the temperature (dependent variable) in the experiment of the prototype and the office, show that moisture (independent variable) strikes much more in it, than in green roofs. Case of the exterior coefficient  $\beta_1 = -0.2595$ , that was a result of the linear regression between the temperature (dependent variable) and relative humidity (independent variable): but variables recorded by the system of monitoring on the outdoor and the prototype demonstrated by 2 comparatives of 3 statistical samples, that atmospheric conditions generated by green panels are varying less in temperature and humidity terms.

When analyzing the total variation of the samples in the prototype and in the building the founding was that determination coefficients (Gujarati, D., 2009 [9]) for the prototype,  $R^2 = 0.3355$ , this means that 33% of the temperature variability is explained by variables humidity and humidity<sup>2</sup> which is greater than in the building, meaning that  $R^2 = 0.2096$  is stating that 20% of the temperature it's explained by its variability in Y (dependent variable) or temperature is explained by the independent variables than in the sample taken in the office. The same coefficient  $R^2 = 0.3294$ , demonstrates that even on the outside the temperature is better explained by the independent variables in the sample (prototype) than the other samples as it's indicated by the determination coefficients or  $R^2$ .

On the other hand, humidity of the substrate inside the green rug covering the top of the ceiling of the prototype, can be compared with former variables as relative humidity of the atmosphere, and the ambient temperature, which generated an equation that indicates that its impact on the other former variables was too small or inexistent, this is because coefficient  $\beta_1 = 8.1594 \times 10^{-5}$  is considered as  $\beta_1 \approx 0$ . When analyzing the scatterplot the slope showed that the estimations of the model of regression, it was comprehensible the relation between humidity of the substrate and the relative humidity of the

atmosphere, the line was horizontal which shows no inclination neither to the left or to the right of the graph.

Remains the other regressions between variables light quantity, temperature and relative humidity for the samples of the exteriors and in the office, there were generated conditions where it was possible to register with the light intensity sensor and with the hygrometer, it was discovered that the correlation was high ( $R = 0.55$ ,  $R = -0.74$ ,  $R = 0.34$  and  $R = 0.42$ ): but in the regression analysis, the results obtained were in form of horizontal lines with no inclination, demonstrating that the atmospheric conditions in the office and on the outside doesn't make impact in any way to the amount of light that exists in that space, therefore, even that its coefficients of regression were kind of high, the graph and regression line showed no slope and demonstrates the behavior of amount of light and the humidity and temperature conditions in a room are not related.

Variable telluric and mechanical vibrations demonstrated that there is no relation between the other variables indicated by the behavior in the scatterplot and the matrix of correlation, which measure the strength of relation between variables, therefore, the regression was not carried out and the results were reported as central tendency measures and the scaling was made with a maximum and minimum percentages.

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