# Influence of the Office Electrical Equipment to the Indoor Environment and Comfort of the Occupants

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Abstract: In the last period of time our work was based on monitoring and controlling the indoor environment conditions in office buildings. To ensure the comfort of the occupants is one of the main tasks to be accomplished. Their productivity depends directly on their comfort. The environment could be influenced by many internal and external factors, and the office electrical equipment (devices) could be one of them. This article presents the description of our work and the success of our results. At the beginning it is described the testing stand developed, and after a deep analyze, the selected sensors, which will be used for the monitoring process. Different types of electrical equipment have been tested and the information obtained has been graphically represented and processed.

*Keywords: office building, thermal comfort, equipment influence, work productivity, waste energy, sensors comparison*

## 1. Introduction

Nowadays there is not well known which is the real influence of the electrical equipment (devices) to the environment. It is known that all of them produce heat and the quantity of heat production depends on equipment efficaciousness. For heat production estimation have been proposed some equations [3], which are difficult to be resolved since not all the parameters values are always known. For some equipment there have been defined some standard values to be used as default, when calculating the total heat production for a space area, but all of them could be just estimated and more complicated to measure exactly [11, 12]. The heat is related on temperature and temperature is just one parameter which could be influenced by the electrical equipment. Other parameters describing the environment are humidity, noise, carbon monoxide, carbon dioxide, etc. Our research work presented in this paper proposes to determine approximately the influence of the office electrical equipment on the indoor environment and indirectly on the comfort of the occupants of an office space.

Some past experiments have been done, the most important of them supervised by Hosni and Wilkins, where they try to determine approximately the amount of heat loss of the electrical equipment [5, 6, 7, 14]. A correlation between the total power consumption presented on the nameplate of each electrical equipment and its heat loss has been determined, but it is not valid in all cases. We try to do some similar experiments, by monitoring the temperature variation inside a closed space where the electrical equipment has been placed and turned on. According to the temperature variation, the head production could be estimated, and also the level of influence of the tested equipment. Together with the temperature, the relative humidity and noise level have been also monitored.

## 2. People's comfort in office buildings

In generally, the comfort of the occupants from office spaces could be described in the same way as the comfort from any type of buildings, but there are some differences which could influence the indoor environment and their comfort. These differences are determined by the functional systems from the building (e.g. heating, ventilation, air-conditioning), the existing furniture, the building materials, electrical equipment, etc.

People's comfort is directly related to the environment conditions. The comfort has been defined, by different researchers, like all existent conditions of a space for which a person will not prefer one with other conditions. It is a very complex concept that depends on setting of external and internal factors. Even if it could be literally described what the comfort represents, it is more complicated to define it into a mathematical format, which will be implemented into a software application for computing and analyze. Even so, many researchers have studied it and have provided solutions for making possible the estimation of the comfort conditions, but it does not include all existent possibilities [9, 10].

Taking into account that a person could feel comfortable from a point of view but uncomfortable from another point of view, the comfort has been divided in different areas, and the most important are:

1) *thermal*: described by temperature, humidity and air velocity parameters. It's one of the most important types of comfort with high impact to the human capacity to accomplish his activities.
2) *visual*: characterized by light intensity and other factors able to influence a person sight of view.
3) *acoustic*: described by the maximum level of noise or repeatable sounds which could start to disturb a person's activities.
4) *air quality*: described by the parameters which define the air conditions suitable for respiration and human health (e.g. oxygen level, pollution level).
5) *stability*: uncomfortable movements, vibrations or shocks should not be presented.
6) *security comfort*: each person should feel safe in the space where he accomplishes his activities.

It is not possible to ensure comfort for all people from a space (they could have different activities, metabolism, etc.), but it is important to ensure it for the most part of them and from as many points of view as possible. Not to forget that the productivity of people is dependent on their working conditions [2].

In what office spaces are concerned, one of the external factors which has influence to inside environment conditions is represented by the installed electrical equipment. The electrical equipment could not transform electrical energy completely into their own specific functionalities without losing heat (waste energy). The produced heat could be easily felt by a person (as temperature difference) but we are interested to know which is the quantity of the produced heat and if there is other kind of influences to the environment.

## 3. Preparing for testing

For a more precise measurement of the influence it was necessary to make an isolation of the tested equipment from the external conditions. A closed box has been built as platform for testing. It has a wood frame and the walls have been made using specific isolation material. At a dimension of 71.5 cm × 71.5 cm × 71.5 cm (a total volume of 0.3655 $m^3$) it is enough space inside to put any of the most common office equipment. The box does not isolate completely but it is able to reduce a lot of the influence from the outside environment.

Inside the box, for each equipment, we were interested to verify which is the variation of the parameters temperature, humidity and noise level during its operating. From all these 3 parameters the temperature could be influenced more by the external temperature (the isolation layer is thin and with low thermal resistance). For this reason we have decided also to monitor the temperature variation outside the box and make a correlation with the variation from the inside. For the humidity and noise it was considered that the external influence will be minimum.

All the sensors used for monitoring are connected to an acquisition board (Arduino Duemilanove) and from there the information is sent to a computer. The computer stores the information into a database and from the database the information could be exported and processed when needed it. Figure 1 presents the architecture of the testing stand.

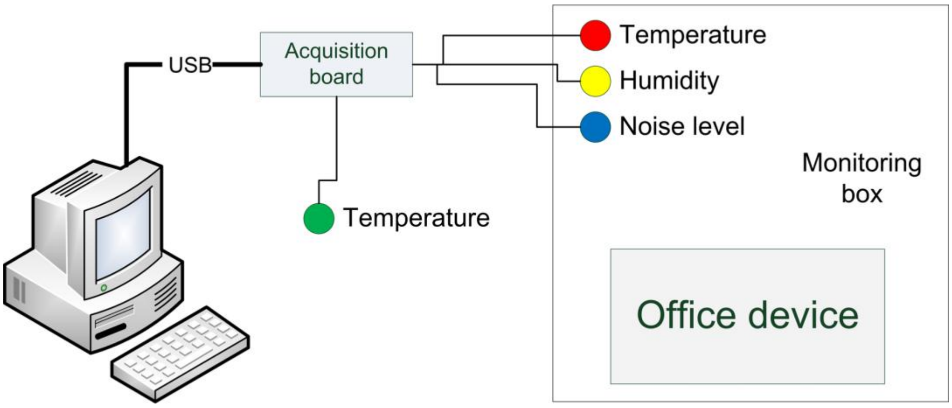


*Figure 1. Architecture of the testing stand*

## 4. Sensors to be used for monitoring

To measure the conditions inside the monitoring box we decided to use a Sensirion SHT11 sensor and an electret microphone sensor. The SHT11 is factory fully calibrated and permits recording information about temperature and relative humidity. The typical accuracy for temperature is ±0.4 °C and for relative humidity is about ±3.0 %. It is a high precision sensor but quite expensive, which makes it not suitable for daily residential applications but for the applications where the correctness of the measurements is very important.

The electret microphone sensor is connected to an amplifier for obtaining a better signal gain and from there the measured parameter value is transformed into a digital format. This type of microphone sensor has a low quality and some tests have been necessary to be made before using it. The tests proved that it is difficult to measure the noise level with this sensor and the output could be just a digital value between 0 and 1023 (the analog-to-digital converter range). It was also established that for a very low noise space the digital value resulted is around 700. Since this was considered to be the minimum noise level, we decided to split the range (675 ... 1023) in 14 equal intervals, each interval identified with a number from 1 to 14. The highest the digital value is the highest the noise level.

For outside environment temperature monitoring another sensor was necessary. Since we did not have another Sensirion SHT11 sensor we decided to try other types of temperature sensors which we have, each one having other characteristics. The goal was to determine which has the best accuracy, even if the typical values are specified into their data sheets, and more appropriate to the SHT11 measurements. For this task an experimental test has been proposed and realized. Since the SHT11 sensor was considered to be the most precise calibrated, it was used as a reference sensor.

## 5. Performance comparison of temperature sensors

Our purpose was to connect 4 types of temperature sensors together (Sensirion SHT11 – digital, Twig – analog, LM35 – analog and LM75 – digital), on the same main board, and to record the registered temperature of each of them at the same time. Since they are placed in a small area with uniform environment conditions the registered temperature values should be the same. Normally the comparison should be made for the entire measurement range of the sensors but since we will use them to monitor values somewhere between 20 °C and 30 °C, a smaller range of values will have been used [8].

While the temperature value from the SHT11 could be provided in digital format on 14 bits, the resolution for LM75 sensor digital conversion is only 9 bits, much lower than in the first case. The value of temperature provided by the LM35 and Twig sensors, which have analog output signal, is converted into digital using the 10-bit ADC integrated into the main board. A better precision could be obtained if we had had the possibility to use a higher resolution digital converter. For our tests we are interested in having at least a precision for the first decimal of a degree C (0.1 °C); more precision is even better considering that we want to use these types of sensors also for monitoring the indoor environment conditions. In Table 1 there are presented the most important specifications for these sensors.

*Table 1. Temperature sensors specifications*

| *Sensor* | *Range* | *Accuracy (at 25 °C)* | *Resolution* | *Least Significant Bit* |
|---|---|---|---|---|
| SHT11 | – 40 ... 123.8 °C | ±0.4 °C | 14 bits (1 sign bit) | 0.01511 °C |
| LM75 | – 55 ... 125 °C | ±2.0 °C | 9 bits (1 sign bit) | 0.5 °C |
| Twig | – 40 ... 125 °C | ±1.5 °C | 10 bits | 0.16113 °C |
| LM35 | – 55 ... 150 °C | ±0.5 °C | 10 bits | 0.10742 °C |

For obtaining better results at the temperature sensors comparison we decided to record the information for a period of time of 16 hours. When we had all the information stored into the database we exported them into a CSV (Comma-separated values) text file. The text file was used as an input source for a Matlab application, developed for displaying the information into a single chart and making different analyses.

An initial performance comparison has been made taking into consideration the chart representation and then more mathematical computation have been done for obtaining better and more accurate results. Observations have been noted as well as during the monitoring process, visual following the variation of the information displayed on the computer application interface. Figure 2 contains the chart with graphical representation of the values evolution for all tested sensors. Having all the variations represented on the same chart makes it much easier to observe the differences between them.

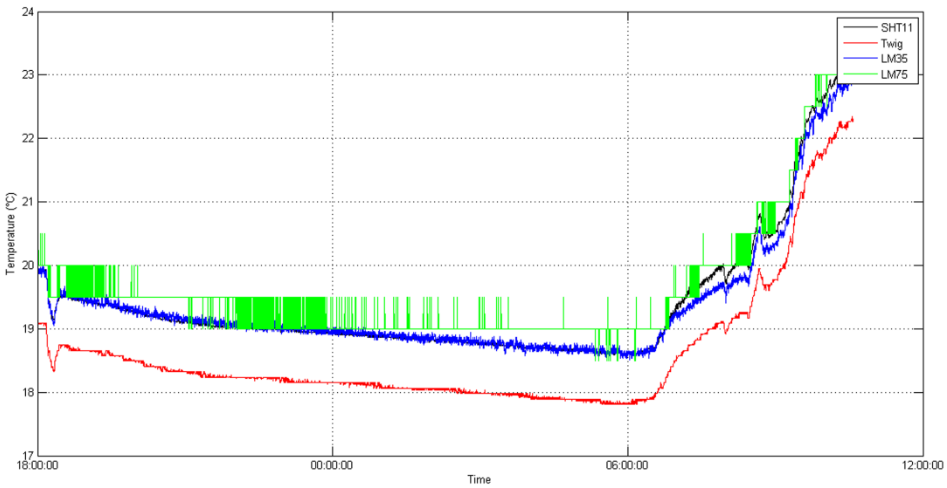


*Figure 2. Temperature value variation - recorded for 4 distinct sensors*

At the LM75 sensor, due to the low resolution at the digital conversion, it was observed a high and continuous variation of precision in a very short period of time (few seconds). In a second the precision could suffer a modification of about 0.5 °C (the LSB – Least Significant Bit – value is high and makes the evolution very instable). This kind of variation is not recommended when there are systems to be controlled at a better precision (decimal of degree Celsius). From the chart it could also be observed easily this kind of variation, and even the measurements are appropriate enough to the measurements of the SHT11 sensor, the LM75 is considered not to be adequate for our purpose. It is the first one which is eliminated from the comparison competition.

From the chart it could be easily observed that the Twig sensor provides a variation of the measurements similar to the SHT11 sensor but there is a difference of about 1 °C between them. A more exact calculation proves having following differences: minimum = 0.65 °C, maximum = 0.98 °C and average = 0.7939 °C (which is quite higher for our purpose). The problem with this sensor seems to be an imprecise calibration. A solution is to make ourselves the calibration of the sensor by adding the average difference value obtained to all measured values. In this way we would obtain a maximum difference of about 0.2 °C. The solution is not optimum since other variation measurements could exist at other temperature ranges but should be taken into consideration.

The last sensor to be compared with SHT11 measurements was LM35. From the chart the measurements obtained with LM35 look very close to the measurements of the reference sensor. The minimum difference is 0 °C, the maximum is 0.44 °C and the average difference is 0.0313 °C. These are the best performances analyzed until now. A smooth variation of the recorded information was obtained from the LM35 sensor, which makes us consider it the best candidate for our further experiments and a veritable replacement of the SHT11 sensor, more expensive than LM35 sensor. With a bigger resolution ADC we would be able to obtain even a better precision from this sensor. Since LM35 sensor has an analog output it is very important to ensure that the external interferences are minimal. Our future work will propose to develop a small circuit board where the LM35 sensor will be attached and the conversion of the analog signal will be made in digital format at a higher resolution. In this way any possible external interference will be diminished.

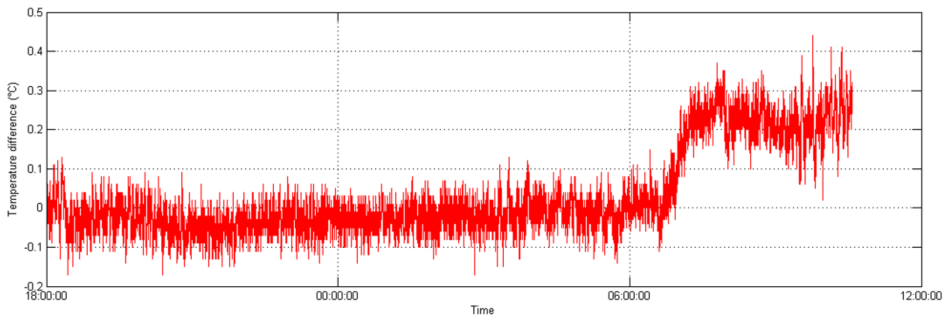


*Figure 3. Measured temperature difference variation - between SHT11 and LM35*

A decrease of the LM35 measurement precision was observed during the period of time when people occupied the nearby space where the test took place (somewhere after 7:00 AM, Figure 3). The phenomenon could be explained by the appearance of higher interferences in the wires which connect the sensor to the acquisition board. For this reason a second test was realized to be sure that the registered information is correct, and this time only with the sensors SHT11 and LM35, separately from any possible higher interference (the length of the connection wires has been also shorten). The results obtained proved that it is possible to have an accuracy of about 0.1 °C between the measured values of the 2 types of sensors.

The final decision was to use the LM35 sensor together with the SHT11 sensor for our next tests, where we monitor the influence of the office equipment on the indoor environment (and indirectly to the comfort of the occupants).

## 6. Equipment to be monitored

Since there is a large variety of office equipment (device) type it is impossible to test all of them. We have decided firstly to select some main categories of equipment mostly used in office spaces. After that, we selected, from whose we had available, one or more types of devices, preferably with different characteristics and different influence type possibilities. In this way it is also possible to compare similar functionalities influences, accomplished by devices with different characteristics. Our main goal is to prove that there are cases when different equipment types could have enough influence to the environment to modify the existing conditions and that there are possibilities to reduce this influence, even reuse the influence for other useful purposes. It is known that each type of electrical equipment produces some heat, but it is also important to know approximately how much it is produced. This produced heat which is not useful is also called waste heat, secondary heat or low-grade heat.

The categories and the selected equipment for this research work are presented below, as:

1) *desk lamp*: 230 V, a single incandescent light bulb at 40 W;
2) *ceiling lamp*:
   a) one incandescent light bulb, 230 V, 100 W, ~1700 lm (luminous flux);
   b) one energy saving bulb (CFL - Compact Fluorescent Lamp), 230 V, 18 W (equivalent to 100 W incandescent light bulb, as the manufacturer specifies), ~1200 lm (luminous flux);
3) *display*:
   a) CRT (Cathode Ray Tube) display: AOC 7 klr, max. 600 W power consumption. Even if it is an old type of display it is still used for image/video processing, where the quality of image is very important. From the specifications it is observable that the power consumption is very high.
   b) LCD (Liquid Crystal Display) display: Samsung SyncMaster 740 N, max. 34 W power consumption. It is the most used type of display nowadays and the power consumption is very low comparing with the CRT display.
4) *computer processing unit*: Fujitsu Siemens (max. 660 W power consumption). The maximum power consumption is very high but the consumption depends on how much the functionalities of the computer are used (which software applications are executed and how much they use the existing hardware resources).

5) *laptop*: Sony Vaio VGN-NR21S (max. 90 W power consumption). Has a lower power consumption comparing with a personal desktop computer but the performances are also lower.
6) *multifunction printer*: Canon MP250 (max. 11 W power consumption). Usually the printers and scanners produce enough noise to disturb the persons which develop activities nearby. The level of noise depends on the printer type and the operation mode.

The list could be completed with even more types of devices to be tested, but for our research project we considered it to be sufficient. There is impossible for each device to detect the exact influence value to the environment but just an approximation of it. Any of them could be operated differently for distinct periods of time, so there will be variable influence to the environment. For our research work the influence will be described by the parameters which we proposed for monitoring: temperature, humidity and noise level. When we speak about the influence we are thinking of a negative influence, since there it could not be a positive influence to the environment from such kind of equipment (except from the equipment dedicated to air quality control, humidity regulation, etc.).

## 7. Equipment influence monitoring

After we decided which sensors to use for the monitoring tests, we assembled them on a main hardware platform for creating the necessary monitoring system, together with the dedicated software applications (for data gathering, processing and storage). Using the developed monitoring system each electrical equipment has been tested one by one.

It is well known that the electrical devices are not able to completely transform the electrical energy for executing their own tasks/functionalities (e.g. mechanical tasks), without losing a part of energy as heat. How much energy is lost as heat depends on the equipment type and characteristics and it is defined as equipment efficiency (lower the energy lost as heat is, higher the efficiency). The heat is the main factor which could influence the indoor environment in case of electrical equipment which don't work with chemical substances (pollution materials) - in special cases when other types of negative influences could appear and have a higher impact on the environment. During the winter days the produced heat may not be a big problem since the indoor building environment should be warmed at a proper temperature value, but in the summer days it should be eliminated, since usually, the temperature inside a building without air-conditioning system is higher than the accepted comfort value. Since it is not produced a constant amount of heat for a period of time, it is impossible to determine the exact value, but estimations could be made. The air-conditioning systems don't have a proper adjustment algorithm based on external factors influences but just to follow the variation of the temperature measured from some sensors. Knowing the approximate value of heat produced could allow deciding which the characteristics of necessary air-conditioning systems are. Another disadvantage of the produced heat by the electrical equipment is that it could be transmitted rapidly by radiation to the persons nearby and more slowly to the entire air from the indoor space, making more complicated to control the entire environment conditions. So, even the ambient air has a lower temperature, measured by the sensors, the persons nearby the electrical equipment could feel a higher temperature and be in thermal discomfort. Similar discomfort conditions could occur if there are local space variations of the humidity and noise level. If it is possible to have uniform ambient conditions into the entire environment it would be much easier to control them. As we already said before our research work is to determine better which kind of influences could exist, their impact levels, to present some solutions to diminish the influences or even to use them as other sources of energy. Until now some research works have been made only on the heat produced by the equipment (in the most cases reporting to the industrial equipment) but without making a link with the thermal comfort or other types of comfort.

After monitoring the behaviour of each equipment, proposed from the beginning, we processed and analyzed the results, using some developed applications into the Matlab working environment. The temperature, the humidity and noise level variation have been analyzed and we tried to determine a correlation between each parameter variation and its influence to the ambient conditions. For a better representation of the results, suggestive charts have been generated.

The monitoring process was split in 3 different stages, each stage taking place in a variable period of time:

1) *the initial stage*: the parameters values are registered while the equipment is placed inside the monitoring box but not operating. These initial measured values would be used as references for comparing with the future values of the parameters. Even if the equipment is not operational it would be a temperature value difference between inside and outside of the monitoring box, since the external sensor could be influenced by some external parameters (e.g. the air movement), but limited external influences which don't disturb badly our testing results.
2) *the operating stage*: the time when the equipment is operating in different modes. This is the main stage when it could be observed the influence of the equipment on the environment conditions, but reported to the other stages.
3) *the final stage*: a period of time after the equipment is stopped from its operating mode, but the influence should be still present (it could not drop suddenly). The isolation material of the monitoring box will delay the moment of reaching the equilibrium between the internal and external conditions (energies equilibrium).

For each stage, the monitoring time, is not constant, but established during the monitoring process by analyzing directly the evolution of the monitored parameters.

### 7.1. Relationship between temperature and relative humidity

From the initial measurements we have noticed that there is a direct connection between the temperature and relative humidity: when the temperature increases the relative humidity value decreases. Since we did not know exactly which the connection between them was, we decided to start a short study about this phenomenon and find a proper explanation.

The humidity level from the air is an important factor for the human comfort and for the human body to function properly. In the summer days, when is very warm outside, the human body needs to cool down in order to keep a lower temperature. This is done automatically by human body by producing perspiration. If the air is saturated with moisture it will be impossible for the perspiration to evaporate and it will be harder to keep the normal temperature of the human body.

But, the study shows us that we had a wrong concept about what relative humidity means. A better explanation for the relative humidity was found as its value is referring to the percent of the available energy, from a space area, which is necessary for the evaporation process to happen, for all moisture quantity. This explains why when the temperature increases, the available energy also increases and a lower percent from it is necessary to evaporation; considering that all the time the amount of water vapours from the air remains approximately the same. The concept of relative humidity still confuses many people and it is recommended to be used a better measuring parameter of the moisture: the dew point temperature. It represents the value of the temperature where the condensation process starts: the water molecules from the air cool, becoming slower in their movement and in this way they are able to stick to other water molecules. The dew point parameter is mostly used by meteorologists [4].

In Table 2 there are presented the levels of comfort percept by the human body according to the dew point and relative humidity, at an air temperature of 32 °C. The dew point is calculated based on the relative humidity and air temperature values.

*Table 2. Human body perception of air humidity*

| *Dew point* | *Relative humidity at 32 °C* | *Human perception* |
|---|---|---|
| > 26 °C | > 65% | severely high |
| 24 – 26 °C | 62 % | extremely uncomfortable |
| 21 – 24 °C | 52 – 60 % | very humid, quite uncomfortable |
| 18 – 21 °C | 44 – 52 % | somewhat uncomfortable |
| 16 – 18 °C | 37 – 46 % | a bit uncomfortable |
| 13 – 16 °C | 38 – 41 % | comfortable |
| 10 – 12 °C | 31 – 37 % | very comfortable |
| < 10 °C | 30 % | a bit dry for some people |

For calculating the dew point value it could be used a well-known approximation, Augut-Roche-Magnus, as presented in the Equations 1.

$$T_d = \frac{b \cdot \gamma\ T, RH}{a - \gamma\ T, RH}, \qquad \gamma\ T, RH\ = \frac{a \cdot T}{b + T} + \ln\ \frac{RH}{100} \tag{1}$$

where parameter $a$ = 17.271 and $b$ = 237.7 °C [13]. The approximation is valid when:

- 0 °C < $T$ < 60 °C (air temperature),
- 1 % < $RH$ < 100 % (relative humidity),
- and 0 °C < $T_d$ < 50 °C (dew point temperature).

Since the SHT11 sensor is able to measure both parameters, the temperature and relative humidity, it is easy to calculate the value of dew point using the Equations 1. Each time the temperature and relative humidity parameters are measured, the dew point is calculated by the software application and the resulted value is stored into the database. The relative humidity parameter could be used and compared with reference values but the dew point parameter could be much easier understood. The conclusions obtained after this short research made us continue our main research study considering the temperature, dew point temperature and noise level as main parameters for analyzing the office equipment influence on the environment.

### 7.2. The heat produced by an electrical equipment

The temperature is one of the parameters related to the environment which could be easily detected by the human body (not its value, but an estimation correlated with the sensation felt by the human body). All electrical equipment produce an amount of heat during their operating. Since this waste energy remains unused, it is important to find applications for it, by converting it into other types of energy and in this way reducing the total amount of energy consumption (relating to an entire building or room space). Transforming it into other types of energy will also permit to control much easier the thermal comfort of the occupants.

For the electrical equipment there have been defined some mathematical equations to permit the heat production estimation, as in Equation 2, but there are not always known the parameters values necessary to resolve the equation.

$$H_{eq} = P_{eq} \cdot K_1 \cdot K_2 \tag{2}$$

where $H_{eq}$ is the heat transferred from electrical equipment (W), $P_{eq}$ is the electrical power consumption (W), $K_1$ is the load coefficient and $K_2$ is the running time coefficient.

The temperature and heat have correlated values. All molecules have kinetic energy (which is proportional with the speed of the molecules) and it is direct proportional with the temperature value. When the temperature increases the speed of the molecules also increases. For this reason the temperature is also defined also as a measure of the average kinetic energy of the molecules. If more heat is added to a substance the kinetic energy and temperature value will increase. To increase the temperature of a substance, more heat should be added, and to decrease the temperature, some heat should be removed. The heat also depends on the mass of the substance and the substance type. Each substance has a specific capacity of absorbing or releasing heat (specific heat). Specific heat represents the heat (calories) necessary to increase 1 gram of substance with 1 °C. Since the temperature could be measured using a thermometer, the heat could not be measured, but it could be calculated using temperature value. Heat as energy could be transmitted from one substance to another.

For calculating the heat gained or lost by a substance the Equation 3 could be used.

$$H_{gained\_lost} = M \cdot \Delta T \cdot S_h \tag{3}$$

where $H_{gained\_lost}$ is the heat gained or lost by the substance, $M$ is the mass of the substance, $\Delta T$ is the temperature difference which appears and $S_h$ is the specific heat. For air the specific heat is considered to be 0.25 cal/g · °C [1].

For our monitoring stage we consider that the monitoring box is filled only with air, at a density of 1.1839 kg/m$^3$ (corresponding to 25 °C temperature).

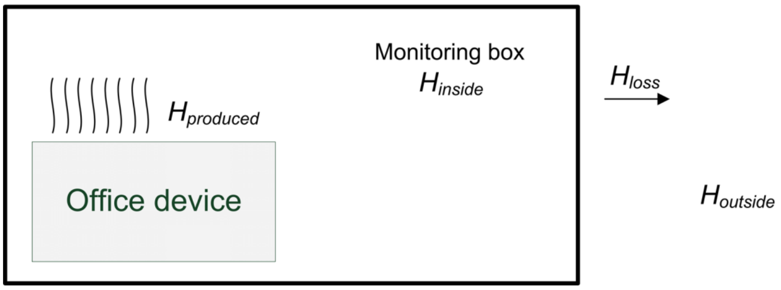


*Figure 4. Thermal energies in the testing conditions*

For the initial conditions (initial stage) of each monitoring test the Equation 4 should be accomplish. For simplifying the computing, $H_{outside\_original}$ in initial conditions has been considered to be 0 (in this case $H_{inside\_original}$ will represent the surplus of heat). And for the next 2 stages (operating and final) the Equation 5 has to be accomplished ($H_{outside}$ and $H_{inside}$ will represent the surplus of heat energy compared with the initial conditions). The equations have been established based on the energies (heats) equilibrium principle (Figure 4).

$$H_{inside\_original} = H_{outside\_original} + H_{aux} \quad (4)$$

$$H_{inside} = H_{outside} + H_{aux} + H_{produced} - H_{lost} \quad (5)$$

where:

- $H_{inside}$: the heat existent inside the monitoring box;
- $H_{outside}$: the heat *existent outside of the monitoring box (into a volume space equivalent with the box volume);*
- *Haux: the supplementary heat (energy), comparing with outside environment, which exists inside of the monitoring box, caused by the absence of some external conditions (e.g. air flow). Its value could be easily determined at the beginning of each test, when the equipment is not operational by measuring the difference of temperature between inside and outside. The value of Haux determined from Equation 4 will be used then in Equation 5.*
- *Hproduced: represents the heat produced by the equipment while it is functioning. Since the equipment does not have a uniform operating mode, the heat production will be also variable. The computing of the heat production will be made based on the measured* values of the parameters.
- $H_{lost}$: the heat lost from the inside environment to the outside environment. It is directly dependent on the thermal resistance of the insulation box walls.

The heat lost ($H_{lost}$) value could be calculated using the Equation 6.

$$H_{lost} = \frac{A \cdot \Delta T}{R_{insulator}} \quad (6)$$

where $A$ represents the surface area (the border between the inside and outside environments) equivalent with 0.715m x 0.715m x 6 = 3.067 $m^2$, $\Delta T$ is the difference of temperature between outside and inside environment and $R_{insulator}$ represents the thermal resistance of the insulator material. The value of the thermal resistance has been taken from specification to be 0.07 $m^2$·°C/(W·cm). Knowing the volume of the monitoring box and the air density constant we determine the mass of the inside air to be 0.4327 kg.

An accurate estimation of the heat loss by electrical equipment would facilitate also the proper sizing of the cooling and ventilation systems required by buildings. The building systems will not be undersized with insufficient capacity or oversized with costly unused excess capability [3].

### 7.3. The tests performed

The first tested equipment was a desk lamp, with a single incandescent light bulb at 40 W power. The desk lamps are a very common device used in almost all office spaces where a separation of lighting from one office desk to another is necessary. The main role of them is to ensure the visual comfort in a small working place.

The results obtained are graphically presented in Figure 5. From the first chart it could be easily observed that the temperature inside the monitoring box started to increase when the lamp was turned on, until almost 4 °C higher than the temperature of the external environment. At the same time with the inside temperature increase the relative humidity level gets lower and increases back when the lamp was turned off. The dew point has an opposite variation comparing to the relative humidity, and increases while the temperature increases as well. The maximum dew point variation was 1.88 °C. After the lamp was turned off it took almost 1 hour for the monitoring environment to return to the approximately same initial conditions. The level of noise was minimal since the incandescent light bulb does not produce any external perceptible noise.

The second test was made on an incandescent light bulb, 220 V, at 100 W power. This type of devices is commonly used in any indoor building environment to ensure the lighting conditions. It is known that they produce a high amount of heat but it is important to know how much and if there is an influence also to the humidity variation. Figure 6 presents the variation of the parameters for the incandescent light bulb.

It could be easily observed that there is an increase of the temperature with almost 7 °C, which is quite high. Like in the previous case the relative humidity decreases, with more than 10%, while dew point increases with almost 3 °C.

During testing the incandescent light bulb we had the idea to test as well an energy saving bulb (economical bulb) and make a comparison between these 2 types of bulbs. It is known that the economical bulb will replace completely the old used incandescent light bulb. In some countries across Europe there are imposed regulations not to use anymore the old types of bulbs which are great consumers of energy with a low efficaciousness.

It is well known that the big advantage of the economical bulbs is the low power consumption for the same amount of lighting, comparing with the incandescent light bulbs. These types of bulbs are known also as CFL (Compact fluorescent lamp). They are in reality fluorescent tubes but at a lower scale and with different shapes. An energy saving bulb of 18 W, used for our tests, has a lighting power equivalent to 100 W incandescent light bulb, as it is written in its specifications, but normally the intensity light is lower than one from the incandescent light bulb (just 1200 lm).

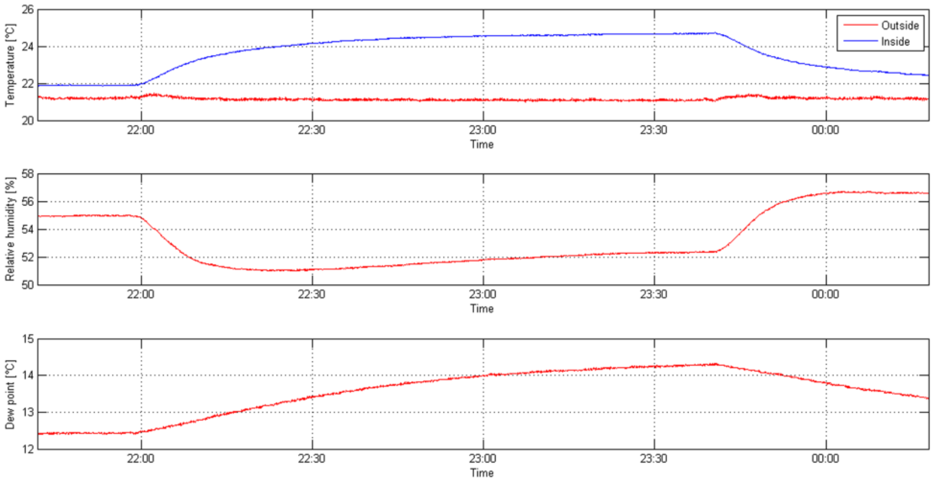


*Figure 5. Environment parameters variation - desk lamp, 220 V, 40 W*

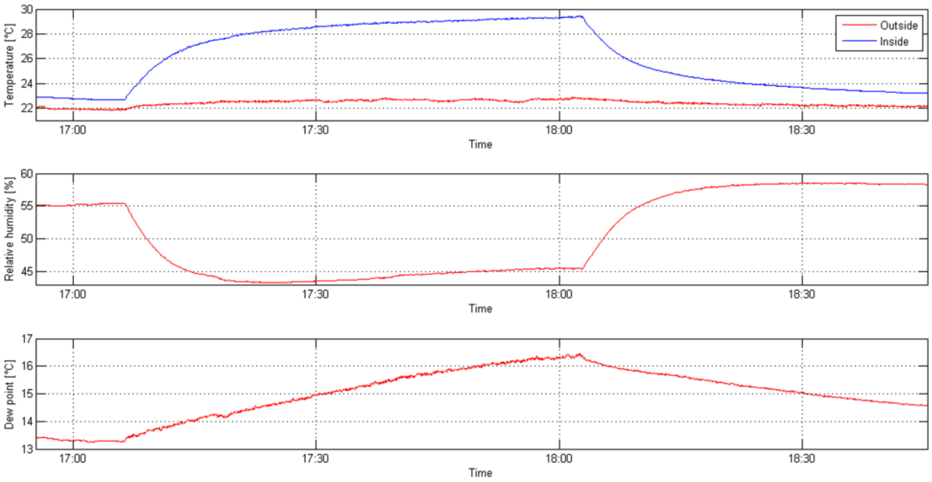


*Figure 6. Environment parameters variation - incandescent light bulb, 220 V, 100 W*

The results obtained, presented in Figure 7, are obvious. They are recommended to be used since they ensure low energy consumption and they produce minimum impact to the air quality (lowest heat transferred to the air). It produces an increase of the temperature with about 1 °C, a decrease of relative humidity of about 3% and a dew point variation of less than 1 °C.

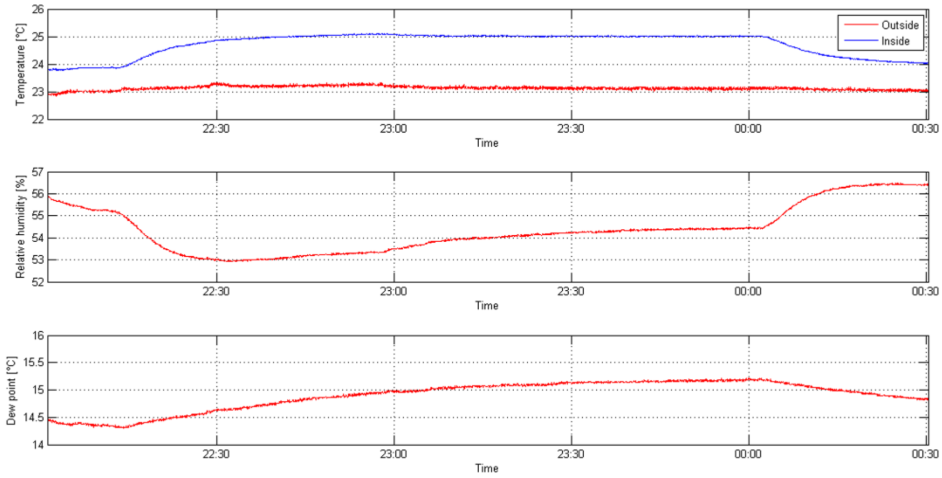


*Figure 7. Environment parameters variation - energy saving bulb, 220 V, 18 W*

Nowadays the CRT displays are seldom used, and especially in the activities where the image quality is very important (the main advantage of them). But the size and power consumption is too high for the today demands. Figure 8 shows a high increase of the temperature of the ambient air after the display has been turned on. There is a maximum increase of 6.8 °C comparing with to the initial value. The dew point temperature increases with 4.16 °C.

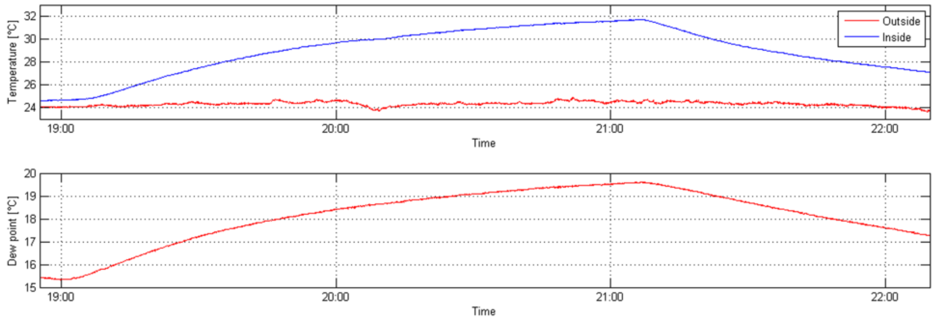


*Figure 8. Environment parameters variation - CRT display, AOC 7 klr*

The LCD display produces less influence to the environment, compared to the CRT display, and an increase of temperature of about 2 °C (Figure 9). It is recommended for its low power consumption and low heat production but the quality of the image could prove sometimes insufficient.

The computer processing unit has produced the biggest temperature increase (Figure 10) comparing to all other equipment tested until now, which could be directly related to the highest electrical energy consumption and a low efficiency. The dew point variation reaches easily 5 °C, comparable to the CRT display. Usually occupants are placed very close to their computer, which produces a transfer of the heat by radiation to the human body. The environment is less influenced but the human body is much more exposed. This situation will cause an appreciable local discomfort.

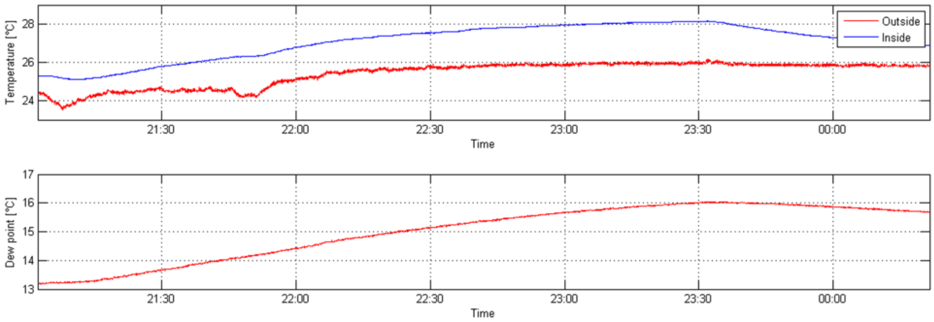


*Figure 9. Environment parameters variation – LCD display, Samsung SyncMaster 740 N*

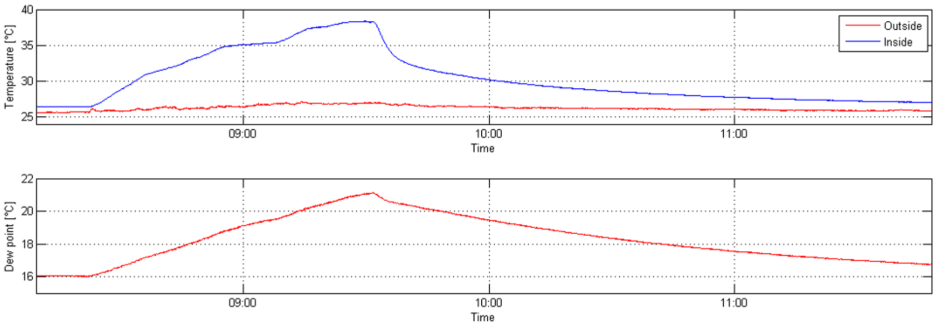


*Figure 10. Environment parameters variation – computer processing unit, Fujitsu Siemens*

As in case of the computer processing unit, the laptop could produce also a local discomfort, since the occupants are placed nearby. It could produce an increase of the air temperature with more than 5 °C (Figure 11).

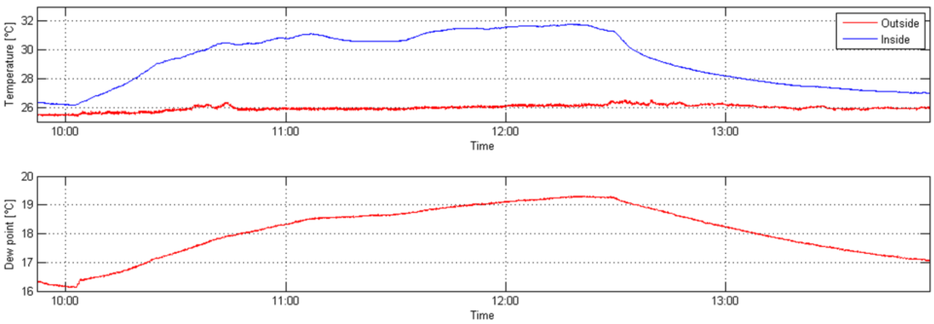


*Figure 11. Environment parameters variation – laptop, Sony Vaio VGN-NR21S*

The last tested equipment was the multifunctional printer. The temperature and relative humidity have been very low influenced during the printer operating but it was measured an increase of the noise level during printing pages or scanning documents. Figure 12 presents the noise level variation with a high increase of the level after the hour 8:35 (when the printing and scanning tasks are done).

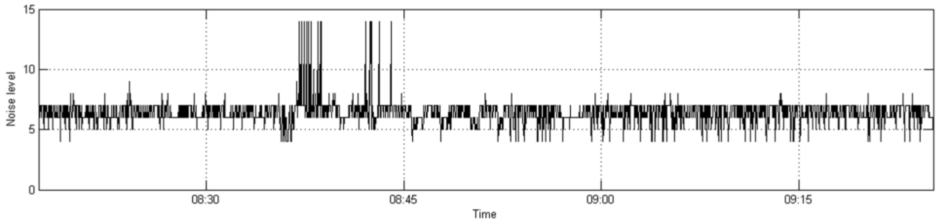


*Figure 12. Noise level variation – multifunction printer, Canon MP250*

### 7.4. The results of the tests

In Table 3 is presented the most important information of the results obtained after testing the office equipment. All maximum difference values have been calculated by comparing the parameter evolution with the value from the beginning of the test. A comparison could be easily done by following the values on each column. In this case it is evidently that the biggest influence, as heat production, is determined by the incandescent light bulbs, CRT displays and the computer processing units.

*Table 3. Results of the performed tests*

| *Equipment type* | *Initial temperature difference* | *Maximum temperature difference* | *Maximum relative humidity difference* | *Maximum dew point difference* | *Heat produced [W/hour (cal/hour)]* |
|---|---|---|---|---|---|
| Desk lamp, 40 W | 0.67 | 3.72 | 3.98 | 1.88 | 0.1433 (123.21) |
| Incandescent light bulb, 100 W | 0.73 | 6.82 | 11.86 | 3.09 | 0.2542 (218.56) |
| Energy saving bulb, 18 W | 0.88 | 1.98 | 2.94 | 0.76 | 0.082 (70.51) |
| CRT display, AOC 7 klr | 0.51 | 7.31 | 7.95 | 4.16 | 0.2645 (227.43) |
| LCD display, Samsung SyncMaster 740 N | 0.78 | 2.32 | 0.72 | 2.82 | 0.0922 (79.25) |
| Computer processing unit - Fujitsu Siemens, without display | 0.87 | 11.5 | 16.2 | 5.1 | 0.408 (350.86) |
| Laptop, Sony Vaio VGN-NR21S | 0.92 | 5.75 | 7.2 | 2.93 | 0.2172 (186.75) |
| Multifunction Printer, Canon MP250 | 0.64 | 0.82 | 0.96 | 0.52 | 0.0397 (34.14) |

Even if the dew point temperature value increases during the equipment functioning, its value tends to the initial value after the equipment was turned off. It is obvious that its variation was directly dependent on air temperature variation. The air temperature value is the main parameter which permits to a human body to distinguish between a more or a less humid air.

Analyzing the noise levels it was easy to determine that the printer is the single device, from all the equipment tested, which produces a very high level of noise during its functioning, being able to create acoustic discomfort to the occupants.

Knowing which types of equipment (devices) have the highest influence to the indoor environment makes it more easily to think at possible solutions for reducing their heat production or separate them from the occupants space. Do not forget that the heat is more easily transmitted to the human bodies placed close to the equipment.

### 7.5. Possible solution to reduce the influence to the environment

The highest influences generated by different types of equipment have been determined and solutions to reduce them must be found. The possibilities are many and are dependent on the working conditions and the necessary equipment to accomplish the office working activities. To establish all possible solutions will represent the work for another research project. Knowing the results of the tests and having the real life experience we could propose in this moment one solution which could be easily and successfully implemented. The technology from today permits the development of this solution and it will allow not only to reduce the influences of the equipment to the environment but also to minimize the amount of energy consumption. A short description of the solution is presented below:

- all processing units of the computers should be stored into a separated dedicated room or even replaced by a server computer, and thin clients will realize the interface between the server and the users displays. On the occupants desks should remain only the display, keyboard, mouse, any additional interface devices and maybe a low power thin client computer. The biggest heat production will be in this way isolated into a single space, from where it could be transferred to other systems (e.g. heating the necessary water by using heater exchangers) or eliminated to the outside environment (in this case it will be just waste energy).
- the noisy equipment, like printers which are often used, should also be placed into a separate room with phonic isolation but which can be easily accessible to the office occupants.
- the incandescent light bulbs will be replaced with energy saving bulbs.

The practical implementation of the solution into an office building will demonstrate its viability and efficaciousness and it will be high depended on the possibility to transfer the heat from one substance to another (e.g. from air to water) and on the possibilities of storing the heat (energy) for later use.

## 8. Real case scenario: heat production estimation for an office space

After all the scheduled tests have been accomplished we were also interested in making estimation for a real case scenario: an office space with multiple working desks where are many electric equipment installed. For this task it was selected as reference (example) one of the rooms from our University's building, with similar characteristics with what we need. Into this room there are installed the next equipment (devices):

- computer processing unit: 11 pieces;
- LCD displays: 11 pieces;
- incandescent light bulb 100W: 8 pieces;
- laptop: 1 piece;
- printer: 1 piece.

The office dimensions are 8.50 m (length), 5.00 m (width), 2.80 m (height) and the total volume is 119.00 $m^3$.

In these conditions, based on the results already obtained, the electrical equipment will produce about 6700 cal (7.79 W) heat energy every hour and the temperature will increase with 0.2 °C (in the conditions when the heat is transmitted directly to the air – no people inside the room). In 10 hours it will be a higher temperature with 2 °C, not a very big value, but even so, it represents a waste energy.

The heat produced by equipment will be transmitted more rapidly to the human body of the persons from nearby (the water from the human body has a much better conductance of the heat than air) and local discomfort would appear. This phenomenon should be also taken into consideration when electrical equipment is installed. In case of the office spaces are occupied with people, the measurements showed a quick growing of the temperature in a short time, higher than in the case when there were no people inside (the human body also produces heat by thermo regulation process).

A solution based on moving the main heat producers into a separate room, as presented into the previous section, will allow a better control of the temperature inside and possibility to reuse the waste energy. With this solution implemented it should be obtained a lower value of the heat production into the office space, of just about 1655 cal (1.92 W).

## 9. Conclusions

The influence of the electrical equipment to the indoor environment conditions have not been so much analyzed until today, and to make only mathematical estimations without testing, about the heat produced by each equipment, could be a very hard and long work. By our research work, presented in this paper, we have succeeded to obtain proper results and the possibility to estimate which equipment produces the most heat or noise and which should be separated into another room space, where the possibility of heat recovery exists. Too much heat inside a room produces thermal discomfort, too much noise produces acoustic discomfort. A main problem is that usually the main goal when designing a building is to ensure as low as possible the energy consumption, and the occupants comfort which influences directly their productivity, is less analyzed.

Even for a large space office the heat production could be considered low (as it was presented in the real case scenario estimation), it is possible to exist local discomfort for the occupants, and since the heat produced is lost energy why not to use it in other existent systems. The results obtained permit us to continue the research work with the designing of the necessary systems which accomplish the task of recovering the heat and store it for later use.

Also as future work would be interesting to verify if there are other types of influences to the environment from the electrical equipment (e.g. carbon monoxide or carbon dioxide variation - other important parameters for describing the air quality).

## Acknowledgements

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