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Analysis of the thermal and acoustic comfort of a BREEAM certified office building

Iulian Florinel NITU[1], Tiberiu CATALINA[*1,2]

[1] *Technical University of Civil Engineering, Faculty of Building Services, Bucharest, Romania*
[2] *Babes-Bolyai University, Faculty of Environmental Science and Engineering 30, Fântânele Street, Cluj Napoca*

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Abstract

This article presents an experimental and numerical study on thermal comfort and acoustic comfort in a BREEAM-certified office building. These aspects are of major importance because the performance of people working in these buildings depends on the quality of the indoor environment, which will be demonstrated in this work. The aim of the study was to analyze the thermal and acoustic comfort by taking the data by measuring the building spaces and comparing them with the data generated by dynamic simulation programs. The study presents measurements data on indoor temperature and humidity but also on indoor sound pressure level. The experimental data are extended to numerical simulations using two programs. The thermal comfort was calculated in three points for the last floor of the building this representing the most critical case for both noise (lowest length to air handling unit) and indoor comfort (high solar gains). The ventilation system increased the noise level from 30 dB to 49 dB and the reverberation time was measured to be 0.5 sec. which corresponds to imposed norms. According to BREEAM certification the operative temperature and predicted mean vote were classified in the category Excellent thermal comfort.

Rezumat

Acest articol prezintă un studiu experimental și numeric privind confortul termic și confortul acustic într-o clădire de birouri certificată BREEAM. Aceste aspecte sunt de o importanță majoră, deoarece performanța persoanelor care lucrează în aceste clădiri depinde de calitatea mediului interior. Scopul studiului a fost de a analiza confortul termic și acustic prin preluarea datelor prin măsurarea spațiilor clădirii și compararea lor cu datele generate de programele de simulare dinamică. Studiul prezintă datele măsurătorilor privind temperatura și umiditatea interioară, dar și nivelul de presiune acustică în interior. Datele experimentale sunt extinse la simulări numerice folosind doua programe de calcul. Confortul termic a fost calculat în trei puncte pentru ultimul etaj al clădirii, cazul cel mai defavorabil atât pentru zgomot (cea mai mică distanta fata de centrala de tratare a aerului), cât și pentru confortul termic (aporturi solare mari). Sistemul de ventilație a mărit nivelul de zgomot de la 30 dB la 49 dB, iar timpul de reverberatie a fost masurat ca fiind 0,5 secunde si corespunde normelor impuse. Conform certificării BREEAM, temperatura operativă și votul termic au fost clasificate în categoria confort termic excelent.

Keywords: BREEAM certified building, thermal comfort, acoustic comfort, experimental measurements, numerical simulations

[*] Corresponding author: Tel./ Fax.:+40.76.391.54.61
E-mail address: Tiberiu.catalina@gmail.com

1. Introduction

Maintaining a good quality indoor environment in office buildings is essential to ensure a healthy environment and occupant productivity. Acoustic comfort is one of the vital aspects of the quality of the indoor environment and is often viewed as the absence of unwanted noise, the consequence being that the occupants can perform comfortably and efficiently. A comfortable acoustic indoor environment is therefore important because it has been found that the presence of noise in "open space" offices has many negative effects on work performance and employee behavior at work. People often experience noise in their daily environments but heating, ventilation, air conditioning systems (HVAC) are usually a major source of background noises in office buildings. In offices, the noise produced by the air handling unit (AHU) can cause discomfort and concentration problems for workers [1-4]. This has led several acoustic researchers to the question of how much noise contributes to decreasing productivity and whether the effect changes over time. Several studies have been conducted focusing on the effects of excessive low frequency energy in background noise [5]. Some of the findings of these studies were that productivity may be affected by background noise and reducing these levels must be a priority during the use of the building. Other studies have shown that those who have indicated annoyance with a decrease in the frequency of noise have also reported symptoms of fatigue, headache and irritation, all of which could lead to reduced performance in the workplace [5]. These past studies have helped to establish this relationship between the noise and the performance of the workers. However, the ways in which the background noise really affects the occupants is still not well understood. Nowadays there is still a great debate on how the time spent by an occupant under a single background noise source can influence its performance and perception. Some have hypothesized that occupants are becoming more and more aggravated by noise, the more they are exposed to them, while others claim that occupants are naturally working with this acoustically affected environment [6-7]. While constructing the main responsibilities for building experts are cost-effective ecological buildings, it should also be a priority to establish appropriate acoustic conditions in these buildings [8]. However, gaining acoustic comfort in buildings is one of the challenges faced by building managers and installers, especially when monetary priorities and investments are often placed to meet other more notable safety and comfort criteria. This problem is most evident in greenhouse-designed and operated buildings, as neglecting acoustic problems in such buildings has been reported in several previous studies [9]. BREEAM (Building Research Establishment Environmental Assessment Method) has been on the market for 25 years and is in a continuous ascendant and is a method of assessing the ecological performance of buildings. This method was developed in the UK by Building Research Establishment (BRE). BREEAM is the most commonly used method used today to assess the impact of buildings on the environment. BREEAM is a standard for sustainable design and has become the primary tool for assessing the ecological performance of a building. BREEAM is applicable to both existing and new buildings. The maximum score is 109 points, getting less than 30 points lead to the non-certification of the building as a green building, 45 points bring a "good" score, 55 points means "very good", 70 "excellent" points and over 85 points " remarkable". The BREEAM International standard offers several types of certifications among which the most important are Health & Wellbeing (Hea 04 - Thermal comfort and Hea 05a - Acoustic Performance).

Ventilation systems represent a certain set of problems in acoustic engineering because the sound pressure level generated by the primary source (usually the fan) [10] is constrained to propagate along the pipes that form the air distribution system. The operation of ventilation equipment can also induce mechanical vibrations that propagate in occupied spaces through structural pathways such as ducts, pipes and supports. Vibrations may cause direct discomfort and may also create secondary radiation from noise caused by vibrated walls, floors, pipes etc. In this chapter, sound and noise are used interchangeably, although only unwanted sound is considered noise.

The installation position of the equipment is of paramount importance for determining the noise level at the noise affected receivers [11]. Fan selection is made taking into account operation as close as possible to maximum rated efficiency when driving the required airflow and static pressure.

Also, selecting the fan so as to generate the smallest possible noise to the required design conditions. The use of an oversized or undersized fan that does not work at peak or near-peak efficiency can substantially increase the noise levels.

According to the international ASHRAE 55 standard [1], comfort is defined as a state of mind that expresses thermal satisfaction to the environment. Although thermal comfort can be considered as a subjective concept, it refers to the decision made by people on the thermal medium and is based on environmentally assessed conditions of the senses. There are different phenomena that contribute to the energy balance between the human body and the environment.

A steady-state thermal comfort assessment for the entire human body is possible using PMV (predicted average vote) and PPD (predictable percentage of dissatisfied people) adopted by ISO 7730. A particular attention should be placed on office buildings as the occupants spent around 8 hours/day in the same space [12]. Multiple studies showed that thermal comfort is related to health or productivity [13]. Afroz et al. [14] presented in their article the modelling techniques of HVAC systems in office building. They showed that beside energy consumption the noise can be a strong design criteria. Li et al. [15] proposed a novel method for HVAC system operation and showed the importance on the indoor environmental quality including thermal comfort, acoustic and indoor air quality.

2. Description of the BREEAM building

The experimental and numerical study was done for an office building located in Bucharest, Romania – Blvd. Aviatorilor nr.8 (Aviatorilor8). The building has 3 underground levels, ground floor and 3 floors, summing a surface of 18 000 m^2. The structure of the building is metallic and the façade is entirely glazed with high energy efficient windows. The heating and cooling of the office spaces is done with fan coils connected to the air diffusers mounted in the false ceiling in the field. Air conditioning systems have been integrated into the building management system (BMS) of the building for programming and monitoring the operation and for energy consumption metering. Local control is realized by wall panel remotes that were mounted during interior partitioning. At the same time, the positions and number of indoor units depends on the internal partitioning project. For the warm season the thermal comfort was calculated for the indoor temperature of 23°C and for the cold season the indoor temperature of 21°C. At the access doors in the building, warm air curtains are fitted to limit cold air penetration into the indoor space. The thermal fluid for the heating installations is heated by a boiler with a thermal power of 450 kW. In the office spaces the average occupation is one person per 10m^2. The fresh air supply rate is 40 m^3/h person representing an excellent value for indoor air quality. The fresh air in the office space is realized using ceiling diffusers connected through plenums to the inlet ducts. Evacuation of polluted air has been achieved through ceiling-mounted extraction diffusers. Air is circulated through a network of horizontal and vertical ducts to a central air node. An air handling unit with a flow rate of 20 000 m^3/h is installed on the building's terrace provides fresh air but also can recover the extracted air heat using two high-efficiency heat recovery units. The building was awarded a class A energy rating using the national reglementation on energy certification using the MC001 methodology [17].

3. Numerical simulations

3.1 Introduction

Thermal comfort simulation was done using the Riuska dynamic simulation program and was designed for the office space on the 3rd floor. The simulation report was made for three reference points in space. This program is a tool for dynamically simulating comfort and energy consumption in designing building services and managing facilities. It calculates indoor temperatures, heating and cooling individual spaces and can be used to compare and dimension HVAC systems as well as to calculate the energy consumption of whole buildings. The 3D modeling of the building of the building was done in AutoCAD with MagiCAD Room [17] extension.

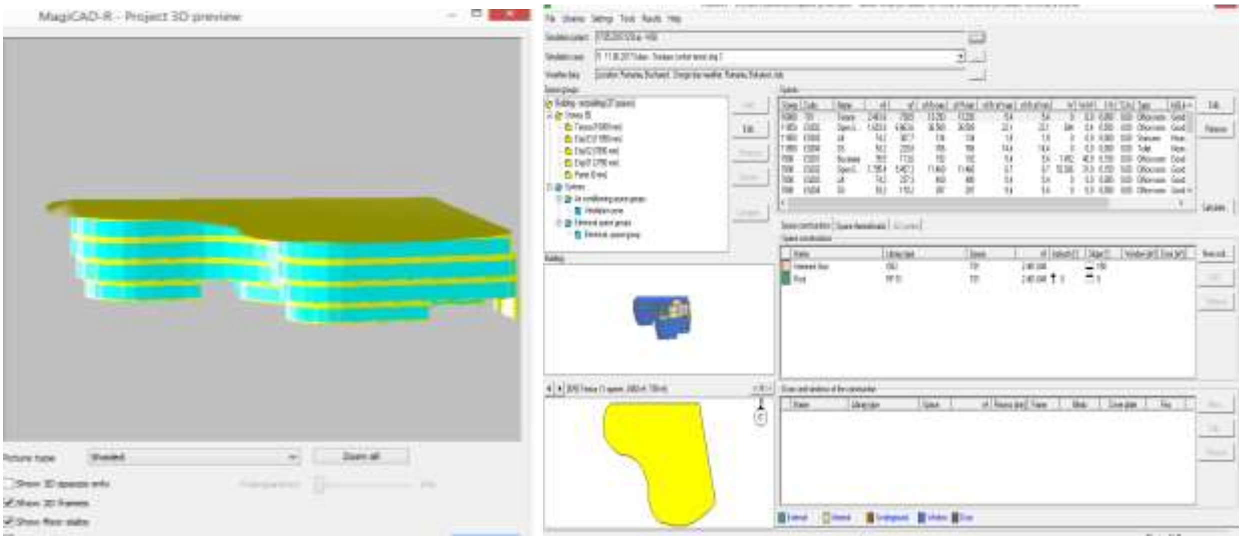

Figure 2. a) Presentation of the 3D model of the building in MagiCAD Room b) Import into Riuska of the 3D model

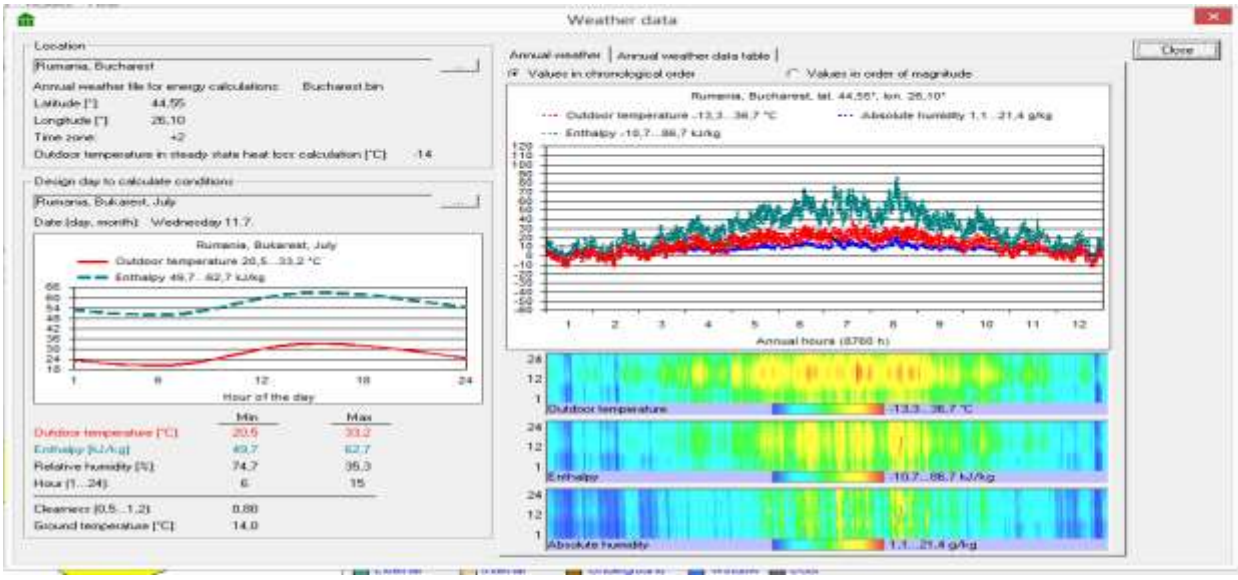

Figure 3. Weather data and building location selection

The simulation of thermal comfort was done in three positions in the office space on the top floor. The results obtained from the simulation were extracted as a report for each observation point. The calculation program analyzes the thermal comfort generated by the hourly values of the PPD index over a period of one day, which is classified according to certain classification levels as shown in Table 3.

Table 3**:** Classification of the thermal comfort dissatisfied persons percentage

PPD, %	Classification
0-10	Excellent
10-20	Good
20-30	Normal
30-40	Satisfactory
40-50	Poor

As we have seen from experimental measurements that the HVAC system can greatly influence the acoustic sound pressure level a simulation with the noise propagation flow was interesting to realize. The noise propagation simulation generated by the air handling unit mounted on the building's terrace came to the idea of establishing the influence of noise mitigation mounting on the air distribution system and the assessment of acoustic comfort. For the acoustic simulation, the MagiCAD program was used for the realization of pipeline distribution plans for air introduction and exhaust. The pipeline distribution plan for the 3rd floor was realized as this is the closest to the air handling unit and therefore the highest risk to perturbate the acoustic comfort.

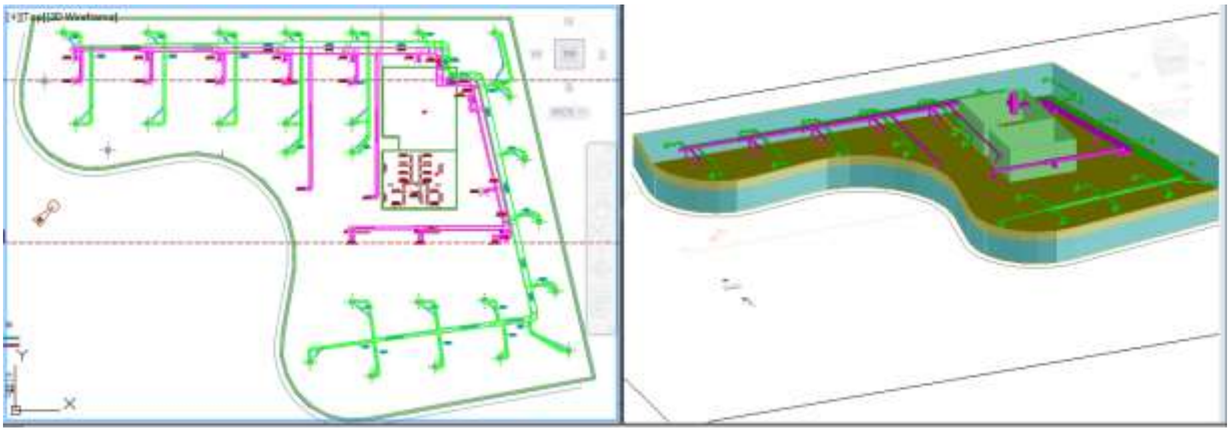

Figure 4. HVAC system distribution (inlet/outlet) and 3D model for noise determination

3.2 Thermal comfort results

The analysis was carried out on three representative points on the 3rd floor - the most unfavorable in terms of solar intakes during the summer period. In the figure below we can see the positioning of the points analyzed in the simulation software. For thermal comfort analysis the air velocity was set to 0.15 m / s, a metabolic rate of 1 met and a clothing level of 0.9 clo.

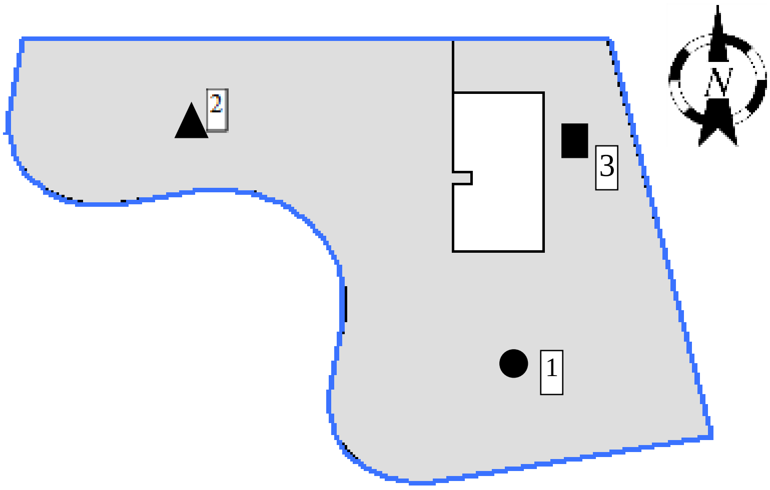

Figure 5. Thermal comfort assesment zones

The maximum values of the PPD and PMV indices are 6 and -0.27 respectively, which means that both values of the two thermal comfort indexes comply with the European norm SR EN ISO 7730.

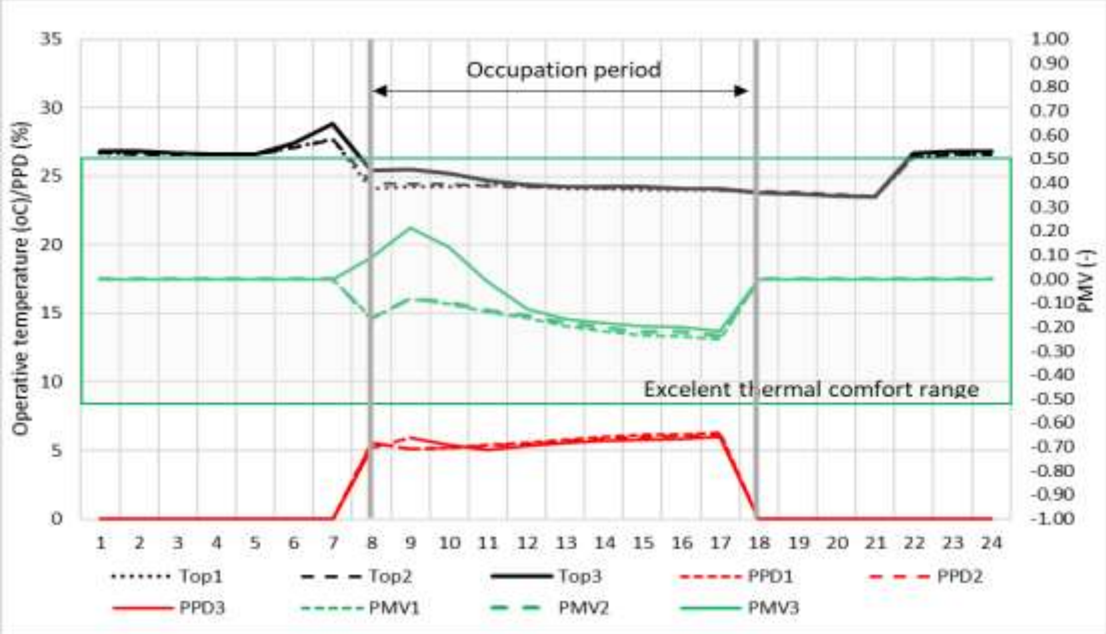

Figure 6. Thermal comfort assesment for one simulation day

3.3 Acoustic comfort results

Based on the results obtained with the MagiCAD simulation program, comparisons of the ventilation system, the distribution of the inlet ducts and the distribution of the exhaust ducts were made. The sound pressure level generated by the air handling unit and propagated inside the office are through the nearest air discharge grille is shown in the figure below according to the permissible noise limits according to the space destination (noise curve NC50). For only one frequency (*f=4000 Hz*) is necessary to use a sound attenuator while for the rest of frequencies the values are under the NC50 limits.

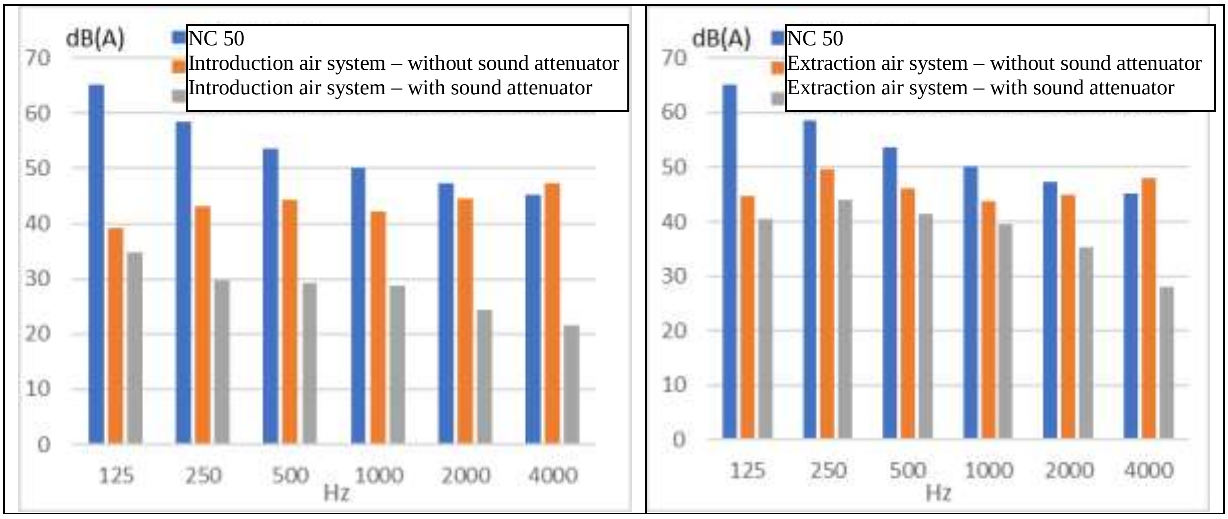

Figure 7. Sound pressure levels [dB] for inlet air diffusion and extraction air

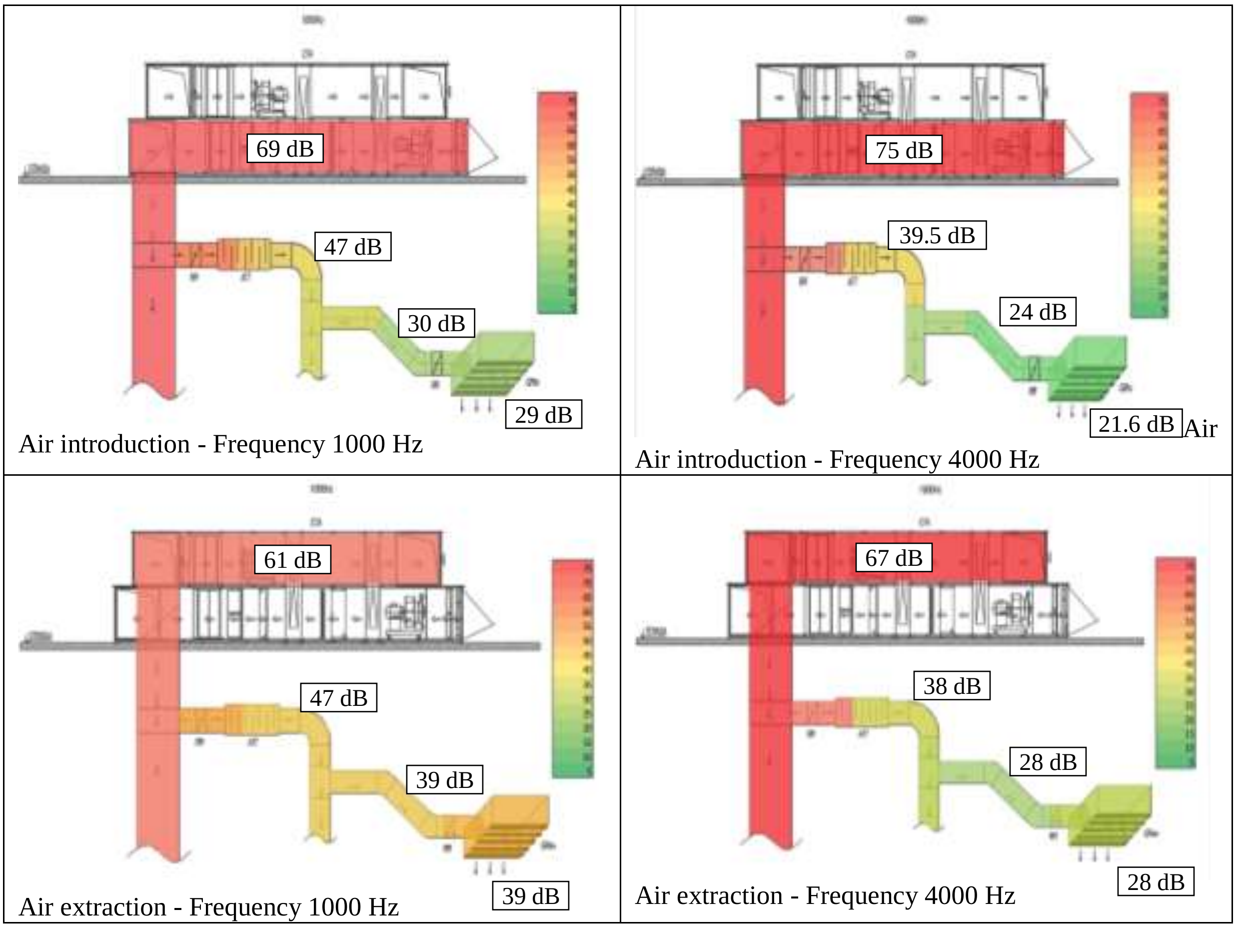

Figure 8. Noise maps for introduction/extraction air at 1000 Hz and 4000 Hz

The AHU generates a noise of 69dB and 75dB respectively on the frequencies of 1000 Hz and 4000Hz, which propagate through the distribution of ventilation ducts to the interior spaces. The disadvantage of the ventilation distribution is the material they are made of, with a very low noise attenuation coefficient. For the attenuation of the noise that could be propagated from the ventilation ducts in the interior spaces, but also for other reasons (temperature, humidity), they were insulated with mineral wool. In this way, the only areas in the ventilation system that are most exposed to noise propagation in the interior spaces are the terminal elements - the air inlet and outlet grilles in the interior spaces.

In order to attenuate the noise that could be propagated through the air inlet and outlet grilles in the interior spaces, noise attenuators were mounted on the piping distribution. These are dimensioned and mounted to attenuate the noise levels according to national standards, international and green building certifications.

The ambient noise levels inside the sample office room with fitouts, located in the south-western part of the building was in compliance with the 40-50dB limit imposed by the BS8233:1999 Sound insulation and noise reduction for buildings - Code of practice, but the value is very close to the upper limit. In all the spaces where the measurements took place, a significant influence of fan coil units on the noise levels was observed; the noise levels are close to the upper limit imposed by BS8233:1999. Similar values were obtained during the experimental campaign, therefore a proof of necessity of using numerical simulations during the design stage of a building.

4. Experimental campaign

4.1 Equipment used for measurements

Measurement of the sound pressure level in the building was done by a sound meter model Svantek SVAN 957. The sound meter is a class 1 precision sound meter able to measure the sound pressure level on a large range of frequencies (from 31.5 Hz to 16000 Hz). The measurements were made on each floor of the building and on three areas on each floor as follows: a) inside the meeting room located in the southwestern part of the building; b) inside a glass partitioned office c) in the south-eastern part of the building, near the fan coil units – this is considered to be the most critical point in terms of noise disturbance. As concerns the air temperature and humidity the measurements were made during the summer of 2017 on the 3rd floor (last floor) of the BREEAM-certified building. The equipment used for long-term acquisition of the measured parameters (temperature, humidity) was the EasyLog EL-21CFR-2-LCD + from Lascar Electronics. It features the following features:

Table 1**:** Characteristics of the experimental equipment

Air temperature measurements	
Measurement range	-35°C to 80°C (-31°F to 176°F)
Internal resolution	0.5°C (1°F)
Accuracy (overall error)	0.45°C (0.86°F) typical (5 to 60°C)
Long term stability	<0.02°C (0.04°F) / year
Relative humidity measurements	
Measurement range	0 to 100%RH
Internal resolution	0.5%RH
Accuracy (overall error)	2.05%RH typical (10 to 90%RH)
Long term stability	<0.25%RH/year

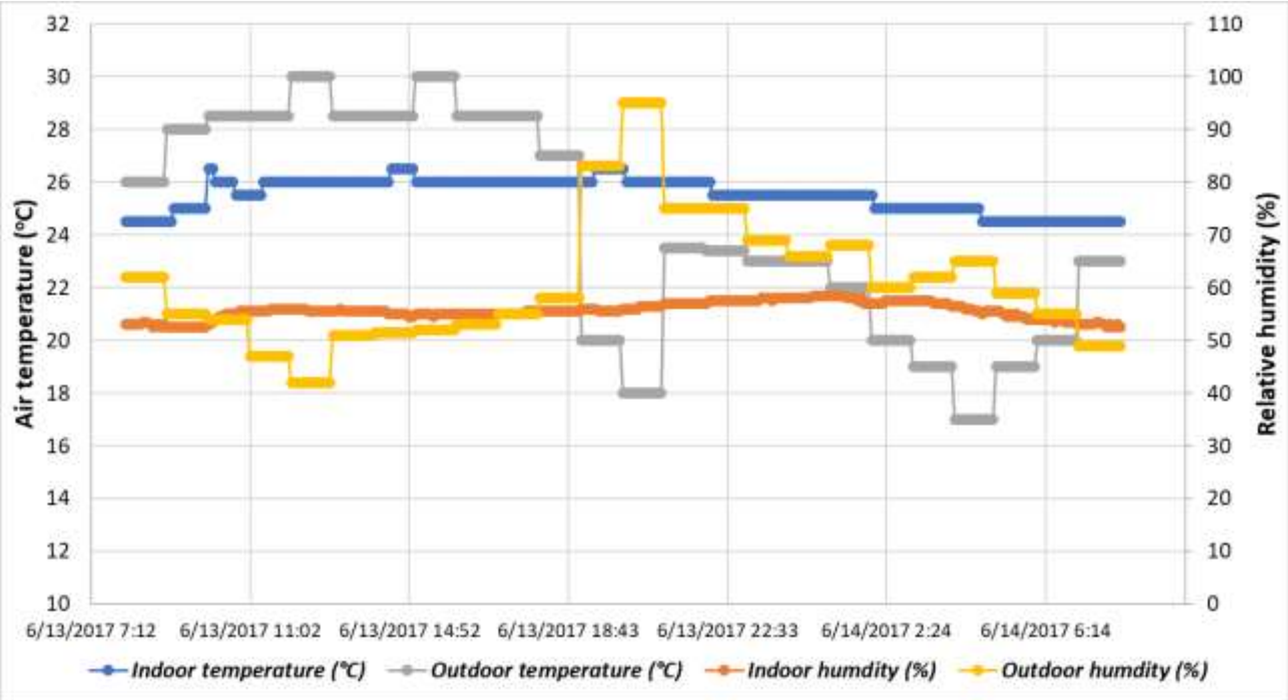

Figure 1. Indoor/Outdoor temperature and humidity of the occupied space

4.2 Thermal comfort measurements

During the experimental campaign the indoor temperature was set by occupants at 25°C and the occupancy rate of that day was around 20 people in the open area space. As a result of the measurements between 13.06.2017, 08:02 and 14.06.2017 at 08:02, a variation plot of the indoor air parameters was made, as shown in the figure 1. Indoor temperature reached the maximum value between 15:00 and 16:00 due to high solar gains at that time. The logging time for the equipment was set to 5 minutes. According to the graph below, we can observe a normal variation of the outside temperature and relative humidity based on the time – lower values during night time. According to the measured temperature and humidity variations, it is noticed that the building was not subjected to abnormal external factors that could compromise the study or provide data that could lead to the conclusion of mistakenly designed and executed systems. We can observe that the BMS is keeping a constant and comfortable temperature all day long. Moreover, the air handling unit with its humification/dehumification system was able to keep the indoor relative humidity between 50% to 58% despite the high outdoor values that reached even 95%.

4.3 Acoustic comfort measurements

To determine the acoustic comfort of the studied building spaces, two measurement sessions were carried out before starting the ventilation and air conditioning systems and after starting them to determine the noise level generated by the fan coil units. Following the measurements made, as shown in the following table, the values of the acoustic pressure level are within the limits imposed by the BREEAM standard.
Achieving the two measurement sessions helped us to calculate the influence of the ventilation and air conditioning equipment on the acoustic comfort experienced by the occupants in terms of the sound pressure level.

Table 2**:** Sound equivalent pressure levels with/without the use of HVAC

The studied area	**Leq,T [dB]**		
	Before starting the ventilation system	**After starting the ventilation system**	**Limit values imposed by BREEAM standard**
Inside the meeting room located in the southwestern part of the building	36.5	48.5	40 - 50
Inside a glass partitioned office	35.0	39.5	35 - 40
In the south-eastern part of the building, near the fan coil units	30	49.0	40 - 50

The reverberation time measured in the three rooms is between 0.5 sec. to 0.6 sec. perfectly fitting into acoustic comfort standards. The ambient noise levels inside the chosen space were in compliance with the 40-50dB limit imposed by the BS8233:1999 Sound insulation and noise reduction for buildings - Code of practice, but the values are very close to the upper limit. The measurements were performed before and after turning on the HVAC equipment and it was observed that the noise was increased considerably with values between 5 to 19 dB depending on the measurement position. The data are a proof that the HVAC can greatly affect the indoor acoustic comfort. Due to excellent façade sound proofing the traffic noise is almost not existent.

5. Conclusions

From the experimental study we can see the importance of the quality of the indoor environment in the office spaces where people are working. A green building aspiring to the BREEAM Excellent Standard should provide perfect indoor conditions. As the experimental measurements of air temperature and humidity shown stable and comfortable values the numerical simulations were the perfect way to calculate the thermal comfort index. The thermal comfort index values were based on the simulation using a dynamic simulation program and were found to be in the range of -0.164 and +0.126. These values of the thermal comfort index place the most disadvantaged space in the building in the category Excellent thermal comfort according to BREEAM Requirements. The PPD index is also less than 10%. Using MagiCAD modeling program we had the advantage for achieving the dynamic simulation goal. In this way, the office building demonstrates the authenticity of BREEAM certification for the indoor thermal comfort category. As concerns the acoustic comfort, the sound pressure level generated by the ventilation system was calculated using the MagiCAD modeling program. This allowed us to calculate the full range of propagation frequencies to the nearest grid in the office space, but also to the entire distribution network of ventilation ducts. Moreover, the analysis of acoustic comfort was done by measurements in space with high precision equipment's in several points of the floor. The data were compared and were similar. Furthermore it was found by simulation that the sound attenuator mounted in the ventilation duct distribution system the pressure level acoustic was reduce by 17%. The data extracted from the measurements, compared to the simulated data, demonstrates the reliability of data extracted with the simulation program. The centralization of measurement results and simulations proved the BREEAM certification and compliance with the noise norms. Similar conclusion is made for the thermal comfort.

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