STRUCTURE AND ENVIRONMENT

KIELCE UNIVERSITY OF TECHNOLOGY

Quarterly
Vol. 13, No. 1, 2021

ISSN 2081-1500
e-ISSN 2657-6902

• Architecture and urban planning • Civil engineering and transport • Environmental engineering, mining and energy

Available online at http://www.sae.tu.kielce.pl

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The quarterly printed issues of Structure and Environment are their original versions

The Journal published by the Kielce University of Technology

ISSN 2081-1500
e-ISSN 2657-6902

25-314 Kielce, al. Tysiąclecia Państwa Polskiego 7, tel. 41 34 24 581
www.wydawnictwo.tu.kielce.pl

Index Copernicus Value (ICV) za rok 2019 = 97.92

Kielce University of Technology
2021

INDEX COPERNICUS INTERNATIONAL


environment
environment

Bronislava Hrnková, Dávid Hečko, Andrej Kapjor, Pavol Mičko, Martin Vantúch
Structure and Environment 2021, vol. 13, (1), pp. 5-9, Article number: el 001
https://doi.org/10.30540/sae-2021-001

Structure and Environment
ISSN 2081-1500
e-ISSN 2657-6902
https://content.sciendo.com/sae
https://www.sae.tu.kielce.pl

sciendo

Kielce University of Technology

DOI: 10.30540/sae-2021-001

LAMINAR FIELD OPTIMIZATION IN CONNECTION WITH THE CURRENT PANDEMIC SITUATION CAUSED BY COVID-19

OPTYMALIZACJA Z WYKORZYSTANIEM POLA LAMINARNEGO W ODNIESIENIU DO OBECNEJ SYTUACJI PANDEMICZNEJ SPOWODOWANEJ PRZEZ COVID-19

Bronislava Hrnková*[1], Dávid Hečko[2], Andrej Kapjor[3], Pavol Mičko[4], Martin Vantúch[5]
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Abstract

COVID-19 is constantly spreading around the world. Doctors, nurses and medical staff spend more time providing their professional help than usual. It is especially important to provide them with a suitable working environment. Therefore, in the following article we will deal with the design of a computational model of a laminar field in a clean room using CFD methods.

Keywords: tlaminar field, clean room, air flow, CFD model, outlet

Streszczenie

COVID-19 nieustannie rozprzestrzenia się w świecie. Lekarze, pielęgniarki i personel medyczny spędzają więcej czasu niż zwykle niosąc, profesjonalną pomoc. Jest zatem szczególnie istotne, aby zapewnić im odpowiednie środowisko pracy. Dlatego też w prezentowanym artykule zajęto się zaprojektowaniem modelu komputerowego pola laminarnego w czystym pomieszczeniu z wykorzystaniem metod CFD.

Słowa kluczowe: pole laminarne, czyste pomieszczenie, przepływ powietrza, model CFD, wywiew

1. INTRODUCTION

Just a few of us realize that the air which a person inhales indoors contains a lot of dirt, it can even be more polluted than outdoors air. Pollution is caused by being in the room and the materials that surround us in the indoor environment, such as the materials of the walls, floors or ceiling. Elevated levels of chemicals in the interior can lead to the so-called Sickbuilding Syndrome (SBS). This is manifested by worsening of central nervous system reactions, headaches, impaired concentration, asthma and respiratory problems. One has a feeling of discomfort and discomfort in such spaces. Elevated levels of CO_2 in the air have a number of adverse effects on human health. These may include headaches, dizziness, tiredness, restlessness, difficulty breathing, sweating, increased heart rate, or high blood pressure. Seeing that a person spends more than 85% of his time indoors, it is very important when choosing materials to make sure that they contain as few harmful chemicals as possible. There are such rooms where this situation is unacceptable, because due to their specifics, the final purity of the air flow is necessary. We are talking about clean rooms.

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High demands on the cleanliness and quality of the indoor environment are placed in particular in the field of healthcare, especially in operating theaters intended for demanding operations such as transplants, heart and joint operations, vascular operations, neurosurgical operations, and also in intensive care units. The arrangement of ventilation systems is an essential part of clean rooms and air conditioning to ensure a suitable microclimate. Ventilating very clean rooms is one of the most challenging tasks a HVAC designer can face. In most cases, the aim of ventilation and air conditioning equipment is to ensure thermal comfort and the required air quality for the occupants. In clean rooms, requirements for indoor environment parameters such as humidity, temperature, flow rate and especially air purity are very important.

In clean rooms, 2 types of flow can occur – laminar and turbulent. We can say that laminar flow is better, but also more expensive. Its main advantage is that the air flows in parallel streams in one direction, in contrast to the turbulent one, in which the particles perform a disordered motion and it is possible to create stagnation zones from which no pollution is removed [4].

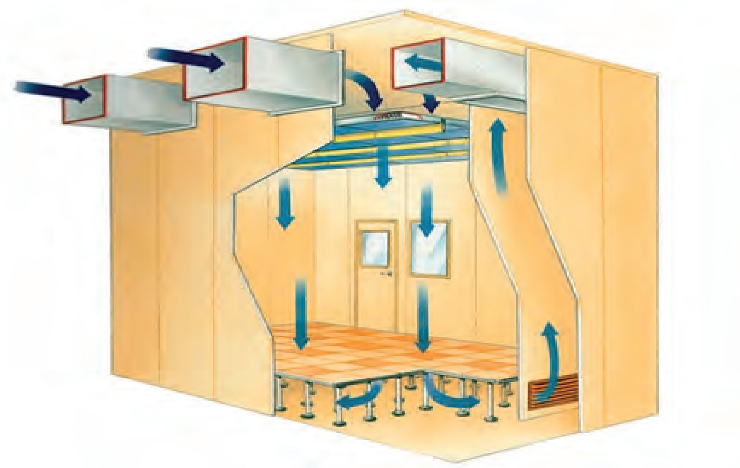

Fig. 1. Laminar flow in clean rooms with closed compact filter cartridges. Source: www.elfa-filtr.cz

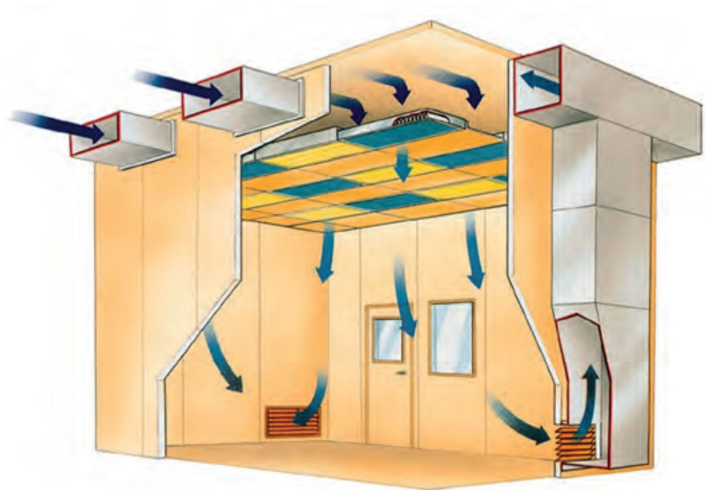

Fig. 2. Turbulent flow in clean rooms with closed compact filter cartridges. Source: www.elfa-filtr.cz

2. MEASUREMENT METHODS

Our goal was to design and model a CFD laminar array suitable for a clean room, to evaluate the benefits and possibilities of this array and, above all, to find out how the variable air supply via the laminar array affects air quality in a clean room.

Laminar field is a technically advanced solution consisting in the installation of ceiling fans with a large surface area. This device provides the whole room with high cleanliness and suitable physical parameters with a low degree of turbulence and elimination of pollutants emitted in the room [1].

Thanks to its construction, the laminar field creates a constant flow of air at a low velocity under the entire supply surface. With this solution, it is not necessary to extract air through the floor, but the diffusers in the side walls will suffice [2].

The simulation software Ansys Fluent was chosen as a program for creating a CFD model of a laminar field in a clean room, the main advantage of which is accurate calculations and graphical outputs in the form of images. Using this CFD model, an analysis of the air flow in the designed clean room was subsequently performed. The results were determined for the area above the operating table.

In the calculation, we considered that the supply air has the same temperature as the air located in the operating room. Our calculation includes a comparison of the velocities of individual air flows for the case where the air extraction is ensured evenly by all 12 outlets.

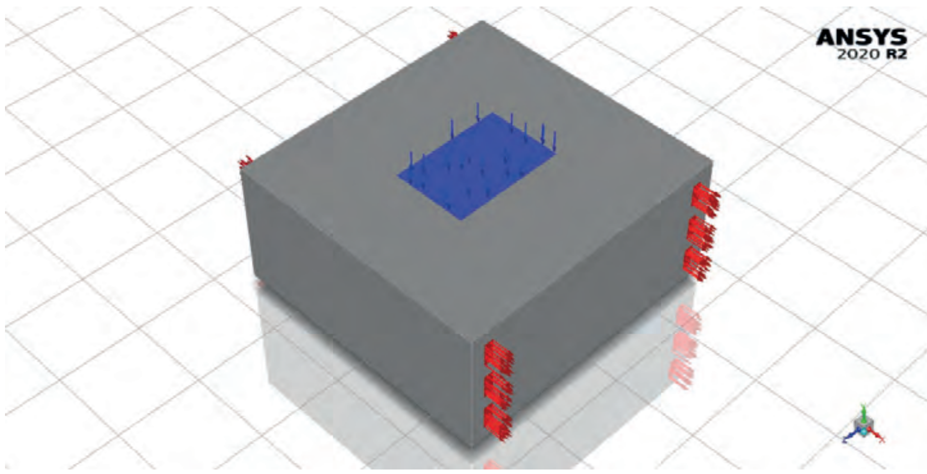

Fig. 3. CFD model of laminar field in the designed clean space (own source)

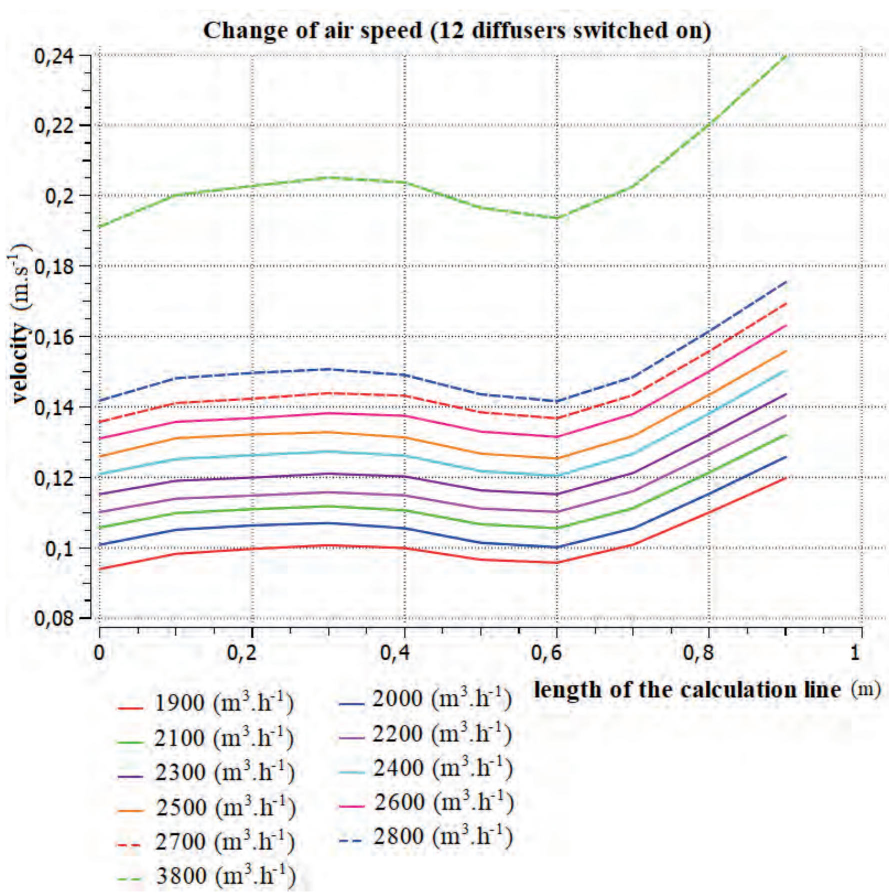

Fig. 4. Analysis of air extraction at constant temperature through 12 diffusers (own source)

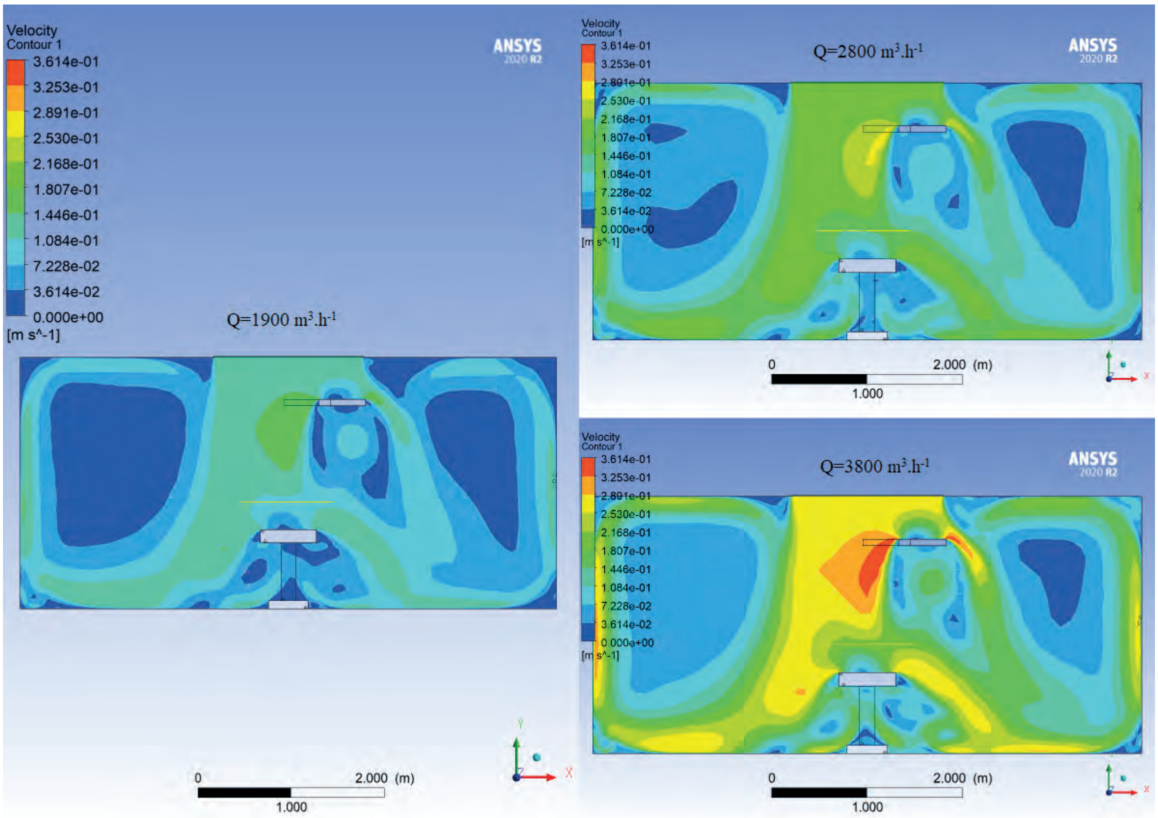

Fig. 5. Simulation of air extraction at constant temperature through 12 diffusers (own source)

3. RESULTS OF THE CLEAN ROOM

As we can see at the pictures (Fig. 4 and Fig. 5), provided that the air extraction from the room is ensured evenly by all 12 outlets, there will be no air turbulence, air flow rates will be low (up to 0.25 $m \cdot s^{-1}$) and with minimal differences in input and output.

The flow of 3800 $m^3 \cdot h^{-1}$ (green dashed line) serves as a control value, which is already beyond the permissible limit and shows us how the curve should no longer look (significant ripple) and at what values it should no longer move. Thanks to the low temperature difference of the supplied air and the low degree of turbulence, the air flow is completely imperceptible. Controlled pressure flow ensures that no airborne contaminants enter the work area of the operating team. The clean air first flows around the patient evenly and only then is they dispersed into the surrounding space.

4. CONCLUSIONS

Although the laminar field has been known in the world for decades, the aim of this work was to modify it and thus reduce the risk of infection of the patient and doctors in the operating room. This innovation could help to make transplants more successful, as operating room conditions play a key role in transplants. By more optimal airflow, we can prevent bacteria and viruses from entering the open wound and thus eliminate the risk of infection.

Since the laminar field is an energy-intensive device, it was necessary to analyze this device from an economic point of view. Since all calculated airflows in the range 1900-2800 $m^3 \cdot h^{-1}$ will ensure the required standardized air exchange, from the point of view of energy intensity, it seems to be the most advantageous option to use lower exhaust air flows, which are also sufficiently efficient. After an overall evaluation of the results, we found that the most advantageous solution is the case where the air extraction is evenly provided by 12 outlets and the flows for air exchange in the operating room will be selected in the range from 1900 $m^3 \cdot h^{-1}$ to 2200 $m^3 \cdot h^{-1}$. These flows ensure the most stable air flow over the operating table with the least turbulence and are also the least energy intensive.

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Acknowledgements:

The research is supported by project APVV PP-COVID-20-0113 "Creation of clean operating rooms in order to reduce the risk of transmission and spread of COVID-19 virus and other viruses and bacteria, with ensured decontamination of exhaust air from the clean room".

Anita Białek, Bade Koltuk
Structure and Environment 2021, vol. 13, (1), pp. 10-15, Article number: el 002
https://doi.org/10.30540/sae-2021-002

Structure and Environment
ISSN 2081-1500
e-ISSN 2657-6902
https://content.sciendo.com/sae
https://www.sae.tu.kielce.pl

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Kielce University of Technology

DOI: 10.30540/sae-2021-002

THERMAL COMFORT MEASUREMENTS IN THE ENERGIS BUILDING

BADANIA KOMFORTU CIEPLNEGO W BUDYNKU ENERGIS

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Abstract

In the paper the measurements of thermal comfort in the modern smart building "Energis" have been presented together with their analysis. The data have been obtained in the spring and the analyses of indoor air parameters as well as subjective responses of the volunteers have been conducted. Based on the performed studies it has been concluded that the people felt fine in the considered room (pleasantly warm, cool and comfortable) and described their feelings as acceptable and comfortable.

Keywords: indoor air quality, thermal comfort, thermal responses

Streszczenie

W artykule przedstawiono wyniki badań i analizę komfortu cieplnego w budynku inteligentnym „Energis". Dane eksperymentalne uzyskano w okresie wiosennym, a analiza dotyczyła parametrów powietrza wewnętrznego, jak również subiektywnych odczuć ochotników. W oparciu o przeprowadzone badania można stwierdzić, że użytkownicy czuli się dobrze w rozpatrywanym pomieszczeniu (przyjemnie ciepło i chłodno, a także komfortowo) i ocenili swoje odczucia jako akceptowalne i komfortowe.

Słowa kluczowe: jakość powietrza wewnętrznego, komfort cieplny, odczucia cieplne

1. INTRODUCTION

Smart buildings are a system in which the energy consumption of the buildings can be controlled automatically with the equipment inside the building in order to increase the energy efficiency. The most important task of the smart building is to ensure that the energy consumption of the building is at the lowest level without sacrificing user comfort. However, many times people complain about the conditions found in such buildings (which might also be caused by poor maintenance). Consequently, it needs to be determined if the complaints might be justified. Thus, the present paper aims to collect data and analyse them in order to conclude about the indoor conditions on a selected smart building located on the campus of Kielce University of Technology in Poland.

2. DATA ACQUISITION

The measurements of thermal comfort have been performed in the Energis building (Fig. 1) in the spring season.

It is located on the campus of the Kielce University of Technology and home to the Faculty of Environmental, Geomatic and Energy Engineering, is an example of a smart building. The Energis building, which was put into use in 2012, is located on Warszawska Street in the western part of the university campus. This building is a 7-storey building, while two of these floors are underground. The building has monolithic reinforced concrete structure. The outer walls are insulated with styrofoam, the inner walls are made of clay brick. The concrete flat roof is also insulated with styrofoam. A characteristic feature of Energis is the presence of the

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Fig. 1. Photo of the Energis building. Source: own resources

BMS (Building Management System), which controls the building services (heating, ventilation, etc.) and a number of other systems that help to manage the whole facility. The building is one of the innovative, smart building examples by working with renewable energy by collecting solar energy as well as the energy accumulated in the ground and in the air.

Measurements were made in lecture room No 1.14 of the considered Energis building. Figure 2 presents the data acquisition unit on the tripod and located in the center of the room.

Thermal environment was assessed in the form of air temperature and velocity, black sphere temperature, pressure, CO_2 concentration, light intensity and relative humidity parameters. The people who were in the room while the mentioned parameters were measured with the device, filled out a questionnaire containing questions about the microclimate in the room. In this questionnaire, participants were asked to rate their current state and wishes for temperature, lighting etc. The purpose of conducting the survey is to allow people to express their thermal comfort and to compare the results of the survey with the measurement results. Age, gender, health status of the person and the current clothing should be considered before the survey that will affect the person's thermal comfort. The measurements covered 15 people at the age of 22-38 years old, including 5 women and 10 men. The schematic of the room has been presented in Figure 3.

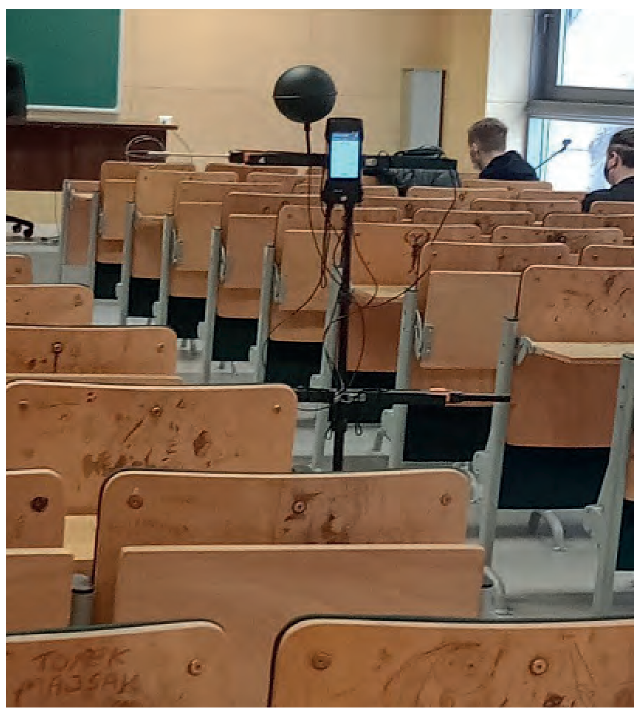

Fig. 2. Microclimate meter with the probes
Source: own resources

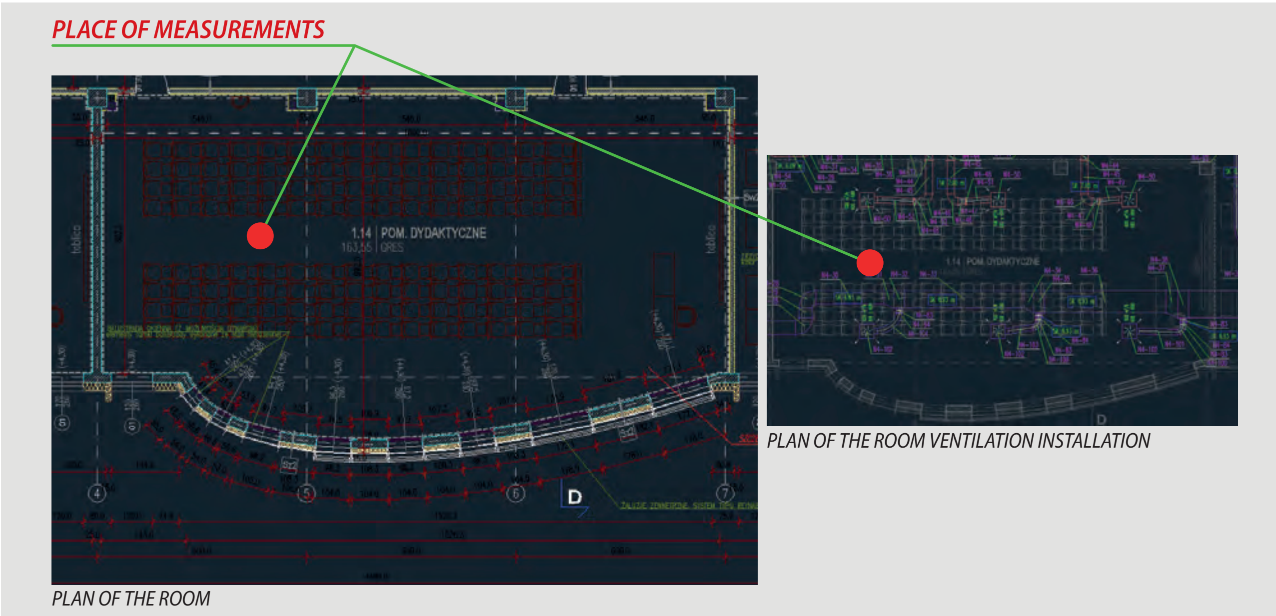

Fig. 3. Schematic of the room and the location of measurements (plan of the building adopted from: Puchała A., Budynek Laboratoryjno-Dydaktyczny Wydziału Inżynierii Środowiska Politechniki Świętokrzyskiej "Energis", Rzut I piętra Wentylacja i Klimatyzacja, 2010)

3. RESULTS OF THE MEASUREMENTS

During the tests a number of parameters were measured that changed with time of 5 minutes (Fig. 4). The first parameter of the four analysed is the temperature – the black line in Figure 4.

The parameter was maintained at the level of 23-25°C. For this type of room, the calculated temperature is +20 (for permanent residence of people without outer clothing, not performing continuous physical work) [1, 2]. The study was carried out in winter conditions (for a dressed person, the temperature should be between 20-23°C to ensure comfort), taking into account low physical activity in the room and maintaining the optimum indoor air humidity of 40-60% [3]. The control panel for the hall was set at a temperature of +22.8°C. The hall is equipped with an internal temperature control system via thermoelectric radiator heads with actuators. As shown, the room was heated to a temperature of approx. +24.8°C before the measurement. The parameter was striving to the set state (+22.8°C) and after the measurement time it reached +23.1°C. Thus, the heating/cooling system for the room reacted and works correctly.

The second parameter tested is carbon dioxide. In the lecture hall, mechanical ventilation was operating during the entire duration of the study. The room

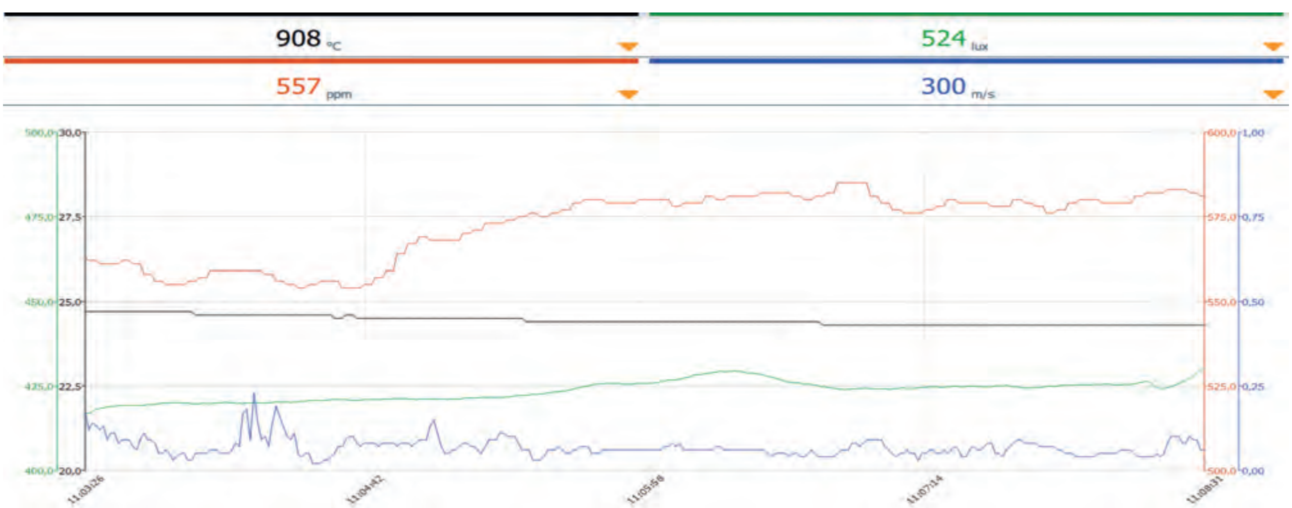

Fig. 4. Changes of selected indoor air parameters: air temperature (black line, left axis, °C), carbon dioxide level (red line, right axis, ppm), illuminance (green line, left axis, lx), air velocity (blue line, right axis, m/s)

was not equipped with a system for measuring the excess of permissible concentration of CO_2 in the room. There were no optical alarms and CO_2 sensors installed. When we talk about the freshness of the air in a room, we mean a value that is preferably close to the concentration in outdoor air between 350-450 ppm [4]. According to various international standards, the recommended CO_2 concentration for very good air quality is below 600 ppm. Poor air quality generally occurs when the CO_2 concentration exceeds 600-800 ppm, and poor air quality occurs when the CO_2 concentration exceeds 1000 ppm (increased respiratory rate). In the literature it is often interpreted that if the CO_2 value is above 1000 ppm this is a reason to improve the ventilation in the room and sometimes in the whole building. 1000 ppm = 0.1% which is the upper limit of freshness of the air according to WHO (World Health Organisation) and ASHRAE (American Society of Heating Refrigerating and Air Conditioning Engineers [5]) standards. Some standards, including those of the USA and the EU, set the concentration in indoor air at 800-1500 ppm, which corresponds to a ventilation air volume of 20-30 m^3/h per person [6, 7]. A CO_2 concentration of 5000 ppm (CO_2 molecules per million air molecules, 5000 ppm = 0.5% [8]) is taken as the safety margin during an 8-hour day in a working environment. However, this is a safety level and not a comfort or health level: Poland – MAC (Maximum Admissible Concentration) Limit; USA – TWA (Time-Weighted Average). Figure 3 shows how the CO_2 concentration level in the hall evolved. At the start of the measurement the index was at about 555 ppm, which is the quality of the fresh outside air. After the first minute we observe an increase in concentration. This increase is proportional to the duration of the measurement and the amount of carbon dioxide exhaled from the respondents' bodies. The measurement was terminated when the value of 580 ppm was reached. In 4 minutes there was an increase of about 25 ppm. Due to the short duration of the measurement it is difficult to say what indications would have been obtained after a 1.5 hour lecture. It can be assumed that a time of 90 minutes would be an increase of 562.5 ppm. Such assumptions can be made when the room is not equipped with a smooth mechanical ventilation air control system. Among others, through variable air volume controllers and when the air handling unit dedicated to the room is set at a constant volume. Otherwise, ventilation of the room should start when the concentration of 1000 ppm is exceeded. If ventilation can be mechanical, there should be a break during the lecture and manual ventilation, e.g. by opening doors and windows. The third parameter is the air velocity in the room. The quality of this parameter also reflects the comfort in the room. Air movement influences the intensity of heat absorption from the human body and thus directly influences the amount of heat released to the environment. Often, even the slightest movement can be perceived as discomfort. In most practical cases, the test result is considered positive when the air velocity is low (<0.2 m/s) and the difference between the radiation temperature and the air temperature is also low (<4°C) [9, 10]. The measurement was made with an air flow probe set at a height of 1.1 m above the floor level in the occupied zone [11]. This is the height of the clean zone – sitting (zone height 1.1 m) or standing (1.8 m). In fact, comfort conditions are only provided in this zone, which results in a reduction in the amount of cooling energy supplied compared with mixed ventilation. The measurement result (blue line in Fig. 3) shows that the air velocity in the room is almost imperceptible, below the value of 0.2 m/s [11]. The two momentary upward peaks are probably the result of movement, in close proximity to the device, of the person carrying out the measurement. For the rest of the test the result is well below the limit value of 0.2 m/s, showing no perceptible movement of the air inside the room. The fourth parameter measured is the illuminance of the room. The operational illuminance, i.e. the lowest value of the average illuminance recommended to be maintained during lighting operation in meeting and conference rooms, is 500 lx and should be adjustable. The readout value of the illuminance measurement is 420-440 lx. The measurement was made in the area between the students' seats, i.e. the illuminance of the immediate surroundings. The illuminance value should depend on, but may be lower than, the illuminance of the work area (visual task area). At the same time, it should ensure a homogeneous distribution of luminance in the field of vision. However, it must not be less than the illuminance values given in [12]. In the case of our hall, the illuminance condition has been met. In the case of lighting, the "ageing of the facility" is observed. The quality of the lighting in the hall commissioned in 2012 is already noticeable. In Figure 3 we see two peaks, in the second and fifth minute of the measurement. The reason for this may be the sunlight entering the room through unshaded windows. In order to eliminate this fact in the future, the measurement should be performed with all window openings in the room fully covered or during the night hours. The four parameters tested above did not show any deviation from the normative values for the measurements performed. Another parameter tested was relative humidity – its value was quite low – ranging from about 20% at the beginning to about 25% at the end of the measurements.

The state of comfort in the room was also questioned by the respondents. 15 participants took part in the survey: 5 women and 10 men. Thermal comfort is experienced differently by each person. It is therefore an individual and subjective feeling. There are, however, certain factors that influence the level of comfort perceived and make it possible to define acceptable values for thermal comfort. This is how the Predicted Mean Vote (PMV) index was defined [9, 10]. It describes the human thermal sensation on a 7-point scale. An increased value of room temperature (Fig. 4) is perceived by respondents. This fact is shown in detail in Figure 5. Namely, 60% of the female respondents find it pleasantly warm, while 40% find it pleasantly cool. On the other hand the results of the men's perception are as follows: 20% indicated that it is too warm, 30% pleasantly warm, 30% pleasantly comfortable, only 20% found it pleasantly cool.

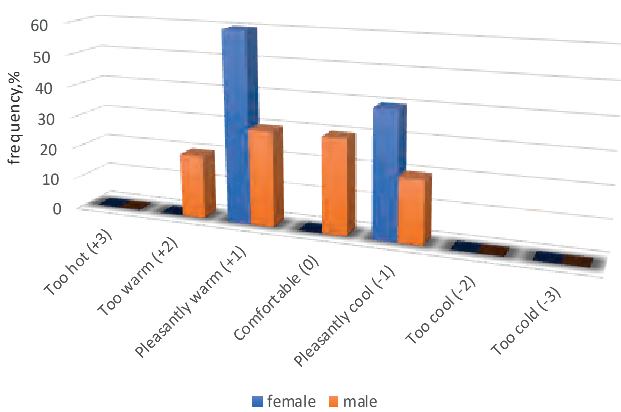

Fig. 5. Frequency of answers on thermal sensations: +3 – too hot, +2 – too warm, +1 – pleasantly warm, 0 – comfortable, –1 – pleasantly cool, –2 – too cool, –3 – too cold

A neutral feeling is considered to be the correct human feeling. The PMV value describing thermal comfort should therefore be between –0.5 and +0.5. As can be seen, this is a relatively narrow range, so it can be difficult to achieve in some types of room.

Figure 6 shows the evaluation of the room temperature. It describes the comfort and its acceptance by the respondents. 40% of both men and women found the room temperature comfortable, while 60% of both men and women found it acceptable. If the respondents had stayed longer in such a heated room (temperature of 24.8°C), the assessment would have been different, i.e. no longer acceptable.

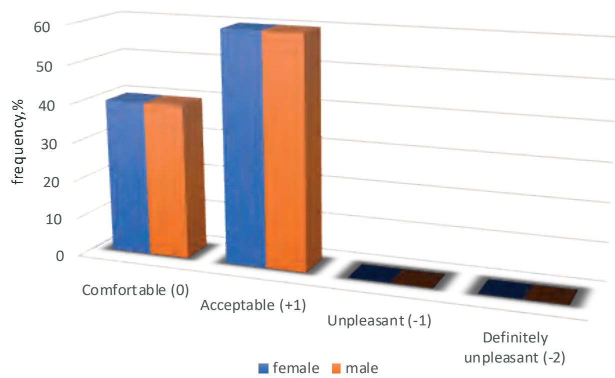

Fig. 6. Frequency of answers on temperatures felt: 0 – comfortable, +1 – acceptable, –1 – unpleasant, –2 – definitely unpleasant

Figure 7 shows the statistics of suggestions to make changes to the room. 40% of the interviewed women thought that the conditions in the room should remain unchanged, while as many as 60% of the women expect changes to be made. The quickest and easiest solution is to lower the temperature in the room. The suggestions made by men are in different proportions: 20% of men said that the room should be warmer, 60% no change, while 20% opted for an expected cooling in the hall.

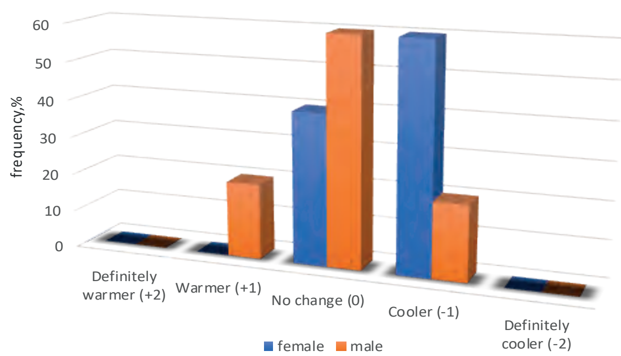

Fig. 7. Frequency of answers on thermal preferences vote: +2 – definitely warmer, +1 – warmer, 0 – no change, –1 – cooler, –2 – definitely cooler

So it is clear how both the temperature and the elevated carbon dioxide levels were perceived by the respondents. They are among the most important parameters affecting health, well-being and concentration especially in educational and training facilities.

Figure 8 shows the results of the respondents' opinions on the quality of lighting in the room. As a reminder, the place of the survey: a lecture hall, i.e. for a workplace there should be an illumination level of 500 lx. 20% of the women said the lighting was too bright, while 80% thought it was adequate. A similar opinion was expressed by men, 90% thought the lighting was adequate. Only 10% of the men said the lighting was too low.

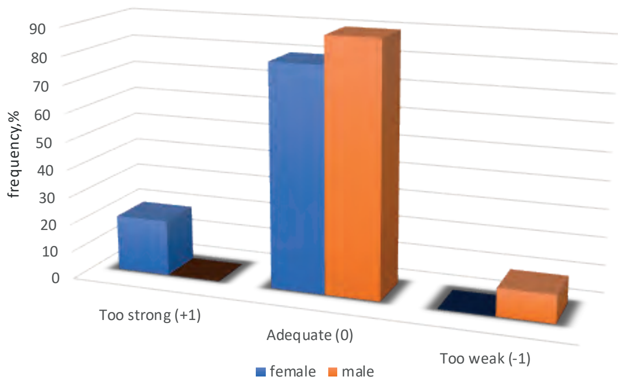

Fig. 8. Frequency of answers on the quality of indoor lighting: +1 – too strong, 0 – adequate, –1 – too weak

4. CONCLUSIONS

The survey and the questionnaire show how important room comfort is. The respondents felt that the temperature was slightly elevated, although this is individual. It is very difficult to maintain comfortable conditions in and out of a building for all occupants. Today, building owners and users strive to make buildings energy-efficient, cost-effective and, above all, comfortable. This is already happening at the stage of the construction process, where the designer, when drawing up the design, takes into account all these guidelines and expectations. In the course of the entire project and its realisation, newer and newer high-energy class buildings are constructed. The buildings are equipped with a full automation and comfort control system. The BMS system ensures and allows for full control and immediate reaction of the user to changes in internal parameters. All this makes it easier to meet the expectations and needs of occupants. Currently, especially in office buildings, there is a trend towards individual measurement of parameters in the working environment by employees. Awareness and expectations are rising compared to previous years. The requirements for permanently occupied rooms should be met satisfactorily for reasons of human comfort and economy. The assessment of the room conditions should be quick and clear and, if possible, improved immediately. Moreover, the analysis of thermal comfort in buildings equipped with renewable energy sources in Poland and abroad [13] is currently of significant interest. Thus, the subject has significant practical potential.

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Peter Olabisi Oluseyi, Ifunanya Lilian Ezike
Structure and Environment 2021, vol. 13, (1), pp. 16-28, Article number: el 003
https://doi.org/10.30540/sae-2021-003

Structure and Environment
ISSN 2081-1500
e-ISSN 2657-6902
https://content.sciendo.com/sae
https://www.sae.tu.kielce.pl

sciendo

Kielce University of Technology

DOI: 10.30540/sae-2021-003

RETROFITTING EXISTING OFFICE BUILDING FOR EFFICIENT ENERGY MANAGEMENT AND PERFORMANCE

MODERNIZACJA ISTNIEJĄCEGO BUDYNKU BIUROWEGO DLA EFEKTYWNEGO ZARZĄDZANIA ENERGIĄ

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Abstract

This study focuses on designing an efficient energy utilization protocol for the University of Lagos Senate office building, to ensure the reduction of energy consumption, reduce the cost of power and also ensure energy efficiency. Pre-retrofitting, the energy consumption cost for the UNILAG senate office building was calculated to be ₦20, 236, 962 i.e. 776.78 EUI (kWh/m²/y) using the appliance approach. The impact of various retrofitting methods was also simulated and measured utilizing BIM tools such as Autodesk Maya, Autodesk Revit and Autodesk Insight. This resulted in an estimated reduction in energy consumption cost to between ₦19,304,038.05 and 18,549,199.3 post retrofitting, this translates to about 712 EUI (kWh/m²/y). Results show that a 4.61-8.34% reduction in energy usage for the senate house can be achieved using the methods proposed in this research.

Keywords: Building Information Management (BIM), Energy Retrofitting Interventions, Heating Ventilation and Air-Conditioning (HVAC), Green Building Extensible Mark-up Language

Streszczenie

Praca koncentruje się na opracowaniu procedury efektywnego wykorzystania energii w budynku biurowym Senatu Uniwersytetu w Lagos w celu zapewnienia redukcji zużycia energii, redukcji jej kosztów i zapewnienia efektywności energetycznej. Przed modernizacją koszt zużycia energii w budynku Senatu został obliczony jako ₦20, 236, 962, tj. 776.78 EUI (kWh/m²/y) w oparciu o zamontowane urządzenia. Symulowano wpływ różnych technik modernizacyjnych i prowadzono obliczenia korzystając z narzędzi opartych o technologię BIM, tj. Autodesk Maya, Autodesk Revit i Autodesk Insight. To doprowadziło do przewidywanej redukcji kosztów energii pomiędzy ₦19,304,038.05 i 18,549,199.3 po modernizacji, co odpowiada ok. 712 EUI (kWh/m²/y). Wyniki wskazują, że możliwa jest redukcja zużycia energii dla budynku Senatu na poziomie 4.61-8.34% w oparciu o metody przedstawione w pracy.

Słowa kluczowe: modelowanie BIM, modernizacja energetyczna, ogrzewanie, wentylacja i klimatyzacja (HVAC), oprogramowanie Green Building Extensible Mark-up Language

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LIST OF ABBREVIATIONS

BIM	–	Building Information Management
CFL	–	Compact Fluorescent Lamp
CF	–	Cubic Foot
CFM	–	Cubic Feet per Meter
DISCO	–	Distribution Company
EE	–	Energy Efficiency
ERI	–	Energy Retrofitting Interventions
FGN	–	Federal Government of Nigeria
GBCN	–	Green Building Council of Nigeria
gbXML	–	Green Building Extensible Markup Language
GENCO	–	Generation Companies
HVAC	–	Heating Ventilation and Air-Conditioning
IC	–	Initial Cost
IEA	–	International Energy Agency
IPP	–	Independent Power Producers
LCC	–	Life Cycle Cost
LED	–	Light Emitting Diode
MEP	–	Mechanical Electrical and Plumbing
NIPP	–	National Integrated Power Projects
OECD	–	Organization for Economic Co-operation and Development
SC	–	Shading Coefficient
SCL	–	Solar Cooling Load
SE4ALL	–	The Sustainable Energy for All Action Agenda
SHGC	–	Solar Heat Gain Coefficient
SF	–	Square Foot
SRR	–	Skylight-to-Roof Ratio
UN	–	United Nations
US	–	United States
VAV	–	Variable Air Volume
WWR	–	Window-to-Wall Ratio

1. INTRODUCTION

Buildings provide shelter for human beings to protect them from dangerous and hazardous social, environmental and economic implications. No wonder it is one of basic necessities of life aside from food and clothing. Significant amounts of the day as humans are spent in the building, whether as home, office, factory, workshop and so on. This means that the effect of buildings in the social, environmental economic wellbeing of humans cannot be overemphasised.

Several social activities go on in the building in the form of play, work, lodging, family bonding, gaming, relaxation and so on which could have almost impossible without a building. This gives the building a strategic role to play in the existence of a balanced human life in maintaining social stability which will enhance social performance. The idea of environmental sustainability arose as a result of themetamorphosis of trying to reduce the energy level consumption and the depletion of natural resources which was highly necessary given it importance in the built environment. This brought about the concept of going green in the built environment to maintain environmental sustainability. The pursuit of this sustainability has become one of the most important design objectives of building design in the built environment [1]. The concept of economic sustainability will always be achieved if there is social and environmental sustainability. When social sustainability and environmental sustainability is increased, it increases satisfaction, desire, want and the urge to acquire which will definitely increase demand and economic value will increase. This process will increase economic sustainability. Green building is therefore the main panacea towards achieving sustainable development while drawing a balance in the social, environmental and economic areas [2]. The creation of green buildings through sustainable development can be used to reduce the negative effects of the building on the environment as well as human life [3]. Also, it will increase the economic value of the building, increase the occupants urge to live in the building as well as their satisfaction [4].

The use of fundamental energy has grown incredibly in Nigeria. It is basic to observe that monetary improvement is a critical clarification behind the high energy use in different countries; this has led to the increase in the amount of force eating up electrical and mechanical assemblies. Along these lines it is basic to research more achievable energy use strategies, approaches and utilization techniques.

Energy retrofit of buildings can help accomplish cost and energy proficiency by improving the productivity of building envelopes, central air frameworks, lighting (outside and insides) and electrical machines. Retrofits for building relate to various objectives, for example, environmentally friendly power energy and zero-discharge building retrofits. Green structure retrofits improve the natural reaction of a structure, decrease water utilization, and increase the solace and estimation of the space with respect to a few variables, for example, light contamination, air contamination, and commotion contamination. Then again, energy building retrofits centre around enhancing the energy execution of a structure [5].

As indicated by Khoshbakht [6] "To compute the energy productivity of a structure, one should consider the energy utilization per square meter or square foot of the space, in correlation with standard energy utilization benchmark of such structure types under certain climate conditions". Benchmarks are applied fundamentally to warming, cooling, ventilation, lighting, fans, siphons and controls, office or other electrical hardware, and power utilization for outside lightings. Amusingly, the immense interests in the force area haven't yielded the ideal yield of power supply.

The economic development and expectation for everyday comforts of any nation is a sign of the size of its power industry. This is on the grounds that the feasible and stable force supply is apropos in advancing the expectation for everyday comforts just as the financial exercises of any country. It likewise shows an impression of the residents' admittance to clean water, improved medical care offices, development and advancement of the different portions of the public economy, for example, correspondence, industry among others. From the above affirmation, power supply is critical to public improvement in Nigeria.

A research carried out by Momoh [7] on the ramifications of helpless power supply on Nigeria's public improvement arrived at the precise resolution that the financial development and expectation for everyday comforts of any nation are a sign of the size of its power industry. He went further to express that the non-appearance or restricted stock of power has antagonistically influenced financial exercises in Nigeria like business exercises. This will prompt infrastructural rot and breakdown, conclusion of ventures just as a fast decrease in the accessibility of social pleasantries, for example, consumable drinking water, improved medical care administrations among others.

Energy utilization soared over in recent years because of the quick development of innovation, with utilization of energy not easing back down whenever soon [8], researchers and scientists the same have investigated different strategies to achieve more productive energy use worldwide and in Nigeria specifically. This literature review will assess a portion of the astonishing works that educated my choices in executing this venture, a portion of the evaluated works will be works done both in Nigeria and abroad to accomplish energy effectiveness in structures through retrofitting.

Onyenokporo [9] in 2018 left on a venture to create reasonable retrofit techniques and materials that can be utilized in existing private structures to improve tenants' warm solace in Lagos Nigeria. Their examination demonstrated that property holders might have the option to decrease their yearly energy utilization by up to 47% by going through a basic energy retrofit; they likewise reasoned that building retrofits might be done not simply to lessen energy utilization by central air and lighting frameworks, yet additionally to improve warm solace inside a structure. He and his group suggested the utilization of aloof plan systems by draftsmen at the configuration phase of making a structure to improve energy execution and advance supportability.

Andoni affirms that energy systems are undergoing extremely fast changes to contain the rapid increase in the number of embedded renewable energy generation like solar PV and wind [10]. Radwan [11] from the mechanical designing division of both Bedouin Institute of Science and Alexandria College in Egypt met up only a year prior to the Francesco group to go through a practically comparative examination in 2016 labelled retrofitting of existing structures to accomplish better energy-effectiveness in business working, with their contextual investigation likewise being an emergency clinic in Egypt. The primary focal point of their work anyway was extraordinary; they cantered around clarifying and considering the issue of building energy productivity execution and to distil helpful encounters and data to apply to building energy guidelines. Their re-enactment indicated that the use of DVC frameworks for air control saves an expected 41% of electrical energy burned-through and that divider protection diminishes energy utilization by 8%.

Khairi [12] and his colleagues in their project: The application, benefits and challenges of retrofitting the existing buildings had the aim to provide information on the application, benefits and challenges of retrofitting an existing building. Two buildings were chosen as case studies followed by site visits and observation to the buildings. At the end of their study they came to the conclusion that retrofitting the existing buildings is one of the most environmentally friendly, economical competent and proven as an efficient solution to optimize the energy performance and could also help to prolong the life of the existing building especially to the historical buildings. Thus, the application of retrofit should be promoted across the construction and conservation industries. More research need to be done in order to have complete sets of detail data on the direct and indirect impacts of retrofit to the environment, cost differences between retrofit with the normal construction of a building, cost of maintenances as well as, the impacts to the end users and to the surround area of retrofitted buildings.

Khoukhi [13] presented in their study; retrofitting an existing office building in the UAE towards achieving low-energy building, a real case study of the retrofitting of an existing building to achieve lower energy consumption in UAE, a monthly computer simulation of energy consumption of an office building in Sharjah was carried out under UAE weather conditions. Several parameters, including the building orientation, heating, ventilation, and air conditioning (HVAC) system, external shading, window-to-wall ratio, and the U-values of the walls and the roof, were investigated as also in this project and optimized to achieve lower energy consumption. Their simulation showed that the most sensitive parameter in the retrofitting alternatives is the roof component, which affects the energy savings by 8.49%, followed by the AC system with 8.34% energy savings if well selected using the base case. Among the selected five components, a new roof structure contributed the most to the decrease in the overall energy consumption (approximately 38%). This is followed by a new HVAC system, which leads to a 37% decrease, followed by a new wall type with insulation, resulting in a 20% decrease.

Dixon [14] in his article found that the inflexible regulations, complicated validating and approval process for new technologies, selective authorized lists of technologies are all seen as aspects that can reduce the entry of new retrofit products into the market. Even though retrofit bring benefits to the buildings, environment and end user of the buildings, the planning of making good the existing buildings such as the historical buildings need to be done with manner and respect to its authentic building elements and the surrounding community. Fail to do so may result on negative impacts such as damaging the most authentic building elements of the buildings or creating nuisance to the community.

Ochedi et al. investigated the methods in energy efficiency approach in achieving energy efficient buildings in Nigeria. This was conducted through the adoption of the passive design approach. The result indicated that the method reduced energy consumption in the range of between 40-60% when compared to the normal buildings. The research proposed the passive design method in obtaining high energy efficiency [15].

Ozarisoy et al. researched on the capacity of retrofitting methods in the optimization of existing energy performance in residential buildings. It investigated the performance of energy before and after retrofitting using Autodesk Revit 2017 and Insight 360 software for its energy performance analysis and simulation. The result indicated a cost effective and efficient energy system [16].

Oluseyi et al. [17] used building information modelling (BIM) approach for the simulating, analyzing and assessing energy usage in buildings. It was used to improve energy in a university office complex and the result indicated savings in energy and cost. The results also show that the consumption of energy could be reduced to at least 40% if energy efficiency practices are applied using BIM. The research indicated that if retrofitting is applied to buildings for the purpose energy savings it will solve the lack of access to energy.

Electricity supply is critical to the public improvement in Nigeria and that energy utilization has a huge relationship with economic development in Nigeria. This was my inspiration to leave on this venture, a more supportable utilization of energy in Nigerian structures will no uncertainty straightforwardly impact the public and monetary advancement of the nation. Contrasted with different techniques these improvements can be accomplished, retrofitting for effective energy use is considered around the world less expensive and more practical over the long haul.

According to the World Bank 2019 report [18], Nigeria has a population of over 200 million people with the potential of future population explosion, there will undoubtedly be a relative increment in the utilization of electrical and electronic machines. The usage speed of energy has been on the climb and Nigeria's ability industry has not had the option to coordinate the interest of energy needed with its developing populace and may not probably accomplish this even sooner rather than later. Because of this energy shortfall in Nigeria, many are left in obscurity without fundamental power, devastating family units and significant areas like medical care.

The aim of this study is the design of an efficient energy utilization protocol for an office complex in a university in Nigeria to ensure the reduction of energy consumption through energy retrofit measures. To achieve this; the following objectives shall be pursued:

– to appraise and analyse the existing energy consumption management for an office complex in the University of Lagos, Nigeria;
– to design energy consumption management and performance procedure for existing office buildings;
– to optimize the energy consumption management and performance for existing buildings;
– to model the energy cost model of the existing building pre and post retrofitting exercise.

As part of efforts to support the Federal Government of Nigeria (FGN) in achieving its target for The Sustainable Energy for All Action Agenda (SE4ALL), this study will focus more on how to redesign the energy distribution channel of an office complex in the University of Lagos in Nigeria to consume minimal electrical power, reduce the cost of self-generating power and also ensure energy efficiency within the building while at the same time reducing the carbon footprint.

Focusing on the reduction of the amount of electricity consumed by a building and how best to optimize usage, this study has the potential to:

1. Reduce the emission of carbon into the atmosphere, thereby, securing the ozone and improving general health.
2. Reduce cost of electricity bills incurred by households and organizations alike as their dependencies on electricity may reduce significantly.
3. Bring more awareness upon the importance of retrofitting and adoption of more efficient and sustainable methods of energy within building.

The paper is structured into four sections. Section 1: The "Introduction" provides the research objectives, Problem statement presents the research motivation, detailed problem definition and literature review. Section 2: "Methodology" describes the approach, including main assumptions, equations and data sources applied to the case study building carried out by using design software. Section 3 is dedicated to discussion and results and te last section is dedicated to Conclusion.

2. METHODOLOGY

2.1. Materials Used

In order to carry out the effective retrofitting of an office complex in the University of Lagos in Nigeria, certain Building Information Modelling (BIM) tools came into use which proved effective in creating a digital twin of the civil and electrical functionality of the case study building. The tools used are Autodesk Maya, Autodesk Revit and Autodesk Insight Cloud.

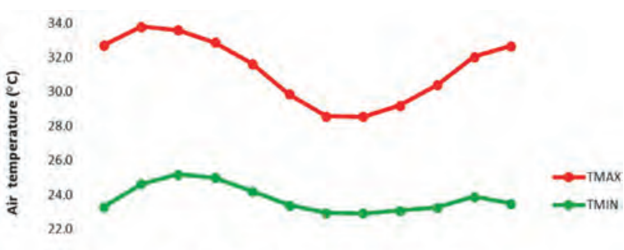
2.2. Case Study Description

The office complex is a marvel, towering above other buildings in the university campus, the 11 storey edifice was designed in 1980 and completed in 1985. It is a combination of executive offices for the Vice Chancellor and Registrar, a new Senate chamber and general offices for the university administration. The case study site lies between latitudes 6°26′ and 6°50′N and longitudes 3°09′ and 3°46′E and was also built to lay across one of the main pedestrian routes of the campus and the design maintains this route, allowing it to pass under the building, rather than diverting it around the building. The building also houses the first university radio station in West Africa.

Fig. 1. University office complex

The topography of the location of the building is important because of the effect the angle of incidence of solar radiation, slope, and orientation of the land in terms of the use of daylight, solar radiation and natural ventilation within the building. It is also extremely important to analyse the climate and demography of Lagos because this directly affects and informs my approach to retrofitting the building.

Lagos is located in the South-western region of Nigeria in West Africa. On the globe, Lagos lies between a latitudes 6°26’ and 6°50’N and stretches between longitudes 3°09’ and 3°46’E. Lagos is made up of two major region i.e. the Lagos island which comprises of the areas such as Ikoyi, Victoria island and Lekki which are all highbrow areas and the Lagos mainland which makes up other parts of the state [19]. Lagos has a landmass of around 3,577.28 square kilometres, it has a wetland of about 22% and a population density to tune of 5,926 persons per square kilometre [20]. Lagos is Nigeria’s main commercial centre harbouring over 70% of the country’s economy and industries [21]. An investigation done by Amadi and Hingam showed that during the design of buildings in Nigeria, designers pay little or no attention to climatic conditions [22]. These climate and climate conditions are typically not thought about during arranging, building and development in the nation, yet they should be contemplated during retrofitting to accomplish the most ideal reasonable preservation of energy planned, how they influence my simulation will be investigated in future sections.



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
TMAX	32.7	33.8	33.6	32.9	31.6	29.9	28.6	28.6	29.2	30.4	32.0	32.7
TMIN	23.3	24.6	25.2	25.0	24.2	23.4	22.9	22.9	23.1	23.3	23.9	23.5

Fig. 2. Average temperature and precipitation for Lagos state [23]

Buildings are designed for a particular number of people, the occupation density of a building is the quantity of individuals involving a square foot (ft2/individual) [24], knowing the quantity of people that possess a territory in the university on a normal day is significant in the investigation of the building warmth and ventilation, the occupation density of a structure is typically determined by separating the region of rooms or storey(s) (m^2) by a story space factor (m^2 per individual), the space factor esteem being utilized here is gotten from the endorsed Britain building standard of 1965 [25].

$$\text{Occupation Density} \; \frac{\text{Total of in the building}}{\text{factor}\left(\text{m}^2 \text{ per person}\right)} \quad (1)$$

In order to simulate the performance of heating and cooling plants and systems, each subsystem (generators, distribution, emission, and control) and auxiliary electric consumption were assessed, the office complex currently uses air-conditioning systems for ventilation, although there are varying brands of air conditioning systems in use in the building, the major ones taken into consideration in this research are National and SAN air conditioners, both with average heating power of 6.2 kW and 7.9 kW with wide range capacities (between 1.4 kW to 12 kW) as stated by their manufacturers. The building also uses hybrid illumination i.e. combination of sun light and electricity.

2.3. Architectural Modelling and Design with Autodesk Maya

Autodesk Maya is an industry leading 3D modelling and design software application developed by Autodesk incorporated that enables engineers and architects to create hyper-realistic architectural models. Many architectural firms are adopting Maya for 3D visualization as a way to help sell a design or idea mainly because of the amount of flexibility it provides for shapes and architectural forms [26]. It is a powerful digital drafting tool, which means projects and models are represented geometrically and has replaced two-dimensional (2D) and three-dimensional (3D) modelling manual hand animation tools as a multi-purpose modelling engine, which made it the right software candidate for the architectural modelling of the case study.

Maya was used to develop the architectural twin model of the case study, this twin model was then exported to Revit which was then used to apply selected energy settings, as observed from the actual case study such as wall types and electricity consumption, to the twin model in order to analyse outcomes for a range of conditions for the final energy management simulation to be carried out.

2.4. Energy Management Simulation with BIM Autodesk Revit and Autodesk Insight Cloud

Energy settings control the behaviour of the energy model created for the case study. Various energy settings had to be made on Revit to ensure proper energy analysis is performed on the building model in order to establish current electrical energy consumption of the building, a 3D model was created in the Autodesk Revit software using the floor plans of the building.

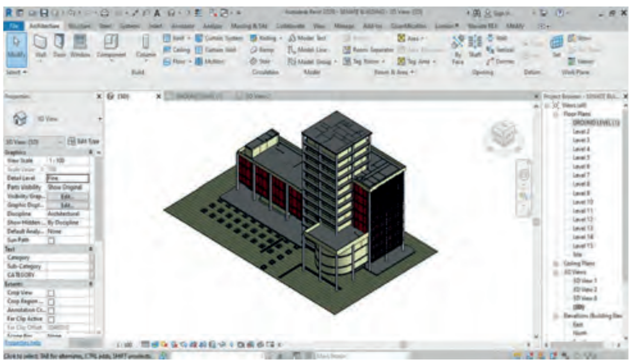


Fig. 3. 3D Revit Model of the university office complex

Fig. 4. Third floor plan with orientation set relative to True North in Revit

Room tags were created on Revit room tool to help identify each room as this helped when exporting the file to gbXML format. gbXML is a type of XML file that has over 500 types of elements and attributes that allow you to describe all aspects of a building. The way gbXML works is, a tool such as Autodesk Revit has an option in the "File" menu that allows you to "Save As gbXML" after designing 3D representation of a building as started on Maya and finished on Revit, there were a few parameters that needed to be established.

These included the building space tolerance, building type, the location of the project in-building elements and all 500 gbXML attributes that clearly describes all aspects of the building. Below are examples of such settings and their relevance to determining and simulating the energy consumption of the case study:

Space Tolerance: This is a setting on Revit MEP used to help manage and simulate heating and cooling loads around narrow unoccupied spaces, like plumbing chases in buildings. For calculating heating and cooling loads it is important that all volumes are accounted for and there are no gaps in the analytical model.

Perimeter Zone Depth: This is the space where the receiving of the bulk effect of the ambient condition is done. Setting the perimeter zone depth is a valuable part of automatic thermal zoning, especially for large buildings such as the case study buildings for energy saving. The core of a building has heating and cooling loads that differ from the perimeter because it is not directly exposed to external weather conditions or daylight through windows.

Mode: Revit offers 3 modes for creating the energy model from the architectural model. For all cases, the mode selected for this project is "Conceptual masses and Building Elements" mainly because it is more suitable for the architectural model of the case study as it is more flexibleand suitable for simulating jointly or independently the energy impacts of masses and elements in the building.

2.5. Steps Taken to Analyse the Existing Energy Consumption management for University Office Complex

The total stepwise technique and work process embraced for the examination pointed towards investigating, planning, and improving the current energy utilization, the executives and execution for the university office complex is depicted underneath.

2.5.1. Simulating Energy and Environmental data in Autodesk Insight Cloud Subscription

After generating the energy model on Autodesk Revit MEP, an optimization on the model, to strip away possible inaccuracies in the inputted environmental data was done. The next stage was to simulate the whole building energy, including daylight analysis, heating and cooling load, HVAC and Plug/Appliances load.

The yellow colour indicatesthat the sunlight intensity in this room is higher as compared to the other room. Looking at the bench mark at the right hand side of the image, the color difference shows the intensity.

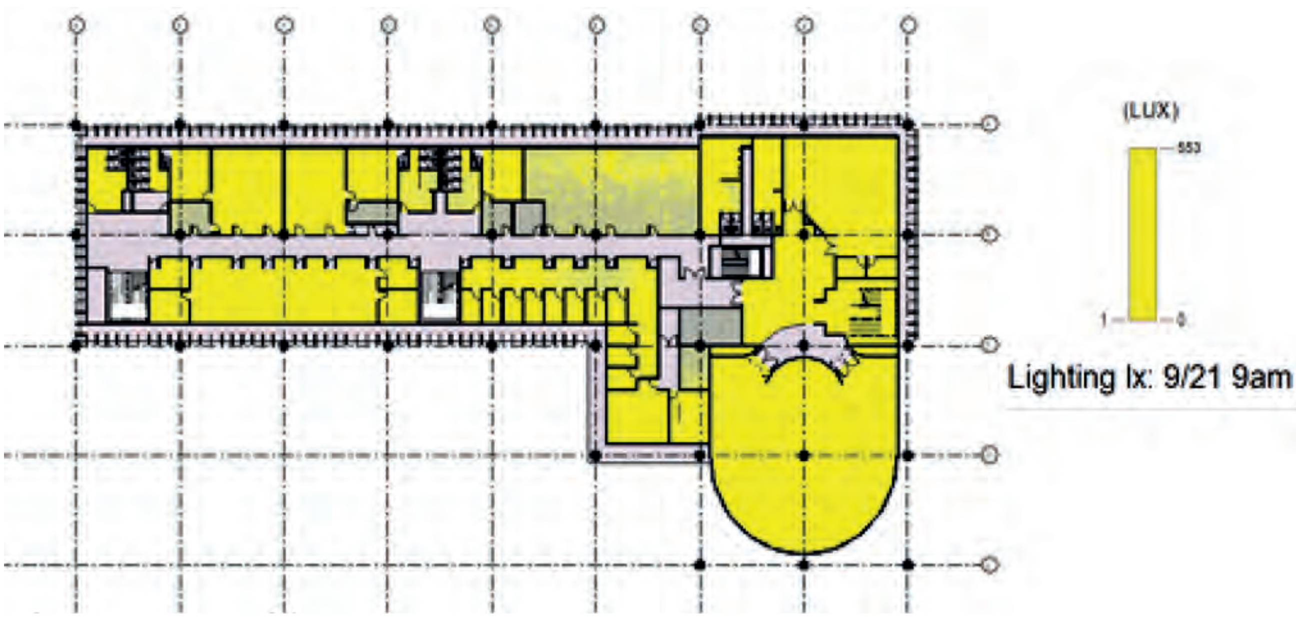


Fig. 5. Floor 2 Illuminance Lighting Analysis Results

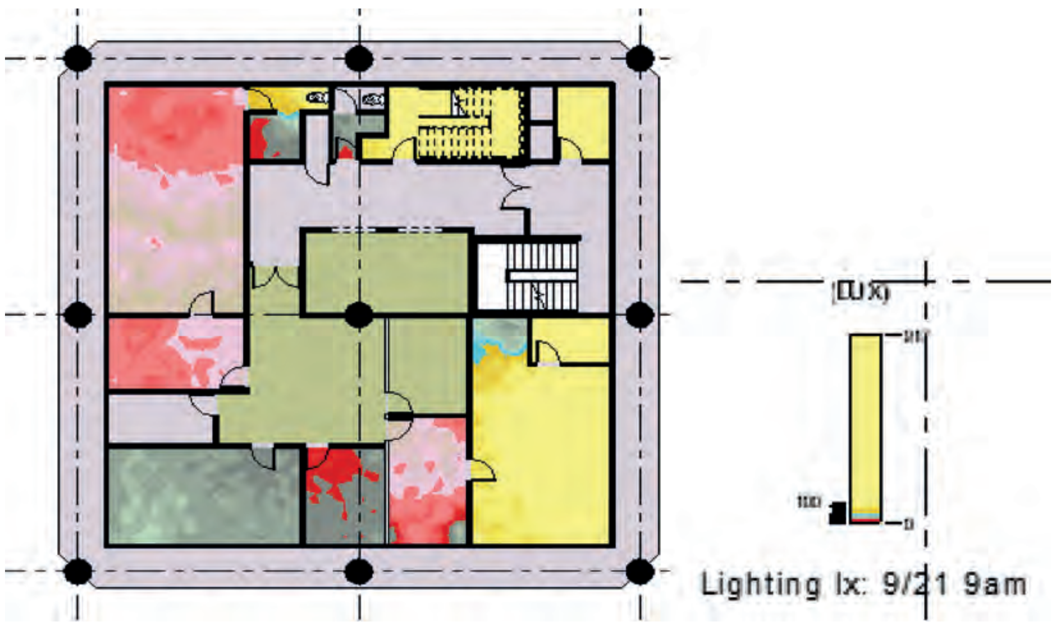


Fig. 6. Level 8 Illuminance Lighting Analysis Results

Primary data was based on a physical observation of both the interior and exterior parts of the building with the support of the building floor plans, while secondary data are based on research and information gotten from the school and academic contributors online, these gathered data were useful in creating a 3 dimensional model replica of the case study building in Autodesk Maya and Revit MEP. The energy twin model of the building was generated in Autodesk Revit while detailed simulation and analysis was done using Autodesk Insight.

2.5.2. Optimizing the University Office Complex Energy Consumption Management and Performance in Revit MEP

The Energy Analysis done on the University of Lagos office complex comprises of 11 focus components which perfectly describes the energy model of the building, and was done to determine the state of the energy management of the building after the application of retrofitting procedures which were then compared with the mathematically calculated state before retrofitting, this simulation was done with Autodesk Insight also known as green energy studio and the result of the simulated conditions for the case study after the input of all data is in the EUI (Energy Use Intensity) which expresses a building's energy use while following the standard energy analysis steps required both in Revit MEP and Autodesk Insight, the 11 focus components are listed with their simulation results below. The results gotten from the simulation are displayed in images captured from the simulation software.

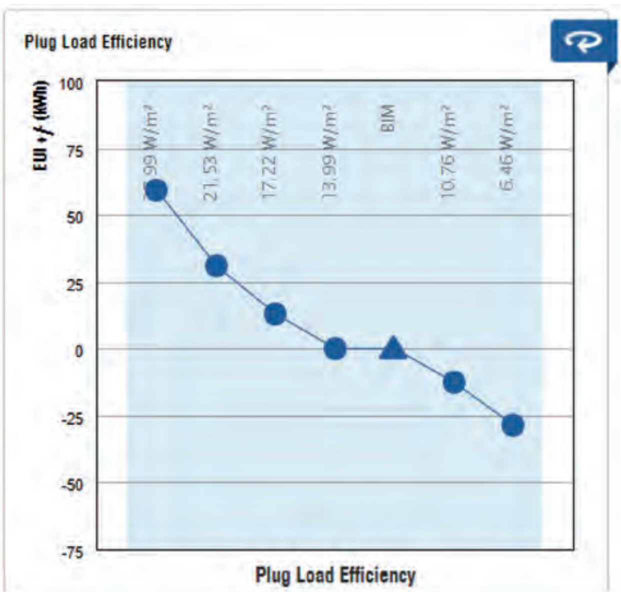


Fig. 7. EUI of the Plug Load Efficiency for the case Study

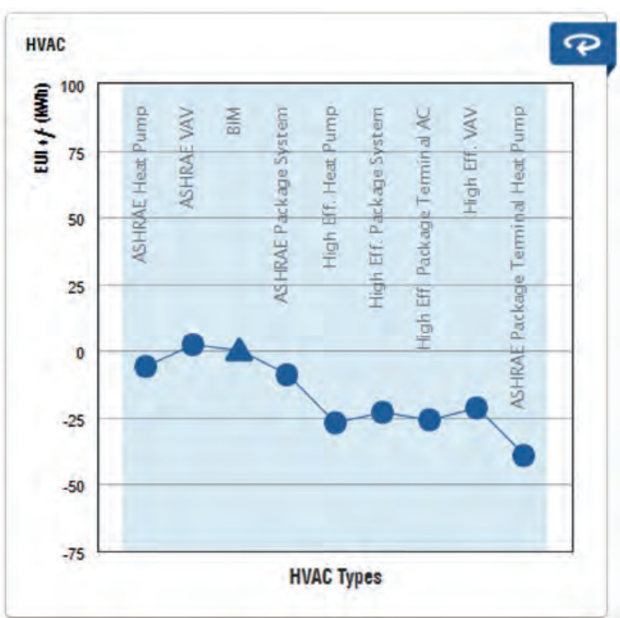


Fig. 8. EUI of the HVAC system

3. RESULTS AND DISCUSSION

The results presented in this study were obtained from focusing on two key methods. The first method is the appliance use approach which deals with the use of relevant mathematical equation to determine energy consumption; the calculated data are used to determine the major outlets where energy is being consumed. The second method is the use of the BIM Tools for the energy simulation, taking into consideration some of the data gotten from the first method.

3.1. Appliance Approach to Analyse the Existing Energy Consumption management for the University Office Complex

This approach is used to determine the case study building electricity consumption depending on data obtained from measurement and observation of key electrical aspects and outlets of the building. As seen in Table 1 below, the AC units seem to be the largest consumer of electricity in the building, with an annual cost of 9,771,210 naira, with a staggering 101 units within the building, and the fire alarms has the least power rating (2 W) while the microwave have the highest (1400 W).

The Refrigerators are run for 24 hours/day and still consumes less amount of electricity and costs less; 2,152,656 naira compared to the AC units which run for just 12 hours. Appliance approach involves summing up end-use energy consumed by various electrical appliances in the course of common office activities.

Table 1. Electrical Energy Consumption for Appliances on all floors of the University of Lagos Office Complex Building

S/N	Appliances	Qty	Rating (Watts)	H (hrs)	Annual Cost (naira)
1	Lighting	147	36	12	590,351
2	AC units	101	1250	10	9,771,210
5	Computers	67	220	10	1,335,444
4	Printers	62	360	10	2,022,192
5	Photocopier	30	1200	10	3,261,600
6	Scanner	10	40	10	36,240
7	Television sets	30	200	8	420,384
9	Toasters	5	1200	2	108,720
10	Laptops	22	90	10	179,388
11	Microwave	6	1400	3	253,680
12	Shredders	12	259	2	72,480
13	Fire Alarm	75	2	24	32,617
14	Refrigerators	33	300	24	2,152,656
	Total	**602**	**6,557**	**135**	**20,236,962**

3.2. Optimizing the Energy Consumption Management and Performance in BIM (Revit and Insight Cloud)

For the BIM energy simulation, various conditions and different elective evaluations were performed to think about framework game plans and obtain extra AEU (Annual Energy Usage). The results obtained from the case building analysis after applying retrofitting (i.e. applying the Energy Protection Methods) and performing the simulations are discussed below. The Annual Energy Usage to be determined depends on both EUI and Building total area. It is important to note that EUI stand for Energy Use Intensity and is given as a building's Annual Energy Use divided by the total area, with the computation of EUI in revit insight, we can simply calculate energy Annual Energy Use of the building before and after retrofitting to compare if there has been a significant decrease.

As stated previously, in calculating the annual usage of electricity, a key component is the total area of the building, this has been computed through the addition of all areas of rooms in the building, made easy through the energy twin GBS model used in Autodesk Insight Cloud, the total area of the building was computed to be 5653 m^2.

Table 2. Data table containing EUI Max and Min gotten from Autodesk Insight after simulation of Retrofitting procedures

EUI Max (kWh/m^2/yr.)	883.91
EUI Min (kWh/m^2/yr.)	712
EUI Mean (kWh/m^2/yr.)	282.02

Thus, as seen in equation (2) the range values of the Annual Energy Usage of the University office complex can be calculated by multiplying both ranges of Energy Use intensity gotten through BIM simulation seen in Table 2 with the total area in meter squared of the building. The AEU value for the building was calculated to be between 4,188,364.23 kWh/y and 4,024,936 kWh/y.

$$\text{EUI}=\frac{\text{Annual Energy Usage}\left(\text{AEU}\right)}{\text{Building gross Squarefeet}} \quad (2)$$

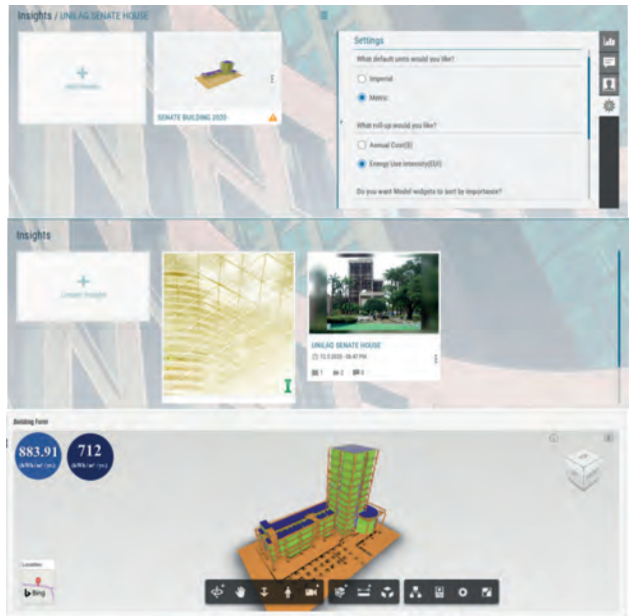


Fig. 9. University of Lagos office complex building 3D model and simulated energy consumption range from insight applying various retrofitting techniques

The results gotten after modelling the energy cost model of the existing building pre and post retrofitting exercise in Revit MEP and Autodesk Insight are shown in Table 3 below.

Table 3. Comparison of the current consumption vs the application of retrofitting simulations with BIM tools

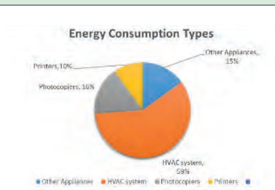
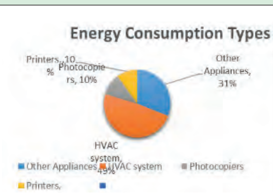
	Case study before retrofitting	Impact of retrofitting on BIM
Total Area (m^2)	5653	5653
Energy Use Intensity (EUI (kWh/m^2/y))	776.78	712
		740.91
Annual Energy Cost (Naira)	20,236,962	18,549,199.37
		19,304,038.05
Annual Electric End-Use		

Table 3 compares the analysis and results of the case study building with the Energy Use Intensity simulation of the building with BIM tools. For this case, it is observed that energy consumption of the building can be reduced by 4.61–8.34% at minimum and maximum impact of the retrofitting strategies, consumption is projected to move from 4,390,988 kWh per year as calculated mathematically to as low as 4,024,936 kWh per year – 4,188,364.23 kWh per year.

The annual electric consumption cost for the case study building mathematically calculated from the appliance approach are; for HVAC system (58.92%), Photocopiers (16.12%), Printers (9.99%) and other appliances (14.97%) totalling 20,236,962 kWh/year. The annual electric consumption cost after retrofitting with BIM tools, it became; for HVAC system (48.70%), Photocopiers (10.44%), Printers (9.99%) and other appliances (30.97%) totalling 4,024,936 kWh/year, projecting a significant improvement.

By examining the case study building used in this paper, as well as the other reports, papers and guides, there is proficient evidence that Energy Retrofits using the Integrative Design Process can drastically reduce carbon emission for existing office buildings. Every case study resulted in an Energy Use Intensity far below pre-retrofitting; proof of the energy reduction potential of Energy Retrofits. This shows that Energy Retrofits provide an excellent way to reduce our societies contribution to climate change. The most obvious benefit of Energy Retrofit is the operational cost savings that can be achieved making it a financially viable option for office buildings.

In contrast to previous approaches, this study provides an integrated framework to identify the stakeholders' requirements and potential energy efficiency measures, to build and optimize a large design space, and to determine the best solutions, in a holistic way. In addition, mathematical optimization and evaluation techniques are incorporated into the decision making process, which simultaneously considers the important role of stakeholders in carrying out the analysis procedure.

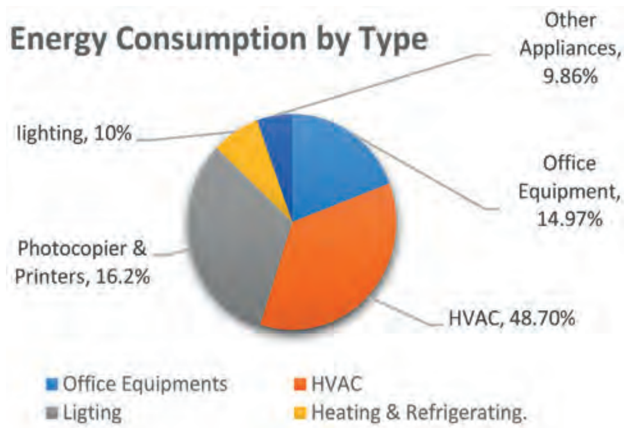


Fig. 10. A distribution of energy consumption types within the case study building

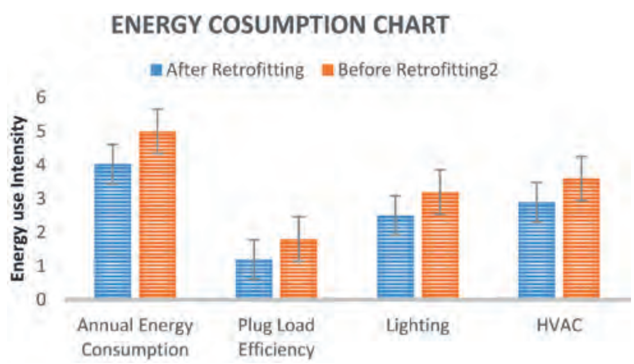


Fig. 11. Comparison of consumption before and after retrofitting

Table 4. Comparing results of finical cost of retrofitting interventions and energy improvements of similar studies

SN	REF	LOCATION	BUILDING TYPE	COST SAVING	% ENERGY SAVING
1	[27]	Empire State Building – Manhattan, New York City, USA	Commercial building	$4,400,000	38%
2	[28]	Kuykendall Hall – Hawaii Mānoa (UHM) campus, Honolulu	Commercial building	$2,702,000	84%
3	[29]	The Christman Building –Lansing Michigan, USA	Commercial building	$45,659	44%
4	[30]	Lucknow, India	Residential building	50,400INR	30%
5	Present study	Senate House – University of Lagos Campus, Nigeria	Commercial building	₦1,687,762	8%

4. CONCLUSION

There are many significant ways energy efficiency can be achieved in everyday activities; a list of energy saving methods was designed during the course of this study specifically for the case study building. The optimization of the building was done on BIM, various conditions and different elective evaluations were performed to think about framework game plans and obtain extra AEU. The results obtained from the case building analysis after applying retrofitting (i.e. applying the Energy Protection Methods) and performing the simulations established that with energy saving procedures explored in this project about 971,807.23 kWh of energy and 1,687,762.63 naira could be saved per year.

It is a clear issue that power generation in Nigeria is inadequate, to worsen these challenges, there is no proper energy metering system to ascertain the actual amount of energy distributed. This has resulted in distribution companies over billing customers and over pricing the cost of energy. In addition to this, there are clear indications that Nigeria as a whole could still tap into several other greener means of generating power both on a small and large scale, to companies and individuals. The energy saved through retrofitting from the university's office building can simply be redirected to other buildings in need of it within the school premises making for more efficient energy usage and a drastic reduction in cost of energy usage of the office building per year.

4.1. Future Research

It is worthy to note that one of the greatest drawbacks in this study was the availability of data from the case study building for this research, hence other key approaches to estimating Annual Energy Usage such as Appliance Approach and Expenditure approach could not be pursued in this study, these could be used as basis for future research.

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Structure and Environment 2021, vol. 13, (1), pp. 29-33, Article number: el 004
https://doi.org/10.30540/sae-2021-004

Structure and Environment
ISSN 2081-1500
e-ISSN 2657-6902
https://content.sciendo.com/sae
https://www.sae.tu.kielce.pl

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Kielce University of Technology

DOI: 10.30540/sae-2021-004

ENERGY EFFICIENCY OPTIMIZATION OF THE OPERATING ROOM DUE TO THE DISPOSITIONAL LOCATION

OPTYMALIZACJA EFEKTYWNOŚCI ENERGETYCZNEJ W SALI OPERACYJNEJ ZWIĄZANA Z LOKALIZACJĄ SYSTEMU WENTYLACJI

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Abstract

Clean rooms, including operating rooms, are energy-intensive. During their operation, the concentration of particles in the air, air temperature and humidity are strictly monitored. HVAC systems in the operating room are subject to high demands on maintaining a stable heat and humidity microclimate, as well as particle concentrations within the permitted range. To cover heat losses and heat loads of the building, it is necessary to dimension ventilation equipment with high outputs and high energy consumption. By suitable optimization of the dispositional location of the operating tract in the building and the use of suitable thicknesses of insulating material, it is possible to reduce the performance requirements for the HVAC system, which significantly reduces energy consumption. Heat loss and heat load of the operating tract were evaluated using TechCon software. The performance values of the heaters and coolers for the HVAC units were calculated in the VentiCad design software. The optimization indicates a significant reduction in heat loss and heat load, as well as a reduction in the required temperature of the air supplied to the room by more than 10°C.

Keywords: energy efficiency, HVAC systems, energy consumption optimization

Streszczenie

Pomieszczenia czyste, łącznie z salami operacyjnymi wymagają dużo energii. Podczas ich pracy dokładnie monitoruje się stężenie cząstek stałych w powietrzu, jego temperaturę i wilgotność. Systemy grzewcze, wentylacji i klimatyzacji (HVAC) w salach operacyjnych podlegają wysokim wymaganiom związanym z utrzymaniem stabilnego mikroklimatu cieplno-wilgotnościowego, jak również stężenia cząstek w dozwolonym zakresie. Pokrycie strat i zysków ciepła budynku wymaga projektowania systemów wentylacyjnych o wysokim zużyciu energii. Poprzez odpowiednią optymalizację lokalizacji przewodów w budynku i zastosowanie właściwiej grubości materiału izolacyjnego możliwe jest odgraniczenie wymagań układów HVAC, co znacząco zmniejsza zużycie energii. Straty i zyski ciepła określono przy użyciu programu TechCon. Parametry nagrzewnic i chłodnic w układzie HVAC wyznaczono w programie VentiCad. Optymalizacja wskazuje na znaczącą redukcję strat i zysków ciepła, jak również zmniejszenie temperatury powietrza dostarczanego do pomieszczenia o więcej niż 10°C.

Słowa kluczowe: efektywność energetyczna, systemy HVAC, optymalizacja zużycia energii

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1. INTRODUCTION

Clean room is defined as the space in which the concentration of particulates in the air is controlled and monitored [1]. Rules for the design and use of such spaces prescribe the use of construction materials, equipment of the space but also the operation with an emphasis on minimizing the emission of particles that could contaminate the space. The construction materials and equipment used must meet strict requirements for surface treatment. Personnel must wear the prescribed clothing and uniforms, depending on the cleanliness class in which the room is classified. According to the standard of operation of the clean room and the need for its cleanliness, based on the EN-ISO 14 644-1 standard, clean rooms are divided into eight categories, where the highest cleanliness class is marked EN-ISO 1 and the lowest clean class is EN-ISO 8. EN-ISO classes 1-5 are typical of the most accurate manufacturing, laser technology, pharmaceutical laboratories and others. Classes EN-ISO 5-8 are used for premises in medical facilities. Aseptic operating rooms for routine surgery fall into category EN-ISO 7 and rooms adjacent to the operating room (operating room background: filter, patient preparation, clean cloakroom and washroom) fall into category EN-ISO 8. The lower cleanliness class compared to the operating room guarantees controlled flow of air particles from a cleaner room to a less clean one, thus reducing the risk of contamination of the operating room.

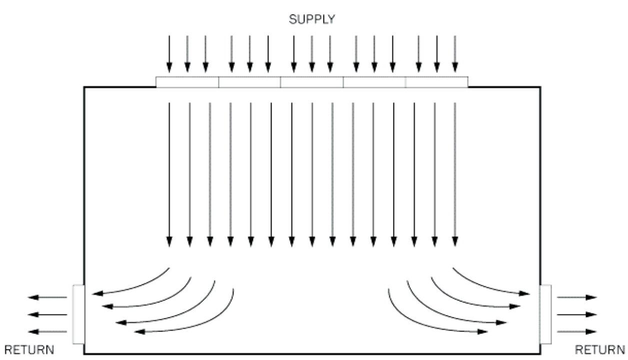

Fig. 1. Laminar air flow in a clean room [2]

The principle of reducing the concentration of particles in the clean room air consists in controlled forced ventilation of the room at high air exchange intensities and the use of supply air filtration with high efficiency of air particle capture. The nature of the air flow in a ventilated clean room is for operating theaters in the form of a laminar field around the operating table on which the patient lies [3]. Air is supplied through a ceiling distribution element located above the operating table. The filtered air flows downwards at flow speeds of 0.15-0.25 $m \cdot s^{-1}$, creating an imaginary air piston which expels air particles around the patient, as shown in Figure 1. The removal of contaminated and polluted air is ensured by diffusers located in the corners of the room, most often in the lower part of the wall.

The size of the air supply distribution element is determined by the size of the clean zone it must overlap. In the clean zone, the operating table must be covered with the patient, but also the medical staff performing the operation. To maintain the required flow rate to create a laminar air stream that also has sufficient kinetic energy to expel air particles in the patient bed area, a high power HVAC device is required for forced clean room ventilation. The operating tract, which consists of an operating room and the necessary facilities (filter, patient preparation, cloakroom and washroom), needs air volume flows of 2500-3500 m^3/h for their proper functioning. In clean rooms, it is not possible to use circulating devices to ensure the required indoor microclimate and thermal comfort. The airflow from the circulator could disrupt the laminar airflow in the patient area, leading to contamination and infectious disease. The total heat loads of clean rooms must therefore be covered by the HVAC device for forced ventilation of the room. Wall-mounted and cassette units for refrigerant or fan-coil units are unsuitable for this purpose. The same ventilation device can then be used to cover heat losses. A popular way of heating operating theaters is radiant floor heating or its combination with hot air heating using a forced ventilation device. Conversely, the use of convectors or heaters is undesirable due to their complicated cleaning and the risk of affecting the controlled air flow [4, 5].

2. OPTIMIZATION OF ARCHITECTURAL DESIGN OF CLEAN ROOMS

The problem that occurs when cooling a room using an HVAC system is the supply air temperature. Air with a low temperature difference from the room temperature should be supplied to the room. If an internal temperature in the range of 24 ±2°C is required, it would be optimal to supply cooling air with a temperature of at least 20°C from the point of view of thermal comfort and comfort in the room. In extreme cases, which occur a few days a year, it would be possible to supply air at a lower temperature. However, the temperature difference should not exceed 6°C compared to the indoor temperature. With such a relatively low temperature drop and specific heat capacity of the air, higher air flows are required. The required amount of supplied air expresses the relation (1).

$$\dot{V}_{C/H} = \frac{Q_{HL} \cdot 3600}{\left(t_{sa} - t_{ra\,r}\right) \cdot c_{sa} \cdot \rho_{sa}} \tag{1}$$

$\dot{V}_{C/H}$ – calculated air volume flow required for cooling/heating, $m^3 \cdot h^{-1}$;
Q_{HL} – heat load/heat loss, W;
t_{sa} – supply air temperature, °C;
$t_{ra\,r}$ – required room air temperature, °C,
c_{sa} – specific heat capacity of the supplied air, $J \cdot kg^{-1} \cdot K^{-1}$;
ρ_{sa} – supply air density, $kg \cdot m^{-3}$.

The specific heat capacity of the supplied air with the temperature change in the interval of 6°C hardly changes and therefore we can use the table value 1010 $J \cdot kg^{-1} \cdot K^{-1}$ for the calculation. However, a more substantial change occurs in air density. The density of the supplied air is a function of the external atmospheric pressure and its temperature. It is expressed by relation (2):

$$\rho_{sa} = \frac{p_a}{287 \cdot \left(273.15 + t_{sa}\right)} \tag{2}$$

p_a – atmospheric pressure, Pa.

From the previous relationships, we can conclude that the higher the heat load of the room, the greater the amount of cooling air at the desired temperature must be supplied to the room.

3. REDUCING ENERGY CONSUMPTION

Clean rooms consume high amounts of energy [6-8]. By ensuring minimum performance requirements with regard to air quality (i.e. J. Concentration of Contaminants), intensively energy-intensive clean rooms provide an opportunity to save large amounts of energy [9]. The size of heat loss and load is affected by the quality and thickness of construction materials, quantity, size and orientation of glazed surfaces, as well as the layout within the floor plan. The current state of many medical facilities is shown in Figure 2.

Many medical facilities have not yet been renovated at all. The perimeter walls are not insulated and in many cases the room with the highest requirements for the heating and ventilation system is in the corners of the floor plan and thus has up to two cooled walls in winter. Some buildings have already been renovated, but the thickness of the thermal insulation often does not exceed 100 mm. Such rooms have high heat losses and even higher heat loads, mainly due to windows, which in most cases do not have effective shading. In the figure of Figure 3 we can see the first two stages of optimization of the architectural design of a medical facility.

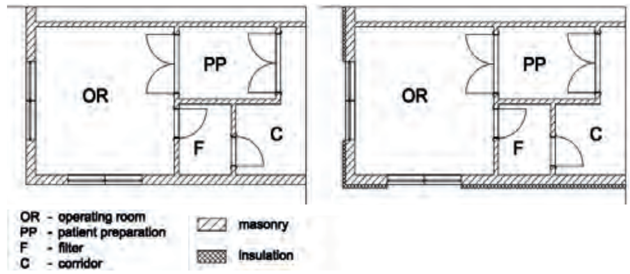

Fig. 2. Typical current state of medical facilities

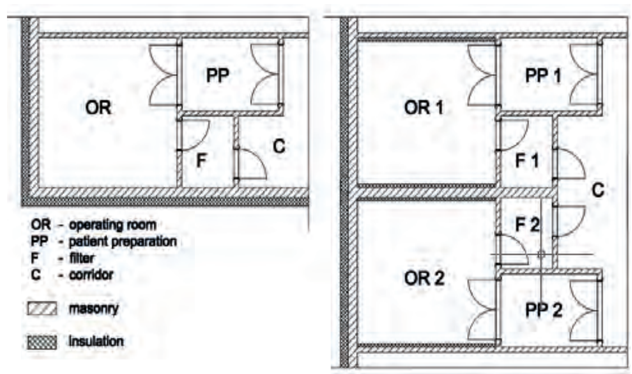

Fig. 3. I. stage (left) and II. stage (right) of architectural optimization

The first stage of optimization of the architectural design consists in the removal of glazed areas from the perimeter walls of the building. Windows in the room are not necessary, as the operating room must be equipped with a number of lamps with the prescribed brightness. These luminaires are often integrated in the ceiling laminar field, or on adjustable arms mounted on the ceiling of the room. This step will reduce the heat loss of the room, but in particular will reduce the heat load depending on the orientation of the building. The thickness of the insulation should correspond to the thickness used for passive houses. The second stage of optimization reduces the heat loss and the load on the building by reducing the number of perimeter walls. The mirror layout of the two operating theaters and their facilities is also complemented by internal insulation against the mutual influence of the climate between the operating theaters.

The third stage of architectural optimization is shown in Figure 4. By horizontal and vertical mirroring of the operating room with the background, we have achieved the creation of the so-called "Cores" without a vertical perimeter wall causing heat stress or loss through heat transfer through the structure. It is advisable to place such halls on the floor so that under the floor is heated, respectively, refrigerated space. From the point of view of savings, it is best to set up an air-conditioning engine room above the operating theaters. The short distance between the air handling unit and the ventilated room will reduce the acquisition costs for the air handling unit, the response time when the required temperature changes, but also the loss of energy through the insulation transmitted by the supply air to the room.

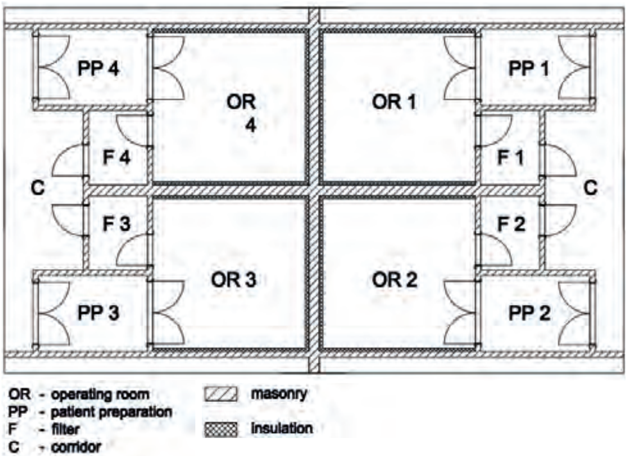

Fig. 4. III. degree of architectural optimization

In rooms with insufficient thickness of thermal insulation or a larger area of glazed structures, there may be a requirement for an even higher flow of supplied air than prescribed by the hygienic minimum. From an economic point of view, such ventilation is unsuitable and therefore it is necessary to eliminate the heat load and loss through the structure as much as possible, which directly results in reducing the required flow to a hygienic minimum.

To evaluate the required temperature of the air supplied to the room, we can use the modified relation (1), which is expressed by relation (3).

$$t_{sa} = t_{ra\,r} + \frac{Q_{HL} \cdot 3600}{\dot{V} \cdot c_{sa} \cdot \rho_{sa}}, °C \quad (3)$$

It is clear from the previous relationship that in order to influence the temperature of the supplied air, it is possible to vary only with the required heat output of the ventilation system, which is given by the heat loss of the ventilated object or the amount of air supplied to the room. Due to the legislative determination of the minimum required air volume flow for clean room ventilation in terms of maintaining a low concentration of aerosol particles in the room, it is possible to reduce only the heat output of the air handling unit, which must depend proportionally on reducing heat loss of the ventilated object. By suitable optimization of the layout and location of the operating tract in the building, it is possible to achieve different heat losses. These were expressed on a model operating tract using TechCon software.

4. REDUCING ENERGY CONSUMPTION FOR CLEAN ROOM HEATING

The horizontal location of the operating tract, thermal-technical properties of building structures as well as architectural-dispositional optimizations have a fundamental impact on the heat loss of the operating room and on the overall heat loss of the operating tract. Table 1 describes the individual variants. A comparison of the decrease in heat load for the whole tract is shown in Figure 5 and Table 2.

Table 1. Description of variants for calculation of heat loss of the operating tract

Variant	Variant description
1A	Influence of the most unfavorable horizontal location of the operating tract (on the 1st floor with a roof above). Figure 1 left
1E = 2A	Influence of the most favorable horizontal location of the operating tract (between heated rooms). Figure 1 left
2B	Use of insulation with a thickness of 50 mm on the perimeter walls and double glazing of windows ($U = 1.3\ W \cdot m^{-2} \cdot K^{-1}$). Figure 1 right
2C	Use of insulation with a thickness of 100 mm on the perimeter walls and triple glazing of windows ($U = 0.8\ W \cdot m^{-2} \cdot K^{-1}$). Figure 1 right
2E	II. Degree of optimization – use of insulation with a thickness of 250 mm on the perimeter walls and removal of windows. Figure 2 left
3A	II. Degree of optimization – reduction of the area of the perimeter walls behind which the exterior is. Figure 2 right
3B	III. Degree of optimization – the absence of perimeter walls behind which is the exterior. Figure 3

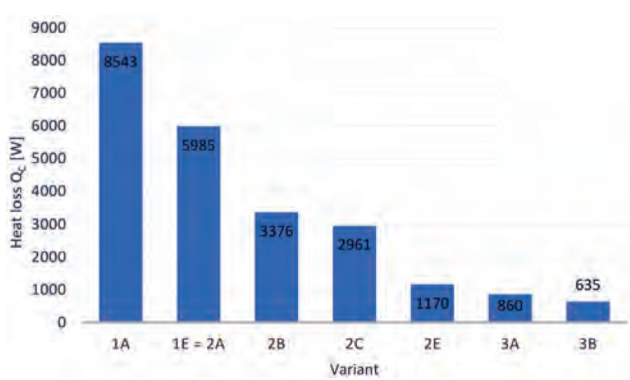

Fig. 5. Comparison of heat loss of the operating tract for different variants

environment

Table 2. Comparison of heat loss of the operating tract for different variants

Variant	Heat loss Q_c, W	t_{sa}, °C	Heater power Q_o, W	Savings over variant 1A, %	Savings over previous variant, %
1A	8 543	35.6	12.8	0.00%	0.00%
1E = 2A	5 985	32.1	10.0	29.96%	29.96%
2B	3 376	28.6	7.1	60.49%	43.58%
2C	2 961	28.0	6.6	65.34%	12.27%
2E	1 170	25.6	4.6	86.31%	60.49%
3A	860	25.2	4.3	89.94%	26.56%
3B	635	24.9	4.1	92.58%	26.24%

5. REDUCING ENERGY CONSUMPTION FOR CLEAN ROOM COOLING

Horizontal and vertical location of the operating tract, thermal-technical properties of building structures as well as architectural-dispositional optimizations have a fundamental impact on the thermal load of the operating room and the overall thermal load of the operating tract. Table 3 describes the individual variants. A comparison of the heat load decrease for the operating tract is shown in Figure 6 and Table 4.

Table 3. Description of variants for calculation of thermal load of the operating tract

Variant	Variant description
1A	Influence of the most unfavorable horizontal location of the operating tract (on the 1st floor with a roof above). Figure 1 left
1D = NW	Influence of the most favorable horizontal location of the operating tract (between heated rooms) + orientation of the windows to the north-west. Figure 1 left
2A = SE	Influence of the most favorable horizontal location of the operating tract (between heated rooms) + orientation of the windows to the south-east. Figure 1 left
2B	Use of insulation with a thickness of 50 mm on the perimeter walls and double glazing of windows ($U = 1.3\ W{\cdot}m^{-2}{\cdot}K^{-1}$). Figure 1 right
2C	Use of insulation with a thickness of 100 mm on the perimeter walls and triple glazing of windows ($U = 0.8\ W{\cdot}m^{-2}{\cdot}K^{-1}$). Figure 1 right
2E	I. Degree of optimization – use of insulation with a thickness of 250 mm on the perimeter walls and removal of windows. Figure 2 left
3A	II. Degree of optimization – reduction of the area of the perimeter walls behind which the exterior is. Figure 2 right
3B	III. Degree of optimization – the absence of perimeter walls behind which is the exterior. Figure 3

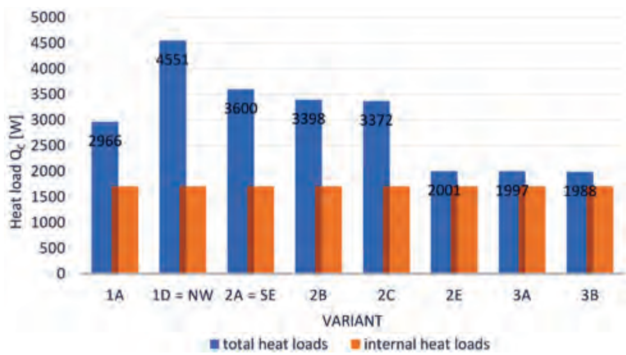

Fig. 6. Comparison of thermal load of the operating tract for different variants

Table 4. Comparison of heat load of the operating tract for different variants

Variant	Heat load Q_c, W	t_{sa}, °C	Cooler power Q_{CH}, kW	Savings over variant 1A, %	Savings over previous variant, %
1A	2 966	20.0	8.8	48.66%	48.66%
1D = NW	4 551	17.8	13.1	0.00%	0.00%
2A = SE	3 600	19.1	10.1	14.06%	14.06%
2B	3 398	19.4	9.6	16.93%	3.34%
2C	3 372	19.4	9.6	25.25%	10.02%
2E	2 001	21.3	6.7	56.52%	41.83%
3A	1 997	21.3	6.7	56.61%	0.21%
3B	1 988	21.3	6.7	57.08%	1.07%

6. CONCLUSION

By suitable vertical and horizontal location, orientation and choice of operating room construction materials, it is possible to achieve up to 92% reduction in annual heat demand due to heat loss through perimeter structures compared to the normal state of existing operating rooms. The annual cooling demand is 57% lower with the same optimization. The optimization of the architectural design will ensure the thermal neutrality of the operating room, which has a positive effect on its energy intensity and undesirable variability of air velocity in the clean room due to the temperature gradient between room air temperature and the temperature of air supplied through the laminar field. Although the total heat loss or heat load of the building is not reduced, the lower required heat and cold source power in the ventilation unit is achieved, which has a positive effect on reducing the risk of laminar flow being affected by natural convection and different vertical temperature gradients in the ventilated room. At the same time, it is possible to dimension lower power lines for the heat and cold source, which reduces the acquisition costs of the system.

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Acknowledgements

The research is supported by project APVV PP-COVID-20-0113 "Creation of clean operating rooms in order to reduce the risk of transmission and spread of COVID-19 virus and other viruses and bacteria, with ensured decontamination of exhaust air from the clean room".

LAMINAR FIELD OPTIMIZATION IN CONNECTION WITH THE CURRENT PANDEMIC SITUATION CAUSED BY COVID-19

OPTYMALIZACJA Z WYKORZYSTANIEM POLA LAMINARNEGO W ODNIESIENIU DO OBECNEJ SYTUACJI PANDEMICZNEJ SPOWODOWANEJ PRZEZ COVID-19

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Structure and Environment vol. 13, No. 1/2021, p. 5 DOI: 10.30540/sae-2021-001

Abstract

COVID-19 is constantly spreading around the world. Doctors, nurses and medical staff spend more time providing their professional help than usual. It is especially important to provide them with a suitable working environment. Therefore, in the following article we will deal with the design of a computational model of a laminar field in a clean room using CFD methods.

Streszczenie

COVID-19 nieustannie rozprzestrzenia się w świecie. Lekarze, pielęgniarki i personel medyczny spędzają więcej czasu niż zwykle, niosąc profesjonalną pomoc. Jest zatem szczególnie istotne, aby zapewnić im odpowiednie środowisko pracy. Dlatego też w prezentowanym artykule zajęto się zaprojektowaniem modelu komputerowego pola laminarnego w czystym pomieszczeniu z wykorzystaniem metod CFD.

THERMAL COMFORT MEASUREMENTS IN THE ENERGIS BUILDING

BADANIA KOMFORTU CIEPLNEGO W BUDYNKU ENERGIS

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Structure and Environment vol. 13, No. 1/2021, p. 10 DOI: 10.30540/sae-2021-002

Abstract

In the paper the measurements of thermal comfort in the modern smart building "Energis" have been presented together with their analysis. The data have been obtained in the spring and the analyses of indoor air parameters as well as subjective responses of the volunteers have been conducted. Based on the performed studies it has been concluded that the people felt fine in the considered room (pleasantly warm, cool and comfortable) and described their feelings as acceptable and comfortable.

Streszczenie

W artykule przedstawiono wyniki badań i analizę komfortu cieplnego w budynku inteligentnym „Energis". Dane eksperymentalne uzyskano w okresie wiosennym, a analiza dotyczyła parametrów powietrza wewnętrznego, jak również subiektywnych odczuć ochotników. W oparciu o przeprowadzone badania można stwierdzić, że użytkownicy czuli się dobrze w rozpatrywanym pomieszczeniu (przyjemnie ciepło i chłodno, a także komfortowo) i ocenili swoje odczucia jako akceptowalne i komfortowe.

RETROFITTING EXISTING OFFICE BUILDING FOR EFFICIENT ENERGY MANAGEMENT AND PERFORMANCE

MODERNIZACJA ISTNIEJĄCEGO BUDYNKU BIUROWEGO DLA EFEKTYWNEGO ZARZĄDZANIA ENERGIĄ

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Structure and Environment vol. 13, No. 1/2021, p. 16
DOI: 10.30540/sae-2021-003

Abstract

This study focuses on designing an efficient energy utilization protocol for the University of Lagos Senate office building, to ensure the reduction of energy consumption, reduce the cost of power and also ensure energy efficiency. Pre-retrofitting, the energy consumption cost for the UNILAG senate office building was calculated to be ₦20, 236, 962 i.e. 776.78 EUI (kWh/m²/y) using the appliance approach. The impact of various retrofitting methods was also simulated and measured utilizing BIM tools such as Autodesk Maya, Autodesk Revit and Autodesk Insight. This resulted in an estimated reduction in energy consumption cost to between ₦19,304,038.05 and 18,549,199.3 post retrofitting, this translates to about 712 EUI (kWh/m²/y). Results show that a 4.61-8.34% reduction in energy usage for the senate house can be achieved using the methods proposed in this research.

Streszczenie

Praca koncentruje się na opracowaniu procedury efektywnego wykorzystania energii w budynku biurowym Senatu Uniwersytetu w Lagos w celu zapewnienia redukcji zużycia energii, redukcji jej kosztów i zapewnienia efektywności energetycznej. Przed modernizacją koszt zużycia energii w budynku Senatu został obliczony jako ₦20, 236, 962, tj. 776.78 EUI (kWh/m²/y) w oparciu o zamontowane urządzenia. Symulowano wpływ różnych technik modernizacyjnych i prowadzono obliczenia korzystając z narzędzi opartych o technologię BIM, tj. Autodesk Maya, Autodesk Revit i Autodesk Insight. To doprowadziło do przewidywanej redukcji kosztów energii pomiędzy ₦19,304,038.05 i 18,549,199.3 po modernizacji, co odpowiada ok. 712 EUI (kWh/m²/y). Wyniki wskazują, że możliwa jest redukcja zużycia energii dla budynku Senatu na poziomie 4.61-8.34% w oparciu o metody przedstawione w pracy.

ENERGY EFFICIENCY OPTIMIZATION OF THE OPERATING ROOM DUE TO THE DISPOSITIONAL LOCATION

OPTYMALIZACJA EFEKTYWNOŚCI ENERGETYCZNEJ W SALI OPERACYJNEJ ZWIĄZANA Z LOKALIZACJĄ SYSTEMU WENTYLACJI

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Structure and Environment vol. 13, No. 1/2021, p. 29 DOI: 10.30540/sae-2021-004

Abstract
Clean rooms, including operating rooms, are energy-intensive. During their operation, the concentration of particles in the air, air temperature and humidity are strictly monitored. HVAC systems in the operating room are subject to high demands on maintaining a stable heat and humidity microclimate, as well as particle concentrations within the permitted range. To cover heat losses and heat loads of the building, it is necessary to dimension ventilation equipment with high outputs and high energy consumption. By suitable optimization of the dispositional location of the operating tract in the building and the use of suitable thicknesses of insulating material, it is possible to reduce the performance requirements for the HVAC system, which significantly reduces energy consumption. Heat loss and heat load of the operating tract were evaluated using TechCon software. The performance values of the heaters and coolers for the HVAC units were calculated in the VentiCad design software. The optimization indicates a significant reduction in heat loss and heat load, as well as a reduction in the required temperature of the air supplied to the room by more than 10°C.

Streszczenie
Pomieszczenia czyste, łącznie z salami operacyjnymi wymagają dużo energii. Podczas ich pracy dokładnie monitoruje się stężenie cząstek stałych w powietrzu, jego temperaturę i wilgotność. Systemy grzewcze, wentylacji i klimatyzacji (HVAC) w salach operacyjnych podlegają wysokim wymaganiom związanym z utrzymaniem stabilnego mikroklimatu cieplno-wilgotnościowego, jak również stężenia cząstek w dozwolonym zakresie. Pokrycie strat i zysków ciepła budynku wymaga projektowania systemów wentylacyjnych o wysokim zużyciu energii. Poprzez odpowiednią optymalizację lokalizacji przewodów w budynku i zastosowanie właściwej grubości materiału izolacyjnego możliwe jest odgraniczenie wymagań układów HVAC, co znacząco zmniejsza zużycie energii. Straty i zyski ciepła określono przy użyciu programu TechCon. Parametry nagrzewnic i chłodnic w układzie HVAC wyznaczono w programie VentiCad. Optymalizacja wskazuje na znaczącą redukcję strat i zysków ciepła, jak również zmniejszenie temperatury powietrza dostarczanego do pomieszczenia o więcej niż 10°C.

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