ISSN 1590-8844
International Journal of Mechanics and Control, Vol. 25, No. 01, 2024
https://doi.org/10.69076/jomac.2024.0006

APPLIED ENERGY EFFICIENCY MEASURES IN INDUSTRIAL BUILDING BY USING ENERGYPLUS SOFTWARE

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ABSTRACT

In the pursuit of sustainable development and reduction of environmental impact, energy efficiency has become a paramount concern in the design and operation of buildings and their mechanical systems. The building envelope plays a critical role in regulating heat transfer, while air conditioning plants are significant energy consumers in buildings. This paper presents an analysis of energy efficiency techniques specifically applied in the industrial buildings. Three important techniques such as light efficiency, motors replacement and heat pump time turning ON/OFF has been used in this research work. Furthermore, there will be an analysis of the economic aspects of these techniques, comparing their costs and potential electricity savings to determine the most advantageous options.

Keywords: Energy efficiency, building envelope, electricity savings, air conditioning

1 INTRODUCTION

In the global pursuit of mitigating climate change and reducing energy consumption, the built environment has emerged as a focal point for implementing energy efficiency measures. Buildings account for a significant portion of global energy consumption, with a substantial portion attributed to heating, ventilation, and air conditioning (HVAC) systems [1-5]. Within the realm of building energy efficiency, attention has increasingly turned to optimizing the industrial buildings, recognizing their pivotal roles in regulating thermal comfort and energy consumption [6-9].

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The building envelope, comprising walls, roofs, windows, and doors, serves as the interface between the interior and exterior environments. Its design and construction significantly influence heat transfer, air infiltration, and insulation levels within a building. Numerous research analysis [1, 7, 10] have been used for implementation of energy efficiency techniques. Based on the different usage energy efficiency it has been found that saving was varied from 15% up to 35% by using retrofitting technologies [11]. The main goal was to find suitable methodology for retrofit technologies that has possibility to be implemented in industrial buildings. Despite the endeavours of previous researchers, lingering concerns remain unresolved, which the current research endeavours to tackle. This study introduces a precise energy model constructed using a calibration approach established in earlier methodologies [12-14]. In the previous research works were analysed different retrofitting technologies where it has been found the most suitable in terms of cost of investments and model calibration of the buildings [14-16]. Ensuring the precise calibration of energy models for buildings stands as a critical prerequisite prior to selecting the optimal retrofitting technologies.

There are various strategies and technologies employed to improve the energy performance of building envelopes. This includes advancements in insulation materials, glazing technologies, shading systems, and architectural design principles aimed at minimizing heat loss. Moreover, economic considerations, potential barriers to adoption, and recommendations for overcoming challenges will be addressed to provide a comprehensive understanding of the broader implications of implementing energy efficiency measures in building envelopes and air conditioning plants.

In this research works we will be focused on the implementation of various energy retrofit technologies in our selected industrial building. Furthermore, three important techniques such as light efficiency, motors replacement and heat pump time turning ON/OFF has been used to implement energy efficiency in industrial buildings.

2. METHODOLOGY

In our research work, building is a two-storey 4200 m2 industrial building containing in the first floor the construction materials and in the second floor contain administration offices, meeting rooms, design studios, sanitary facilities, archive, and controlled temperature rooms. The facility is located on the outskirts of the capital of Albania, in the “Vaqarr” administrative unit. Energy-plus software has been used to model the building, see Figure 1. The model geometry of the selected industrial building comes from Mechanical Ventilation drawings. Subsequently, AutoCAD drawings (DWG) has been used and generate DXF files. Figure 2 depict the model of the industrial building with a series of each zones. The individual zones are denoted with ground floor (GF) and first floor (FF).

Figure 1 3D general view of the industrial building.

ISSN 1590-8844
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These zones represent varying thermal characteristics within the building, encompassing both physical properties and air properties. The envelope of the building is made with ceramic bricks with holes with a thickness of 20 cm and in some places. The building is reinforced with concrete structure and provide high levels of thermal mass for allowing the natural and mechanical ventilation in night cooling as required.

The windows and doors are made of plastic glass and are closed with elements made of aluminium boxes. The building operates as a unified fire zone, promoting airflow throughout its spaces via interconnecting laboratory openings, loosely fitted sliding doors, and doors propped open towards stair stacks. The internal stair stacks serve dual purposes as ventilation stacks. They facilitate airflow through the industrial building in warm weather and contribute to the automated night cooling strategy. This multi-functional use of the stairs provides the advantages of a building atrium without incurring the extra costs typically accompanied with a dedicated atrium stack [14]. Three energy efficiency techniques have been implemented to reduce electricity consumption in the industrial building. The main three techniques are as follows:

- heat pump time turning ON/OFF
- motors replacement
- lighting with efficiency.

During the cooling season, a heat pump is employed to warm the building, with manual control utilized for its activation and deactivation. The schematic view of the heat pump implemented in industrial building is depicted in Figure 3.

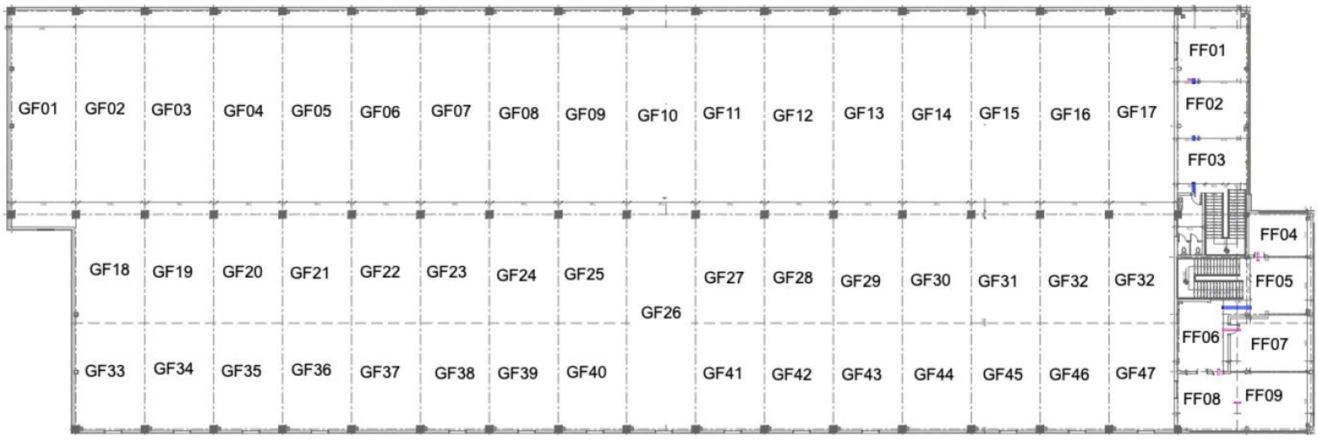

Figure 2 Schematic view of each zone of the industrial building.

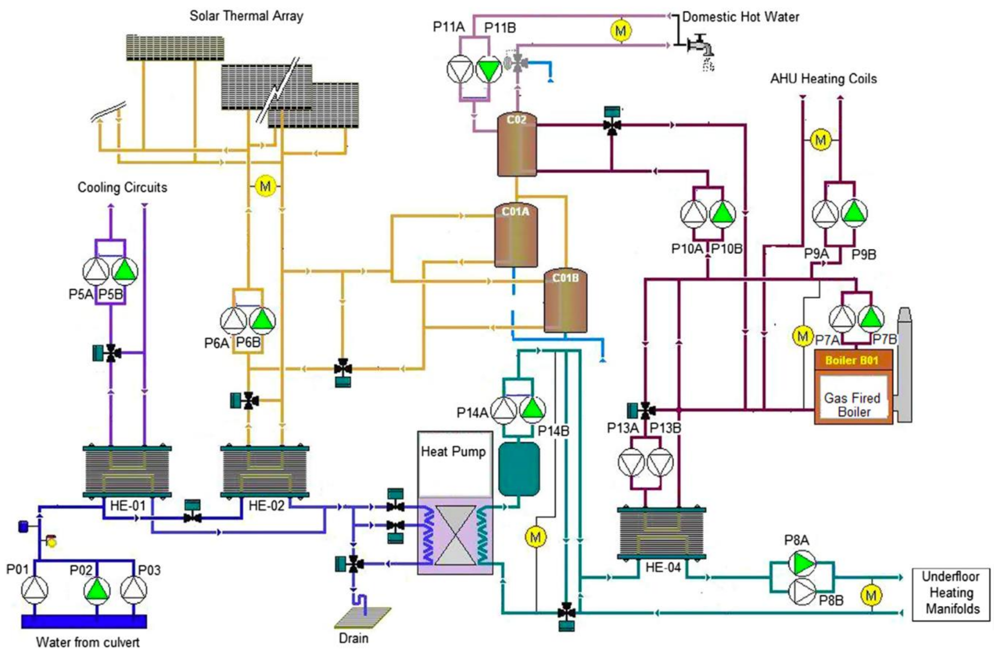

Figure 3 Schematic view of the heat plant in industrial building [14, 17, 18]

2.1 HEATING VENTILATION AIR CONDITIONING SYSTEM

The industrial building's heating is provided by an underfloor heating system, primarily powered by a geothermal heat pump that utilizes a water supply. This water is preheated using heat recovered from the cold stores and from the solar thermal array. The control system manages the heat pump compressor to maintain the necessary heating system flow temperature. The ground floor (GF01 till GF47) and first floor (FF01 till FF09) heating system operates at a maximum temperature of 35 °C. In total, the heat pump fulfils 75% of the building's heating needs, while the remainder is supplied by a condensing gas boiler designed to serve as a complete backup system. The ground floor heating system is supported by 12 distribution hubs positioned at diverse points across the building. Within each hub, separate zone control valves regulate the flow for individual circuits. A room thermostat has been used to control each zone. The solar thermal collector, comprised of 26 flat collectors, is installed to supply hot water, with the remaining domestic water demand met by a direct gas-fired water heater. In this research, a meticulous analysis was undertaken to determine the heat generated by the solar panels over the course of the year 2022. A cooled beam system positioned at Ground floor is used in summer time to support cooling for the zones (GF41, GF42, GF43, and GF44). Sensible cooling is accomplished by circulating chilled water at cooled beam units mounted on the ceiling. The temperature of the chilled water varies between 10 and 15 °C and is achieved by transferring heat to the water sourced from the aquifer via the heat exchanger HE-01. Based on the real weather data we have performed automatically the simulation of the heat pump.

2.2 VENTILATION SYSTEM

Most of the part of the industrial building is naturally ventilated except some small areas such as cold rooms, WCs, clean rooms, cold rooms and stores. The natural airflow plan is augmented by leveraging the building's exposed mass. The ventilation plan incorporates various openings designed to promote high-quality airflow and effectively control summertime overheating, maintaining it well within acceptable thresholds. The ground floor accommodates laboratories, with additional laboratories situated on the southern side of both the ground and first floors. Offices and computer labs are positioned on the northern side of the building's ground and first levels to capitalize on passive solar heating and maximize natural daylight. Motorized windows are installed in laboratories and offices to enable the implementation of an automated daytime cooling approach and ensure ample ventilation for the expulsion of warm air from the upper regions of the office areas. Additionally, an automated night-time cooling system is integrated with the motorized windows positioned at the top of the staircases. During the night we have used cooling strategy that operates from April till September when heating system is switched OFF. EnergyPlus has been used to simulate natural ventilation system [19].

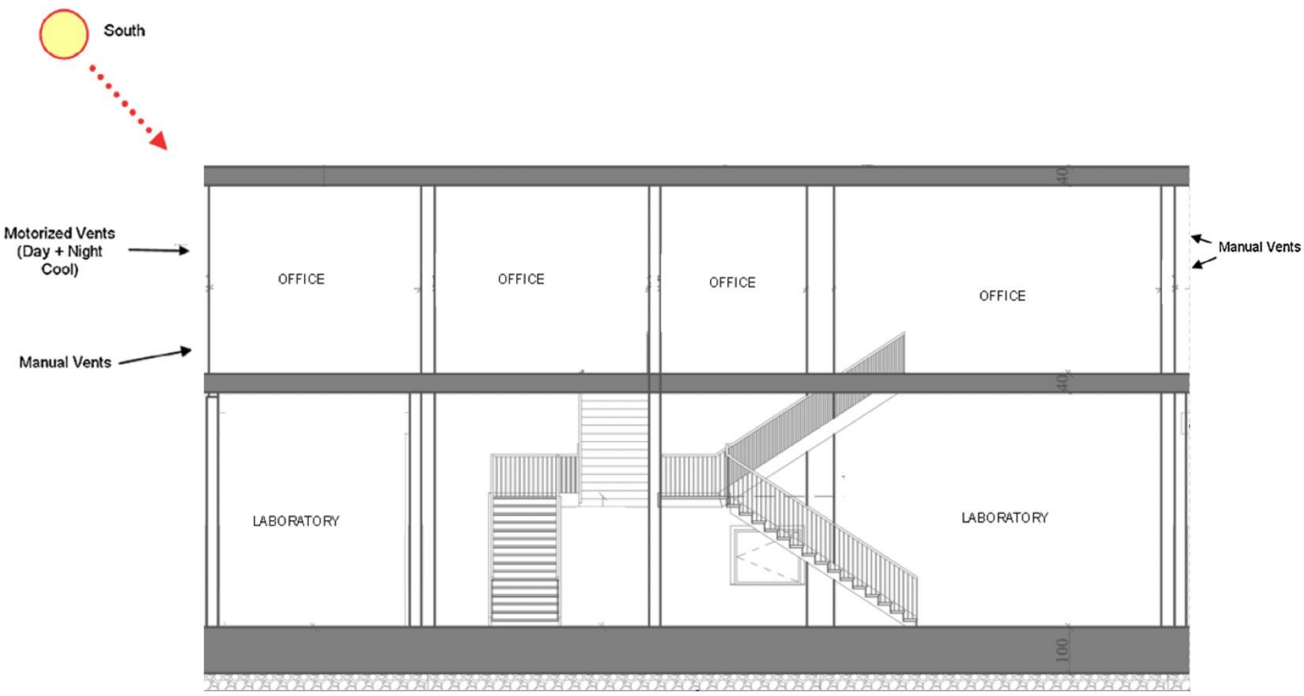

Figure 4 Schematic view of natural ventilation system.

ISSN 1590-8844
International Journal of Mechanics and Control, Vol. 25, No. 01, 2024

2.3 LIGHTING SYSTEM

The lighting fixtures commonly used are fluorescent luminaires of the T5H0 bulbs, equipped with high-frequency control gear, resulting in a division of 50% radiant and 50% convective output. Occupancy sensors and daylight adjustment mechanisms govern the system's operation. Additionally, task-specific lighting is implemented within the laboratory spaces. Restricting lighting loads is crucial for minimizing both energy consumption related to lighting and the heat influx generated by lighting systems. External lighting employs LED fixtures to reduce energy consumption and offer a lighting solution with minimal maintenance requirements [14, 17]. Radiance tool has been used in EnergyPlus for modelling the lighting system in the selected industrial building [19].

2.4 CALIBRATION PROCESS

The calibration process plays an important role for the accuracy of the methodology used in this research work and was developed previously by [14, 20], see Figure 5.

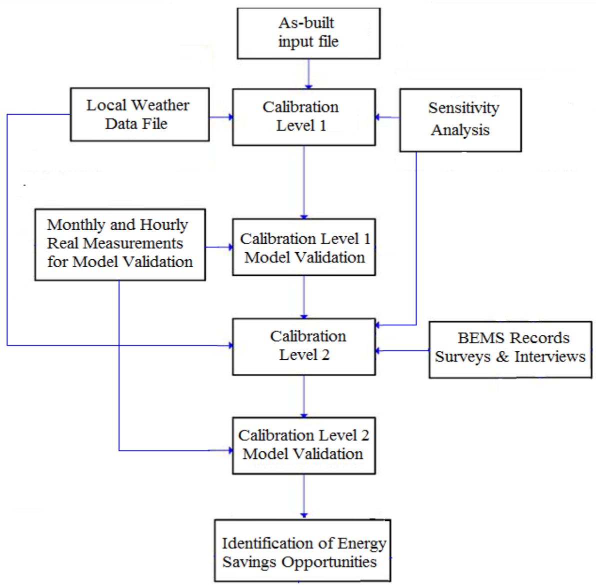

Figure 5 Calibration methodology [14, 20]

The Mean Bias Error (MBE) and Coefficient of Variation of Root Mean Square Error (CV(RMSE)) equations were used for calibration methodology [12, 21-23], on monthly basis for the year 2022 as can been seen in equations 1 until 3.

$$MBE = \frac{\sum_{i=1}^{N_p}(X_i - S_i)}{\sum_{i=1}^{N_p} X_i} \quad (1)$$

$$CV(RMSE)_p = \frac{\sqrt{\sum_{i=1}^{N_p}((X_i - S_i)^2/N_p)}}{\bar{X}p} \quad (2)$$

$$\bar{X}p = \frac{\sum_{i=1}^{N_p} X_i}{N_p} \quad (3)$$

where *Xi* and *Si* are measured and simulated data for observation *i*, *p* is the interval in one year; *Np* are the values at interval *p* in one year and $\bar{X}p$ is the average of the measured data.

3. SUMMARY RESULTS

The results have been based on three selected techniques that we have used in our methodology for implementation of energy efficiency measures in industrial buildings. Figure 6 illustrates a difference between the manual and simulated of the heat pump control. By adjusting the heat pump based on actual weather data, a reduction in energy consumption of 5500 kWh annually was achieved compared to manual adjustments made by technicians.

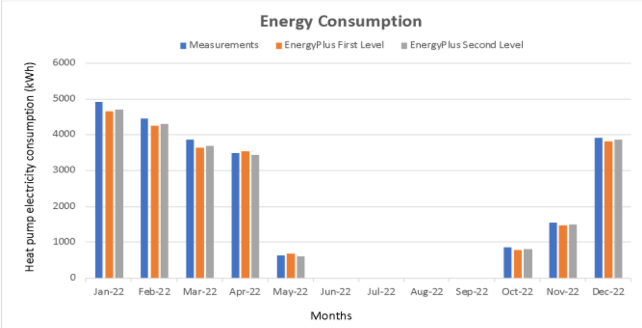

Figure 6 Energy consumption from heat pump in one year.

Figures 7 and 8 depict the enhancements achieved through the substitution of low-efficiency lights and motors with their high-efficiency counterparts.

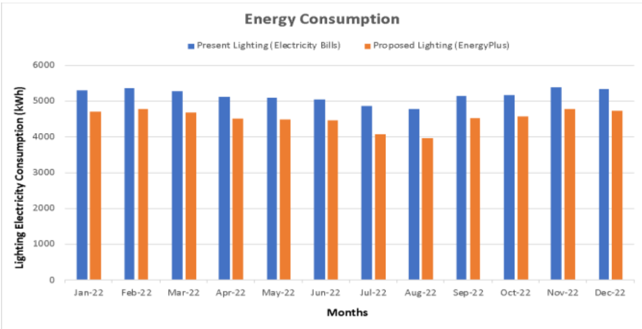

Figure 7 Energy consumption from lighting in one year.

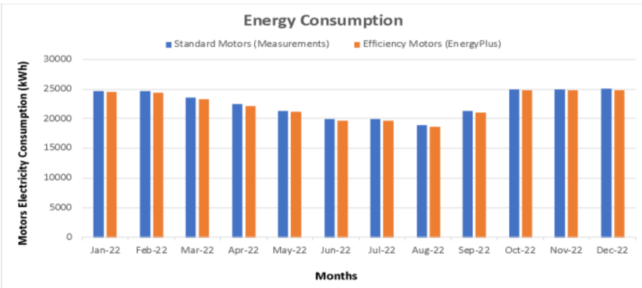

Figure 8 Energy consumption from motors in one year.

Table I presents a condensed overview of three electricity-saving methods chosen, with results displayed in Figures 4-6. The analysis demonstrates that the implementation of these techniques yields a simple payback period (SPP) of less than one year [24, 25]. Monthly aggregate electricity usage and natural gas consumption data were extracted from invoices, with a detailed assessment of calibration precision presented in Table II. Table III illustrates the fluctuation in Mean Bias Error (MBE) and Coefficient of Variation (CV) Root Mean Square Error (RMSE) across the spectrum from minimum to maximum levels subsequent to the application of the secondary calibration procedure, with calculations conducted on both hourly and monthly bases. Based on ASHRAE guideline the calibration results fulfil the accuracy requirements which are between of the intervals $-5\% \leq MBE_{monthly} \leq 5\%$ and $CV(RMSE)_{monthly} \leq 15\%$ [23].

Based on our results, the novelty of applied energy efficiency in our industrial building by using EnergyPlus software lies in its ability to provide sophisticated simulation capabilities, tailored solutions, optimization of energy conservation measures, integration with building automation systems, and demonstrated environmental and economic benefits. EnergyPlus software enables the development of tailored solutions specifically designed for the unique characteristics of industrial buildings. These solutions can address factors such as high energy demand, specialized equipment, and variable operating conditions, ensuring that energy efficiency measures are both effective and practical in industrial settings. This approach represents a cutting-edge methodology for achieving sustainable energy management in industrial settings [1, 8, 26-30].

Table I – Results of various techniques for efficiency energy in industrial building.

Description of Energy Retrofit Technologies	Potential Savings (€/year)	Cost Implement. (€)	SPP (years)	Energy Savings (kWh/year)	Demand Reduction (kW)
Heat Pump Modification	1450	0	Immediate	5500	0
High Efficiency Lighting	2500	1153	0.7	11360	0.445
High Efficiency Motors	2300	1585	0.9	10130	1.546

Table II – Calibration results at First level.

First Level	MBE (Monthly)		CV(RMSE) (Monthly)	
	Min. (%)	Max. (%)	Min. (%)	Max. (%)
Heat pump electricity consumption	- 1.6	4.3	4.9	13.8
Building total electricity consumption	- 4.3	4.7	4.8	14.9
Natural gas consumption	- 3.2	4.4	3.9	12.7

Table III – Calibration results at Second level.

Second Level	MBE (Monthly)		CV(RMSE) (Monthly)	
	Min. (%)	Max. (%)	Min. (%)	Max. (%)
Heat pump electricity consumption	- 1.2	4.8	4.5	12.5
Building total electricity consumption	- 3.2	4.6	4.9	11.9
Natural gas consumption	- 1.5	4.1	4.8	13.7

These benefits include reduced energy costs, lower greenhouse gas emissions, improved indoor environmental quality, and enhanced competitiveness for industrial enterprises in Albania [27, 31, 32]. By identifying the most cost-effective and impactful measures through simulation, industrial stakeholders in Albania can make informed decisions to maximize energy savings.

4. SUMMARY AND CONCLUSIONS

The methodology for implementation of the energy efficiency in the industrial building has been briefly described in this research work. The facility is located on the outskirts of the capital of Albania, in the "Vaqarr" administrative unit. EnergyPlus software has been used to model the building. Calibration results fulfil the accuracy requirements which are between of the intervals $-5\% \leq MBE_{monthly} \leq 5\%$ and $CV(RMSE)_{monthly} \leq 15\%$. Furthermore, following the implementation of the chosen optimal energy efficiency measures, annual electricity savings amounted to approximately 28%, equating to 26990 kWh. Furthermore, the optimal approach involves enhancing the efficiency of heat pump control using real-time weather data, requiring minimal investment with immediate payback. It is suggested that future research endeavours explore additional techniques for improving heating, ventilation, and air conditioning systems, as well as enhancing the building envelope, building upon prior research findings [14, 17]. The novelty of our research work lies in its ability to provide sophisticated simulation capabilities, tailored solutions, optimization of energy conservation measures, integration with building automation systems, and demonstrated environmental and economic benefits.

ACKNOWLEDGEMENTS

This research work is supported from the Faculty of Mechanical Engineering of the Polytechnic University of Tirana, Albania.

REFERENCES

[1] Chidiaca, S.E., Catania, E.J.C., Morofskyb, E., Foob, S. A screening methodology for implementing cost effective energy retrofit measures in Canadian office buildings", *Energy and Buildings*, Vol. 43, pp. 614-620, 2011.

[2] Dorri, A., Dhoska, K., Kodhelaj, S. Energy Efficiency Analysis in Korça Regional Hospital. *International Journal of Innovative Technology and Interdisciplinary Sciences*, Vol. 06, No.1, pp. 1121–1129, 2023.

[3] Tyxhari, G., Gorishti, A., Dhoska, K. Energy Audit Evaluation in the Private Residential Building, *International Journal on Technical and Physical Problems of Engineering (IJTPE)*, Issue 57, Vol. 15, No. 4, pp. 294-298, 2023.

[4] Mustafaraj, G., Dhoska, K. Comparison of Different Energy Efficiency Techniques Applied to Building Envelope and Air Conditioning Plants. *Lecture Notes on Multidisciplinary Industrial Engineering*. Springer, Cham, pp. 317-322, 2024.

[5] Dhoska, K., Bebi, E., Markja, I., Mustafaraj, G. Analysis of Energy Audit in the Architectural Design Office Located in Tirana. *Lecture Notes on Multidisciplinary Industrial Engineering*. Springer, Cham, pp. 244-252, 2024.

[6] Lutz, C., Becker, L. *Effects of Energy Price Shocks on Germany's Economy and Private Households*. In: Bardazzi, R., Pazienza, M.G. (eds) Vulnerable Households in the Energy Transition. Studies in Energy, Resource and Environmental Economics. Springer, Cham, pp. 11-28, 2023.

[7] Aste, N, Pero, C.D. Energy retrofit Commercial Buildings: Case Study and Applied Methodology. *Energy Efficiency*, Vol. 06, pp. 407-423, 2011.

[8] Dhoska, K., Markja, I., Bebi, E., Milo, P., & Sita, E. Energy Consumption Processes Overview in Metallurgical Sector for Aluminium Production: The Case of Albania. *Environmental Industry Letters*, Vol. 01, No. 02, 64-70, 2023.

[9] Cristodaro, M., Fortuna, S., Greco, A., Petrolino A.C. and G. Carbone, G. Design of solar panels cleaning device - Cleanator, *International Journal of Mechanics and Control*, Vol. 23, No. 01, pp. 35-44, 2022.

[10] Griffith, B., Long, N., Torcellini, P., Judkoff, R. Assessment of the Technical Potential for Achieving Net Zero-Energy Buildings in the Commercial Sectorr.*Technical Report NREL*/TP-550–41957, 2007.

[11] Ma, Z., Cooper, P., Daly, D., and Ledo, L. Existing building retrofits: Methodology and state-of-the-art. *Energy and Buildings*, Vol. 55, pp. 889-902, 2012.

[12] Dhoska, K., Hofer, H., Rodiek B., Lopez M. Kübarsepp T. Kück, S. Improvement of the detection efficiency calibration and homogeneity measurement of Si-SPAD detectors, *Springerplus*, Vol. 05, No. 01, pp. 2065, 2016.

[13] Abou EL-Hassan, Azza., Khairat Dawood, M.M., EL Morse, M.S., Abdel-Mageed, S.I., & A. Sharaf, O. The Effective Techniques for Enhancing the Turbulent Flow Between Two Parallel Plates: A Comprehensive Review. *Journal of Transactions in Systems Engineering*, Vol. 01, No. 01, pp. 10-30, 2023.

[14] Mustafaraj, G., Marini D, Costa A. and Keane M. Model Calibration for Building Energy Efficiency Simulation. *Applied Energy*, Vol. 130, pp. 72-85, 2014.
[15] Qosja, S., Rolle, R., & Gebremedhin, A. Solving the Bottleneck Issue of Energy Supply. Case Study of a Wind Power Plant. *International Journal of Innovative Technology and Interdisciplinary Sciences*, Vol. 05, No. 02, pp. 874-891, 2022.
[16] Dorri, A., Dhoska, K., & Kodhelaj, S. Computational Simulation of Heat Transfer Through Fins of Different Shapes in an Air-Cooled Internal Combustion Engine. *International Journal on Technical and Physical Problems of Engineering*, Issue 54, Vol. 15, No. 1, pp. 248-254, 2023.
[17] Keohane, M. Development of an integrated life cycle energy performance model for the ERI utilizing a combination of dynamic energy simulation (e.g. IES, Energy-Plus) and the installed building management System (BMS). University College Cork – Master's Thesis, 2007.
[18] Ploennings, J., Ahmed, A., Hensel, B., Stack, P., Menzel, K. Virtual sensors for estimation of energy consumption and thermal comfort in buildings with underfloor heating. *Adv. Eng. Inform.*, Vol. 25, pp. 688-698, 2011.
[19] EnergyPlus Version 8.3. U.S. Department of Energy, Energy Efficiency and Renewable Energy, Office of Building Technologies.
[20] Bertagnolio, S. Evidence Based Model Calibration for Efficient Building Energy Services. PhD Thesis, University of Liège, 2012.
[21] Koka, K., & Dhoska, K. Analysis of Vibration and Acoustic Sound Radiation of a Rotationally Symmetrical Plate. *Journal of Transactions in Systems Engineering*, Vol. 02, No. 01, pp. 156-169, 2024.
[22] Dhoska, K., Lumi, D., Sulejmani, A., Koça, O. Measurement uncertainty for mechanical resistance of manufactured steel bar. *Pollack Periodica*, Vol. 17, No. 2, pp. 104-108, 2022.
[23] ASHRAE Fundamentals Handbook. Atlanta: American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., 2005.
[24] Dhoska, K., Bebi, E., Markja, I., Milo, P., Sita, E., Qosja, S. Modelling the wind potential energy for metallurgical sector in Albania. *Scientific Reports*, Vol. 14, No. 1, 1302, 2024.
[25] Farghali, M., Osman, A.I., Mohamed, I.M.A., Chen, Z., Chen, L., Ihara, I., Yap, P.S., Rooney, D.W. Strategies to save energy in the context of the energy crisis: a review. *Environ. Chem. Lett.*, Vol. 21, pp. 2003–2039, 2023.
[26] Koysuren, O., Dhoska, K., Koysuren, H.N. Markja, I., Yaglikci, S., Tuncel, B., Bebi, E. $SiO_2/WO_3/ZnO$ based self-cleaning coatings for solar cells. *J. Sol-Gel Sci. Technol.*, Vol. 110, pp. 183–203, 2024.
[27] Dorri, A., Alcani, M., Gjeta, A. The Role of the Agriculture and Forestry Sectors in Greenhouse Gas Emission: The Case of Albania. *Journal of Integrated Engineering and Applied Sciences*, Vol. 01, No. 02, pp. 32-39, 2023.
[28] Amoako Kyeremeh, K., Kofi Otchere, I., Twum Duah, N., & Owusu, J. Distribution Network Reconfiguration Considering Feeder Length as a Reliability Index. *International Journal of Innovative Technology and Interdisciplinary Sciences*, Vol. 06, No. 01, 1100–1111, 2023.
[29] Carlin, A., Valerio, R.M., Lo Verso, V.R.M., Invernizzi, S., Polato, A. Optimised Daylighting For Comfort and Energy Saving for the Factory of the Future. *International Journal of Mechanics and Control*, Vol. 18, No. 01, pp. 15-29, 2017.
[30] Sholanov, K., Omarov A., and Ceccarelli, M. Improving efficiency of converting wind energy in modified sail wind power station. *International Journal of Mechanics and Control*, Vol. 23, No. 02, pp. 101-110, 2022.
[31] Prifti, V., Sinoimeri, D., Lazaj, A., Keci, J., Impact of the Information Systems and Technology on Enterprises. *Journal of Integrated Engineering and Applied Sciences*, Vol. 1, No. 1, pp. 23-31, 2023.
[32] Mustafaraj, G. High Quality of Calibration Accuracy for Smart Building Energy-Efficiency Opportunities. *Mediterranean Green Buildings & Renewable Energy*, Springer, Cham. pp. 465-477, 2017.