How the Use of Unmanned Aerial Vehicles to Detect Lost Energy in Buildings Leads to Sustainability- A Systematic Review

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Abstract

To develop more sustainable societies, industries should focus on solving environmental and economic challenges using unmanned aerial vehicles (UAVs) technologies for monitoring and energy auditing of buildings. Building defects, such as heat loss, moisture, and air leakage, inevitably lead to inefficient space heating or cooling, essentially explaining high energy consumption and associated emissions. UAVs contain modern monitoring equipment and thermal cameras to document building performance energy, creating digital models, and 3D photogrammetry. By advanced technology of UAVs, energy auditors can analyze the energy used rapidly and accurately while reducing operational costs and minimizing safety risks by reaching remote or inaccessible areas without compromising the pilot's life. This paper aims to provide a comprehensive overview of how the use of UAVs for energy audit leads to sustainability through a systematic review of seventeen studies by following the steps of PRISMA. The results reveal that the UAVs contribute to improving the energy performance of the building, which leads to reducing carbon emissions, saving energy costs, and improving human life and health. In this study, I attempted to shed light on how the use of UAVs drives sustainability by focusing on the economy, energy consumption, environmental impacts, social and safety issues.

Keywords
Unmanned aerial vehicles (UAVs), sustainability, Building's energy, Infrared Thermography (IRT), and Energy auditors.

1. Introduction
Unmanned aerial vehicles have been growing in buildings energy auditing to achieve sustainability in built environments. Energy efficiency is considered one of the significant factors prohibiting the advancement towards the global purpose of Green House Gas emissions (GHG) reduction (Intergovernmental Panel on Climate Change, 2014). With the ever-rising worldwide energy demand, management and auditing strategies have risen in critical importance(Ariffin *et al.*, 2021). Reducing energy consumption has resulted in positive environmental and economic returns. Overall, buildings accounted for 36 percent of global energy demand and 37 percent of energy-related CO2 emissions in 2020. see Figure 1 (*2021 GLOBAL STATUS REPORT FOR BUILDINGS AND CONSTRUCTION Towards a zero-emissions, efficient and resilient buildings and construction sector*, 2021). According to the International Energy Agency (IEA 2021), the total energy consumption in buildings can be classified into five sectors, as shown in Figure 2. The transition towards mainstream net-zero carbon standards requires immediate and strict action to achieve greater awareness, innovation, improved processes to calculate and process lost energy in buildings. The energy audit and inspection is the key to a structured approach to energy management decision-making (Patravale *et al.*, 2018).

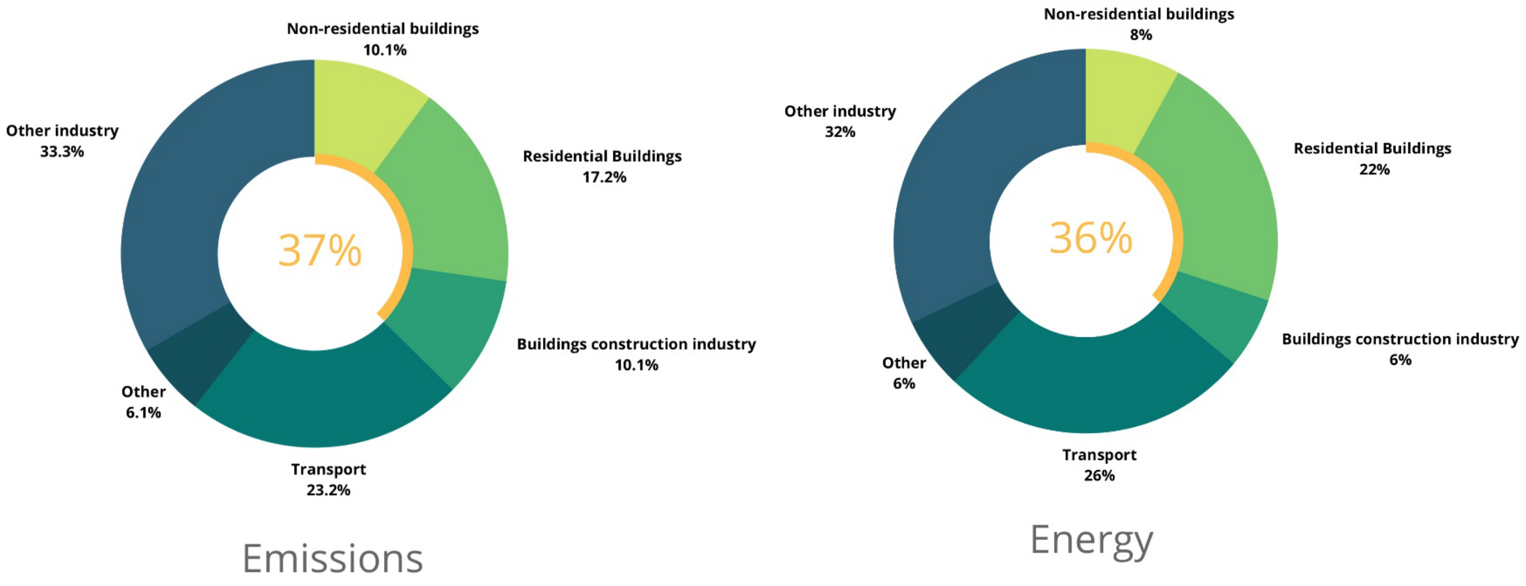

Figure 1. Buildings and construction's share of global final energy and energy-related CO2 Emissions.(2021 GLOBAL STATUS REPORT FOR BUILDINGS AND CONSTRUCTION Towards a zero-emissions, efficient and resilient buildings and construction sector, 2021)

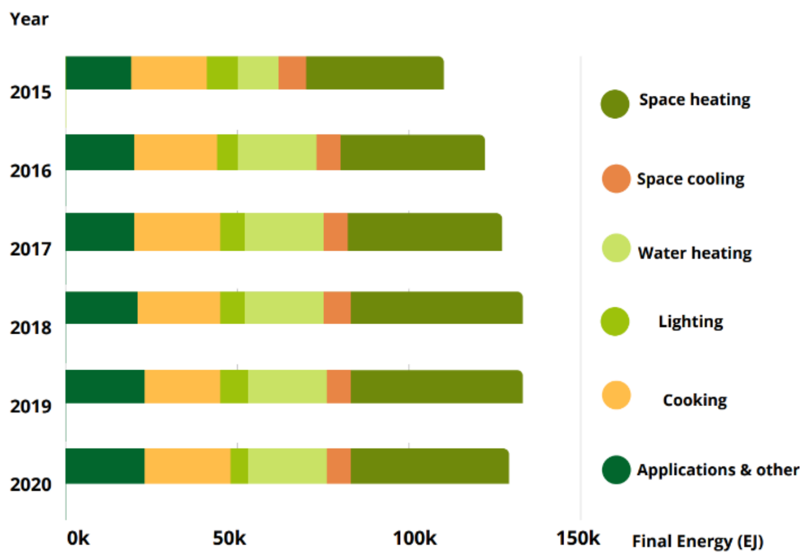

Figure 2. According to the International Energy Agency (IEA 2021), the total energy consumption in buildings can be classified into five sectors.(*2021 GLOBAL STATUS REPORT FOR BUILDINGS AND CONSTRUCTION Towards a zero-emissions, efficient and resilient buildings and construction sector*, 2021)

Despite the appearance of modern sustainable building methods such as green building, the overall energy reduction challenge and CO2 emissions will remain high because most green building codes and regulations focus on new buildings (Wang *et al.*, 2021). The number of green buildings increases depending on their prevailing socio-economic surroundings; therefore, inspection and energy inspection for existing buildings are required to meet the targets for controlling greenhouse emissions by using UAVs. International Energy Agency (IEA) evaluates that recognizing the potential of sustainable buildings can save USD 1.1 trillion by 2050 (Energy Agency, 2021). Thermal imaging integrated with UAVs can be successfully used in the construction and building sector to identify the thermal losses and bridges, construction defaults, detect defects, lack of insulation or air leakage, and control energy losses. Regular monitoring by thermal imaging techniques can lead to significant cost savings and defects removal at an early stage. Thermal imaging results will be necessary for modernization, technical, and economic improvement of the building energy performance, as it needs less than 10 minutes to start, and its flight speed is relatively fast (Krawczyk *et al.*, 2015). Thermal patterns gathered with infrared cameras attached to UAVs can be converted into automatically generated 3D CAD models using software of 3D photogrammetry. These models and the imagery gathered are visual tools that aid the professional assessment to raise energy efficiency and conservation in buildings (Green, Gregory and Karachok, 2020). UAVs provide experts across industries with a unique aerial perspective that allows easy access to remote or inaccessible areas without compromising the pilot's safety (Mavromatidis *et al.*, 2014). The process of buildings evaluation using thermography can be classified into three steps: measurement, analysis, and documentation (Bayomi *et al.*, 2021). First, the measurement step includes data collection and primary assessment of the building's existing condition. Second, the quantification of data using numerical analysis to identify types of thermal abnormalities and their severity. Finally, documentation summarizes the detection of thermal anomalies, class, location, and overall buildings (Bayomi *et al.*, 2021).

This paper reviews and compiles former studies to gain broader knowledge about the impact of buildings inspection by UAVs on sustainability and presents an international review in this field for forthcoming studies. The research purposes can be formulated as three key questions to analyze the impact of detect energy in the buildings by UAVs, as follows:

- Q What is the impact of using UAVs to detect lost energy in the buildings
  1. On energy consumption and environmental issues?
  2. On economy?
  3. On the social sector and safety issues?

2. Literature Review

2.1 The Recent Interest in UAVs Technology in Buildings Inspection

Figure 3. below shows the increase in building inspection research to improve energy efficiency from 2015 to 2021 through Science Direct databases. It confirms that UAVs are going to play even more critical roles in the future. From observing this potentially expanding phenomenon, the present research aims to shed light on how the use of UAVs for building inspection leads to industrial sustainability by focusing on its impact on the economy, energy consumption, environmental impacts, related safety issues, and regulations.

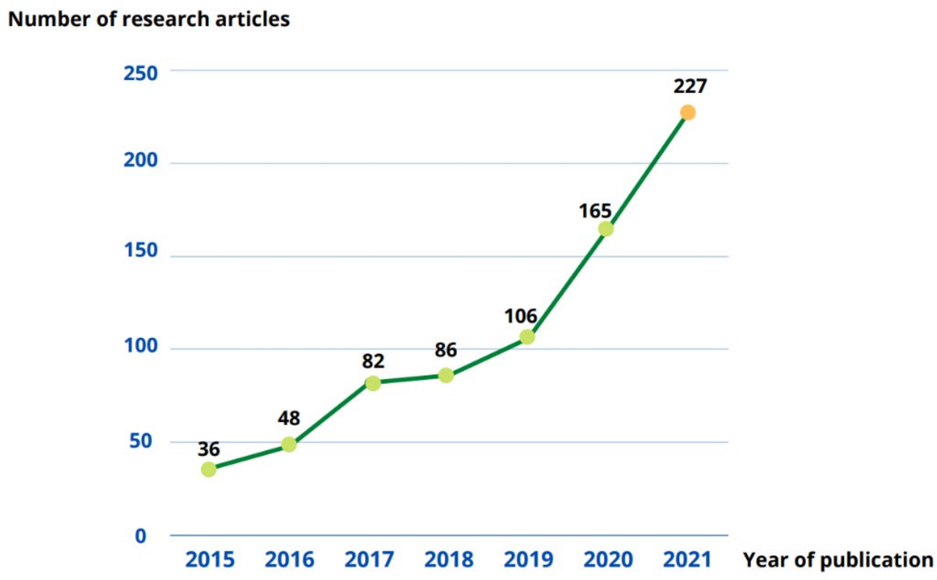

Figure 3. The number of research articles in the buildings inspection sector over the past six years.

2.2 Relationship Between Energy Efficiency and Sustainability

In the construction sector, mention that buildings with high energy efficiency and good management of the heating system, cooling system aids to reduce polluting gases (Pata, 2018). It is expected that energy efficiency measures could conserve over 28% energy costs of these buildings (Gillingham and Palmery, 2014). There is an associate degree increasing range of countries that have introduced energy-efficient strategies in the buildings because of the rise in energy needs and CO2 emissions (de la Cruz-Lovera *et al.*, 2017). For making a significant contribution to a more sustainable energy economy, we should improve the energy efficiency of buildings (Neij *et al.*, 2021). UAVs will contribute to the more efficient use of resources and be crucial in achieving climate change, air pollution, and. Environmental issues.

2.3 Integration of UAVs, Automation, and AI

During the last decade, UAVs and machine learning, among the technological developments, have revolutionized automation for many industries at a whole new level, both with data-driven and knowledge-driven methods (Zhao *et al.*, 2019). The recent integration of UAVs for building energy audit applications has shown positive results. UAVs, along with AI, provide the right diagnosis of lost energy and consequently aid in reducing overall CO2 emissions from buildings more efficiently.

3. Methods

The systematic review promotes the capability of research in terms of finding the most relevant literature available. The methodology followed the four-way technique of identification, screening, eligibility, and inclusion.

3.1 Search Method for the Identification of Studies

Preliminary assessment of studies on using UAVs in buildings energy audit and sustainability through using database research (Scopus, ScienceDirect, Web of Science) and online search using search engines Google Scholar. Figure 4. shows the PRISMA Flow Chart (Preferred Reporting Items for Systematic Reviews and Meta-Analyses). Studies were collected based on their titles and abstracts in the screening phase to gather all relevant studies.

3.2 Inclusion/Exclusion Criteria for the Selection of Studies

A total of 54 studies were compiled by searching the keywords "UAVs", "Energy audit" and "Energy efficiency in buildings" in their titles and abstracts. In the identification stage, duplicate studies were removed. Hence, 50 studies were screened, and 17 of them were excluded regarding their topics and contents. In the eligibility stage, full-text articles were assessed for eligibility, and 33 studies were selected based on the relevance of their data to the main research purposes of this study.

3.3 Selection and Analysis of Studies

In the inclusion phase, 17 scientific articles, journal articles, conference proceedings, and reports were selected to be reviewed. Those studies were categorized into sub-tonics depending on the research questions.

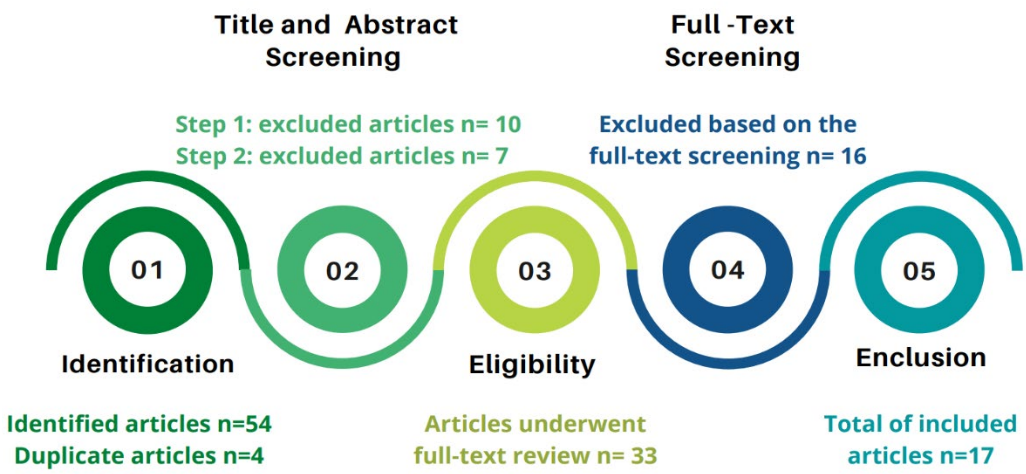

Figure 4. Flowchart of systematic review.

4. Results and Discussion

By reviewing previous research in building energy inspection by drones, energy efficiency, and sustainability, the results can be summarized in Table 1 below. The results were categorized into three areas (environment, economy, safety, and social field).

Table 1. Results of the study

Sector / Results	Environmental sector	Economic sector	Social & Safety sector
Reduce greenhouse gas emissions (GHG)	✓		✓
Save money		✓	
Create jobs		✓	✓
Meet growing energy demand	✓	✓	
Lower individual utility bills		✓	
Help stabilize electricity demand		✓	
Help diversity utility resource		✓	
Energy security		✓	✓
Improving lives		✓	
Reduce work stress			✓
Energy efficiency	✓	✓	
Reduce energy auditing time		✓	
Investment on sustainable technologies improvement		✓	
Reduce energy consumption	✓	✓	
Fast data acquisition		✓	
Operation cost		✓	✓
High accuracy of data	✓		
Quality of buildings	✓		
Life cycle cost		✓	✓
Carbon cycle economy	✓	✓	✓
Increase comfort level			✓
User satisfied			✓
Easy access to remote area	✓	✓	✓
Access to inaccessible areas without compromising the pilot's life			✓
Less human intervention		✓	✓

References: (Sánchez *et al.*, 2021) , (Ferreira, Almeida and Rodrigues, 2017) , (Krawczyk *et al.*, 2015) , (Neij *et al.*, 2021), (Pata, 2018), (Gillingham and Palmery, 2014), (Krawczyk *et al.*, 2015),(Green, Gregory and Karachok, 2020),(Mavromatidis *et al.*, 2014)

5. Conclusion

UAVs technology has massive potential and is a solution to the challenges of the energy audit. With the advancement of the Fourth Industrial Revolution, we will witness new technologies and improvements to advance the energy monitoring process by using UAVs that detect and analyze lost energy in buildings to reach the highest levels of quality in maintenance, auditing. Energy processing work will become automated, requiring less human input, participation, and expectedly yielding more accurate results. UAVs are estimated to cut audit time and increase reporting accuracy, resulting in reliability (Oh, Ham and Lee, 2021). This paper has presented how the use of UAVs for energy audit leads to sustainability in three main sectors (environment and energy consumption, economy, and safety sector), based on up-to-date published literature.

The battery power is drained at different rates depending on how it is operated. In the case of wall crack inspection, UAVs inevitably must travel upwards. However, thrust and acceleration are the two motions that drain the battery quickly. Thus, it is critical to minimize the thrust and acceleration motions while navigating and inspecting walls. To reach the goal of making a drone travel its maximum. Solar energy can be used to charge the UAVs for longer and safer audit energy flights. The author firmly believes that more research is needed to develop UAVs for energy audit as one of the main contributors to achieve sustainability. Due to some weak capabilities in UAVs, such as the battery save and their inability to fly in some rainy and windy weather conditions.

In conclusion, there are integrated interrelationships between UAVs for energy auditing, energy consumption, environmental impact, economy, and safety sector that are shown in Figure 5. a Causal Loop Diagram by Vensim software.

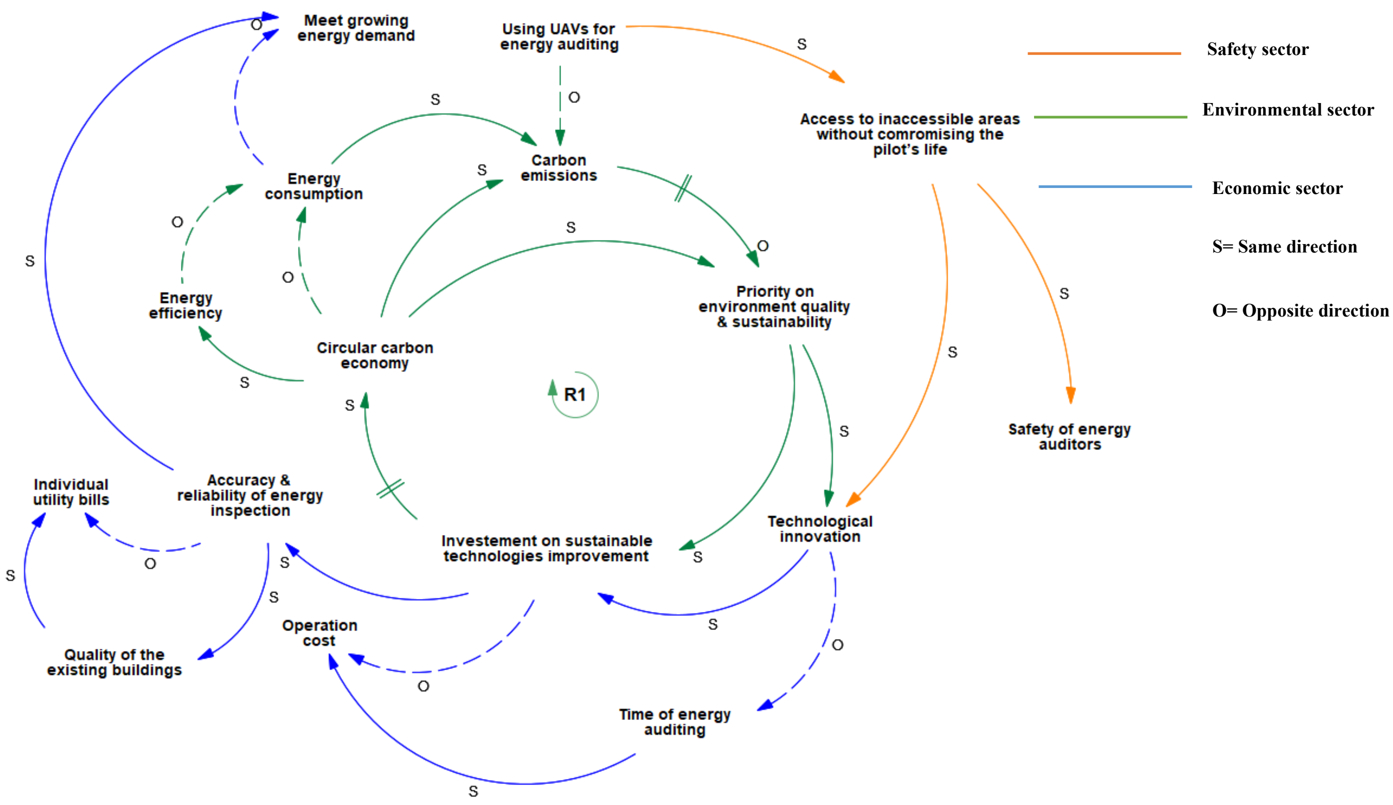

Figure 5. Casual loop diagram.

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Biography

Sarah Ali A Alshahrani is a junior industrial engineering student at King Khalid University. She achieved many awards for academic excellence. Sarah has international internship experience at TU Berlin. She got a certified industrial engineer from University of Missouri–St. Loui. She also got Full Stack Engineer Certification during her training at Smart Methods Est that focused on producing robots and automated systems. The designs and codes developed by her have been implemented in more than four robotic projects that were executed by Smart Methods Est and used in commercially available products. She is actively involved in industrial engineering projects and courses where she combines her knowledge, passion, and training experience in industrial engineering and operations management to help students achieve excellence in their studies. Sarah participated in several international conferences and workshops in the development, sustainability, and planning fields. She has many professional memberships in engineering, quality, and volunteering.