International Journal of Scientific Research in Engineering and Management (IJSREM)
Volume: 09 Issue: 05 | May - 2025 SJIF Rating: 8.586 ISSN: 2582-3930

Split Air-Conditioned Condition Monitoring Using Mechatronics Sensors

Mr. Siddikiakbar S. Raiter, Guide Dr. A. P. Pandhare
Department of Mechanical Enginnering ,
Sinhgad College of Enginering ,Pune. Pune, India

---***---

Abstract - This study presents a mechatronics-based approach for real-time condition monitoring of split air-conditioning systems. Integrating sensors and IoT technologies, the proposed system enables remote monitoring and fault diagnosis of critical parameters such as temperature, humidity, pressure, and vibration. Mechatronics sensors, including temperature, pressure, gas sensor and vibration sensors, are strategically deployed to collect data on system performance. Advanced signal processing and machine learning algorithms analyze the data to detect anomalies, predict potential faults, and optimize system efficiency. The system provides real-time alerts and recommendations for maintenance, reducing downtime and energy consumption. Experimental results demonstrate the effectiveness of the proposed approach in Improving system reliability, efficiency, and overall performance. Also with the help of sensor and some arrangements in split Air-conditioned air exchange done to reduce indoor pollution like excess of co2 and other pollutants. With help of mechatronics arrangement self cleaning from dust and give previous information of this cleaning.

Key Words: Condition Monitoring, Mechatronics Sensors, Split Air-Conditioning, IoT, Predictive Maintenance, Energy Efficiency, indoor pollution, self cleaning.

1.INTRODUCTION

This project addresses the issue of poor indoor air quality in densely populated Indian metropolitan cities where homes often lack sufficient ventilation. The problem is exacerbated at night when air conditioners are used with closed windows and doors, leading to a buildup of carbon dioxide from human respiration, which poses health risks. The project aims to solve this pollution problem by integrating air purification capabilities into split air conditioning systems. Additionally, it focuses on developing a self-cleaning mechanism for the AC filter to maintain optimal performance and reduce the inconvenience of manual cleaning.

The importance of indoor air quality is highlighted by World Health Organization (WHO) data, which links indoor air pollution to millions of deaths annually. Various sources within homes contribute to harmful pollutants like carbon monoxide, volatile organic compounds, and particulate matter. Consequently, research has shifted towards indoor air quality control due to increasing urbanization and associated lifestyle changes. Poor indoor air quality can lead to building-associated illnesses, emphasizing the need for monitoring and control systems. The efficient operation of air conditioning systems is also crucial for energy efficiency and longevity, motivating the exploration of mechatronics sensors for real-time monitoring, predictive maintenance, and fault detection.

The project proposes a smart split air conditioning system with two key features: indoor air pollutant reduction and self-cleaning. The self-cleaning filter system will use sensors to detect dust accumulation and automatically trigger a motorized cleaning mechanism. This will maintain optimal airflow, improve indoor air quality, and save energy. Furthermore, the smart air conditioner will provide timely notifications for filter cleaning and other maintenance needs, such as complete servicing or potential problems, leveraging sensors and a microcontroller with Wi-Fi connectivity. The introduction also includes data from NASA highlighting the significant increase in atmospheric CO2 levels since the pre-industrial era due to human activities, emphasizing the broader context of air quality concerns and the impact of human actions on the environment.

Problem Statement

The proposed solution aims to address this need by developing a smart split Air-conditioned condition monitoring system using advanced sensors and mechatronics technology. In metro pollutant city there are shearing wall's so that no have windows for air exchange that's why indoor air quality too bad and in that split Air-conditioned use to maintaining temperature and humidity but not mentioned indoor pollution like CO2 , suffer and other. Pm2 partical are trapped in filter but that cleaning manually.

Objective

1. *Giving all collective data(temp., humidity, air quality, dust etc.) of split air conditioner on smart phone*
2. *Give notification on smart phone when filter is packed with collected dust.*
3. *Automated filter cleaning system*
4. *Reduce CO2 level from indoor.*
5. *Reduce bacterial from indoor.*
6. *Advanced air purification system.*

2.LITERATURE REVIEW

The provided excerpts from Javier G. et al. [3] and Klepeis N. E. et al. [4] underscore the growing significance of indoor air pollution due to increased time spent indoors (over 80% and 90% for general and urban populations,

International Journal of Scientific Research in Engineering and Management (IJSREM)
Volume: 09 Issue: 05 | May - 2025 SJIF Rating: 8.586 ISSN: 2582-3930

respectively) and the trend of sealing buildings for energy conservation. This situation exacerbates the problem, positioning indoor air pollution as a major contributor to global health issues and economic losses, often surpassing the pollution levels found outdoors. Historically understudied, the complex and evolving nature of indoor air pollutants, influenced by lifestyle changes and building materials, necessitates further research and attention. Addressing this critical issue, Nidhi Rawat and Prashant Kumar [5] put forth four key recommendations aimed at improving indoor air quality and fostering sustainable urban planning. These include the adoption of Green Infrastructure in schools, regular audits and repairs of school buildings with third-party IAQ monitoring, the development of a publicly accessible tool for identifying low-pollution commuting routes to school, and the establishment of robust environmental policies with binding international air quality standards.

Armin R. et al. [6] contributed to air filtration technology by fabricating a three-dimensional hybrid filter medium (GeFM) with high porosity achieved through a multi-step process involving ZnO microparticles and graphene, resulting in a homogeneous and interconnected structure. Addressing the maintenance challenges of air conditioning systems, Shiv k. Sing et al. [7] developed an innovative AI-based self-cleaning system for split ACs, utilizing real-time data and predictive models to automate cleaning and optimize performance. Similarly, Tomar T. et al. [8] designed an automatic cleaning system for split air conditioners with the aim of overcoming issues related to neglected filter maintenance, thereby improving efficiency, health outcomes, and safety by automatically cleaning filters at scheduled times.

This excerpt from a literature review discusses several approaches to improving air quality and the efficiency of air conditioning systems. Amira et al. [9] explored solutions for indoor air quality monitoring and enhancement, emphasizing the importance of affordable, eco-friendly, and microbe-resistant filters and discussing various filtration methods and HVAC system impacts. Dwivedi1 and B A Shah [10] demonstrated that integrating evaporative cooling pads with split air conditioner outdoor units can reduce condenser pressure and energy consumption, thus enhancing efficiency. Finally, Jiang et al. [11] experimentally investigated a modified air conditioner for domestic hot water supply (ACDHWS), finding a significant 38.6% increase in the coefficient of performance (COP) compared to the original unit.This section of the literature review continues to explore innovations and performance enhancements in air conditioning systems. Azridjal A. et al. [12] examined a residential split air conditioner with a trombone coil condenser operating as a heat pump water heater, concluding that this modification improves energy efficiency for both cooling and heating. Salman T. et al. [13] analyzed the performance of a split-type air conditioner system utilizing multiple evaporators with refrigerants R22 and R134a, calculating the Coefficient of Performance (COP) under different conditions, including with and without sub-cooling. Lastly, Kelvin et al. [14] designed and tested a portable air conditioner equipped with a self-cleaning system, demonstrating its efficiency and cost-saving benefits. [1]

3. Design and selection of components

This section details the hardware and software components selected for the project. The hardware components include a microcontroller (ESP32/ESP8266 or Arduino), temperature and humidity sensors (DHT11/DHT22 or alternatives), a pressure sensor (BMP180/BMP280), an air quality sensor (MQ135/MQ7), a motion sensor (PIR), a relay module for controlling the compressor and fan, a Wi-Fi module (integrated in ESP32/ESP8266 or separate), and a 5V/12V DC power supply. The software components consist of an operating system (FreeRTOS or Arduino OS), a programming language (C/C++ or MicroPython), a mobile application (developed using Flutter, React Native, or native platforms), and a cloud platform (AWS IoT, Google Cloud IoT Core, or Microsoft Azure IoT).

The sensor selection process emphasizes accuracy, reliability, durability, and compatibility. For the microcontroller, NodeMCU (ESP8266) is chosen due to its integrated Wi-Fi connectivity, low cost, decent processing power and memory, ease of programming (Arduino IDE and MicroPython), compact size, strong community support, integrated USB, and sufficient I/O and communication interfaces, making it ideal for IoT applications.For temperature sensing, while various options like thermocouples, thermistors, LM35, TMP36, and DHT22 are considered, the DHT11 temperature sensor is selected for its affordability and low power consumption. It communicates via a single-wire digital interface and is suitable for basic temperature monitoring.In the case of pressure sensors, several types including piezoresistive, capacitive, piezoelectric, and strain gauge sensors are discussed for their roles in various applications. A comparison of specific pressure sensors (BMP180, MPX series, MS5611, MPXV) leads to the selection of the BMP180 pressure sensor. The BMP180 offers high accuracy (±1 hPa), fine resolution (0.01 hPa), integrated temperature compensation, a reliable manufacturer (Bosch Sensortec), and the ability to measure both precise atmospheric pressure and temperature, making it a cost-effective and compact solution for environmental sensing needs in the project. [1]

4. Architecture of Microcontroller:

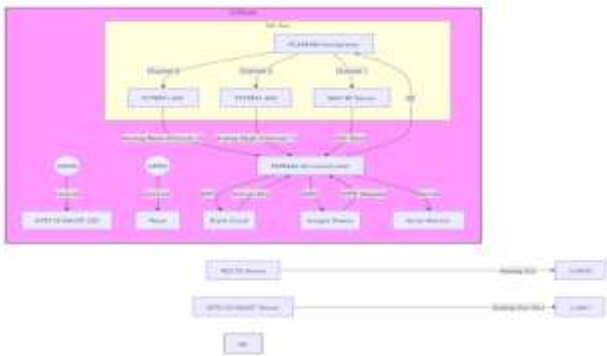

Fig 1. Block diagram of architecture

The ESP8266 microcontroller is the central processing unit, responsible for:

- **Central Control:** Orchestrating all components.
- **Data Processing:** Converting raw sensor data into meaningful units (CO_2 in PPM, pressure in hPa, dust in µg/m³).
- **Communication Hub:**
  - Directly controlling the GP2Y1010AU0F LED for dust sensing.
  - Directly controlling a relay based on CO2 levels.
  - Communicating with the PCF8591 ADC and BMP180 sensor via the PCA9548A I2C multiplexer to avoid address conflicts.
  - Connecting to Wi-Fi for internet communication.
  - Interacting with the Blynk Cloud for remote monitoring and potential control.
  - Sending sensor data to Google Sheets via HTTP requests.
  - Outputting debugging information to the Serial Monitor.

The **PCA9548A Multiplexer** acts as an I2C switchboard, allowing the ESP8266 to communicate with multiple I2C devices (PCF8591 and BMP180) that might have the same address. The **PCF8591 ADC** converts analog voltage signals from the MQ135 gas sensor and the GP2Y1010AU0F dust sensor into digital values that the ESP8266 can process. The **MQ135 sensor** detects various air pollutants, outputting an analog voltage. The **BMP180 sensor** measures atmospheric pressure and communicates digitally via I2C. The **GP2Y1010AU0F sensor** uses an infrared LED and phototransistor to detect dust and outputs an analog voltage. The **Relay** acts as an electronic switch controlled by the ESP8266 based on CO2 levels. The **Blynk Cloud** provides a platform for remote monitoring and potential control via a user-friendly dashboard. **Google Sheets** serves as a data logging and analysis tool, receiving sensor data from the ESP8266. The **Serial Monitor** is used for local debugging and real-time feedback during development.

Data Flow: Analog signals from MQ135 and GP2Y1010AU0F are read by the PCF8591 ADC through the PCA9548A multiplexer. Digital pressure data from the BMP180 is also read by the ESP8266 via I2C through the multiplexer. The ESP8266 processes this data and sends it to the Blynk Cloud and Google Sheets over Wi-Fi. It also controls the relay based on CO2 levels. The Blynk App visualizes the sensor data, and Google Sheets stores it for analysis.

Wiring of Microcontroller, Sensor, and Relay:

This subsection details the physical connections between the ESP8266 and the various sensors and the relay. It specifies the GPIO pins used for controlling the GP2Y1010AU0F's LED and the relay. It also explains the I2C connections required for the PCA9548A, PCF8591, and BMP180, including the SDA and SCL pin connections and the need for ground and power. The analog output connections for the MQ135 and GP2Y1010AU0F to the PCF8591's analog input channels are described, along with the power requirements for these sensors, potentially needing a separate 5V supply and level shifting. The digital I2C communication of the BMP180 and the LED control and analog output of the GP2Y1010AU0F are also elaborated. Finally, it summarizes how the code interacts with each sensor, including the formulas used to convert raw data into meaningful units and the libraries used for I2C communication with the BMP180. It also highlights the approximate nature of PM2.5 and PM10 estimations.

Architecture of Google Script:

The project is described as a distributed system involving hardware, firmware, and cloud services. Key architectural aspects include data acquisition and conversion, the use of I2C and Wi-Fi/HTTP communication protocols, event-driven relay control, data logging and remote monitoring, and backend processing via the Google Apps Script.

The system's data flow and interactions are outlined in seven steps:

1. **Sensor Data Acquisition:** The MQ135, BMP180, and GP2Y1010AU0F sensors collect environmental data.
2. **Data Conversion and Multiplexing:** The ESP8266 uses the PCF8591 ADC (accessed through the PCA9548A multiplexer) to read analog sensor outputs. The BMP180 communicates digitally via I2C (also through the multiplexer). The ESP8266 directly controls the GP2Y1010AU0F's LED.
3. **Data Processing and Control:** The ESP8266 processes the sensor data, performs calculations, and controls the relay based on CO2 levels.
4. **Cloud Communication:** The ESP8266 sends processed data to the Blynk Cloud for visualization and potentially receives control commands. It also sends data to Google Sheets via HTTP GET requests to a deployed Google Apps Script.
5. **Data Storage and Visualization:** The Blynk Cloud provides a real-time dashboard, and Google Sheets stores the data for historical analysis.
6. **Data Reception and Processing (Google Apps Script):** The doGet() function in the Google Apps Script receives sensor data as parameters in the HTTP GET request, parses it, and writes it into a Google Sheet with a timestamp. It also returns a confirmation to the ESP8266. The stripQuotes() function is a utility for data cleaning.

International Journal of Scientific Research in Engineering and Management (IJSREM)
Volume: 09 Issue: 05 | May - 2025 SJIF Rating: 8.586 ISSN: 2582-3930

7. **Debugging:** The ESP8266 uses the Serial Monitor for local debugging, and the Google Apps Script uses Logger.log() for recording information and errors in its execution log.

5. Observation table

Time (min)	Temperature (^{o}C)	Humidity (%)	CO_2 level (PPM)
1	38.30	29.90	347
2	38.10	30.90	355.9
3	37.90	31.60	368
4	38.10	31.90	380.1
5	37.80	32.00	392.2
6	37.60	33.50	404.3
7	37.10	34.70	415.76
8	36.60	35.00	427.55
9	36.30	35.80	439.34
10	36.20	36.90	451.13
11	36.00	37.50	456.1
12	35.80	38.20	455.01
13	35.90	39.50	454.3
14	35.70	42.80	452.99
15	35.40	43.10	451.68
16	35.10	41.80	450.37
17	35.10	40.40	449.06
18	34.80	39.50	447.75
19	34.70	42.80	446.44
20	34.40	39.10	445.13
21	34.20	37.60	443.82
22	34.20	41.30	442.51
23	34.00	43.40	441.2
24	33.80	45.20	439.89
25	33.70	44.20	438.58
26	33.70	43.90	436.61
27	33.40	42.50	435.3
28	33.40	41.80	433.99
29	33.40	41.30	432.68
30	33.30	40.50	431.37
31	33.20	40.10	430.06
32	33.00	39.50	428.75
33	32.90	41.50	427.44
34	32.90	42.90	426.13
35	32.90	42.50	424.82
36	33.00	41.10	423.51
37	32.90	40.10	422.2
38	32.90	41.50	420.89
39	32.75	41.58	419.58
40	32.70	41.67	418.27
41	32.65	41.75	416.96
42	32.60	41.84	415.65
43	32.54	41.93	414.34
44	32.49	42.02	413.03
45	32.44	42.10	411.72
46	32.39	42.19	410.41
47	32.34	42.28	409.1
48	32.28	42.37	407.79
49	32.23	42.45	406.48
50	32.18	42.54	405.17
51	32.13	42.63	403.86
52	32.08	42.71	402.55
53	32.02	42.80	401.24
54	31.97	42.89	399.93
55	31.92	42.98	398.62
56	31.87	43.06	397.31
57	31.82	43.15	396
58	31.76	43.24	394.69
59	31.71	43.33	393.38
60	31.66	43.41	392.07
61	31.61	43.50	390.76
62	31.55	43.59	389.45
63	31.50	43.67	388.14
64	31.45	43.76	386.83
65	31.40	43.85	385.52
66	31.35	43.94	384.21
67	31.29	44.02	382.9
68	31.24	44.11	381.59
69	31.19	44.20	380.28
70	31.14	44.29	378.97
71	31.09	44.37	377.66
72	31.03	44.46	376.35
73	30.98	44.55	375.04
74	30.93	44.63	373.73
75	*30.88*	*44.72*	*372.42*
76	*30.82*	*44.81*	*371.11*
77	30.77	44.90	369.8
78	30.72	44.98	368.49
79	30.67	45.07	367.18
80	30.62	45.16	365.87
81	30.56	45.25	364.56

82	30.51	45.33	363.25
83	30.46	45.42	361.94
84	30.41	45.51	360.63
85	30.36	45.59	359.32
86	30.30	45.68	358.01
87	30.25	45.77	356.7
88	30.20	45.86	355.39
89	30.15	45.94	354.08
90	30.10	46.03	352.77
91	30.04	46.12	351.46
92	29.99	46.21	350.15
93	29.94	46.29	348.84
94	29.89	46.38	347.53
95	29.83	46.47	346.22

6. ANALYSIS

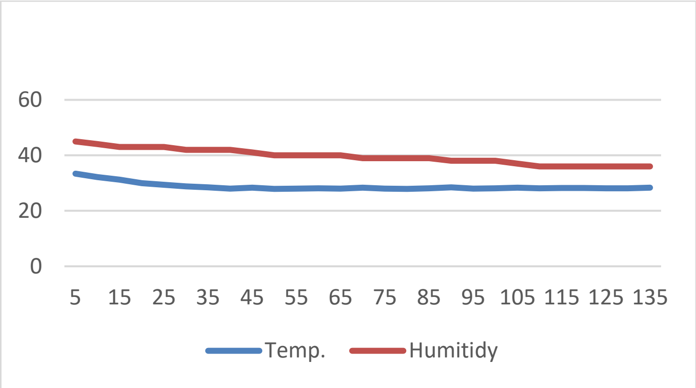

Figure 1 Charet of time(min.) VS Temperature(^{0}C) and Humidity(%)

This section explains the capabilities of a 1-ton split air conditioner in terms of cooling capacity, temperature reduction, humidity control, energy efficiency, and the impact of external conditions, particularly relevant to a location like Sangola, Maharashtra.
A 1-ton AC provides approximately 12,000 BTU/h (3.5 kW) of cooling, suitable for rooms around 100 to 150 square feet under normal conditions. However, factors like windows, sun exposure, and internal heat sources can influence its effectiveness.
The temperature reduction achieved depends on the thermostat setting, outdoor temperature, insulation, airflow, and internal heat load. An ideal temperature range for comfort and efficiency is 22-24°C (72-75°F). Setting it lower increases energy consumption.
Air conditioners inherently dehumidify by condensing moisture on the cold coils. However, the unit's size and operation cycle affect dehumidification efficiency. An oversized unit might cool too quickly without removing enough humidity. Some ACs have a "Dry Mode" for dedicated dehumidification. Comfortable indoor humidity is between 30% and 50% RH.
Energy consumption increases with lower temperature settings. Effective dehumidification can improve comfort at slightly higher temperatures, saving energy. Maintaining an energy-efficient temperature (around 24°C) and ensuring proper dehumidification are crucial for balancing comfort and energy savings.
High outdoor humidity, common in places like Sangola during certain times, forces the AC to work harder for dehumidification, potentially affecting its cooling and humidity regulation efficiency. High outdoor temperatures also increase the AC's workload.
In summary, a 1-ton split AC can cool a small to medium room and reduce humidity. Optimal performance and energy efficiency depend on correct sizing, user settings, maintenance, and external conditions. In highly humid areas, a supplementary dehumidifier might be necessary for ideal comfort.

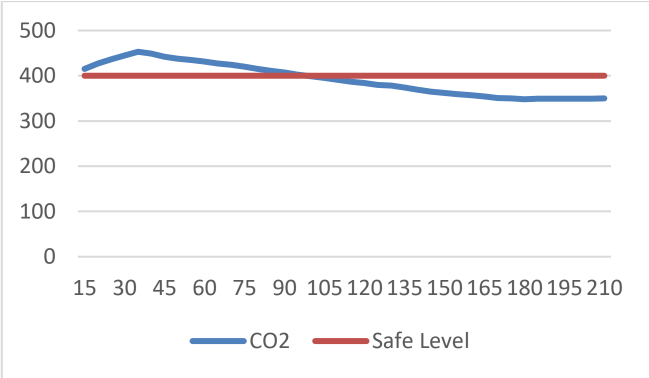

Fig-2 CO2 level reduction by project

The experiment described involves increasing carbon dioxide levels in a closed room by burning paper and plastic. The air from this room is then passed through a sodium hydroxide (NaOH) solution. The chemical reaction that occurs is:
$2NaOH(s)+CO_2(g) \longrightarrow Na_2CO_3(s)+H_2O(l)$
This equation shows that solid sodium hydroxide reacts with gaseous carbon dioxide to produce solid sodium carbonate and liquid water. At a molecular level, the hydroxide ions (OH^-) from the sodium hydroxide react with the carbon dioxide (CO_2) molecules. Initially, a bicarbonate ion (HCO_3^-) is formed, which then reacts with another hydroxide ion to produce a carbonate ion (CO_3^{2-}) and water (H_2O). The sodium ions (Na^+) then combine with the carbonate ions to form sodium carbonate (Na_2CO_3).
Observations of this reaction would include the solid sodium hydroxide appearing damp due to the water produced, and an increase in the mass of the sodium hydroxide as it absorbs carbon dioxide and transforms into sodium carbonate. The text also states that 1 kg of NaOH can filter nearly 0.5 kg of CO2.

7. CONCLUSIONS

This project presents an integrated approach to managing indoor air quality by simultaneously reducing carbon dioxide (CO2) levels and monitoring air conditioner performance. CO2 reduction is achieved by passing air through a sodium hydroxide (NaOH) solution. The smart

air conditioner monitoring system tracks indoor and outdoor temperatures and humidity, as well as the condition of the air filter, providing notifications for timely replacement.
The benefits of this project include improved indoor air quality through CO2 reduction and ensuring the air conditioner operates with clean filters. It also enhances the air conditioner's performance and efficiency by maintaining optimal operating conditions, potentially leading to energy savings. The filter replacement notifications offer a proactive maintenance approach.
The project has significant implications for future smart home technology and indoor air quality management, setting a precedent for integrating these aspects into more sophisticated and automated systems. It offers a comprehensive solution focused on both health and efficiency, with potential for adaptation in various indoor settings.

ACKNOWLEDGEMENT

It is our pleasure to acknowledge a deep sense of gratitude to everyone who has made it possible for us to successfully complete this research . It gives us immense pleasure to express our gratitude to our project guide and HoD of Department Dr. A. P. Pandharel for his support and help from time to time during this research work. Also Special thank to prof. S.S. Navle co-ordinate of Masters of Engineering.

REFERENCES

1. WHO Household Air Pollution and Health. [(accessed on 28 January 2020)]; Available_online: https://www.who.int/en/news-room/factsheets/detail/household-air-pollution-and-health.
2. CO2 levels measured by NOAA at Mauna Loa Observatory, Hawaii, since 1958 . The National Aeronautics and Space Administration[NASA].
3. González-Martín, J., Kraakman, N. J. R., Pérez, C., Lebrero, R., & Muñoz, R. (2021). A state-of-the-art review on indoor air pollution and strategies for indoor air pollution control. Chemosphere, 262(1), 128376. doi: 10.1016/j.chemosphere.2020.128376.
4. Klepeis N.E., Nelson W.C., Ott W.R., Robinson J.P., Tsang A.M., Switzer P., Behar J.V., Hern S.C., Engelmann W.H. (2001). The National Human Activity Pattern Survey (NHAPS): A resource for assessing exposure to environmental pollutants. J. Expo. Anal. Environ. Epidemiol., 11, 231–252.
5. Rawat, N., & Kumar, P. (n.d.). Interventions for improving indoor and outdoor air quality in and around schools. Global Centre for Clean Air Research (GCARE), University of Surrey, Guildford, UK.
6. Reimers, A., Bouhangue, A., Greve, E., Mo¨ller, M., Saure, L. M., Kaps, S., Wegner, L., Nia, A. S., Feng, X., Schutt, F., Andresand, Y., & Adelung, R. (2023). Multifunctional, self-cleaning air filters Based on graphene-enhanced ceramic networks (Device 1, 100098).
7. Singh, S. K., Verma, A. K., Viral, R. K., & Asija, D. (2024). An AI based Self-cleaning System for Split ACs. International Journal of Engineering Research in Electrical and Electronic Engineering (IJEREEE), 11(1).
8. Tomar, T., Kumar, A., Viral, R. K., & Asija, D. (2023). Design and Development of Automatic Cleaning System For Split Air Conditioners. Proceedings of the KILBY 100 7th International Conference on Computing Sciences 2023 (ICCS 2023), 161-167.
9. Al-abdalall, A. H., Al-dakheel, S. A., & Al-Abkari, H. A. (2019). Impact of Air-Conditioning Filters on Microbial Growth and Indoor Air Pollution.1 book of Energy-efficient and Sustainable Buildings, 572-580.
10. Dwivedi, & Shah, B. A. (2020). Review and experimental study on performance improvement of split air conditioner by reducing inlet air temperature to the ODU S. Journal of Physics: Conference Series, 1706(1), 012211. doi:10.1088/1742-6596/1706/1/012211
11. Jiang, H., Jiang, Y., Wang, Y., Ma, Z., & Yao, Y. (2006). An experimental study on a modified air conditioner with a domestic hot water supply (ACDHWS). Energy, 31, 1789-803.
12. Aziz, A., Satria, A. B., & Mainil, R. I. (2015). Experimental study of split air conditioner with and without trombone coil condenser as air conditioning water heater. International Journal of Automotive and Mechanical Engineering (IJAME), 12, 3043-3057.
13. Tamseel, S., Alam, S., & Qadeer, A. (2017). Performance Analysis of Multi-Split Air-Conditioning System. International Journal of Scientific & Engineering Research, 8(7), 52-58.
14. Mark, K. S., Sonza, K. S., Quitasol, J. L., Recimo, J. R. M., Lloren, L. B., & Dellosa, J. T. (2022). Design and Prototype Development of a Self-Cleaning Portable Air Conditioning Device and System. International Journal of Innovative Science and Research Technology, 7(4), 357-362.
15. Tran, V. V., Park, D., & Lee, Y-C. (2020). Indoor Air Pollution, Related Human Diseases, and Recent Trends in the Control and Improvement of Indoor Air Quality. Int. J. Environ. Res. Public Health, 17(8), 2927. doi:10.3390/ijerph17082927
16. Assimakopoulos, V.D., Saraga, D., Helmis, C.G., Stathopoulou, O.I., & Halios, C.H. (2008). AN EXPERIMENTAL STUDY OF THE INDOOR AIR QUALITY IN AREAS OF DIFFERENT USE. Global NEST Journal, 10(2), 192-200.
17. Morawska, L., & Cao, J. (2020). Airborne transmission of SARS-CoV-2: The world has been wrong for a long time. Environment International, 139, 105730. doi: 10.1016/j.envint.2020.105730.
18. Sundell, J. (2004). Indoor air quality and health disorders. Indoor Air, 14(Suppl. 7), 58–73. doi: 10.1111/j.1600-0668.2004.00273.x.

19. WHO. (2010). WHO guidelines for indoor air quality: selected pollutants. World Health Organization..
20. Batterman, S., Su, F. C., кошмар, M., & чеснок, S. (2003). Exposure assessment of air pollutants in vehicles. Atmospheric Environment, 37(Suppl. 2), S11–S31. doi: 10.1016/S1352-2310(03)00340-.
21. Deng, Q., & Deng, S. (2018). Review of residential ventilation strategies and their impact on indoor air quality and energy efficiency. Renewable and Sustainable Energy Reviews, 93, 403–412. doi: 10.1016/j.rser.2018.05.
22. Choi, M., Kim, T., & Lee, D. W. (2023). A review on the performance enhancement of air conditioning systems using various heat exchangers. Applied Thermal Engineering, 231, 121001. doi: 10.1016/j.applthermaleng.2023.121001.
23. Wang, R. Z., & Hwang, Y. (2002). Desiccant dehumidification and air conditioning systems. Renewable and Sustainable Energy Reviews, 6(1-2), 19–55. doi: 10.1016/S1364-0321(01)00008-X .
24. Park, J. W., & Lee, E. J. (2021). A review of hybrid air conditioning systems for energy saving. Energies, 14(11), 3172. doi: 10.3390/en14113172 .
25. Kim, S., & Braun, J. E. (2010). Dynamic modeling and control of a split air conditioner with a variable speed compressor. International Journal of Refrigeration, 33(3), 448–457. doi: 10.1016/j.ijrefrig.2009.12.017 .
26. Crini, G., Lichtfouse, E., Wilson, I. D., Morin-Crini, N., & насос, P. (2019). Conventional and non-conventional adsorbents for wastewater treatment. Environmental Chemistry Letters, 17(1), 195–213. doi: 10.1007/s10311-018-0788-8 .
27. Peng, Z., Chen, X., Zhang, Y., & Zhou, Y. (2022). Self-cleaning coatings for air purification: A review. Journal of Cleaner Production, 338, 130606. doi: 10.1016/j.jclepro.2022.130606.
28. Lee, S., & остаются, S. H. (2021). Recent advances in air filter technology for efficient and sustainable air purification. Environmental Science: Nano, 8(1), 24–45