iJRASET
International Journal For Research in
Applied Science and Engineering Technology

INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 13 **Issue:** XII **Month of publication:** December 2025

DOI: https://doi.org/10.22214/ijraset.2025.76205

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.538
Volume 13 Issue XII Dec 2025- Available at www.ijraset.com

Automated Window and Ventilation System

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Abstract: The proposed Automated Window and Ventilation System addresses key challenges in maintaining indoor air quality, thermal comfort, and energy efficiency in residential and institutional settings. This research presents a low-cost, sensor-based smart ventilation solution that autonomously responds to real-time environmental changes. The system utilizes sensors such as DHT11 for temperature and humidity, MQ2 for gas detection, KY-026 for flame detection, and rain sensors to monitor indoor and outdoor conditions. Based on sensor data, a microcontroller operates servo motors to open or close windows, ensuring optimal ventilation. Additional features include IR-based pinch protection for user safety, Bluetooth control for manual override, and a dual power supply using both lithium-ion battery and solar panel for improved energy sustainability.

Designed with a focus on practicality, affordability, and user-friendliness, the system is particularly suited for smart homes, schools, and green buildings. It includes an LCD for displaying system status and alerts, enhancing the user experience. Prototype testing showed improvements in indoor air quality and energy use compared to conventional methods. With the potential for future IoT integration, this automated system offers a scalable and sustainable approach to modern building ventilation, promoting healthier living environments and contributing to reduced carbon emissions.

Keywords: Smart Ventilation, Arduino, Sensors, Bluetooth Control, Automation.

I. INTRODUCTION

In recent years, rapid advancements in smart automation and sustainability technologies have significantly influenced how we design and manage indoor environments. With growing awareness about energy conservation, environmental safety, and air quality, there is a pressing demand for solutions that not only enhance comfort but also ensure safety and responsiveness to dynamic conditions. Despite the availability of modern HVAC systems, many continue to face limitations such as high energy consumption, lack of real-time adaptability, and minimal user interaction capabilities.

Indoor spaces especially in homes, schools, and healthcare institutions demand effective ventilation and safety systems that are both intelligent and easy to deploy. Existing methods often lack the responsiveness to factors like sudden temperature rise, toxic gas leaks, rain ingress, or fire hazards, leading to compromised occupant safety and resource wastage. Furthermore, in places where constant human monitoring is impractical, an automated system becomes crucial.

To address these gaps, this paper presents a comprehensive, low-cost, and scalable Automated Window and Ventilation System model that uses real-time sensor feedback to regulate window operation and environment alerts. The model integrates key environmental sensors such as temperature and humidity (DHT11), smoke and gas (MQ2), flame (KY-026), and rain detection, along with servo-controlled window panels for ventilation. An IR sensor provides pinch protection during window movement, adding a vital layer of safety.

Bluetooth-enabled control via the HC-05 module allows mobile command operation, and a 16x2 LCD displays real-time system information. A dual power system using a rechargeable 18650 lithium-ion battery and a 5V solar panel ensures sustainable, standalone operation even during power outages. The entire setup is driven by the Arduino Uno microcontroller, making it accessible for educational, residential, and institutional use.

With an emphasis on environmental monitoring, user convenience, and operational safety, this model contributes to the development of affordable and adaptable smart infrastructure. It is particularly relevant in today's context where indoor air quality, safety, and energy efficiency are more important than ever.

II. LITERATURE REVIEW

Zhang, Wei, and Liu in *"Design and Implementation of an Intelligent Ventilation System for Indoor Air Quality Improvement"* (2020) presented a microcontroller-based system that adjusts ventilation fan speed and window openings in response to temperature, humidity, and CO_2 levels. Their system used DHT11 and MQ135 sensors, combined with servo motors and fan controllers, to create a feedback loop for maintaining comfortable indoor environments. Testing showed that the automated system significantly improved air quality compared to manually operated windows, proving its potential for energy-efficient building applications.

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Ali Hassan, Mohamed F. Younis, and Sahar Al-Saleh in *"Development of an IoT-Based Smart Home Ventilation System"* (2021) introduced a ventilation solution integrating IoT platforms like Blynk for remote access and real-time monitoring. The system used temperature, gas, and motion sensors interfaced with an Arduino microcontroller to control windows and fans based on occupancy and environmental conditions. Their findings emphasized the convenience and efficiency of remote operation, highlighting the relevance of IoT in modern smart homes.
Rahul K., Deepa S. in *"Automatic Ventilation System using Embedded Technology"* (2019) developed a low-cost embedded system that responds to parameters like smoke, temperature, and gas concentration. Utilizing MQ2, LM35, and rain sensors, the system included an automatic shut mechanism during poor weather conditions and fire emergencies. Their model demonstrated real-time responsiveness, enhanced safety, and suitability for budget-conscious residential buildings.
Sangamesh G. H., Shivakumar, and colleagues, in *"Smart Ventilation and Lighting System for Home Automation using IoT"* (2022), combined ventilation control with ambient light sensing to reduce energy usage in homes. Their system operated windows and fans based on sensor thresholds and incorporated solar energy for powering the setup. The research showed a notable decrease in energy consumption and user intervention, promoting sustainable living environments.

III. METHODOLOGY/EXPERIMENTAL

The development and implementation of the Automated Window and Ventilation System was carried out in the following systematic steps:

A. Microcontroller Selection

Arduino UNO was selected as the central controller due to its ease of programming, open-source support, and sufficient digital/analog I/O pins for interfacing multiple components.

B. Sensor Integration

A variety of sensors were connected to the Arduino for real-time environmental monitoring:

1) DHT11 Sensor: Measures ambient temperature and humidity.
2) MQ2 Sensor: Detects smoke or gas leakage (e.g., LPG).
3) Flame Sensor (KY-026): Detects fire or high-intensity light indicative of flame.
4) Rain Sensor (YL-83): Senses rainfall to initiate automatic window closure.
5) IR Sensor: Provides pinch protection by detecting obstacles during window closure.

Sensor Threshold Table

PARAMETER	SENSOR USED	THRESHOLD VALUE	ACTION TAKEN
AIR QUALITY (CO_2 INDEX)	MQ135	HIGH (TEMP ≥ 32°C)	OPEN WINDOW
TEMPERATURE	DHT11	HIGH (≥ 30°C)	OPEN WINDOW
HUMIDITY	DHT11	HIGH (> 65%)	CLOSE WINDOW
RAIN DETECTION	RAIN SENSOR	LOW (ANALOG < 400)	CLOSE WINDOW
FIRE DETECTION	FLAME SENSOR	LOW (FLAME DETECTED)	CLOSE WINDOW + ACTIVATE BUZZER
GAS LEAK	MQ135	HIGH (> 200 PPM)	CLOSE WINDOW + ACTIVATE BUZZER

Fig.1. Sensors Threshold Table.

C. Actuator Configuration

Two SG90 servo motors were used to control the opening and closing of the window panels. A buzzer was included to sound alerts in case of danger (fire, smoke, pinch, or high temperature).

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D. Display System

A 16x2 I2C LCD module was used to display sensor readings and warning messages such as "Danger Detected", "Pinch Detected", or "All Normal".

E. Bluetooth Communication Setup

The HC-05 Bluetooth module was integrated to enable wireless control of the window from a mobile phone.
The module receives string commands (OPEN, CLOSE, STATUS) to control servos or get real-time data feedback.

F. Power Supply Design

The system is powered by a 18650 rechargeable lithium-ion battery, managed via a TP4056 charging module. A 6V solar panel was added as an optional sustainable power source, making the system energy-efficient and independent of grid supply.

G. Programming and Logic Development

Arduino IDE was used to write and upload the code Logic flow:

1) Read sensor data.
2) Evaluate conditions (e.g., temp ≥ 32°C, smoke/flame detected).
3) Trigger corresponding actuators (servo, buzzer).
4) Display results on LCD.
5) Receive and act on Bluetooth commands.

H. Physical Window Construction

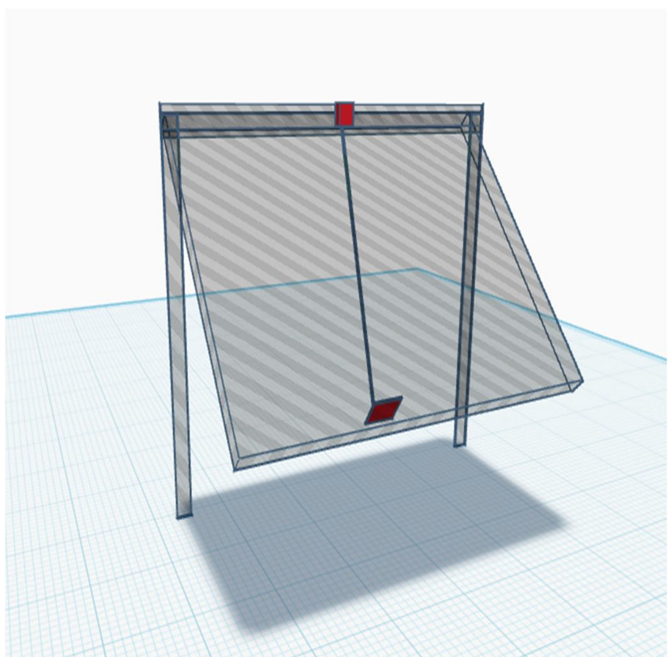

Fig.2. Window prototype design.

A physical prototype of a double-panel window was created using cardboard and plastic sheet. First, the design was made on the Tinkercad and then building of the window was started. Servos were mounted on each panel using brackets/hot glue. Wiring was secured to allow motion without disconnection.

I. Testing and Calibration

Each sensor and actuator were tested individually. Final system testing was done with combined input conditions (e.g., smoke + flame + pinch). The system was calibrated to ensure reliable readings and proper servo angles.

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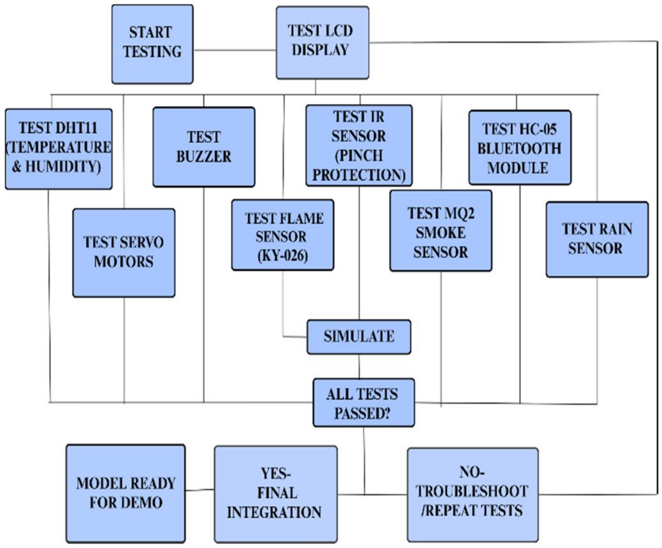

Fig.3. Testing Phase Flowchart - Automated Window and Ventilation System

J. *Safety and Fail-Safe Measures*

Pinch protection with the IR sensor prevents injury during window closure. Servo shutdown occurs on detecting any emergency condition. Manual override is always available via Bluetooth commands.

This project presents a low-cost, efficient automated window and ventilation system that enhances indoor air quality and safety. It intelligently responds to environmental changes using sensors and provides manual control via Bluetooth. The system includes safety features like pinch protection and uses a sustainable power supply with a battery and solar panel. Its simple design and effective functionality make it suitable for homes, classrooms, and smart building applications.

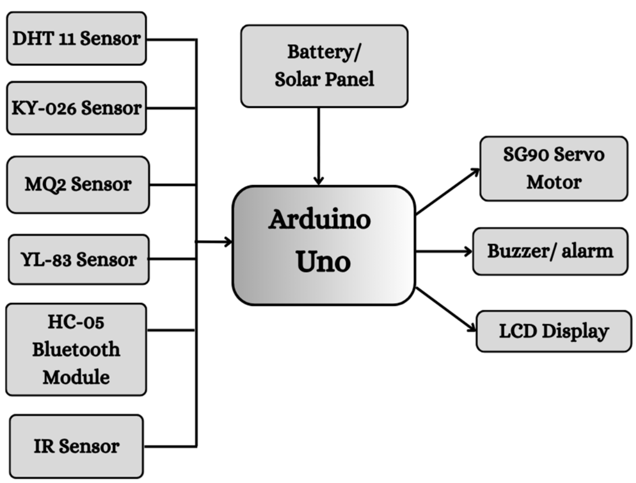

Fig.4. Block diagram of the model.

IV. RESULTS AND DISCUSSIONS

The automated window and ventilation system was developed and tested successfully across various environmental conditions and sensor inputs. Each module—sensor, actuator, power, and communication—was first tested independently and then integrated into the full system.

During testing, the temperature and humidity readings from the DHT11 sensor were displayed accurately on the LCD, with updates every 2 seconds. The servo motors responded reliably to both automatic triggers (like temperature exceeding the threshold of 32°C) and manual commands sent via Bluetooth using the HC-05 module.

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The flame sensor (KY-026) and smoke sensor (MQ2) were able to detect hazardous conditions quickly, triggering the buzzer and closing the window as intended. The IR sensor effectively provided pinch protection, detecting obstacles and reopening the window immediately when anything blocked its path. Mobile control through the Bluetooth app worked as expected, allowing remote opening and closing of the window and receiving live environmental data. The LCD display clearly communicated system status, sensor values, and safety warnings. Additionally, the rain sensor accurately detected moisture and forced the window to close during simulated rainfall. The power supply, including the 18650 rechargeable battery and TP4056 charging module, kept the system running stably even during unplugged operations. The optional solar panel was capable of maintaining the battery charge under daylight conditions, making the setup sustainable and suitable for remote or power-limited environments.

In integrated tests, the system consistently responded to all inputs within 1–2 seconds, demonstrating high reliability and real-time performance. The combination of automated triggers and manual override added flexibility and user control.

Traditional ventilation systems rely on manual controls or fixed schedules, often leading to energy inefficiencies and suboptimal indoor air quality. These systems may not respond effectively to changing environmental conditions like temperature, humidity, or occupancy. In contrast, automated ventilation systems use sensors to monitor real-time data and adjust window openings and ventilation accordingly, ensuring optimal air quality and energy efficiency. These systems also offer added convenience through IoT integration and remote control, while their dual power source (battery and solar) promotes sustainability. Compared to traditional systems, automated solutions provide a more dynamic, energy-efficient, and user-friendly approach to maintaining a comfortable indoor environment.

COMPARISON TABLE: TRADITIONAL VS AUTOMATED WINDOW SYSTEM

FEATURE	TRADITIONAL WINDOW SYSTEM	AUTOMATED WINDOW SYSTEM
OPERATION & CONTROL	Manual	Automatic + Bluetooth/manual override
ENVIRONMENTAL SENSING	Not responsive to environment	Senses air quality, temperature, rain, etc.
SAFETY FEATURES	No detection for fire or gas leaks	Includes gas, flame sensors + buzzer
POWER SOURCE	No dedicated power system	Solar or rechargeable battery powered
SMART COMPATIBILITY	Not smart-home compatible	Ready for smart city & IoT integration

Fig.5. Comparison Table for Traditional Vs Automated Ventilation System.

V. FUTURE SCOPE

While the current prototype successfully demonstrates automated environmental control with basic safety and user interaction features, several enhancements can be made to improve scalability, intelligence, and real-world application

1) Wi-Fi and IoT Integration: Replacing the HC-05 Bluetooth module with a Wi-Fi-enabled microcontroller like ESP32 can enable remote access, cloud data storage, and integration with smart home platforms (e.g., Blynk, Google Home, or Alexa).
2) Mobile App with GUI: Developing a dedicated mobile application with a user-friendly graphical interface would allow real-time monitoring, historical data tracking, and customized alert settings.AI-Based Blood Collection Assistance – Implement AI powered feedback systems to analyze finger placement, predict optimal prick locations, and provide real-time guidance for improved efficiency.
3) AI-Based Decision Making: Machine learning algorithms could be integrated to adapt window behaviour based on user preferences, time of day, or historical environmental data.
4) Solar Energy Optimization: An improved solar charging system with MPPT (Maximum Power Point Tracking) could make the system more energy-efficient and fully self-sustainable.
5) Weather Forecast Integration: Fetching live weather data through APIs could allow the system to act pre-emptively (e.g., closing windows before rain starts).
6) Voice Control: Integration with voice assistants like Alexa or Google Assistant would add hands-free interaction.
7) Scalability to Larger Systems: The model can be scaled for use in commercial buildings, schools, hospitals, or agricultural storage units where ventilation and safety are critical.

VI. CONCLUSION

The Automated Window and Ventilation System successfully demonstrates the integration of sensors and control systems to optimize indoor air quality, temperature, and humidity. By automating the opening and closing of windows and activating ventilation based on environmental conditions, the system enhances comfort, reduces energy consumption, and supports a healthier living environment. It offers a practical solution for modern buildings seeking energy-efficient and smart home technologies.

Furthermore, the system contributes to energy efficiency by ensuring that natural ventilation is utilized when conditions are favourable, potentially reducing the dependency on air conditioning systems. This not only helps lower electricity consumption but also supports environmentally sustainable living. The modularity and adaptability of the system mean it can be implemented in a variety of settings, from residential buildings to educational institutions and office spaces.

From a technological perspective, this project demonstrates the effective application of embedded systems, IoT principles, and automation in addressing real-world problems. It encourages a shift towards smarter and more responsive living environments and aligns well with the global push for smart cities and sustainable building solutions.

In summary, the Automated Window and Ventilation System is a forward-thinking project that merges convenience, efficiency, and sustainability, paving the way for more intelligent and eco-conscious infrastructure.

VII. ACKNOWLEDGMENT

We would like to thank Vishwakarma Institute of Technology and the department of Instrumentation and Control Engineering for providing us with the necessary resources, laboratory facilities, and research support to carry out our work effectively. In order to complete this model, I extend my sincere appreciation to our guide and advisor, Professor Vikas Nandeshwar for his invaluable guidance, constant encouragement, and insightful suggestions. I am also incredibly grateful to my teammates, whose dedication, collaboration, and hard work made this research possible. The willingness to brainstorm ideas, solve challenges, and contribute tirelessly to various aspects of the paper has been truly commendable. This journey would not have been the same without all these efforts and enthusiasm.

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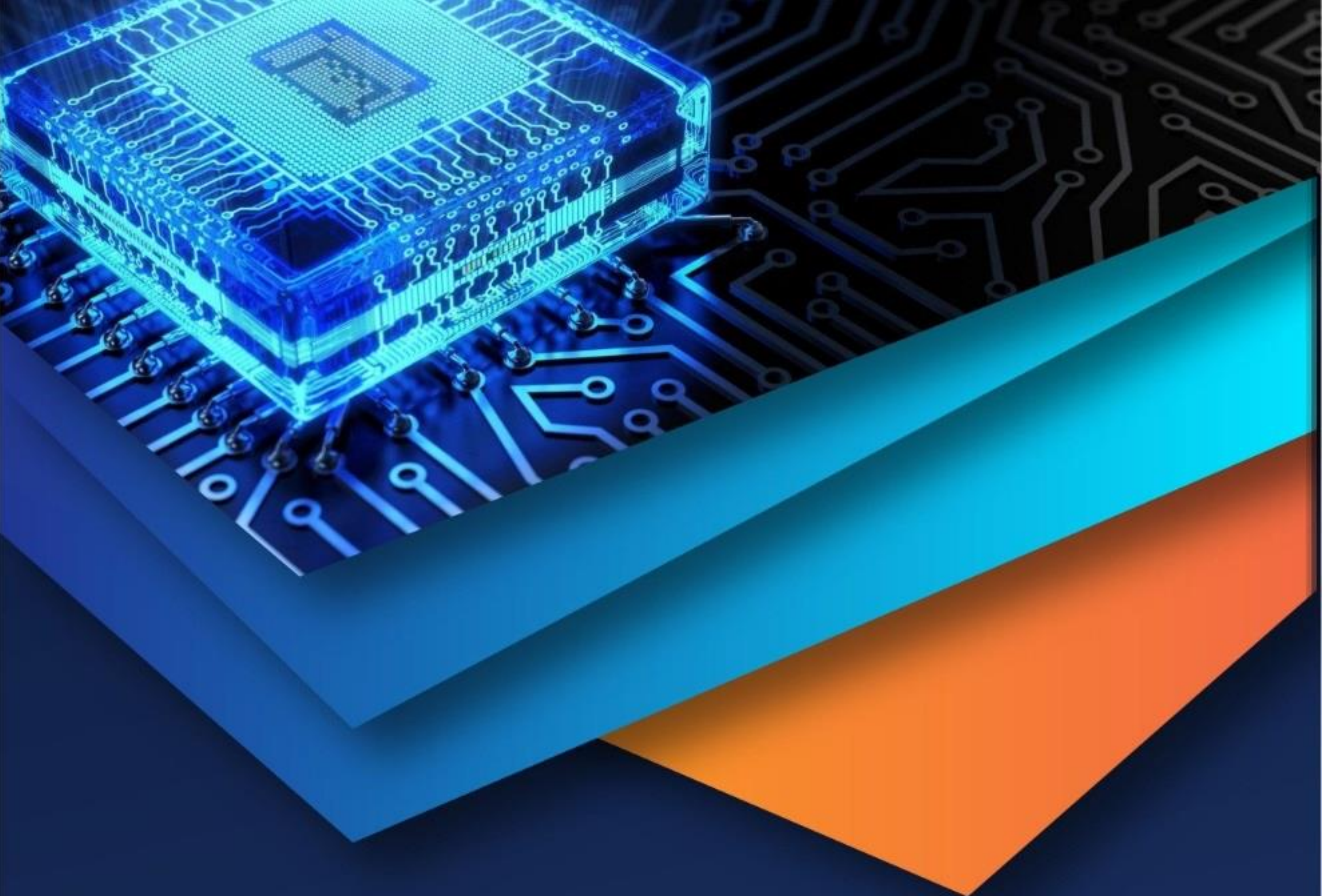

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