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Design and Development of Dehumidification System for Indian Railways Sanitary Compartments

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Abstract

In the context of improving sanitation and passenger experience in Indian Railways, this project focuses on the implementation of dehumidifier technology in train toilets to address issues related to excess water accumulation on the floor, foul odours, and unhygienic conditions. The persistent challenge of maintaining clean and dry toilet facilities within the railway network necessitates innovative solutions to enhance passenger comfort and well-being. The proposed project aims to integrate dehumidifiers strategically within train toilet compartments to actively remove excess moisture, preventing the formation of stagnant water and minimizing the potential for foul odours. Dehumidification technology will be employed to create a more sanitary environment by efficiently extracting moisture from the air, thereby reducing the breeding ground for bacteria and unpleasant smells. Additionally, the project seeks to explore the use of environmentally friendly and energy-efficient dehumidifier units to align with sustainable practices.

Keywords: *Railways, Dehumidifier, Sanitation, Foul odour, Moisture, Sustainability.*

1. INTRODUCTION

India's extensive railway network, often referred to as the "lifeline of the nation," serves as the backbone of the country's transportation system, facilitating the movement of millions of passengers daily. While the Indian Railways has made significant strides in various aspects of its service, the issue of maintaining clean and hygienic toilet facilities remains a persistent challenge. The damp and humid conditions in these toilets not only compromise passenger comfort but also raise concerns regarding health and sanitation. The Indian Railways, catering to millions daily, faces a daunting task in maintaining sanitation standards. Until the late 2010s, it relied heavily on old Integral Coach Factory (ICF) coaches, which, despite lacking modern amenities, boasted larger toilet areas. Surprisingly, these spacious layouts inadvertently contributed to drier toilet conditions, a vital aspect of sanitation. The ample space facilitated better air circulation, helping to reduce moisture and unpleasant odours. Furthermore, features like flaps and exhaust fans, common in these older coaches, aided in ventilation, enhancing overall hygiene. While lacking in insulation for noise and air, the older coaches inadvertently addressed sanitation challenges through their design, highlighting the pragmatic solutions borne out of necessity.

The sanitation challenges faced by Indian Railways, stemming from heavy usage and a large population, necessitate innovative solutions to ensure optimal comfort and hygiene for passengers. Traditional cleaning efforts, while essential, often struggle to keep pace with the high demand and frequent use of sanitary compartments. As a result, moist and wet toilets become common issues, leading to discomfort and unhygienic conditions for passengers.

Our project proposes the implementation of an integrated dehumidification system within the sanitary compartments of trains to address this pressing issue effectively. By strategically placing dehumidifiers within these compartments, excess moisture in the air will be extracted, preventing the buildup of mold, mildew, and unpleasant odours. This technology not only ensures drier and cleaner sanitary compartments but also significantly improves the overall comfort and satisfaction of passengers.

The transition to modern LHB coaches by Indian Railways represents a significant upgrade in passenger amenities, with sanitary compartments boasting advanced features like Electro-Pneumatic flush systems, hand soap dispensers, and jet sprays for improved hygiene. Despite these advancements, challenges persist due to the difficulty in effectively managing excess moisture, often resulting in foul odours and unhygienic conditions within the toilets. Our project aims to address this issue by implementing a comprehensive moisture removal system tailored to the specific requirements of LHB coach sanitary compartments. By utilizing efficient dehumidifiers or similar technology, we intend to extract excess moisture from the air, thereby ensuring a drier and more hygienic environment. This proactive approach not only enhances passenger comfort and safety but also aligns with Indian Railways' commitment to providing top-tier amenities and maintaining high sanitation standards throughout their modernized fleet.

2. LITERATURE REVIEW

Sanitation plays a crucial role in development interventions, encompassing the provision of facilities for the proper disposal of human waste to maintain hygienic conditions. Inadequate sanitation leads to various diseases such as diarrhea, dysentery, and malaria. The Indian Railways, operating as one of the world's most densely utilized train systems, faces significant sanitation challenges, affecting its image and progress. The existing toilet system, discharging waste directly onto railway tracks, poses hygienic and environmental concerns, including contamination of water sources and the spread of diseases to nearby settlements. This paper proposes a solution to address these challenges by collecting and processing human waste from railways to generate fertilizers and biogas. The resulting biogas can be used to generate electricity, benefiting railway stations and nearby households [1].

Indian Railways (IR) is a major consumer of electricity in India, utilizing it for various purposes such as running trains, illuminating platforms, compartments, tracks, and for traffic signalling. With a current power demand of 2000 MW, the transition to 100% electrified broad-gauge tracks will increase this demand to 3400 MW. To address this, energy conservation is essential. Formerly, lighting systems on railways relied on incandescent bulbs, fluorescent tubes, HPMV lamps, metal halide lamps, and HPSV lamps. However, LEDs have emerged as a more energy-efficient alternative, widely adopted in stations, service buildings, and residential premises. This article discusses the current energy consumption scenario in Indian Railways, initiatives to reduce consumption, and the role of energy conservation, particularly focusing on the transition to LED lighting systems [2].

Air dehumidification is increasingly recognized for its role in enhancing air quality and ensuring thermal comfort. A notable advancement in this field is the membrane-based technology, which operates on the principle of water vapor transmembrane transport driven by mass transfer potential, coupled with sensible heat transfer due to temperature differences. This approach has found applications in various sectors including heating, ventilation, and air conditioning (HVAC), compressed air dehumidification, environmental control in space vehicles, and other engineering domains [3].

The experiment aimed to assess how humidity affects human comfort and productivity during transitions from hot and humid to neutral environments. Participants experienced different humidity levels (30%, 40%, 50%, and 70%RH) in Chamber 2 after initial exposure to 30°C/70%RH air in Chamber 1. Despite no significant differences in thermal sensation, low humidity was found to enhance subjective pleasantness due to increased evaporation from the body. Subjective performance remained consistent across conditions, but participants reported feeling more tired at 70%RH after the humidity change. These findings highlight the importance of humidity control for maintaining comfort and productivity during environmental transitions[4].

Wind energy has seen rapid growth since 2000, with Horizontal Axis Wind Turbines (HAWTs) dominant in large-scale projects but less effective in urban areas. Vertical Axis Wind Turbines (VAWTs) are gaining traction for urban and semi-urban settings due to their performance in weak winds, noise-free operation, and aesthetic integration. This review paper focuses on VAWT development and integration into urban infrastructure, emphasizing key advancements and recommendations for future research to make VAWTs a viable and affordable power generation option for urban areas [5].

This paper reviews Savonius wind turbines, offering an alternative to conventional models with advantages such as simple construction, omnidirectional wind acceptance, and low noise. Various rotor configurations impact performance, with reported power coefficient values ranging from 0.05 to 0.30. Potential performance enhancements of up to 50% have been achieved with the use of stators. The article aims to provide useful insights for future studies on Savonius turbine performance [6]. The objectives of this paper are i) Analyzing the current trends used in IR for integration of Dehumidifier technology with the Toilets. ii) Increasing the Efficiency and Dehumidification Rate of the Compartment, and iii) Design of Dehumidification system for the Railway Sanitary Compartments.

3. METHODOLOGY

We conduct research and analyze various Research Papers, that provide with a sufficient data about the current technologies and trends that are used in the Indian Railway Systems. This includes the study of various types of toilet systems used in IR, steps taken for good drainage systems and hygiene by the IR, and the utmost need to clear the stagnant water on the floors of the sanitary compartments, that result in foul smell and unhealthy environment. We try to create a Model that will depict the actual working of the Dehumidification system in the Railway Sanitary compartments with the accurate values of calculation, giving a brief idea about how the technology integrates and if the Railways can consider it to be in their ternary of services.

Our process is demonstrated below:

a) When a passenger flushes the toilet, it activates the Arduino board.
b) The Arduino board runs a program that controls the sequence of events, that includes the running of the Dehumidifier and the exhaust fan.
c) The program activates the relay module, which switches on the cycle.
d) The cycle starts with the dehumidifier spreading hot air over the surface, facilitating drying.
e) The program also initiates the exhaust fan to run for a set time, likely to remove moisture-laden air from the area.
f) Once the set time for the exhaust fan has elapsed, the cycle completes, and the program stops until another flush activates it again.

This system seems designed to maintain hygiene and prevent moisture buildup in the toilet area by automatically initiating a drying cycle after each use.

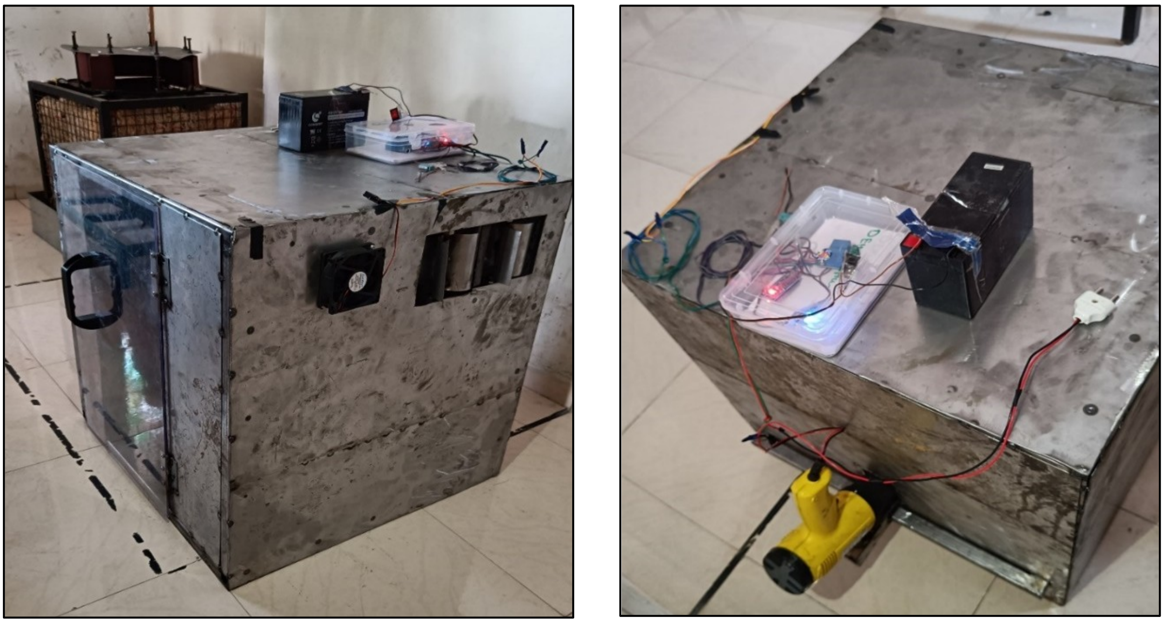

Figure: 01 Actual Model and its detail Connections

4. EXPERIMENTAL CALCULATIONS

The evaporation rate of water is directly proportional to the surface area exposed and the dehumidifier's capacity. Relative humidity represents the ratio of saturation pressure at the water surface to the saturated water vapor pressure, indicating air's moisture content. Higher humidity inhibits evaporation due to decreased vapor pressure differential.

4.1 Required Design Calculations

(Standard and Proportionate calculation of actual design and conditions)

Required parameters:

1. Temperature = 30 °C
2. The Appropriate Activity factor (Fa) = 1.00 (For high-moist region)
3. Surface area (A) = Length × Breadth = 0.989 m × 1.144 m = 1.13 m sq.
4. Saturation Pressure (Pw) = 0.0425 (for 30°C from ASHRAE Table)
5. Saturation Pressure at Room Air due point (Pa) = 0.0255 (60% at 30°C)

a) (All these values are considered and calculated using the above table and Formulae)

Dehumidifier Capacity Calculation (W): W = Evaporation Rate in kg/hr or lit/hr

$$W = 15 \times [A \times (Pw - Pa) \times Fa]$$

$$= 15 \times [\,1.13 \times (0.0425 - 0.0255)]$$

$$= 0.28815\ lit/hr.$$

$$= 0.3\ lit/hr.$$

The Evaporation Rate is 0.3 lit/hr.

4.2. Performance Calculations

Coefficient of Performance:

COP = (Heat Extracted)/(Work Done) = Output/Input

= Q/W

Q = Flow of Heat Energy through a defined area over a defined time

Specific Heat Capacity → q = m c ΔT

where,

m = mass (gm)

c = J / gm °C

ΔT = °C

$\Delta T = T_f - T_i$

Q) How much energy is required to Heat 50g of water from 20 °C to 80 °C? The specific heat capacity of water is 4.184 J / g °C.

C_{H2O} = Specific Heat capacity of Water = 4.184 J / g °C[If one gm of water is taken, it requires 4.184 J energy to heat by 1 °C]

Temp 1 = 27 °C

Temp 2 = 101 °C

C_{H2O} = 4.184 J / g °C

m = 15 g

$q = m\,c\,\Delta T$

q = 15 gm × 4.184 J / gm °C × (101 – 27) °C

q = 4644.24 J

[Work done = F × d]

Work is defined as the product of Force (F) applied over a distance (d) in the direction of the applied force. In case of electrical appliances like hair-dryer, the work done is in the form of energy transfer, converting electrical energy into another forms like heat and kinetic energy of air.

Energy consumption = Power (p) × time (t)

E = 1000 W × 30 sec (cycle time)

E = 30000 Joules

So, the hairdryer consumes 30000 Joules of energy when operated for 1 hour.

COP = q/E = 0.1548

Efficiency:

= Output/Input = (15 gm)/(30 sec)

1 hour → 0.3 lit

60 min → 0.3 lit

60 × 60 sec → 0.3 lit

1 sec → x lit

According to the Experimental setup:

Water evaporated in 120 sec = 15 ml

1 sec = x ml

15/120 = x ml

Water evaporated in 1 sec = 0.125 ml

Cycle Time = 30 sec

= $30 \times 0.125 = 3.75$ ml

Evaporation rate = $3.75 \times 2 \times 60 = 450$ ml / hr.

Evaporation rate is 0.45 lit/hr.

5. RESULT AND DISCUSSION

Here is the comparison between the theoretical and experimental setups in terms of their evaporation rates and how it impacts efficiency.

Evaporation Rate Comparison

- The theoretical evaporation rate is stated as 0.3 liters per hour.
- The experimental setup, however, exhibits a higher evaporation rate of 0.45 liters per hour.

Efficiency Implications

- The higher evaporation rate of the experimental setup indicates that it is more effective at removing moisture from the system compared to the theoretical model.
- With a faster evaporation rate, the cycle time required for completing a certain task or process is reduced. This means products can be produced or tasks completed more quickly, leading to higher overall efficiency.

Factors Affecting Efficiency

- The efficiency of an evaporation setup can be influenced by various factors such as temperature, surface area, airflow, and the properties of the liquid being evaporated.

Potential Applications

- The increased efficiency provided by the experimental setup could be beneficial in a range of industries such as food processing, chemical manufacturing, wastewater treatment, and pharmaceutical production, where evaporation processes are common.
- Faster evaporation rates can lead to increased throughput, reduced production costs, and improved product quality in these applications. In conclusion, the experimental setup's higher evaporation rate signifies its superiority over the theoretical model in terms of efficiency. This improved efficiency can have significant implications for various industrial processes, potentially leading to cost savings, increased productivity, and better overall performance.

6. CONCLUSION

The project's completion achieved drier sanitary compartments, mitigating foul odours and improving passenger experience. Enhanced hygiene contributes to passenger satisfaction and bolsters the railway's reputation. This advancement marks a significant stride in elevating sanitation standards, fostering comfort, and instilling confidence in the railway system among passengers.

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Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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