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(RESEARCH ARTICLE)

Development of Fault Simulator for Refrigeration System Diagnostics

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Abstract

This study developed and evaluated a fault simulator for refrigeration systems to improve the diagnostic and troubleshooting skills of learners at Palamon Institute of Technology. Addressing the lack of instructional tools that replicate real-world refrigeration and air conditioning (RAC) faults in TESDA- and CHED-regulated institutions, the project used a developmental-descriptive research design with 30 students, three instructors, and two technicians as respondents. Results showed a significant improvement in student performance, with mean test scores rising from 68.5% to 89.4%, confirmed by a paired t-test ($t = 60.25$, $p < 0.05$). The simulator also received "Very Acceptable" ratings for usability (mean = 4.59) and acceptability (mean = 4.61). These findings validate the simulator's effectiveness and practicality as a training tool for refrigeration and air conditioning education.

Keywords: Refrigeration System; Fault Simulator; Instructional Tool; Heat Pumps; System Identification

1. Introduction

Refrigeration and air conditioning (RAC) systems were indispensable in food preservation, industrial processes, and comfort applications. In the Philippines, the demand for skilled RAC technicians continued to grow as urbanization and economic development increased reliance on cooling technologies. To address this demand, institutions under TESDA and CHED were mandated to ensure graduates were equipped with relevant competencies, particularly in diagnosing and troubleshooting technical issues (CHED, 2021; TESDA, 2020).

Although existing RAC training programs emphasized hands-on practice, most training devices only demonstrated ideal operations and failed to replicate realistic system faults. A system made up of recycled components of a refrigeration unit and locally available materials was also developed, which was capable of recovering refrigerant gas (Baldos, 2014). Simulation-based learning addressed this gap by replicating authentic system faults in controlled environments. Numerous studies confirmed that fault simulators improved learners' diagnostic skills and technical understanding (Behfar and Yuill, 2018). However, imported simulators remained costly and inaccessible to many Philippine institutions, which limited their integration into RAC education.

The development of locally made simulators presented a viable alternative (Baldos, 2014). Prior initiatives in electrical (Pereyras, 2020) showed that low-cost, effective simulators could enhance technical training. Furthermore, advances in educational technology highlighted the value of simulation-based learning strategies in improving student outcomes. These findings emphasized the importance of designing a cost-effective, locally developed RAC fault simulator that bridged existing gaps in training while remaining accessible to institutions. This paper presented the design, development, and evaluation of a fault simulator for refrigeration systems that was affordable, replicable, and aligned with TESDA's RAC NC II curriculum.

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2. Methodology

The study adopted a developmental research design. The process involved designing, fabricating, testing, and evaluating a refrigeration fault simulator. Participants included 30 HVAC students, 3 instructors, and 2 refrigeration technicians, selected purposively for their expertise and relevance. Students undertook pre- and post-tests to measure skill improvement. Experts completed evaluation forms on acceptability and usability. Descriptive statistics summarized evaluations, while a paired t-test determined the significance of learning improvements.

3. Results and Discussion

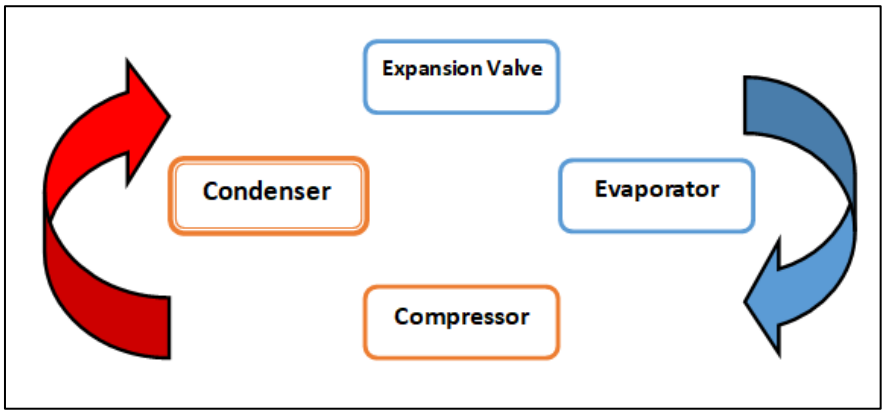

Figure 1 Fault Simulator Refrigeration System

Based on the findings in a fault simulator was designed to reflect a basic refrigeration cycle with components. The trainer includes evaporator, condenser, access valves, pressure gauges, thermostat, and fans (figure 1).

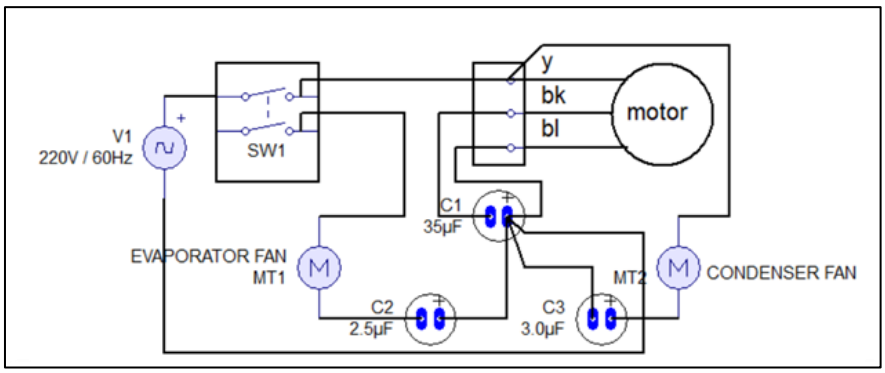

Figure 2 Schematic Wiring Diagram of Fault Simulator

These features allow users to simulate faults such as undercharge, overcharge, electrical failure, and pressure differences. The schematic wiring diagram of Fault simulator refrigeration system (figure 2). The design was developed to be modular, replicable, and aligned with the learning outcomes of TESDA's RAC NC II program.

3.1. Common faults

Experts identified refrigerant undercharge (100%), electrical faults (93%), overcharge (93%), blocked filter-drier (87%), and pressure imbalance (87%) as the most critical to include.

3.2. Simulator design

The simulator replicated a standard RAC cycle with condenser, evaporator, access valves, gauges, and thermostat, designed for modularity and low cost.

3.3. Effectiveness testing

Table 1 Summary of Pre-Test and Post-Test Results and Paired Sample t-Test Results

Test Type	Mean Score (%)	Highest Score (%)	Lowest Score (%)	Standard Deviation
Pre-Test	68.5	72	64	±1.9
Post-Test	89.4	92	85	±1.8
Score Improvement	+20.9	+25	+18	±1.9
Metric		T-Value		
Pre-Test Mean		68.5%		
Post-Test Mean		89.4%		
Mean Improvement		20.9%		
Standard Deviation		±1.9		
t-Statistic		60.25		
Degrees of Freedom		29		
p-value		< 0.05 (very significant)		

The 20.9% improvement was statistically significant ($t = 60.25$, $p < 0.05$).

3.4. Acceptability and usability

Table 2 Acceptability and Usability Ratings by Respondents

Dimensions	Instructors (n = 3)	Students (n = 30)	Technicians (n = 2)	Overall Mean	Descriptive Rating
Acceptability	4.70	4.55	4.80	4.61	Very Acceptable
Usability	4.70	4.56	4.70	4.59	Very Acceptable

Both dimensions were rated "Very Acceptable."

4. Conclusion

The developed fault simulator significantly improved students' troubleshooting performance, as evidenced by the substantial increase in mean test scores from 68.5% to 89.4% after its use. Statistical analysis confirmed this improvement to be highly significant ($t = 60.25$, $p < 0.05$), demonstrating the simulator's effectiveness in enhancing diagnostic skills and technical understanding of refrigeration system faults. In addition, the simulator was rated highly acceptable and usable by all respondent groups, with mean ratings of 4.61 for acceptability and 4.59 for usability, both within the "Very Acceptable" range. These positive evaluations highlight its functionality, ease of use, safety, and instructional value, further confirming its potential for integration into the Bachelor of Industrial Technology–HVAC Program of Palamon Institute of Technology. Overall, the study affirms that the simulator is a practical and effective tool for advancing technical training in refrigeration and air conditioning education

Compliance with ethical standards

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Disclosure of conflict of interest

No conflict of interest to be disclosed.

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