Vol. 15, No. 1 (2026): 19 - 32 http://dx.doi.org/10.23960/jtepl.v15i1.19-32

JURNAL TEKNIK PERTANIAN LAMPUNG

ISSN 2302-559X (print) / 2549-0818 (online)
Journal homepage : https://jurnal.fp.unila.ac.id/index.php/JTP

Design and Development of a Web-Based Thermal Application for Vapor Compression Refrigeration Systems

Ratu Yanra Dewi[1], Muhamad Yulianto[1,2,✉], Mohamad Solahudin[1], Leopold Oscar Nelwan[1], Ida Afriliana[2], Roni Darpono[3], N. Nasruddin[4]

[1] Department of Agriculture and Biosystems Engineering, Faculty of Engineering and Technology, IPB University, Bogor, West Java Indonesia.
[2] Department of Mechanical Engineering, Faculty of Engineering and Technology, IPB University, Bogor, West Java, Indonesia.
[3] Departement of Computer Engineering, Vocational School Faculty, Harkat Negeri University, Tegal, Central Java, Indonesia.
[4] Departement of Electrical Engineering, Vocational School Faculty, Harkat Negeri University, Tegal, Central Java, Indonesia.
[5] Department of Mechanical Engineering, Faculty of Engineering, Universitas Indonesia, Depok, West Java, Indonesia.

Article History:

Received : 25 September 2025
Revised : 27 January 2026
Accepted : 27 January 2026

Keywords:

Cold Storage Design Application,
Digital Twin Technology,
Life Cycle Climate Performance,
Refrigeration System,
Web-Based Thermal Simulation

Corresponding Author:
✉muhamad_yulianto@apps.ipb.ac.id
(Muhamad Yulianto)

ABSTRACT

The growth of the global food industry has led to an increased demand for cold storage systems to maintain product quality. Cold storage systems based on the vapor compression cycle offer high energy efficiency. However, their design involves multiple stages, ranging from cooling load calculations to prototype development for performance evaluation. This study integrates digital twin–based thermal simulation with Life Cycle Climate Performance (LCCP) analysis into a single web-based platform, namely THE POCI, for cold storage design. The application allows system design, performance calculation, and estimation of the system emission. The development process followed the System Development Life Cycle (SDLC) methodology. Functional testing was conducted using Black-box Testing, while user evaluation was performed using the System Usability Scale (SUS). The results show that all modules provide the expected information and can be used effectively. Model validation against experimental data resulted in Mean Absolute Percentage Error (MAPE) values of 11% for compressor power, 17% for cooling capacity, and 14% for the coefficient of performance (COP). User evaluation involving 47 respondents across the four modules yielded a SUS score of 64.41, indicating that the application is well accepted and has an adequate level of usability.

1. INTRODUCTION

The growth of global industries, especially in the sectors of food, pharmaceutical, and cold chain logistics, has increased the demand for refrigeration systems. Low temperature and freezing processes are needed to maintain product quality during storage and distribution (Tassou *et al.*, 2010; Dhanya *et al.*, 2023; Khan *et al.*, 2023). Maintaining temperature conditions is crucial to preserve product quality and also to reduce spoilage, prevent microbial growth, and extend shelf life, which are essential factors in ensuring food safety (Smith *et al.*, 1994; Vaishali *et al.*, 2020; Lee *et al.*, 2021). Cold storage systems based on vapor compression refrigeration cycles remain the most widely used solutions due to their high efficiency and reliability (Ma *et al.*, 2017; IIFIIR, 2019).

However, to build a cold storage facility is not a straightforward process. Designing the refrigeration system involves several technical stages, including cooling load calculations, determining system capacity and components, and prototyping to validate the system's performance before full-scale operation (Bodys *et al.*, 2018; Yohannes *et al.*, 2018; Lauff *et al.*, 2019; Setyawan *et al.*, 2021). These stages require significant time and financial resources. The time-consuming and high cost of design and prototype testing pose major obstacles, especially when the system needs to be customized to specific products or storage conditions. These challenges can delay project timelines and increase investment risks.

To overcome these issues, digital simulation approaches have emerged as effective alternatives. Currently, various thermal simulation applications assist in thermodynamic analysis during the design process. However, most available thermal tools are standalone software requiring installation and technical expertise. Web-based applications offer advantages in accessibility and convenience by enabling users to perform calculations and simulations directly through browsers without specialized software installations and with internet connectivity (Purwanto & Kuswandi, 2017; Singh *et al.*, 2020; Wahyuni *et al.*, 2023). This accessibility expands the reach to a broader range of users and simplifies the design process, potentially reduce the reliance on physical prototyping, and cut down time and costs.

This research adopts the concept of Digital Twin Technology, which creates a virtual replica of a physical system allowing for in-depth analysis, simulation, and optimization in a virtual environment (Ruzsa, 2020; Soori *et al*., 2023). Digital twin models provide the flexibility to explore various operational scenarios and system configurations without risking material loss or damage due to design errors (Byrne *et al*., 2010). Such an approach not only accelerates the design process but also improves the accuracy and reliability of the system before actual construction.

Moreover, vapor compression refrigeration systems contribute to environmental concerns. Direct emissions from refrigerants and indirect emissions from electricity consumption are significant contributors to global warming. Many refrigerants contain Ozone-Depleting Substances (ODS), which harm the ozone layer, while electricity consumption leads to carbon emissions (Harby, 2017; Islam *et al.*, 2021; Jones *et al*., 2022). Therefore, environmental impact assessment is crucial in refrigeration system design.

The Life Cycle Climate Performance (LCCP) method provides a comprehensive evaluation of environmental impact throughout the system's lifespan, considering both direct and indirect emissions related to HVAC-R systems (Lee *et al.*, 2016; Yulianto *et al.*, 2022; Dubey *et al.*, 2024; Suhengki *et al.*, 2024).

Despite the rapid development of thermal simulation and digital twin technologies, most available software primarily focuses on system performance analysis and operates as standalone applications, requiring local installation and limiting accessibility. Moreover, these tools generally do not integrate environmental impact assessment, particularly Life Cycle Climate Performance (LCCP), into the early design stage. To address these gaps, this study proposes THE POCI, a web-based thermal simulation application that integrates digital twin concepts with refrigeration performance analysis and LCCP evaluation. Although many HVAC-R manufacturers and principals offer free design tools, they are often limited to specific brands, proprietary equipment, or predefined system configurations. In contrast, THE POCI is designed as an open and flexible platform that supports a broader range of design scenarios and enables users to perform cooling load calculations, system performance simulations, energy consumption estimations, and environmental impact assessments through a single web platform accessible across devices. Therefore, THE POCI provides a more versatile and integrated solution for early-stage design and decision-making in cold storage refrigeration systems.

2. MATERIALS AND METHODS

2.1. Materials

This research was conducted at the Refrigeration Laboratory, Department of Mechanical and Biosystems Engineering, IPB University. The study was carried out from August 2024 to March 2025.

Research materials involved hardware and softwares. The main hardware used in this research was an MSI Notebook GF63 Thin 11UCX equipped with an 11th Generation Intel® Core™ i7 processor. This specification was sufficient to support web-based application development and computational analysis. Several software programs were installed on hardware devices and used to develop applications, as shown in Table 1.

2.2. Methods

This research developed Thermal Energy and Power Integrated (THE POCI), a web-based application for design, performance simulation, and emission estimation of thermal systems. The application was developed using the SDLC

Table 1. Programming Languages and Applications Specification

Language / Application	Version	Role
Visual Studio Code	1.102.3	A code editor used for all programming languages
XAMPP	V3.3.0	Local server for running web applications
Google Chrome	138.0.7204.184	Browser used for interface testing
Microsoft Edge	139.0.3405.86	Alternative browser used for interface testing
Refprop	v10	Provides thermodynamic property data of refrigerants
phpMyAdmin	10.4.32-MariaDB	Graphical interface for MySQL database management
HTML	v2.0.13	Defines the basic structure of the user interface
CSS	v2.0.13	Styles and arranges layout of UI elements
JavaScript	-	Adds interactivity to the user interface
PHP	v1.0.3	Handles backend logic and database CRUD operations
Python	v1.7.0	Performs technical calculations and data processing

(Software Development Life Cycle) method, which is a structured process model for designing, developing, and delivering software products (Shylesh, 2017). This method allows for a flexible and iterative process (Ghanghro *et al.*, 2021). The SDLC stages applied as depicted in Figure 1.

During application development, errors can occur that require repeating certain processes. Figure 2 shows the flow of THE POCI application development using the SDLC method.

2.3. System Investigation

The system investigation phase aimed to identify application requirements and system objectives. This phase was conducted through literature review and observation to determine the type of thermal system to be modeled, target users, and development procedures. The outputs of this phase served as the basis for subsequent system analysis and application design. Based on observations and a literature review, the adopted system is a vapor compression refrigeration system, recognized for its high efficiency (She *et al.*, 2018). The target users of this system are workers or engineers who are responsible for managing, maintaining, and implementing the systems according to specific environmental needs (Soori *et al.*, 2023).

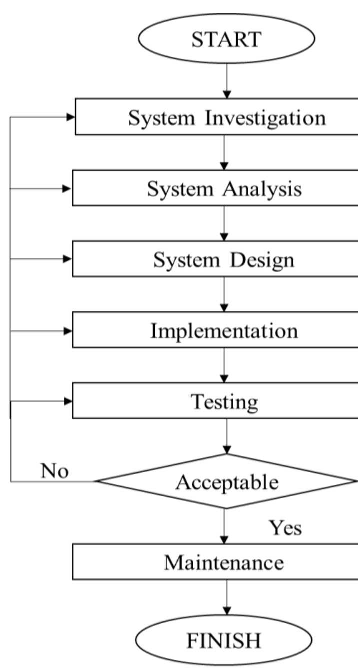

Figure 1. SDLC method

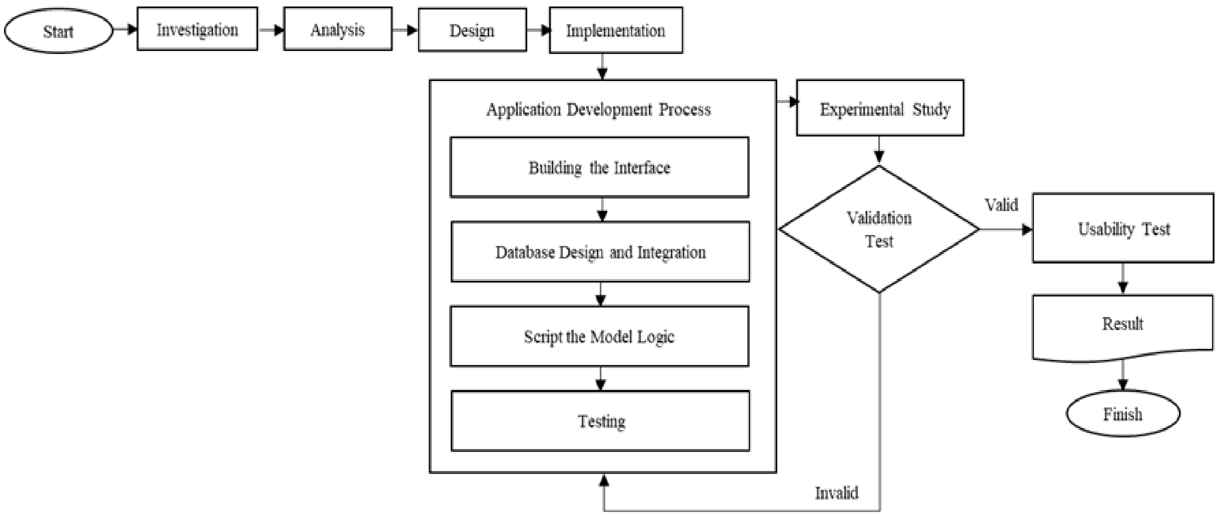

Figure 2. THE POCI development procedure

2.4. System Analysis

System analysis was conducted to evaluate the thermal performance and environmental impact of the proposed refrigeration system. Thermal analysis aims to determine the total cooling load required by the refrigeration system. The total cooling load is defined as the sum of all cooling loads acting on the system, including internal loads, external transmission loads, and infiltration loads. Internal loads are primarily generated by the products (Q_p) stored in the refrigerated space and consist of sensible heat load (Q_s) and latent heat load (Q_l) (Yohannes *et al*., 2018; Dhumane *et al.*, 2021). Mathematically, the total product load can be expressed as:

$$Q_p = Q_s + Q_l \quad (1)$$

The sensible heat load is calculated based on the product mass (*m*), the specific heat capacity of the product (C_p), the temperature difference between the initial temperature and the target temperature (ΔT), and the required cooling time (*t*) (She *et al.*, 2018; Cengel, 2019). It is expressed as:

$$Q_s = \frac{m \cdot C_p \cdot (\Delta T)}{t} \quad (2)$$

The latent heat load is calculated based on the product mass (*m*), the latent heat of the product (*L*), and the target cooling time (*t*), as expressed by:

$$Q_l = \frac{m \cdot L}{t} \quad (3)$$

The freezing load is calculated when a certain mass of product (*m*) is below the freezing point and all heat has been completely removed. This load considers the specific heat of the frozen product (C_{pf}) and the temperature difference before and after freezing (ΔT) as presented in Equation (4).

$$Q_f = \frac{m \cdot C_{pf} \cdot (\Delta T)}{t} \quad (4)$$

The external load is represented by heat transmission through the wall (Q_w), calculated using thermal resistance as seen in Equation (5) (Holman, 1999). The infiltration load (Q_i) caused by door opening during operation is calculated using Equation (6) (Cengel, 2019). The total cooling load is obtained by summing all heat loads as in Equation (7).

$$Q_w = \frac{\Delta T}{\Sigma R_{th}} \quad (5)$$

$$Q_i = v \cdot A(h_i - h_r) \cdot \rho_r \cdot D_t \quad (6)$$

$$Q_t = Q_p + Q_w + Q_i \quad (7)$$

After the total cooling load is determined, an analysis of the cooling system is conducted, which includes several key parameters. Compressor power (W_{comp}) is defined as the energy required for the compression process and is calculated by multiplying the refrigerant mass flow rate by the enthalpy change during compression (Yohannes *et al*., 2018; Cengel, 2019):

$$W_{comp} = \dot{m}\,(h_2 - h_1) \tag{8}$$

Heat rejected (Q_h) represents the heat released by the refrigerant during the condensation process, expressed in Equation (9) (Strommer *et al.*, 2016; Constantino & Kanizawa, 2022; Naduvilakath-Mohammed *et al.*, 2024):

$$Q_h = \dot{m}\,(h_2 - h_3) \tag{9}$$

Cooling capacity (Q_e) is calculated based on the refrigeration effect, which is the enthalpy difference of the refrigerant entering and leaving the evaporator (Cengel, 2019). While, COP is defined as the ratio of cooling capacity to compressor power (İşkan *et al.* 2021) and is formulated in Equation (11).

$$Q_e = \dot{m}\,(h_1 - h_4) \tag{10}$$

$$COP = \frac{Qe}{Wc} = \frac{\dot{m}\,(h_1 - h_2)}{\dot{m}\,(h_2 - h_1)} \tag{11}$$

Furthermore, environmental impact was assessed using the Life Cycle Climate performance (LCCP) approach, considering both direct and indirect emissions throughout the system lifecycle (IIFIIR, 2016; Yulianto *et al.*, 2022). Direct emissions are associated with refrigerant leakage during operation and at the end of the system's lifetime, and are calculated as the following:

$$\text{Direct Emission} : C \times (L \times ALR + EOL) \times (GWP + Adp.GWP) \tag{12}$$

Indirect emissions originate from energy consumption during system operation as well as emissions related to material production, recycling, and refrigerant manufacturing and disposal. These emissions are calculated as follows:

$$L \times AEC \times EM + \sum(m \times MM) + \sum(mr \times RM) + C \times (1 + L \times ALR) \times RFM + C \times (1 - EOL) \times RFD \tag{13}$$

2.5. Testing, Data Collection, and Validation

Testing was performed using the Black-box method to validate the functions of THE POCI application and the System Usability Scale (SUS) test to assess the ease of use by respondents. Data were collected through a questionnaire, consisting of 10 statements rated on a 1–5 Likert scale (Lewis, 2018; Mahendra & Asmarajaya, 2022). The SUS instrument test used in this research is shown in Table 2.

Table 2. Instrument for SUS test

Question	Strongly disagree	Somewhat Disagree	Neutral	Somewhat Agree	Strongly Agree
1. I think I would like to use this tool frequently.	-	-	-	-	-
2. I found the tool unnecessarily complex.	-	-	-	-	-
3. I thought the tool was easy to use.	-	-	-	-	-
4. I think that I would need the technical support or assistance to be able to use this system.	-	-	-	-	-
5. I found the various functions in this tool were well integrated.	-	-	-	-	-
6. I thought there was too much inconsistency in this system	-	-	-	-	-
7. I would imagine that most people would learn to use this system very quickly	-	-	-	-	-
8. I found the system very cumbersome to use	-	-	-	-	-
9. I felt very confident using the system	-	-	-	-	-
10. I needed to learn a lot of things before I could get going with this system	-	-	-	-	-

Validation was performed by comparing the THE POCI results with experimental data obtained from an existing cold storage system. Input parameters were set according to the experimental conditions, and the application's outputs were directly compared with measured results. Accuracy was assessed using the Mean Absolute Percentage Error (MAPE) method, with adapted testing instruments and procedures to ensure reliable evaluation of the application's performance. The MAPE value is calculated using the formula (Singh *et al.*, 2020; Al-Khowarizmi *et al.*, 2021):

$$\text{MAPE} = \frac{\left(\sum_{i=1}^{n}\left|\frac{Actual-Predict}{Actual}\right|\right)}{n} \times 100\% \tag{14}$$

2.6. Data Analysis

Black-box testing results were analyzed qualitatively to ensure all application functions operated correctly (Khan & Farmeena, 2012; Mahendra & Asmarajaya, 2022). SUS questionnaire data were analyzed quantitatively by converting responses into usability scores ranging from 0 to 100, following the method proposed by Lewis (2018).

3. RESULT AND DISCUSSION

3.1. System Design and Implementation

The system implementation process is carried out through several stages, including database system, user workflow design, and user interface design. The POCI is designed for a single-user level, ensuring that all users have the same access rights to all available features. The system consists of three main features: (1) cold storage design based on cooling load calculations, (2) cold storage performance simulation based on component enthalpy analysis, and (3) cold storage emission estimation using the Life Cycle Climate Performance (LCCP) approach. These features are designed to be used sequentially to ensure a consistent calculation flow that corresponds to the actual stages of refrigeration system design, as illustrated in Figure 3.

The system design includes three main aspects: user interface design, data design, and process design. User interface design focuses on user interaction with the web-based application and is developed using a prototyping approach based on user feedback. Data design defines the database structure used to store calculation inputs and outputs, while process design describes the logical workflow and calculation procedures implemented in the system. To support the calculation process, the system is developed using a modular structure consisting of four main modules, where each module processes a set of input data and produces corresponding outputs according to the type of calculation performed, thereby facilitating data management and integration between modules, as shown in Figure 4.

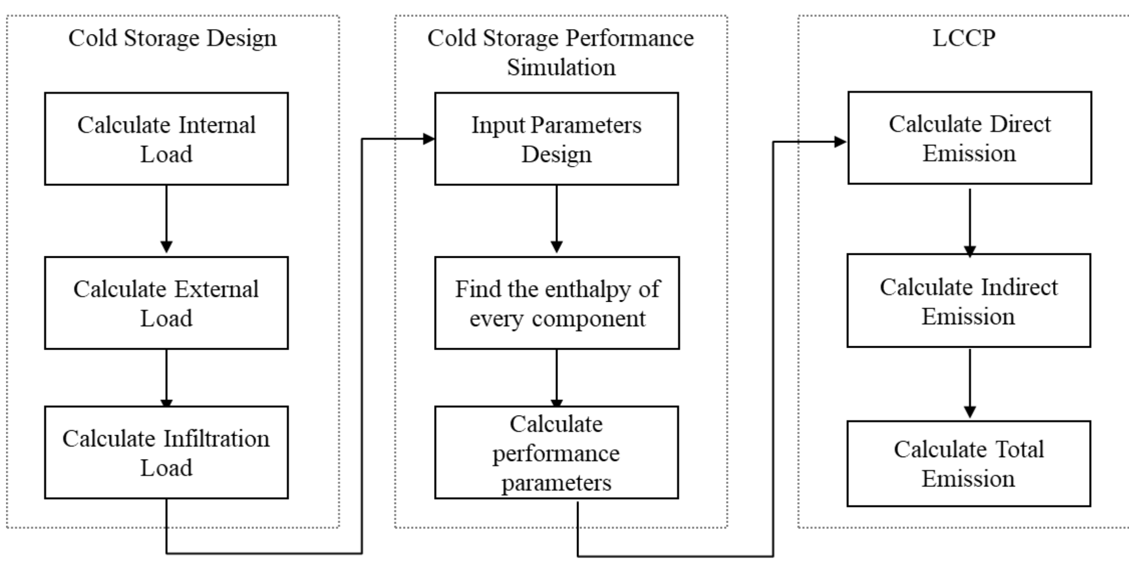

Figure 3. THE POCI calculation flow

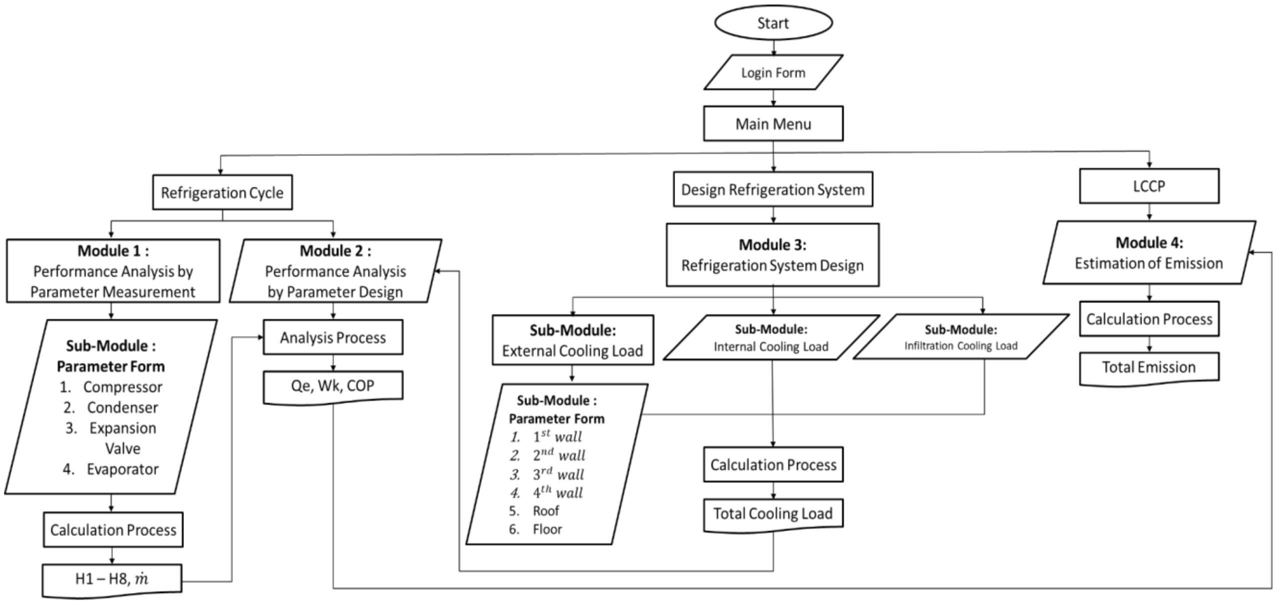

Figure 4. THE POCI workflow

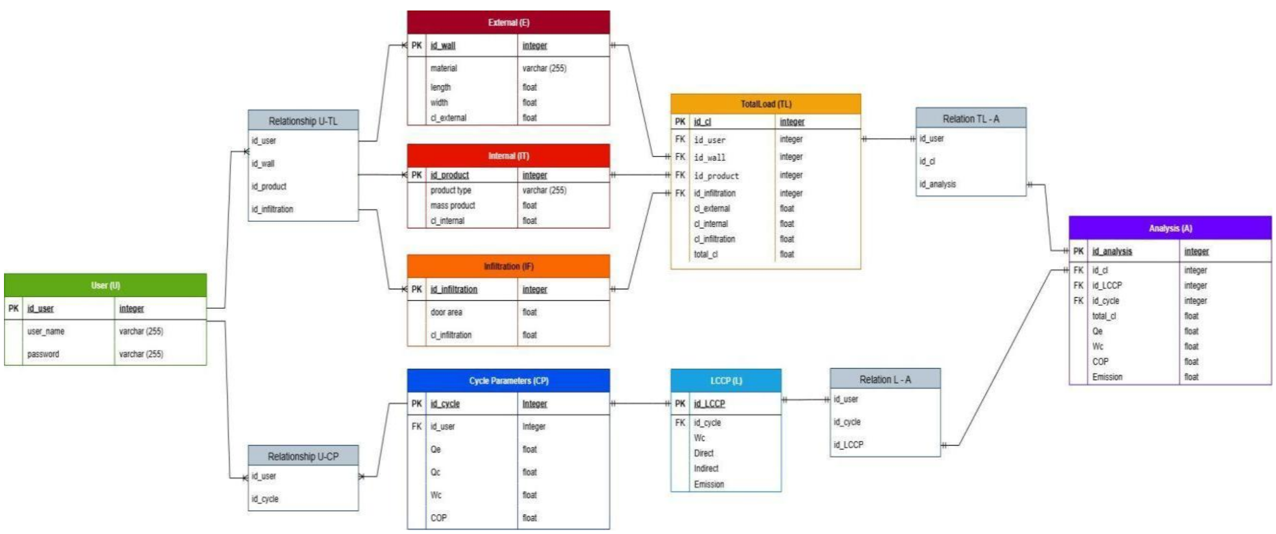

Figure 5. Entity relationship diagram of THE POCI

The system is implemented within a local server environment using XAMPP. During the implementation phase, a database is developed using MySQL and phpMyAdmin. The database consists of input tables containing design parameters according to the main module of The Poci, as well as output tables that store the results of calculations performed by the module. All data are organized according to their respective entities and are represented in an Entity Relationship Diagram (ERD), as illustrated in Figure 5.

The user interface (UI) and user experience (UX) were developed using HTML, JavaScript, and PHP, and CSS was used to create the page layout, buttons, and navigation. The pages were built based on the designed modules and include input and output forms. Users can enter design data into the input forms, which are then stored in the database. The calculation results are retrieved from the database and displayed back to the user, creating a two-way data flow. A simple illustration of the vapor compression cycle is also provided to help users understand the system and fill in the required data. The implementation results of THE POCI UI/UX are presented in the Figure 6.

Figure 6. THE POCI Page Preview: (a) Login Page, (b) Main Menu, (c) Performance Analysis Result of Refrigeration System, (d) Parameter Input Form of Module 1, (e) Navigation Page for Cooling Load Calculation, (f) Parameter Input Form of Module 2, (g) Parameter Input of LCCP Module

THE POCI was developed as part of a refrigeration system functional module aimed at facilitating users in calculating the heat load that must be handled by the refrigeration system. The calculated heat load serves as the basis for determining the required cold storage capacity as well as evaluating the performance of the refrigeration system under operating conditions. The design module of the application is equipped with a database of materials commonly used in cold storage wall construction, enabling more accurate heat transfer analysis. In addition, the application provides various refrigerant options sourced from the REFPROP library, allowing reliable modeling of the thermophysical properties of refrigerants. The outputs generated by the application include cooling capacity, system energy consumption during operation, and estimated environmental emissions expressed in units of kg CO_2 equivalent.

3.2. Functional Verification of THE POCI Application

Black box testing was conducted to verify the functionality of all main modules in the system, including user authentication, navigation, data input, database operations, computational processes, and result visualization. The testing covered the Login and Main Menu modules, Refrigerasi Sederhana module, Life Cycle Climate Performance (LCCP) module, Refrigeration Design modules (external, internal, and infiltration cooling load), refrigeration cycle parameter input, and final performance analysis display. Each test case was evaluated by comparing the actual system output with the expected output based on predefined scenarios. The results demonstrate that all modules functioned as intended, with correct navigation flow, accurate data processing, reliable thermodynamic and cooling load calculations, and successful integration of energy consumption and emission analysis, indicating that the application is functionally reliable and ready for operational use.

Table 3. Functional verification of system modules based on Black Box testing

Module	Tested Features	Expected Outcome	Result
Login & Main Menu	User login, menu navigation	Successful login and redirection to selected module pages	Pass
Refrigerasi Sederhana	Refrigerant selection, component navigation, data input, enthalpy and cycle calculation	Correct data processing and thermodynamic outputs	Pass
LCCP Module	Input, save, calculation, result integration	Emission calculation completed and displayed correctly	Pass
External Cooling Load	Surface input, material selection, load calculation	External cooling load calculated accurately	Pass
Internal & Infiltration Load	Internal and infiltration parameter input, load calculation	Individual and total loads calculated correctly	Pass
Total Cooling Load	Load aggregation and navigation	Total cooling load displayed and forwarded to cycle parameters	Pass
Refrigeration Cycle Parameters	Refrigerant selection, parameter input, cycle performance calculation	COP and cycle parameters calculated without error	Pass
Final Results (Siklus Refrigerasi)	Display of performance, enthalpy, and emission results	All analysis results displayed correctly	Pass

Table 4. Input parameters for simulation

Parameters	1.3 bar	1.8 bar	2.3 bar	2.8 bar
Evaporation temperature (°C)	-35.39	-30.26	-25.58	-21.97
Condensation temperature (°C)	26.75	27.34	28.19	29.80
Heat loss (%)	15.00	10.00	10.00	8.00
Superheat (°C)	60.37	54.84	50.11	44.78
Subcool (°C)	0.78	0.29	0.74	0.54
Volumetric efficiency (%)	85.00	85.00	85.00	85.00
Compressor rotational speed (rps)	220.05	170.20	146.24	136.58

3.3. Validation of Cold Storage Performance

The simulation was conducted using input parameters obtained from the design results and experimental data. These parameters were used to simulate the operating conditions of the cold storage system at various suction pressures in order to evaluate the consistency of the model under different operating conditions. Table 2 presents the simulation input parameters derived from the experimental results. The main performance parameters evaluated include the coefficient of performance (*COP*), cooling capacity (Q_e), compressor work (W_c), and refrigerant mass flow rate ($\dot{m}$). The validation process was primarily carried out on the refrigerant mass flow rate, as it is a key factor influencing the thermodynamic behavior of the refrigerant during the compression cycle. However, to evaluate overall system performance, the comparison was focused on cooling capacity, compressor work, and their ratio expressed as *COP*. The accuracy of the simulation results was assessed using the Mean Absolute Percentage Error (MAPE) method by comparing the experimental data with THE POCI simulation results, as presented in Table 5.

The results indicate that THE POCI error for the refrigerant mass flow rate parameter is 1.99%, demonstrating a high level of accuracy. The simulated mass flow rate ranged from 0.0154 to 0.0173 kg/s, which is comparable to values reported in previous studies. In a ship cold storage system, the refrigerant mass flow rate was reported as 0.018 kg/s for a ¾ HP capacity unit (Suhengki *et al.*, 2024). Meanwhile, the errors for cooling capacity (Q_e) and compressor work (W_c) are 17.78% and 11%, respectively, resulting in an overall system performance error of 14.30%. The simulated Q_e ranges from 4.9 to 5.3 kW, which is comparable to the 4.98 kW reported for a ship cold storage system with a ¾ HP unit (Suhengki *et al.*, 2024). The simulated W_c ranges from 0.7 to 0.8 kW, also aligning with previous studies. Suhengki *et al*. (2024) reported 0.66 kW for an R32 ship cold storage system with a ¾ HP capacity, while (Hadya *et al*., 2015) and (Pujianto & Nugroho, 2024) reported compressor work values of 1.038 kW and 0.8 kW, respectively, for 1 HP air conditioner units. These findings suggest that the mathematical model is capable of predicting the performance of a cold storage system that has not yet been constructed or is still in the design stage. Therefore, the POCI application can be considered a reliable tool for predicting system performance and providing valuable information to users without the need to experimentally test a prototype.

Table 5. Comparison of experimental and simulation results for system performance

Parameters	Suction Pressure	Experimental	THE POCI	APE (%)	MAPE (%)
Mass flow rate (kg/s)	1.3 bar	0.0154	0.0158	2.76	1.99
	1.8 bar	0.0150	0.0153	1.57	
	2.3 bar	0.0156	0.0160	2.28	
	2.8 bar	0.0173	0.0175	1.36	
Work of Compression (kW)	1.3 bar	0.631	0.708	12.08	11.00
	1.8 bar	0.710	0.862	21.36	
	2.3 bar	0.796	0.740	7.03	
	2.8 bar	0.883	0.852	3.54	
Cooling Capacity (kW)	1.3 bar	4.7028	4.9006	20.12	17.78
	1.8 bar	4.5443	4.6843	17.39	
	2.3 bar	5.0218	4.8691	17.19	
	2.8 bar	5.0218	5.2274	16.44	
COP	1.3 bar	6.46	6.92	7.18	14.30
	1.8 bar	5.62	5.44	3.28	
	2.3 bar	5.22	6.58	26.05	
	2.8 bar	5.08	6.14	20.71	

3.4. LCCP Simulation

The potential emissions generated by the cold storage system during its operational lifetime were calculated using the Life Cycle Climate Performance (LCCP) method. This calculation was performed directly through simulation in THE POCI application. For the refrigeration system using R32 refrigerant, the main properties used in the LCCP calculation were GWP = 675, ADP GWP = 0, and RFM = 7.2, with an assumed operating time of 5,760 hours per year (Saito 2017; Islam *et al.* 2021). These parameters refer to the LCCP guideline (IIFIIR, 2016) with some modifications based on experimental results. The lowest emission value was obtained at a suction pressure of 1.3 bar, amounting to 31,598 $kgCO_2e$. This result is consistent with the emission calculation based on experimental data, which yields 25,261 $kgCO_2e$ with a power consumption of 0.63 kW.

3.5. System Usability Scale Test

The System Usability Scale (SUS) test involved 47 respondents and yielded an average score of 65.41, which falls into the marginal category (grade C) (Figure 7). This indicates that THE POCI application is usable, but still requires improvements, particularly in terms of interaction efficiency and ease of use. Based on the adjective rating, the application is classified as “OK”, while the Net Promoter Score (NPS) falls into the passive category, suggesting that users are moderately satisfied but not strongly motivated to recommend the application. The item-level analysis shows that core system functions received relatively high scores (odd-numbered questions), indicating that users generally agree that the main features work well. However, several even-numbered questions also received relatively high scores, suggesting that many users perceived the system as difficult to use. This issue is likely related to the fact that the majority of respondents were students with limited practical experience and limited understanding of the role of THE POCI in cold storage design. Therefore, to reduce perceived complexity and improve usability, it is recommended to provide clearer guidance, simplify the workflow, and enhance the clarity of the interface and output presentation (Figure 8). Respondent characteristics also influenced the results. Most respondents (81%) were students with limited practical experience, which increased the need for clearer guidance (Figure 9). Meanwhile, HVAC professionals (11%) and academics (9%) were more concerned about workflow efficiency and the clarity of output.

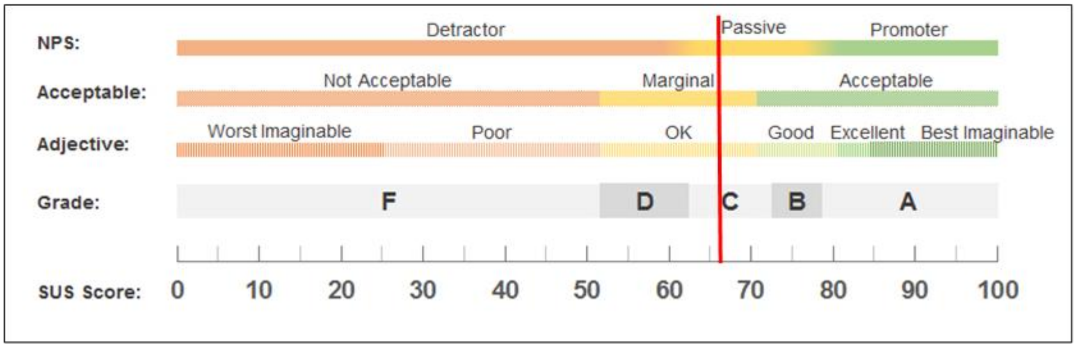

Figure 7. Interpretation result of SUS

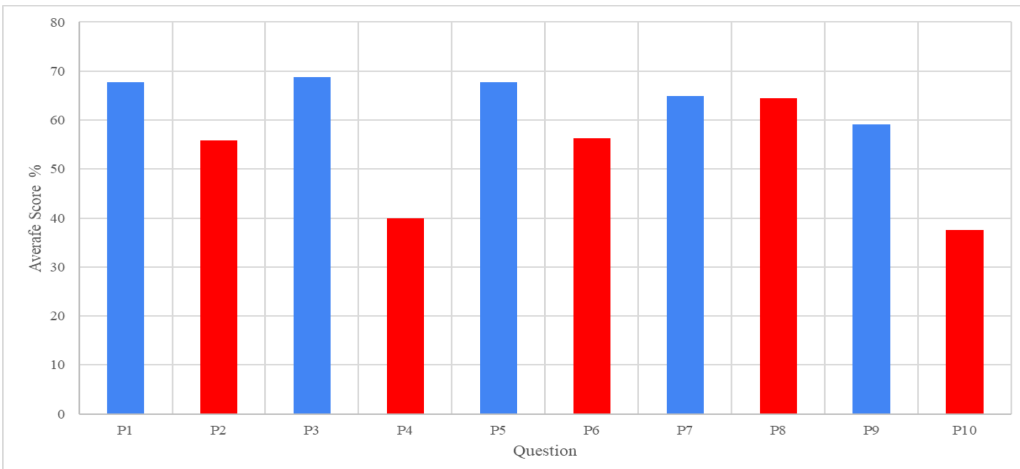

Figure 8. SUS item scores

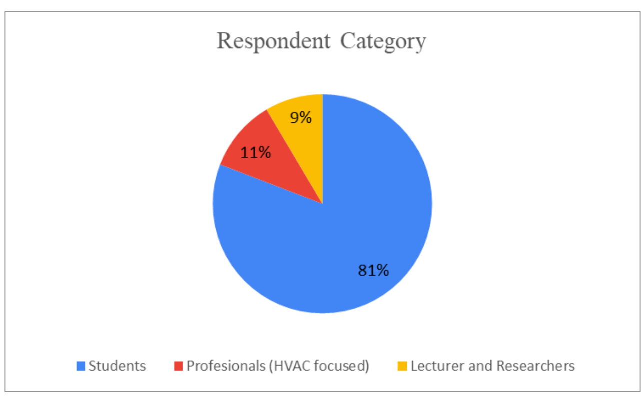

Figure 9. Respondents category

4. CONCLUSION

THE POCI web-based thermal application for vapor compression refrigeration systems has been successfully developed with three main features, system design, system performance calculation, and environmental impact estimation based on LCCP. The application enables interactive simulation and analysis of cold storage refrigeration systems, integrating both technical performance and emission assessment within a single platform. Model validation shows acceptable accuracy in representing system performance. The MAPE values for refrigerant mass flow rate ($\dot{m}$), compressor work (W_c), cooling capacity (Q_e), and *COP* are 2%, 11%, 17%, and 14%, respectively. These results indicate that the model can reasonably predict system behavior, although performance prediction for some parameters still requires improvement. The LCCP simulation results indicate that the lowest emission value occurs at a suction pressure of 1.3 bar, with emissions of 31,598 kgCO_2e, which is consistent with the low electrical power consumption of 0.631 kW. Usability evaluation involving 47 respondents resulted in a SUS score of 65.41 (marginal, grade C). The application is categorized as "OK" in adjective rating, and NPS falls into the passive category, indicating moderate user satisfaction but limited willingness to recommend the application. The study has limitations, including validation under specific operating conditions and a usability test sample dominated by students, which may affect generalizability. Future work should focus on improving model accuracy and extending validation under varied operating conditions, adding transient simulation capability, and enhancing usability through clearer guidance, standardized input formats, and simplified workflows.

ACKNOWLEDGMENTS

The author would like to thank the Indonesian Directorate of Higher Education, Research, and Technology through the BIMA-PFR grant (Contract No.23050/IT3.D10./PT.01.03/P/B/2025) for funding this research.

AUTHOR CONTRIBUTION STATEMENT

Author	C	M	So	Va	Fo	I	R	D	O	E	Vi	Su	P	Fu
RYD						✓		✓	✓					
MY	✓	✓								✓		✓	✓	✓
MS		✓	✓	✓										
LON				✓	✓						✓			
IA			✓											
RD						✓	✓							
NN										✓		✓		

C: Conceptualization	Fo: Formal Analysis	O: Writing - Original Draft	Fu: Funding Acquisition
M: Methodology	I: Investigation	E: Writing - Review & Editing	P: Project Administration
So: Software	D: Data Curation	Vi: Visualization	
Va: Validation	R: Resources	Su: Supervision	

REFERENCES

Al-Khowarizmi, Syah, R., Mahyuddin, K., Nasution, M., & Elveny, M. (2021). Sensitivity of MAPE using detection rate for big data forecasting crude palm oil on k-nearest neighbor. *International Journal of Electrical and Computer Engineering*, ***11***(3), 2696–2703. https://doi.org/10.11591/ijece.v11i3.pp2696-2703

Bodys, J., Hafner, A., Banasiak, K., Smolka, J., & Ladam, Y. (2018). Design and simulations of refrigerated sea water chillers with CO_2 ejector pumps for marine applications in hot climates. *Energy*, ***161***, 90–103. https://doi.org/10.1016/j.energy.2018.07.126

Byrne, J., Heavey, C., & Byrne, P.J. (2010). A review of Web-based simulation and supporting tools. *Simulation Modelling Practice and Theory*, 18(3), 253–276. https://doi.org/10.1016/j.simpat.2009.09.013

Cengel, Y.A.& Bols, M.A. (2019). *Thermodynamics an Engineering Approach*. McGraw Hill Higher Education, Boston.

Constantino, M.C., & Kanizawa, F.T. (2022). Evaluation of pressure drop effect on COP of single-stage vapor compression refrigeration cycles. *Thermal Science and Engineering Progress*, ***28***, 101048. https://doi.org/10.1016/j.tsep.2021.101048

Dhanya, R., Panoth, A., & Venkatachalapathy, N. (2023). A comprehensive review on isochoric freezing: a recent technology for preservation of food and non-food items. *Sustainable Food Technology*, ***2***(1), 9–18. https://doi.org/10.1039/d3fb00146f

Dhumane, R., Ling, J., Aute, V., & Radermacher, R. (2021). Performance comparison of low GWP refrigerants for a miniature vapor compression system integrated with enhanced phase change material. *Applied Thermal Engineering*, ***182***, 116160. https://doi.org/10.1016/j.applthermaleng.2020.116160

Dubey, S., Guruchethan, A.M., Reddy, Y.S.K., & Maiya, M.P. (2024). Energy, environmental and economic analysis of low GWP refrigerant heat pumps for simultaneous heating and cooling applications. *Thermal Science and Engineering Progress*, ***51***(April), 102605. https://doi.org/10.1016/j.tsep.2024.102605

Ghanghro, S.A., Sawand, M.A., Channa, W.A., Kashif, U.A., Tunio, M.H., Kumar, K., & Nooruddin, N. (2021). Comparative Analysis of Software Process Models in Software Development. *International Journal of Advanced Trends in Computer Science and Engineering*, ***10***(3), 2593–2599. https://doi.org/10.30534/ijatcse/2021/1521032021

Hadya, B., Prasad, A, M, K., & Suresh, A. (2015). Performance Assessment of HFC Group Refrigerants in Window Air Conditioning System. *International Journal of Mechanical Engineering and Applications*, ***3***(5), 81. https://doi.org/10.11648/j.ijmea.20150305.11

Harby, K. (2017). Hydrocarbons and their mixtures as alternatives to environmental unfriendly halogenated refrigerants: An updated overview. *Renewable and Sustainable Energy Reviews*, ***73***, 1247–1264. https://doi.org/10.1016/j.rser.2017.02.039

Holman, V. (1999). Introduction. *Visual Resources*, 15(3), ix–x. https://doi.org/10.1080/01973762.1999.9658510

IIFIIR (Institut International du Froid International Institute of Refrigeration) (2016). *Guideline for Life Cycle Climate Performance*. IIFIIR, Paris, France: 26 pp. https://iifiir.org/en/documents/46564/download

IIFIIR (Institut International du Froid International Institute of Refrigeration) (2019). *The Role of Refrigeration in the Global Economy - 38th Informatory Noteon Refrigeration Technologies*. IIFIIR, Paris, France: 12 pp.

Islam, M.A., Mitra, S., Thu, K., & Saha, B.B. (2021). Study on thermodynamic and environmental effects of vapor compression refrigeration system employing first to next-generation popular refrigerants. *International Journal of Refrigeration*, ***131***, 568–580. https://doi.org/10.1016/j.ijrefrig.2021.08.014

Jones, A., Wolf, A., & Kwark, S.M. (2022). Refrigeration system development with limited charge of flammable Refrigerant, R-290. *Thermal Science and Engineering Progress*, ***34***(July), 101392. https://doi.org/10.1016/j.tsep.2022.101392

Khan, A., Soni, B.K., Gupta, S., & Mukherjee, S. (2023). Emerging technologies in food processing. *Journal of Current Research in Food Science*, ***4***(2), 57–63.

Khan, M.E., & Farmeena, K. (2012). A comparative study of White Box, Black Box and Grey Box testing techniques. *International Journal of Advanced Computer Science and Applications*, 3(6), 12–15.

Lauff, C., Menold, J., & Wood, K.L. (2019). Prototyping canvas: Design tool for planning purposeful prototypes. *Proceedings of the International Conference on Engineering Design* (*ICED*), 1563–1572. https://doi.org/10.1017/dsi.2019.162

Lee, H., Troch, S., Hwang, Y., Radermacher, R. (2016). LCCP evaluation on various vapor compression cycle options and low GWP refrigerants. *International Journal of Refrigeration*, ***70***, 128–137. https://doi.org/10.1016/j.ijrefrig.2016.07.003

Lee, H.S., Park, Y.I., & Kang, S.H. (2021). Effects of fat meat and storage temperature on the qualities of frozen minced beef products. *Quality Assurance and Safety of Crops and Foods*, ***13***(1), 93–104. https://doi.org/10.15586/qas.v13i1.817

Lewis, J.R. (2018). The system usability scale: Past, present, and future. *International Journal of Human-Computer Interaction*, ***34***(7), 577–590. https://doi.org/10.1080/10447318.2018.1455307

Ma, W., Fang, S., Su, B., Xue, X., & Li, M. (2017). Second-law-based analysis of vapor-compression refrigeration cycles: Analytical equations for COP and new insights into features of refrigerants. *Energy Conversion and Management*, ***138***, 426–434. https://doi.org/10.1016/j.enconman.2017.02.017

Mahendra, G.S., & Asmarajaya, I.K.A. (2022). Evaluation Using Black Box Testing and System Usability Scale in the Kidung Sekar Madya Application. *Sinkron*, ***7***(4), 2292–2302. https://doi.org/10.33395/sinkron.v7i4.11755

Naduvilakath-Mohammed, F.M., Lebon, M., Byrne, G., & Robinson, A.J. (2024). An experimental investigation of vapor compression refrigeration cooling and energy performance for CPU thermal management. *Case Studies in Thermal Engineering*, ***54***, 103963. https://doi.org/10.1016/j.csite.2023.103963

Pujianto, M.E., & Nugroho, A. (2024). Performance air conditioner on retrofitted refrigerant hydrocarbon. *Jurnal Polimesin*, 22(1). http://dx.doi.org/10.30811/jpl.v22i1.3584

Purwanto, P., & Kuswandi, K. (2017). Effects of flexibility and interactivity on the perceived value of and satisfaction with e-commerce (evidence from Indonesia). *Market-Trziste*, ***29***(2), 139–159. https://doi.org/10.22598/mt/2017.29.2.139

Ruzsa, C. (2020). Digital twin technology-external data resources in creating the model and classification of different digital twin types in manufacturing. *Procedia Manufacturing*, ***54***, 209–215. https://doi.org/10.1016/j.promfg.2021.07.032

Saito, K. (2017). Latest heat pump technologies in Japan. *12th IEA Heat Pump Conference 2017*, Rotterdam: 3–4.

Setyawan, E.Y., Lomi, A., & Saleh, C. (2021). Penggunaan wood pellet untuk bahan bakar produksi tahu di UKM Kab. Kediri. *Jurnal Aplikasi Sains Teknologi Nasional*, ***02***(02), 22–28.

Vaishali, V., Sharma, H.P., Dholu, U., Sharma, S., & Patel, A. (2020). Effect of freezing systems and storage temperatures on overall quality of perishable food commodities. *The Pharma Innovation Journal*, 9(9), 114–122.

She, X., Cong, L., Nie, B., Leng, G., Peng, H., Chen, Y., Zhang, X., Wen, T., Yang, H., & Luo, Y. (2018). Energy-efficient and -economic technologies for air conditioning with vapor compression refrigeration: A comprehensive review. *Applied Energy*, ***232***, 157–186. https://doi.org/10.1016/j.apenergy.2018.09.067

Shylesh, S. (2017). A study of software development life cycle process models. *SSRN* (*Social Science Research Network*), 7 pp. https://doi.org/10.2139/SSRN.2988291

Singh, V.P., Pandey, M.M., Singh, P.S., & Karthikeyan, S. (2020). An LSTM based time series forecasting framework for web services recommendation. *Computacion y Sistemas*, ***24***(2), 687–702. https://doi.org/10.13053/CyS-24-2-3402

Smith, D.W., Sims, B.G., & O'Neill, D.H. (1994) *Testing and Evaluation of Agricultural Machinery and Equipment – Principles and Practices*. Food and Agriculture Organization (FAO) Agricultural Services Bulletin 110.

Soori, M., Arezoo, B., & Dastres, R. (2023). Digital twin for smart manufacturing, A review. *Sustainable Manufacturing and Service Economics*, ***2***, 100017. https://doi.org/10.1016/j.smse.2023.100017

Strommer, S., Niederer, M., Steinboeck, A., & Kugi, A. (2016). Combustion processes inside a direct-fired continuous strip annealing furnace. *IFAC-PapersOnLine*, ***49***(20), 208–213. https://doi.org/10.1016/j.ifacol.2016.10.122

Suhengki, S., Manik, H.M., Yulianto, M., Hartulistiyoso, E., & Sumantri, W. (2024). Performance profile of cold storage using R32 as refrigerant for traditional fishing boat with photovoltaic as energi source. *Jurnal Keteknikan Pertanian*, ***12***(2), 184–203. https://doi.org/10.19028/jtep.012.2.184-203

Tassou, S.A., Lewis, J.S., Ge, Y.T., Hadawey, A., & Chaer, I. (2010). A review of emerging technologies for food refrigeration applications. *Applied Thermal Engineering*, ***30***(4), 263–276. https://doi.org/10.1016/j.applthermaleng.2009.09.001

Wahyuni, S., Akbar, A., Khaliq, A., & Akbar, A. (2023). Web-Based Application for Sea Products Trading To Increase Fishermen'S Income in Secanggan Village. *Prosiding Seminar Nasional Dan Internasional Universitas Dharmawangsa*, ***3***(1), 736–745.

Yohannes, H.Y., Muhammad, A.M., & Daisy, D.K.R.A. (2018). Perancangan sistem refrigerasi untuk blast freezer pada kapal ikan 200 GT. *Proceedings Conference on Marine Engineering and its Application*, ***1***(1), 145–150.

Yulianto, M., Suzuki, T., Ge, Z., Tsuchino, T., Urakawa, M., Taira, S., Miyaoka, Y., Giannetti, N. Li, L., & Saito, K. (2022) Performance assessment of an R32 commercial heat pump water heater in different climates. *Sustainable Energy Technologies and Assessments*, ***49***, 101679. https://doi.org/10.1016/j.seta.2021.10167