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Design and Simulation of a Compact Window Air Conditioner Setup

Project Guide: **Prof. S. P. Lokhande, Teeya R. Awale, Rohit S. Asole,**

Shreenath R. Dhole, Ukesh V. Bhoyar

Department of Mechanical Engineering

Priyadarshini College of Engineering Nagpur, Maharashtra, India

ABSTRACT

Students of refrigeration and air conditioning rarely get to watch a vapour-compression cycle at work, because commercial window units hide every component behind a sealed casing. This paper describes the design of a compact, open-frame window air-conditioner setup built to remedy that for HVAC teaching and laboratory demonstration. The proposed unit contains a hermetic compressor, an air-cooled condenser, an expansion device, an evaporator, an indoor blower, a condenser fan, copper piping, an electrical panel and planned instrumentation, all arranged so that each part can be seen, reached and measured. The arrangement was developed through a literature survey, component selection, three-dimensional CAD modelling and a pre-fabrication review of layout, clearances and expected operating sequence. Temperature, pressure and airflow measurement points are fixed in the design, and space is kept for a later data-acquisition system. A steady-state energy-balance model is presented for computing cooling capacity, compressor work, heat rejection and coefficient of performance once the unit is tested. No measured data or solved state-point values exist at this stage, so the paper makes no numerical performance claims. It offers a reviewed design basis for fabrication, experimental validation and later work on digital monitoring.

Keywords - Window air conditioner, Vapour-compression refrigeration, HVAC education, CAD modelling, Compact test setup, Coefficient of performance.

I. INTRODUCTION

Air conditioning keeps indoor spaces comfortable by managing temperature, humidity, air movement and cleanliness, and it is one of the main branches of heating, ventilation and air conditioning (HVAC). The window air conditioner is its most compact self-contained form. A single chassis holds the compressor, condenser, expansion device and evaporator, and the refrigerant looping through them carries heat from room air to the outdoors.

Every thermal engineering course teaches this cycle, yet a diagram on a board does not show how pressure, temperature, refrigerant flow and airflow change together. A commercial unit offers no help, since its metal enclosure conceals the components and the changes between them. Large laboratory rigs can fill the gap but tend to be bulky, costly and fixed in position, which makes close observation and repeated demonstration awkward.

This work proposes a compact, open-frame window air-conditioner setup for teaching. Every principal component is kept visible and within reach, instrument positions are planned from the start, and the whole arrangement is checked in CAD before any metal is cut. The aim is an integrated, safe and portable platform on which students can follow refrigerant flow and relate readings of temperature, pressure and airflow to the cycle.

1.1 Research Gap

The literature examined for this paper covers separate pieces of a teaching air conditioning platform. Training kits expose components, portable apparatus lets learners follow air-side processes, and test rigs show how measurements describe system behaviour. What the examined studies do not present is a compact arrangement built around the window air

conditioner itself, with the refrigerant circuit, both air streams and the instrument locations designed together and reviewed digitally before fabrication. Questions of service clearance, visibility of the refrigerant path, separation of indoor and outdoor air and sensor placement are normally settled during construction. The present work moves them to the design stage. Its contribution is a design framework and evaluation method, not a measured performance result.

1.2 Related Work

Ismail et al. built a smart window air-conditioner training kit with exposed, working components and found it effective for teaching refrigeration servicing and electrical wiring to vocational students [1]. Ryan described a portable benchtop experiment for air conditioning processes, with provision for temperature, humidity, airflow and a controlled heat load [2]. Amran et al. developed an automotive air-conditioning test rig and used temperature and pressure readings to obtain cooling load, compressor power and coefficient of performance (COP); they also observed that a faster evaporator blower lowered COP [3].

Other work shows what a compact unit will have to account for. Kang et al. analysed a closed-loop air-circulation vapour-compression system running on R236fa and stressed accurate superheat and refrigerant charge [7]. Luo et al. reported that a C-type heat exchanger limited the harm of non-uniform airflow in a duct air conditioner and raised heat-transfer capacity by 19.1% over an A-type design [5]. Chaiyat added phase-change material to a 2 TR building air conditioner and recorded a 9.10% fall in daily electrical consumption [4], and Elsaid et al. paired vapour compression with indirect evaporative cooling to reach COP values of 5.1 to 5.3 [6]. Comparisons of low-GWP refrigerants against R134a on a common platform [8], [9], [10] suggest a route for later experiments on the proposed apparatus.

2. Methods and Materials

2.1 Design Approach

The work proceeded as a chain of design and evaluation steps. It began with a study of the vapour-compression refrigeration (VCR) cycle and of existing teaching and test equipment. Requirements were then fixed: a small footprint, visible components, safe operation, portability, easy access and room for instruments. Major components were chosen with attention to compatibility, operating conditions, available space and ease of access for learners. The layout was built in CAD software, and three-dimensional modelling was used to verify dimensions, clearances, component positions and pipe routes. The expected operating sequence was reviewed, limitations in the arrangement were noted, and the design was revised before being accepted as a basis for fabrication. This paper covers those stages. Fabrication and testing are future work.

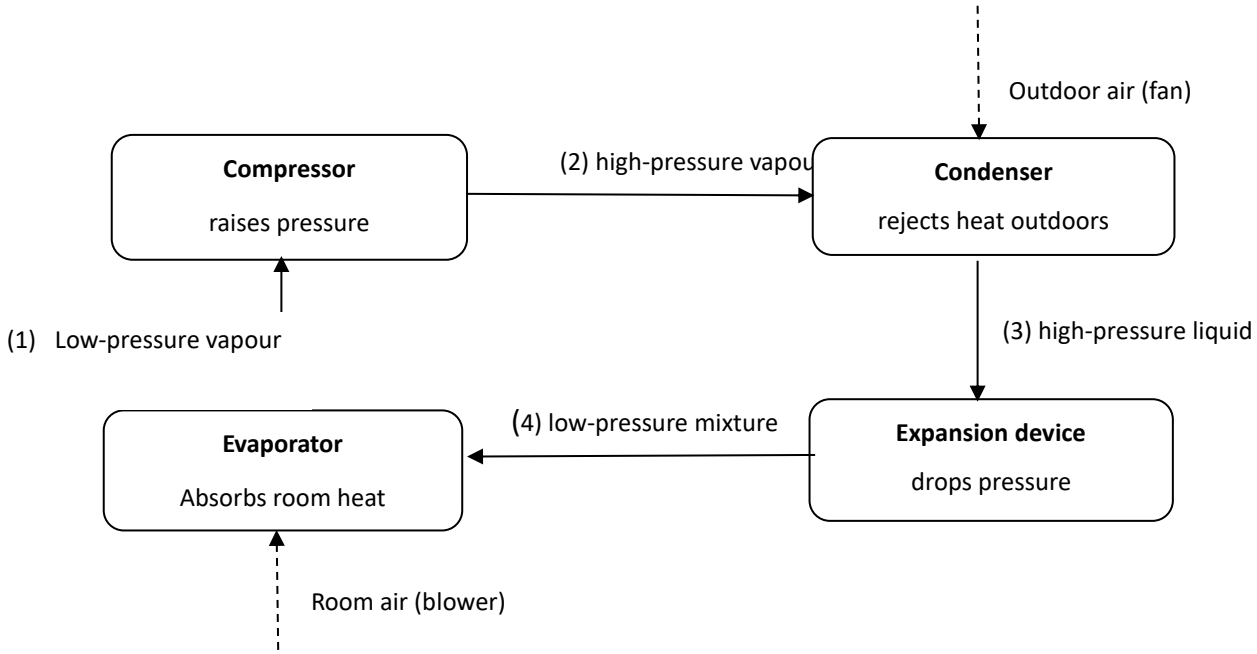
2.2 Description of the Proposed System

The proposed setup is a benchtop window air conditioner with its casing removed and its parts spread on an open frame. An indoor side carries the evaporator and the blower that pushes room air across it. An outdoor side carries the compressor, the condenser and the fan that moves ambient air through the condenser. Copper piping links the parts in the order of the refrigeration cycle and is routed with few bends, so the high-pressure and low-pressure sections are easy to tell apart and follow by eye.

A hermetically sealed reciprocating or rotary compressor suits the application because of its small size and simple operation. A fin-and-tube condenser and a compact fin-and-tube evaporator give large heat-transfer area in limited space. A capillary tube is the preferred expansion device for an educational unit because it is simple and needs little maintenance, although a thermostatic valve or another metering device remains possible. A filter-drier protects the circuit, and a protected, clearly labelled electrical panel controls the motor loads. Sensors for temperature, pressure and airflow, together with an optional display or data-acquisition (DAQ) unit, complete the arrangement.

2.3 Block Diagram

Heat enters at the evaporator and leaves at the condenser



Refrigeration loop: 4components, 4 state points, 2 air streams

Fig. 1. Block diagram of the proposed setup. Refrigerant circulates through the four numbered state points, while outdoor air crosses the condenser and room air crosses the evaporator (dashed arrows).

2.4 Working Principle

The unit runs on four linked processes. Low-pressure refrigerant vapour leaving the evaporator is drawn into the compressor, which raises its pressure and temperature. The hot, high-pressure vapour passes to the condenser, where outdoor air carried by the condenser fan removes heat and the refrigerant turns to liquid. The liquid then flows through the expansion device, losing pressure and temperature as it enters the evaporator. There it absorbs heat from room air driven across the coil by the indoor blower, boils back to vapour and returns to the compressor, which closes the loop. The two air streams are kept separate so that students can contrast the cooling side with the heat-rejection side.

2.5 Components Used

Table 1 lists the major components and the part each plays in the setup.

Sr. No.	Component	Specification (proposed)	Function
1	Compressor	Hermetic, reciprocating or rotary	Raises refrigerant pressure and temperature and circulates it
2	Condenser	Air-cooled, fin-and-tube	Rejects heat to outdoor air and condenses the vapour
3	Expansion device	Capillary tube (preferred)	Reduces pressure and meters flow to the evaporator

4	Evaporator	Compact fin-and-tube coil	Absorbs heat from indoor air and gives the cooling effect
5	Indoor blower	Sized to airflow and pressure drop	Moves room air across the evaporator
6	Condenser fan	Sized to condenser airflow	Moves ambient air across the condenser
7	Refrigerant piping and filter-drier	Copper tubing	Connects the circuit and protects it from moisture and debris
8	Temperature sensors	Thermocouples, RTDs or electronic sensors	Show temperature at chosen cycle and air points
9	Pressure gauges or sensors	High- and low-side	Show operating pressures on both sides
10	Airflow measurement	Anemometer or airflow meter	Gives air velocity and estimated flow rate
11	Electrical and control panel	Switch, circuit protection, relays	Gives safe, labelled operation
12	Display or DAQ unit	Optional	Shows and records readings

Final ratings depend on the capacity and space settled during detailed design, so the specifications above are proposals and not purchased items.

2.6 Measurement Provisions

Temperature sensors are planned at the compressor suction and discharge, the condenser inlet and outlet, the evaporator inlet and outlet, and in the indoor and outdoor air streams. Pressure gauges or transducers will sit on the high- and low-pressure sides, near the compressor suction or evaporator outlet and near the compressor discharge or condenser outlet. Air velocity will be measured at the indoor outlet and, where needed, along the condenser air path. These are design provisions, since no experimental readings have been taken.

3. Mathematical Model and System Operation

3.1 Thermodynamic Model

The cycle is analysed through steady-state energy balances at four state points: compressor inlet (1), compressor outlet (2), condenser outlet (3) and expansion-device outlet (4). The model assumes steady operation with constant refrigerant mass flow, negligible pipe pressure loss and heat exchange with surroundings, isenthalpic expansion, and specified compressor efficiency, superheat and subcooling.

The evaporator's cooling capacity equals refrigerant flow times the enthalpy rise across the coil:

$$\dot{Q}_e = \dot{m}_r(h_1 - h_4)$$

Compressor power and condenser heat rejection follow the same pattern:

$$\dot{W}_c = \dot{m}_r(h_2 - h_1)$$

$\dot{Q}_c = \dot{m}_r(h_2 - h_3)$

Throttling through the expansion device leaves enthalpy unchanged, and the cycle must balance as a whole:

$h_4 = h_3$, $\dot{Q}_c = \dot{Q}_e + \dot{W}_c$

The coefficient of performance compares cooling gained with compressor work spent:

$COP = \dot{Q}_e / \dot{W}_c$

Here $\dot{Q}e$ is cooling capacity, $\dot{Q}c$ is condenser heat rejection, $\dot{W}c$ is compressor power, $\dot{m}r$ is refrigerant mass-flow rate, and h1 to h4 are specific enthalpies at the numbered point.

3.2 Air-Side Evaluation

After fabrication, cooling capacity can also be estimated from the air stream using measured air mass flow and the temperatures entering and leaving the evaporator, and the overall COP follows from the measured electrical input under a clearly stated boundary:

$\dot{Q}_{cool} = \dot{m}_{air}\, C_{p,air}\, (T_{in} - T_{out})$, $COP = \dot{Q}_{cool} / \dot{W}_{input}$

These relations define how the setup will be evaluated. They are not evaluated here because no measured data or enthalpy values are available.

3.3 Advantages and Applications

The open arrangement offers a smaller space requirement than fixed laboratory rigs, clear identification of the refrigerant path, planned measurement points for temperature, pressure and airflow, scope for troubleshooting and maintenance exercises, possible portability between laboratories and workshops, and room for later digital monitoring. Likely uses include demonstrations of the VCR cycle, experiments linking airflow, pressure and temperature to cooling, and practice in CAD modelling and performance evaluation for mechanical engineering and polytechnic students. The unit is a teaching and experimental platform and is not intended to replace a commercial room air conditioner.

3.4 Future Development

The next stage is to fix final dimensions and the component schedule, fabricate the prototype, and fit calibrated sensors, with refrigerant handling, electrical protection, ventilation and leak prevention left to qualified personnel. Measured results should then be compared with the model across defined operating conditions, including the effect of blower speed and condenser airflow. A DAQ interface, automatic controls and IoT monitoring can follow, as can comparisons of low-GWP refrigerants on the same apparatus, subject to safety and component compatibility, and laboratory manuals for operation, testing and troubleshooting.

Design and Simulation of a Compact Window Air Conditioner Setup for HVAC Education. Results and Discussion The design work produced a compact CAD arrangement in which the compressor, condenser, expansion device, evaporator,

both fans and the piping all remain identifiable. Reviewing the model showed that the layout can hold these parts in a small footprint without hiding any of them, and that service access, pipe routing and instrument positions can be settled on screen. Indoor and outdoor air streams are kept apart, and the high- and low-pressure sections of the circuit can be told apart at a glance. The expected operating sequence of compression, condensation, expansion and evaporation was reviewed against the layout, and suitable points for temperature, pressure and airflow measurement were identified. These points follow the guidance of earlier test rigs, which show that readings at the compressor, condenser outlet and evaporator inlet are needed to determine capacity, compressor power and COP [3]. A protected electrical panel and a space for a display or DAQ unit are included so that readings can later be shown and recorded during demonstrations. The results are limited to design evaluation. The project documentation gives no final dimensions, complete component schedule, boundary conditions, solved state-point values or experimental measurements, so cooling capacity, power consumption and COP are not reported. A CAD layout cannot confirm refrigeration performance. Earlier work shows that blower speed, condenser airflow, compressor speed, load and condenser inlet temperature all affect pressure, power and COP [3], [7], which is why the fabricated unit should be tested across those variables before any numbers are published. The setup is meant to support learning and experiment, and it should not be compared with a commercial room air conditioner.

CONCLUSION

A compact window air-conditioner setup based on the vapour-compression cycle has been designed and reviewed as a platform for HVAC teaching. Its open layout keeps the compressor, condenser, expansion device, evaporator, fans, piping and instrument points visible and accessible, and CAD modelling allowed placement, clearances and safety to be examined before anything is built. The main contribution at this stage is a design framework and an evaluation method that treat visibility, access and measurability as design goals. Because no measured data or solved state-point values exist, the paper reports no cooling-capacity or COP figures, and those will have to come from the fabricated and tested unit. The setup is intended for laboratory demonstration and experiment and gives a base for fabrication, data acquisition and further study.



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