PERFORMANCE ANALYSIS OF ALTERNATIVE HVAC SYSTEMS INCORPORATING RENEWABLE ENERGIES IN SUB-TROPICAL CLIMATES

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Performance analysis of alternative HVAC systems incorporating renewable energies in sub-tropical climates

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Abstract

Over the past 40 years, energy consumption has increased dramatically to become a significant crisis faced today. The peak demand is growing at approximately 50% greater than the demand base growth in many Australian cities, which, in turn, requires greater finite resources and infrastructure to meet the required generation capacity needed. Currently, approximately 40% of electrical energy is consumed by HVAC systems in commercial building. This level of energy consumption emphasizes the necessity of developing an eco-friendly air-conditioning system, where possible, harnessing low-grade thermal energy such as solar energy rather than electricity. In this paper, a comparison of energy performances of three different HVAC is undertaken. Mathematical models are developed with TRNSYS17 to simulate the HVAC system within a typical small commercial building with various cooling options. The model is implemented to provide a comparative analysis across various cooling systems such as Vapour Compression System, Vapour Absorption System and Desiccant Evaporative Cooling System. This paper implements the developed model to investigate and compare the energy consumption and running costs over an eight-month cooling period of the widely used Vapour Compression System against alternative solar assisted cooling options for a sub-tropical location of Brisbane, Australia.

Keywords: Vapour Compression; Vapour Absorption; Desiccant Evaporative Cooling; Solar Assisted Air-conditioning; TRNSYS; Koppen Climate Classification Cfa.

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1. Introduction

Over the past 40 years, the energy consumption in buildings has increased drastically to become a significant crisis faced in the 21st Century. This has mainly caused due to the vast load required to meet the increasing demand for thermal comfort, As the energy demands continue to increase, power generation demand is primarily met by burning vast amounts of finite resources which is widely considered to be developing negative impacts on the environment. Innovative ideas are required to rein in this ever- growing rate of energy consumption seen over the past decades. Most of the current air-conditioning system works a vapour compression refrigerant system (VCRS) which consume approximately 40% of all commercial energy [1]. These challenges emphasize the necessity of developing an eco-friendly air-conditioning system. The alternatives for these HVAC systems are vapour absorption cooling system (VACS) and desiccant evaporative cooling system (DECS). This investigation aims to evaluate and compare performances of these three systems.

The main objective of this study is to conduct a comparative analysis between the widely installed VCRS against the solar assisted VACS & DECS in a medical clinic which works from 8 am-6 pm weekdays. The analysis focuses on whether alternative HVAC systems overall performance is better than VCRS with respect to economic, environmental and cultural sustainability criteria by reducing electrical consumption, operational costs whilst maintaining the desired thermal comfort (TC) region described under ASHRAE standards for the Koppen Climate classification (KCC) C_fa [2] representing sub-tropical location for a clinic in Brisbane Australia.

Nomenclature

AMV	Analytic Model Validation
ASHRAE	American Society of Heating, Refrigeration & Air-conditioning Engineers
DBT	Dry Bulb Temperature (℃)
DECS	Indirect Desiccant Evaporative Cooling System
EC	Electrical Consumption
ECOP	Electrical Co-efficient of Performance
FV	Face Validity
H	Enthalpy
HVAC	Heating Ventilation and Air-conditioning
IV	Internal Validity
KCC	Ko ̈ppen Climate Classification
kWh	Kilowatt Hours
LHB	Left Hand Boundary
$\dot{m}$	Mass Flowrate (kg/s)
OV	Operational Validity
RH	Relative Humidity (%)
RHB	Right Hand Boundary
SCS	Solar Collector Subsystem
SH	Specific Humidity (kg/kg)
T	Temperature (℃)
TC	Thermal Comfort
TCC	Thermal Cooling Capacity
UB	Upper Boundary
VACS	Single Stage Vapour Absorption Cooling System
VCRS	Vapour Compression Refrigeration System
%	Percentage
δ	Change in value

2. Methodology

This study uses TRNSYS 17 software develop the mathematical models of different HVAC systems and the building. TRNSYS is a graphically based software environment used to simulate the behaviour of transient systems and for assessing the performance of thermal and electrical energy system. The development of mathematic models of the VCRS, VACS and DECS are based on working principles identified in external literature for the VCRS [3], DECS [4-11] & VACS [12] as shown in Figures 1-3. For the simulated models, the weather data was sourced from the TRNSYS Meteonorm Australia-Oceania 945780 dataset for Brisbane for a period of 8-months from the beginning of October to the end of May. This period was selected as simulation period as the building uses HVAC systems only during this period. The thermal load of the clinic was estimated as 24.22 W/m^2 taking consideration standard clinical hardware, lighting and occupancy density for the 121m^2 clinic with 2.8 m ceilings. Additionally, an infiltration rate through door & window jams of 0.18 m^3/hr was also implemented for the Type 88 subroutine, which reflected similar values from a previous study [11]. The individual parameters of each sub-routine were selected based upon theoretical knowledge and refined based upon numerous simulations attempts to produce the outputs which were validated using a combination of analytic model Validity (AMV), Face Validity (FV), Internal Validity (IV) and Operational Validity (OV) methods to generate confidence in the results [17].

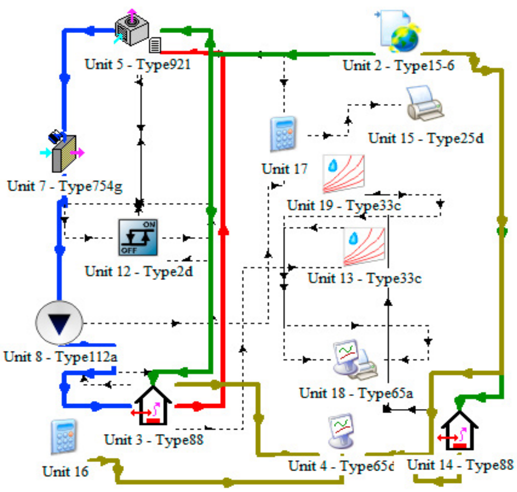

Fig.1 Vapour compression system model

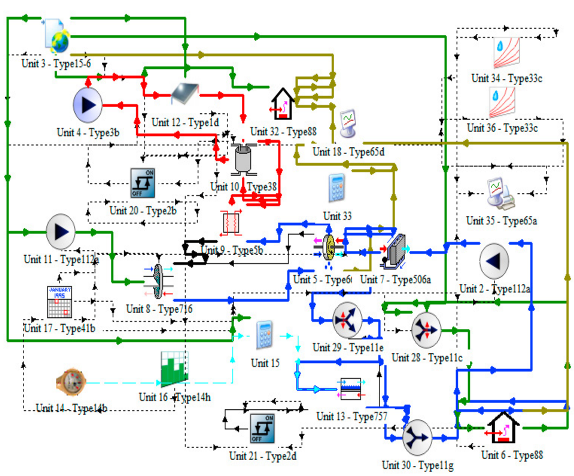

Fig. 2. Desiccant evaporative cooling system model

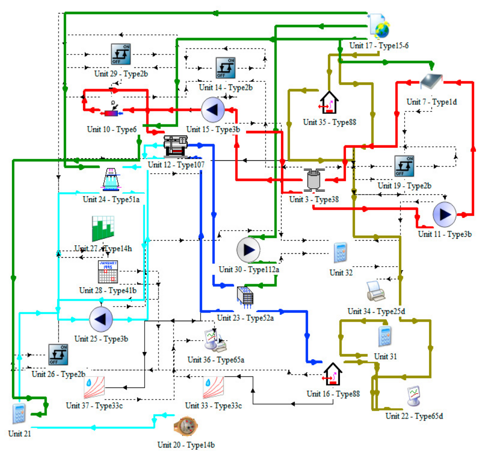

Fig. 3. Vapour Absorption Cycle System Model

2.1 *Thermal Comfort Region*

The thermal performance analysis of these models is assessed whether they can achieve a combination of TC region framework on a psychrometric chart set down in the ASHRAE standards [14-15] taking into consideration an airflow within the clinic of 1.5 m/s. As the target temperature to develop ideal TC is subjective to the average ambient temperature individuals are exposed to [14-17], the ideal temperature is determined by taking into consideration of the average monthly temperature as per Equation 1[14-15].

$$T_{target} = 17.8 + 0.31T_{avg} \quad (1)$$

If the system is unable to achieve the target temperature, there is a region which provides TC. For this analysis, Fig 4 presents the maximum TC region at airflows of 1.5 m/s in the Brisbane climate contained by LHB, UB & RHB which is subjected to DBT & SH criteria presented by [13-14].

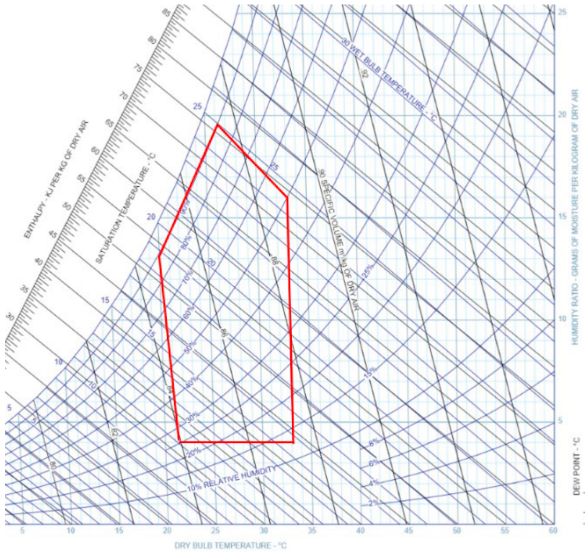

Fig. 4. Psychrometric TC Region for Brisbane Australia

2.2 HVAC Thermal Cooling Capacity (TCC)

Determining the TCC of the three HVAC systems began by taking the reference building's that had no HVAC cooling and using the dry bulb temperature (DBT) and the specific humidity (SH) datasets generated by TRNSYS17 Type88 subroutine and feeding them into the Unit 33c sub-routine to calculate the enthalpy values throughout the operating hours. After this was determined, the same process was implemented upon each of the buildings with the different HVAC systems. Utilising the Eq. 2 below with the appropriate mass flowrate of the refrigerant used for each system the cooling capacity could be found

$$TCC = \dot{m}(h_{non} - h_{HVAC}) \quad (2)$$

The TCC was calculated for this study across the 8-month simulation period only considering the commercial operating hours.

2.3 Electrical Consumption & Operating Costs

The electrical energy consumption for each HVAC system was recorded utilising the TRNSYS component Type 25d sub-routine during commercial operating times. Capturing this total consumption enabled the determination of total electrical energy consumption in kWh for the 8-month period and that was used to extrapolate the operational costs from Ergon Energy's Tariff 20 charges.

2.3 Electrical Co-efficient of Performance (ECOP)

The ECOP of each system is determined to allow for appropriate comparison. Each system utilises different processes to generate the TCC. The electrical COP is the ratio of the total cooling produced against the electrical power consumption (EPC) required to operate the HVAC system during the same period as shown in Eq.3.

$$COP_{ELECTRICAL} = \frac{TCC}{EPC} \quad (3)$$

3. Results

Utilising the TRNSY17 models developed building with the different options, no HVAC system, VCRS and solar assisted VACS & DECS systems; the thermal performances are determined and presented in Figures 5-8 respectively. The top and bottom horizontal lines in the figures represent the RHB and LHB respectively to maintain within the TC region whilst the middle horizontal line represents the target DBT temperature. Figure 5 shows the DBT and SH of the clinic building without any cooling device subjected to ambient conditions and the buildings thermal load. With no HVAC system, the thermal load from the building increases the DBT significantly which exceeds the RHB of the TC region numerous times during the 8-month simulation period with minimal SH effect.

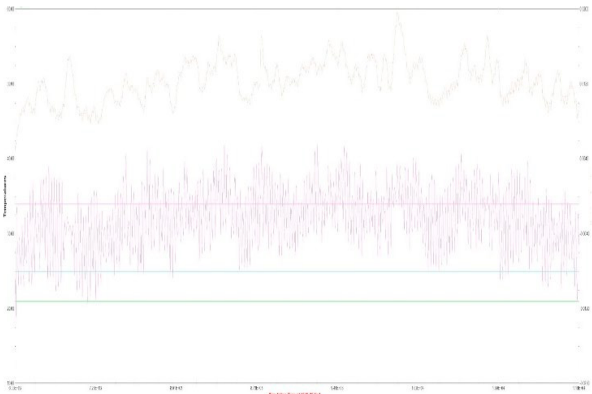

Fig. 5. Non-HVAC Controlled Thermal Performance

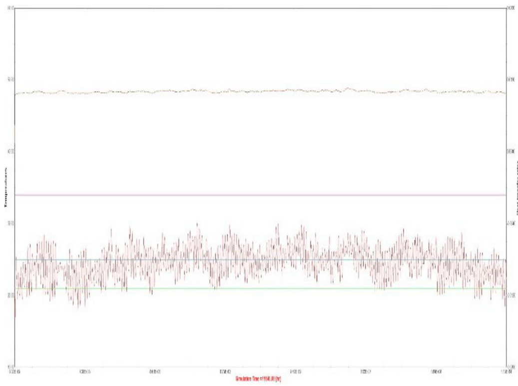

Fig. 6. VCRS HVAC Controlled Thermal Performance

The performance of VCRS system is shown in Figure 6. The Latent & Sensible heat are significantly controlled to remove SH fluctuation and maintain the DBT for the clinic within the TC DBT region 95-98% of the time, which is as expected.

The performance of solar assisted VACS is shown in Figure 7. It clear that it does little to control the latent heat when compared to the non-cooled building presenting similar SH values throughout the simulation show in Figure 5. However the sensible heat is significantly reduced to maintain the DBT within the TC DBT region 95% of the time.

The solar assisted DECS system's performance is shown in Figure 8. It is clear that this system produces significant latent heat control during commercial hours when the desiccant evaporative wheel is being desorbed by the heated processed airflow returning from the controlled environment past the heat exchanger. Outside commercial hours is beyond the scope of this study. The Sensible heat fluctuates significantly throughout the 8-month period; however, a reduction of sensible heat has ensured that the DBT does not exceed the RHB or LHB during business hours.

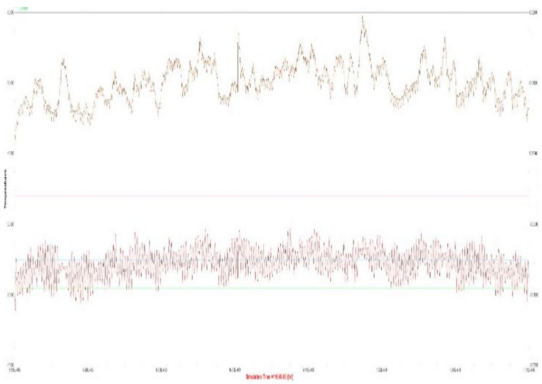

Fig. 7. VACS HVAC Controlled Thermal Performance

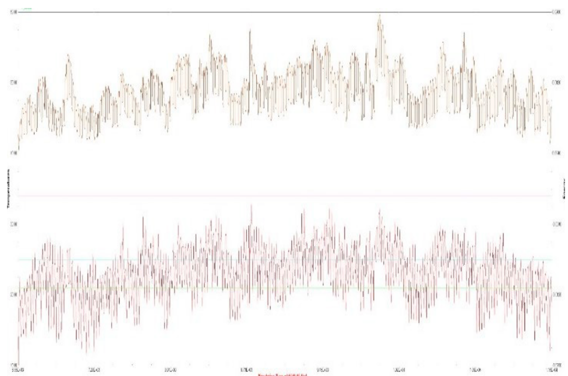

Fig. 8. DECS HVAC Controlled Thermal Performance

Figure 9 presents a sample of DBT & SH at the same six intervals ranging from 18 October through to 17 April captured to present the random thermal performance of each HVAC system. The non-HVAC environment is beyond the TC region whilst each HVAC system can maintain the TC region. The VCRS of the three systems produce the highest and most stable TC region whilst the VACS contain greater amount of enthalpy at each sample times than the the VCRS & DECS systems. The DECS produces the driest indoor environment most of the time.

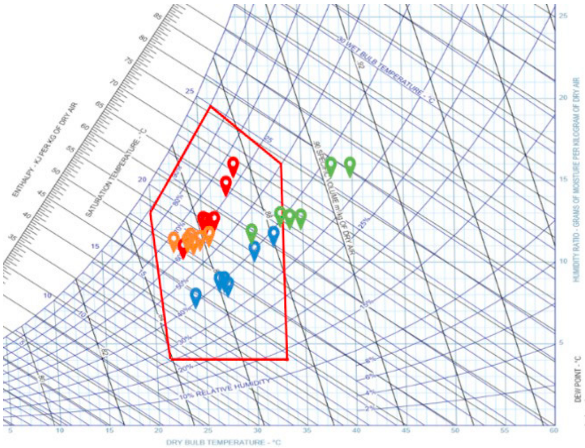

Fig. 9. Psychrometric TC Region HVAC Thermal Performance

3.2 Thermal Cooling Capacity Calculations

Utilising Figure 9, the system with the reduced change in enthalpy was the VACS followed in order by the VCRS and then the DECS. After collating the enthalpy differences between the non-HVAC system and each HVAC system during business hours, the change in enthalpy for the order mentioned above was 19101 kJ/kg, 30764 kJ/kg & 37346 kJ/kg. Utilising these enthalpy changes in the indoor environment, the TCC was found. Figure 10 presents each HVAC systems' enthalpy and TCC performance across the entire 8-month period. This presents the VCRS developed the greatest level of cooling effect over the entire 8-month simulated period.

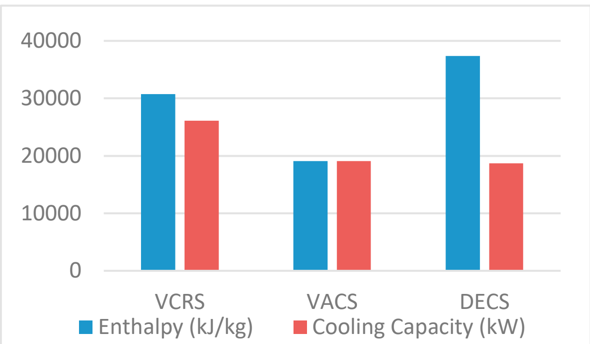

Fig. 10. HVAC Thermal Performance over Total Simulation Period

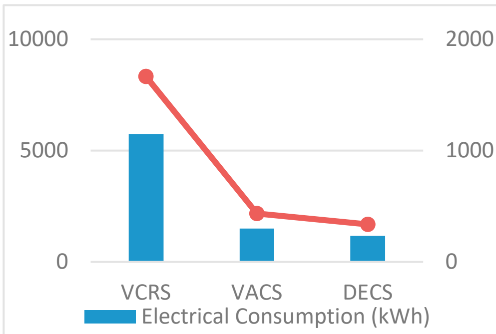

Fig. 11. HVAC Electrical Consumption & Operational

3.3 Electrical Consumption & Operational Costs Calculations

From the TRNSYS17 simulation, the energy consumption calculated for throughout the 8-month timeframe for each HVAC system. The VCRS, VACS & DECS each consumed 5740kWh, 1494kWh & 1162kWh which when utilising the electrical entities tariff charges of $0.29 per kWh cost $1,664.50, $433.25 and $337.00 which equates to daily costs of approximately $10, $2.60 & $2 for the VCRS, VACS & DECS respectively. This indicates the DECS is the cheapest and less energy demanding system to operate by almost a factor of 5.

3.4 Electrical Coefficient of Performance (ECOP)

Implementing Eq.3 with the variables identified from the TCC calculations and EC, the ECOP for the VCRS, VACS & DECS have been determined to be 4.5, 12.8 & 16 respectively as shown in Figure 12. This shows that the DECS has the highest ECOP value of the three HVACS.

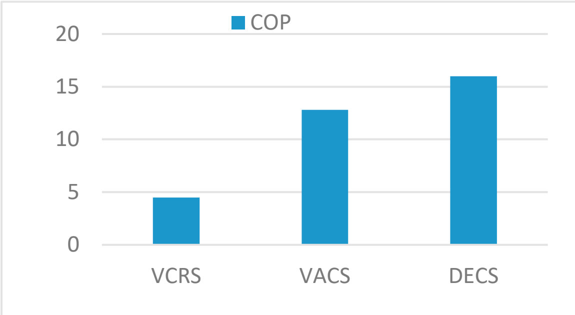

Fig. 12. HVAC Electrical COP

4. Discussion

Comparing the VCRS HVAC system against the solar assisted VACS & solar assisted DECS HVAC each system has strengths and weakness. The VCRS can meet the DBT and SH TC performance criteria extremely effectively which in turn produces a close to ideal target temperature throughout the entire simulation timeframe. The VCRS weakness however lays with the economic and environmental sustainability. Economically it is the most expensive system of the three HVAC simulated with the worse ECOP value. This is potentially because the other two HVAC systems source significant amount of energy from low grade solar energy as well as the replacement of high energy demanding components. The VCRS system scored low for environmental sustainability because of the chloro-fluoro hydrocarbons that the system uses as refrigerants which can produce excessive CO_2 emissions.

The solar assisted DECS HVAC scored the highest out of each of the systems based upon its ability to meet the TC region which achieved the cultural sustainability criteria. Additionally, the DECS had the lowest EC and therefore economically it was ranked the best and having the lowest EC and a reasonable DBT & SH TC performance it had the best ECOP value. The combination of all of these criteria provides the empirical evidence and justification that the solar assisted DECS HVAC is the most sustainable HVAC system to be implementing for future use from the three systems that have been simulated using TRNSY17.

Although this recommendation identifies the solar assisted DECS as the most sustainable system, this is based on the operational and design parameters assumed in the simulation, other systems such as double stage VACS are not included. Future studies are required in this area to continue refining and developing greater innovations to provide an improved path for implementation of HVAC systems in the future. The correct selection of HVAC systems will be able to reduce electrical consumption from these systems significantly.

5. Conclusions

Today, energy is an important resource and as the world continues to grow the finite resources are being used up at a quicker rate. If this energy usage cannot be reduced, humanity may suffer greater energy crisis. Implementing sustainable technologies may provide a short-term reduction in the consumption of energy which could develop great savings economically as well as environmentally without compromising comfort. The solar assisted DECS can maintain the TC region in Brisbane whilst dramatically reducing electrical consumption and cost as well as providing an environmentally friendly alternative to that of the VCRS.

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