UNIVERSITY OF TECHNOLOGY SYDNEY

Combining Heat-Pipes Heat-Exchanger and Solar Energy for Comfort Cooling

by Zulkarnaini bin Abdullah

Thesis submitted in fulfilment of the requirements for the degree of

Doctor of Philosophy

under the supervision of Dr Ba Phuoc Huynh

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Faculty of Engineering and Information Technology

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ABSTRACT

COMBINING HEAT-PIPES HEAT EXCHANGER AND SOLAR ENERGY FOR COMFORT COOLING

By

Zulkarnaini Abdullah

There are concerns over energy difficulties, resource exhaustion and environmental impacts. Among the substantial reasons for these concerns is the increase in the energy demand, to maintain the comfort levels and the time spent in buildings which contribute to the rise in energy consumption. The energy consumed for heating, ventilation and air conditioning is so significant that energy-saving and efficiency have become the main objective in every energy policy. As a result of the growing demand, there is always a great need for energy reduction in the heating and cooling processes. Thus, this research aimed to evaluate the potential of solar energy in energy-saving applications. The first task involved modelling a room using an acrylic test-box with different opening configurations for temperature distribution collection. The second task was designing a 'heat-pipes heat-exchanger' to be attached to the test box to lower the air intake to the box. The third task involved operating a refrigerator that runs on plate photovoltaic solar panels without the need for grid electricity. It is an understandable fact that solar energy is no match against the grid electrical energy; however, a room's cooling system could benefit from the abilities of the heat pipes in transferring heat, thus resulting in a reduction of energy consumption. A refrigerator that runs on solar energy reduces energy consumption by cutting the dependency on non-renewable energy resources.

The methods used were both experimental and computational. Regarding the experiments, the capabilities of the heat-pipes heat-exchanger in reducing temperature were tested with the test-box in five opening configurations. Three of the configurations were tested in Sydney's medium ambient temperature while the other two configurations and the solar energy refrigerator were tested in Kuala Lumpur's high ambient temperature. The aim was to verify the solar energy's capability in operating a cooling system with optimal converted solar energy. Regarding computation, the commercial software CFD-ACE and ANSYS-Fluent were used. Various room air intake openings, locations, side edges and boundaries were replicated rigorously and verified. Additionally, the natural and forced ventilation that influences the airflow to the room has been considered. SOLARGIS software was applied to verify the annual energy consumption of the solar panels.

The Computational Fluid Dynamics satisfactorily converge all the properties and the conditions using the RANS method to solve the velocity components, pressure and k-ε (epsilon) scheme. Numerical and graphical presentations with different plots, streamline data and curves were compared to predict the best room-airflow configurations. Based on the governing equations of fluid dynamics, namely the conservation of mass, momentum, and energy, the computational fluid dynamic solved the mathematical modelling. By the simulation, the heat-pipes heat-exchanger of R134a as a refrigeration medium recorded a 5 K of differences from the inlet evaporator end to the outlet condenser end, while with the experimental studies the difference is between 5 to 9 K.

The main achievement obtained from the experiments is that the heat-pipes heat-exchanger was found capable of pre-cooling a room by up to 9 K. The best opening configuration showed that the cooling energy saving was in the range of 93 W/m^3 to 140 W/m^3 or about 25% to 33% of the room's required energy. The experiment using the solar energy refrigerator found that the application could achieve the desired temperature of 5°C with 31% savings of annual power consumption. An additional experiment was also performed for a refrigerator driven by solar and wind energy. The objective was to verify the energy-saving capability of wind turbines combined with solar energy. It was thus demonstrated that the installed wind turbine was capable of operating the refrigerator for 7 hours.

The significance of the research is that the heat-pipes heat-exchanger reduces room temperature while solar energy reduces the dependence on grid electricity. Thus, the combined solar energy and passive cooling have a huge potential in reducing energy while maintaining comfort cooling.

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CONTRIBUTION BY THE AUTHOR

Articles Peer-reviewed and Presented in Conferences

Author

A total of ten conferences and journal papers have been produced throughout the study. Five of the papers are Scopus-Elsevier Excellence in Research for Australia (ERA) Ranked-A category, including one international conference of the Scopus h - index. Two papers related to passive cooling options.

1. Abdullah Z., Huynh B.P., Idris A. (2014). Numerical Study of Heat-pipes heat-exchanger to a 3-Dimensional Room with Natural Driven Ventilation. *ASME IMECE2014 Montreal, Canada.*
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10. Theoretical and Experimental Analysis of Desiccant Wheel Performance of Solar Hybrid Desiccant Air-Conditioning System. Zuraini Hashim, Tri Suyono, Arifidian Rachman, Zulkarnaini, Sohif Mat. *Solar Energy Research Institute, National University of Malaysia.*

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LIST OF SYMBOLS

%	Relative humidity percentage
ε	Dissipation rate, m^2/s^3
η	Efficiency
g	Gravity acceleration, m/s^2
°C	Temperature Celsius
C_μ	Empirical constant, 0.09
T_i	Turbulence intensity
U_{ave}	The average flow velocity, m/s
$U_j(j = 1 - 3)$	A component of the average velocity vector, m/s
μ_t	Turbulent viscosity, Pa/s
A_s	Solar panel surface area
COP	Coefficient of performance
GW_{el}	Giga Watts of electrical
GW_{th}	Giga Watts of thermal
I_p	Solar irradiation
K	Temperature Different
K	Temperature Kelvin
K	Turbulent kinetic energy, m^2/s^2
κ	Von Karman’s constant, 0.41

l/s	litre per second
L	Length scale, m
Q_c	Condenser work done kJ/kg
Q_e	Evaporator work done kJ/kg
Q_e	Cooling power
Q_s	Solar power
T_c	Condensing temperature ºC
T_e	Evaporating temperature ºC
TW_{el}	Total Watts of electrical
TW_{th}	Total Watts of thermal
W, kW, kWh	Watts, kilowatts, kilowatt hour,
W/m^2	Watts per square meter
W/m^3	Watts per cubic meter
W	Compressor work done kJ/kg
x	Flash gas %

ABBREVIATIONS

ABM	Australian Bureau of Meteorology, Climate Statistics.
ACORN-SAT	Australian Climate Observations Reference Network – Surface Air Temperature.
AEC	U.S. Atomic Energy Commission
AEL	United Kingdom Atomic Energy Laboratory

AER	Australia Energy Resource.
AFMC	Australasian Fluid Mechanics Conference
ASHRAE	American Society of Heating, Refrigeration and Air Conditioning Engineers.
ASME	American Society of Mechanical Engineers
CFC/HCFC	Chlorofluorocarbon/ Hydro-chlorofluorocarbon.
CFD	Computational Fluid Dynamics.
CLTD	Cooling Load Temperature Different.
CPU	Central Processing Unit
DOS	Daily Observation of Sydney.
ESDU	Engineering Sciences Data Unit, United Kingdom
GWP	Global Warming Potential.
H2O-LiBr	Water- Lithium Bromide
HPHE	Heat-pipes Heat-exchanger
HVAC	Heating, Ventilating, and Air-Conditioning.
IEA	International Energy Agency.
IIF/IIR	International Institute of Refrigeration
IMECE	International Mechanical Engineering Congress and Exposition
LHP	Loop Heat-pipes
NH3-H2O	Ammonia-Water
NTU	Number of Transfer Units
ODP	Ozone Depletion Potential.
PV	Photovoltaic Panel

RANS	Reynolds-Averaged Navier–Stokes Equations
UTS	University of Technology Sydney.

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