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ENERGY SAVINGS IN DOMESTIC REFRIGERATOR USING TWO THERMOELECTRIC MODULES& WATER COOLING OF CONDENSER

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ABSTRACT

The study deals with hybrid refrigerator that combines thermoelectric (TER) and vapor compression refrigeration (VCR) and also entail experimental details of combined VCR & TER system. Objective is to configure hybrid refrigerator by introducing two Peltier modules (TER) in domestic refrigerator and to analyze compressor cycles of conventional refrigerator with TER to increase energy efficiency of vapor compression cycle. For this comparison of standalone VCR and Hybrid VCR+TER system is carried out. A Peltier module of size 4cm×4cm×0.4cm is introduced in the refrigerator cabinet & the effect on energy efficiency in terms of trip time of compressor is recorded. The effect of Air cooled & Water cooled condenser with TER in different structures is also investigated. It is observed that by introducing thermoelectric effect, energy consumption of VCR is reduced by almost 10.92% annually, which accounts for 80 units per year. Thus ultimately improving COP of the hybrid system with better control on temperature over the total run time.

KEYWORDS – Energy Efficiency, thermoelectric effect, energy consumption, savings, Peltier module, Cyclic TER, Intermediate TER.

INTRODUCTION

Refrigerator and air conditioners are the most energy consuming home appliances and for this reason many researchers had performed work to enhance performance of the refrigeration systems. Most of the research work done so far deals with an objective of increasing energy efficiency of domestic devices.

Thermoelectric refrigeration is one of the techniques used for producing refrigeration effect. Thermoelectric cooling could be better alternative for the conventional refrigeration and air conditioning systems due to their distinct advantages. Thermoelectric refrigerators, air conditioners and cooling devices are developed based on Peltier and See beck effect which has experienced a major advances and developments in recent years. This is due to the development in semiconductor materials and devices. As the coefficient of performance of the thermoelectric refrigeration is less when it is used alone, thermoelectric refrigeration is often

used with other methods of refrigeration. In this view Vapor compression system (VCR) is better option to combine with TER system as it gives higher COP values.
Thus it is required to develop such a technology which combines the advantages of VCR and TER i.e. high COP and better temperature control. Hence this desire leads to development of hybrid refrigerator, a combination of VCR and TER technologies.

NOMENCLATURE

COP	Coefficient of performance
CTER	Cyclic Thermoelectric Refrigeration
CWC	Cyclic Water Cooled
DC	Direct Current
I	Current [A]
ITER	Intermediate Thermoelectric Refrigeration
IWC	Intermediate Water Cooled
K	Conduction heat transfer coefficient [$Wm^{-1}K^{-1}$]
P	Input power [W]
Q	Rate of heat transfer [W]
R	Total electrical resistance [Ω]
T	Absolute temperature [^0C]
TER	Thermoelectric Refrigeration
V	Voltage [V]
VCR	Vapour Compression Refrigeration
Z	Figure of merit [1/K]

Subscripts

C	Cold junction side
H	Hot junction side

Greek Letters

α	See beck coefficient [VK^{-1}]

The simplest mode of thermoelectric refrigeration is to use a single-stage thermoelectric device. However, due to the performance limits of thermoelectric materials, a single-stage thermoelectric refrigerator can only be operated over a small temperature range. For example, a commercially available single-stage thermoelectric refrigerator can provide at most a 70 K maximum temperature difference when it’s hot end remains at room temperature. If the temperature ratio between the heat sink and the cooled space is large, a single-stage thermoelectric refrigerator will lose its effectiveness. Thus, the application of two- or multi-stage combined thermoelectric refrigerators is an important method of improving the performance of thermoelectric refrigerators.[1]
Hence Jincan Chen et al [2] compared the performance of single stage and two stage thermoelectric refrigeration system. For this they established cycle model of single and two stage TER system and derived general expressions of three important performance parameters such as COP, Rate of refrigeration and power input.

Jincan Chen et al[2] found maximum COP of two stage is larger than that of single stage but maximum rate of refrigeration is smaller. In general, it is more convenient to use directly a single-stage thermoelectric refrigeration system when the temperature ratio of the heat sink to the cooled space is small. However, when the temperature ratio of the heat sink to the cooled space is larger, both the maximum COP and the maximum rate of refrigeration of a two-stage thermoelectric refrigeration system are larger than those of a single-stage thermoelectric refrigeration system. In such a case, a two-stage thermoelectric refrigeration system should be used. Moreover, the relation between the COP and the rate of refrigeration of a two-stage thermoelectric refrigeration system is discussed. The study of Chen et al. may provide some theoretical bases for the optimal design and operation of a two-stage thermoelectric refrigeration system.[2]

Using reference of the above study a new device with multistage or stack of single stage TE module is fabricated and analyzed by G. Karimi et al.[3] Multi-stage thermoelectric coolers offer larger temperature differences between heat source and heat sink than single or two stage thermoelectric coolers. In the study of G. Karimi et al.[3], a pyramid type multi-stage cooler is analyzed, focusing on the importance of maximum attainable target heat flux and overall coefficient of performance, COP. Having considered the COP and the thermal resistance of a heat sink as key parameters in the design of a multi-stage thermoelectric cooler, analytical formulas for COP and heat sink thermal resistance versus working electrical current are derived. The study concludes that multistage TER system allows use of heat sink with higher thermal resistance which helps in improvement of COP.[3]

Gao Min et al. (2006)[4]investigated number of prototype thermoelectric refrigerators and their cooling performances evaluated in terms of the coefficient-of-performance, heat-pumping capacity and cooling-down rate. The coefficient-of-performance of a thermoelectric refrigerator is found to be around 0.3–0.5 for a typical operating temperature at 50^0 C with ambient at 250^0 C. The potential improvement in the cooling performance of a thermoelectric refrigerator is also investigated employing a realistic model, with experimental data obtained from this work. The results show that an increase in its COP is possible through improvements in module contact resistances, thermal interfaces and the effectiveness of heat exchangers. The energy efficiency of thermoelectric refrigerators, based on currently available materials and technology, is still lower than its compressor counterparts. However, a marketable thermoelectric refrigerator can be made with an acceptable COP. [4]

Goktun et al (1992)[5]revives design methodology by considering irreversibility in thermoelectric module caused by electrical resistive losses. Defines new parameter called device design parameter which characterized both internal and external irreversibility. It has been shown that the internal and external irreversibility in a thermoelectric refrigerator can be characterized by a single parameter X, named the device-design parameter. This parameter appears in both the equation for optimum refrigeration effect and maximum input power.[5]

Jiajitsawat et al (2012) [6]performed work with objective of theoretically and experimentally investigate the feasibility of employing a thermoelectric refrigeration system to improve the air-cooling performance of a portable DEAC system. A portable hybrid thermoelectric-direct evaporative air cooling system has been fabricated and tested. A portable hybrid thermoelectric-direct evaporative air cooling system can improve the cooling performance of DEAC system by 10% & up to 20% with higher fan speed. 2.6 degrees of temperature drop. The concept of applying TE to cool the water is reliable and possible for commercial development.[6]

Experimentation

As per the objectives listed, first task is to configure the hybrid refrigerator by introducing Peltier module in domestic refrigerator. As shown in **Error! Reference source not found.** Peltier module is to be fixed on separator of freezer & cooler section in refrigerator. In this particular configuration, cold side of the module is inside the cooler compartment of refrigerator and hot side is exposed to atmosphere. Similarly, different configurations are to be made and tested simultaneously for better COP of the module. Seven thermocouples are to be placed according to the positions given in setup diagram.

Where,
T_1= Temperature of Compressor suction
T_2= Cabinet temperature.
T_3= after condenser
T_4= after expansion
T_5= Atmosphere temperature
T_6= Temperature of Freezer section
T_7= Temperature of Compressor discharge

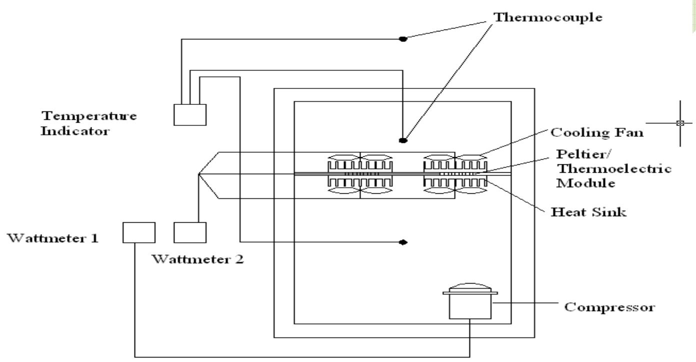

Figure 1Schematic Diagram of Experimental setup (Front view)

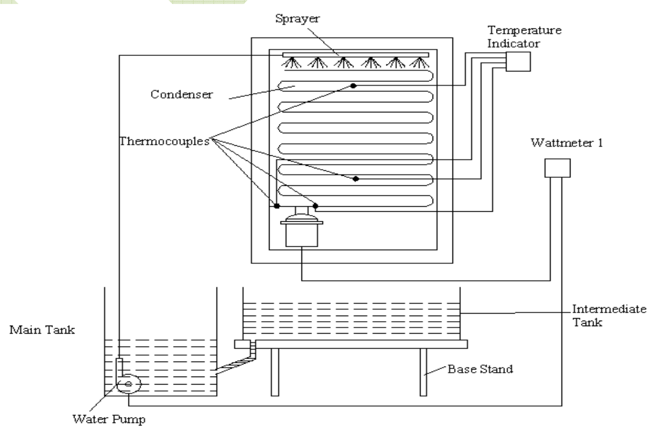

Figure 2Schematic Diagram of Experimental setup (Back view)

To develop the setup for the experiment 2 configurations are taken into consideration:
Structure I: Cold side of the module is exposed to cooler compartment while hot side is placed in freezer compartment.
Structure II: Hot side is placed in cooler compartment & cold side is in freezer compartment.

In order to achieve above said objectives following procedure is followed and observations are taken:

Experimental Procedure

Experiment with standalone VCR

- Turned on the refrigerator & noted down the initial temperatures.
- Waited for compressor to trip for & noted down the time as well as corresponding temperatures.
- Then observed every trip cycle of the compressor & readings are recorded.
- Procedure is carried out for the span of 6 hours.

Similar procedure is carried out for experiment in combination with TER system in structure 1 & structure 2.

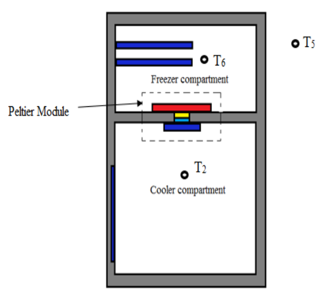

FIGURE 3EXPERIMENTAL SETUP IN STRUCTURE I

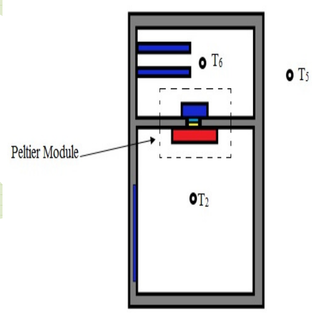

FIGURE 4EXPERIMENTAL SETUP IN STRUCTURE II

Some important terms

- Cyclic TER: Energy supplied to TE Module from start of the compressor
- Intermediate TER: TE module is kept on during trip time only.
- AC & WC: Air Cooled condenser & Water Cooled Condenser.
- Cyclic WC: Water pump is put on from start of the compressor.
- Intermediate WC: Water pump on during trip time only.
- Alternate structure: One module in structure 1 & other in structure 2, while using Two modules for operation

OBSERVATIONS

- Compressor work input: 110 W
- TE module input: 20 W
- Water Pump input: 20 W

METHODOLOGY

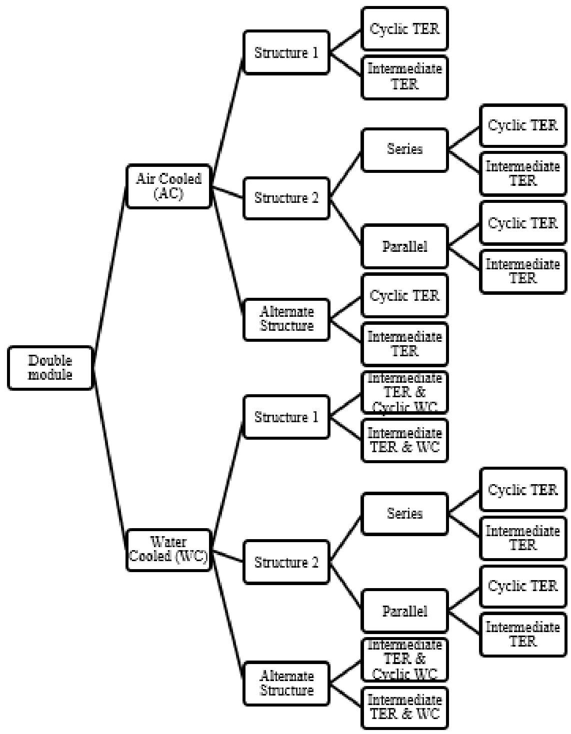

Figure 5 Experimentation methods for single TE module

Analyzing Energy Consumption

Energy consumption is determined by calculation of total run time for compressor, TE module & water pump. Energy consumed by these three devices is calculated in terms of units (KWh) for a period of 24 hours i.e. KWH/day.

Therefore, (For span of 6 hours)

Energy Consumed by Compressor/Day (E_{Comp}) = Compressor Input (KW) × Run Time (hours) × 4

Energy Consumed by TE Module/Day (E_{TE}) = TE Module Input (KW) × Run Time (hours) × 4

Energy Consumed by Water Pump/Day (E_{Pump}) = Water Pump Input (KW) × Run Time (hours) × 4

Total Energy Consumption = $E_{Comp} + E_{TE} + E_{Pump}$

Analyzing COP of hybrid system:

The coefficient of performance is determined from the P-H chart by plotting temperature & pressure values observed during experimentation. For this we assumed suction pressure of the compressor as 0.97 bars & discharge pressure is calculated from the formula of temperature ratios.

$$P_2 = P_1\left(\frac{T_2}{T_1}\right)^{\frac{\gamma}{\gamma-1}}$$

Using this equations & values of pressure & temperature we have plotted refrigeration cycle on P-H chart of R-12 refrigerant. Reading the corresponding enthalpy value, COP is calculated by the formula,

$$COP = \frac{h_1 - h_4}{h_2 - h_1}$$

Table 1 Result Table

Process	Comp Run Time (mins)	TER Run Time (mins)	Water Pump Run time (mins)	Total Energy Cons (units)KWh	Energy Cons/Day KWh	COP (From P-H Chart)
Structure 1, ITER	283	77	0	0.5445	2.178	2.134
Structure 2, ITER	227	133	0	0.4605	1.842	2.545
Structure 3, ITER	260	100	0	0.51	2.040	2.014
Structure 1, ITER & CWC	280	80	360	1.2	4.800	1.905
Structure 1, ITER & IWC	239	121	121	0.70033	2.801	2.015
Structure 2, ITER & CWC	266	94	360	1.179	4.716	2.225
Structure 2, ITER & IWC	225	135	135	0.705	2.820	2.635
Structure 3, ITER & CWC	275	85	360	1.1925	4.770	1.954
Structure 3, ITER & IWC	235	125	125	0.70167	2.807	2.063

RESULTS & DISCUSSION

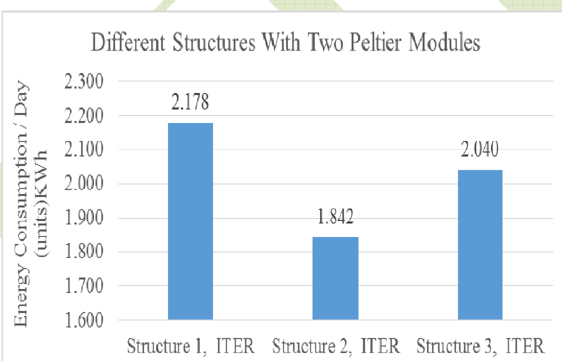

Figure 6 Energy Consumption with different methods with Air cooled

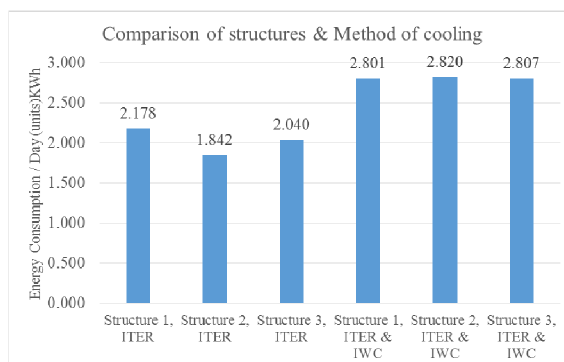

Figure 7 Comparison of Structures with Air cooled& water cooled

Figure 6 shows the comparison of structures with different methods of experimentation for Air cooled condenser. Here Structure 2 with intermediate power supply gives better energy efficiency as it consumes 1.842 units per day compared to Structure 1 system which consumes 2.178 units. Structure 3&intermediate power supply consumes energy in between Structure 1& Structure 2 system.

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Figure 7 shows the comparison of structures with different cooling method for condenser, in which again Structure 2 with intermediate power supply seems to be superior. In case of water cooled condenser pump consumes additional units of energy which leads to greater energy consumption.

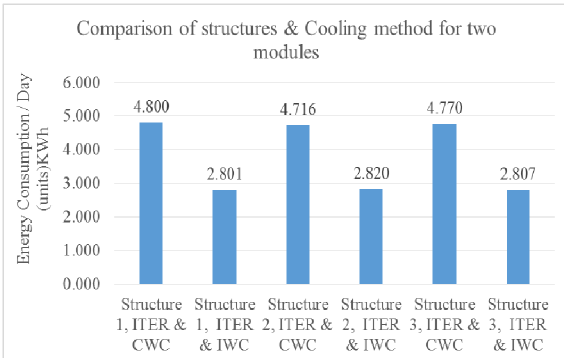

Figure 8Energy consumption with different structures & water cooled

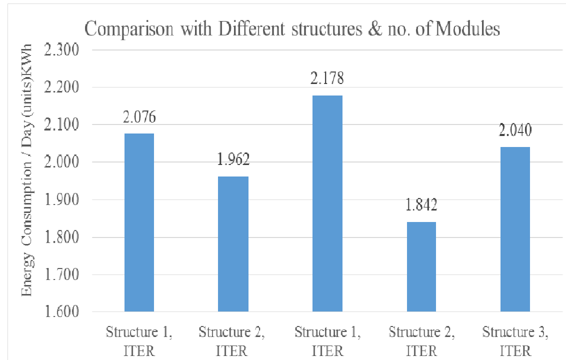

Figure 9Comparison with different structures & no. of modules

Also Figure 8 shows that intermediate supply to TER is efficient to reduce the energy consumption. Water cooled condenser doesn't have any useful impact on the energy efficiency of refrigerator.

Figure **9** shows the comparison between different structures when used with single & two Peltier modules. By using two modules in structure 2 energy efficiency of domestic refrigerator is greatly increased.

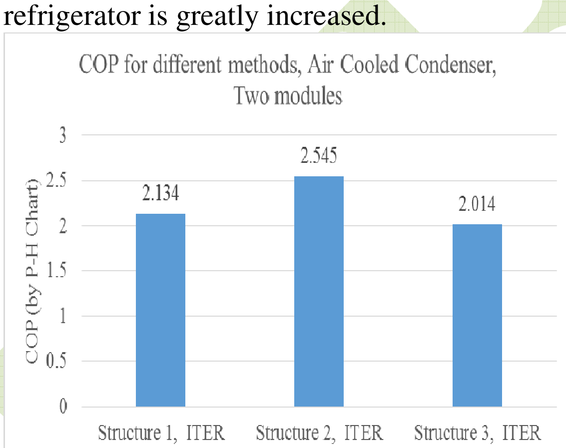

Figure 10 COP for different structures with Air Cooled condenser

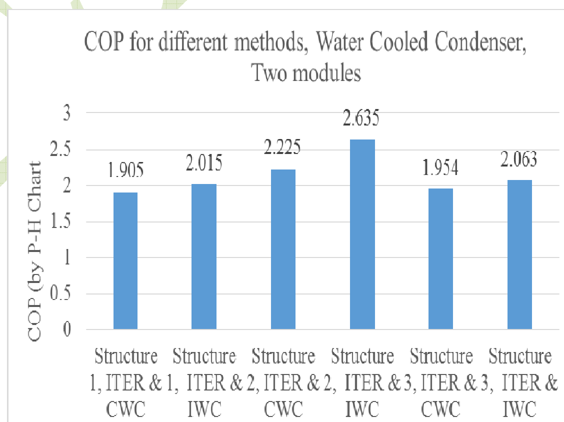

Figure 11 COP for different structures with Water Cooled condenser

Figure 10&Figure 11 shows the COP variation in different methods of experimentation with Air cooled & Water cooled condenser. COP is calculated from the P-H chart & corresponding values of temperature & pressure. From both the graphs we can say that COP is increased in case of TER with structure 2 & intermediate supply.

CONCLUSION

Present study deals with hybrid refrigerator that combines thermoelectric (TER) and vapor compression refrigeration (VCR) and also entail experimental details of combined VCR & TER system. Comparison of standalone VCR and Hybrid VCR+TER system with air cooled & Water cooled condenser is carried out. Two Peltier modules of size 4cm×4cm×0.4cm is introduced in the refrigerator cabinet & the effect on energy efficiency in terms of trip time of compressor is recorded. The effect of Air cooled & Water cooled condenser with TER in different structures is also investigated.

It is observed that by introducing Peltier module during compressor trip time, run time of compressor is reduced. Out of two structures, structure 2 gives fairly good results. Using Peltier module in structure 2 intermediate supply & air cooled condenser, energy reducedto increased up to 10.92% and almost 80 units of reduction per year compared to standalone VCR. As the refrigerator used for the experimentation is of old technology using R-12 as a refrigerant, reduction in consumed units can be increased up to 100-110 units per year in modern refrigerators. We can say that structure 2 with intermediate operation & air cooled condenser is best possible location of Peltier module in refrigerator.

The study of this paper also concludes that, to achieve better COP & temperature control we can combine TER with VCR systems. Hence it is better to have such hybrid systems & devices to reduce total energy consumption.

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