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Controversial Second Law of Thermodynamics in the Application of Refrigeration Systems

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***Abstract*—There are two parts of the 2nd law of thermodynamics (Clausius statement), the first states, “Heat energy transports from a high temperature body to a low temperature body in nature” and the second states, “heat energy can be pushed in reverse (from low temperature to high temperature) if external work is applied.”**

This research has reported that the statement, “heat energy can be pushed in reverse (from low temperature to a high temperature) if external work is applied”, seems erroneous. This paper demonstrates that heat energy cannot travel from low temperature to high temperature in nature even if an external source is applied.

This is demonstrated by a refrigeration cycle in which work is done to create the conditions where heat is transferred naturally from a higher temperature to a lower temperature in accordance with the natural process. This experiment is conducted on the Lab-Volt Refrigeration Vapor Compression System.

Keywords— Thermal Energy, Second Law of Thermodynamics, Refrigeration Compression Cycle, Refrigerant, Refrigerator

I. INTORDUCTION

Thermodynamics is the science of energy and contracts with the amount of heat transfer .It deals with equilibrium states and changes from one equilibrium state to another. There are several principal laws of thermodynamics involved in this branch of physics. These laws of thermodynamic lay the framework for the science of heat transfer. The Zeroth Law states that if two bodies are in thermal equilibrium with some third body, then they are also in equilibrium with each other.[1] The first law requires that the rate of energy transfer into a system be equal to the rate of increase of the energy of that system. The second law requires that heat be transferred in the direction of decreasing temperature due to the presence of temperature difference in nature and can be pushed in reverse if external work is applied.[2] The third law states that the entropy of a pure crystal at absolute zero is zero. The second law of thermodynamics is one of the most fundamental laws of nature that heat flows spontaneously from a hotter region to a cooler region.

Various in-depth researches on the second law of thermodynamics have been carried out in detail, the succeeding authors and numerous others have focused on the various significant aspects of this law but did not address that, even external work cannot push heat energy from a low temperature region to a high temperature region.

Joseph[3] discussed that Clausius, the German mathematical physicist who probably did the most to cast thermodynamics on a scientific basis, gives a more precise statement of the second law: Second law of thermodynamics: “Heat cannot, of itself, pass from a colder to a hotter body. Max Planck[4] described that in one case the heat falls from a higher to a lower temperature, and in the other the heat transfer can take place low to high temperature body but using some external work, is denoted as the second fundamental principle of energies. The Cengel and Boles[5] explained Clausius statement, which is related to refrigerators or heat pumps. The Clausius statement is expressed that it is impossible to construct a device that operates in a cycle and produces no effect other than the transfer of heat from a lower-temperature body to a higher-temperature body until employing of external work. W. Ma et al.[6] reported a second-law-based analysis of the vapor-compression refrigeration cycle (VCRC), which leads to a set of explicit theoretical formulas for the coefficient of performance (COP). Grazzinig and Brochette[7] discussed and analyzed, an irreversible inverse cycle, operating at steady state conditions with finite thermal capacity heat sources, in order to obtain an expression for the coefficient of performance accounting for the Second Law. A graphical analysis, based on data from literature, is presented to show the use of this thermodynamic optimization criteria in design and verification process of refrigerators. H. Tan et al[8] presented a theoretical analysis based on the second law of thermodynamics to evaluate the optimal performances of a single-stage thermoelectric cooling system. H. Su et al[9] has established a thermodynamic model of an irreversible Carnot refrigerator with heat recovery (CRHR) working between two high temperature reservoirs (TH and TR) and one low temperature heat reservoir (TL) has for optimization of allocation of heat transfer areas. A numerical example of the CRHR has been studied and the effect of the heat leakages (q and q_0) and internal irreversibility factor (U) have been analyzed. W. Ma et al.[10] reported a second-law-based analysis of the vapor-compression refrigeration cycle, which leads to a set of explicit theoretical formulas for the coefficient of performance (COP). These analytical expressions provide a fast and accurate approach to computer simulations of the vapor-compression cycle without recourse to thermodynamic diagrams or equations of state. Uçkan et al[11] evaluated the potential of a desiccant based evaporative air conditioning system, a second law analysis of the systems was investigated. In this work, a wide range of working parameters that are regeneration temperature from 90 ^{0}C to 110 ^{0}C, volume flow rate from 2000 m^3 to 4000 m^3 and ambient air conditions which are relative humidity, ambient air temperature and wet-

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bulb temperature is carried out for performance calculation of the system. It is observed from results that the Carnot coefficient of performance (COP) and the thermal coefficient of performance (COP) of the system varies vice versa during the day. Robert[12] talked that second law of thermodynamics is stated as the existence of an extensive function of state called the entropy that can only increase for an isolated system. He discussed Carnot Cycle and Engines. G. Alefeld[13] reported the efficiencies of compressor heat pumps and refrigerators are usually calculated by enthalpy balances. Complete and accurate enthalpy diagrams are needed. Starting from the Second Law of Thermodynamics an alternative calculation method yielding analytic equations for the coefficient of performance have been derived. John[14] concludes with an historical survey of characterizations of thermodynamically reversible processes and a critical analysis of their shortcomings. John discussed that no single process, that is, no system undergoing change, equilibrium or otherwise, carries those limiting properties. Author discussed the heat can flow from low temperature to high temperature source using external source. Afif Akel et al.[15] discussed the combined power and refrigeration cycle was mathematically optimized using the second law efficiency. The first and second laws of thermodynamics were used to analyze a novel thermodynamic cycle proposed by Goswami in 1995 that uses an ammonia–water binary mixture as the working fluid, while producing both power and refrigeration simultaneously. Zubair et al.[16] reported thermodynamic analysis of HFC-134a vapor-compression refrigeration cycles is investigated by both the first and second laws of thermodynamics. Second-law analysis is carried out for both two-stage and mechanical-sub cooling refrigeration cycles. The analysis is performed on each of the system components to determine their individual contribution to the overall system irreversible losses. It is found that most of the losses are due to a low compressor efficiency. Salah[17] has developed the optimal design of refrigerators and heat pumps. The results show that there is an optimum balance between the sizes of the heat exchangers at the hot and cold ends of the machine which maximize the rate of heat removed by a refrigerator or the rate of heat delivered by a heat pump.

Irfan et al.[18] reported in this article a second-law-based analysis. It is discussed the cooling capacity has significant effect on the second law efficiency. The importance of this study shows that the second law analysis can provide useful information with respect to the theoretical upper limit of the system performance, which cannot be obtained from the first law of thermodynamic analysis alone. Ya-Ling et al.[19] reported in this paper a comprehensive performance analysis on the three generations of pulse tube refrigerator (PTR) is conducted based on the first and second law of thermodynamics. Detailed dynamic characteristics of the thermodynamics, flow and heat transfer processes in the PTR were revealed, including the dynamic pressure variations, transient gas temperature, and mass flow rate in the PTR. W. Chen et al.[20] investigated a second law analysis of the systems. The thermodynamic performance of a proposed split-type vapor compression refrigerator (SVCR) for heat hazard control in a deep mine was numerically analyzed. The thermodynamic characteristics of the suction process of the proposed system were also simulated and analyzed. Ali Kodal et al.[21] has performed a performance analysis, based on the thermo economic criterion for an irreversible refrigerator and a heat pump. The paper has focused on second law of thermodynamic principle and talked about the heat flow from the refrigerator to the heat sink using external source. Chen Lingen et al.[22] discussed a classical end reversible Carnot refrigeration model, irreversibility in the form of heat resistances between the reversible Carnot cycle and its heat reservoirs is taken into account. An optimization analysis of the model has been carried out that allows assessments of the effects of the various irreversibilities on the performance of the cycle. Numerical examples are given to illustrate the practicality of the model. Author addressed needed external work while flowing heat energy from low temperature source to high temperature. Jitao[23] described an achievement of thermodynamics has influence not only on natural sciences, but also on social sciences and philosophy. Author is suggested that extended Carnot theorem and dissipation decrease theorem, together with the laws of thermodynamics, are the most fundamental theorems in thermodynamics discipline.

In refrigeration and air-conditioning systems, it is misinterpreted that heat moves from a low temperature to a high temperature reservoir (evaporator, in the application of refrigeration), by applying external work (compressor, in the application of refrigeration). The fact is, the compressor is an external source which is only driving the refrigerant towards the evaporator.

The objective of this study is to highlight that it is impossible for heat energy to transfer from low temperature body to high temperature body even if an external source is used. Various significant aspects of the second law of thermodynamic have been discussed by many authors, but this area has not been discussed.

II. THEORY

There are various types of refrigeration compression machines that are used for refrigeration for example, window A/C, split A/C, chiller, cold storage, freezers, and etcetera. The refrigeration (cooling) process takes place with the combination of four main components; compressor, condenser, refrigerant control and evaporator. The various refrigerants like HFC-134a (Tetra fluoroethane, CH2FCF3), HCFC-22 (Monochloro difliuoromethane, $CHClF_2$) are used to pick up heat. These refrigerant undergoes phase transitions from a gas to a liquid and back again.[24] Like other ozone free refrigerants e.g. 134a (Tetrafluoroethane) is known as a very good refrigerant with thermodynamic properties similar to R-12 (dichlorodifluoromethane) but with insignificant ozone depletion potential and a somewhat lower global warming potential. It is very good replacement of R-12.[25]

The function of the compressor is to take refrigerant vapour at a low temperature and pressure and raise it to a higher temperature and pressure. Condenser is used for removing heat from the refrigeration system. It converts high temp and pressure refrigerant vapors to high temp & pressure liquid refrigerant by removing latent heat of condensation.

Refrigerant control or metering device is employed to regulate the flow of refrigerant and to establish two pressure zones. It converts high temp and pressure refrigerant liquid to

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a low temp & pressure liquid refrigerant by throttling the refrigerant.

Evaporator is used for absorbing heat from the refrigeration system. It converts low temp and pressure refrigerant liquid to low temp & pressure refrigerant vapors by absorbing latent heat of vaporization due to temperature difference, as refrigerant HFC134a (Tetrafluoroethane, CH2FCF3) passes through evaporator at very low temperature while evaporator cabinet temperature remains higher as compared to refrigerant temperature. This is why heat transfers from evaporator cabinet to the refrigerant which changes phase from liquid to vapor[26].

The ideal refrigerant flow process is displayed subsequent on vapor-compression refrigeration cycle and Pressure enthalpy diagram[27] as shown in Fig.01 and 02.

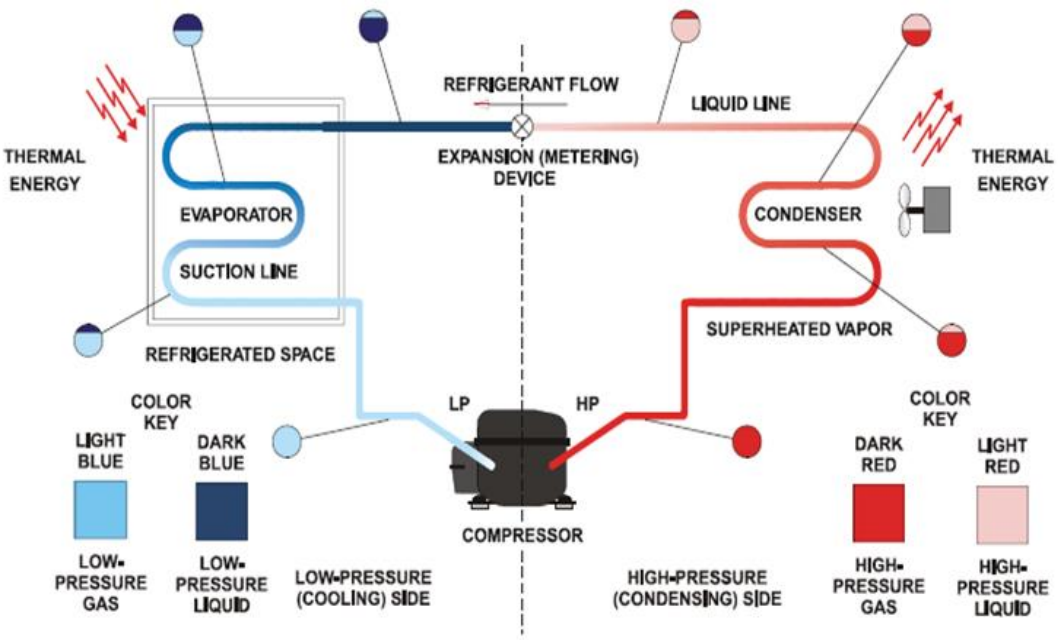

Fig.01. Refrigerant flow process in Refrigeration cycle

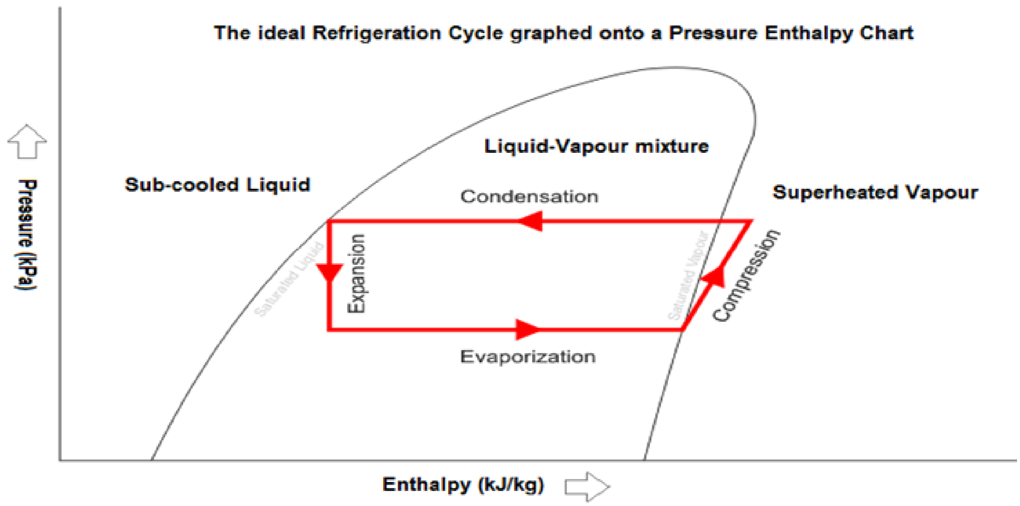

Fig.02. Refrigerant flow process in Refrigeration cycle on Ph diagram

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Hence, the external source (compressor) maintains the two pressure zones and pushes the refrigerant to carry the heat energy due to the temperature difference. During the evaporating process the refrigerant's boiling temperature is very low and the evaporator cabinet's temperature is set at a high temperature. This creates a temperature difference and heat energy flows from evaporator cabinet to refrigerant. Therefore, heat transfer takes place from high temperature to low temperature in both processes (condenser and evaporator). That is why it is impossible for heat energy to transfer from a low temperature body to a high temperature body even if an external source is used.

III. METHOD/CALCULATIONS

The Lab-Volt Refrigeration Vapor Compression Training System has used for experiment to check the means of heat transfer during evaporator and condensing process. This training system consists of refrigeration components, as well as instrumentation and control components. The Refrigeration Training System is intended for use with the Lab Volt Heating, Ventilating, and Air Conditioning (LVHVAC) software, which permits the real-time monitoring of the system variables.

This system consist of four main components hematic compressor, mechanical air cooled condenser, refrigerant control and air cooled evaporator as shown in Fig. 03 and 04. There are also installed mechanical and electrical accessories and several temperature sensors.

The test points T1 through T7 all provide a proper temperature reading, which approximately corresponds to the room temperature. This occurs because the associated temperature transmitters are currently powered via the USB cable between the Training System and the computer.

The training system has run and several experimental data has been collected. It is observed that compressor as an external source is pushing the refrigerant and maintaing low and high pressure zones but heat transfer is taking place only from higher temperature to low temperature during evaporating process in the evaporator and condensing process in the condenser.

Fig.03 & 04. Lab-Volt Refrigeration Vapor Compression System (front & rear view)

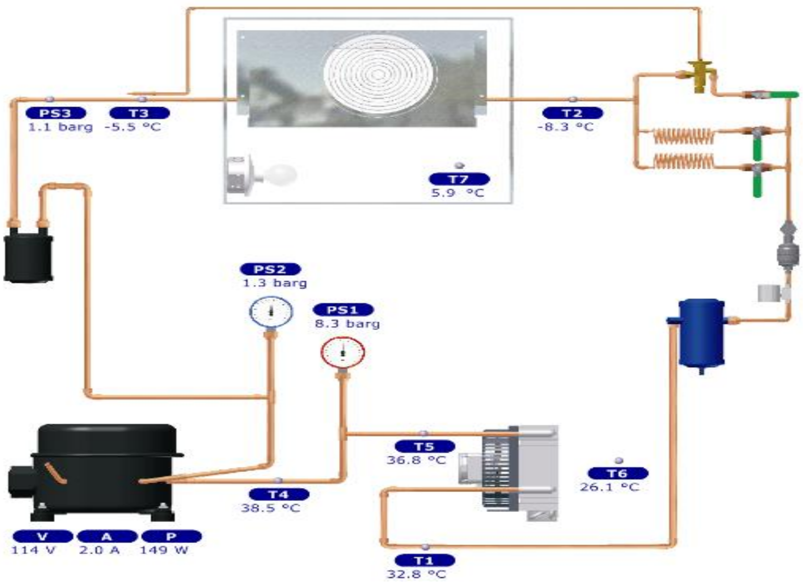

Fig.05. T1 - T7, Temperatures monitoring on refrigeration cycle (Lab-Volt)

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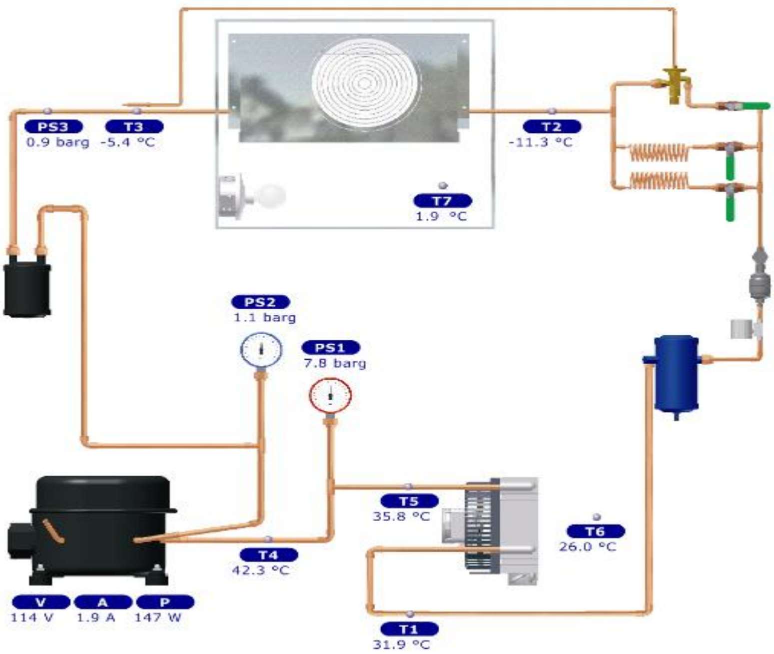

Fig.06. T1 - T7 temperatures monitoring sensors on refrigeration cycle (Lab-Volt)

IV. RESULTS

The subsequent refrigerant thermodynamic properties' data has been recorded during experiment as presented in table-01 and Fig.07. It is observed that heat energy (Q) is not being pushed from low temperature to higher temperature in the evaporator. Heat energy is transferring from evaporator cabinet to the refrigerant as it is at very low temperature as compare to evaporator cabinet. The compressor as an external source is only driving the refrigerant towards the evaporator and then other main parts of refrigeration system consequently. Similarly, the heat energy is getting transferred from higher to lower temperature in condenser as ambient air is at low temperature while refrigerant temperature at condenser is high, as displayed in table-02 and Fig.07. The refrigerant effect (heat absorbed in the evaporator) and heat of condensation (heat rejection in the condenser) can only be possible if the heat energy flows from high temperature to low temperature as shown in table-01 and 02 using the subsequent equations (01) and (02).

$$RE = h3 - h2 \qquad (01)$$

$$HRC = h5 - h1 \qquad (02)$$

	T7(^{0}C) Evaporator Cabinet Temperature	T2(^{0}C) Refrigerant Evaporator Entering Temperature	h2(kJ/kg) Refrigerant Evaporator Entering Enthalpy	T3(^{0}C) Refrigerant Evaporator Leaving Temperature	h3(kJ/kg) Refrigerant Evaporator Leaving Enthalpy	RE(kJ/kg) Refrigerant Effect (Heat Absorbed in Evaporator
Sample 1	5.9	-8.27	245.85	-5.46	395.38	149.53
Sample 2	1.9	-11.32	244.48	-5.44	395.39	150.91
Sample 3	0.1	-12.84	244.00	-7.65	394.08	150.08
Sample 4	-0.6	-13.16	243.37	-6.55	394.73	151.36
Sample 5	-1.9	-14.50	242.84	-8.17	393.76	150.92

Table 01. Refrigerant's thermodynamic properties & heat absorbed in evaporator

	T6(^{0}C) Ambient Air Temperature entering Condenser	T5(^{0}C) Refrigerant Condenser Entering Temperature	h5(kJ/kg) Refrigerant Condenser Entering Enthalpy	T1(^{0}C) Refrigerant Condenser Leaving Temperature	h1(kJ/kg) Refrigerant Condenser Leaving Enthalpy	HRC(kJ/kg) Rate of Heat Rejection in Condenser
Sample 1	26.1	36.80	418.01	32.84	245.85	172.16
Sample 2	26.0	35.78	417.55	31.90	244.48	173.07
Sample 3	25.9	36.15	417.72	31.14	243.37	174.35
Sample 4	25.8	36.22	417.75	32.16	244.85	172.9
Sample 5	25.83	36.50	417.87	30.77	242.84	175.03

Table 02. Refrigerant's thermodynamic properties & heat rejection in condenser

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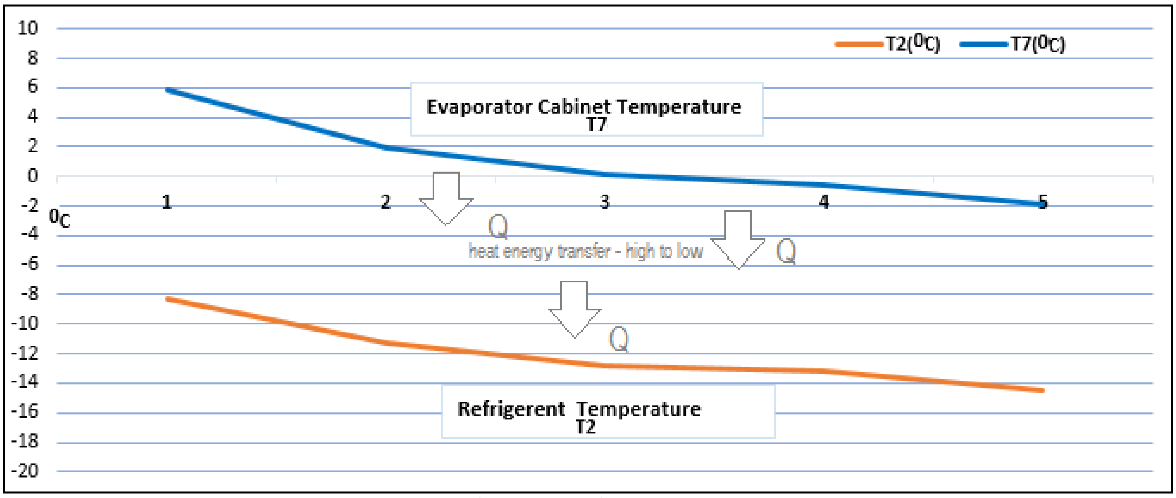

Fig.07. Heat transfer between refrigerant & evaporator cabinet

V. DISCUSSION

The purpose of this discussion is to highlight the main point of this study, the misconception of the second law of thermodynamics, which states that heat does flow in the opposite direction, from a low temperature body to a high temperature body, if external work is applied. (In the case of refrigeration systems).

In a refrigerator during the condensation process in the condenser, the heat energy transfers from high temp to low temp as shown in figure-8 which satisfies the first part of the thermodynamic law that states "Heat energy transports from a high temperature body to a low temperature body"
It is said, during the evaporation process in the evaporator, in the refrigerator heat energy can be pushed in reverse if external work (compressor) is applied.
This paper reports that heat energy cannot be pushed from low temperature to higher temperature in the evaporator even if an external device is used. Refer Fig 08&09, the refrigerant is delivered at a very low temperature (-8.3 ^{0}C), which is below than the evaporator cabinet temperature (5.9 ^{0}C), hence energy transfer takes place from high temperature region (in this case, Evaporator cabinet) to low temperature region (in this case, refrigerant). The compressor is an external source which is only driving the refrigerant towards the evaporator as shown in figure-05.
Therefore, if we want to cool or freeze the product in the refrigerator, we will have to pass the refrigerant at a lower temperature than the evaporator cabinet temperature which removes the heat energy from the cabinet (Heat transfer from high (cabinet) to low (refrigerant)).

At a glance it seems like the heat from the refrigerator is travelling from low temperature body (cabinet) to high temperature body (outside environment) using external work, but in reality that is not the case, the heat from the cabinet is transferred to the refrigerant, which is then transferred outside to the environment, throughout this whole process heat is always being transferred from a high temperature body to a low temperature body.

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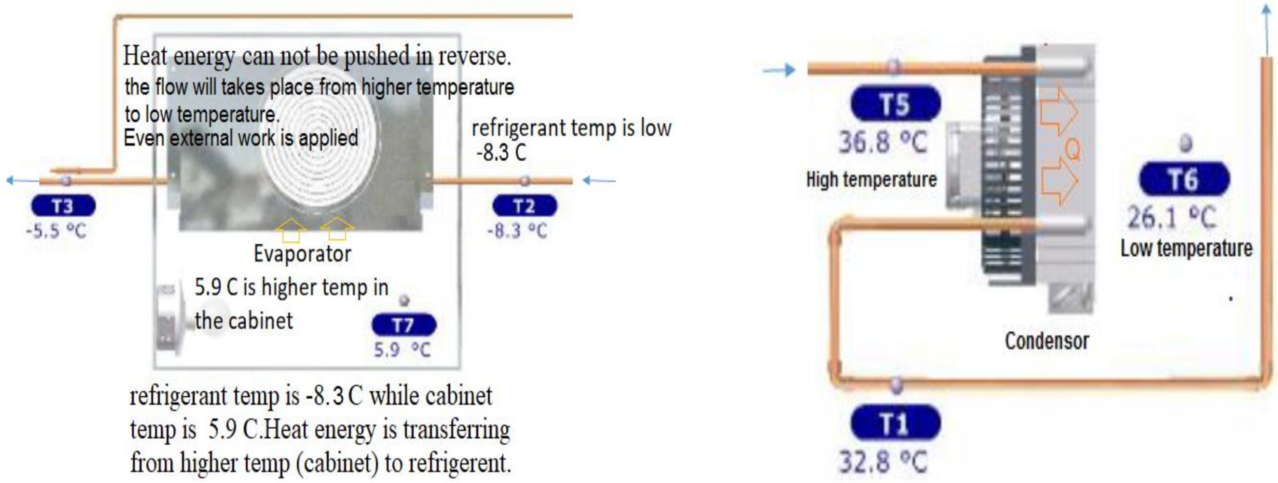

Fig.08 & 09. Heat transfer process in evaporator & condenser.

VI. CONCLUSION

The heat energy transport from high temperature body to a low temperature body in nature. Heat transfer cannot be reversed i.e. from low temperature body to a high temperature body, and this has been explained by the experiment and in the discussion section.

VII. VARIABLES AND ACRONYMS

ASHRAE: American Society of Heating, Refrigerating and Air Conditioning Engineers
A/C: Air Conditioner
AHU: Air Handling Unit
COP: Coefficient of Performance
CRHR: Carnot Refrigerator with Heat Recovery
FCU: Fan Coil Unit
HFC-134a: Tetra fluoroethane
HCFC-22: Monochloro difliuoromethane
HRC: Rate of Heat rejection in Condenser, kJ/kg
h: Enthalpy, kJ/kg
LVHVAC: Lab Volt Heat, Ventilating, and Air Conditioning software
PTR: Pulse Tube Refrigerator
Q, q: Heat energy, kW, kJ/s
R-12: Dichlorodifluoromethane
RE: Refrigerant Effect, kJ/kg
SVCR: Split-type Vapor Compression Refrigerator
TH: High Temperature Reservoirs
TL: Low Temperature Reservoirs
T1 to T7: Various Refrigerants, Condenser and Evaporator, Ambient Temperatures, ^{0}C
USB: Universal Serial Bus
U: Internal Irreversibility Factor (Over all coefficient pf performance)
VCRC: Vapor-compression Refrigeration Cycle

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