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Heat Transfer Analysis Using Solar Panel with Forced and Natural Convection Methods

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A B S T R A C T

The sun provides an abundant source of energy, which can be harnessed through the use of solar panels to produce electricity. When photons of light from the sun strike the photovoltaic cells within the solar panel, they generate an electric current. However, losses occur during this process, with one of the most significant being the production of heat beneath the panel, which can reduce its efficiency. To counteract this, fluid is circulated through the ducts beneath the panel to absorb the heat and transfer it away. This convective heat transfer process can increase the power output of the solar panel beyond its typical levels.

Keywords: solar panel, photovoltaic cells, sunlight, and convection.

1. Introduction

Solar energy is an important renewable energy source that encompasses both radiant light and heat from the sun. Numerous technologies are available to tap into solar energy, including solar heating, photovoltaics, solar thermal energy, solar architecture, molten salt power plants, and artificial photosynthesis. Active and passive solar techniques are used to capture and distribute solar energy and convert it into solar power. Examples of active solar techniques include photovoltaic systems, concentrated solar power, and solar water heating, while passive solar techniques involve orienting buildings towards the sun, using materials with favorable thermal mass or light-dispersing properties, and designing spaces that encourage natural air circulation.

Solar energy is a highly attractive source of electricity due to its vast potential. According to the United Nations Development Programme's 2000 World Energy Assessment, solar energy has an annual potential of 1,575-49,837 exajoules (EJ), which is several times greater than the world's total energy consumption of 559.8 EJ in 2012.

The importance of developing affordable, clean, and renewable solar energy technologies was acknowledged by the International Energy Agency in 2011. Such technology could provide long-term benefits by increasing a country's energy security with the use of a domestically available, renewable resource that is mostly independent of imports. Furthermore, it could help to reduce pollution, promote sustainability, and lower energy costs.lower the costs of mitigating global warming, and keep fossil fuel prices lower than they would otherwise be. These benefits are global and should be considered as wise investments in learning. The costs of incentives for early deployment must be widely shared and used appropriately.

The upper atmosphere of Earth receives an estimated 174 petawatts of solar radiation, with approximately 30% being reflected back to space and the remainder absorbed by the planet's land masses, oceans, and atmosphere. The visible and near-infrared ranges make up most of the solar spectrum at the Earth's surface, with a small portion in the near-ultraviolet range. The insolation levels for most of the world's population range from 150-300 watts/m² or 3.5-7.0 kWh/m² per day.

Solar radiation is absorbed by Earth's land masses, oceans, and atmosphere, which leads to atmospheric circulation and convection. The evaporated water from the oceans creates warm air that rises, and when it reaches a high altitude, the temperature is low enough for water vapor to condense into clouds. The process of water condensation can intensify convection, resulting in various atmospheric events, such as wind, cyclones, and anti-cyclones. Green plants use photosynthesis to convert solar energy into chemically stored energy, which produces biomass, food, and wood, and is the source of fossil fuels.

The total amount of solar energy that is absorbed by the Earth's atmosphere, oceans, and land masses each year is estimated to be around 3,850,000 exajoules. Of this energy, approximately 3,000 EJ is captured through photosynthesis and converted into biomass. The amount of solar energy that reaches the planet's surface is so immense that it is believed to be twice as much as the total energy that can be obtained from all other sources, including fossil fuels, nuclear power, and renewable sources such as wind and hydro power.Solar power can be generated through photovoltaics or concentrated solar power, which uses lenses or mirrors and tracking systems to focus sunlight into a small beam.

Solar power has been experiencing rapid growth in recent years, and it is predicted to become the largest source of electricity globally by 2050. Solar photovoltaics and concentrated solar power are expected to contribute 16% and 11%, respectively, to the world's overall consumption. As of 2016, solar power generated 1.3% of global power.

Solar power has been growing rapidly in recent years and is expected to continue its growth trajectory in the future. According to projections, solar power is expected to become the world's largest source of electricity by 2050, with solar photovoltaics and concentrated solar power contributing 16% and 11%, respectively, to the global overall consumption. In 2016, solar power generated 1.3% of global power, indicating its increasing significance as a source of renewable energy.

A solar cell or photovoltaic cell is a device that changes light energy into electricity. Photovoltaics are best known as a method for making electricity by using solar cells to change energy from the sun into a flow of electrons. This solar cell works on the principle of photovoltaic effect. The photovoltaic effect is the creation of voltage and electric current in a material upon exposure to light and it is a physical and chemical property/ phenomenon.

2. Methodology :

Heat is the transfer of thermal energy from one object to another due to a temperature difference between them. This transfer occurs across a well-defined boundary around a thermodynamic system.The thermodynamic free energy of a system is the amount of work it can perform, while enthalpy is the sum of the internal energy of the system plus the product of pressure and volume. The unit of energy, work, or the amount of heat is the joule.

Heat transfer is a process function, meaning that the amount of heat transferred in a thermodynamic process that changes the state of a system depends on how that process occurs, not just the net difference between the initial and final states of the process.

Classification of heat transfer:

Heat transfer is classified into three types they are

- Conduction
- Convection
- Radiation

CONDUCTION:

Thermal conduction refers to the process by which heat is transferred through the microscopic collisions of particles and movement of electrons within a body, without any net transfer of matter. This transfer of energy occurs due to the disorganized microscopic kinetic and potential energy of molecules, atoms, and electrons, also known as internal energy. Conduction can take place in all phases of matter including solids, liquids, gases, and waves. The rate at which heat energy is conducted between two bodies is dependent on the temperature gradient between them and the properties of the conductive medium through which the heat is being transferred. Originally known as diffusion, thermal conduction is also referred to as the transfer of heat through direct contact.

Heat naturally flows from a hotter body to a colder one, and this process is known as thermal conduction. It occurs as a result of microscopic collisions of particles and the movement of electrons within a body, transferring disorganized microscopic kinetic and potential energy, collectively known as internal energy. Thermal conduction takes place in all phases of matter, including solids, liquids, gases, and waves. The rate at which energy is conducted as heat between two bodies depends on the temperature difference between them and the properties of the conductive medium through which heat is transferred

Several examples illustrate the process of heat conduction. stovetop to the skillet. This transfer of heat occurs through direct contact between the skillet and the stovetop, as heat flows from the higher temperature stovetop to the lower temperature skillet. The rate of heat conduction depends on various factors, including the temperature difference between the two objects, the materials of the objects, and the area of contact.As a result, the handle of the skillet also becomes hot, as heat was conducted through the portion of the skillet in contact with the stovetop. Similarly, when a shirt is placed on an ironing board to be ironed, heat from the iron is conducted to the shirt, making it easier to iron out wrinkles and giving it a crisp appearance. Finally, when the engine of a car is turned on, the hood becomes warm due to the conduction of heat from the engine to the hood of the car. These examples demonstrate the fundamental process of heat conduction in different contexts.

CONVECTION:

Convection is a type of heat transfer that occurs due to the movement of molecules within fluids, including gases and liquids. This movement can happen through advection, diffusion, or a combination of both. While convection is not possible in most solids because they lack bulk current flows or significant diffusion of matter, it can occur in soft solids or mixtures where particles can move past each other. Both convective heat and mass transfer take place through a combination of diffusion and advection, where matter or heat is transported by the larger-scale motion of currents in the fluid.

There are various types of convection that can occur, depending on the circumstances that give rise to the necessary forces for natural or forced convection. These forces include body forces acting within the fluid, such as gravity. Convection can occur in fluids at all scales larger than a few atoms, making it a fundamental process in many natural and industrial systems.

Convection can occur in fluids of all scales larger than a few atoms, and it can be either natural or forced depending on the circumstances. Natural convection occurs due to body forces within the fluid, such as gravity, and does not require any external influence. Forced convection, on the other hand, is caused by external influences such as fans or pumps that force the fluid to move. Both types of convection can lead to different types of flows, depending on the fluid properties and the external influences present.

Classification of convection

Convective heat transfer is classified into two types they are

- Free (or) natural convection
- Forced convection

2.1. Natural convection:

Natural convection is a type of heat transfer that occurs spontaneously without any external source of energy, such as a fan or pump. It is driven purely by differences in temperature and density within a fluid. When a fluid is heated, it expands and becomes less dense, causing it to rise. Cooler, denser fluid then moves in to take its place, creating a convection current. This process continues, transferring heat energy from the bottom of the convection cell to the top. Natural convection can occur in any fluid with temperature gradients, including gases and liquids. It is also influenced by gravity, with heavier components sinking and lighter components rising, leading to bulk fluid movement. Natural convection plays an important role in many natural phenomena, such as weather patterns, ocean currents, and geological processes, as well as in many engineering applications, such as cooling systems and ven

2.2. Forced convection:

Forced convection is a type of heat transport in which fluid motion is generated by an external source such as a pump, fan, or suction device. It is considered one of the main methods of useful heat transfer as it can transport significant amounts of heat energy very efficiently.

Fluid movement in forced convection results from external surface forces such as a fan or pump, and it is typically used to increase the rate of heat exchange. Forced convection is also utilized in many types of mixing to distribute one substance within another, and it occurs as a by-product of other processes, such as the action of a propeller in a fluid or aerodynamic heating. Examples of forced convection include fluid radiator systems and the heating and cooling of parts of the body by blood circulation.Natural convection, on the other hand, is a type of heat transport in which the fluid motion is not generated by any external source, but only by density differences in the fluid occurring due to temperature gradients. Fluid surrounding a heat source receives heat and by thermal expansion becomes less dense and rises. The surrounding, cooler fluid then moves to replace it. This cooler fluid is then heated, and the process continues, forming a convection current. This process transfers heat energy from the bottom of the convection cell to the top.

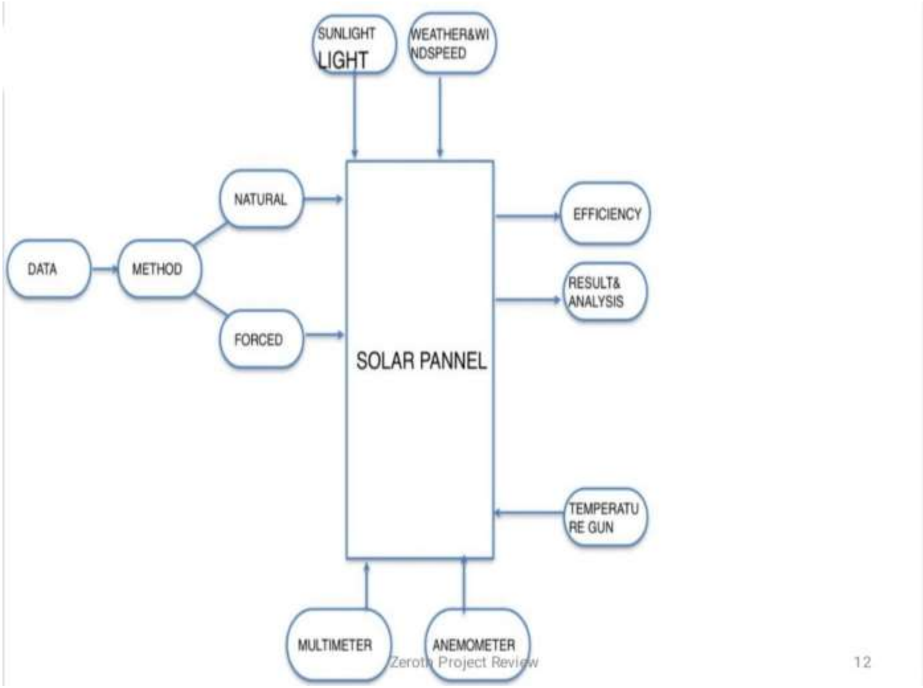
2.3. RADIATION:

Both conduction and convection involve the transfer of heat through matter, while radiation is a method of heat transfer that doesn't require any physical contact between the heat source and the object being heated. For example, we can feel the heat from the sun even though we are not touching it.

Radiation, also known as thermal radiation or infrared radiation, is a type of electromagnetic radiation that travels at the speed of light through space. Unlike conduction and convection, no mass is exchanged, and no medium is required for heat transfer to occur through radiation.

Objects emit radiation when high-energy electrons in a higher atomic level fall down to lower energy levels. This energy is emitted as light or electromagnetic radiation. Energy that is absorbed by an atom causes its electrons to "jump" up to higher energy levels. All objects absorb and emit radiation, and when the absorption of energy balances the emission of energy, the temperature of an object stays constant. If the absorption of energy is greater than the emission of energy, the temperature of an object increases, while if the absorption of energy is less than the emission of energy, the temperature of an object decreases.

3. BLOCK DIAGRAM:



4. HARDWARE USED :

4.1. MULTIMETER:

A multimeter, also known as a multitester or a VOM (volt-ohm-milliammeter), is an electronic instrument that is capable of measuring various electrical quantities. These quantities include voltage, current, resistance, and sometimes other parameters like capacitance, frequency, and temperature. Multimeters come in two main types: analog and digital.Analog multimeters use a micro-ammeter with a moving pointer to display readings. These are relatively simple and inexpensive, but they may not provide the accuracy and precision that digital multimeters can offer. Digital multimeters, on the other hand, use a numeric display to show the measured values. They may also have additional features such as graphical displays, data logging, and connectivity options.

A multimeter typically has several measurement ranges and modes, which can be selected using switches or buttons. For example, to measure voltage, the user selects the appropriate range and probes the meter leads across the voltage source. The meter then displays the voltage reading. Similarly, to measure current, the meter is placed in series with the circuit, and the current flows through the meter, producing a reading.

Multimeters can be used in a variety of applications, including electrical and electronics troubleshooting, circuit design and testing, and quality control. They are an essential tool for anyone working with electrical or electronic systems, and their versatility and convenience make them a popular choice among professionals and hobbyists alike.

4.2. ANEMOMETER

In addition to their use in weather monitoring, anemometers are also used in a variety of industries such as aviation, marine navigation, and wind energy. For example, pilots use anemometers to determine the wind speed and direction during takeoff and landing, while sailors use them to monitor wind conditions for safe navigation. Wind energy companies use anemometers to measure wind speed and direction to determine the best locations for wind turbines. Anemometers can also be used in environmental monitoring to measure air flow and ventilation in buildings or to assess air quality. Overall, anemometers are essential instruments for measuring and monitoring wind speed and pressure in a variety of applications.

4.3. TEMPERATURE INDICATOR:

Temperature indicator is an electronic device which is used for measuring temperature by contact and Non-contact method.

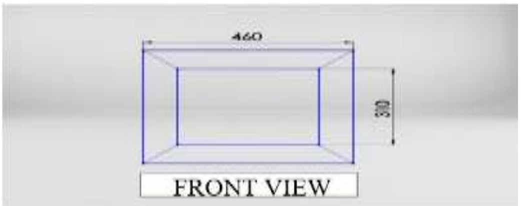
4.4. SOLAR PANEL :

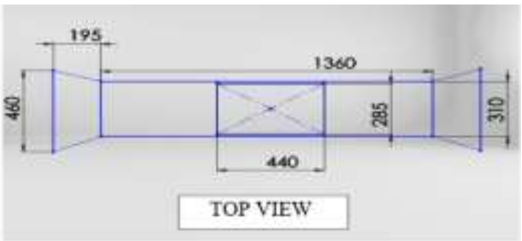
Panel is placed on the table exposed to sunlight for the 6 hours and starting from 9:00 AM voltage reading is taken by using multimeter. Bottom temperature is measured by temperature indicator.

4.5. DUCT

Duct is a pipe, tube, or canal which carries a gas or liquid from one place to another.

DUCT SPECIFICATION:



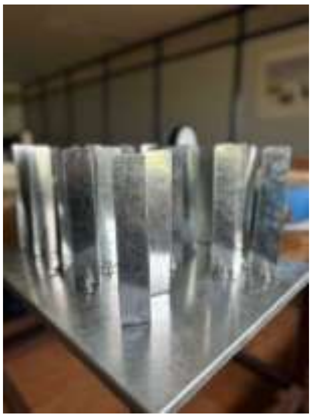


4.6. EXHAUST FAN :

Exhaust fan helps in ventilation and give us a proper set to keep the temperature at level

4.7. Barriers:

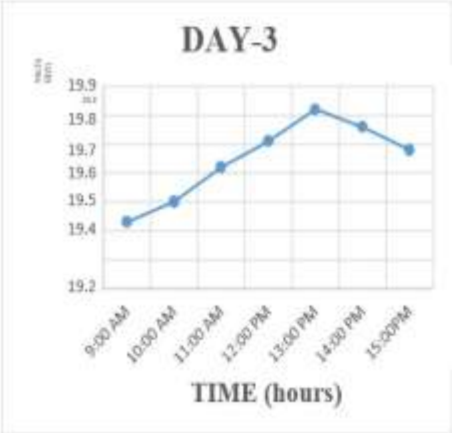
Barriers are Metal sheets carved to its duct measurements and used here to disturb the air flow in the duct to maintain a proper reading from the solar panel



5.Result And Discussion:

TIME(hours)	VOLTAGE(V)
9:00 AM	19.4
10:00 AM	19.45
11:00 AM	19.5
12:00 PM	19.54
13:00 PM	19.78
14:00 PM	19.66
15:00 PM	19.55

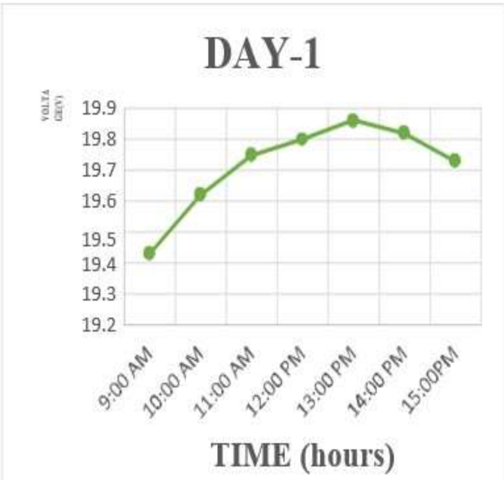
TIME(hours)	VOLTAGE(V)
9:00 AM	19.42
10:00 AM	19.46
11:00 AM	19.58
12:00 PM	19.76
13:00 PM	19.8
14:00 PM	19.66
15:00 PM	19.62



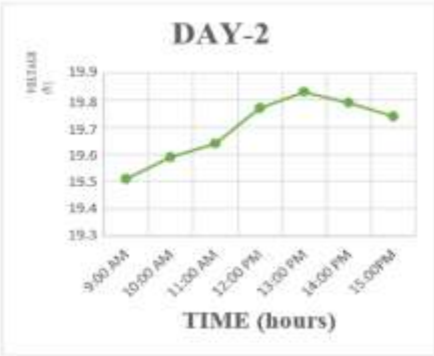
TIME(hours)	VOLTAGE(V)
13:00 PM	19.82
9:00 AM	19.43
10:00 AM	19.5
11:00 AM	19.62
12:00 PM	19.71
14:00 PM	19.76
15:00 PM	19.68

5.1. SOLAR PANEL WITH DUCT – FREE CONVECTION

Solar panel is placed in the duct exposed to the sunlight for 6 hours, starting from 9:00 AM to 3:00 PM voltage reading is taken by using multimeter. Bottom temperature is measured by temperature indicator.



TIME(hours)	VOLTAGE(V)
9:00 AM	19.43
10:00 AM	19.62
11:00 AM	19.75
12:00 PM	19.8
13:00 PM	19.86
14:00 PM	19.82
15:00 PM	19.73

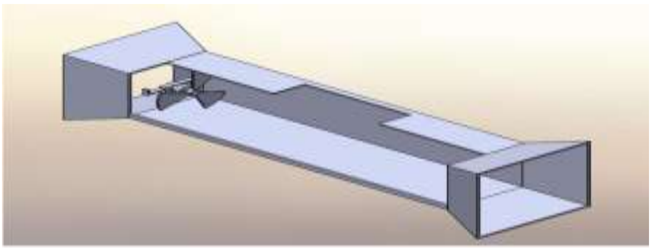


TIME(hours)	VOLTAGE(V)
9:00 AM	19.51
10:00 AM	19.59
11:00 AM	19.64
12:00 PM	19.77
13:00 PM	19.83
14:00 PM	19.79
15:00 PM	19.74

TIME(hours)	VOLTAGE(V)
9:00 AM	19.49
10:00 AM	19.56
11:00 AM	19.64
12:00 PM	19.84
13:00 PM	19.86
15:00 PM	19.74

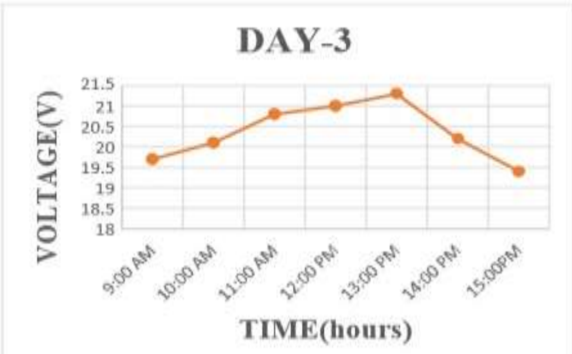
5.2SOLAR PANEL WITH DUCT – FORECD CONVECTION

Solar panel is placed in the duct with electric fan and the setup is exposed to the sunlight for 6 hours, starting from 9:00 AM to 3:00 PM voltage reading is taken by using multimeter. Bottom temperature is measured by temperature indicator.



TIME(hours)	VOLTAGE(V)
9:00 AM	19.56
10:00 AM	19.85
11:00 AM	20.33
12:00 PM	21.04
13:00 PM	21.1
14:00 PM	20.7
15:00 PM	19.8

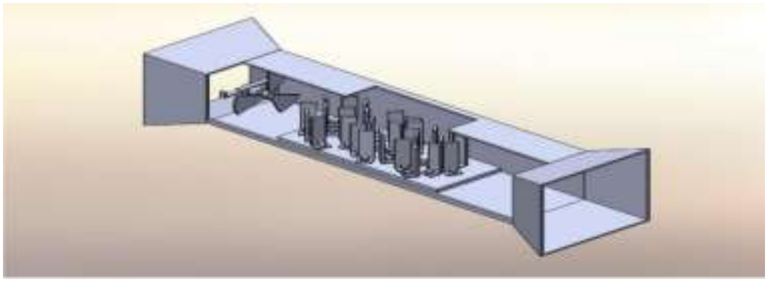
TIME(hours)	VOLTAGE(V)
9:00 AM	19.8
10:00 AM	20.9
11:00 AM	21
12:00 PM	21.1
13:00 PM	21.3
14:00 PM	20.8
15:00 PM	19.6



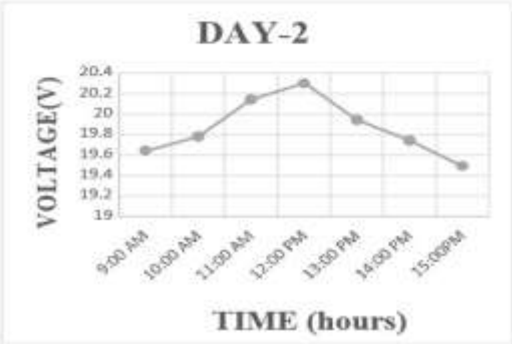
TIME(hours)	VOLTAGE(V)
9:00 AM	19.7
10:00 AM	20.1
11:00 AM	20.9
12:00 PM	21.14
13:00 PM	21.31
14:00 PM	20.47
15:00 PM	19.4

5.3SOLAR PANEL WITH BARRIERS

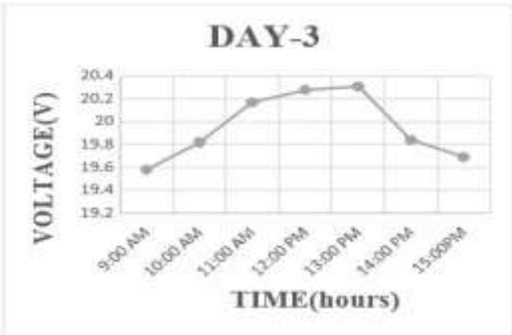
Solar panel is placed in the duct with electric fan and barriers and the setup is exposed to the sunlight for 6 hours,starting from 9:00 AM to 3:00 PM voltage reading is taken by using multimeter.Bottom temperature is measured by temperature indicator.



TIME(hours)	VOLTAGE(V)
9:00 AM	19.88
10:00 AM	19.96
11:00 AM	20.52
12:00 PM	20.61
14:00 PM	20.1
15:00 PM	19.6



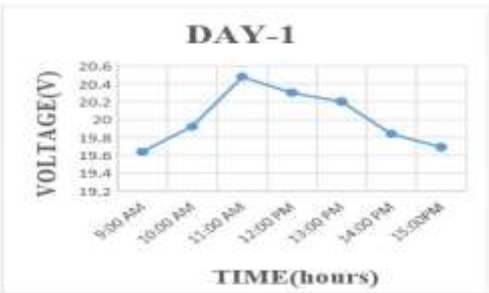
TIME(hours)	VOLTAGE(V)
9:00 AM	19.64
10:00 AM	19.78
11:00 AM	20.14
12:00 PM	20.3
13:00 PM	19.94
14:00 PM	19.74
15:00 PM	19.49



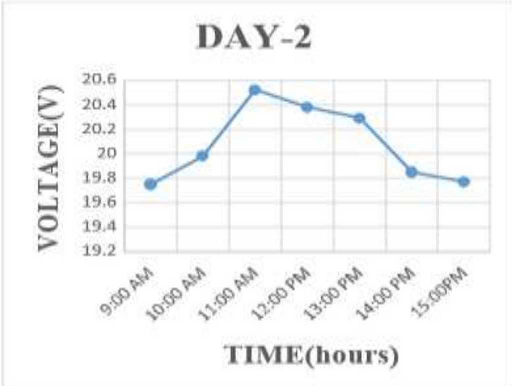
TIME(hours)	VOLTAGE(V)
9:00 AM	19.58
10:00 AM	19.82
11:00 AM	20.17
12:00 PM	20.28
13:00 PM	20.31
14:00 PM	19.84
15:00 PM	19.69

5.4 SOLAR PANEL WITH INDUCED DRAFT FAN

Solar panel is placed in the ductwith induced draft fan and the setup is exposed to the sunlight for 6 hours, startingfrom 9:00 AM to 3:00 PM voltage reading is taken by using multimeter. Bottomtemperature is measured by temperature indicator.



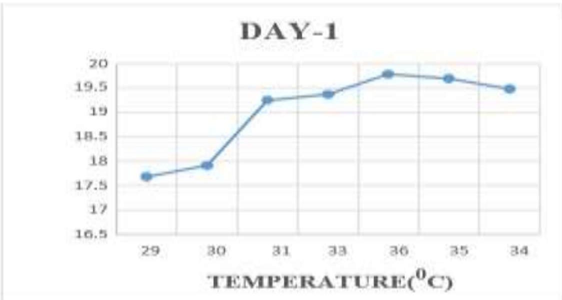
TIME(hours)	VOLTAGE(V)
9:00 AM	19.64
10:00 AM	19.92
11:00 AM	20.48
12:00 PM	20.3
13:00 PM	20.2
14:00 PM	19.84
15:00 PM	19.69



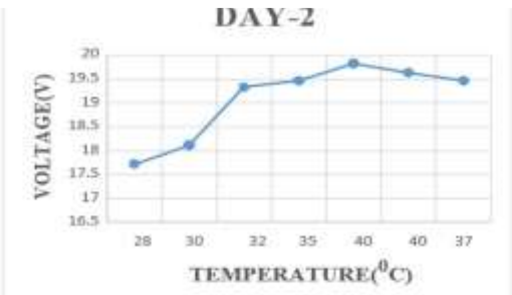
TIME(hours)	VOLTAGE(V)
9:00 AM	19.75
10:00 AM	19.98
11:00 AM	20.52
12:00 PM	20.38
13:00 PM	20.29
14:00 PM	19.85
15:00 PM	19.77

TIME(hours)	VOLTAGE(V)
9:00 AM	19.86
10:00 AM	19.98
11:00 AM	20.55
12:00 PM	20.4
13:00 PM	20.3
14:00 PM	19.9
15:00 PM	19.77

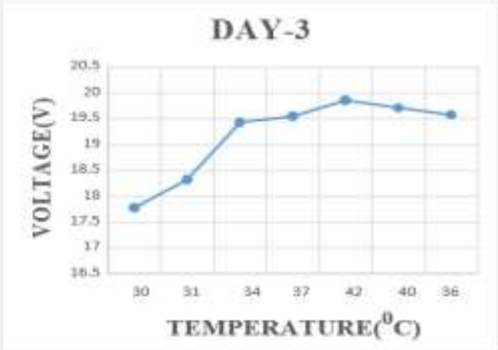
5.5. SOLAR PANEL WITHOUT DUCT:



TEMPERATURE(^{0}C)	VOLTAGE(V)
29	17.68
30	17.91
31	19.25
33	19.37
35	19.69
34	19.48

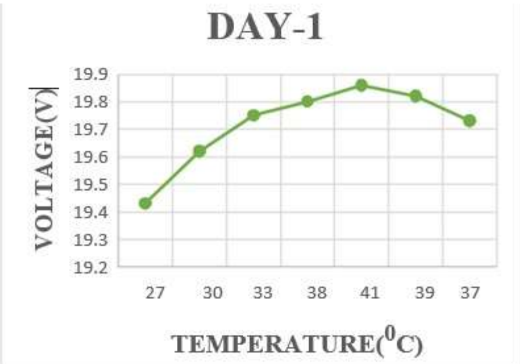


TEMPERATURE(^{0}C)	VOLTAGE(V)
28	17.72
30	18.11
32	19.33
35	19.46
40	19.82
42	19.63
37	19.46

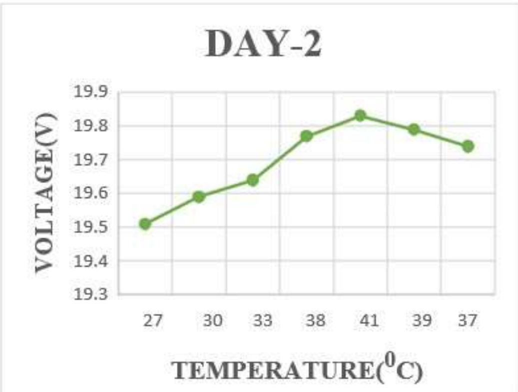


TEMPERATURE(^{0}C)	VOLTAGE(V)
30	17.78
31	18.32
34	19.43
37	19.55
42	19.86
40	19.71
36	19.58

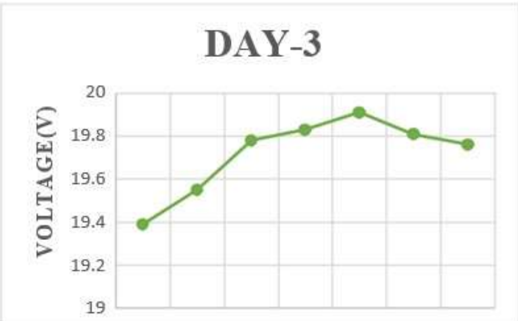
5.6 SOLAR PANEL WITH DUCT – FREE CONVECTION:



TEMPERATURE(^{0}C)	VOLTAGE(V)
27	19.43
30	19.62
33	19.75
38	19.8
41	19.86
39	19.82
37	19.73

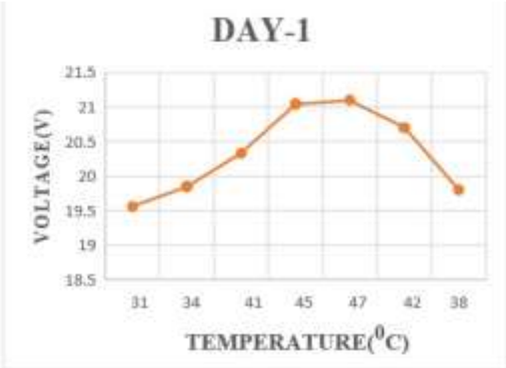


TEMPERATURE(^{0}C)	VOLTAGE(V)
27	19.51
30	19.59
33	19.64
38	19.77
41	19.83
39	19.79
37	19.74

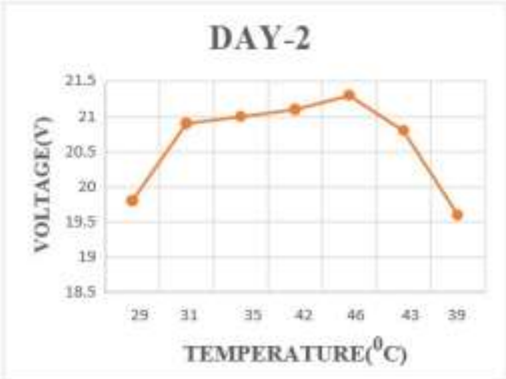


TEMPERATURE(^{0}C)	VOLTAGE(V)
30	19.39
32	19.55
35	19.78
39	19.83
43	19.91
39	19.81
36	19.76

5.7. SOLAR PANEL WITH DUCT – FORCED

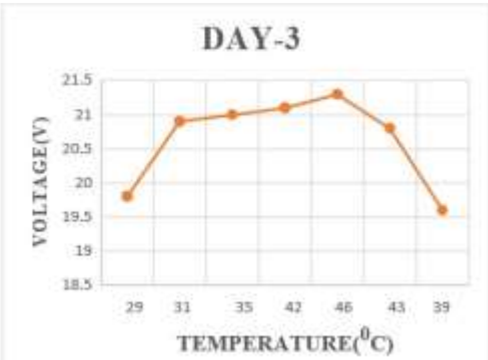


TEMPERATURE(^{0}C)	VOLTAGE(V)
31	19.56
34	19.85
41	20.33
45	21.04
47	21.1
42	20.7
38	19.8



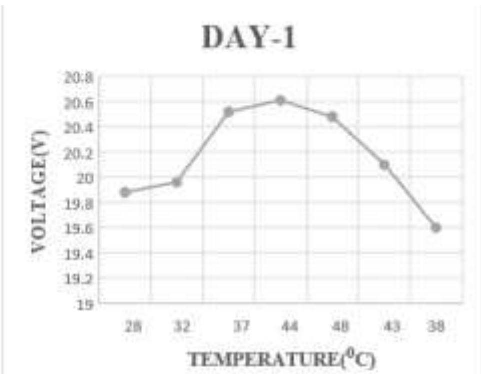
TEMPERATURE(^{0}C)	VOLTAGE(V)
31	19.8
34	20.9
41	21
45	21.1
47	21.3
42	20.8
38	19.6

CONVECTION:

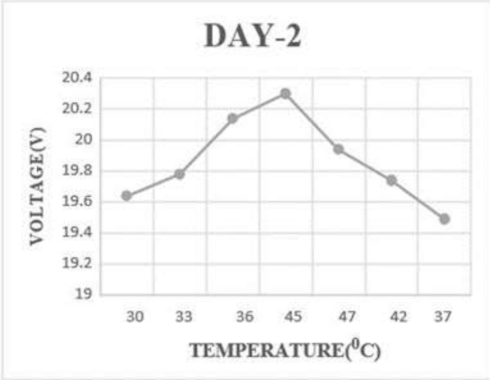


TEMPERATURE(^{0}C)	VOLTAGE(V)
31	19.7
34	20.1
41	20.9
45	21.14
47	21.31
42	20.47
38	19.4

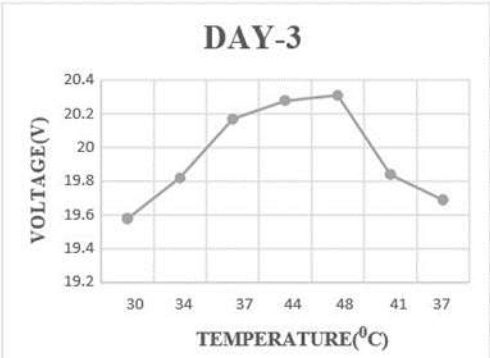
5.8. SOLAR PANEL WITH BARRIERS:



TEMPERATURE(^{0}C)	VOLTAGE(V)
28	19.88
32	19.96
37	20.52
44	20.61
48	20.48
43	20.1
38	19.6

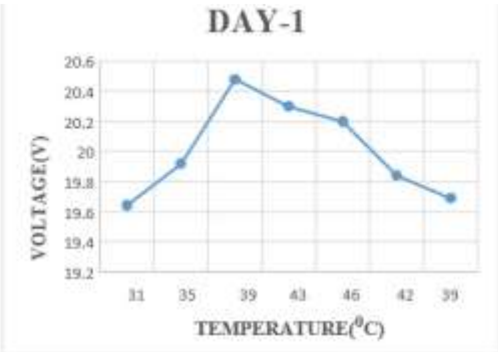


TEMPERATURE(^{0}C)	VOLTAGE(V)
30	19.64
33	19.78
36	20.14
45	20.3
47	19.94
42	19.74
37	19.49

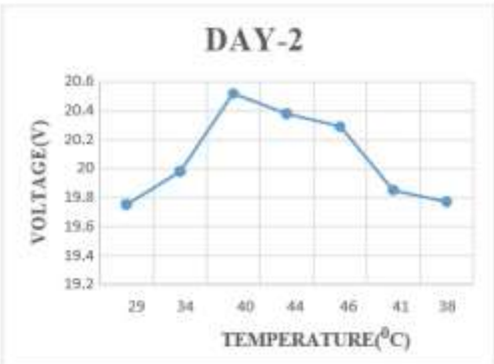


TEMPERATURE(^{0}C)	VOLTAGE(V)
30	19.64
33	19.78
36	20.14
45	20.3
47	19.94
42	19.74
37	19.49

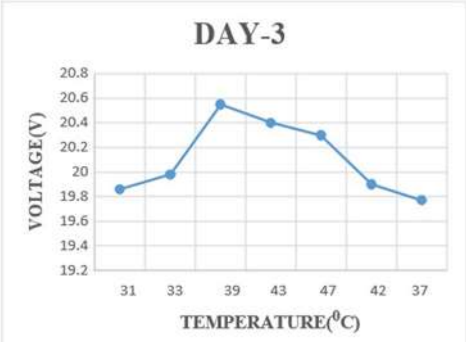
5.9. SOLAR PANEL WITH INDUCED DRAFT FAN:



TEMPERATURE(^{0}C)	VOLTAGE(V)
31	19.64
35	19.92
39	20.48
43	20.3
46	20.2
42	19.84
39	19.69

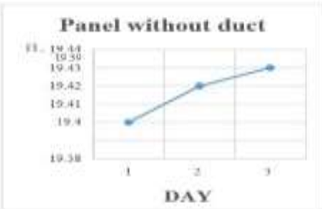


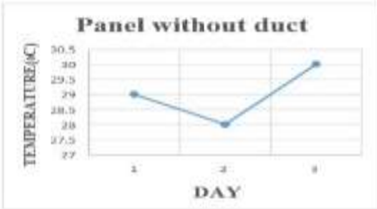
TEMPERATURE(^{0}C)	VOLTAGE(V)
29	19.75
34	19.98
40	20.52
44	20.38
46	20.29
41	19.85
38	19.77



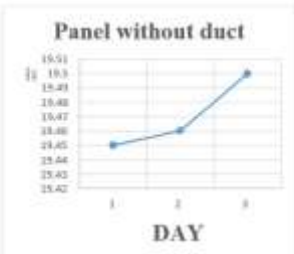
TEMPERATURE(^{0}C)	VOLTAGE(V)
31	19.86
33	19.98
39	20.55
43	20.4
47	20.3
42	19.9
37	19.77

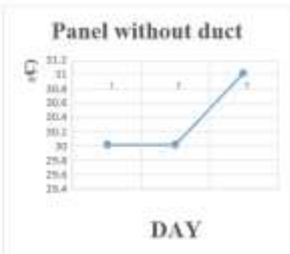
TIME – 9:00 AM

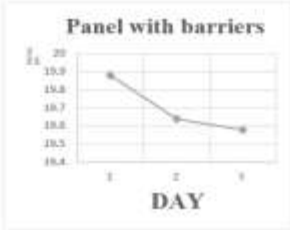


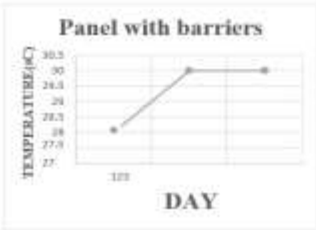


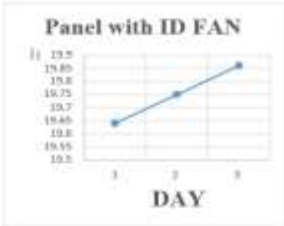
TIME – 10:00 AM

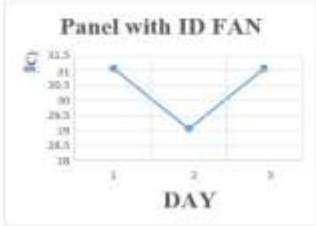




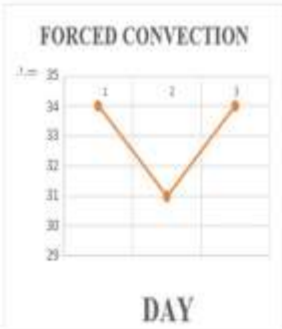

Panel with barriers
DAY

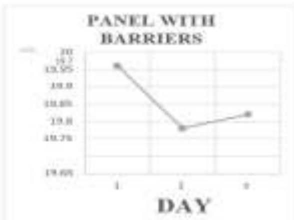

Panel with barriers
DAY

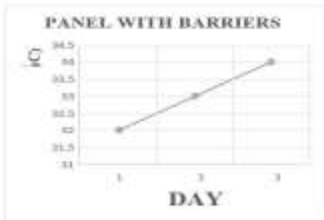

Panel with ID FAN
DAY

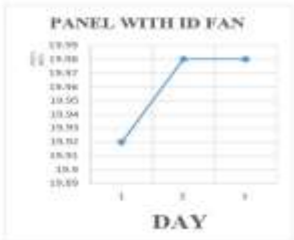

Panel with ID FAN
DAY

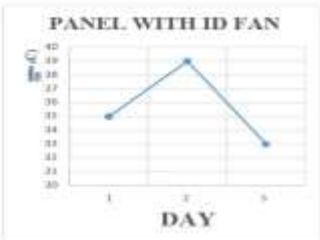

FORCED CONVECTION
20.15
20.1
20.05
20
19.95
19.9
19.85
19.8
19.75
19.7
DAY


FORCED CONVECTION
35
34
33
32
31
30
29
DAY


PANEL WITH BARRIERS
DAY

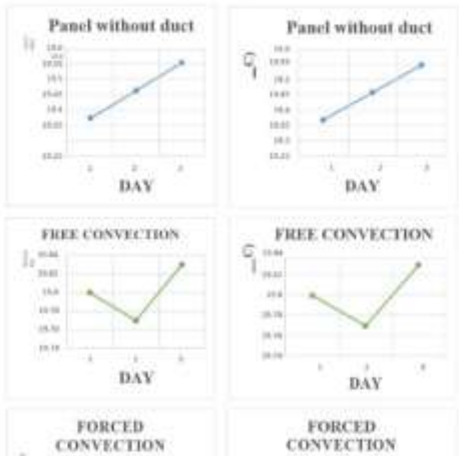

PANEL WITH BARRIERS
DAY

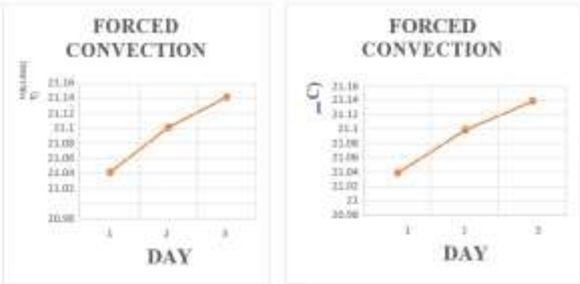

PANEL WITH ID FAN
DAY

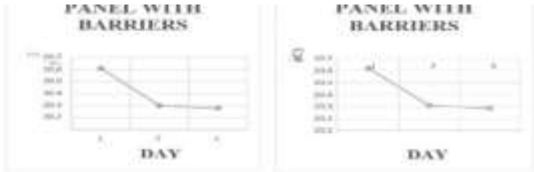

PANEL WITH ID FAN
DAY

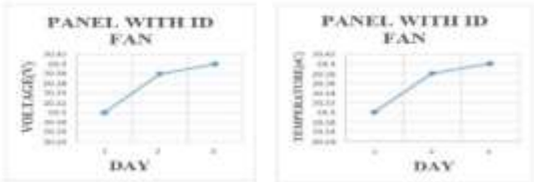
TIME – 11:00 AM

TIME – 12:00 PM

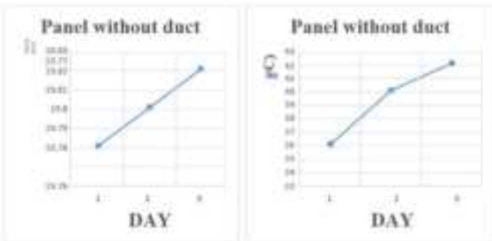


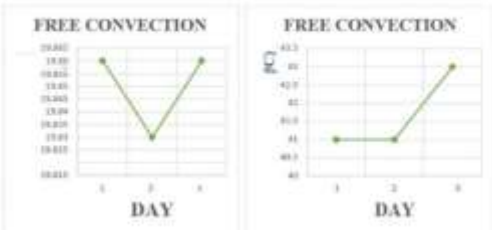

FORCED CONVECTION
DAY
FORCED CONVECTION
DAY

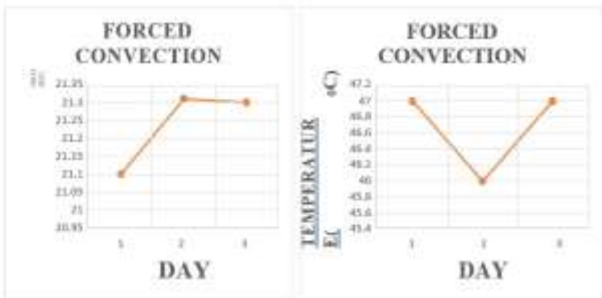

PANEL WITH BARRIERS
DAY
PANEL WITH BARRIERS
DAY

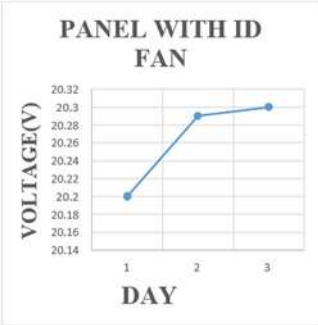

PANEL WITH ID FAN
VOLTAGE(V)
DAY
PANEL WITH ID FAN
DAY

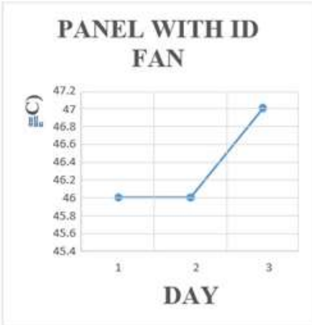
TIME – 01:00 PM

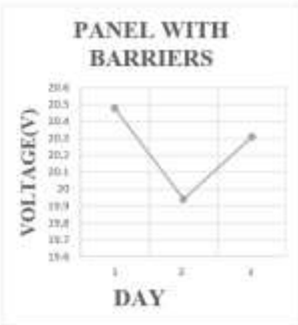

Panel without duct
DAY
Panel without duct
DAY

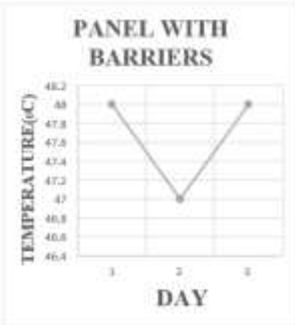

FREE CONVECTION
DAY
FREE CONVECTION
DAY


FORCED CONVECTION
DAY
FORCED CONVECTION
TEMPERATURE(
DAY









6.Conclusion:

The study conducted experiments on a solar flat collector with and without duct using different convection modes. The analysis of the results showed that the mode of SOLAR PANEL WITH DUCT – FORCED CONVECTION produced the highest voltage compared to other modes. On the third day of forced convection experimentation, at 1:00 PM, the panel generated a voltage of 21.31V, which is the highest voltage generated among all the modes tested.

7.Acknowledgment:

We would like to express our gratitude to our Guide for providing support and guidance. We got to learn a lot more from this project, which will be very helpful for us, in our future endeavours.

8.References:

[1]. Gagandeep Singh Bagga and Sandeep Kumar “Analysis of Flat Plate **S**olar Air Collector in Different Convection Mode with InducedTurbulence “International Journal of Engineering Research & Technology” (IJERT) ISSN: 2278-0181 Vol. 5 Issue 07, July-2016

[2]. Umayorupagam P. Arunachalam, Mohan Edwin “Experimentalinvestigations on thermal performance of solar air heater with differentabsorber plates”, INTERNATIONAL JOURNAL OF HEAT AND TECHNOLOGY ISSN: 0392-8764 Vol. 35, No. 2, June 2017.

[3]. FouedChabane NoureddineMoummi Said Benramache **“**Experimental analysis on thermal performance of a solar air collector with longitudinal fins in a region of Biskra”, JournalofPowerTechnologies (2013) 52–58