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Waste Heat Recovery System (WHRS)

A Sustainable and Impactful Technology For Reduction of Fuel Consumption and Emissions.

Presented by:-

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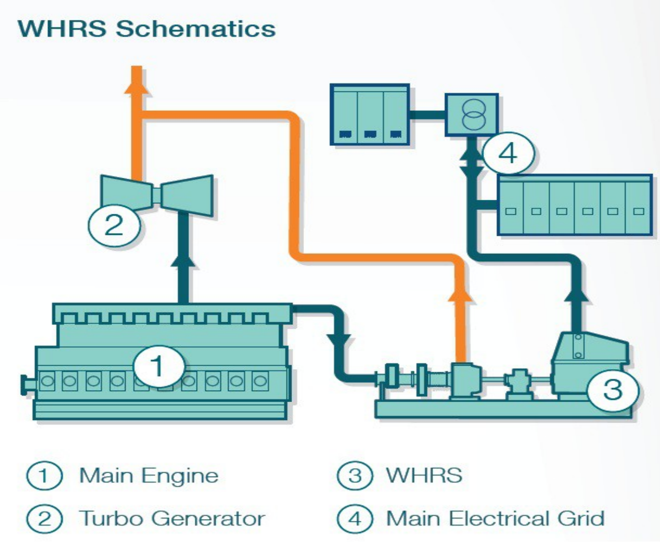
Abstract

The increasing interest in emission reduction, ship operating costs reduction and the newly adapted IMO EEDI rules calls for measures that ensure optimal utilisation of the fuel used for main engines on board ships. Main engine exhaust gas energy is by far the most attractive among the waste heat sources of a ship because of the heat flow and temperature. It is possible to generate an electrical output of up to 11% of the main engine power by utilising this exhaust gas energy in a waste heat recovery system comprising both steam and power turbines, and combined with utilising scavenge air energy for exhaust boiler feed-water heating. This paper describes the technology behind waste heat recovery and the potential for ship owners to lower fuel costs, cut emissions, and the effect on the EEDI of the ship. This technology is quite impactful on human life and environment. large scale industries and shipping has just started to embrace it.

Introduction

After successful implementations on shore based plants, WHRS has an even more promising results on-board instalments. Using advanced industrial instalments it can help merchant vessels to sustain the ever-updating regulations.

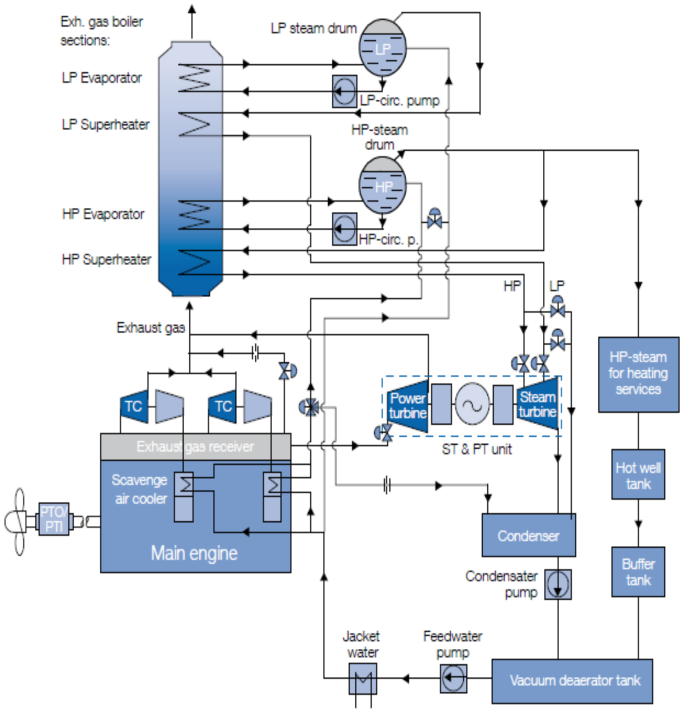
With the rapid growth of economies of developing nations, e.g. in Asia, trading activity is increasing and along with it comes an increase in ship traffic and the need for large ships that are able to carry more cargo. This creates a need for balanced economic growth and also for improving and maintaining the air quality. It is estimated that 2.7% of the global carbon dioxide emission comes from international shipping. It is inevitable that ships contribute to unwanted emissions as they use bunker fuel which contains high level sulphur, ash and nitrogen compound and generate higher emissions than distillate fuel. To make matters worse, they use unrefined fuel, the dirtiest in the market, thus emitting various global warming pollutans which include COx, SOx, HCx and NOx. These pollutants all contribute to global climate change either directly by acting as agents that trap heat in the atmosphere or indirectly by aiding the creation of additional Green House Gases (GHG). Main engine exhaust gas energy is by far the most attractive among the waste heat sources of a ship because of the heat flow and temperature. It is possible to generate an electrical output of up to 11% of the main engine power by utilising this exhaust gas energy in a waste heat recovery system comprising both steam and power turbines, and combined with utilising scavenge air energy for exhaust boiler feed-water heating.



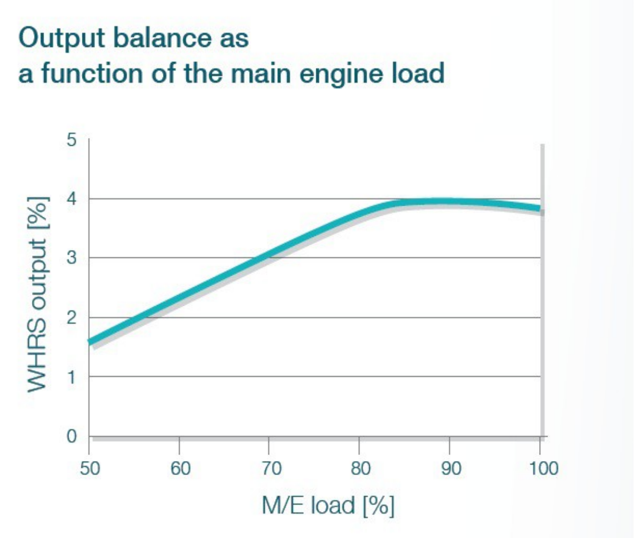
The waste heat recovery system generates electrical energy from a ship's exhaust gases. This reduces the ship's fuel consumption and CO_2 emissions by up to twelve percent. Energy costs consequently fall by some 10 percent, so the ship runs more economically.

With the aid of the waste heat recovery system, the exhaust gas from the main diesel engine is used to generate steam in a waste heat boiler which, in turn, drives turbo-generators. The electrical power thus generated can be used to supply the ship's power system and/or the booster drive – an electric motor integrated into the propulsion shaft. If the output from the main engine is not fully utilized, the motor can act as a shaft generator and supply electrical energy to the ship’s power supply system, thus enabling the diesel engines of the on-board power supply system to be temporarily switched off. This shaft generator can also be used as a booster electric motor to increase the ship's propulsive power. The shaft generator can also be used in motor mode as the sole source of propulsion for maneuvering in harbor or cruising at slow speed with the main engine switched off. Utilizing the waste heat improves the overall efficiency of the propulsion system, and reduces not only the operating hours but also operating and maintenance costs of the existing auxiliary generators.All the functions of the WHR system are controlled by an energy management system.

A WHR system can be easily incorporated into the design of a new ship or retrofitted in a completed ship. The main engine can also be designed with a lower rated power, and the engine room can be used more flexibly because the shaft generator is installed in the propulsion shaft tunnel, thus requiring no extra space.

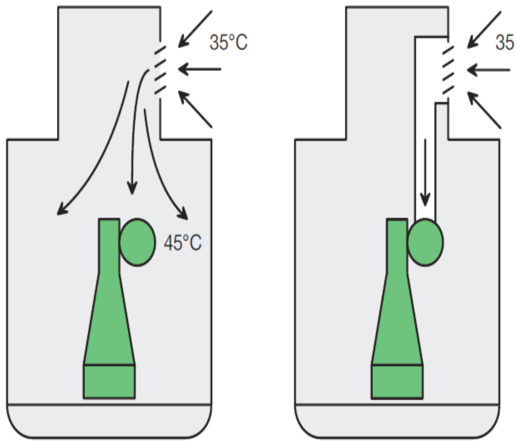


The fuel efficiency of ship main engines is currently approximately only 50% – only half of the energy content of the fuel is converted into electricity, while the rest is lost as heat energy. Up to half of this waste heat – around 25% of the overall energy content of the fuel goes into hot exhaust gases which are then released to the atmosphere. Modern marine engines – such as the super longstroke MAN B&W S90ME-C9 type or the Wartsila RTflex series – I use these exhaust gases to increase the power that the engine can produce. In a typical arrangement, the gases leaving the engine are passed through a turbocharger, which uses the energy of the gas to spin a turbine that forms part of an air compressor. This compressor increases the mass of air that flows into the engine, enabling large quantities of fuel to be burnt more efficiently. However, the energy of the exhaust gas can be used in other ways. First, it can be used to spin a power turbine that produces electricity. Secondly, it can be used to generate steam which can then be used in a gas-fired boiler to meet onboard heat demands. Systems that achieve either or both of the above are labelled as Waste Heat Recovery (WHR) systems.WHR systems are typically located in the main engine room. To make the most of the energy in the exhaust gases, some WHR systems include an exhaust gas bypass which channels part of the gas flow away from the turbocharger. This means that the temperature of the gas can be kept higher so that the WHR system can extract more energy from it.


Output balance as a function of the main engine load

Heating of Exhaust Gas

The exhaust gas temperature can be increased by adapting the engine for ambient suction air intake. Usually marine engines are designed for intake temperatures of up to 45°C for tropical conditions with turbochargers drawing intake air from the engine room. If instead the intake air is drawn from outside the engine room through an air intake duct, the maximum intake temperature can be assumed to be no more than 35°C In such a case, the turbochargers can be re matched to return the thermal load of the engine back down to what prevails for the intake temperature at 45°C. When considering such a tuning to reach an increased exhaust gas temperature, it is important that the thermal load of the adapted engine is no greater than that of the usual engine so as not to jeopardise engine reliability. This adapted tuning, however, incurs a penalty in slightly increased fuel consumption at ISO reference conditions. But the gain in recovered energy more then compensates for the loss in efficiency from the higher fuel consumption.



Classification

Today several different WHRSs are readily available. Depending on the level of complexity acceptable to the owner and shipyard and the actual electrical power consumption onboard, it is possible to choose between the following systems:

(PTG) Power Turbine Generator
(STG) Steam Turbine Generator
(ST-PT) Steam Turbine-Power Turbine Generator

1) Power Turbine Generator

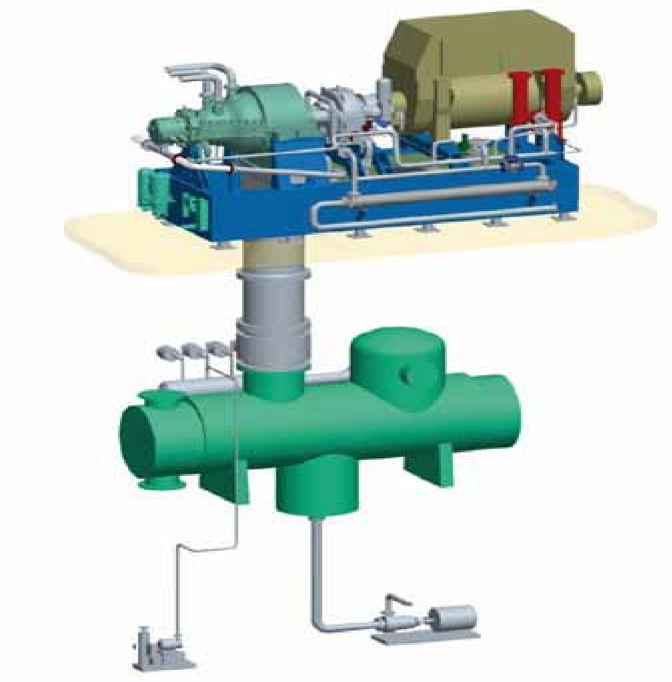
The simplest and cheapest system consists of an exhaust gas turbine (also called a power turbine) installed in the exhaust gas bypass, and a generator that converts power from the power turbine to electricity onboard the ship. The power turbine and the generator are placed on a common bedplate. The power turbine is driven by part of the exhaust gas flow which bypasses the turbochargers. The power turbine produces extra output power for electric power production, which depends on the bypassed exhaust gas flow amount.

The exhaust gas bypass valve will be closed at an engine power lower than about 50% SMCR, where the engine will run with the same high efficiency as for a normal low speed engine Using a PTG WHRS solution will provide a 3-5% recovery ratio, depending on the main engine size. The simplest installation is considered to be the PTG system, as the system is the smallest of the different systems, and because the main connection between the PTG and the engine is only the exhaust gas by-pass line.

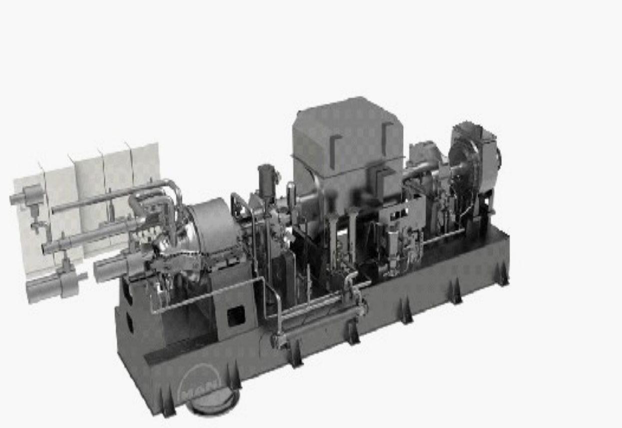
2) STEAM TURBINE GENERATOR

The second system builds on the principle exhaust gas bypass and, thereby, increasing the exhaust gas temperature before the boiler without using a power turbine. When applying the steam turbine (ST) as a stand-alone solution, the exhaust gas bypass stream is mixed with the exhaust outlet from the turbocharger(s), increasing the exhaust gas temperature before the boiler inlet. When part of the exhaust gas flow is bypassed the turbocharger, the total amount of air and gas will be reduced, and the exhaust gas temperature after the turbocharger and bypass will increase. This will increase the obtainable steam production power for the exhaust gas fired boiler. By installing a steam turbine (often called a turbo generator), the obtainable steam production from the exhaust boiler system can be used for electric power production. The steam turbine is installed on a common bedplate with the generator in the same manner as the power turbine and the generator. The STG solution can function both as a standalone and as a parallel running electric power source for the ship – depending on the actual demand for the particular ship design. Using a WHRS STG system, it will be possible to recover some 5 to 8%, depending on the main engine size, engine rating, and ambient conditions. The steam turbine installation is quite extensive as many different components must be connected. Firstly, it is likely that the boiler installation has to be increased in size. From the boiler, one or two pipes should be connected to the steam turbine, depending on whether the single or dual pressure system is applied. The condenser must be installed under the bedplate of the steam turbine and, in some cases; it may be as large as the steam turbine and generator

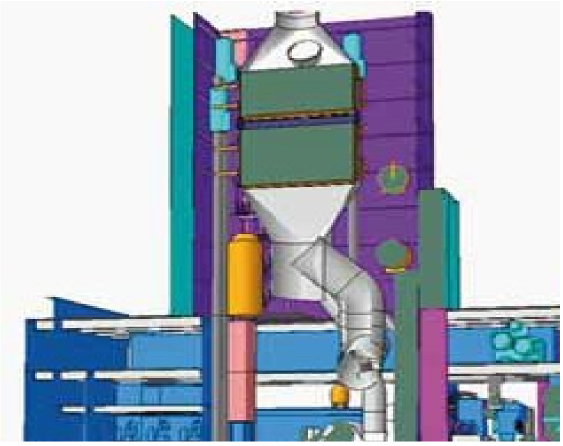
installation. The condenser piping is connected to the boiler system so that the water can be recirculated. The condenser is furthermore equipped with cooling water piping.
As mentioned above the WHRS steam turbine solution will require space for a large condenser installation an aspect which the shipyard needs to consider in respect of the machinery room.



3) STEAM TURBINE-POWER TURBINE GENERATOR



If the electric power demand on the ship is very high, e.g. a container ship, the power turbine and the steam turbine can be built together to form a combined system. The power turbine and the steam turbine is built onto a common bedplate and, via reduction gearboxes, connected to a common generator. The power output from the power turbine can be added to the generator via a reduction gear with a special clutch. However, first the steam turbine will start at 30 – 35% SMCR main engine power followed by the power turbine which starts power production at 40 to 50% SMCR. It reduces the fuel costs of the ship considerably by being able to cover the total electric power needs in many conditions onboard the ship. Otherwise, a shaft motor / generator connected to the main engine shaft could be an option, making it possible to add either electric power to the ship grid if needed, or to boost propulsion by supplying the electric power to the PTI.



Selecting the full WHRS combining both steam and power turbines some 8-11% power can be recovered, depending on the main engine size, engine rating and ambient conditions. Choosing the system most suitable for a specific ship project requires careful evaluation based on requirements concerning fuel efficiency, arrangement restrictions, emission requirements, operational profile for the ship, payback time, etc.

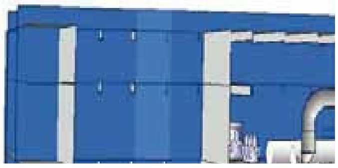
If the combined PT-TG system is considered, a number of installation aspects must be considered. The power turbine will need an inlet and exhaust gas pipe connected to the existing exhaust gas system One challenging installation aspect is the fact that the power turbine takes the exhaust gas from the exhaust gas receiver, which sits on the engine, and the steam turbine receives steam from the boiler system, which can be situated some distance away from the engine.

With WHRS including steam turbine, more space is required in the engine room and casing areas. Steam exhaust boilers, normally as a dual pressure system, will include LP economiser, LP super heater ,LP

steam drum, HP economiser, HP super heater, HP steam drum ,Pumps, etc.
The ship designers must make reserve space for all components in the machinery arrangements and casing a typical arrangement for a container ship can be seen in Fig.

The heat recovery system generates more electrical power than is needed for shipboard service. The surplus electric power is applied in motor/alternator adding power to the propeller shaft. If the heat recovery system generates less electrical power than is needed for shipboard service the missing electrical power is generated by the motor/alternator system. The system thus offers considerable flexibility in optimising plant operation to minimise operating costs or maximise propulsion power.
Ships with a relatively stable operating profile, especially with higher propulsion loads, have the biggest potential for savings. The more the vessel has a high-load operation, the shorter the payback time for the WHRS will be.

Where and when can the WHRS be used?

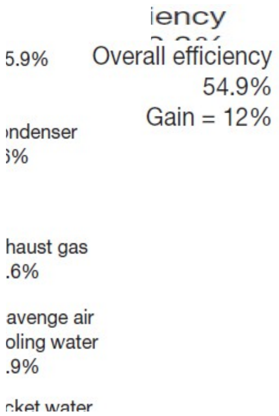


The WHRS can be applied to any propulsion plant with sufficient power output to make the investment economically viable. There is a clear economy of scale here, and the bigger the main engine output, the more waste heat can be recovered. The power level above which the WHRS becomes economical depends on the price of fuel, as well as required payback time, and should be validated by making detailed calculations as to system efficiency. As an indication, however, given various parameters prevailing at the beginning of 2012, various surveys estimated that it would be economically feasible to use WHRS on board container ships with main propulsion machinery with a mechanical output of 20 MW or more.

Another consideration, which determines the economic viability of the WHRS, is the operating profile of the propulsion plant. Ships with a relatively stable operating profile, especially with higher propulsion loads, have the biggest potential for savings. The more the vessel has a high-load operation, the shorter the payback time for the WHRS will be. The WHRS is not run in port or manoeuvring situations, so the smaller these are as a portion of a ship's overall operating profile, the greater the economical potential of the WHRS. To date, WHRS have typically been installed on deep sea container vessels and very large crude oil carriers (VLCCs), equipped with a two-stroke engine propulsion plant. The WHRS will function only when the main engine load is above a certain limit. That limit depends on the system design for each project, but is typically about 40 percent of the main engine MCR for a WHRS. The propeller shaft generator/motor is functional from any low load, the main engine can run up to 100 percent of the main engine MCR and the shaft generator/motor can be optimised to give 100 percent output power at a specified main engine load, for example 80 percent of the main engine MCR. Optimising specifications during the design phase allows for maximum flexibility in the recovery and utilisation of waste energy during the ship's operation

Emission Effects of using WHRS

there is no particular method to calculate reduction in emission because it depends upon main engine load engine, exhaust temp etc temperature however various estimation for standard sized vassal Based on a HFO fuel saving of 3,555 tons per year (with 3% sulphur content), the installation of a WHRS on a large container ship, as illustrated will save the environment for the following emission amounts:



CO2 emission saving per year: 11,260 tons
NOx emission saving per year: 319 tons
SOx emission saving per year: 214 tons
Particulates saving per year: 29 tons

Benefits of 'waste heat recovery' can be broadly classified in two categories:

Indirect Benefits:

a)Reduction in pollution: A number of toxic combustible wastes such as carbon monoxide gas, sour gas, carbon black off gases, oil sludge, Acrylonitrile and other plastic chemicals etc, releasing to atmosphere if/when burnt in the incinerators serves dual purpose i.e. recovers heat and reduces the environmental pollution levels.

b) **Reduction in equipment sizes**: Waste heat recovery reduces the fuel consumption, which leads to reduction in the flue gas produced. This results in reduction in equipment sizes of all flue gas handling equipments such as fans, stacks, ducts, burners, etc.

c)Reduction in auxiliary energy consumption: Reduction in equipment sizes gives additional benefits in the form of reduction in auxiliary energy consumption like electricity for fans, pumps etc.

Financial Benefits

The financial benefits from using WHR can be significant, although these vary between technology providers and depend on the efficiency of the engine. The engine manufacturer Wartsila states that their high-efficiency WHR system – which uses both power and steam turbines – could cut exhaust emissions and deliver fuel savings of up to 12%, with a return on investment of less than 5 years. The global engineering, electrical and electronics company Mitsubishi Heavy Industries (MHI) claims that their WHR system for containerships saves 10% on fuel costs. The engine manufacturer Man Diesel & Turbo is more conservative in their claims. They suggest energy savings of 4-11% for their WHR systems, depending on a range of factors such as the operational profile of the ship, electricity demand whilst at sea, and the power level of the engine. However, for a ship which installs an ST-PT system, MAN Diesel and Turbo predict a payback of approximately 4.3 years, based on a conservative price for heavy fuel oil (HFO) of $US650/tonne. For a ship-owner who keeps their vessels for 20 years, MAN states that this would equate to a $USD 36 million reduction in fuel costs. The class society DNV has also made an independent estimate of payback times. In a study released in 2011, researchers concluded that a modern container ship, running on heavy fuel oil (HFO), could expect a payback period from a WHR system of around 8 years.

DRAWBACKS

1. The installation cost to implement a WHRS may outweigh the profits initially but the various manufacturer claims that after a certain period of time all the cost of installation can be recovered and after that it becomes profitable. For a standard size sea going vassal such as Emma Mearsk it costs around 10 million us $.which is quite expensive and requires financial planning.
2. The retrofitting in older class ships brings congestion in space.
3. It requires additional maintenance due to introduction of new machinery.

Conclusion

In the immediate future it will be no surprise to find WHRS systems attached to every equipment generating excess heat in any form and converting the same into some useful form right there within the system. It is an efficient way of using the existing systems to reduce its impact on environment. This Total Heat Recovery Plant is attracting much attention from ship owners interested in saving fuel costs and reducing CO2 missions. It must be remembered that modern large, low-speed engines are very highly developed and there is little potential for achieving significant savings in fuel consumption, and thereby reducing CO2 emissions by engine developments alone. Yet major improvements can be gained by using proven technology and hardware through applying the Total Heat Recovery Plant. It is thus a practical path forward. This paper shows that significant fuel cost savings can be achieved by adding a WHRS to a ship project. Whether a full WHRS (ST & PT), a stand-alone WHRS (ST) or a stand-alone PTG solution are selected, all of these solutions offer large fuel savings.

Fuel reductions of between 4-11% are possible, depending on the selected WHRS solution, main engine power level, electric need at sea, operational profile, etc. The larger the engine power, the greater the possible fuel saving In addition to large fuel savings, a WHRS gives large CO2, NOx, SOx and particulate reductions to the benefit of the environment. The payback time is short for all three WHRS solutions, which alone can give the ship-owner high fuel savings throughout the lifetime of the ship. Furthermore, a WHRS will rather substantially reduce the ship’s energy efficiency design index – same reduction level as the WHRS recovery ratio – thereby helping the ship owner meet even tighter EEDI requirements from IMO in the future. This system can prove substantially important step towards a new era of energy optimization and can improve the existing energy lifestyle of people aross many countries.