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Energy Management Practices for Improving Energy Efficiency in Industries: Furnace, Steam Boiler, HVAC, and Cooling Systems

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Abstract

The aim of this study is to demonstrate and analyse energy management practices to increase energy efficiency in industries. In the study, examples of energy efficiency increasing applications that can be carried out in industrial organizations were discussed and the amount of savings for these applications was calculated. The main energy efficiency applications discussed in the study are the heat recovery in boilers and furnaces, thermal insulation, and heat recovery in HVAC systems. As a result of this study, with energy management and energy efficiency applications, 38.2% of heat recovery and 15.79% of fuel savings were achieved when recuperators were used in the furnace. While the boiler thermal efficiency was 64.46% when the recuperator was not used, the boiler thermal efficiency increased to 76.54% when the recuperator was used. In HVAC systems, heat recovery was achieved with 47% efficiency with the recuperator, heat exchanger with 51% efficiency and 1.09 COP in heat pump. In cooling applications, 30.4 % energy saving was achieved in the insulated room.

Keywords: Energy management, Energy efficiency, Energy saving, Energy efficiency improvement project

Sanayide Enerji Verimliliğini Arttırıcı Enerji Yönetimi Uygulamaları: Fırın, Kazan HVAC ve Soğutma Sistemlerinde

Öz

Bu çalışmanın amacı, endüstrilerde enerji verimliliğini artırmaya yönelik enerji yönetimi uygulamalarını göstermek ve analiz etmektir. Çalışmada, endüstriyel kuruluşlarda gerçekleştirilebilecek enerji verimliliği artırıcı uygulamalarının örnekleri ele alınmış, bu uygulamalar için tasarruf miktarı hesaplanmıştır. Çalışmada ele alınan başlıca enerji verimliliği uygulamaları: kazanlarda ve fırınlarda ısı geri kazanımı, ısı yalıtımı ve HVAC sistemlerinde ısı geri kazanımıdır. Bu çalışmanın sonucunda enerji yönetimi ve enerji verimliliği uygulamaları ile fırınlarda reküperatör kullanıldığında %38,2 oranında ısı geri kazanımı, %15,79 oranında yakıt tasarrufu sağlanmıştır. Reküperatör kullanılmadığında kazan ısıl verimi %64,46 iken, reküperatör kullanıldığında kazan ısıl verimi %76,54 'e yükselmiştir. HVAC sistemlerinde

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reküperatör ile %47 verimle, ısı değiştiricisi %51 verimle ve ısı pompasında 1,09 COP ile ısı geri kazanımı sağlanmıştır. Soğutma uygulamalarında, yalıtımlı odada %30,4 enerji tasarrufu sağlanmıştır.

Anahtar Kelimeler: Enerji yönetimi, Enerji verimliliği, Enerji tasarrufu, Enerji verimliliği arttırıcı proje

1. INTRODUCTION

With population growth, urban development and industrialization, the world's primary energy consumption is also increasing. Population growth is one of the main factors that cause energy consumption to increase. Projections show that the world population will rise to 9 billion in 2040. This situation demonstrates the need to provide additional energy supplies for 1.9 billion people. While the world's total energy supply in 2035 should be 18.676 Mtoe according to current policies, it is estimated to be 17.197 Mtoe with a decrease of 8%, according to the new policies scenario. The total primary energy supply of the world, which was 8.779 Mtoe in 1990, increased by 45% after the last 20 years and reached 12.730 Mtoe in 2010. According to the Current Policies, world primary energy supply is estimated to increase by 47% to 18.676 Mtoe in 2035 compared to 2010, and according to the New Policies Scenario, the world's total primary energy supply will increase by 35% to 17.197 Mtoe. It is expected that the amount of energy used for electricity generation will increase by 70%, with an annual average of 2%, until 2040, and this increase corresponds to 42% of the global primary energy growth rate [1]. An increase of 81% is expected in the primary energy consumption used in industry, which constitutes 50% of the world primary energy growth rate. At this point, increasing efficiency and energy saving with energy management in the industry are gaining more and more importance day by day.

Energy management is a process of optimizing energy consumption; it is multidisciplinary in nature, combining the skills of architecture, engineering, management, finance, and others to carry out the required management functions [2]. Energy management includes training, energy audit, measurement, monitoring, planning, and implementation activities carried out to ensure efficient and economical use of energy resources and energy. Energy saving is the reduction of energy consumption using new technologies, without reducing production, quality, and performance, without hindering social welfare. Energy efficiency is the highest efficiency evaluation of energy resources at all stages from generation to transmission-distribution and consumption. Energy efficiency is the reduction of energy consumption per unit service or product amount without causing a decrease in the standard of living and service quality in buildings, and production quality and quantity in industrial enterprises. The aim of energy efficiency is to increase efficiency in the use of energy resources and energy to use energy effectively, to prevent waste, to alleviate the burden of energy costs on the economy and to protect the environment. The main goal is to reduce the energy consumed per unit of national income. Its vision is to be a country that transforms all its energy into benefits, to be among the countries with low per capita energy consumption and energy intensity.

The energy consumed in the world; 40% is spent on buildings, 32% in transportation and 28% in industry [3]. At this point, efficient use of energy and energy saving in industry are gaining more and more importance day by day. In the industrial facilities, it is ensured that the necessary measures are implemented to eliminate energy wastes, losses and inefficiencies, and that electricity generation systems based on renewable energy sources or cogeneration systems with a total cycle efficiency of at least eighty percent or more are established within a maximum distance of ten kilometres to meet some of the energy needs of industrial facilities. Energy efficiency improvement precautions covers the architectural design, thermal insulation, heat recovery, mechanical installation, oven, boiler, steam systems, drying systems, fan, and pump, compressed air systems, lighting, compensation, heating-cooling-ventilation, automation, lighting, electrical systems, electrical devices, engines, and minimum performance criteria. Main applications that ensure the efficient use of energy with energy management applications in the industry: demand side management, increasing efficiency in production, transmission, distribution facilities and outdoor lighting, rehabilitation of thermal power plants and benefiting from waste heat, encouraging the use of alternative fuels, increasing the use of renewable energy sources, reducing energy intensity, using fuels with low CO_2 emissions, improving fuel quality, diversifying resources in energy production, and improving fuel quality.

The concept of energy management was first used by a British scientist after the Second World War. It was mainly used for buildings. After the 1973 oil crisis, this concept began to be used in industry as well [4]. The gap between the actual level of energy efficiency and what theoretically could be reached is referred to as the energy efficiency gap by Hirst and Brown [5]. Bunse et al. [6] have defined energy management in the production area as activities including control, monitoring, and improvement of energy efficiency. Making a relation between both concepts, the International Energy Agency [7, 8] has defined: “Energy management involves the systematic tracking, analysis and planning of energy use. Energy management systems include energy management activities, practices and processes”. Thollander and Palm [9] have stated: “Energy management can be defined as the procedures by which a company works strategically on energy, while an energy management system is a tool for implementing these procedures”. In the literature review, Schulze et al. [10] have identified that energy management comprises “strategy/planning, implementation/ operation, controlling, organization and culture”. Energy management: it is a whole formed by functions that can be ineffective when they are independent of each other, such as planning, coordination, and control, come together. Energy Management in Industry is a structured and organized disciplined work in line with the efficient use of energy without sacrificing product quality, safety or environmental conditions and reducing production.

Different countries in the world addressed the problem of lack of energy efficiency measures and conducted several types of research in the energy management field [11]. For example, previous studies from China [12], United States of America [13], Ethiopia [14], Thailand [15] and Turkey [16] explored the potential of energy efficiency in cement industry from the different perspective. Hasan et al. investigated two prior research [17] on the prospect of energy efficiency in the industry of Bangladesh. Andersson and Thollander [18] studied the current level of implementation and operationalization of energy-related key performance indicators in the Swedish pulp and paper industry.

The literature presents studies on energy behaviour [19] and on environmental behaviour [20] in organizations. These studies emerge from the behavioural theory in organizations. In an organizational structure, a management team is important to lead the operations of the company [21]. Sola and Mota [22] analysed the influencing factors on energy management in industries from these perspectives. A study developed by Martin et al. [23] shows that better energy efficiency and productivity are strongly associated to management practices. The market also influences the adoption of environment management system (ISO 14001), according to a study developed by Neves et al. [24]. Competitive advantage is an external motive to implement ISO 50001 in organizations Marimon and Casadesús [25]. Energy management activities within an industrial company are comprised of several components, of which one is controlling energy end-use [26]. The controlling elements of energy management include data collection and monitoring, benchmarking energy performance, and performance evaluation.

In this study, energy efficiency analysis in industry was carried out with controlled experiments carried out in the Energy Efficiency Test

Laboratory of the Ministry of Energy and Natural Resources of the Republic of Turkey, Department of Energy Efficiency and Environment. While determining the experimental conditions in the applications, the real working and operating conditions in the industry were considered. What is meant by experimental study is the controlled experiments carried out in the real size and capacity test units in the laboratory where the real working and operating conditions in the industry are met. Energy efficiency-improvement practices have been used in experimental setups designed for training in boilers, furnaces, heat recovery in HVAC systems, and insulation in the cooling process. Efficiency and energy saving values were calculated for each system using the measurement data obtained from the experiments. The aim of this study is to demonstrate energy management applications used to increase energy efficiency in industries and to determine the energy savings of each system by analysing the data of the experimental studies. The contribution of this study to the literature is to emphasize that under which conditions the energy efficiency of boilers, furnaces, HVAC systems, and cooling systems can be maximized, and energy savings can be achieved by minimizing energy consumption, by considering the real working and operating conditions in the industry and applying these conditions in laboratory test units. Since constant working conditions are required in order not to impair the quality of the process in factories, it is inconvenient to conduct experiments in such variable conditions in real practice in an industrial establishment.

2. METHODOLOGY

2.1. Experimental Test Units

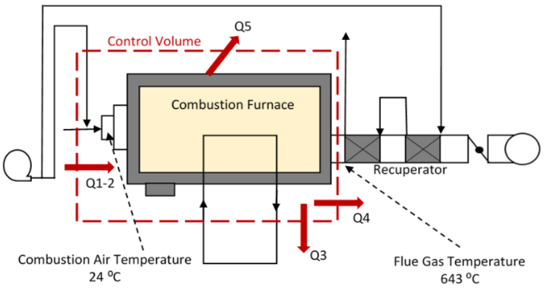
Combustion furnace experimental test unit

The combustion furnace test unit is shown in Figure 1. The internal volume of the furnace is 3 m^3. The furnace is insulated with ceramic fiber material. When the oven is operating, the outer surface temperature is close to the ambient temperature. While the ambient temperature is 23.2 ^oC, the average temperature of the furnace surface is 31.8 ^oC. It is possible to increase the furnace operating temperature up to 1000 ^oC. In the experiments, the furnace indoor temperature was set as 700 ^oC. Natural gas is used as fuel in the furnace. The most important loss in the furnace is the heat loss with the flue gas. Figure 2 shows the flow chart of combustion furnace test unit.

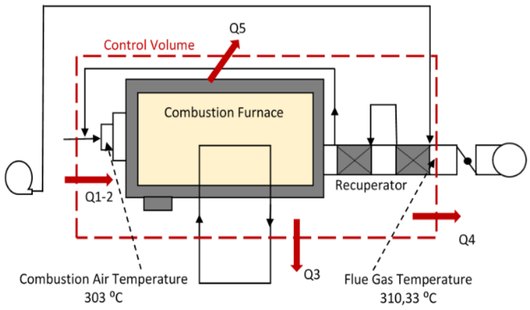
In order to ensure real ambient conditions in a furnace designed for educational purposes, the energy that should be transferred to the product in normal applications is transferred to the water with 6 m^3/h fixed flow rate water pipes placed inside the furnace. The reason for using high flow rate water is to prevent the water from evaporating. The amount of useful energy that should be transferred to the product is calculated by using the water mass the inlet and outlet temperature difference of the water. If the pressure inside the furnace is less than the outdoor pressure ($P_{furnace}>P_{environment}$), the hot gases inside will come out through various openings and cause energy loss. To prevent this, a damper is placed in the chimney. By adjusting this damper, the appropriate pressure value is adjusted.

The chimney of the furnace is designed as recuperator to make heat recovery. The heat in the flue gas is transferred to the combustion air by means of two intertwined pipes in the recuperator, and efficiency is increased by heat recovery. Savings are achieved by not using as much fuel as the equivalent of this recovered energy.

Figure 1. Combustion furnace test unit



a) Without recuperator



b) With recuperator

Figure 2. Flow chart of combustion furnace test unit

Energy inputs and outputs to the control volume in Figure 7: Q_{1-2} is the energy entering the furnace. Q_3 is the heat transfer to process water (useful energy). Q4 is the flue gas heat, Q_5 is the heat loss from the surface. Q_6 is the other heat loss.

Steam boiler experimental test unit

The steam boiler can produce steam at a mass flow rate of 1000 kg/h per hour and at 6 bar pressures. The water taken from the mains in the steam boiler is not given directly to the boiler. In order to get the hardness of the water, it is passed through the water softening system. The water whose hardness is removed is stored in the feed water tank, and when needed in the boiler, it is sent to the boiler by the feed water pump. The water is evaporated until it reaches 6 bar pressures with the heat released by the combustion of natural gas in the boiler. System elements are seen in the Figure 3 and Figure 4. In Figure 3, 1 is the water softening system, 2 is the feed water tank, 3 is the difference pressure transmitter, 4 is the water level indicator, 5 is the natural gas pressure measurement, 6 is the natural gas meter. In Figure 4, 7 is the economizer, 8 is the combustion air fan, 9 is the combustion air fan flap, 10 is the measuring and control board. Natural gas is used as fuel. The proportional burner regulates the amount of fuel.

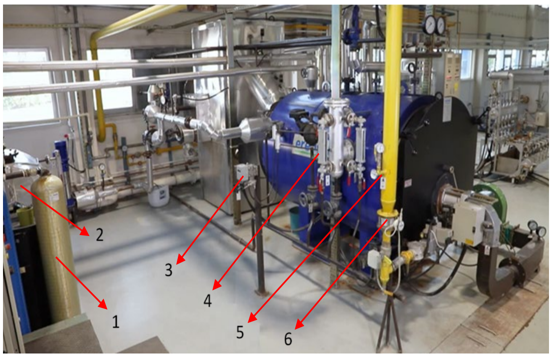


Figure 3. Steam boiler test unit (left side view)

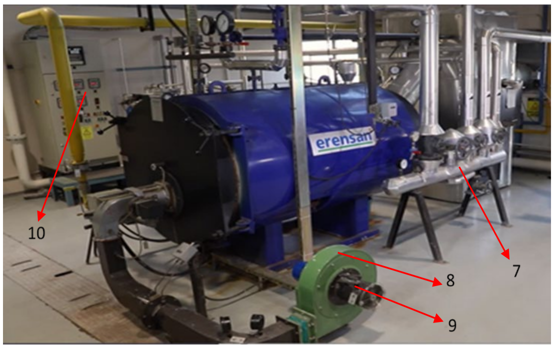


Figure 4. Steam boiler test unit (right side view)

Heat recovery systems in HVAC experimental test unit

In HVAC experimental facility, plate heat exchanger (recuperator), water heat exchanger and heat pump heat recovery methods were applied separately. It is provided to transfer the heat from the exhaust air of the HVAC system to another system and to recycle the heat in different ways. Thus, the heat obtained is transferred to another system in a controlled manner. Figure 5 and Figure 6 show HVAC test unit. In Figure 5, 1 is the recuperator, 2 is the heat exchanger, 3 is the heat pump (hot) (Condenser), 4 is the heat pump (cold) (Evaporator) and 5 is the heat wheel (Regenerator), 6 is the fan (Frequency drive controlled). In Figure 6, 7 is the heater, 8 is the damper, 9 is the compressor, 10 is the valve, 11 is the by-pass valve and 12 is the pump.

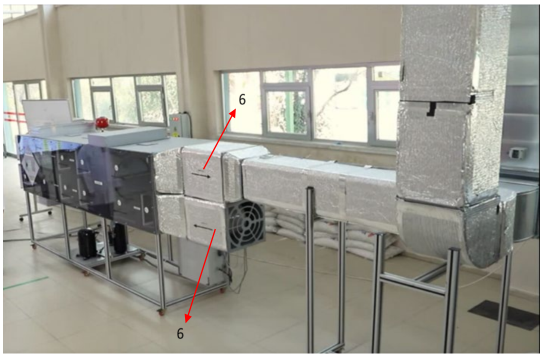


Figure 5.a. HVAC test unit

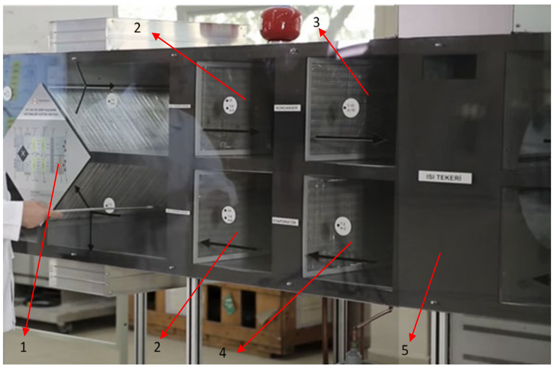


Figure 5.b. HVAC test unit

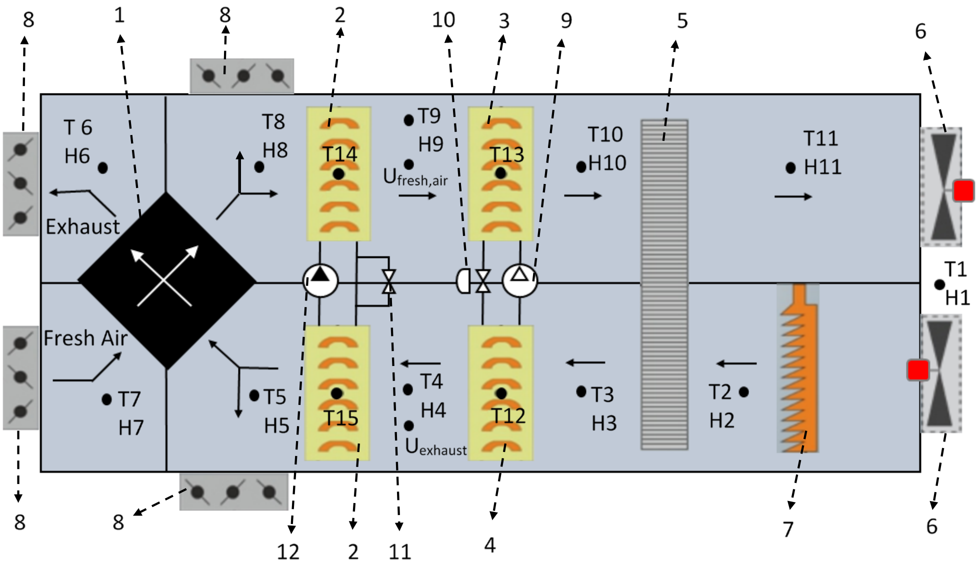


Figure 6. Flow chart of HVAC test unit

Since the experimental installation simulates a heat recovery unit operating in winter, the air sucked in by the fan is heated with a resistance to simulate the hot air indoor. The sucked air represents the polluted exhaust air in the indoor.

Automatic air flow control was carried out with 4 different dampers in the experimental installation. During the experiments, (T) dry bulb temperatures, (H) relative humidity, (U) air velocity and electrical data were measured digitally.

Experimental test unit of thermal insulation in cooling application

The energy savings provided by thermal insulation in cooling applications have been examined. In the controlled experiments in the cooling system designed for educational purposes, the efficiency increases in the insulated room compared to the uninsulated island was calculated by determining how many times the compressor stopped in a 60-minute period, how long the active cooling was made and the total energy consumption of the system. The heat gains in the insulated and uninsulated room were determined separately.

With the automation system, the indoor temperature of the cooling room was adjusted to 10 ^oC, allowing the cooling system to operate for 60 minutes. When the compressor was turned off, the energy consumed because of the experiment, the electrical data of the evaporator (active power, reactive power, apparent power), the outer surface temperatures of the insulated and uninsulated cooling rooms, the inner surface temperatures and the indoor temperatures were measured. What needs to be considered while performing the cooling test is to determine how long the compressor is in operation and how long it does not work.

Figure 7 shows the cooling application test unit and system components. There are two rooms, insulated and non-insulated, in the experimental installation. With the cooling system, the indoor temperatures of both rooms were cooled to 10^o. Measurements were made by adjusting the room indoor setting set temperature from the measurement and control panel. The heat gains in the two rooms were determined separately and compared in terms of efficiency. Heat gains are one of the most important factors affecting the cooling load. The heat gains from the walls of the cold room increase the cooling load. Figure 13 shows the schematic picture of the test installation, the temperature and pressure measurement points. In Figure 7 and Figure8, 1 is the compressor, 2 is the condenser, 3 is the liquid tank, 4 is the filter holder, 5 is the flowmeter, 6 is the expansion valve, 7 is the evaporator, 8 is the insulated Room, 9 is the measurement and control panel and 10 is the uninsulated room. Table 1 show the measuring points of cooling system test unit.

Figure 7. Cooling system test unit

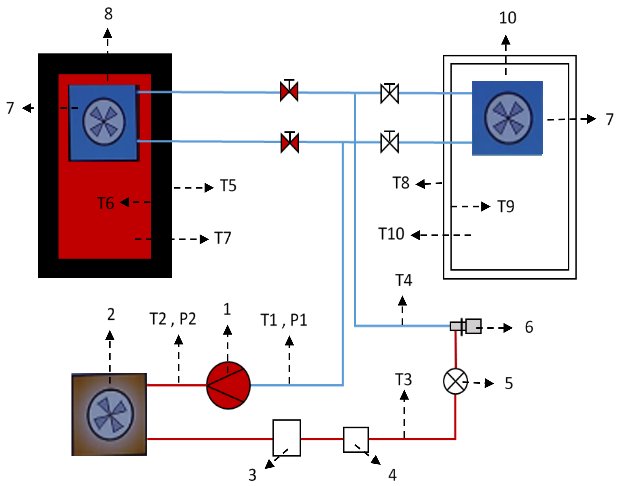


Figure 8. Flow chart of cooling system test unit

Table 1. Measuring points of cooling system test unit

Measuring point		Measuring point	
T1	Pump inlet temperature	T7	Insulated room indoor temperature
T2	Condenser inlet temperature	T8	Non-insulated room outer surface temperature
T3	Expansion valve inlet temperature	T9	Non-insulated room interior surface temperature
T4	Evaporator inlet temperature	T10	Non-insulated room interior
T5	Insulated room outer surface temperature	P1	Compressor inlet pressure
T6	Insulated room inner surface temperature	P2	Compressor outlet pressure

3. EXPERIMENTAL STUDIES, RESULTS, AND DISCUSSION

Combustion furnace experiment

Savings are made by transferring the recovered heat to the combustion air or by using the energy in a different part of the enterprise by pre-drying the product by heat recovery in the furnace. Sustainable increase in efficiency is ensured.

Waste heat is taken from the hot flue gas with the recuperator and transferred to the combustion air. Fuel will not be used as much as the equivalent of the recovered energy and energy savings are achieved. In the experiments, 2 different test conditions in Table 2 were made to use the combustion furnace efficiently.

Table 2. Experimental variations in combustion furnace test unit

Experiment	Recuperator
1	Without recuperator
2	With recuperator

In each experiment, 3 measurements were made at 15-minute intervals. The reason for taking three values is to minimize reading errors. Table 3 shows the combustion furnace test parameters.

Table 3. Combustion furnace test parameters

	Without recuperator	With recuperator
Relative humidity (%)	31.2	26.2
Ambient temperature (^oC)	23.2	25.6
Furnace temperature (^oC)	715.33	713.33
Furnace pressure (mm SS)	-3.2	-2.53
Combustion air temperature in burner (^oC)	24	303
Gas temperature at the chimney entrance (^oC)	278.33	244.33
Fuel	Natural gas	Natural gas
Fuel flow rate (instantaneous) (m^3/h)	8.8	7
Excess air coefficient	1.1	1.1
Combustion air flow rate (m^3/h)	50	69.3
Process water flow rate (m^3/h)	6	6
Process water temperature (^oC)	8 (inlet) – 15 (outlet)	7.33 (inlet) – 14.33 (outlet)
Flue gas components (%)	0.216 (CO)	0.282 (CO)
	10.08 (CO_2)	10.18 (CO_2)
	5 (O_2)	4.87 (O_2)

Figure 9 shows the energy inputs and outputs to the combustion furnace. Q_{1-2} is energy entering the furnace, Q_3 is the (useful energy) heat transfer to process water, Q_4 is the flue gas heat, Q_5 is the heat loss from the surface and Q_6 is the other heat loss. Figure 10 shows the combustion furnace energy output.

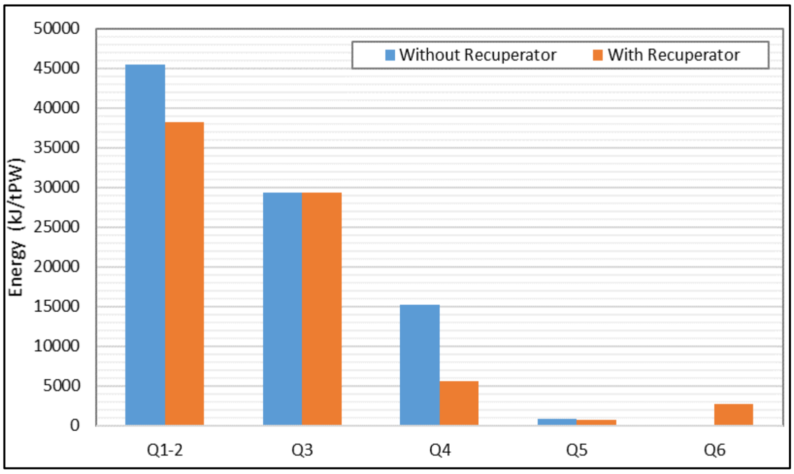
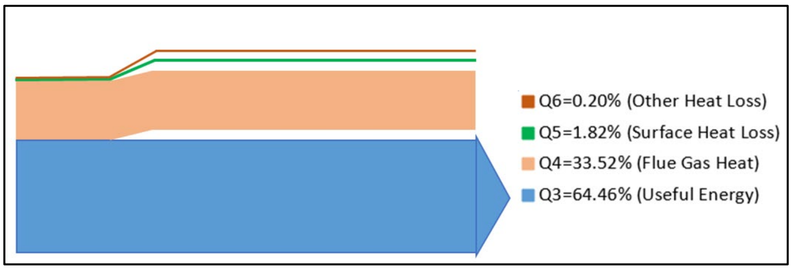
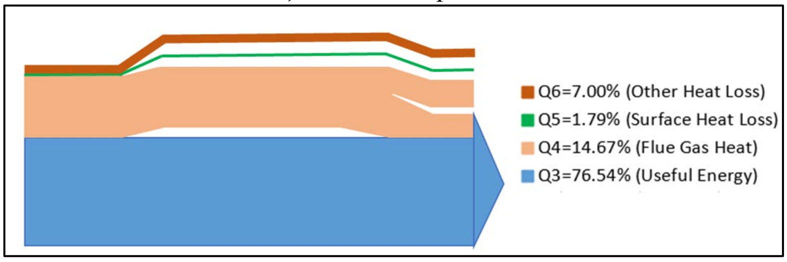


Figure 9. Energy inputs and outputs to the combustion furnace



a)Without recuperator



b) With recuperator

Figure 10. Sankey Chart of combustion furnace energy output

Figure 11 shows the thermal efficiency, heat recovery and fuel saving for furnace with and without recuperator. When heat is recovered from the flue gas with the recuperator, the natural gas consumption decreased to 6.4 Sm^3/h. When the recuperator is used, 1.2 Sm^3/h fuel savings, 38.2% heat recovery and 15.79% fuel savings are achieved. While the boiler thermal efficiency was 64.46% when the recuperator was not used, the boiler thermal efficiency increased to 76.54% when the recuperator was used, and 4803.62 kJ/t PS energy was recovered from the chimney.

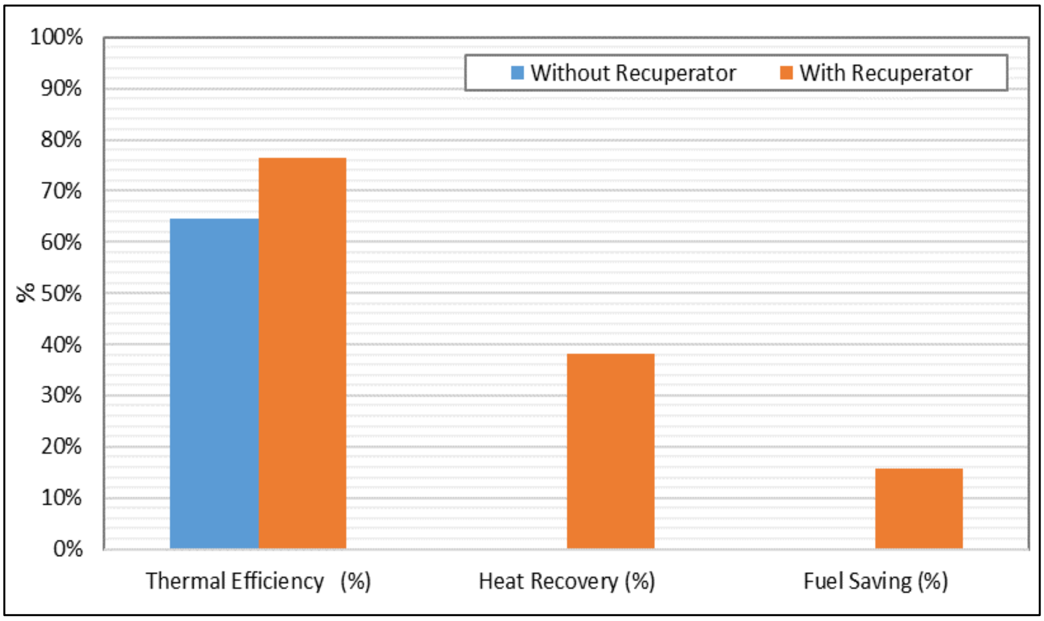


Figure 11. Thermal efficiency, heat recovery and fuel saving for furnace with and without recuperator

Steam boiler test

To increase the boiler efficiency, it is necessary to optimize the air-fuel mixture ratio, reduce the flue gas losses and the heat lost from the surface by convection and radiation. Efficiency calculations have also been made in the steam boiler in the experiments. The boiler operating with natural gas was operated with insufficient air, optimum air and excess air, and analysis was made using the measurement data in the experiments. Two measurements were made with an interval of 15 minutes for each experimental condition. Fuel flow rate, pressure and temperature entering the boiler, air flow rate, steam pressure, produced steam index, flue gas temperature, flue gas temperature after economizer, ambient temperature, boiler surface temperatures, conductivity degree of water entering the boiler, O_3 and CO measurements were made.

Boiler efficiency was calculated using the loss calculation method. Since it is aimed to increase efficiency by determining and reducing losses, the loss method has been chosen. The total boiler efficiency can be easily calculated if the flue gas loss and the surface loss are known:

Boiler efficiency (%) = 100 – (flue gas loss) – (surface loss) – (bluff loss)

In the steam boiler experiments, measurements were made in 5 different experimental conditions described in the Table 4 to examine the efficient working conditions of the boilers. In Figure 12, the loss percentages in 5 different variations are given.

Table 4. Experimental variations in steam boiler test unit

Experiment	Economizer	Combustion Air
1	Without economizer	100% (Excess air)
2	With economizer	100% (Excess air)
3	With economizer	60% (Optimum air)
4	With economizer	40% (Insufficient air)
5	Without economizer	40% (Insufficient air)

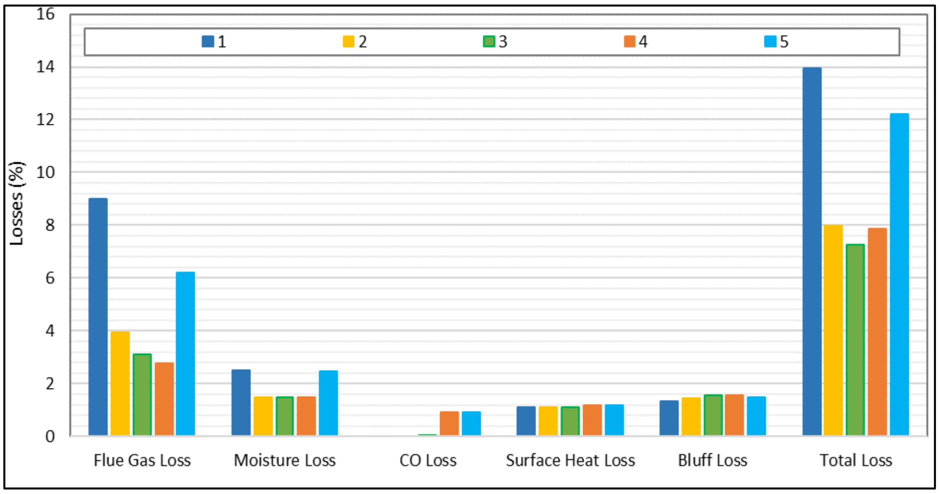


Figure 12. Steam boiler losses in the 5 different experiments

Figure 13 shows the steam boiler efficiency and efficiency increase in the 5 different experiments. With the economizer, the heat of the flue gas combustion air is transferred to the feed water or combustion air, thus saving is achieved. Efficiency increase is achieved by using optimum air and economizer in the 1st, 2nd, 3rd, and 5th experimental conditions and making improvements. The 3rd experiment was carried out under optimum conditions with the highest efficiency. The amount of fuel provided by heat recovery is determined by the product of fuel consumption and efficiency increase.

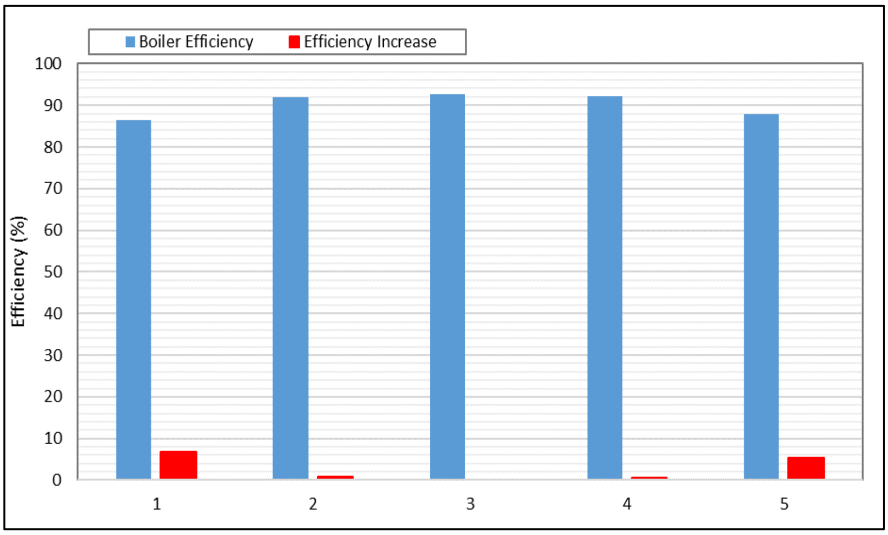


Figure 13. Steam boiler efficiency and efficiency increase in the 5 different experiments

Periodically controlling and modifying the air-fuel ratio in boilers is one of the easiest ways to increase efficiency. Most high temperature boilers use 10% to 20% excess air. If the amount of air is too much or less than the theoretical amount, it will reduce the efficiency. The air-fuel ratio can be determined by measuring the flow rates or by analysing the exhaust gases [4].

Heat recovery experiment in HVAC system

In HVAC systems, the efficiency of three different systems that provide savings with heat recovery from the hot exhaust air evacuated from the indoor environment has been compared. In order to minimize the measurement errors that can be made in the experiments, three measurements were made for each system. In this study, the average of the calculated efficiencies for the measurement data obtained in three experiments is presented. In the experiments, 3 systems described in the Table 5 were used to provide heat recovery.

Table 5. Experimental variations in the heat recovery in HVAC systems test unit

Experiment	Heat recovery unit
1	Recuperator
2	Heat exchanger
3	Heat pump

During the experiments, analysis was made by determining the control volume for each of the recuperator, water heat exchanger and heat pump heat recovery systems separately.

Figure 14 shows the heat recovery efficiencies in HVAC experiments for 3 different unit. In HVAC systems, heat recovery was achieved with 47% efficiency with the recuperator, 51% efficiency with the heat exchanger and 1.09 COP in the heat pump. In Table 6, the area, air velocity and flow rate, fresh air and exhaust air enthalpies, and heat transfer values in the experiments performed separately for 3 different heat recovery systems are given.

Table 6. Experimental parameters for 3 different heat recovery systems

Control Volume 1 (Recuperator)			
Fresh air		Exhaust	
Area [m^2]	0.231	Area [m^2]	0.231
Air velocity [m/sec]	0.7	Air velocity [m/sec]	0.8
Air density [kg/m^3]	1.292	Air density [kg/m^3]	1.292
Mass flow rate [kg/h]	682.136	Mass flow rate [kg/h]	748.5
h_8 [kJ/kg]	44.179	h_5 [kJ/kg]	56.702
h_7 [kJ/kg]	38.128	h_6 [kJ/kg]	45.078
Q_{8-7} [kcal/h]	986.143	Q_{5-6} [kcal/h]	2078.34
Control Volume 2 (Water - Heat changer)			
Fresh air		Exhaust	
Area [m^2]	0.231	Area [m^2]	0.231
Air velocity [m/sec]	0.8	Air velocity [m/sec]	0.9
Air density [kg/m^3]	1.173	Air density [kg/m^3]	1.292
Mass flow rate [kg/h]	780.88	Mass flow rate [kg/h]	843.138
h_9 [kJ/kg]	43.386	h_4 [kJ/kg]	59.291
h_8 [kJ/kg]	39.500	h_5 [kJ/kg]	52.535
Q_{8-9} [kcal/h]	724.895	Q_{4-5} [kcal/h]	1360.726
		Q_{pump} [kcal/h]	60.2
Control Volume 3 (Heat pump)			
Fresh air		Exhaust	
Area [m^2]	0.231	Area [m^2]	0.231
Air velocity [m/sec]	0.8	Air velocity [m/sec]	0.8
Air density [kg/m^3]	1.196	Air density [kg/m^3]	1.1538
Mass flow rate [kg/h]	795.71	Mass flow rate [kg/h]	767.598
h_{10} [kJ/kg]	46.691	h_3 [kJ/kg]	54.41
h_9 [kJ/kg]	36.832	h_4 [kJ/kg]	46.48
Q_{9-10} [kcal/h]	1493.979	Q_{3-4} [kcal/h]	336.015
		Q_{comp} [kcal/h]	1034.58

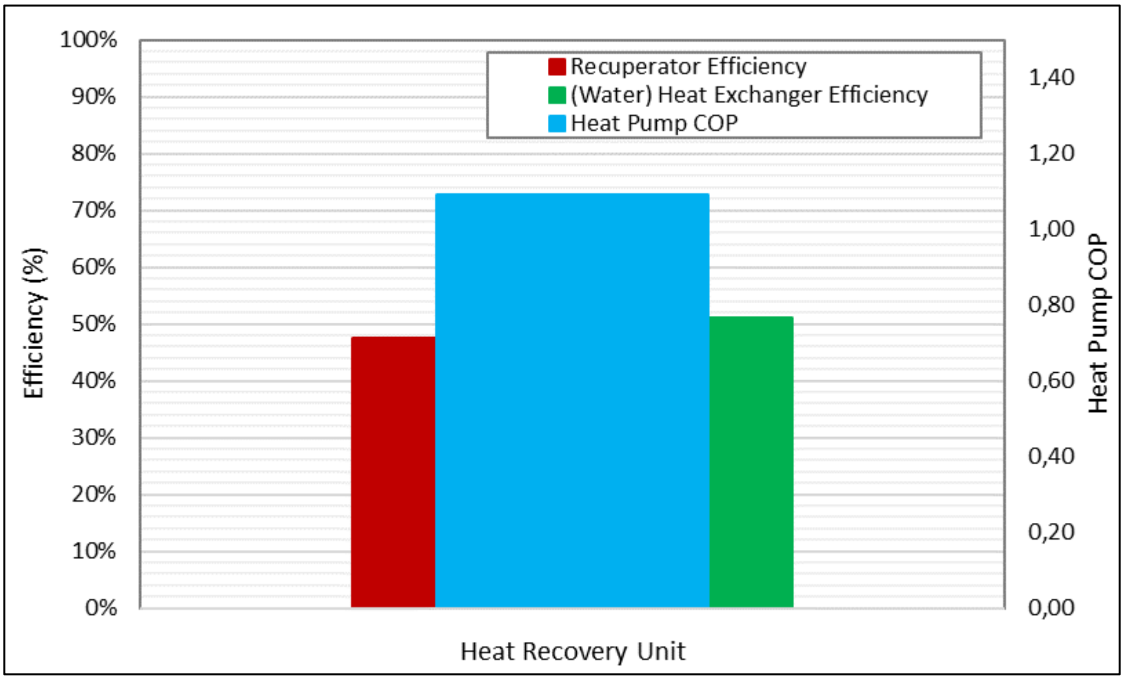


Figure 14. Heat recovery efficiencies in HVAC experiments for 3 different unit

Thermal insulation experiment in cooling system

The energy savings provided by thermal insulation in cooling applications have been examined. In the controlled experiments in the cooling system designed for educational purposes, the efficiency increases in the insulated room compared to the uninsulated island was calculated by determining how many times the compressor stopped in a 60-minute period, how long the active cooling was made and the total energy consumption of the system. The heat gains in the insulated and uninsulated room were determined separately.

With the automation system, the indoor temperature of the cooling room was adjusted to 10 ^{o}C, allowing the cooling system to operate for 60 minutes. When the compressor was turned off, the energy consumed because of the experiment, the electrical data of the evaporator (active power, reactive power, apparent power), the outer surface temperatures of the insulated and uninsulated cooling rooms, the inner surface temperatures and the indoor temperatures were measured. What needs to be considered while performing the cooling test is to determine how long the compressor is in operation and how long it does not work. In the experiments, measurements were made in 2 different experimental conditions described in the Table 7 to prove the importance of thermal insulation in cooling systems. Table 8 shows the cooling experimental unit parameters. Figure 15 shows the temperatures of insulated and uninsulated rooms in the cooling system. Table 9 shows the energy consumption and savings of insulated and uninsulated rooms in the cooling system.

Table 7. Experimental conditions in the thermal insulation test unit

Experiment	
1	Insulated room
2	Uninsulated room

An extra 0.176 kWh of energy was consumed for cooling in the uninsulated room. In the uninsulated room, 43.71% more energy was spent for the cooling process. 30.4% energy saving was achieved in the insulated room.

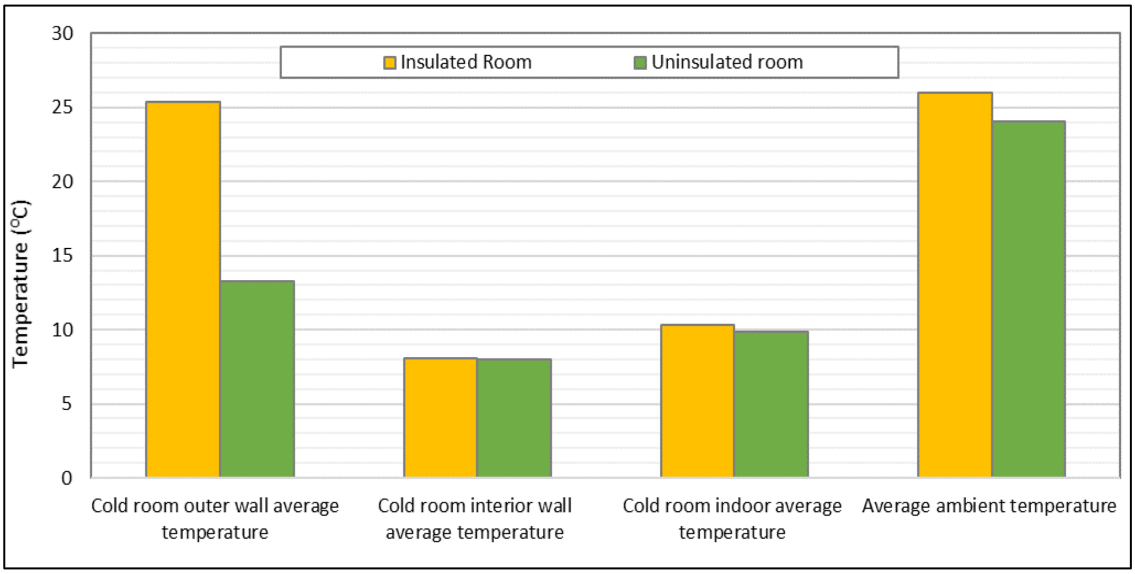


Figure 15. Temperatures of insulated and uninsulated rooms in the cooling system

Table 8. The cooling experimental unit parameters

	Insulated Room	Uninsulated Room
Set temperature (°C)	10	10
Compressor differential temperature (°C)	1	1
Experiment time (minutes)	60	60
Ambient temperature (average) (°C)	26.00	24.05
Surface material emissivity	0.16	0.16
Total wall surface area (m^2)	1.50	1.50
Total ceiling surface area (m^2)	0.25	0.25
U_R three side surface (W/m^2K)	0.967	0.901
U_R ceiling (W/m^2K)	0.967	0.901
U_C three side surface (W/m^2K)	1.276	1.496
U_C ceiling (W/m^2K)	2.626	3.078

Table 9. Energy consumption and savings of insulated and uninsulated rooms in the cooling system

	Insulated room	Uninsulated room
Insulated room total active energy (kWh)	0.403	0.579
Extra energy consumed (kWh)	-	0.176
Energy saving (%)	30.40	-

4. CONCLUSIONS

Energy saving methods that can be applied in industrial facilities are scientifically proven practices. Thanks to energy management, undesirable emissions will decrease because of burning fewer fossil fuels and the effects of global warming caused by carbon emissions will decrease. In addition, energy saving, and efficiency will reduce the burden of new energy investments that countries must make and require very high investment.

The energy efficiency applications in the industry discussed in the study are the heat recovery in boilers and furnaces, thermal insulation, and heat recovery in HVAC systems to minimize the amount of energy consumed without reducing quality and performance. When the recuperator is used in combustion furnace, 1.2 Sm^3/h fuel savings, 38.2% heat recovery and 15.79% fuel savings are achieved. While the boiler thermal efficiency was 64.46% when the recuperator was not used, the boiler thermal efficiency increased to 76.54% when the recuperator was used, and 4803.62 kJ/t PS energy was recovered from the chimney. With the economizer, the heat of the flue gas combustion air is transferred to the feed water or combustion air, thus saving is achieved in boiler. For a constant boiler heat output rate, every 1% increase in combustion efficiency means 1% fuel savings. The heat recovery efficiencies in HVAC experiments for 3 different unit. In HVAC systems, heat recovery was achieved with 47% efficiency with the recuperator, 51% efficiency with the heat exchanger and 1.09 COP in the heat pump. In the uninsulated room, 43.71% more energy was spent for the cooling process. 30.4% energy saving was achieved in the insulated room.

The planned studies on energy management in the industry are to carry out an energy study in an operating factory and to determine the current situation in the factory, to increase the energy savings in the factory with efficiency improvement project applications and to save energy.

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