Original Research Article

Thermal Optimization of Partitioned Electric Water Heaters for Energy Conservation

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ABSTRACT

Optimum design and selection of storage type electric water heaters were analyzed for energy conservation. The thermal performance of a single tank electric water heater is compared with that of partitioned electric water heater for the same average domestic hourly hot water use pattern according to Becker's profile. Both water heaters have the same volume capacity and total power rating while the temperature of the hot water was kept between 60 and 65oC. It is concluded that a partitioned electric water heater provides more hot water and reduces energy consumption whereas the upper part of the tank has 25% of the total volume and 75% of the total power rating.

To evaluate single tank and partitioned electric water heaters transient energy balance equations have been derived and solved. Some assumptions made and thermodynamic properties received to use the evaluate differential equations. To represent water heater models equations required data obtained from literature.

Keywords: energy saving; heat storage; tank simulation; thermal optimization

1. INTRODUCTION

A large number of households use electricity for water heating for domestic hot water consumption. One of the most common ways of generating hot water for domestic use by utilizing electricity is to use a storage type electric water heater. A domestic electric water heater is a simple system including an insulated tank, one or more heating elements, control and safety devices and associated piping. Electric water heaters are more flexible than the other water heating appliances. Such large energy consumption has been the subject of considerable study to determine the factors that affect its magnitude. The most important factor affecting the performance of residential water heaters is the hot water use patterns of households. Several studies have provided a considerable amount of data concerning the patterns of domestic hot water use [1, 2, 3, 4]. These studies were collected, compiled and critically analyzed to provide a more relevant database for the performance and sizing of service hot water heaters. One of these factors identified and quantified, they can be utilized to effectively design and select water heaters for efficient energy use.

Residential storage type water heaters range, approximately, from 20 L to 500 L. Single-element heaters are available with a range of 8 to 26 W/liter electric heater capacity. Residential electric water heaters are selected by using rating tables that take into account the number of occupants, bathroom fixtures and the presence of laundry appliances and dishwashers. Estimation of the maximum hourly hot water demand and the duration of the peak periods are important factors in this selection process. In selection of a storage type hot water heater for service hot water, the standard method of calculation employs steady state analysis of thermodynamic characteristics of the water heater. It is a common practice to assume that 60 to 90% of the hot water in a tank is usable before dilution by cold-water lowers the temperature below an acceptable level. In practice almost all designers assume that 70% of the stored water is usable regardless of the fact that the usability factor depends on several parameters, such as the entering water temperature, heat recovery rate and heat loss from tank.

The thermal performance of storage tanks depends on the rate of mixing between the incoming cold-water and storage hot water. A storage type domestic electric water heater investigated, according to average hourly hot water use profile, to reduce energy consumption. Utilizing stratified tank model, tank will be divided into two parts with varying volumes and electric energy inputs. Single tank and dual sectioned tank model with stratification will be compared to determine savings in energy consumption through simulation.

Domestic water heating represents a significant use of energy in many countries. One of the most common ways of generating hot water for domestic use is storage type electric water. A domestic electric water heater is consisting of an insulated tank, one or more heating elements, valves, control sensors, and piping. Domestic water heating represents the second largest use of energy, next to the space heating, in residences of North America. Such large energy consumption should be the subject of considerable study to determine the factors that affect its magnitude. Once these factors are identified and quantified, they can be utilized to design and select water heaters for efficient energy use. Many studies were performed on water heaters in order to analyze their performances under different conditions. One of these studies was undertaken to determine the structure of domestic hot water consumption using data acquired from seven New Zealand households. The study shows that there is a high proportion of low volume hot water draw offs depending on the household [5, 6]. In addition, draws tent to be separated by relatively short intervals of not more than 10 to 20 min. Thermal losses in the piping exceed 20% of the heat energy supplied by the hot water heater and the losses can be reduced by 5-7% using insulated pipes [5].

Energy efficiencies electric water heaters of internal heating elements mounted at the bottom of the tank are not always high since the whole tank of water is heated for even a quick shower, where the hot water requirement is only a small fraction of total tank volume. It is obtained experimentally for two draw-off rates of 5 and 10 L/min, and by locating a standard heating element at three different positions; mounted vertically at the bottom and horizontally on the lateral surfaces 380 and 600 mm from the bottom surface [7]. It is found that with the heater located on the lateral surface of the storage tank only the water above the heater can be heated while the water below the heater remains almost unaffected by the heating process. For the heater located at a height of 600 mm from the bottom, 85% of the stored energy can be utilized to supply almost 50 L warm water. It is possible to design a tank with dual heaters, giving the users the chance of switching between the elements depending on the amount of water required. Considering that the extra cost of producing an electric water heater with an auxiliary heating element is less than US$50, the application of dual heaters is worth considering by the manufacturers. For the horizontal heater, which is, located 600 mm above the tank can supply about 50 L of warm water after mixing with cold mains water. At 40^{o}C of 50 L warm water is enough in a shower.

Optimum design and selection of storage type electric water heaters were investigated [5]. Single tank electric water heaters of various tank sizes and power ratings were examined using an average hourly hot water use profile obtained from US households. It was found that the amount of hot water provided by single tank water heaters does not vary with tank but does not vary with power rating. However, the energy consumption increases with increasing tank volume single tank volume. Single-tank storage-type electric water heaters were compared to dual-tank storage-type water heaters to determine the amount of hot water output gain and energy conservation provided by dual-tank water heaters. It was determined that dual tank water heaters in series, where the size of the second tank is 25% of the total tank volume and the power rating, provide more hot water and less energy per liter of hot water.

The results of a comparative study and performance on thermally stratified tanks for hot storage presented [8, 9, 10]. A two dimensional model is employed. A numerical solution was obtained using the control volume technique due to Patankar. The two dimensional model was simplified for the pure conduction case. Results from the two models were compared with each other and with available numerical and experimental results. The numerical study was initiated by optimizing the grid size and the time step for both coupled equations model and the pure conduction model. The numerical trials were performed on a storage tank of 360 mm diameter 900 mm height, using water as the working fluid for the numerical simulations. They showed that for the coupled equations model, 15 radial points, 130 axial points and time interval of 1 s are adequate for the numerical calculations. In case of pure conduction model, 30, and 40 points respectively and 30 s are adequate. They found that the simple conduction model consumes about 5 min while coupled equations model 200 min on a computer.

To predict the thermal behavior during the charging the stratified thermal storage tanks under variable inlet temperature, approximate analytical approach to the two-region one-dimensional model which accounts for momentum-induced mixing has been attempted [11]. Arbitrarily varying inlet temperature was decomposed into a number of continuous and discontinuous changes. Then each continuous interval was approximated as a set of piecewise linear functions. In this manner, temperature of the perfectly mixed region admits an analytical solution, which constitutes the interfacial condition for the adjacent plug-flow region.

Three types of function emerge in the transient temperature of perfectly mixed region: constant, linear and exponential with respect to the time.

Performance of one-dimensional models for stratified thermal storage tanks carried out [12]. The aim of that study was to give some recommendations as to which tank model should be used under which conditions in energy system simulations. The assumption of a uniform tank temperature leads to considerable under prediction of the energy input into the tank and the delivered energy under all considered conditions. The relationships between the recommended number of nodes and mean number of tank turnovers are useful as guideline for choosing the most appropriate number of nodes under given operating conditions. Use of the multi node model with variable inlets is recommended, at this model requires fever nodes than the multi node model with fixed inlets foe equivalent accuracy and is therefore computationally more efficient. The plug flow models are computationally more efficient than the multi node models, but both the fixed and variable inlet models tent to over predict energy quantities. Use of the plug flow model including plume entrainment is recommended as an alternative to the multi node with variable inlets for the mean number of tank turnovers lower than five. Care should be taken in choosing the simulation time step because result obtained with the plug flow models were found to depend on the simulation time step.

The influence of the thermal stratification in the storage tank on the performance of solar heating system has been studied intensively since the 1970s and Jordan and Furbo have compared storage tanks with different cold-water inlet devices for small solar domestic hot water systems [13, 14, 15]. The objective of the investigation is to reveal the impact of the cold-water inlet device on the thermal stratification in two marketed tanks and to evaluate the possible enhancement in the annual system performance of small solar heating systems. Two different marketed inlet designs are compared. One connected to a small curved plate placed above the inlet tube, the other one connected to a much larger flat plate. The cold domestic water enters the stores in vertical direction from the bottom of the tanks. Temperatures measurements were carried out for different operating conditions. It was shown that the thermal stratification inside the two tanks depends differently on the flow rate, the draw-off volume as well as the initial temperature in the storage tank. A multi-node storage model was used and expanded by an additional input variable to model the mixing behavior depending on the operating conditions. The inlet device with a comparatively large plate compared to the less favorable design results in an increase of the solar fraction of about 1-3% points in annual system simulation with a solar fraction about 60% and fairly large domestic hot water flow rates. This corresponds to a reduction of the auxiliary energy supply of the solar heating system of about 3-7% for the investigated solar domestic hot water system.

The influence of the flow rate and the tank stratification degree on the performances of a solar flat-plate collector searched [14]. After the first oil crisis in 1973, the strategies used by industrialized and developing countries to reduce their oil dependence have been numerous. A diversification of energy import, a structural change of the large domestic product or an increase of the national supply have been the essential measures taken by the countries with various degree of importance.

Temperature stratification and performance of water heaters of similar capacity but different geometry compared and how this stratification can be used in designing the simplified controls for load leveling type electric water heaters and finally reviews test result of standby loss measurements with various concepts of heat traps on electric storage type residential water heaters investigated [16]. These tests look at actual draw characteristics of two water heaters of equal capacity but different geometry. The results of draw and stratification tests indicate potential for simpler lower cost control of electric water heaters designed for load leveling (as opposed to straight off peak) installations.

Water tanks may operate with significant degrees of stratification, that is, with the top of the tank hotter than the bottom. Many stratified tank models have been developed; they fall into either of two categories. In the first, the multi node approach, a tank is modeled as divided into N nodes (sections), with energy balances written for each section of the tank; the result is a set of N differential equations that can be solved for the temperatures of the N nodes as functions of time. In the second, the plug approach, segments of liquid at various temperatures are assumed to move through the tank in the plug flow, and the models are essential bookkeeping methods to keep track of the size, temperature, and position of segments. Each of these approaches has many variations, and selection of a model depends on the use to which it will be put. The degree of stratification in a real tank will depend on the design of the tank, the size, location, and design of the inlets and outlets, and flow rates of the entering and leaving streams. It is possible to design tanks with low inlet and outlet velocities that will be highly stratified. The effects of stratification on solar process performance can be bracketed by calculating performance with fully mixed tanks and highly stratified tanks.

Stratification is difficult to evaluate without considering the end use. If the lot can use energy at the same efficiency without regard to its temperature level (that is, thermodynamic availability), then maximum stratification would provide the lowest possible temperature near the bottom of the tank and this would maximize the collector output. On the other hand, if the quality of the energy to the load is important, then minimizing the destruction of available energy may be the proper criteria for defining maximum stratification (although all parts of the system should be simultaneously in such an analysis).

2. MATERIAL AND METHODS

2.1 Modeling and Simulation

In this study, the performance of a single tank water heater and a partitioned water heater in series are compared to determine the one, which the greater amount of daily hot water without the outlet temperature dropping below 60oC while providing hot water based on the average hourly hot water use profile according to the literature shown in Fig. 1.

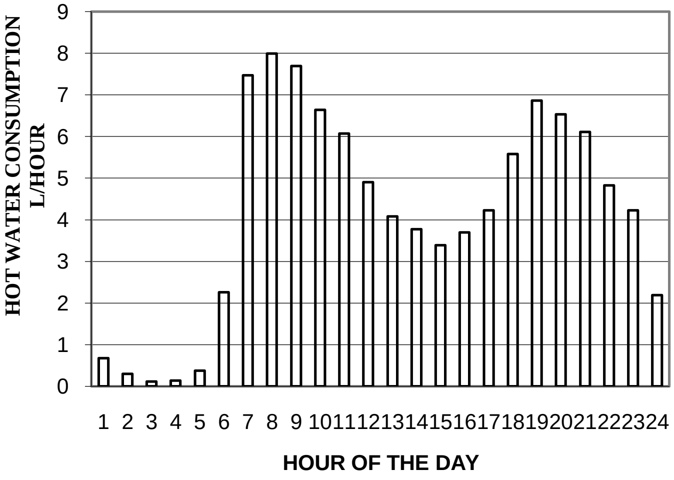

Fig. 1. Hourly hot water use profile [1].

Hot water supply according to hot water consumption is a time dependent process. Hot water supply can be met with an instantaneous hot water heater without storage, but it requires high power input and the necessary wiring. Utilization of low power input requires a storage tank. Energy storage provides a buffer between these two time-dependent functions. To determine process dynamics, load dynamics must be known. According to this profile, hot water consumption is the minimum from midnight to early morning. There are two peak usage hours: One around 8:00 o’clock in the morning, the other around 20:00 o’clock in the evening. Between these hours, hot water consumption steadily remains high.

2.2 Single Tank Modeling

The single tank electric water heater used in this study was modeled as a fully mixed tank with one electric heating element as shown in Fig 2.

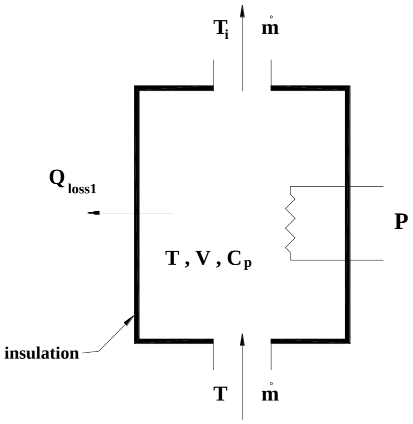

Fig. 2. Schematic diagram of a single tank water heater.

The water heaters modeled are steel tanks with a wall thickness of 2 mm, and 50 mm fiber glass insulation on the outside [17]. The outside surface area of the tank approximately related to the volume of each tank by

$$A = 6V^{2/3} \qquad [1]$$

by taking the height to diameter ratio as 2 and accounting for about 10% of the increase of the outside surface results from the insulation thickness.

Heat loss from the tank surface is calculated as

$$Q_{loss} = UA(T-T_a) \qquad [2]$$

where U is the overall heat transfer coefficient, A is the surface area of the tank, T is the hot water temperature inside the tank in appropriate section and T_a is the surrounding air temperature assumed to be 20°C. The incoming water temperature T in assumed to be 15°C.

In this study, electric water heater problem involves mass and heat flow in and out of the system and, therefore, is modeled with a control volume, as shown in Fig.2. A cold-water stream with a mass flow rate is continuously flowing into the water heater, and a hot-water stream of the same mass flow rate is continuously flowing out of it (hot water is assumed to be incompressible). The water heater (the control volume) is losing heat to the surrounding air at a rate of , the electric heating element is doing electrical work (heating) on the water at the rate of and control volume is storing energy at the rate . By this line of reasoning, the first law of thermodynamics for this water heater can be expressed [18, 19 20]:

$$\frac{dE_{cv}}{dt} = \dot{Q} - \dot{W} + \sum \dot{m}h_i - \sum \dot{m}h_e \qquad (3)$$

where h is the enthalpy of the flowing hot water, (kinetic and potential energy changes are assumed negligible). It can also be expressed as

$$\rho V C_P \frac{dT}{dt} = P + \dot{m} C_P (T_i - T) - AU(T - T_a)$$

[4]

where, $E_{cv} = \rho V C_p T$ (Internal energy of control volume),

$\dot{Q} = -UA(T - T_a)$ (Heat loss to environment),

$\dot{W} = -P$ (Electrical power input to water heater),

T is the temperature of hot water in the tank, V is the volume of the tank, ρ is the density of water, T_i and T_a are incoming cold-water and surrounding temperatures respectively, C_p is the specific heat at the constant temperature of the water and t is time.

2.3 Two-Partition Fully Mixed Tank Modeling

Partitioned water heater is considered to consist of two main sections in series. Upper section is 25% of the total tank volume, and bottom section is 75% of the total tank volume, since it is found the best sizing.

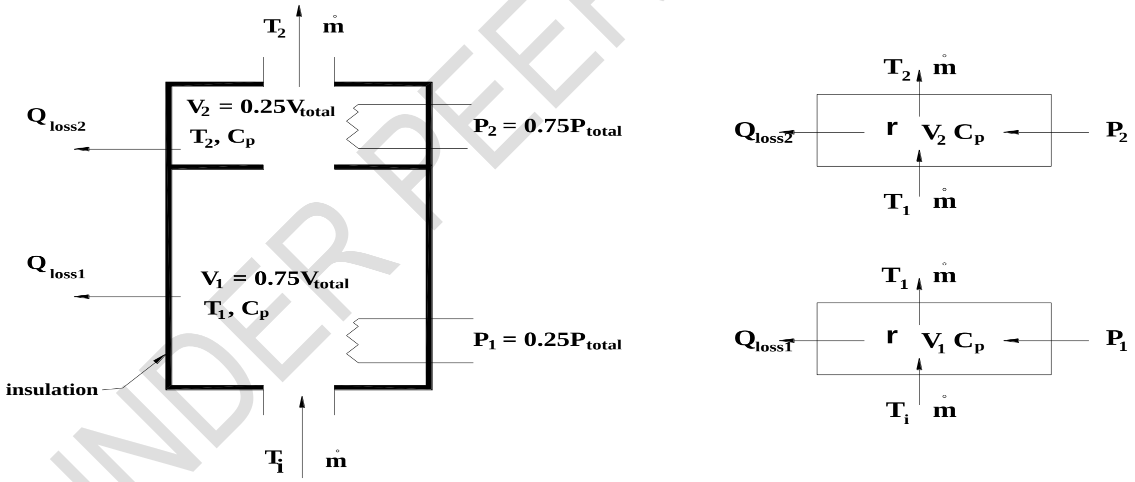

Fig. 3. Schematic diagram of two-partition water heater tank.

Transient heat balance equations of the tank with two fully mixed partitions can be expresses, using Eq. (4), as

$$\rho V_1 C_P \frac{dT_1}{dt} = P_1 + \dot{m} C_P (T_{in} - T_1) - A_1 U(T_1 - T_a)$$

[5]

$$\rho V_2 C_P \frac{dT_2}{dt} = P_2 + \dot{m} C_P (T_1 - T_2) - A_2 U (T_2 - T_a)$$ [6]

where T_1 and T_2 are the temperatures of hot water in the tank partitions 1 and 2, respectively, V_1 and V_2 are the corresponding volumes of the partitions, A_1 and A_2 are the corresponding surface areas of the partitions, P_1 and P_2 are the corresponding power rating of heaters in partitions and the hot water flow rate through the heater. Power inputs P1 and P2 are equal to the total power input P, and are fractions as $P_1 = 0.25$ P and $P_2 = 0.55$ P, since it was found optimum [5]. An on-off controller is used to control power input, to keep the temperature of the upper section between 60 ^{o}C to 65^{o}C. Both power inputs are turned on and off at the same time.

2.4. Two-Partition Stratified Tank Modeling

Water tanks may operate with significant degree of stratification, that is, with the top of the tank hotter than the bottom. Many stratified tank models have been developed; they fall into two categories. . In the first, the multi node approach, a tank is modeled as divided into N nodes (sections), with energy balances written for each section of the tank; the result is a set of N differential equations that can be solved for the temperatures of the N nodes as functions of time. In the second, the plug flow approach, segments of liquid at various temperatures are assumed to move through the tank in plug flow, and the models are essentially bookkeeping methods to keep track of the size, temperature, and position of the segments. Each of these approaches has many variations, and the selection of a model depends on the use to which it will be put.

The degree of stratification in a real tank will depend on the design of the tank, the size, location, and design of the inlets and outlets, and flow rates of the entering and leaving streams. It is possible to design tanks with low inlet and outlet velocities that will be highly stratified. The effects of stratification on solar process performance were bracketed by calculating performance with fully mixed tanks and with highly stratified tanks [21, 22].

With large number of nodes, the tank model represents a high level of stratification that may not be achievable in actual life. As a practical matter, many tanks show some degree of stratification, and it is suggested that three or four nodes may represent a reasonable compromise between conservative design (represented by systems with one-node tanks) and the limiting situation of carefully maintained high degrees of stratification [23]. Stratified tanks have a tendency to stratify over time due to diffusion and wall conduction. This has been experimentally studied by [21]. Recently researches are being done for new designs and thermal optimization in order to save energy use [24, 25].

In this study, the objective is to study the effect of the stratification in the tank on the energy consumption. Hence, total tank is divided into two partitions. Upper partition, which is 25% of the total volume, is divided into 2 equal sections for simulation studies to indicate stratification. Bottom partition, which is 75% of the total volume, is divided into 6 equal sections. Plug flow model is assumed for its simplicity, as shown in Fig. 4. The total capacity and power rating are the same as the single-tank water heater model. Power rating of the upper tank is 75% of the total power, and the bottom is 25%, from [5].

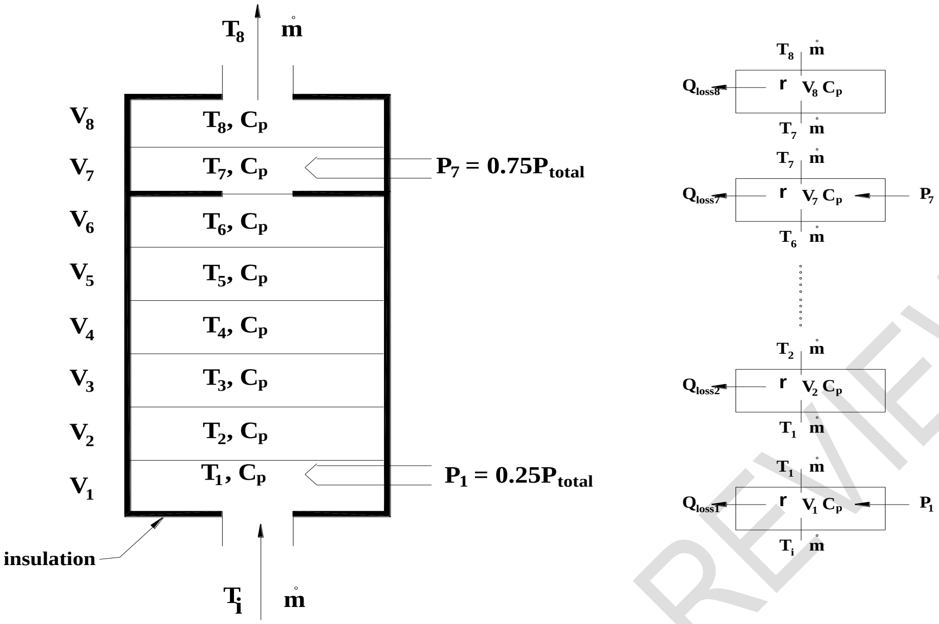

Fig. 4. Schematic diagram of partitioned water heater tank.

The transient energy balances for the 8 sections are written, utilizing Eq.(4), as

$$\rho V_1 C_P \frac{dT_1}{dt} = P_1 + \dot{m} C_P (T_{in} - T_1) - A_1 U(T_1 - T_a) \qquad [7]$$

3. RESULTS AND DISCUSSION

3.1 Single Tank Simulations

Single tank water heaters with tank size of 100, 200, 300 and 400 L were selected. Power ratings of 1, 2, 3 and 4 kW were used for each tank during optimization. At the beginning of each optimization, the temperature of the hot water in the heater was assumed to be at 60^{o}C and according to ANSI standard was kept between 60^{o}C and 65^{o}C during optimization. So on-off thermostatic controller is running between 60^{o}C and 65^{o}C. Parametric optimization was performed on single-tank water heaters to obtain the maximum amount of daily hot water producible for each value of tank volume and power rating. This was accomplished by integrating equation and distributing the daily total hot water consumption to hours according to the pattern given in Fig.1.

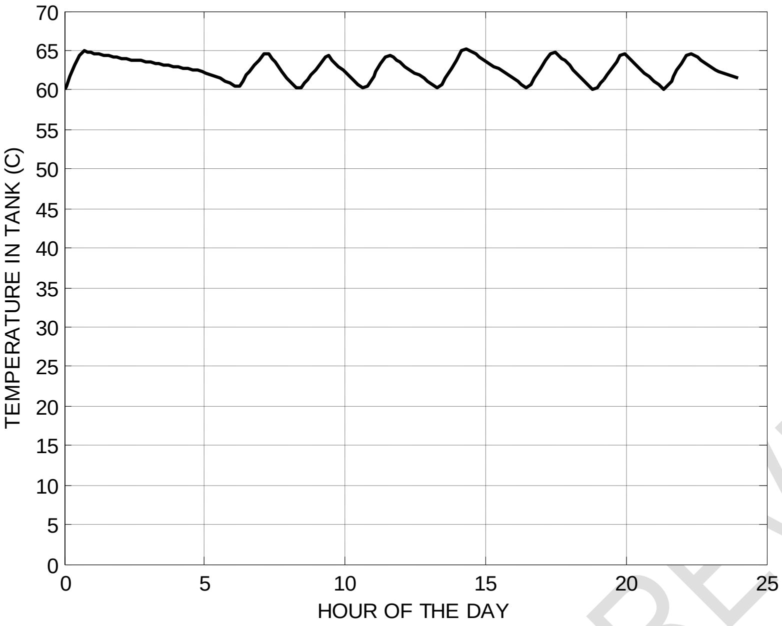

Fig. 5.Time vs. temperature variation according to Becker's profile ($T_{initial}$=60^{o}C).

Fig. 5 shows the relationship between time and the in temperature of the tank. Based on the assumption that the initial temperature of the tank is 60^{o}C, the volume of the tank is 100 L and the power rating of the tank is 1 kW, Fig. 5 shows the temperature variation according to the hours of the day. Maximum hot water provided with this tank, without water temperature falling below 60^{o}C becomes approximately 213 L per day.

Fig. 6 illustrates the amount of hot water output of a heater as function of tank volume for different total power rating. The energy required to provide the amount of hot water outputs was computed and is presented for various tank sizes and power ratings. Fig.6 shows that, even for the same power rating and same hot water output, the required energy per liter of hot water increases with tank size. For smaller tanks, more energy is required per liter of hot water, but less hot water is obtained. Fig. 6 and 7 provide a way of selecting single tank water heaters for energy conservation.

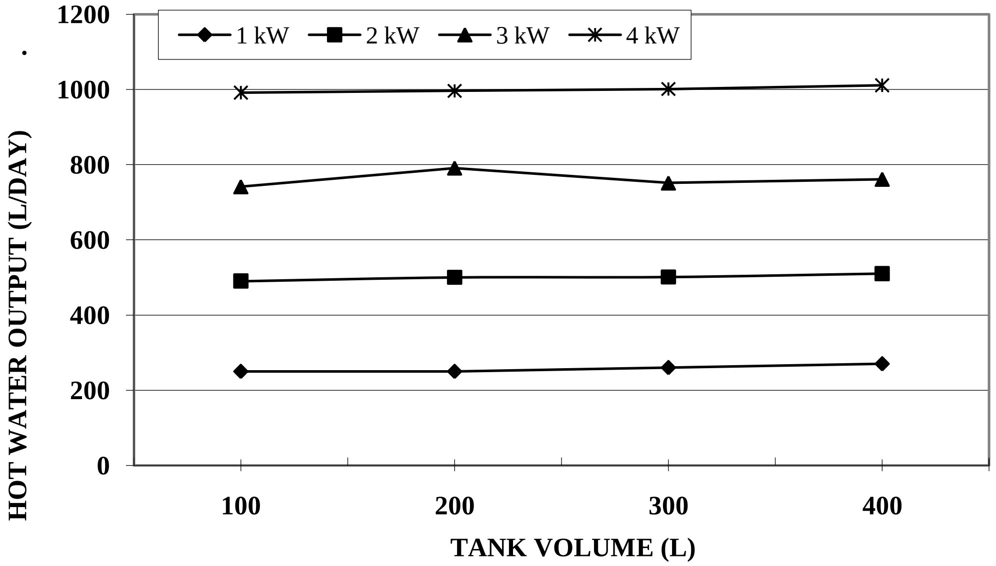

Fig. 6. Thermal performance of single tank electric water heaters.

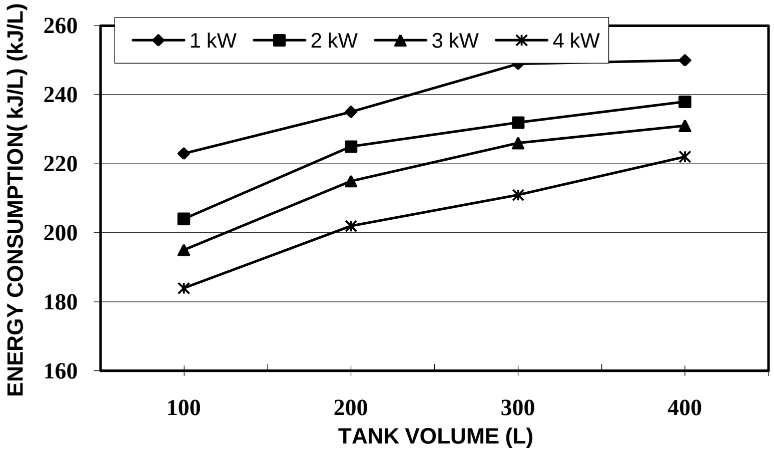

Fig. 7. Energy consumption curves per liter of hot water delivered.

3.2 Two-Partition Fully Mixed Tank Simulations

An electric water heater with two partitions in series is simulated with the same data. Total tank size is taken to be 100, 200, 300, 400 L. Power ratings of 1, 2, 3 and 4 kW were used during optimization. Volume of the upper partition is selected to be 25% of the total volume and the power rating of the upper heater is 75% of the total power rating [5]. (Kar and Kar 1996). At the beginning of each optimization, the temperature of the hot water in the heater was assumed to be at 60^{o}C and according to ANSI Standard was kept between 60 and 65^{o}C during optimization. So on-off thermostatic controller is running between 60 and 65^{o}C.

Parametric optimization was performed on this heater to obtain the maximum amount of daily hot water producible for each value of tank volume and power rating. Temperature vs. time profile of the upper partition is shown in Fig. 8. It stays within the required range.

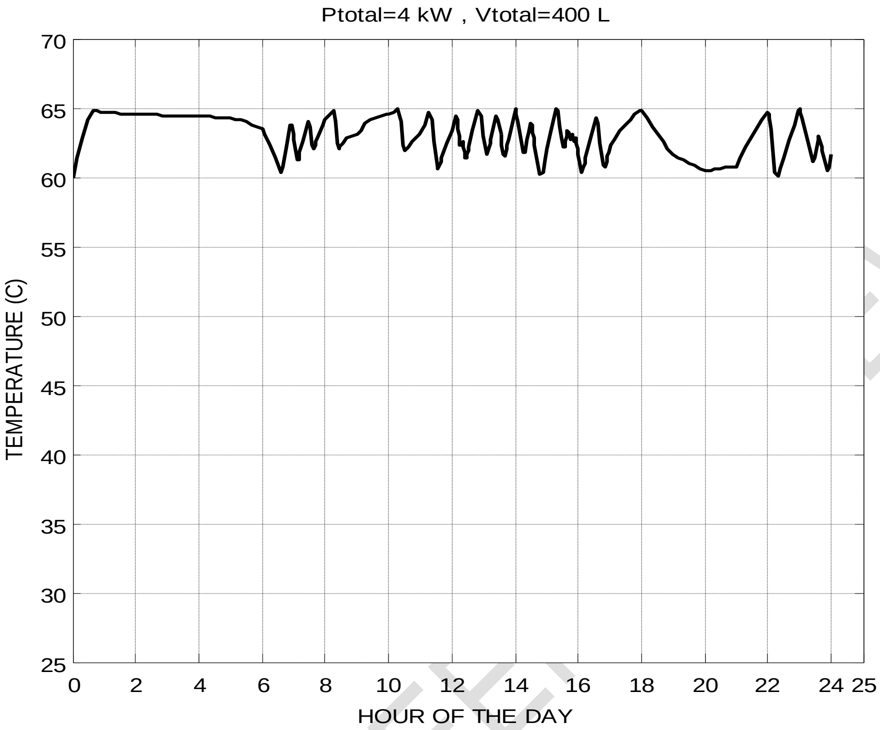

Fig. 8. Outlet temperature vs. time variation according to Becker's profile in fully mixed partitioned heater ($T_{initial}$=60^{o}C).

In Fig. 9 shows each section of the electric water heater temperature and hour of the day. Section 1 shows temperature and time variation at the bottom part of the tank and section 2 shows temperature and time variation according to the Becker's hot water use profile at the top part of the tank.

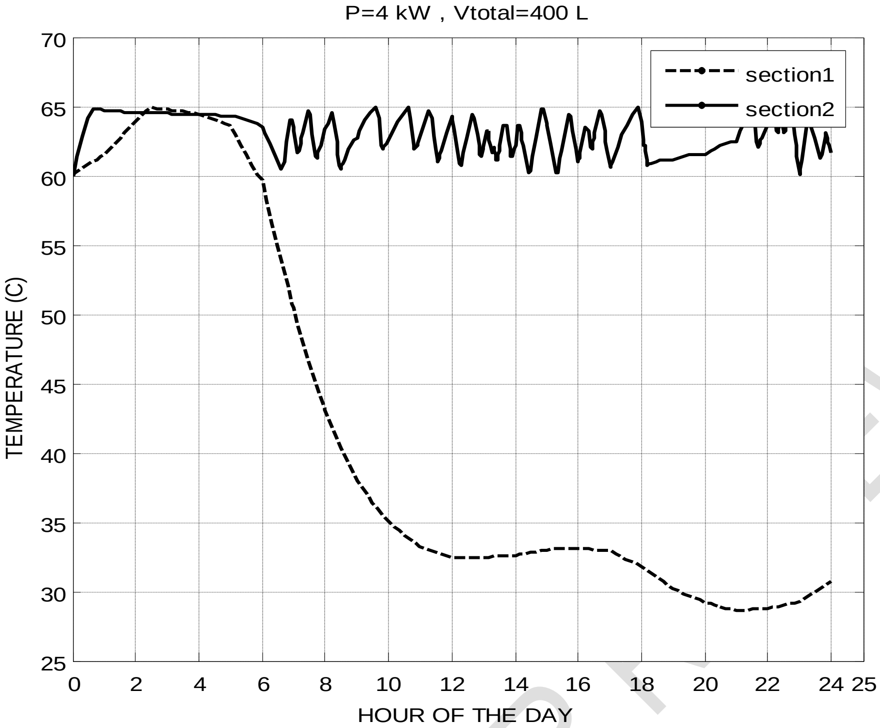

Fig. 9. Temperature vs. time profiles for 2 sections.

Hot water output is presented in Fig. 10 as a function of tank volume and total power rating. The Fig. indicated that hot water output varies slowly with tank volume, but change is higher for change in power rating. Energy required providing the amount of hot water outputs in Fig.10 are computed and presented in Fig. 11 for various tank sizes and power ratings. Fig.11 indicates that even for the same power rating and the same hot water output, the required energy per liter of hot water decreases with tank size. For smaller tanks, more energy is required per liter of hot water but less hot water is obtained.

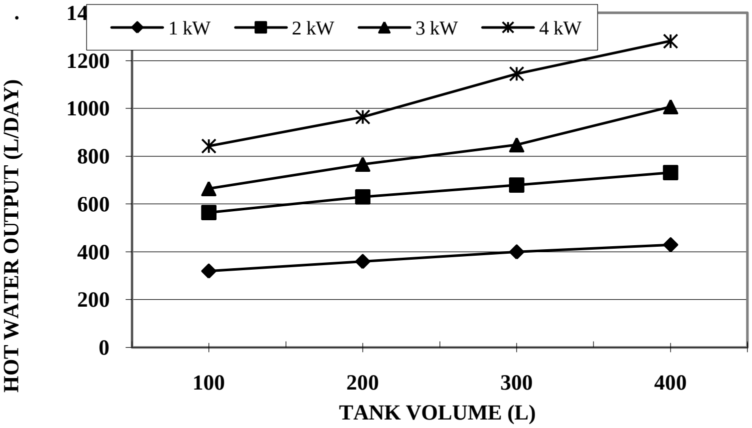

Fig. 10. Thermal performance of two-partition fully mixed tank electric water heater.

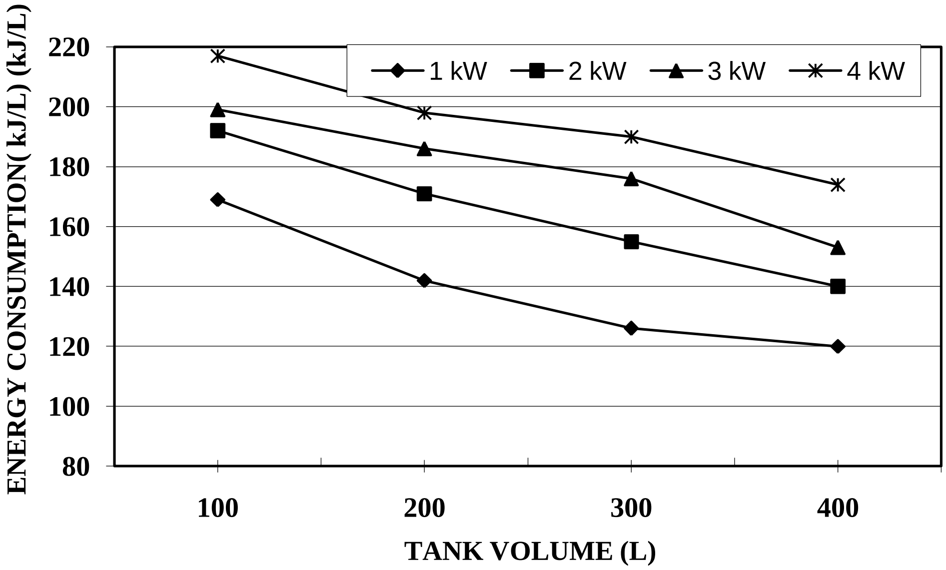

Fig. 11. Energy consumption per liter of hot water delivered by fully mixed two-partition heater.

3.3 Two-Partition Stratified Tank Simulations

In order to see the effect of the stratification in the hot water tank, Eq. 7 is utilized to simulate a stratified electrical hot water heater. Same data as before is used for total tank size and total power rating. Temperature vs. time profile for the uppermost section is shown in Fig12. It indicated much smoother change, compared to single tank and fully mixed partitioned tank heaters. Fig.13 illustrates the temperature change of 8 stratified partitions. Energy required providing the amount of hot water outputs in Fig.14 are computed and presented in Fig.15 for various tank sizes and power ratings. Fig.15 indicates that even for the same power rating and the same hot water output, the required energy per liter of hot water decreases with tank size. For smaller tanks, more energy is required per liter of hot water but less hot water is obtained. It is similar to fully mixed tank; energy consumption per liter of hot water output is smaller than the fully mixed tank for similar tank size and power rating.

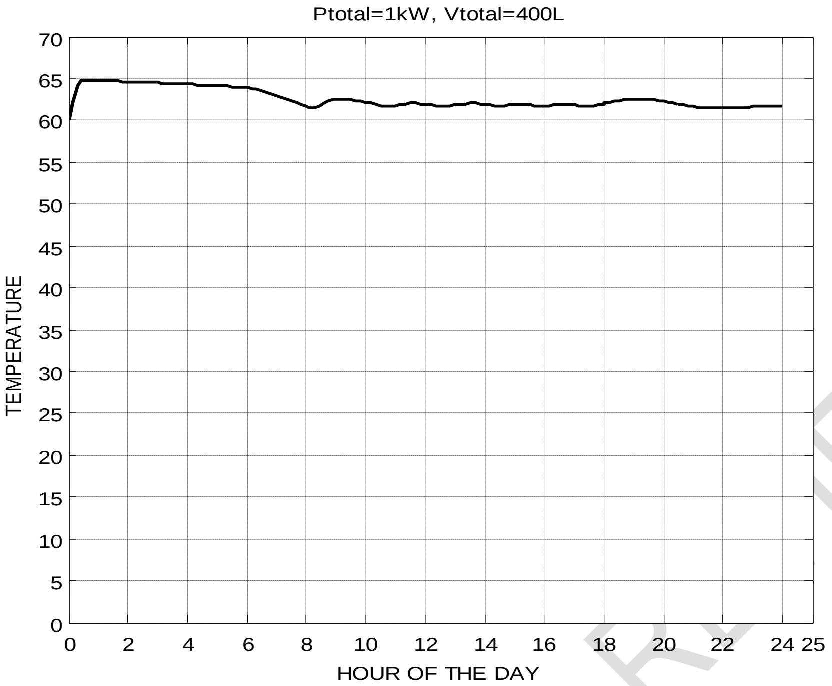

Fig. 12. Temperature vs. time variation according to Becker's profile in stratified partitioned heater ($T_{initial}$=60°C).

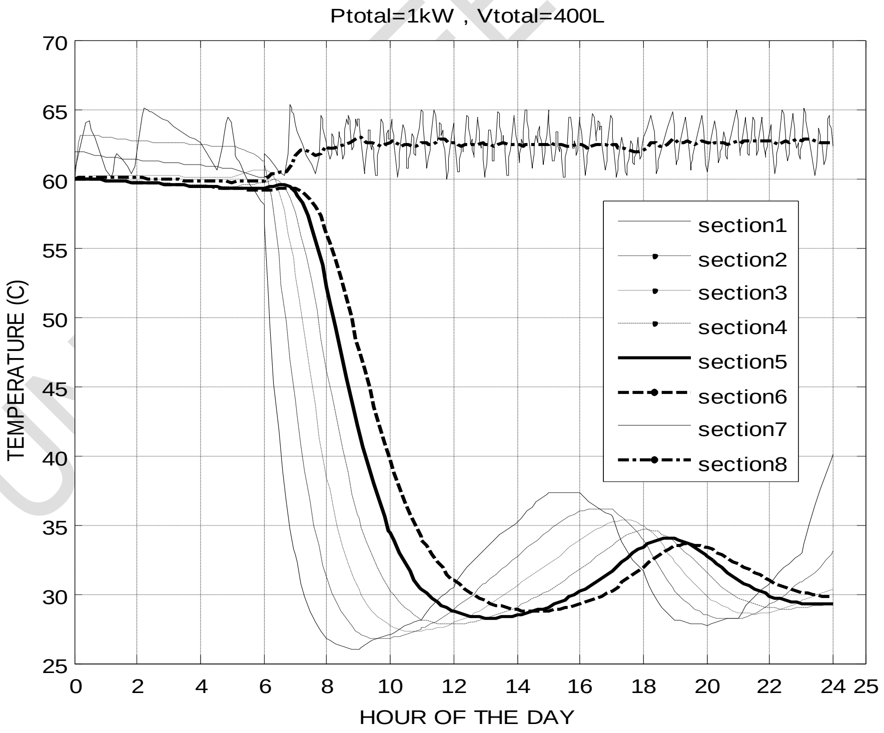

Fig. 13. Temperature vs. time profiles for 8 stratified sections.

Fig. 13 shows temperature variation according to time for each section in tank. Initial conditions are the same of the two-partitioned fully mixed tank. Section 1 is the bottom part of the tank. Section 8 is the upper part of the tank. After 6 hours, first 6 sections cannot keep the water temperature at 60 C, because power rating is not sufficient. At the section 7 temperature variation is too much than the other sections because of the hot water using, so heating element becomes on off often.

Fig.14 shows that hot water output increases with tank size for the same power rating. However, energy consumption per liter decreases with tank size.

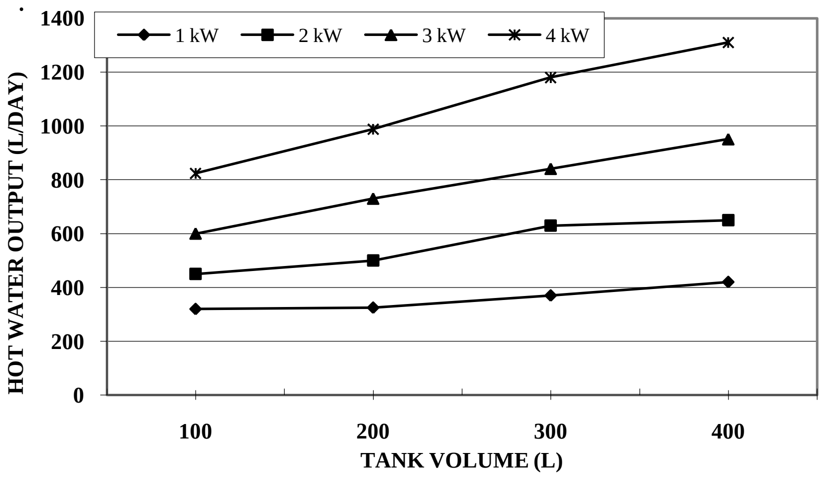

Fig14 Thermal performance of two-partition stratified tank electric water heater.

Results of the simulation on single tank, two-partition fully mixed tank and two-partition stratified tank evaluated and compared in this part of the study. In order to determine whether there will be beneficial to have stratification in water heater tank, hot water output and energy consumption of single and partitioned fully mixed tanks, single fully mixed and partitioned stratified tanks and partitioned fully mixed and partitioned stratified tanks are compared.

3.4 Comparison of Performances of Single Tank and Fully Mixed Partitioned Tank Water Heaters

Hot water output of fully mixed partitioned tank water heater is compared to single tank water heater. Simulation studies indicate that hot water output of partitioned electrical water heater increases with tank size. As power rating increases, the same behavior is observed, but increase is smaller. For a total electrical power input of 1 kW, increase in hot water output goes from 30% for 100 liter tank to 60% for 400 liter tank. However, for a total electrical power input of 4 kW, increase in hot water output goes from 3% for 100 L tank to 27% for 400 L tank. This means that larger tank size with a smaller electrical power rating is better. For a total electrical power input of 1 kW, decrease in energy consumption from 25% for 100 liter tank to 55% for 400 liter tank However, for a total electrical power input of 4 kW, decrease in electrical power consumption goes from 2% for 100 L tank to 25% for 400 L tank.

Similar hot water output increase and energy consumption per liter of hot water decrease are observed in stratified partitioned tank electrical water heaters as compared to single tank electrical water heaters.

Simulation studies indicate that hot water output of stratified electrical water heater increases with tank size. As power rating increases, the same behavior is observed, but increase is smaller. For a total electrical power input of 1 kW, increase in hot water output goes from 28% for 100-liter tank to 56% for 400 liter tank. However, for a total electrical power input of 4 kW, increase in hot water output goes from 2% for 100 liter tank to 22% for 400 liter tank This means that larger tank size with a smaller electrical power rating is better.

Energy consumption per liter of hot water of stratified partitioned tank water heater as compared to single tank water heater. For a total electrical power input of 1 kW, decrease in energy consumption from 38% for 100 L tank to 65% for 400 L tank. However, for a total electrical power input of 4 kW, decrease in electrical power consumption goes from 2% for 100 L tank to 30% for 400 L tank. This means that larger tank size with a smaller electrical power rating is better.

3.5 Comparison of Performances of Fully Mixed and Stratified Partitioned Tank Electrical Water Heaters

In this study, objective was to determine whether a stratified partitioned tank electrical heater would provide more hot water with less energy consumption. Hot water output increases up to 20% due to stratification. Energy consumption per L of hot water decreases on the average 15% due to stratification.

Final simulation studies indicate that hot water output of partitioned stratified electrical water heater increases with tank size. As power rating increases, the same behavior is observed, but increase is smaller. For a total electrical power input of 1 kW, increase in hot water output stays around 5 to 10% for tank sizes of 100 to 400 Ls. However, for a total electrical power input of 2 kW, increase in hot water output goes from 18% to 25% for the tank sizes from 100 to 400 Ls. According to the simulation, electrical water heaters of tank sizes between 100 to 300 L fare better. Energy consumption per L of hot water of fully mixed partitioned tank water heater as compared to single tank water heater. For a total electrical power input of 1 kW, decrease in energy consumption from 8% to 18% for tank sizes 100 to 400 L. However, for a total electrical power input of 4 kW, decrease in electrical power consumption goes from 2% for 100 L tank to 8% for 400 L tank. On the average stratified tank electrical water heater improves hot water output with about 8 to 10% less energy consumption.

4. CONCLUSION

Single tank, fully mixed partitioned tank and stratified partitioned tank electrical water heater performances are simulated and compared. It is found that, fully mixed partitioned tank provides up to 60% more hot water and up to 55% decrease in energy consumption per L of hot water for same tank size and same power rating. Stratified partitioned tank provides up to 55% more hot water and up to 65% decrease in energy consumption per L of hot water for same tank size and same power rating. It is concluded that, single tank water heaters performance not good. Partitioned water heaters are better in any case. This indicates that providing means for stratification in hot water electrical heaters is useful to reduce energy consumption state the major findings of the study.

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