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Energy Efficient Cooking – The EffiCooker

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1 Abstract

Substantial energy savings in moist heat cooking may be achieved by employing a pan with integrated electric heating element rather than an ordinary pan on a conventional electric range. The electric pan should be thermally insulated and equipped with an "intelligent" controller and timer. A working prototype of a saucepan, dubbed the EffiCooker, has been constructed according to these guidelines.

The EffiCooker has demonstrated energy savings in the range from 28% to 81% compared to conventional equipment when performing ordinary cooking tasks. The user need not be particularly aware of energy conservation to realize such savings; even those who are more concerned with their culinary achievements than with energy efficiency are likely to benefit.

Besides being energy efficient the EffiCooker is user friendly. Many cooking tasks, once initiated, are performed automatically without any further user attention.

The EffiCooker also may replace many other kitchen appliances, e. g. steamer, rice cooker, double boiler, chocolate melter, deep fat fryer, etc.

Keywords: Energy Efficient Cooking, Energy Conservation, Saving Energy

2 Moist or dry heat

When food is heated in a container in the presence of ample water, and ample heat is applied, then the temperature will stabilize at the boiling point of water (100°C for pure water at normal atmospheric pressure). The temperature cannot rise above the boiling point because the surplus energy will be expended evaporating water. This so-called *moist heat* cooking is an easy, if energy-inefficient, way of achieving a constant, well-defined temperature; it has probably been used ever since our ancestors learned how to make suitable cooking vessels. In this work we concentrate on this kind of cooking heat.

In the absence of free, liquid water (cooking with *dry heat*) the temperature may rise above that of the boiling point. Such temperatures are necessary to obtain *browning* of the food.

Boiling is cooking food immersed in boiling liquid, usually water. Heat is transferred to the food through convection in water. In *steaming* the food is not covered by water; instead heat is transferred from boiling water to food in a closed container by steam. As the temperature approaches the boiling point the space above the water is almost entirely filled with vapor, most of the air being expelled. The *steaming temperature* must be maintained slightly below the boiling point; this ensures that little steam will escape, provided the lid is reasonably tight-fitting. It also means that a slightly longer cooking time will be required, compared to boiling. In the EffiCooker, described later, the steaming temperature is fixed at 95°C, and the measured steam emission is approx. 7 g/h, corresponding to 4 W.

Steaming may be carried out in an ordinary covered pan, with just a minimal amount of water at the bottom. The food may be placed on a perforated steam plate or basket, or it may rest directly on the pan bottom. For types of food that do not "cling" to the pan bottom it is of no practical consequence whether the food is partly submerged or not. It follows that much less water is needed for steaming than for boiling; this may lead to substantial savings of time and energy, simply because less water has to be heated. Besides, the cooking water ends up being more concentrated and better suited for sauce making, even if less nutrients are leached from the food.

In some cases steaming is not feasible, for example if the food must be cooked in salted water, or if it is supposed to absorb much water, like rice or pasta, or for the preparation of soup or stew. Otherwise steaming should be preferred to boiling.

When using an ordinary cooking surface the heat setting must be manipulated manually. A high initial setting is necessary to accomplish fast boil-up, then the heat must be lowered to maintain just the right degree of boiling. Turning down the heat too late, or selecting a too high setting for continued boiling, will cause waste of energy through excessive evaporation; conversely, if a too low setting is selected the food may not be done as expected. Even for a careful user it may prove difficult to administer the heat setting properly, i.e. getting the food done without undue waste of energy. Also one must monitor the process closely to determine when the correct cooking temperature has been reached, in order to achieve correct timing. In the EffiCooker these problems have been solved by the automatic control, resulting in substantial energy savings for the careless user, too.

For a more thorough description of these and the following items see [1].

3 Saving Energy

Heat lost during (indoor) cooking is not always completely lost. In the heating season it may be put to good use heating the house, although it probably represents a higher quality form of energy than does that used for space heating. Conversely, in the cooling season it incurs an extra load on the air-conditioning system. Heat loss is often accompanied by vapor emission, which may contribute undesirably to the indoor air humidity.

Heating by induction or microwaves eliminates some of the heat losses mentioned above, but incurs an additional loss inherent in the conversion of electricity to high frequency. The resulting energy efficiency may be comparable to that of conventional methods. It will probably improve with future technological advancements.

The following applies to moist heat cooking in an ordinary pan on an electric cooking surface with resistance heating. These measures may be taken to improve the energy efficiency of the pan:

- Integrate heating element in pan
- Insulate pan
- Equip the pan with an "intelligent" power control that minimizes heat loss and assists the user in adopting energy efficient cooking practices

4 EffiCooker: The Electric Pan

An electric pan, dubbed the "**EffiCooker**" (**Effi**cient **Cooker**), has been constructed according to the above. It features thermal insulation, integrated heating element, and an "intelligent" controller and timer.

4.1 Construction

The prototype has been realized in the form of two parts: the pan proper and a "docking station" or base, that holds the controls; of course other configurations might be considered.

The pan prototype, shown in section view in Figure 1, is made out of two ordinary stainless steel pans, the smaller one fitted inside the larger one, so as to form a double-wall vessel. The two are bonded together along the rim using a silicone sealant. The "double-glazing" lid consists of two ordinary transparent lids glued together along the edge, also using silicone. In mass production some other bonding method, like welding, should be employed, so as to make the pan dishwasher-safe. The useful capacity is 1.7 L.

The heating element is a resistance filament encapsulated in a meander-shaped stainless steel tube. It is brazed onto the outside of the bottom of the inner pan and so conveniently concealed within the air space between the two pans. It would have been a good idea to sandwich a heat-distributing plate of e. g. copper or aluminum between the pan bottom and the heating element, but this has been left out in the present prototype. In mass production other types of heating element, e. g. a foil type, might be considered, that afford a more even heat distribution.

The dual-wall construction is used in order to reduce thermal losses. We shall show later that losses are reduced by more than 50%. In addition, it makes for easier handling, because the outer surfaces are kept cool to the touch. For example, one needs no kitchen mitts to drain the water from the vegetables. The insulation properties might have been further improved by vacuum or by some sort of insulation in the gap between inner and outer pan.

The protruding ends of the heating element form an electrical power connector on one side of the pan. Adjacent to it is a connector for carrying the temperature measurement signals (not shown in the

Figure 1. Section view of EffiCooker

drawing). It is important that the user keep the connector clean and dry when in use in order to avoid short circuits.

The base unit accommodates the cooker when in use. The unit contains electronic controller, display, and control knobs. When the cooker is placed in operating position on the base (Figure 2, center), its connector makes contact with a matching connector on the base. In the figure the two controls are visible in front, and behind the cooker is the rear panel with display.

Figure 2. EffiCooker flanked by rice cooker (left) and ordinary pan

4.2 Electronic controller

The electronic controller resides inside the base. It consists of a microprocessor and various input/output circuits, an LCD (**L**iquid **C**rystal **D**isplay), and two control knobs, both serving as rotating dials and as pushbuttons.

The controller determines the amount of electric power to be supplied to the heating element, based on the function selected by the user and the temperature inside the pan. It also works as a timer to end the cooking process once the predetermined cooking time is up.

One control knob facilitates selection of *boiling, steaming*, or a certain *temperature*. When *boiling* is selected the controller aims at a gentle boil, maintaining the temperature of the food at the boiling point. When *steaming* the controller attempts to maintain the *steaming temperature*, i.e. the temperature of the vapor above the water surface, at 95°C. In both *Boil* and *Steam* there are 9 settings that control the maximum power of the heating element during warm-up. E. g. to scald milk a low setting should be selected in order to avoid scorching but still end up at the boiling point. *Temperature* settings are used when not boiling or steaming. E. g. to slow-cook a stew one might set the temperature at 80°C in connection with a time of several hours. For deep fat frying a temperature of 180°C might be selected. Pushing the power button turns the power on or off.

Whether boiling, steaming, or temperature is selected, the controller provides tight regulation of the power delivered to the heating element, keeping energy consumption to a minimum. High power is applied at the beginning to accomplish fast boil-up. Boiling over is prevented, and in case of boiling dry the power is shut off.

The scheme for boiling and steaming is designed for a boiling point in the range of 98°C...102°C, i.e. cooking at sea level with only modest concentrations of solute in the water. In its present form it will not work at reduced pressure (high altitudes) or increased pressure (pressure cooker). For such applications modifications of the controller will be necessary.

The other control is the *timer* setting. The selected cooking time, shown on the display, may be adjusted whenever you want, even during countdown. The timing starts automatically once the required condition (steaming, boiling, or the selected temperature) is satisfied, so it metes out the actual cooking time accurately. The timer may also be started or stopped manually by pushing the button. The selected time as well as the elapsed and the remaining time are shown on the display. When the time expires an acoustic signal is emitted, and shortly before that the power is turned off. Usually no user attention is required once the process is started.

4.3 Versatility

Due to its good thermal properties and "intelligent" control the EffiCooker doubles as a

- Steamer
- Rice cooker
- Double boiler
- Deep fat fryer
- Egg cooker
- Chocolate melter
- Slow cooker ("Crock-pot")
- Pressure cooker (requires further development)

Many cooking tasks may be carried out automatically. Once started, no further user intervention is required. Tasks that are easily carried out, in addition to common cooking, include

- Scalding milk
- Reducing
- Thawing frozen food
- Reheating food
- Keeping food warm

The thermal insulation provides for easy handling: No oven mittens are required to drain the water from the vegetables. If one can tolerate a pan on the dining table it may be used for serving; the food will stay warm longer.

4.4 Cost

The EffiCooker will be more expensive than the simpler appliances that are on the market. The price depends very much on the production batch size. A rough guess based on the price of available appliances of more or less comparable complexity would be a US retail price of $150...300, corresponding to kr. 1500...3000 in Denmark, for a set of one pan and one base.

The simple payback period in Denmark for such a set may be calculated assuming the following conditions, not taking into account the appliances that it may replace

Retail price = 2200 kr.

Daily energy saving = 100 Wh = 0.1 kWh

Electrical energy price = 2 kr./kWh

$$\text{Payback period} = \frac{2200}{0.1 \times 2 \times 365} \approx 30 \text{ years}$$

Obviously one shouldn't buy the EffiCooker based solely on the payback period. Because of its versatility, energy efficiency, and user friendliness, however, the price and payback period are considered to be justified.

5 Energy Consumption

5.1 Testing Standards for Cooking Equipment

Most test procedures for cooktops are based on measuring the amount of energy required to raise a metal test block from room temperature to a specified higher temperature, or to boil a specified amount of water.

Existing testing standards, as far as is known, don't facilitate the comparison of the efficiency of an electric pan with that of an ordinary pan, nor the comparison of energy consumption when performing actual cooking tasks. In this treatment we mainly compare steady-state consumption and actual cooking tasks.

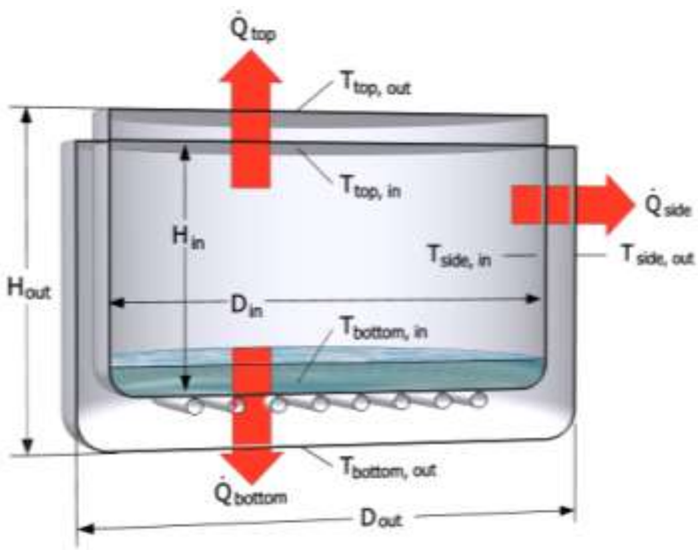

Figure 3. Simplified section view of EffiCooker showing three principal heat flows

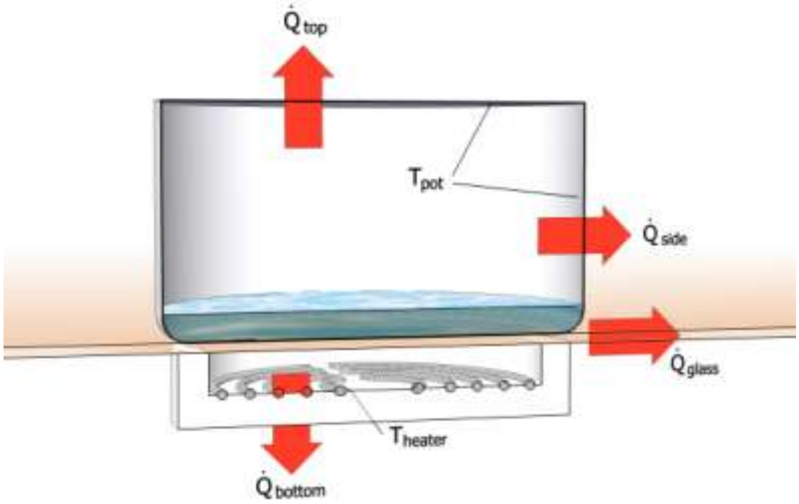

Figure 4. Simplified section view of conventional pan on electric kitchen range showing four principal heat flows

5.2 Steady-State Energy Consumption

The total steady-state (i.e. at stabilized temperatures) heat losses for the EffiCooker and the ordinary pan have been measured when steaming at 95°C. The total losses are split into theoretical shares of losses from the top, side, and bottom, and in the case of the ordinary pan also heat conducted laterally through the glass-ceramic panel. These are called $\dot{Q}_{top}$, $\dot{Q}_{side}$, $\dot{Q}_{bottom}$, and $\dot{Q}_{glass}$, respectively.

Figure 3 is a simplified section view of the EffiCooker. Figure 4 is a similar view of a conventional pan sitting on an electric glass-ceramic cooking surface; beneath the panel is the bowl-shaped heater carrier, made of insulating material; the heating element is fitted in a groove in the carrier. The above-mentioned heat flows are shown in the figures.

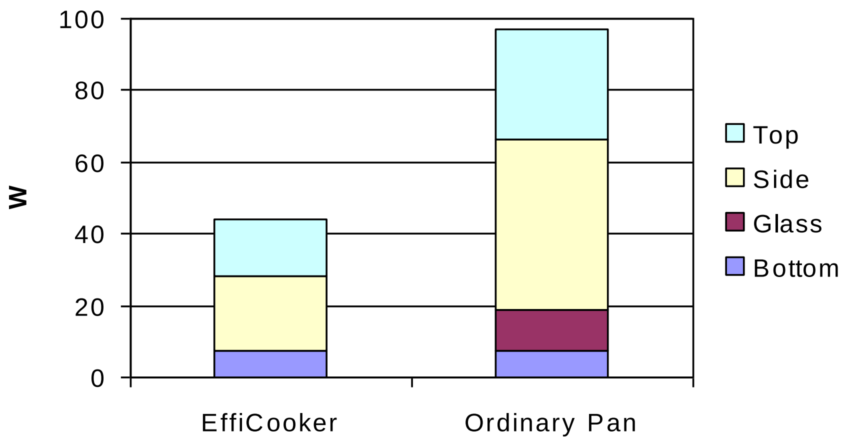

Figure 5. Steady-state energy losses steaming at 95°C

The measured steady-state EffiCooker and ordinary pan convection and radiation heat losses when steaming at 95°C are shown in Figure 5, also showing the shares of Top, Side, Glass, and Bottom losses. The EffiCooker loss (44 W) is about 55% less than that of the ordinary pan (97 W).

5.3 Boiling water

The process of heating water to the boiling point is often used as a means of describing the energy efficiency of cooking equipment, as it is rather well defined, although in the case of manual control there may be some uncertainty regarding the exact moment to turn the power off. Figure 6 shows the results of boiling 1 kg water in the EffiCooker, in an electric kettle, and in a conventional pan on a glass-ceramic range. The initial water temperature is 15°C.

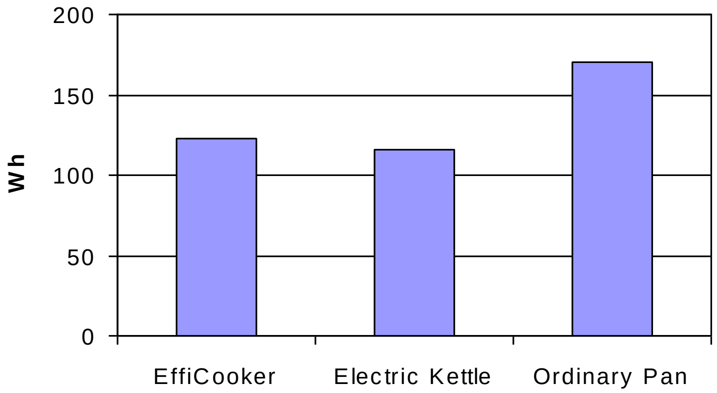

Figure 6. Energy consumptions boiling 1 kg water

The electric kettle performs slightly better than the EffiCooker. At 116 Wh it saves 32% compared to the ordinary pan (170 Wh), whereas the EffiCooker (123 Wh) saves 28%. The nominal power of the electric kettle (2200 W) is about twice that of the EffiCooker (approx. 1100 W), which of course makes the electric kettle faster and also may account for the slightly higher efficiency. So for heating water the electric kettle is the better alternative.

5.4 Soft-cooked eggs

This subject will be treated in some depth because it is an example of a rather critical process regarding time and temperature, and because it proves how efficiently and effortlessly it is handled by the EffiCooker.

To soft-cook an egg, i.e. to end up with a firm white and a runny yolk, the egg is usually placed in hot water or steam for a certain time. The temperature at the white-yolk interface should ideally reach about 67°C.

The formula below gives the time t_{cooked} needed to obtain the temperature T_{yolk} at the outer boundary of the yolk, from the moment the egg is plunged into the hot water. The parameters of the formula are given with typical values [3].

$$t_{cooked} = \frac{m^{\frac{2}{3}} c_p \rho^{\frac{1}{3}}}{k \pi^2 (\frac{4}{3}\pi)^{\frac{2}{3}}} \ln\left(0.76 \times \frac{T_{egg} - T_{water}}{T_{yolk} - T_{water}}\right) \text{ [s]}$$

T_{egg}	initial temperature of egg = 6°C
T_{water}	temperature of hot water or steam = 100°C boiling, 95°C steaming
T_{yolk}	desired temperature at yolk outer boundary = 67°C
m	mass (weight) of egg [g]
ρ	density of egg = 1.038 g/cm^3
c_p	specific heat of egg = 3.7 J/(g·K)
k	thermal conductivity of egg = 0.0054 W/(cm·K)

According to the formula the cooking time for a 64 g egg will be about 6 minutes if boiling at 100°C and 6.5 minutes if steaming at 95°C. We compare the EffiCooker with the conventional range preparing two soft-cooked eggs of 64 g each. In this example we try to imitate a user who is more concerned with getting the eggs cooked right than with energy conservation. Such a user is believed to use ample water, ensuring more exact timing with less attention.

The eggs are placed in the EffiCooker along with 50 g water, covered. Because of the automatic timing even the prodigal user sees no reason to add more water. "Steam 8", "6:30" are selected, and the power turned on. At the sound of the beep the eggs are removed, chilled briefly, and served.

In the case of the kitchen range an ordinary pan of capacity similar to the EffiCooker is filled with 1 kg water, enough to just cover the eggs. The pan is covered and the water brought to a boil at maximum heat setting. The eggs are slipped in, the lid replaced, and the timer started. After one minute, when the water has returned to a rapid boil, the heat is turned down to just keep the water boiling. One minute before the eggs are done the heat is turned off. After 6 minutes of immersion the eggs are taken up, briefly chilled, and served.

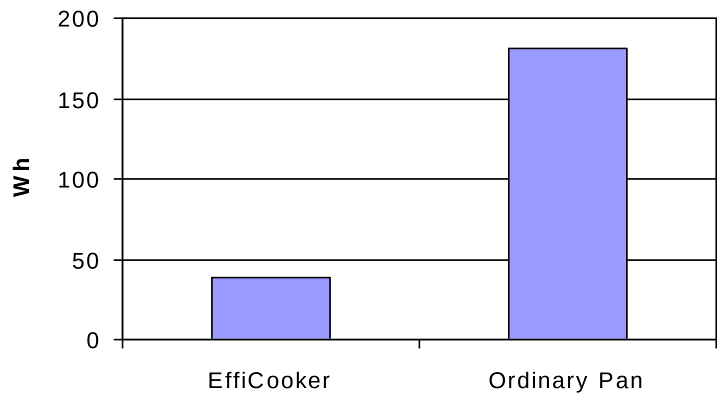

Figure 7. Energy consumptions preparing 2 soft-cooked eggs

The results are compared in Figure 7. Employing the EffiCooker results in a saving of energy of 78% (39 Wh versus 181 Wh). It also saves time (8 minutes versus 19 minutes).

5.5 Boiling pasta

Dry pasta is cooked in boiling water to a standard called "al dente", meaning it should be tender but not too tender. During cooking it absorbs water corresponding to approximately 1.5 times its own weight. Consequently steaming cannot be employed.

It is a persistent notion that pasta should be cooked in an overly large amount of rapidly boiling water, not covered, to keep it from sticking. For example, Joy of Cooking [2] states "7 quarts of rapidly boiling water for a pound of pasta", which corresponds to an amount of water that is 15 times that of pasta by weight. This looks like a striking example of squandering energy; using this method leads to an energy consumption more than five times greater than that of the EffiCooker. An experiment cooking 200 g pasta shows that excellent results may be obtained using much less water, about 3.5 times the weight of the pasta. Besides the EffiCooker we try two cooking methods using an ordinary pan: the "Joy of Cooking" and an ordinary method using less water. The dry pasta at hand is labeled "Cooking time 9...11 minutes".

EffiCooker: Put 200 g dry pasta and 700 g water into the EffiCooker and cover. Select "Boil 7" and "10 m" and turn the power on. At the sound of the beep the pasta is ready. The excess water may be conveniently drained from the pasta by holding the lid askew. This may be done with one's bare hands, because the pan and lid are thermally insulated. If the pasta is served in the cooker it will keep warm for a long time.

Joy of Cooking: Bring 3000 g water to a rapid boil. Add 200 g dry pasta. Reduce heat to maintain rapid boil. Don't cover. When pasta is al dente turn heat off and remove the pasta from the water with a pasta scoop.

Ordinary pan: Put 200 g dry pasta and 700 g water into the pan and cover. Turn the heat to maximum; when boiling start timer and reduce heat to maintain boil. After 9 minutes of boiling turn heat off. After an additional minute scoop up pasta or use a colander.

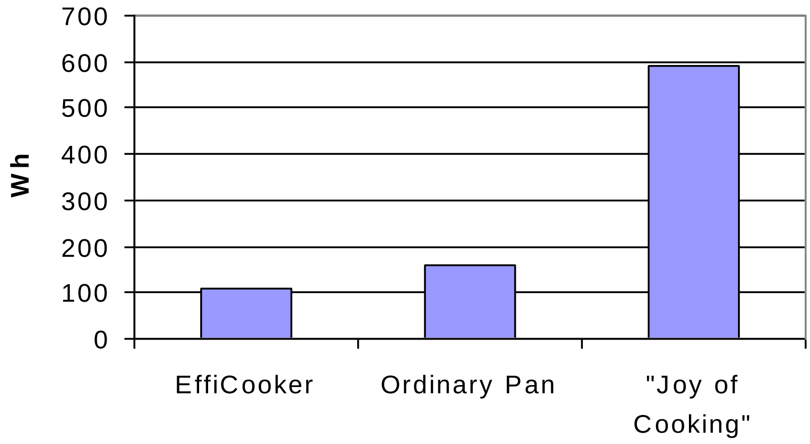

Figure 8. Energy consumptions boiling 200 g pasta

The results in Figure 8 show the substantial energy consumption caused by the "Joy of Cooking" method (590 Wh) over those of the ordinary method (160 Wh) and the EffiCooker (110 Wh). The saving obtained with the EffiCooker over the Joy of Cooking method is 81%. Over the ordinary method it is 31%.

5.6 Steaming potatoes

The EffiCooker is compared to an ordinary pan steaming 1 kg potatoes using 100 g water, as expected by a user who takes an interest in energy consumption. In Figure 9 the energy consumptions are compared. In the case of the EffiCooker there is an energy saving of 30% (132 Wh versus 190 Wh).

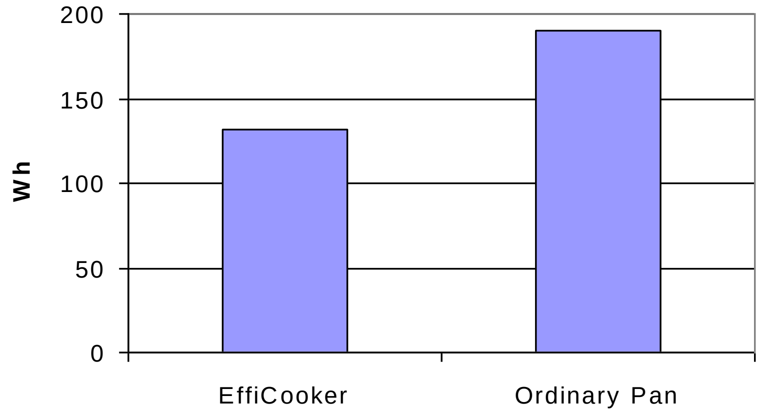

Figure 9. Energy consumptions steaming 1 kg potatoes

5.7 Boiling rice

A rice cooker is an appliance that automatically controls the heat and timing. It is primarily meant for cooking rice, as the name implies, but may also be employed for other kinds of food. Once the user has loaded the ingredients into the rice cooker and turned the power on, the food is supposed to be cooked with no further attention.

Rice cookers come in various degrees of sophistication. A simple type is very popular, especially in Asian countries. The automatic timing is based on the time it takes water to partly be absorbed in the food, partly evaporate, so the more water is added, the longer the cooking time. Therefore it is important to correctly estimate and measure the required amount of water. The power rating of the heating element must be sufficient for a reasonably fast heating of the food and water, so boiling will be rather

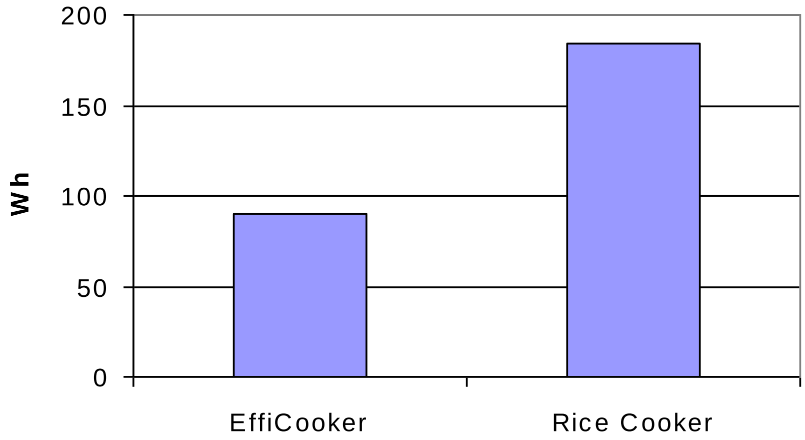

Figure 10. Energy consumptions boiling 200 g rice

rapid, as it takes place at this same power level. Thus a relatively large amount of water is evaporated, resulting in low energy efficiency, and a tendency to boiling over. Besides a crust may form at the bottom, where the rice is heated above the boiling point.

In this experiment we compare the EffiCooker with the Tefal Classic 2.0 L (Figure 2, left), which is representative of the simple type of rice cooker, boiling 200 g of ordinary long-grain, white rice.

In the EffiCooker 440 g water (= 2.2 times the amount of rice by weight) is poured over the rice. "Boil 7" and "20 m" are selected and the power turned on. After ca. 30 minutes the audible signal sounds and the rice is ready to serve.

In the rice cooker 500 g water is added to the rice. The switch is moved to the "cook" position. After 23 minutes the rice cooker switches to "keep warm" and the rice is ready to serve.

The rice cooker is faster than the EffiCooker by 7 minutes but uses about twice as much energy (184 Wh versus 90 Wh), see Figure 10.

6 Conclusion

A working prototype of an electric saucepan, dubbed the EffiCooker, has been constructed. It features integrated heating element, thermal insulation, and an "intelligent" controller and timer.

The EffiCooker has demonstrated energy savings in the range from 28% to 81% compared to conventional equipment when performing ordinary moist heat cooking tasks. Even users who are more concerned with their culinary achievements than with energy conservation are likely to realize such savings.

Besides being energy efficient the EffiCooker is user friendly. Many cooking tasks, once initiated, are performed automatically without any further user attention.

The EffiCooker may replace many other kitchen appliances, e. g. steamer, rice cooker, double boiler, chocolate melter, egg cooker, deep fat fryer, slow cooker, etc. In addition to ordinary cooking the EffiCooker performs such tasks as scalding milk, reducing, thawing frozen food, and keeping food warm.

The energy efficiency, versatility, and user friendliness are considered to justify a rather high price and long payback period.

7 References

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