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## **A new methodology to find out cooking energy needs for a rural household**

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**Abstract:** In the era of global warming and ever rising energy demand, climate justice has become the need of the hour. Sustainable solution has become the key to the success for environment. The cooking sector is considered as one of the major energy consuming sectors in developing and underdeveloped countries. Inherently, associated hazardous effects and energy inefficiencies of conventional biomass cooking system forces unconventional cooking energy to become popular day by day. In this study, a new census based approach is being presented to find out cooking energy requirement of a single rural household of India. Mathematical modelling is being done while scrutinising coke, firewood and chips, coal, and LPG as cooking fuel and by eliminating charcoal, petrol, diesel and kerosene. Exact heat energy required per household per meal has been achieved 4,212.02 kJ. Out of which vaporisation of water, heating food to boiling temperature and convection losses from vessels shares 1,474.21 kJ, 842.40 kJ and 1,895.41 kJ respectively. The outcome of this study can serve a baseline for inventors, researchers and policymakers of micro-scale unconventional/solar cooker.

**Keywords:** stove; cooking energy; modelling; household; solar cooking system; cooking fuel.

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## 1 Introduction

Per capita energy consumption reflects the living standards of any country. Global energy demand is increasing very fast with the upgradation in living standard and development of the country. World energy consumption is growing with a fast rate as shown in Figure 1 (EIA, 2016). In order to achieve sustainability in real manner researchers and policy makers are focusing to enable the countries to meet climate, energy access and air quality goals while maintaining a strong focus on the reliability and affordability of energy for all. There is an urgent need for researchers and policy makers to rethink for their working model, as alarming 2.3 % rise has been observed in 2018. According to the current energy practices, path and policies without any significant changes, energy demand rises by 1.3% each year till 2040. The Sustainable Development Scenario maps

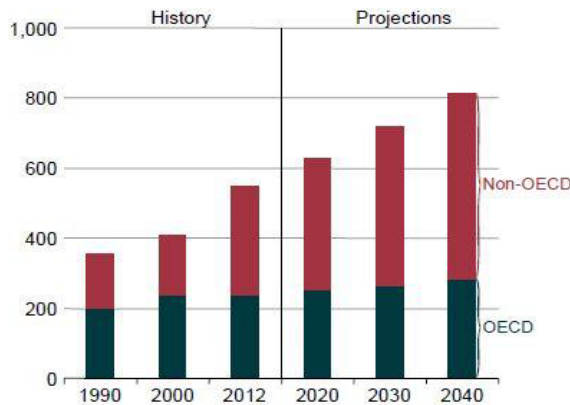
out a way to meet sustainable energy goals in full, requiring rapid and widespread changes across all parts of the energy system (IEA, 2019).

Scarcity of fossil fuels and their harmful effects on environment are the two major challenges for today’s world. As these fossil fuels are the major sources of energy being utilised by the human. Hence, with the increase in energy demand increases risk the survival and sustainability of life support system (Singh, 2018). In this regard depletion of fossil fuel reserves, energy scarcity, global warming, and increase in pollutants in atmosphere are matters of great concern today (WEC, 2011).

Renewable energy is gaining popularity day by day by not only seeking attention of its researchers and end users, but also reasonably affects its policy makers, as the energy demand is growing very fast and supply is limited.

The thermal application of solar energy is seeking attention very rapidly in sustainable cooking by knowing the fact of inefficiencies of conventional cooking and ever rising cost of fossil fuels. Apart from that cooking energy also contributes 36% in the world’s total primary energy consumption. Rural folks usually use wood, charcoal, agricultural residues and dung cakes as a cooking fuel.

**Figure 1** Energy consumption of the world for the period 1990–2040 (in quadrillion Btu)



Source: EIA (2016)

**Table 1** World energy consumption by country/region (in quadrillion Btu)

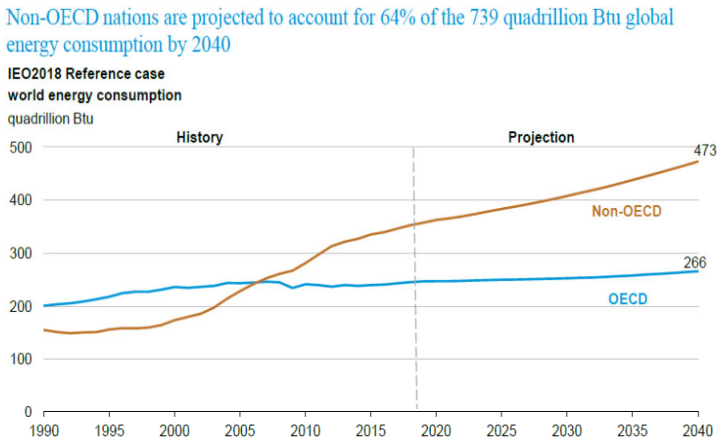
		2012	2020	2025	2030	2035	2040
OECD	America	118	126	128	131	134	138
	Europe	81	85	87	90	93	96
	Asia	39	43	45	46	47	48
NON OECD	Europe	51	52	55	56	58	58
	Asia	175	223	246	270	295	322
	Africa	22	26	30	34	38	44
	Middle East	32	41	45	51	57	62
	America	31	33	37	40	43	47
	Total	549	629	673	718	765	815

Source: EIA (2016)

86.1% of the rural households uses fuel wood and cow-dung for cooking (Pohekar et al., 2005). In order to get this cooking fuel around 16 million hectares of forest are destroyed annually (Prasanna and Umanand, 2011). These cooking fuels also inherently associated with indoor air pollution which results hazardous effect on rural folks.

To mitigate all these environmental and health hazards (WHO and UNDP, 2009) arise due to conventional cooking practice, there is an urgent need to focus on innovation and development of non-conventional cooking stove (Kalogirou, 2014). Although several advances in cooking stoves are reported by researcher, improvements are also reported in improving thermal efficiency of cooking stoves from baseline (conventional) level to up to benchmark level as high as 58% (Urmee and Gyam, 2014).

**Figure 2** World energy consumption by energy source (in quadrillion Btu) (see online version for colours)



Source: EIA (2018)

Prime most data which is required to design any thermal system is the need in terms of its heat load requirement (ASAE S580 JAN-03, 2003; Funk, 2000; Nahar, 1990). Although some innovative approaches are reported (Habib et al., 2004) for estimating biofuel consumption for cooking, but there is a still of paucity of literature reflecting exact heat energy cooking a meal or particular food stuff.

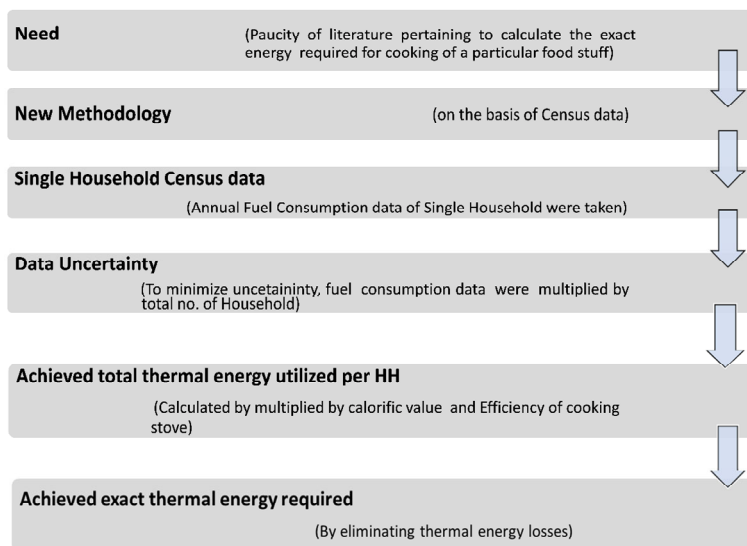
As the conventional cooking system involves energy losses largely associated with convection and radiation from the top surface and side wall of cooking vessel mainly. These energy losses are significantly considered while calculating heat load requirement to cook particular food stuff. There are so many technical and non-technical literature available, showing heat energy associated with cooking of certain food stuff. But all these data are inclusive of convective and radiative energy losses from cooking vessel side walls. Some researcher also reported the energy losses from the top end of cooking vessel. An attempt was made by Kuhnke and Schwefel. (1997) by investigating uninsulated cooking pot that would need heat energy about 900 W without a lid and 300 W with a lid. Convection and radiation energy losses from the side wall of the vessel need to be excluding for exact heat load requirement for cooking. For designing a new cooking system, one has to find the exact heat required for cooking a particular meal or cooking energy required for a single rural household of the system.

This paper will present an innovative census based approach for modelling of cooking energy need and the objective was kept in mind while performing this study was to find out the exact cooking energy requirement of a single rural Household (consists of four persons) of India. This may also provide a baseline/ basis for researchers, inventors and policy makers for unconventional cooker/ solar cooker.

## 2 Methodology

For designing of any thermal energy system need pertaining to thermal energy should be clearly and precisely defined/drafted. Similarly, while designing any unconventional cooking system, researcher and policy maker needs actual thermal energy required for cooking of a particular food item/stuff (Kumar et al., 1997; Thulasi Das et al., 1994). There is paucity of literature pertaining to actual thermal energy required for cooking of a particular food item/stuff. There is so much heat loss incurred from top and side wall of cooking vessel associated with conventional cooking methods; which are unaccountable. Due to this unaccountability, it seems no fix way/ formula available to calculate the exact energy required for cooking of a particular food item/stuff. In order to calculate heat energy required for cooking, a new methodology was adapted on the basis of Census data (NSSO, GoI., 2014).

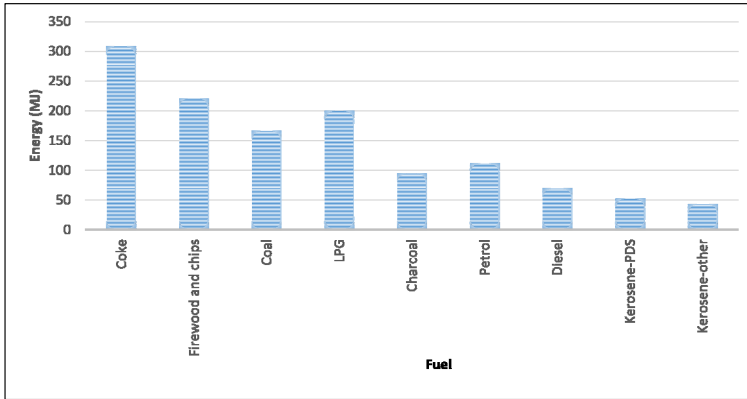
**Figure 3** Step by step methodology (see online version for colours)



To calculate rural Indian per household per month consumption of energy, census data (NSSO, GoI, 2014) are taken. Coke, firewood and chips, coal, LPG, charcoal, petrol, diesel, kerosene PDS, kerosene-others are of quantity 69.78 kg, 118.02 kg, 55.1 kg, 8.69 kg, 21.35 kg, 3.87 kg, 2.5755 kg, 2.352 kg and 1.932 kg are found prime energy sources for rural Indian folks. To minimise the error and normalising the calculations, these quantities have been multiplied by total number of individual fuel samples, which were found 262, 49,221, 940, 20,354, 595, 101, 121, 40,891 and 13,301 respectively.

Calorific values and efficiencies of cooking stove have been taken 29,500 kJ/kg, 12,500 kJ/kg, 20,125 kJ/kg, 46,100 kJ/kg, 29,600 kJ/kg, 48,000 kJ/kg, 44,800 kJ/kg, 44,500 kJ/kg and 44,500 kJ/kg respectively.

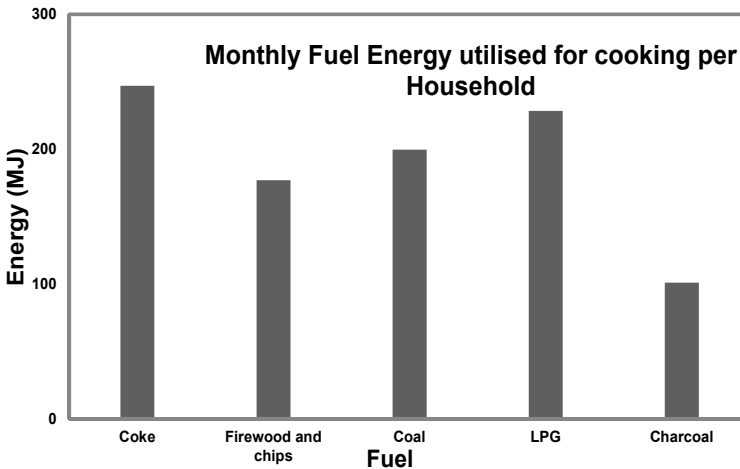
**Figure 4** Monthly cooking fuel energy consumption pattern for rural Indian HH per fuel sample (see online version for colours)



Source: CSO, GoI (2014)

As per the bar chart (Figure 4) drawn from the available data (NSSO, GoI. 2014) monthly energy consumption of LPG is 200.30 MJ. Hence LPG consumption & LPG stove efficiency ( $\eta_{\text{stove}}$ , LPG = 50%) is also validated as according to this rate a family of 4 members consume 4.34 kg of LPG/month i.e. they need a (14.2 kg) LPG cylinder refill in every 2.8 months; which is very close to usual LPG consumption pattern for cooking (Jain et al., 2018). Hence the available data seems reliable.

**Figure 5** Scrutinised monthly cooking fuel energy consumption pattern for rural Indian HH per fuel sample



Source: CSO, GoI (2014)

For refinement of result as shown in Figure 5, another calculation for cooking energy required per household per meal are done by considering the coke, firewood-chips, coal, LPG, and charcoal as cooking fuels. From this data as shown in Table 2, energy utilised per household per meal of rural Indian was found to be 4.21 MJ.

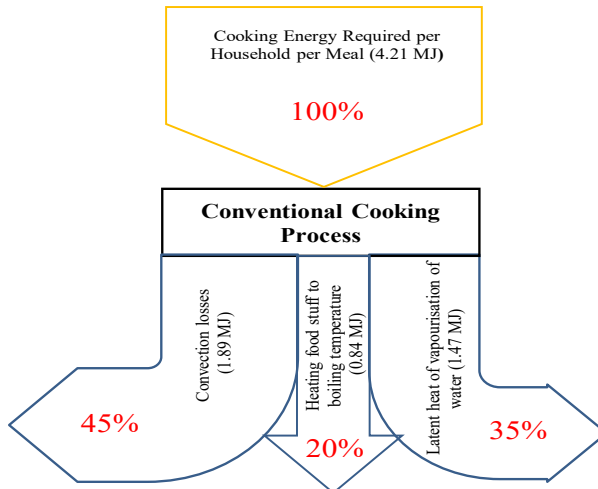
**Table 2** Scrutinised cooking energy required per household per meal

Energy source	Quantity (kg) (NSSO, GoI., 2014)	No. of household (NSSO, GoI., 2014)	Calorific Value (MJ/kg) (Habib et al., 2004)	Efficiency of cooking stove (Habib et al., 2004)	Total monthly Energy utilised per household (MJ)	Energy utilised per household per month (MJ)	Energy utilised per household per meal (MJ)
Coke (kg)	69.8	262	29.50	0.12	247.02	252.72	4.21
Firewood and chips(kg)	118	49,221	16.20	0.14	263.85		
Coal(kg)	55.1	940	20.12	0.18	199.60		
LPG (kg)	8.7	20,354	46.10	0.57	228.35		

### 3 Result

As shown in Table 2, cooking energy required for per household per meal for rural Indian has come out to be 4.21 MJ. Out of which 35 % is used as a latent heat of vaporisation of water, 45 % of energy lost in convection losses and only 20% is utilised in heating food stuff to boiling temperature (Lof, 1963; Kuhnke and Schwefel, 1997). For better scientific representations of these design data (cooking heat balance sheet) a proportionate diagram known as Sankey diagram of cooking heat balance sheet of a single HH of India presented in Figure 6.

**Figure 6** Sankey diagram of cooking heat balance sheet of a single household of India



This result also validated from average LPG consumption of the calculated cooking energy need and it has shown close resemblance to the available data in literature by Jain et al. (2018).

#### 4 Conclusions

For designing a new unconventional/solar cooking system heat load requirement is calculated by a census based approach, which was found 4.21 MJ. It can act as a basis (useful design parameter) for designer, inventor and researchers working for unconventional cooking stove for single rural Indian household, if the new proposed cooking system's cooking vessel side wall would be uncovered/bare insulated. For the new proposed cooking system in which cooking vessel side wall would be insulated, cooking system heat load requirement could be reduced to 2.31 MJ.

The result not only encourages the designer, inventor and researchers to shift towards unconventional cooking practice like solar cooking system due to its inherent advantages, but also to design a such cooking system in which cooking vessel side wall is either insulated or covered by heat transfer fluid (heat transfer fluid operated stove).

As rural area is always being a major concerning area for researchers and policy makers as they constitute a significant portion of country's population and quenching of energy deprivation in that area has to coincide with the requirements of the rural folks for their overall socio-economic development.

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