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Low energy catering strategy: insights from a novel carbon-energy calculator

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Abstract

This paper presents a highly original carbon-energy calculator, designed with the aim of realistically and holistically evaluating the carbon and energy impacts of different food preparation options in delivering a restaurant menu. Its design (based on life-cycle principles) brings the customer demand (number, type and timings of meals served) during typical, peak and special weeks together with the food storage, warewashing, ventilation, cooking and hot holding appliance capacities, carbon emissions and energy usage in various states. An assessment of separate and specific behavioural, equipment maintenance, preparation and cooking strategies are performed. The baseline energy use results were validated to within 0.65% of the findings from an extensive and detailed monitoring study of a leading operator of UK public houses and restaurants [1]. Seven energy reduction scenarios were then assessed using the developed calculator. Potential energy savings of 58% (195 MWh) and emissions savings of 46% (55,224 $kgCO_2e$) per year were indicated from replacing the chargrill, fryers and microwave combi ovens with two combi steam ovens and reducing freezing demand in the case study restaurant. This scenario projects reductions in energy use of 37.77 million kWh (£2 million) per year for the whole restaurant chain and up to 346 million kWh (£18.3 million) if applied to the whole case study organisation.

Peer-review under responsibility of the scientific committee of the 1st International Conference on Sustainable Energy and Resource Use in Food Chains.

Keywords: Catering; Energy Reduction; LCA; Carbon-Energy Calculator.

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1. Introduction

Catering businesses feature in virtually every town and city in the world and are vital establishments to be considered in any low carbon plan. Commercial kitchens are some of the most profligate users of gas, water and electricity in the UK. Recent statistics indicate that 42 TWh (11%) of all UK service sector energy consumption was described as being used during "catering" activities [2]. Despite high and wasteful energy usage, very little has been achieved in reducing the energy used in food preparation in these facilities. Commercial catering appliances have increased in efficiency in recent decades, adding features such as lower idle and warm up energies, insulation, thermostatic controls and cooking activity sensors. However, procurement of these modern appliances is still uncommon, due in part to high capital costs, long replacement cycles and difficulty in relating possible energy savings to the operator's frequently changing menu specifications and food throughput.

A recent and substantial energy monitoring study quantified the energy use of common commercial catering appliances in their typical states [1]. It was concluded that operator behavior, management planning choices and over specification of appliances are large sources of energy waste in the foodservice operation. However, the quantification of overall energy and environmental impact reductions remained largely unresolved due to the diverse range and volume of food served, different appliance configurations and capacities, and variable behavioral strategies employed within different kitchens.

Life cycle assessment (LCA) and carbon calculators are established methods to assess the energy and environmental impacts of products and services. While many LCA type studies exist which involve food products, focus on the commercial or contract foodservice sector is particularly scarce. This is partially due to difficulties associated with modelling the multiple and intangible behavioral determinants of user interaction with appliances and the complexity of large restaurant menus. The physical principles of cooking are overridden by the manner in which the appliances are used by the staff. Of the few studies which include cooking and consumption of food, it is interesting to note that cooking contributes almost half of the overall emissions of the product [3]. A rare study that focused on varying food preparation methods in a foodservice context (pasta cooking) concluded that the "best" option would depend on many factors aside from lowest energy, including overall equipment flexibility, efficiency, costs and convenience [4]. Furthermore, processes upstream and downstream of the actual cooking activities, namely chilled and frozen food storage, warewashing and extraction and ventilation (E&V) are also impacted by the operational management decisions involving cooking options. It was therefore recommended that these parameters be considered in future studies. Key improvements upon existing methodologies also include the requirement for full menus, ingredients and realistic portions to be modelled [6].

The true evaluation of such complexity found within the commercial kitchen operation calls for the development of a novel catering energy, cost and carbon calculator, to simplify the assessment of these operational choices and impacts and link realistic food diversity and volume to energy consumption. Given the staggering range of options available to a commercial caterer concerning the delivery of a diverse menu, this tool must be highly flexible to account for the variety of factors which may impact upon energy use. The aim of the present study is to realistically and holistically model and evaluate the carbon and energy impacts of different food preparation options in delivering a restaurant menu.

2. Methods

Using a bottom up approach and the principles of LCA, the carbon and energy calculator is built to model energy, cost and emission reduction in various food preparation scenarios. This paper refers to the "case study" site, which the baseline and energy reduction scenarios are based upon. The site is a gastro-pub representing a wider chain of 194 restaurants serving a varied menu. It is the most typical, "average" restaurant from the 14 monitored sites detailed in [1] and represents the median energy use, number of meals and typical suite and configuration of kitchen appliances. The overall design and approach of the tool was informed by consultation and collaboration with stakeholders, including the UK Carbon Trust, the Catering Equipment Suppliers Association (CESA) and the case study kitchen operators. Within the case study organization, heads of department from the Energy, Environment and Sustainability, Operations, Building, Procurement and Food Development teams, as well as the kitchen manager and head chef at the case study site provided regular input.

Combining the intangible aspects of catering, a holistic approach is proposed for the tools development, taking account of the processes upstream and downstream of prime cooking within the kitchen. Broadly, the calculator is split into five key components; the analysis of meals and menu, food storage requirements, warewashing, cooking (including hot holding), and E&V. Calculations are in terms of embodied, use phase (including fugitive) and end of life energy, costs and emissions for all appliances. The vast majority of calculator inputs are designed to be adaptable and to make use of primary data specific to each kitchen being studied, thereby minimizing assumptions and maximizing the tools' applicability. The case study site activity was monitored for one week (the "typical week"), and any periods of increased service such as "specials weekends" (i.e. Mother's Day) and "peak weeks" (i.e. Christmas) were taken into account by uplifting the typical week by a calculated percentage. For the case study, inventory data regarding recipe instruction, ingredient quantities and cook times and number, type and timings of meals served were collected via the operator's records. Equipment specifications were sourced from the manufacturers and included information such as bills of materials, dimensions (for E&V calculations) and rated power. These data were supplemented by a large scale primary data collection exercise. Door opening frequencies, capacities of equipment and energy consumption in different states were determined experimentally. Further data for embodied and end of life calculations were obtained from a range of European Ecodesign Directive studies and the Ecoinvent database [6-12].

The use phase calculations for cooking appliances are largely split into the preparation and hot finishing demands placed upon them, by way of gram-minutes (g.mins) cooking rates, adjusted for earlier and later preparation strategies. Total usage for each appliance (minutes cooking required) is presented against total capacity. An indication of typical user behaviour in relation to the operation of cooking equipment is captured, as this was identified as a key factor affecting use-phase energy, cost and emissions from the appliances in [1]. User behaviour is classified into four categories:

1. Equipment left at normal operating settings throughout a shift (default);
2. Unused equipment turned off or onto stand-by mode during prolonged quiet periods;
3. Energy use minimised by turning appliances off at every reasonable opportunity (this is synonymous with appliances including cooking activity sensors).
4. A bespoke % between options 2 and 3 which is able to be defined by the user within the behaviour input table. For example, this may be used in relation to increased staff training.

Excluded from study are impacts from the front of house operations (restaurant lighting, heating, entertainment etc.) location of appliances and lighting requirements of the kitchen. Water usage, food miles and transport to and from the kitchen (including staff) are also outside of the scope of this research. This is in order to concentrate the research solely on the energy, cost and emissions of the chosen cooking methods to deliver the specified menu.

This study found that outputs in terms of kJ in functional units such as a quantity (i.e. 1 kg) of a singular food stuff are irrelevant to the commercial kitchen operator, whose focus is on the overall energy consumption, cost and GHG emissions of the typical full service food demand and menu offerings. Therefore, there exists a need for outputs to result in energy use (kWh), cost (£) and GHG emissions (kgCO_2e). The functional unit studied using the developed tool may be viewed as "delivery of a catering service for one year".

The tool was designed and structured on an MS Excel 2013 platform composed of user facing input worksheets and "hidden" calculation worksheets. Such a platform allows the user to enter multiple datasets into a tabulated structure, or worksheet(s) (WS), and then maintain and manipulate those datasets, utilizing MS Excels features to create a user friendly interface for each of the variables and to simplify results.

Following baseline analysis, seven energy reduction scenarios were formulated by extensive industry stakeholder consultation and literature review as follows;

1. Replace chargrill with two combisteam ovens
2. Replace fryers with two combisteam ovens
3. Replace chargrill, fryers and microwave combi ovens with two combisteam ovens
4. Reduce freezer demand
5. Elimination of hot-holding
6. Baseline with induction hobs

7. Replace chargrill, fryers and Merrychefs, and remove freezer demand

3. Results and Discussion

3.1. Baseline

Table 1 summarizes the results from all phases of the overall kitchen energy (kWh), costs (£) and emissions ($kgCO_2e$) in the "business as usual" baseline. Total kitchen energy consumption was calculated at 335,187 kWh.

Table 1. Baseline results summary

Summary	Refrigeration	Cooking	Washing	E&V	Total
Use Phase					
Use phase energy kWh/year	40,125.99	241,961.42	12,508.44	40,591.41	335,187.26
Use phase emissions $kgCO_2e$/year	22,360.21	71,154.63	6,521.28	21,162.33	121,198.45
Use phase cost £/year	4,815.12	13,653.96	1,501.01	4,870.97	24,841.06
Embodied phase					
Total embodied emissions	5,662.52	4,023.23	791.53	959.32	11,436.60
Embodied emissions / year	628.55	402.32	113.08	47.97	1,191.92
£ to buy	13,842.86	28,296.60	3,058.00	5,400.00	50,597.46
£ / year	1,653.32	2,829.66	436.86	270.00	5,189.83
End of life phase					
Total end of life emissions	10,984.00	20.34	3.63	6.55	11,014.51
End of life emissions / year	1,474.79	2.03	0.52	0.33	1,477.67

Table 2 presents a comparison between the calculated results (behavioral strategy 1 - equipment left on maximum input all day) for cooking and food storage appliances verses empirical data. The metered data is accurate to within 0.5%.

Table 2. Calculator results again measured consumption data (kWh)

Equipment category	Measured weekly consumption (kWh)	Scaled to annual consumption (kWh)	Baseline scenario (Behavioral strategy 1)	Difference (%)
Chillers	442.97	23,034.44	21,033.02	9.52
Freezers	368.50	19,162.00	19,091.83	0.37
Chargrill	2,889.79	150,269.08	157,852.66	-4.80
Salamander	302.19	15,713.88	16,117.09	-2.50
Steamer	43.69	2,271.88	2,110.07	7.67
Fryers	154.19	8,017.88	7,634.16	5.03
Microwave Combi-oven	216.30	11,247.60	11,137.71	0.99
Microwave	33.35	1,734.20	1,878.95	-7.70
Hob	432.54	22,492.08	23,868.31	-5.77
Warming	231.81	12,054.12	10,996.44	9.62
Total kitchen consumption	5,389.60	280,259.20	282,080.77	-0.65

The highly similar data, as indicated by the percentage difference in each category, indicates that the calculator is able to simulate average energy consumption to a good degree of accuracy.

Fig. 1 presents the energy consumption (kWh) for a selection of appliance categories (excluding the chargrill and total kitchen consumption for clarity) for behavioral scenarios 1-3. In extreme cases such as the hob usage, savings of 91-99% are calculated from improved operator behavior. In terms of the overall kitchen, energy consumption savings of 29.36% for behavioral strategy 2 are indicated, compared with strategy 1. This represents actual savings of 71,041 kWh, 21,087 kgCO_2e and £4,031 per year. Energy consumption savings of 46.24% using behavioral strategy 3, represent actual savings of 111,892 kWh, 35,486 kgCO_2e and £7,034 per year.

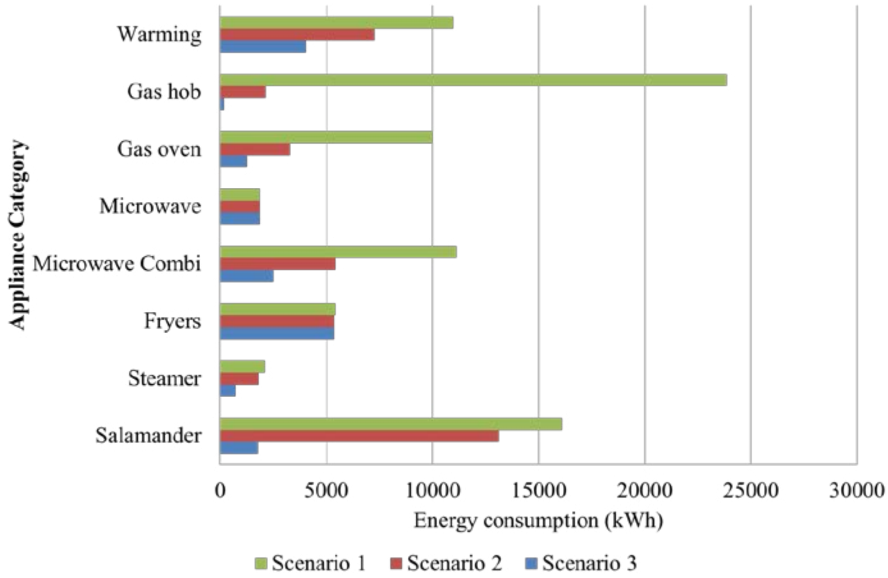

Fig. 1. Appliance energy consumption from behavioural strategies 1-3 (kWh)

As shown in Table 1, the use-phase forms the highest contribution of energy, emissions and cost of the lifetime of each of the appliances as expected. Refrigeration leakage and disposal at the end of life results in emissions due to refrigeration being greater than all other categories outside of the use-phase. Of particular relevance to the operator, embodied costs (per year) were found to be just 16% of the total yearly costs over the life time of the kitchen. These results demonstrate the significance of operational cost verses purchase costs. As procurement teams are most often targeted with lowest purchase cost, these results have significant implications for the importance of consideration of operational cost of appliances.

In terms of appliance utilization, the calculator revealed sufficient capacity in all of the appliances during the typical week. However, the results indicate that there is insufficient capacity in the chargrill usage for peak and special weekends. This is backed up with observations, in that staff often struggled to cope with chargrill demand during these periods. In all other cases, the appliances showed less than 35% of capacity at all times, with levels of less than 3% of the maximum capacity utilized in several categories (steamers, combi ovens). This suggests great over specification. For example, the microwave usage increased to a maximum of 35% during special weekends. The case study kitchen utilized four microwaves. These results indicate that the number of microwaves could be reduced to two whilst still delivering the required food turnover. During a preliminary re-run of the calculator specifying two microwaves instead of four, the maximum capacity still only reached 55% during a typical week, and 71% during special weekends. This over-specification is particularly pertinent when considering appliances with high “idle” cooking energies (and those without cooking activity sensors), such as the salamander grill, gas oven and gas hob. These appliances use close to maximum power input regardless of food throughput, unless chefs practice appropriate energy minimizing behavior.

3.2. Reduction scenarios

Fig. 2 presents the results of each of the seven energy reduction scenarios studied.

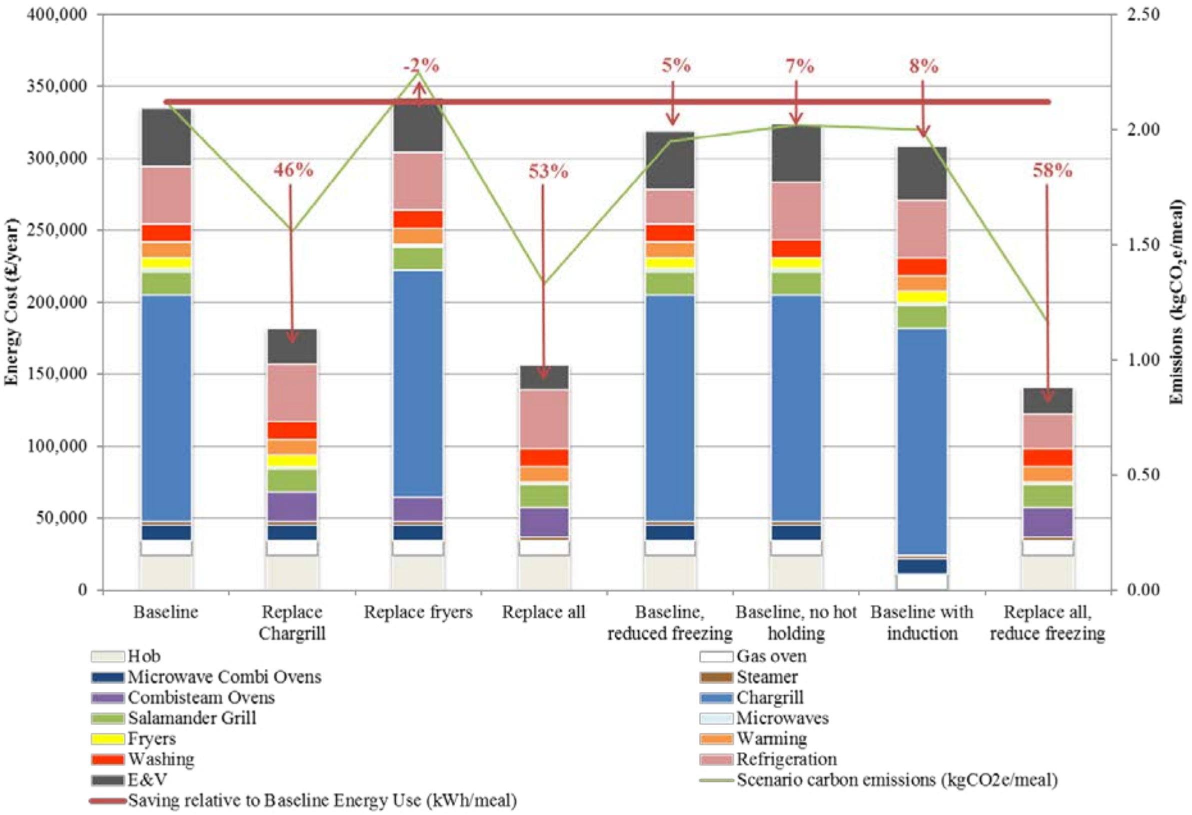

Fig. 2. Energy and emissions findings from reduction scenarios

Energy use of the overall operation was found to be increased upon replacing two fryers with two combi steam ovens, despite a reduction in connected load and reduced E&V consumption. This result places further importance on the consideration of realistic food volumes and operator behaviour.

Fig. 3 displays the energy results from Scenario 7 (replace the chargrill, fryers and microwave combi ovens with two combi steam ovens and reduce freezing demand), using behavioural strategy 1. Energy consumption was reduced by 58% from 335,187 kWh to 140,514 kWh (55,224 $kgCO_2e$). Of this, the cooking, food storage and E&V use phases were reduced by 64%, 41% and 55% respectively. The average cook times increased from 7.2 minutes to 18.6 minutes using the combi-steam oven. Although this is almost double the cooking time, these increases were thought to be acceptable given the energy, cost and emission savings. Other ancillary benefits include space savings of 72% from the reduction in cooking appliances. In terms of capacity, the combisteam ovens only reached 40%, even during peak weeks and special weekends. Embodied and end of life emissions were reduced by 29% and 63%. This scenario sees an increase in capital expenditure of £2,339 (4.62%) and an annual energy cost saving of £10,303 (41.48%). Therefore, a simple payback of 3 months was calculated.

Though it would be inappropriate to draw firm conclusions at a sector-wide level from the outcomes of specific case studies, an indication of potential savings may be drawn by projecting the findings to the wider chain of restaurants that the case study kitchen resides within. Scaled up to the entire brand of restaurants (which serve the same menu, with a similar kitchen template and staff receiving the same levels of training), Scenario 7 represents savings of 37.77 million kWh, 10.71 million $kgCO_2e$ and £2 million per year (Table 3). This saving is comparable to 2,302 UK households (based on 16,405 kWh total energy consumption for average UK household) [12]

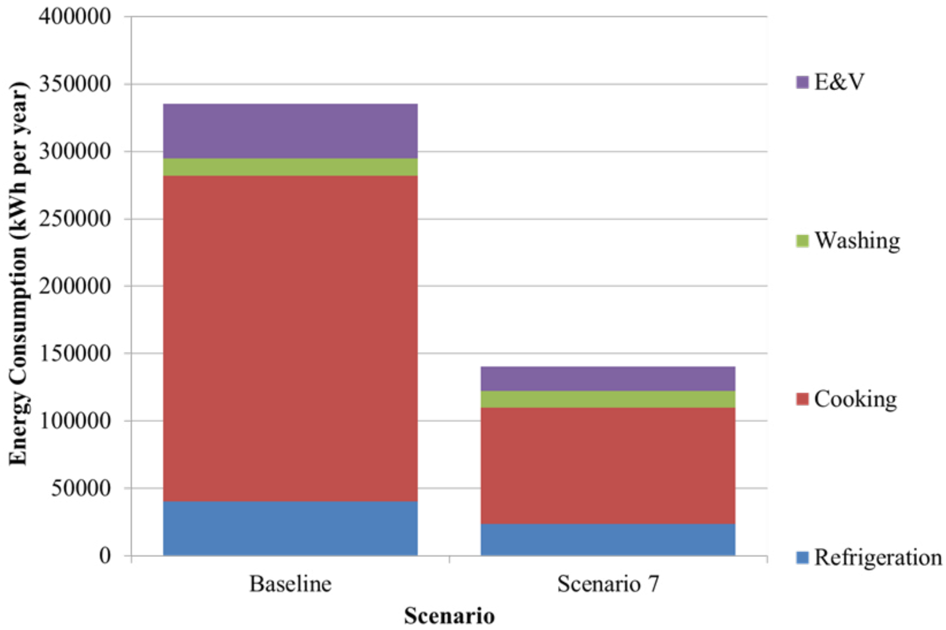

Fig. 3. Summary of total use phase savings in Scenario 7 relative to baseline (behavioural strategy 1)

Table 3. Prospective estimated savings within the sector using Scenario 7

Sector area	Number of sites	Energy consumption (kWh)	Emissions ($kgCO_2e$)	Cost (£)
Case study chain	194	37,766,708	10,713,437	1,998,778
Case study estate	1,779	346,324,601	98,243,318	18,329,001
Pub sector [13]	51, 178	17,154,213,592	6,202,694,274	1,271,315,769
% reduction from Scenario 7		58.08	45.56	41.48

4. Conclusions

A commercial kitchen belonging to a chain of restaurants deemed to represent typical practice was thoroughly investigated and monitored. A carbon calculator was developed based on LCA principles, underpinned by primary and secondary data collected from the case study site. Such data included ingredient volumes, timings and number of meals served, detailed sub metering of appliance energy use and their detailed specifications, door opening frequencies and equipment capacity metrics. The tool was designed to be used by academics and operators to evaluate the above parameters in food preparation methods. Its basis upon highly detailed data from actual working kitchens adds much value to the application of the results to practice. It is the first tool linking adjustment in the composition and creation of restaurant menus with energy consumption. The tool was found to generate results comparable to within 0.65% of the empirical data collected. This, combined with the holistic approach of including processes up and downstream of actual cooking (food storage, ventilation requirements etc.) provides a high degree of confidence in the modelling approach and results for this specific case study.

The absence of LCA studies examining the realistic diversity and turnover of food within commercial kitchens renders comparisons of findings against literature challenging. The calculated results regarding operator behavior agree well with the estimated behavioral savings of 40% in the literature [14-16]. Results also compare well with empirical data; 89% savings from behavior have been calculated for the salamander grill based on the food throughput requirements, compared with 71% found in the use of the monitored salamander grill [1].

Seven energy reduction scenarios were examined, five of which resulted in financial payback periods of one year or less. In the most favorable scenario (replacement of fryers, grills and microwave combi oven with two steam combi ovens and a reduction in freezing demand), energy savings of 58% were calculated. Scaled up to the rest of the case study chain, savings of 37.77 million kWh, 10.71 million kgCO_2e and £2 million per year are achievable without further staff training to minimize wastage through behavior. Underutilization of appliances was quantified, with levels of less than 3% of the maximum capacity found in several categories (steamers, combi ovens), implying that many appliances are over specified. Embodied costs of less than 16% have significant implications for procurement strategies, placing importance on the consideration of operational cost for the operator.

Further work should include application to further businesses, development from MS Excel into sophisticated software with the ability to run reports and analysis of further energy reduction scenarios. The adjustment of a menu to migrate away from the more energy profligate and costly appliances and the vast variety of catering appliances available gives rise to virtually limitless reduction scenario assessments.

The tool is highly beneficial in the evaluation of energy reduction strategies as it presents a methodology to assess a large variety of appliance, recipe and menu choices as well as further inputs and their interactions and impacts upon each other. It is envisaged that the tool may be further used to provide educators with an enlightening method for staff training (be it "in house" or formal qualifications) to highlight the importance of appliance choice and behavioral strategies for delivering a given menu.

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