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COMMUNAL RESIDENTIAL LAUNDRY WASHING AND DRYING – CAN IT PROVIDE DEMAND-SIDE ELECTRICAL LOAD FLEXIBILITY?

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ABSTRACT

Changes in lifestyle have led to increased use and ownership rates of domestic appliances resulting in increasing electrical consumption in the residential sector. An important element of this consumption is due to domestic washing and drying of laundry. Given current and predicted ownership rates, the market for drying facilities is still not fully saturated and electrical demand for these functions will therefore increase. This paper looks at energy loads for laundering in high density housing such as blocks of flats and explores the benefits of communal facilities. Benefits of such facilities include reduced high humidity levels and the mitigation of decreased indoor air quality associated with indoor drying of laundry in individual dwellings. However from the perspective of integrating microgeneration into buildings, communal facilities may facilitate increased flexibility in the electrical demand profile, hence better complementing low carbon and localised energy supplies.

In order to investigate the possible effects on the electric demand load profile, this paper presents the scenario of a hypothetical housing block and analyses the effect of moving from washing and drying in individual households to communal facilities. The study includes the effects of appliance energy-efficiency improvements and increased ownership rates. Results obtained show that communal laundering is successful in terms of time-shifting and hence lowering of peak electrical demand but is ineffective in reducing consumption.

INTRODUCTION

Notwithstanding efforts to reduce the electrical energy demand in the residential sector, the increased use and ownership of domestic appliances has resulted in increased electrical energy demand (Bertoldi and Atanasiu 2007). Over the period 2002-2008 the residential electrical energy demand in the UK has increased by an annual average rate of 1% (EUROSTAT), strongly compromising any efforts to reach the end-use energy-efficiency (2006) targets and greenhouse gases reduction targets set by the Kyoto Protocol. Similarly, over the same period of time the UK National Grid experienced a 0.67% average annual increase in the annual maximum electrical peak demand (UK National Grid 2011), adding pressure on both generation and distribution of the electrical supply.

A number of international studies have targeted reducing the energy demand characteristics of certain appliances such as television sets (Varman *et al* 2005, Varman *et al* 2006) and domestic lighting (Mahlia *et al* 2005) through appliance replacement or energy efficiency measures. Very few studies however, have tackled domestic washing and drying of laundry, despite the fact that this constitutes a highly energy intensive and possibly flexible demand. The drying process alone accounts for approximately 4.3% of the total UK domestic energy consumption (DEFRA[b] 2008). In terms of appliance ownership within UK households, washing machines are fast approaching saturation at 94% ownership; however tumble dryers only have a market penetration of 42% ownership (DEFRA[c] 2008) and so have a potential to increase in number, especially in flats and high rise buildings in cities where both access and propensity for drying in open areas are limited.

On a European level, this issue has been partly addressed through the European Energy Labelling Directive (1992). This scheme has proved successful in terms of market adoption of ‘A-rated’ type washing machines (DEFRA[a] 2008), which are now the dominant type. There has been less success with tumble dryers (DEFRA[b] 2008), with the market being predominantly made up of ‘C-Rated’ machines.

Due to the potential health effects arising from reduced indoor air quality and high internal humidity levels resulting from indoor drying of laundry, it could be beneficial to shift laundry washing and drying from individual household owned units to communal washing and drying appliances within dedicated areas in individual housing blocks. Menon *et al* (2010) describe the main differences between the two practices, indicating that further research in terms of its energy performance is required. Communal washing and drying was a common practice in the UK during the 19th century, and today could possibly prove beneficial in terms of electrical energy demand reductions as well as changing the temporal nature of electrical demands.

This paper reports on a detailed analysis of the effect on the electrical demand profile of a residential block of flats in a scenario where domestic washing and drying is shifted from the traditional individual household-based appliances to a regulated staggered use of communal washing and drying facilities. The analysis considers the potential of a communal laundry to improve the electrical demand characteristics of the building through time-shifting demand and reducing peak electrical loading, both of which could provide more favourable operating conditions for low carbon and localised energy supplies.

METHOD

Overview

The methodology used in this paper relies on creating fine 1-minute resolution electrical demand profiles for a hypothetical housing block under different scenarios for three specific days; a characteristic winter day, a characteristic summer day and one day representative of the transition months. The three days selected help identify the main trends from shifting to communal laundry facilities at different times of the year. The use of a 1-minute resolution for the profiles ensures that certain key characteristics such as the maximum peak demand and load duration can be clearly identified. Apart from understanding the difference between the use of individual washing and drying units and the use of communal facilities this research also aims to analyse other related aspects, such as the effect of increased demands for drying and the use of more energy-efficient technologies.

Building the non-HVAC demand profiles

As a first step towards building the desired scenarios, the non-HVAC (heating, ventilation and air conditioning) demand profiles of each individual household within the residential housing block were created for each of the three characteristic days. In this research the residential housing block was assumed to have 24 households, with occupancy levels typical of the national UK average (NS 2004). Consequently, two sets of 8 households were modelled each having either one or two occupants; similarly two sets of 4 households were modelled each having either 3 or 4 occupants.

The appliance ownership of each individual household was populated considering the national UK average (Stokes 2004) and includes the most common appliances such as TV sets, lighting fixtures, electric ovens, microwave ovens plus additional loads listed under miscellaneous appliances. Washing machines and tumble dryers were excluded as these were modelled separately for each scenario. A summary of appliance ownership and occupancy by household is given in Appendix 1.

For each household and for each of the 3 characteristic days, the individual 1-minute resolution electrical demand profile for each owned appliance was created using the validated procedure described by Stokes (2004). Based on the individual appliance ownership of each household, the electrical demand for all appliances was aggregated to form an individual household's demand profile and then further aggregated to form the entire housing block's demand profile (excluding laundry and HVAC) as shown in Figure 1.

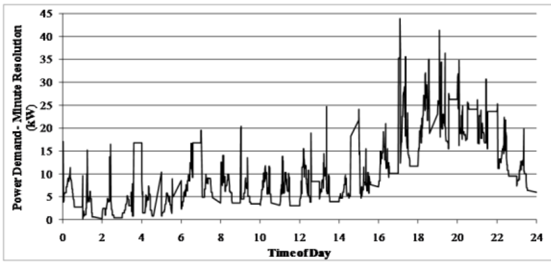

Figure 1 Demand profile for a characteristic winter day excluding HVAC and laundry loads

Throughout the research and for all modelled scenarios the initial household load profile created for each of the three characteristic days was used as a base-line, with the contribution due to washing machines and tumble dryers subsequently modelled and added according to the characteristic scenario being analysed. This ensured that any changes between scenarios were only due to the washing and drying loads and independent of any other appliance.

Creating Individual *vs.* Communal use scenarios

In order to compare the use of individual washing machines and tumble dryer appliances *versus* the use of communal units, three scenarios were considered, namely:

- individual use of washing machines and tumble dryers at current ownership rates;
- individual use of washing machines and tumble dryers at saturated ownership rates;
- regulated staggered use of communal washing machines and tumble dryers.

The first two scenarios rely on the current practice of individual household washing and drying laundry, with the only difference between the two being the appliance ownership rate. In the first case it is assumed that only half of the households own and use a tumble dryer whilst in the second case it was assumed that tumble dryer ownership has reached saturation and that each individual household owns and uses a tumble dryer with every washing cycle. In both cases washing machines are assumed to have reached a saturation ownership rate. These first two scenarios were created by adding to each individual household's base demand profile a demand profile associated with a 40ºC washing cycle and an ensuing 2 hour drying cycle. The 40ºC washing cycle was chosen since it is the most common cycle used by UK households, with research showing that 68% of domestic laundry washing is performed at this temperature (Stokes 2004). The 1-minute demand profile for the 40ºC washing cycle is based on data by Newborough and Augwood (1999), whilst the two hour tumble drying cycle is based on data presented by Stokes (2004). Figure 2 shows a 40ºC washing cycle followed by a drying cycle.

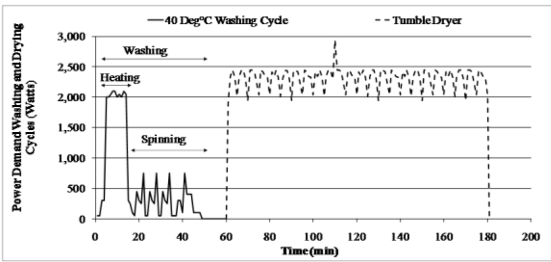

Figure 2 40ºC washing cycle followed by a drying cycle

The timing when each washing cycle was triggered for each individual household for the first two scenarios was based on a uniform distribution of the probability that a washing machine is 'On' at certain times of the day. Figure 3 shows the grouped normalised energy consumption for each half-hour calculated for the three characteristic days elaborated using data presented by Stokes (Stokes 2004).

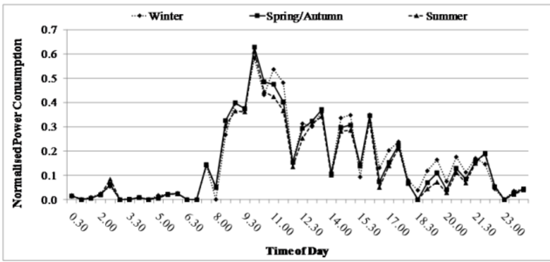

Figure 3 Normalised energy consumption

Using this data for each half hour, the probability that a washing machine was 'On' can be calculated as a percentage of the energy consumption during any half hour over the total daily consumption. Figure 4 illustrates the cumulative distribution function of the probability that a washing machine is 'On' during a summer day. It is clear that even though most households include working individuals, washing, aided by electronic timers and automatic controls, is still predominantly a morning activity.

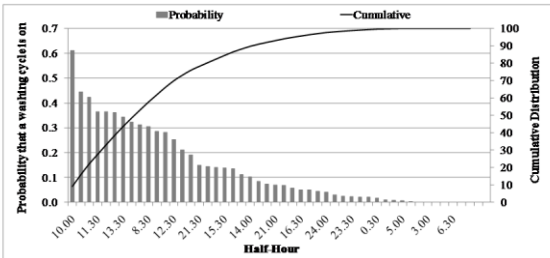

Figure 4 Probability that a washing cycle is 'On'

The third scenario is the regulated staggered use of communal washing machines and tumble dryers. In this scenario communal facilities in the form of domestic size washing machines and tumble dryers are provided and a regulated timetable is in place so that each household can make use of the appliances at a pre-defined time. In order to permit all households to have an allocated time each day of the week, it is assumed that there are four sets of washing machines and tumble dryers and each household can use the communal appliances during a specific three hour period between 06:00 and 24.00 hours. The assumption that all households will be using washing machines and dryers every single day of the week on average is an assumption extrapolated from an end-use survey conducted on the laundry washing and drying habits that shows that people tend to use these appliances 5 to 6 times a week (Porteous 2010). In terms of their electrical demand, the appliances are assumed to have similar profiles to those used in the individual scenario cases. It is clear that for such a scenario to function properly, a great degree of co-operation between households would be needed, possibly including a designated housekeeper to cater for when households cannot use their allocated times.

Current *vs.* energy-efficient technology

Another important aspect being presented in this research is to factor in possible improvements in appliance energy efficiency. In order to do this, the three scenarios described were repeated for both current and energy-efficient technology. The current technology assumes an 'A-Rated' washing machine and a 'C-Rated' Tumble Dryer, and the profiles described in Figure 2 are reasonable approximations to such technologies. The energy-efficient technology on the other hand, assumes an energy-efficient 'A+ Rated' washing machine and a 'B-Rated' tumble dryer.

In the case of the washing machine, although still not defined by the European Energy Labelling Directive, an 'A+ Rated' washing machine is assumed to be 10% more energy efficiency than a conventional 'A-Rated' machine (DEFRA[a] 2008). The profile presented in Figure 2 was thus adjusted to reflect a continuous electrical demand reduction of 10%. It is also worth noting that although the most common wash cycle is the 40ºC washing cycle, the current energy label test uses a 60ºC washing cycle for its testing (DEFRA[a] 2008).

In the tumble dryer case, the profile presented in Figure 2 has an energy consumption of approximately 4.6 kWh/cycle; assuming a typical 6/7 kg load the energy consumption is about 0.77/0.66 kWh/kg suggesting an appliance with a 'C' or 'D' energy efficiency rating (DEFRA[b] 2008). DEFRA's Market Transformation Programme (DEFRA[c] 2008) suggests that an 'A-Rated' tumble dryer having an energy consumption lower than 0.55 kWh/kg is still far away from becoming a commercial proposition and recommends that the best available technology for the near future is a 'B-Rated' tumble dryer with an energy consumption equal to 0.55 kWh/kg (DEFRA[b] 2008). Using a similar assumption to that used for the washing machine profile, the tumble dryer profile described in Figure 2 was adjusted to reflect a continuous electrical demand reduction of 28.5%.

Scenarios and analysis

Considering the 3 different types of uses and the two technology scenarios, a total of six scenarios were simulated. The first scenario, the '*individual use of washing machines and tumble dryers at current ownership rates with current technology*', was considered as the base case scenario, against which all other scenarios were compared.

RESULTS AND DISCUSSION

In this section the results for the different scenarios are tabulated and discussed by first presenting the results of the base case scenario and then presenting the results of the other scenarios as a percentage difference compared to the results obtained for the base case scenario. The results presented are for the entire housing block.

Total daily load, average load and energy intensity

Table 1 in Appendix 2 shows the results obtained for the three days under review for the base case scenario and a comparison with the other scenarios.

Apart from a seasonal diversity, which is also related to the use of other appliances, Table 1 shows how energy intensive the washing and drying process is. At current penetration rates using the current technologies, the energy intensity of the laundry activity compared to the total daily load of the total housing block varies seasonally between 21% and 32%. The rate reaches even higher values at saturated ownership rates. In this context it is interesting to note that, in terms of energy consumption and average load demand, even with the suggested energy efficiency improvements, an increased ownership rate of washing machines and tumble dryers still offsets any of the beneficial effects brought about by the more energy-efficient appliances. At saturated ownership rates the total load using current technology increases by an annual average of about 23%. An important aspect of these specific results is that the difference between the individual and communal use of washing machines and tumble dryers is not an issue since these results are exclusively related to the number of washes and technology used. However, it should be pointed out that similar to the concept of the 'rebound effect', where energy savings brought about by a better and more energy-efficiency technology are offset by the increased use of this technology (Sorrell and Dimitropoulos 2008), the availability of communal facilities, which are currently mostly pre-paid, could result in a higher usage. It could be therefore reasoned that with the introduction of communal facilities in a housing block all residents will use these 'freely' available appliances and therefore increase consumption. In terms of number of washes and drying cycles a communal facility can therefore be considered identical to the case where all individual households own a washing machine and a tumble dryer.

It could also be debated that the energy-efficiency measures suggested and modelled in this research are not the best possible solutions. The use of communal appliances might make use of economies of scale to introduce commercial type washing machines and dryers, thus improving on the energy consumption in terms of kWh/kg or opt for the more efficient type of tumble dryer, such as an 'A rated' heat pump tumble dryer (DEFRA[b] 2008). In the former case this may lead to a shift in user behaviour towards larger but less frequent washing and drying cycles whilst in the latter case there would be a considerable energy efficiency improvement. Doubts, however remain as to the availability and costs of such appliances (DEFRA[c] 2008) and to the eventual response from the users to such changes. Based on the results, it appears that at current conditions and with the foreseeable energy-efficiency improvements, communal washing and drying will have no overall beneficial impact on energy consumption.

Maximum peak demand and load duration

Table 2 in Appendix 2 and Figures 5 and 6 show that regulated staggered communal washing and drying as a form of Demand Side Management (DSM) should be preferred over the individual use of washing machines and tumble dryers.

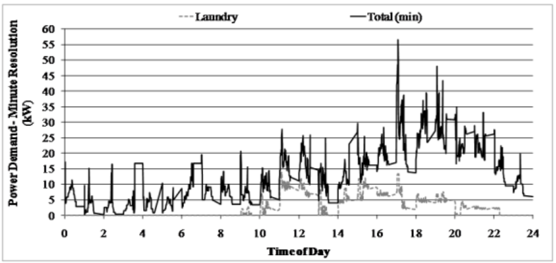

Figure 5 Laundry and total demand load profile for the 'individual use of washing machines and tumble dryers at current ownership rates with current technology' scenario for a winter day

The use of communal washing and drying appliances using a regulated, staggered timetable (Figure 6) leads to lower maximum peak demands, with an average reduction of 4 to 5%, compared to the individual use of such appliances by each household (Figure 5). The reason behind this is that the number of simultaneously switched on appliances is limited to the number of communal appliances.

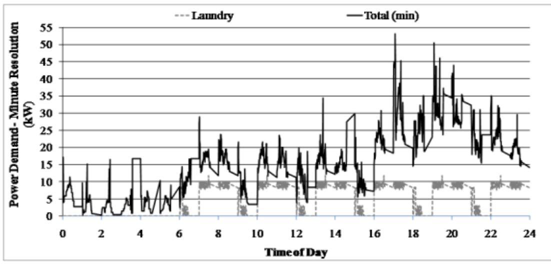

Figure 6 Laundry and total demand load profile for the 'regulated staggered use of communal washing machines and tumble dryers with current technology' scenario for a winter day

Another important aspect is the load duration. Table 2 summarises the expected load for different time duration percentiles for the different scenarios. It is clear from the results that due to the use of communal washing/drying, the expected load for 50% and 75% of the time (the mid-range and low demand values) are much higher for the 'communal use' scenarios than the 'individual scenarios' with a corresponding lowering of the maximum peak demand and the high range value (25% of the time). This indicates that less variability in demand provides a more benign climate for the operation of microgeneration devices.

CONCLUSION

This paper has presented the main aspects and characteristics of washing and drying-related electrical loads and energy consumption. Both are important loads within the total electric load profile of a household unit or a housing block with an annual average energy intensity of 27% of the total electrical energy consumption of a housing block calculated at current appliance ownership rates and technologies.

An analysis has been undertaken to evaluate the use of a regulated, staggered system of communal washing/drying rather than the current practice of using appliances based in each individual household. The effect of increased tumble dryer ownership rates and use of more energy-efficient technology was analysed to obtain a thorough understanding of how the future demand for washing and drying may shape domestic load profiles. Results suggest that the use of communal facilities would lead to a flattening of the electrical load with lower peak demands. This could improve the matching with local microgeneration electricity supplies. However, the increased use of tumble dryers (whether individual or communal) would lead to a considerable increase in terms of total daily load, average load and load intensity. To get maximum benefits, the communal use of laundry washing and drying appliances should be accompanied by a changeover to more energy-efficient appliances. Such future reductions in energy intensity of commercial type washing machines and dryers could add to the benefits of communal facilities.

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Appendix 1

Appliance / Room Lighting	4 Person Households				3 Person Households				2 Person Households								1 Person Households							
	A	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**	**J**	**K**	**L**	**M**	**N**	**O**	**P**	**Q**	**R**	**S**	**T**	**U**	**V**	**W**	**X**
Fridge-Freezer	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Oven/Hobs	X		X		X		X		X		X		X		X		X		X		X		X	
Microwave Oven	X	X	X		X	X	X		X	X	X	X	X	X			X	X	X	X	X	X		
Kettle	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Dish Washer	X					X				X	X													
Lights Bedroom 1	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Lights Bedroom 2	X	X	X	X	X	X	X	X																
Lights Kitchen	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Lights Living Room	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Lights Other	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
TV 1	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
TV 2	X	X	X	X		X	X	X					X	X	X	X								
Computer	X	X	X	X	X	X	X	X	X	X	X	X							X	X	X	X		
Misc Appliances	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X

X denotes ownership of the appliance

Appendix 2

Table 1

Total load, average load and energy intensity results of the *'individual use of washing machines and tumble dryers at current ownership rates using current technology'* scenario (in bold) and the percentage difference of other scenarios

	Winter	**Spring/Autumn**	**Summer**
Total Load (kWh)	**313.900**	**226.300**	**211.800**
Current Ownership Rates - Efficient Technology (%)	-5.428	-7.527	-8.043
Saturation Ownership Rates - Current Technology (%)	17.664	24.495	26.173
Saturation Ownership Rate - Efficient Technology (%)	7.189	9.970	10.653
Average Load (kW)	**13.100**	**9.400**	**8.800**
Current Ownership Rates - Efficient Technology (%)	-5.428	-7.527	-8.043
Saturation Ownership Rates - Current Technology (%)	17.664	24.495	26.173
Saturation Ownership Rate - Efficient Technology (%)	7.189	9.970	10.653
Energy Intensity Laundry Load / Total Load	**21.600**	**29.900**	**31.900**
Current Ownership Rates - Efficient Technology (%)	-20.892	-19.096	-18.642
Saturation Ownership Rates - Current Technology (%)	54.647	46.161	44.217
Saturation Ownership Rate - Efficient Technology (%)	24.415	21.269	20.521

Table 2

Maximum peak electrical demand and load duration results of the *'individual use of washing machines and tumble dryers at current ownership rates using current technology'* scenario (in bold) and the percentage difference of other scenarios

	Winter	**Spring/Autumn**	**Summer**
Maximum Peak Demand (kW)	**56.600**	**33.770**	**40.960**
Individual Use – Current Ownership Rates – Energy Efficient (%)	-4.314	-4.421	-4.715
Individual Use – Saturation Ownership Rates – Current Efficiency (%)	8.130	14.159	9.905
Individual Use – Saturation Ownership Rates – Energy Efficient (%)	1.493	5.488	2.360
Communal Use – Current Efficiency (%)	-6.154	7.638	-0.022
Communal Use – Energy Efficient (%)	-10.800	-0.282	-5.647
Expected minimum load for 75% of the time (kW)	**5,808.00**	**5,288.00**	**4,656.00**
Individual Use – Current Ownership Rates – Energy Efficient (%)	-1.515	-3.253	-1.203
Individual Use – Saturation Ownership Rates – Current Efficiency (%)	1.274	5.900	12.801
Individual Use – Saturation Ownership Rates – Energy Efficient (%)	1.274	2.421	7.388
Communal Use – Current Efficiency (%)	5.896	0.246	10.587
Communal Use – Energy Efficient (%)	10.682	0.454	18.479
Expected load for 50% of the time (kW)	**10,854.00**	**9,744.00**	**8,312.00**
Individual Use – Current Ownership Rates – Energy Efficient (%)	-6.995	-9.511	-4.078
Individual Use – Saturation Ownership Rates – Current Efficiency (%)	36.586	23.594	25.337
Individual Use – Saturation Ownership Rates – Energy Efficient (%)	20.177	9.319	13.724
Communal Use – Current Efficiency (%)	42.307	35.755	40.135
Communal Use – Energy Efficiency (%)	20.211	15.928	20.385
Expected maximum load for 25% of the time (kW)	**19,167.00**	**12,838.00**	**12,106.00**
Individual Use – Current Ownership Rates – Energy Efficient (%)	-7.797	-9.970	-8.471
Individual Use – Saturation Ownership Rates – Current Efficiency (%)	21.793	31.859	38.824
Individual Use – Saturation Ownership Rates – Energy Efficient (%)	7.092	14.161	13.579
Communal Use – Current Efficiency (%)	12.882	26.873	31.555
Communal Use – Energy Efficiency (%)	1.222	8.379	11.865