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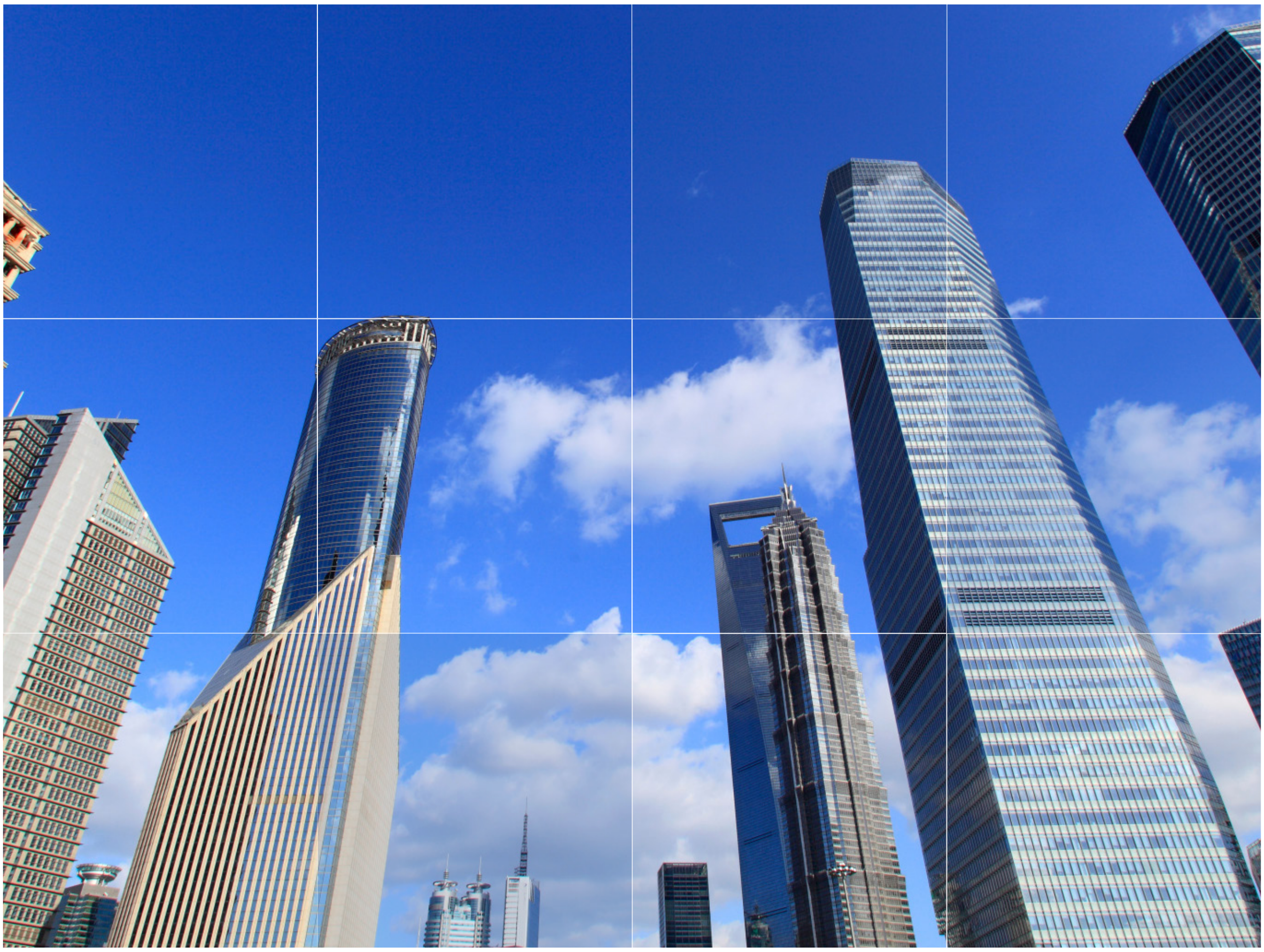
Follow-up Analysis of DR Potential of Commercial Buildings for Summer and Winter in Shanghai

November 2016



Authors

The Environmental Change Institute, University of Oxford

Mr Yingqi Liu

Dr Nick Eyre

Dr Sarah Darby

The Oxford Institute of Energy Studies, University of Oxford

Dr David Robinson

Prepared for

Natural Resources Defense Council

Supporting Partner

China Prosperity Strategic Programme Fund of the Foreign and Commonwealth Office

ACKNOWLEDGEMENTS

This report was produced by the collaboration of team members from the Environmental Change Institute (ECI) and the Oxford Institute for Energy Studies (OIES), University of Oxford. The team worked together to undertake a follow-up analysis of DR potential in summer and winter in Shanghai, with new dataset made available by the pilots in Shanghai.

We would like to express our gratitude to Ms Hyoungmi Kim and her colleagues at the Demand-Side Management Team of NRDC China Program, for their guidance, support and feedback through all stages of the project. We are very grateful for the valuable support from the Shanghai DR Implementation Team, in particular, Shanghai Municipal Commission of Economic and Informatization (EIC), Load Control Centre of State Grid Shanghai Municipal Electric Power Company, NRDC, Shanghai Twenty-First Century Energy Conservation Technology Co., Ltd. We would like also to extend our gratitude to these experts who have provided highly valuable and insightful comments and guidance: Professor Yanmin Han from Shanghai Jiaotong University, Dr Yudong Ruan from Shanghai Electrical Apparatus Research Institute, Jennifer Chen, Amenda Levin and Christina Swanson from NRDC.

CONTENTS

Demand-side response (DR) plays an important role in promoting the economic and operational efficiency, as well as the flexibility, of electrical systems. In China, a number of policy imperatives such as increasing economic efficiency in the electricity system, mitigating air and carbon pollution, and integrating renewable energy resources, underlines the need to explore non-traditional measures like DR. The value of DR involves replacing or avoiding construction of generator capacity and transmission, enhancing economic efficiency of the power system, avoiding dirty generation at times of peak demand, and strengthening system flexibility and network management, while simultaneously delivering high-quality services. Moreover, by engaging in DR, customers may become more aware of system conditions and requirements, altering their thinking about how they can help manage power systems.

Shanghai is the first municipality in China to pilot the DR programme to a range of diverse, non-domestic customers (e.g. manufacturing, office buildings, retail and hospitality). While the practice of demand-side management has been implemented in China for decades, previous approaches have focused on energy efficiency and regulatory load control in relation to large industrial users. The importance of the DR pilot in Shanghai is two-fold: 1) to design and test a market-based mechanism that incentivizes customers to participate and promotes continued compliance; and 2) to reach a wide range of commercial and industrial users, in addition to the large industrial customers.

In July 2015, we conducted a study, the Assessment of Demand Response Market Potential and Benefits in Shanghai (hereafter referred to as 'the July report')[1], to synthesise international experiences of encouraging DR development. We assessed these experiences in terms of regulatory, market, and customer-related provisions, and provided a preliminary evaluation of the potential value of DR in Shanghai. We also outlined high-level recommendations for promoting DR in China.

This report follows up on the July report in order to assess the potential of DR in the summer and winter seasons in Shanghai. It draws upon new evidence, especially of how customers used electricity (i.e. load profiles) and responded in DR events (i.e. when pre-defined conditions occur and the system operator calls for participants to reduce their demand during system peak period) in the summer of 2015 and winter of 2015/16. As with the July report, this follow-up study focuses on the role of DR in reducing peak demand, which typically involves a longer response time than other system services (e.g. balancing) that require resources to respond almost immediately.

This report has two main objectives:

- Update the assessment of DR potential in summer, based on a stronger evidence base for the load profiles and DR response of customers.
- Estimate the DR potential in winter, based on the evidence from the winter DR pilot. Since in Shanghai the peak demand in a year typically occurs in the summer (although it may change if the penetration of electric heating or the heat pump is high), the potential of DR in the summer is currently the most relevant for reducing capacity needs in generation as well as in transmission and distribution networks. Yet, the type of DR as piloted in Shanghai might well be valuable for other purposes (e.g. system flexibility and network management) in both seasons. However, as this study relies on the evidence of a winter DR pilot that focuses on the abilities of customers to reduce demand during 12pm-4pm, it should be seen generally as an estimate of the potential of downward load flexibility in that period.

Key findings are:

- For summer, in the Top Performance scenario, the potential for curtailable programmes in these two sub-sectors reaches 345 MW in 2030, considerably higher than that for DLC programmes (34 MW). Commercial buildings in finance, real estate, business and services could make up 80% of the summer DR potential of curtailable programmes.
- For winter, in the Top Performance scenario, the potential for curtailable programmes focusing on HVAC (e.g. electric heating) in these two sub-sectors reaches 189 MW in 2030. Commercial buildings in finance, real estate, business and services could take up 78% of the winter DR potential in the two sub-sectors covered by this analysis.

It should be noted that this follow-up report is to be read together with the July report. Any difference in the assessment results should be seen as the outcome of using new evidence from the pilot and adjusting the methodology accordingly.

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1. Liu, Y., Eyre, N., Darby, S., Keay, M., Robinson, D. and Li, X. (2015). Assessment of Demand Response Market Potential and Benefits in Shanghai. Prepared for Natural Resources Defense Council. Accessible at: http://www.eci.ox.ac.uk/research/energy/downloads/Assessment%20of%20Demand%20Response%20Market%20Potential%20and%20Benefits%20in%20Shanghai.pdf

TARGET COMMERCIAL BUILDINGS

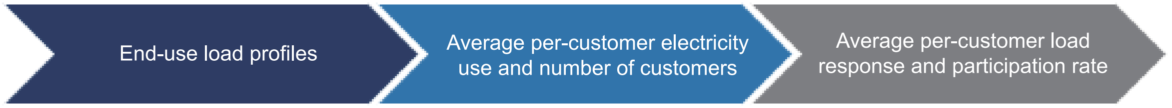
This analysis focuses on two sub-sectors of commercial buildings in Shanghai:

- Finance, real estate, business and services; and
- Retail, hospitality and catering.

There are two reasons for focusing on these two sub-sectors:

- Firstly, the paucity of samples showing the patterns of electricity demand and the load response in a given DR event for other commercial customers (e.g. public buildings) makes it difficult to undertake the assessment with adequate confidence. There is especially a lack of evidence for sub-sectors (e.g. transport, warehouse and postal services) whose electricity-using characteristics are vastly different from those of these two sub-sectors.
- Secondly, these two sub-sectors represent major electricity customers in Shanghai, or key customer segments that may make meaningful contributions to DR. In 2014, these two sub-sectors constituted over 60% of the total electricity consumption in the commercial sector of Shanghai[2].

However, this does not suggest lack of DR potential from other commercial customers – further research is needed to strengthen the evidence of electricity-use patterns and feasibility to provide DR for other commercial sub-sectors[3].



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2. Share of these two sub-sectors in the total peak demand of commercial sector is not reported by the State Grid.
3. Aggregate peak load of each sub-sector is not available to this study. Further research would benefit from more granular understanding of the contribution of each sub-sector to system peak demand to identify those with high potential for DR.

METHODOLOGY

The DR potential assessment follows a three-step approach. Since the analytical framework for the DR potential assessment is detailed in the July report, this report describes the key parts of methodology not already covered by the July report.

END-USE LOAD PROFILES

The first step of the analysis, average end-use load profiles, is constructed for: a) finance, real estate, business and services and b) retail, hospitality and catering, to characterise the patterns of electricity demand by end-uses. This report uses the 24-hour end-use load profiles of sample commercial buildings in summer (128 buildings) and winter (117 buildings) on a day chosen by the aggregator Tengtian[4] for each season. Although these sample load profiles provide valuable insight into the characteristics of electricity use in the two sub-sectors, a number of caveats are nonetheless noteworthy:

- Load profiles –the estimated average end-use load profiles should represent the average or typical patterns of electricity use in a given customer population or segment. There are two conditions that must be satisfied to ensure that the estimated load profiles are 'typical'. Firstly, a load profile should reflect the diversity of customer segments (e.g. size and nature of operation or electricity use). Secondly, it should be representative for a given sample for the summer/winter (i.e. how 'typical' the load profile is for the whole summer/winter). For a sample, this usually involves taking an average of load profiles for a number of similar days and adjusting for external factors that may influence the electricity demand (e.g. temperature, operational activities). It should be noted that the samples in this follow-up analysis might not be representative of the diverse customer segments (see below) or 'typical' for the summer/winter (since the load profiles provided to us are not adjusted for temperature or other external factors, rather they are the load profiles on a chosen day of summer/winter).
- System peak period – similar with the July report, this follow-up analysis focuses on the potential of DR to reduce system peak demand (i.e. as a capacity resource). In other words, the potential of DR to provide ancillary services for system operation[5] is not covered here, although it may become valuable and possible in the long-term. In the summer, the daily peak demand usually occurs during 12pm-4pm; in the winter, based on the system-level load curve provided by the State Grid, the daily peak demand also occurs during this period, although the level of peak demand is significantly lower than that reached in the summer.

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4. Tengtian is the only aggregator in the Shanghai DR Pilot and all commercial buildings have to take part in the DR Pilot through Tengtian.
5. Examples include the Short-Term Operating Reserve (STOR) and Frequency Response of National Grid in the UK, the Load Resources Programme of ERCOT, Synchronised (Spinning) Reserve of PJM and the Regulation Market of PJM. For a comparative study of DR in providing ancillary services in the US wholesale markets, refer to MacDonald et al. (2012) 'Demand Response Providing Ancillary Services: A comparison of opportunities and challenges in the US wholesale markets', accessible at: http://eetd.lbl.gov/sites/all/files/lbnl-5958e_0.pdf

For estimating the average end-use load profiles for summer for the two sub-sectors, this report uses the ratio of instantaneous end-use load and annual average demand (i.e. annual electricity use divided by 8,760 hours). In other words, we try to identify the 'typical' relationship between end-use load and annual average demand. This primarily has to do with the availability of data on annual average demand of customers in these two sub-sectors. By doing that, we implicitly assume that the average relationship of end-use load and annual average demand, as estimated from the samples, is representative of that for all customers in these two sub-sectors.

The Appendix provides a detailed description of the end-use categories. Three steps are taken to estimate the average end-use load profiles for the summer:

1. Firstly, an average aggregate load profile is determined for each of these two sub-sectors. The new load profile dataset has 24-hour load profiles on a summer day chosen by Tengtian for a) 82 samples of finance, real estate, business and services and b) 46 samples of retail, hospitality and catering. For each sample, the ratio of instantaneous aggregate load and annual average demand is calculated for each 30-minute interval of 24 hours in a day; then for each sub-sector, a median value of these ratios among samples in that sub-sector is taken for each 30-minute interval of 24 hours in a day ($L_{t\text{-annual}}$).

2. Secondly, average aggregate load profiles are broken down into end-uses. For each end-use in each sample, the report determines a) the share of average end-use load in the average aggregate load during peak periods of 12pm-4pm (P_{Peak}) and b) the ratio of instantaneous end-use load and average end-use load during peak periods for each 30-minute interval of 24 hours in a day ($R_{t\text{-Peak}}$). For the former, an average is taken among samples in the same sub-sector. For the latter, a median value is taken among samples in the same sub-sector for each 30-minute interval of 24 hours in a day.

3. Thirdly, for each end-use in each sub-sector, the average P_{Peak} and median $R_{t\text{-Peak}}$ are applied to the average of $L_{t\text{-annual}}$ during system peak period to determine the ratio of instantaneous end-use load and annual average demand (EUL-AAD). Then for each 30-minute interval of 24 hours in a day, EUL-AAD of all end- uses are added together and scaled proportionately to fit the established average aggregate load profiles.

For estimating the average end-use load profiles for winter for the two sub-sectors, the new load profile dataset has 24-hour load profiles on a winter day chosen by Tengtian for a) 76 samples of finance, real estate, business and services and b) 41 samples of retail, hospitality and catering. The average relationship between end-use load and annual average demand could not be identified, as the samples provided for assessing DR potential in the winter lacked information on annual electricity use. Because the pilots in the summer and winter targeted different customers, it is impossible to link any sample building from the winter to the summer dataset.

Given this challenge, we used an alternative approach for estimating the average end-use load profiles for winter: extrapolating from those already estimated for summer. The key factor is the seasonal relationship of end-use load that can be used to adjust the average end-use load profiles estimated for summer. For this follow-up analysis, we use the seasonal relationship of air-conditioning and non-air-conditioning loads, on the system aggregate level, to adjust the average end-use load profiles estimated for summer. The calculations involve three main steps:

1. Firstly, for HVAC and non-HVAC loads respectively, the ratios of winter and summer loads ($R_{W\text{-}S}$) for each 30-minute interval in a 24-hour period are calculated at the system aggregate level. The data source is the 24-hour system aggregate load for Shanghai, as provided by the State Grid in 2015, on a typical day in summer and winter, which is broken down into HVAC and non-HVAC uses. These two categories are separated for calculating the $R_{W\text{-}S}$ largely because of their different seasonal relationship (Figure 1). This allows us to put forth a bold assumption, that the seasonality seen for HVAC and non-HVAC loads broadly reflects the patterns in the two commercial sub-sectors. While this constitutes a 'crude' approximation, it is the only possible way for this follow-up analysis to estimate the average end-use load profiles for winter. Further evidence and analysis are needed to improve the knowledge of the relationship of end-use loads and annual average demand in various customer segments in Shanghai.

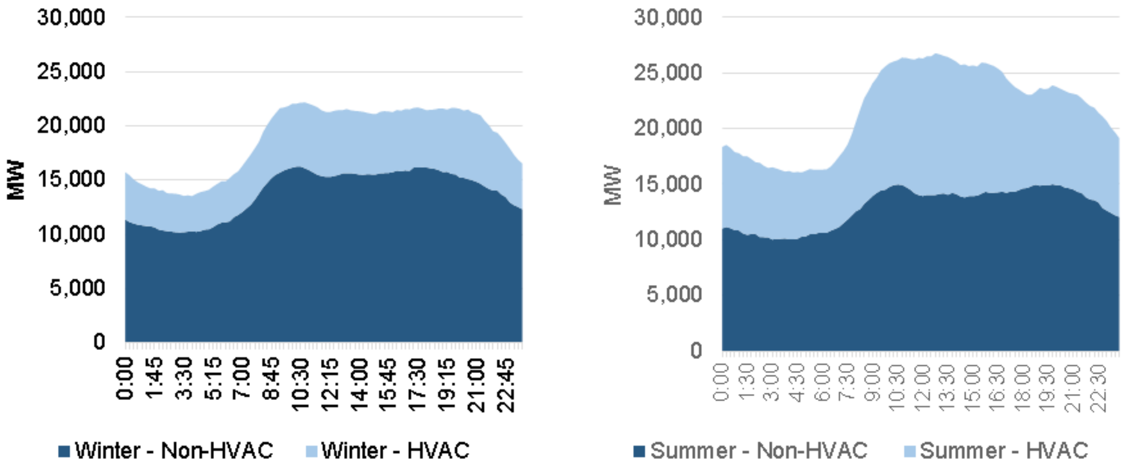

Figure 1. Seasonal relationship of aggregate HVAC and non-HVAC loads for the electricity system in Shanghai[6]

Source: State Grid

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6. Some other end-uses (e.g. lighting) may be seasonal in their load profiles. However, limited information available to this study does not allow 'breaking-out' of those end-uses with potentially marked seasonality from the aggregate non-HVAC category.

2. Secondly, for each 30-minute interval in a 24-hour period, the estimated EUL-AAD for summer is adjusted to produce EUL-AAD of HVAC and non-HVAC loads for winter. This is done in two parts – firstly, aggregate the EUL-AAD of lighting and plug loads, motors and others to calculate the aggregate EUL-AAD for summer for non-HVAC loads; secondly, apply the R_{W-S} of HVAC and non-HVAC loads to the aggregate EUL-AAD for these two categories respectively.

3. Thirdly, break down the estimated aggregate EUL-AAD for non-HVAC loads for winter into three end-use categories (i.e. lighting and plug loads, motors and others). This entails understanding 1) the percentage of average peak demand by these end-uses and 2) for a given end-use category, the ratio of instantaneous demand and average peak demand for every 30-minute interval in 24 hours. For the former, in each individual sample, the share of these three non-HVAC end-use categories in the average aggregate non-HVAC peak demand (during 12pm-4pm) is calculated, and an average is taken across all samples in a sub-sector. For the latter, in each end-use category, the ratio of instantaneous load and average peak demand for that period's end-use is estimated for each sample for every 30-minute interval in 24 hours of the chosen day. A median value is taken of these ratios across all samples in a sub-sector for each 30-minute interval in 24 hours. Subsequently, for each end-use category, the estimated percentage of average aggregate peak demand, and the estimated ratio of instantaneous load and average peak demand are applied to the average of aggregate EUL-AAD during 12pm-4pm to produce the EUL-AAD for winter for each 30-minute interval in 24 hours. Finally, the estimated EUL-AAD for winter for all three end-use categories are added together and proportionately scaled to fit the estimated aggregate EUL-AAD for non-HVAC loads for each 30-minute interval in 24 hours.

For the summer and winter periods, the estimated average of end-use load profiles for 1) finance, real estate, business and services and 2) retail, hospitality and catering are shown in Figure 2-3. Some key observations are as follows.

- Peak demand of commercial buildings in these two sub-sectors during summer and winter tends to coincide with system peak periods. The highest demand of average load profiles of sample buildings in a) finance, real estate, business and services and b) retail, hospitality and catering occurs during the system peak period of 12pm-4pm on working days. This underlines the value of exploring the potential of DR in these two commercial sub-sectors since DR will directly contribute to a reduction in peak demand. Moreover, lighting and plug loads and HVAC in the two sub-sectors also have peak demands that correspond to the system peak period, which suggests the value of exploring the potential in these end-use categories.

- Commercial buildings in the two sub-sectors demonstrate different load profiles. Despite similarities, the average load profiles of the two sub-sectors show differences in areas like the relationship between instantaneous aggregate load and annual average demand (i.e. the maximum peak level or 'peakiness' of load profile) and the shape of end-use loads. For example, in the summer, the aggregate load for lighting and plug loads as well as air conditioning are 'peakier' in sample buildings in finance, real estate, business and services than those in retail, hospitality and catering. Despite difference in maximum peak level (or 'peakiness'), the period when peak demand of these two end-use categories occurs tends to coincide with the system peak period. A number of reasons may have contributed to the difference, including the distinct pattern of electricity use among sub-sectors and the extent to which the sample load profiles are representative of the sub-sectors and their electricity use (e.g., whether load profiles represent typical electricity use patterns for sample buildings). In light of this, it is important to delineate appropriate customer segments (e.g. sub-sectors and different groups within a sub-sector) to reflect any unique characteristics of electricity use and drivers behind the differences. It is important to understand how and whether such differences would influence the flexibility in demand for each of the customer segments.

- In the summer, lighting and plug loads, and air conditioning appear to show significant intra-day variation in instantaneous load. These two end-uses make up a considerable share of the aggregate demand during system peak period. In the average load profile for these two sub-sectors, three patterns are noteworthy. Firstly, the difference between highest and lowest instantaneous load is considerably larger for lighting/plug loads and air conditioning than that for motors and other end-use categories. Secondly, lighting/plug loads and air conditioning each appear to contribute roughly 40% of aggregate peak demand. Given the perceived flexibility of air conditioning, which can be seen from the evidence in the Shanghai pilots (as discussed below), there seems to be great potential for developing HVAC's DR capability to contribute to system reliability (e.g. reducing peak demand). The large share of air conditioning in aggregate load during non-peak hours may also suggest its value for other aspects of system operation (e.g. balancing service to support the integration of renewables). As for lighting and plug loads, while the evidence in pilots shows some possibility of responding to DR dispatch, the level of load response is lower than that for air conditioning (as discussed below). This means that while there may be scope for DR from lighting and plug loads[7], it is valuable to explore the potential benefits of improving energy efficiency in these end-uses to reduce peak demand. In fact, higher efficiency in lighting (e.g. LEDs, lighting sensors and daylighting) and plug loads as well as other end-uses may result in less heat waste being generated, reducing the demand for air conditioning. Thirdly, the load of lighting and plug loads seems to correlate closely with that of air conditioning, during the system's peak period in particular. While it is difficult for this study to see why this would be so[8], future research would benefit from understanding how end-uses interact in terms of their flexibility and scale of potential (e.g. effect of high efficiency level in lighting and plug loads on the load of air conditioning and its scale of potential). This would require more information about the origins and labelling of the data, to prevent cases where there are unintentional overlaps between categories of end-use. Clarification of meta-data

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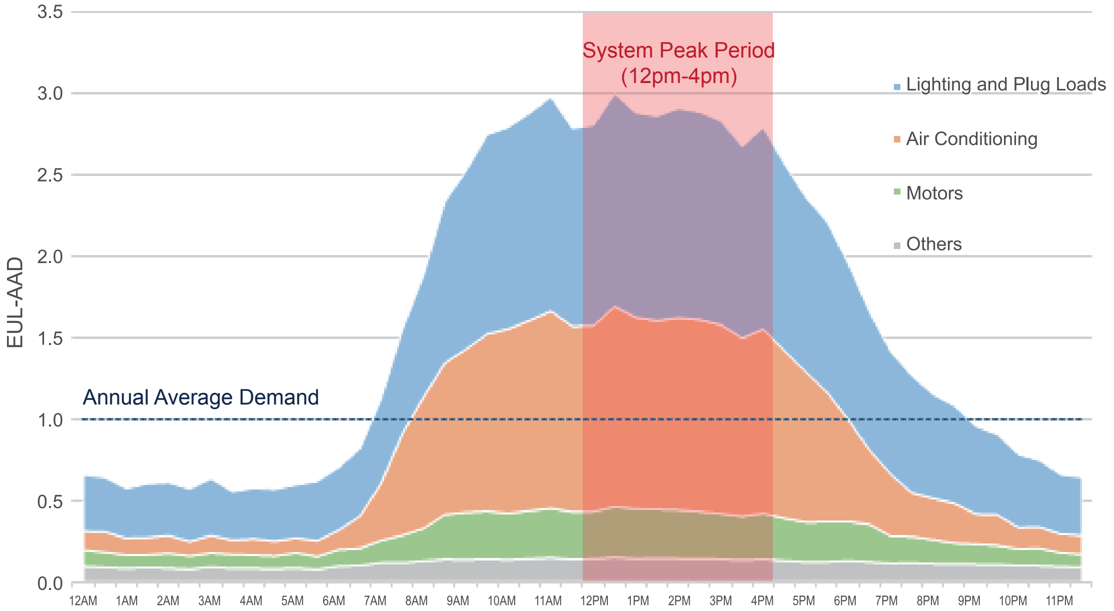
[7] Examples from international experience include Albertsons managing to reduce overhead lighting to 50% (switching off half of fluorescent tubes in a fixture) without noticeable negative impacts on worker productivity in an auto-DR research project in the US. See Piette et al. (2004) 'Development and Evaluation of Fully Automated Demand Response in Large Facilities' for details.

[8] There are multiple hypotheses, including the waste heat from lighting and plug loads increasing the need for air conditioning, or the practice of setting air conditioning at a certain temperature during business hours (and corresponding with the use of lighting/plug loads). However, this study is unable to test which hypothesis is true.

issues and further analysis will be important in order to identify any relationships between end-uses that could influence the DR potential.

Summer - Finance, real estate, business and services (n=82)



Summer - Retail, hospitality and catering (n=46)

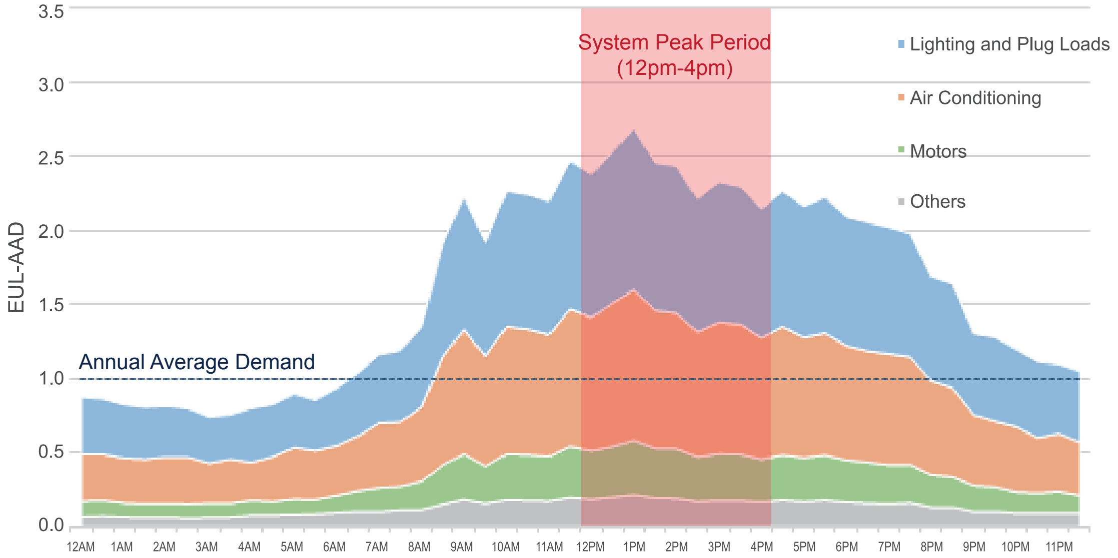
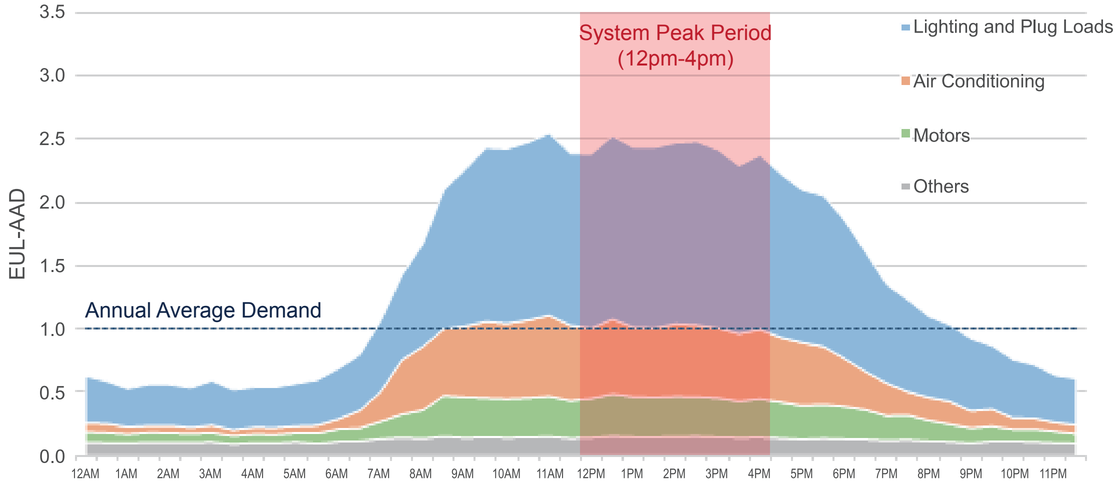


Figure 2. Estimated end-use load profiles for two commercial sub-sectors in summer

Source: Own analysis

Summer - Finance, real estate, business and services (n=76)



Summer - Retail, hospitality and catering (n=41)

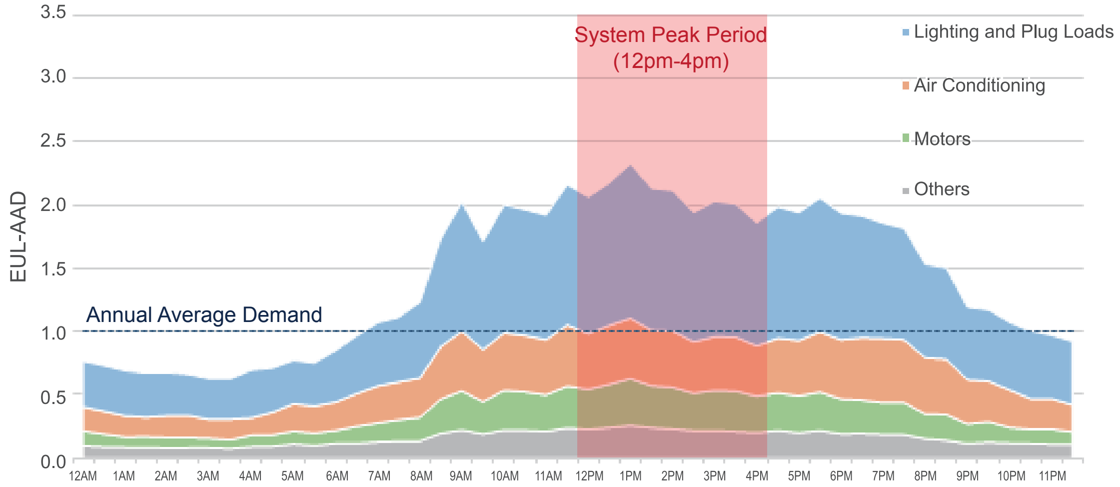


Figure 3. Estimated end-use load profiles for two commercial sub-sectors in winter

Source: Own analysis

- In the winter, lighting and plug loads make significant contributions to the overall peak demand, while compared with the summer the load of HVAC uses is considerably lower. Based on the estimated end-use load profiles, lighting and plug loads represent over 50% of aggregate peak demand (12pm-4pm), while the share of HVAC during the same period is slightly above 20%. This is primarily driven by the lower electricity demand of HVAC uses in the winter, as the penetration of gas- or oil-fuelled heating is higher in Shanghai than that of electric heating. While as seen below there is some DR potential from HVAC in the winter (e.g. electric heating), the extent to which customers in Shanghai are willing to change lighting/plug load in the winter remains to be seen, although there is some international evidence showing the possibility (as noted in footnote 7). In light of this, the DR potential in the winter (i.e. reducing demand during 12pm-4pm) may not be as large[9]. If the purpose is to reduce load during that period (e.g. for local network management), other options like electric energy efficiency or distributed generation may become more important.

AVERAGE PER-CUSTOMER ELECTRICITY USE AND NUMBER OF CUSTOMERS IN FUTURE YEARS

Without adequate information on how each sub-sector is segmented (e.g. customer size of electricity use), this study uses average per-customer electricity use (i.e. total electricity use of a sub-sector divided by number of customers in that sub-sector) to establish the average per-customer and aggregate peak demand for each sub-sector. In other words, this analysis only focuses on the average per-customer electricity use, without being able to identify how and whether it may vary among different segments within the same customer sub-sector.

In the absence of detailed projections for future electricity use, this study performs a linear regression analysis for total annual electricity use and the number of customers for these two sub-sectors, based on historical data covering 2008-2014[10]. Linear regression results are used to extrapolate total annual electricity use and number of customers for each sub-sector in future years. In other words, we assume that the rate of change for total annual electricity use and number of customers for each sub-sector as seen in 2008-14 would remain constant for 2015-30. Dividing annual electricity use by the total number of customers gives the average per-customer annual electricity use for a given sub-sector in any year Table 1 shows assumptions for average per-customer electricity use and number of customers in future years.

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[9] Electric water heating may be a potential source of DR in winter. However, the dataset available to this study does not delineate 'water heating' as a type of load, making it difficult to assess its DR potential in winter.

[10] For annual electricity use, data sources include the Shanghai Statistical Yearbook 2011, 2013 and 2014 and the datasets for 2013 and 2014 as provided by the State Grid. For number of customers, data sources include the Compilation of Statistical Materials of Electric Power Industry 2009-2011.

Table 1. Assumptions for average per-customer electricity use and number of customers in future years

	Average per-customer electricity use (MWh)				Number of customers (in thousands)			
	2015	2020	2025	2030	2015	2020	2025	2030
Finance, real estate, business and services	29	30	30	31	636	822	1,007	1,193
Retail, hospitality and catering	63	63	63	63	129	148	167	186

Source: Shanghai Statistical Yearbook 2011, 2013 and 2014; State Grid dataset on annual electricity use for 2013 and 2014; and Compilation of Statistical Materials of Electric Power Industry 2009-2011

As shown in Table 2, considerable difference exists between the average electricity use of sample buildings and average per-customer electricity use of the same sub-sector. This suggests that individual sample buildings are unlikely to be representative of their sub-sector and there is a wide range of customers, in terms of their electricity use, in these two sub-sectors. In light of this, there is significant uncertainty to the extent in which the end-use load profile for each sub-sector sampled would be representative of all the customers in that sub-sector. Further studies would benefit from nuanced segmentation of customers and more representative sampling. The difference also implies a large number of small businesses or individual customers in these two sub-sectors, which may have the potential to participate in DLC programmes.

Table 2. Annual electricity use of sample buildings and estimated average per-customer annual electricity use

	Annual electricity use of sample commercial buildings (MWh)		Estimated average per-customer electricity use (MWh)
	Average	Range	
Finance, real estate, business and services	5,680	7-55,927	29
Retail, hospitality and catering	6,396	13-86,245	63

Source: Shanghai DR pilot dataset; own analysis.

AVERAGE PER-CUSTOMER LOAD RESPONSE AND PARTICIPATION RATE

Consistent with the July report, for the summer, this follow-up study considers two types of DR – direct load control (DLC) for air conditioning and curtailable programmes. While DLC allows utilities to remotely cycle the load of air conditioning if customers give them permission, curtailable programmes typically allow customers the flexibility to decide how to respond to DR dispatch orders (e.g. which end-uses and how much demand to curtail). For the winter, however, only curtailable programmes are considered, mainly because the use of DLC for electric heating in commercial buildings is limited and there is no evidence showing how likely commercial buildings in Shanghai would be to provide this kind of DR service.

Three scenarios – namely Basic, Median and Top Performance – are devised to reflect the different levels of load response and participation rate that can be expected for future years based on the existing evidence in Shanghai (e.g. load response in curtailable programmes) or international programme[11] (e.g. load response in DLC for air-conditioning, and participation rate for curtailable and DLC programmes). Of these scenarios, the Top Performance reflects the 'high-end' participation rate and load response from the available evidence in the Shanghai pilots and/or international benchmarking, thus representing the most optimistic scenario. However, it should be noted this study does not regard any scenario as more likely than other ones to materialise, since this depends on a variety of factors (e.g. cost-benefit consideration for customers and system operator, market conditions) that are difficult for us to determine without considerably more information.

For curtailable programmes, the assumptions for average per-customer load response by end-use are based on the review of end-use-level response to DR dispatch order in the summer pilots of 2014 and 2015, and the 2015/16-winter pilot. During the summer pilot, for the end-use in each sample that successfully responded to DR in each sub-sector, the load response is established as the percentage reduction between average load during DR event and average baseline load during the same hours of the day[12]. Among samples in the same sub-sector, 1st, 2nd and 3rd quartile of the load response is identified for each end-use category to represent the load response level under Basic, Median and Top Performance scenarios, respectively (Table 3). For the winter, by contrast, since the load response is reported for the aggregate load, it is not possible to disaggregate the load response by end-use categories. Therefore, the average reduction in aggregate load is calculated for each sample that successfully responded in the winter pilot. However, since most buildings have responded by turning down electric heating, the curtailable programmes are assumed to be for HVAC uses. Among samples in the same sub-sector, 1st, 2nd and 3rd quartile of the load response is identified to represent the load response level under Basic, Median and Top Performance scenarios respectively (Table 4).

For DLC in the summer, as detailed in the July report, the assumptions for load response are based on a review of FERC DR survey in 2012, as well as a number of international DR potential assessment studies and evaluation reports[13]. Since these assumptions differ among customer groups depending on their per-customer peak demand, this study applies the established load profile to estimated average per-customer electricity use to assess the approximate average per-customer peak demand and to identify applicable assumptions accordingly (Table 5).

Table 3. Assumptions for average per-customer load response in curtailable programmes in the summer

	Basic	Median	Top Performance
Finance, real estate, business and services			
Lighting and plug loads	4%	10%	13%
Air conditioning	13%	40%	57%
Motors	5%	8%	27%
Others	15%	22%	34%
Retail, hospitality and catering			
Lighting and plug loads	6%	7%	13%
Air conditioning	24%	46%	53%
Motors	12%	17%	25%
Others	9%	9%	9%

Source: Shanghai DR pilot dataset; own analysis.

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[11] The dataset of sample buildings in the Shanghai DR Pilot is used to estimate the load response for curtailable programmes, while evidence from international programmes, as collated and analysed in the July report (see footnote 1), is used to estimate the load response for DLC for air conditioning and participation rates for curtailable and DLC programmes.

[12] Baseline load profiles are provided by Tengtian

[13] FERC (2009) 'A national assessment of demand response potential'; Cadmus (2013) 'Comprehensive assessment of demand-side resource potentials (2014-2030)', prepared for Puget Sound Energy; Brattle (2014) 'Demand response market potential in Xcel Energy's Northern States Power Service Territory'; Goldman et al. (2007) 'Estimating demand response market potential among large commercial and industrial customers: a scoping study'; Element Energy (2012) 'Demand-side response in the non-domestic sector'.

Table 4. Assumptions for average aggregate load response in curtailable programmes in the winter

	Basic	Median	Top Performance
Finance, real estate, business and services	5%	13%	21%
Retail, hospitality and catering	5%	13%	21%

Source: Shanghai DR pilot dataset; own analysis.

Table 5. Assumptions for average per-customer load response in DLC for air conditioning in the summer

	Basic	Median	Top Performance
Finance, real estate, business and services	2% of aggregate load (or 5% of air conditioning)	3% of aggregate load (or 7% of air conditioning)	5% of aggregate load (or 12% of air conditioning)
Retail, hospitality and catering	2% of aggregate load (or 5% of air conditioning)	3% of aggregate load (or 8% of air conditioning)	5% of aggregate load (or 13% of air conditioning)

Source: Own analysis based on international experience reviewed in Liu et al. (2015) Assessment of Demand Response Market Potential and Benefits in Shanghai.

As for participation rates[14], local evidence in Shanghai is not available, mainly due to the novelty of DR pilots, and the difficulty of assessing the viability of different DR options in the timeframe of this study. Therefore, consistent with the July report, assumptions under the Top Performance scenario reflect the high-end participation rate identified in international benchmarking, while the participation rate under Basic and Median scenarios represents ¼ and ½ of that under Top Performance[15]. Table 6 lists assumptions for the participation rates. For the curtailable programmes, the same participation rate is assumed for the DR programmes in the summer and in the winter.

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[14] As percentage of relevant customer population. Since the DR programme is still in the pilot phase, there is no local evidence to suggest any likely participation rate.

[15] As discussed earlier, it is likely that these two sub-sectors have a large number of small customers, who may accept and be willing to participate in DLC programmes. To the extent that small customers take up a higher share of customer population in Shanghai, it is likely the participation rate of DLC could be higher than international benchmarking. However, this study bases assumptions on international benchmarking.

Table 6. Assumptions for participation rate

	Basic			Median			Top Performance		
	2020	2025	2030	2020	2025	2030	2020	2025	2030
Finance, real estate, business and services									
Curtailable programmes	1%	2%	3%	2%	3%	5%	3%	7%	10%
DLC for air conditioning	0%	1%	1%	1%	2%	3%	2%	3%	5%
Retail, hospitality and catering									
Curtailable programmes	1%	2%	3%	2%	3%	5%	3%	7%	10%
DLC for air conditioning	0%	1%	1%	1%	2%	3%	2%	3%	5%

Source: Own analysis based on international experience reviewed in Liu et al. (2015) Assessment of Demand Response Market Potential and Benefits in Shanghai.

For a particular DR event, it is possible that not all customers signing up for DR programmes will be able to deliver. Thus, consistent with the July report, this study considers DR response rate under different scenarios to reflect the probability of participating customers responding to any given DR event (Table 7). The assumptions are based on the empirical relationship between the response rate and degree of load reduction in the administrative demand-planning programme in Shanghai (i.e. higher response rate for lower load reduction).

Table 7. Assumptions for DR response rate

	Basic	Median	Top Performance
Finance, real estate, business and services	90%	80%	70%
Retail, hospitality and catering	90%	80%	70%

Source: Shanghai DR team.

ASSESSMENT OF SUMMER DR POTENTIAL IN COMMERCIAL BUILDINGS

The potential of DLC and curtailable programmes in the summer for a) finance, real estate, business and services and b) retail, hospitality and catering in the summer is assessed (Figure 4-5). Some key findings are as follows.

- Curtailable DR programmes have significant potential for reducing the summer system peak demand. In the Top Performance scenario, the potential for curtailable programmes in these two sub-sectors reaches 345 MW[16] in 2030, considerably higher than that for DLC programmes (34 MW). There are two noteworthy points. Firstly, the scale of assessed potential for DLC and curtailable programmes is lower than that in the July report, which could be due to changes in the methodology or because this report focuses on only two sub-sectors of commercial buildings, whose load-profile evidence is stronger. Secondly, the low levels of load response and participation rates, as evidenced from international experience (see footnote 11 and the July report), are a driving factor for the low potential of DLC for air conditioning. Since such programmes are not offered in Shanghai, it is difficult to gauge the willingness of commercial customers to allow utilities to control their air conditioning use and the amount of air conditioning load that can be remotely controlled. As seen in the US, DLC as a DR option is mainly offered to residential customers for air conditioning, whereas its market penetration towards commercial and industrial customers is low.[17] However, this has partly to do with the high contribution of residential cooling demand to the system peak loads[18] and the feasibility of DLC for air conditioning in households. The actual uptake of DLC in the C&I sectors may depend on a number of factors such as how businesses would react to letting utilities control some of their electricity demand, availability of enabling technologies (e.g. remote control or energy management system), the business case for utilities to offer such programmes and the attractiveness of programme design (e.g. financial compensation, requirements and ease of participation).
- Potential for finance, real estate, business and services is larger than that for retail, hospitality and catering. Particularly for curtailable programmes, commercial buildings in finance, real estate, business and services could make up 80% of the summer DR potential under the Top Performance scenario in 2030. In comparison with retail, hospitality and catering, this sector has significantly higher electricity consumption[19] and a 'peakier' average load profile.

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[16] 0.6% of system peak demand in 2030 as roughly estimated in the July report. Refer to the July report for the uncertainty in future peak demand estimation.

[17] FERC (2012). Assessment of Demand Response and Advanced Metering – Staff Report. Accessible at: http://www.ferc.gov/legal/staff-reports/12-20-12-demand-response.pdf

[18] http://www.cpuc.ca.gov/cfaqs/howhighiscaliforniaselectricitydemandandwheredoesthepowercomefrom.htm

[19] In 2014, the sub-sector of finance, real estate, business and services made up 42% of total electricity consumption in commercial buildings.

- Air conditioning appears to be the main reason for peak demand and to have the potential to provide significant DR. For curtailable programmes, air conditioning could make up nearly 70% of the DR potential assessed by the report, contributing almost 238MW in the Top Performance scenario in 2030. More than 80% of the potential of curtailable DR programmes from air conditioning could be found in finance, real estate, business and services. Therefore, there seems to be value in further exploring the DR potential in air conditioning and the options to realise it. Apart from air conditioning, there could also be sizable potential in other end-use categories, particularly in lighting and plug loads, which could contribute 61MW in the Top Performance scenario in 2030.

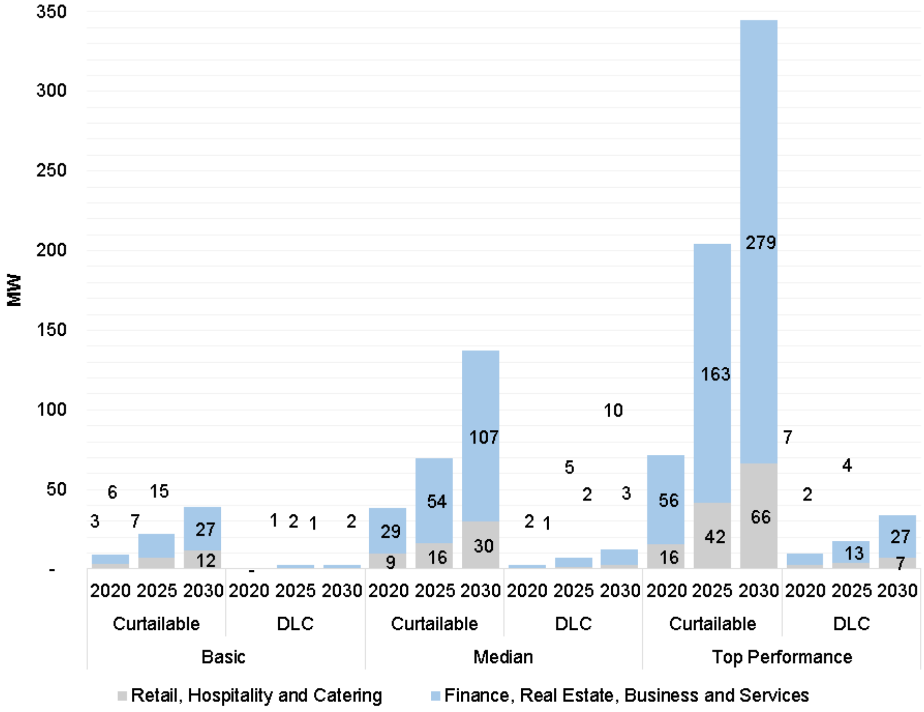

Figure 4. Overall summer DR potential for curtailable and DLC programmes

Source: Own analysis

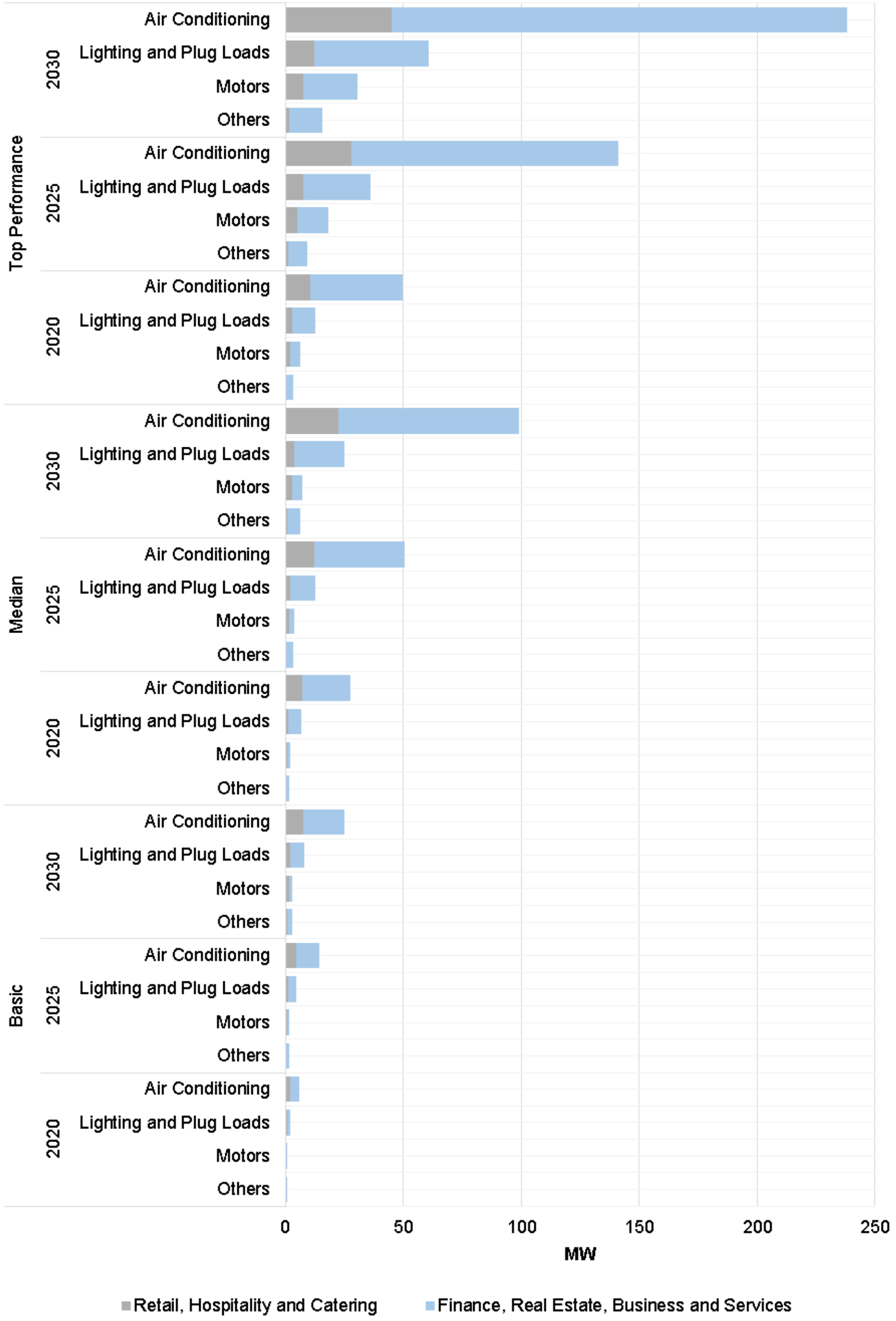

Figure 5. End-use breakdown of DR potential for curtailable programmes

Source: Own analysis

ASSESSMENT OF WINTER DR POTENTIAL IN COMMERCIAL BUILDINGS

Figure 6 shows an assessment of potential of curtailable programmes in the winter for a) finance, real estate, business and services and b) retail, hospitality and catering.

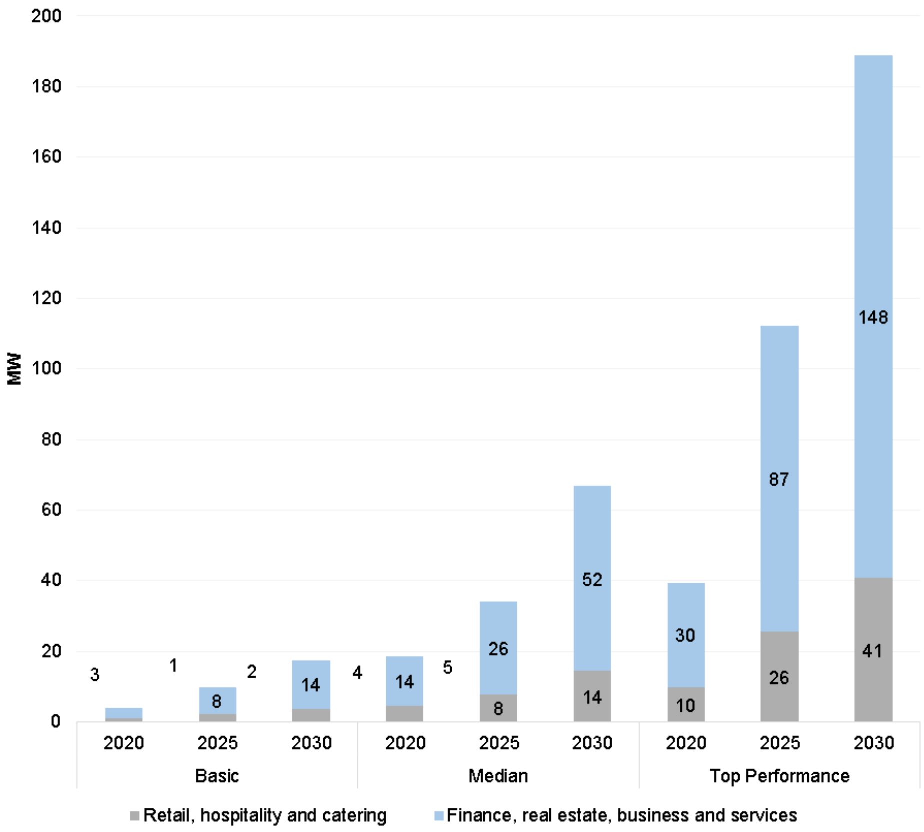

Figure 6. Overall winter DR potential for curtailable programmes

Source: Own analysis

Some key findings are as follows:

- The potential of curtailable programmes for HVAC in the winter is significant, although it is lower than the potential in the summer. In the Top Performance scenario, the potential for curtailable programmes focusing on HVAC (e.g. electric furnace) in these two sub-sectors reaches 189 MW in 2030, which is almost 1% of the average winter peak demand (typical load in the winter is around 21GW according to the State Grid, see Figure 1). However, there still exist a few uncertainties apart from those related to the estimation of end-use load profiles. Firstly, the assessment is based on a number of sample buildings that have responded to the winter DR events by turning down electric furnaces. In other words, it is not yet clear whether other end-use categories are also capable of providing DR (e.g. whether there are any barriers and, if so, what actions may be taken by the customer or programme administrator). If other end-use categories can also provide DR services, the potential may be higher than estimated here. Secondly, the participation rate is derived from the international benchmarking (see footnote 11 and the July report), which may not be fully applicable to the curtailable programmes in the winter. Moreover, as discussed above, the specific regulatory and market conditions in Shanghai also play an important part in affecting how customers respond to the winter curtailable programme. Again, it should be noted that this estimate focuses on the peak-saving potentials of DR – there are other types of benefits, which might be of greater value in the winter (e.g. fast response for system flexibility and local network management).
- Potential for finance, real estate, business and services is larger than that for retail, hospitality and catering. This is similar to the results of the assessment of the summer potential for DR. In the Top Performance scenario in 2030, commercial buildings in finance, real estate, business and services could take up 78% of the winter DR potential in the two sub-sectors covered by this analysis. This is largely due to the estimated load profiles of finance, real estate, business and services being 'peakier' and this sub-sector's high share of overall electricity use in Shanghai.
- Energy efficiency/conservation should play a key role in helping to reduce the peak demand. Based on the estimated end-use load profiles, lighting and plug loads constitute 52-58% of average peak demand of the two sub-sectors during 12pm-4pm. As discussed above, it is not clear if this end-use category can provide much DR. However, if the challenge in doing so is insurmountable, it should be possible to increase the efficiency of electricity-using equipment or systems to reduce their load and thus the peak demand. Moreover, the benefits of energy saving, which are likely to be higher than those from providing DR capacity to reduce peak demand[20], may strengthen the business case for doing so.

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[20] Examples include installation of LEDs by Walmart on sales floors to achieve savings in operation and maintenance as well as improvement in productivity and comfort (https://www.rila.org/sustainability/RetailEnergyManagementProgram/Documents/EnergySavingOpportunities+TacticsforRetail.pdf), and the partnership of PG&E and IKEA in energy efficiency initiatives (https://www.pge.com/includes/docs/pdfs/mybusiness/energysavingsrebates/incentivesbyindustry/cs_ikea.pdf).

DISCUSSIONS FOR FUTURE RESEARCH

It is important to note several caveats of this study and the need for future research.

- The way sample load profiles are generated suggests uncertainty about the established load profiles and thus the assessment results. Firstly, the sample load profiles are daily load profiles of sample commercial buildings on the day with highest system peak demand in 2015. In other words, these load profiles may not adequately reflect the 'typical' electricity use pattern and thus 'typical' peak demand of individual sample buildings. Nor are they normalised for weather or other external factors that could affect the load profiles. Secondly, as discussed earlier, the sample of commercial buildings for which load profiles are provided may not be representative of all customers in their sub-sector. These two considerations suggest that the load profiles established in this study may not adequately reflect the 'average' or 'typical' patterns of electricity use. For future studies, it would be valuable to analyse load profiles of a more representative sample over a longer period of time. Thirdly, for the winter DR pilot, due to the lack of information on annual electricity use of sample buildings, this study has derived the relationship of peak demand and annual average demand from the estimated average load profiles for summer. This suggests a high level of uncertainty in the data – in fact, for future research it is vital to undertake rigorous load profile studies for various customer groups to strengthen the evidence upon which the analysis is based.
- Local evidence is vital as the DR pilots in Shanghai continue measuring output. It is important to note that many assumptions in this study are based on international experience. While those for load response in curtailable programmes consider how participants in previous pilots have responded to DR dispatch, these participants are nonetheless small in number and may not represent other customer segments of their sub-sector. Moreover, as the pilots are new, it is unclear whether these participants have fully tapped their potential for providing DR. Local factors including the design and compensation level of DR programmes, regulatory and market conditions to support DR, customer engagement and acceptance of various DR designs, characteristics of system operation and customer electricity use, and availability of enabling technologies (e.g. energy management system or back-up generation) have implications for the willingness to respond and the level of load changes, thus the DR potential. As the DR pilots in Shanghai develop and continue measuring load responses, it is valuable to regularly review and strengthen the evidence base to account for these factors, in order to improve the DR potential assessment and, more importantly, the DR programme design.
- Differences may exist among customers in the same sub-sector, which could influence load response and participation rate. As mentioned earlier, due to limited information for customer segmentation, this study relies on established average load profiles and does not differentiate customers based on their distinct willingness and capability to provide DR. In fact, the nature of business activities (e.g. whether their use of electricity can be interrupted), the characteristics of buildings as well as external factors (e.g. temperature and humidity), the design

of the DR programme and its financial compensation, the availability of enabling technology and customer engagement will all influence the DR potential. Future studies would benefit from detailed analysis of key factors influencing DR potential in Shanghai and how customers in each sub-sector could segment into different groups reflecting these factors.

- It is important to consider the interaction between end-uses, especially how it could affect the DR potential. In the established average load profiles, it appears the instantaneous load of lighting and plug loads and that of air conditioning tend to move in synchronisation during system peak hours. While this does not necessarily seem unusual, the lack of information does not allow this study to explore the likely reasons. If a strong link exists between end-uses, then less flexible end-uses may become a limiting factor for the extent to which loads can be curtailed. However, this study does not account for interactions of this nature.
- Future research should consider the potential of DR to provide a wider range of system services. Our analysis has so far focused on the potential of DR to reduce system peak demand. This is an important issue, given the big peak-valley difference in electricity demand and the emerging imperative of economic efficiency in planning and operating the system. However, other services DR can provide (e.g. fast response to offer more system flexibility) may become more important, with the development of enabling infrastructure (e.g. information and communication) and changes in the fuel mix (e.g. high share of inflexible generation like intermittent renewables). Future research should assess the potential value of DR in providing these types of system services in addition to reducing the system peak demand.
- Future studies need to consider the location of DR resources. By reducing peak demand, DR would avoid or defer the investment in not only generation capacity, but also electricity networks, which may experience localised congestion conditions[21]. If the intermittent renewable generation is concentrated in specific locations or the demand is highly uncertain, DR may be deployed to increase or decrease demand accordingly, to lower the burden on the local network. The implication is that future studies should not only be concerned with the total scale of DR potential, but also where it is located and whether it can be used to address more location-specific issues.
- Additional potential solutions to reduce peak demand need to be explored, such as energy efficiency/conservation and distributed generation[22]. In the estimated load profiles, lighting and plug loads, which may be less flexible as a way of providing DR, constitute a large share in system peak demand. This suggests the value in assessing whether energy efficiency/conservation as well as distributed generation (e.g. solar PV) can help with lowering the peak demand. In fact, many system operators in the US and UK have a long history of using energy efficiency and distributed generation as well as DR to meet the capacity needs. However, it may be necessary to consider whether higher efficiency in one end-use could affect the load of others (e.g. high efficiency in lighting may result in lower waste heat and thus lower demand of air conditioning). For the latter, this can affect the total amount of demand that is adequately flexible to provide DR services (e.g. peak demand reduction, network management and fast response for system balancing).

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[21] Examples include the Low Carbon London trial in the UK, and New York's Reforming the Energy Vision (REV) project.

[22] Polluting forms of distributed generation (e.g. fuelled by oil) are to be discouraged for environmental reasons.

Appendix: Definition of end-use categories

Lighting and plug loads	Communal area lighting	
	Corridor and emergency lighting	
	Exterior lighting	
	Basement lighting	
	Lighting and plug loads	
Air conditioning	Cooling and Heating Station	Refrigeration pump
		Cooling pump
		Air conditioning units
		Cooling tower
		Hot water circulating pump
		Furnace
	Terminal air conditioner	All-air air conditioning units
		New air handling units
		Exhaust fan units
		Fan coil units
		Split air conditioner
Motors	Lift	Lift
	Water pump	Water pump
	Fans	Fans
	Other motors	Other motors
Others	Information technology centre	
	Laundry	
	Kitchen and cafeteria	
	Swimming pool and shower room	
	Gym	
	Others	

Natural Resources Defense Council
Taikang Financial Tower, Suite 1706,
No. 38 Dongsanhuan Bei Road, Chaoyang,
Beijing, China 100026
T: +86(10)5927-0688
www.nrdc.org / www.nrdc.cn