Building as a power plant

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The building sector has been reported to be responsible for:

1. 20% of total delivered energy worldwide [1]
2. 31% of global final energy demand [2]
3. 40% of primary energy consumption in International Energy Agency (IEA) member countries [3]

At the same time we have change driven by:
- Decarbonisation
- Digitalisation
- Decentralisation

What if buildings were VPPs?

Virtual Power Plant definition [1]:

- A virtual entity involving multiple stakeholders and comprising decentralized multi-site heterogeneous technologies
- Formed by aggregating distributed energy sources and energy storage systems, including EVs (electric vehicles) and controllable loads.
- It is supported by information and communication technology to form the equivalent of a single VPP
- Power and information should flow among VPP stakeholders in order to minimize generation costs, maximize profits, and enhance participation in DR as well as trade within the electricity market

How can buildings be part of the solution?

What if, on the Science Central site, we tried to operate the Urban Sciences Building in a way that helps the local energy network?
The Urban Sciences Building

- 12,500 square metre (337 zones)
- £58m asset
- Instrumented by:
  - 182 Heat meters
  - 266 Electrical meters
  - 24 Water meters
  - 4 Gas meters

15,800 data streams logged by Urban Observatory
The services

Heat pumps
Swegon Teal range, 25 units at 51.5kW to 112.3kW heating capacity. All reversible (cooling mode) except 3 rooftop units for hot water. CoP 4.4 (heating) and 3.46 (cooling). 1542.2kW Cooling and 1975.7kW heating capacity (of which 166.5kW (8.4%) is for hot water.

<table>
<thead>
<tr>
<th>Level</th>
<th>No. of heat pumps</th>
</tr>
</thead>
<tbody>
<tr>
<td>L00 (ground)</td>
<td>3</td>
</tr>
<tr>
<td>L01</td>
<td>4</td>
</tr>
<tr>
<td>L02</td>
<td>3</td>
</tr>
<tr>
<td>L03</td>
<td>4</td>
</tr>
<tr>
<td>L04</td>
<td>4</td>
</tr>
<tr>
<td>L05</td>
<td>2</td>
</tr>
<tr>
<td>L06</td>
<td>2</td>
</tr>
<tr>
<td>Roof</td>
<td>3</td>
</tr>
<tr>
<td>Total</td>
<td>25</td>
</tr>
</tbody>
</table>
The building interior and exterior
The Urban Observatory data

• https://3d.usb.urbanobservatory.ac.uk/
# Audit of building assets for demand response (DR)

<table>
<thead>
<tr>
<th>Description</th>
<th>No</th>
<th>Maximum turndown ratio</th>
<th>Share of building load (%)</th>
<th>Advance time needed</th>
<th>Maximum DR duration</th>
<th>Occupant-comfort-derived thresholds</th>
</tr>
</thead>
</table>
| 1 Heat pumps           | 25[^1] | 100%                   | 0                          | 4 hour              |                     | [a] $T_{zone}$: Min: 19°C Max: 28°C  
[b] Thermal drifts: 0.5°C per hour of thermal drift per hour found to be imperceptible, with maximum allowable drifts in the 1st, 2nd and 3rd hour as 2.2°C, 2.8°C and 3.3°C. |
| 2 Secondary circulating pumps | 21 HTG 20 CHW | 100%               | 0                          | 4 hour              |                     | None                                |
| 3 Primary circulating pumps | 12 | 100%                   | 5 minutes [^2]             | 4 hour              |                     | None                                |
| 4 AHU                   | 22 | 100%                   | 0                          | 4 hour              | 1000 ppm CO₂ [^3]   |                                     |
| 5 Lighting              |     | Spread over 421 zones | 24% [^4]                  | 0                   | Not limited         | Illuminance level (Lux)             
Office: 400(N) 300 (DR) 100 (HSE) [^5]  
Labs: 400(N) 300 (DR) 200 (HSE)  
Kitchen 400(N) 300 (DR) 50 (HSE)  
Circulation 150(N) 100 (DR) 5 (HSE) |
| 6 Lifts                 | 6[^6] | 100%                   | 0                          |                     | N/A                 |                                     |

[^1]: Of which 3 have DHW duties.  
[^2]: Need to be shut 5 minutes before and 5 minutes after HP are turned on/off  
[^3]: As outlined in section 2.1  
[^4]: As outlined in section 2.2.  
[^5]: N: Normal; DR: Demand response mode; HSE: Health and Safety Executive minimum statutory requirement as outlined in section 2.2  
[^6]: Two lifts out of 6 are discounted for fire, emergency and disabled person access.
**DR: Air Handling Units (AHUs)**

**Typical office (design occupant density: 8m²/person)**

- **Air permeability**: 10m³/(h.m²)@ 50Pa
- **Area**: 449 m²
- **AHU base/boost supply capacity**: 986 l/s (1160 l/s)
- **Max occupant observed**: 25
- **Start (end) of DR**: 11am (3pm)/6pm (00am)
- **Starting CO2 level (ppm)**: 470 ppm
- **CO₂ Threshold reached after**: 3.5hrs
- **Post DR recovery time**: 15 min: 761 ppm, 30 min: 642 ppm, 45 min: 558 ppm

**Worst case scenario (design occupant density: 2.3m²/person)**

- **Air permeability**: 10m³/(h.m²)@ 50Pa
- **Area**: 160 m²
- **AHU base/boost supply capacity**: 1040 l/s (1556 l/s)
- **Max occupant observed**: 56
- **Start (end) of DR**: 11am (11:30pm)/6pm (00am)
- **Starting CO2 level (ppm)**: 594 ppm
- **CO₂ Threshold reached after**: 30 minutes (no window opening), not reached (window opening)
- **Post DR recovery time**: 15 min: 820 ppm, 30 min: 643 ppm, 45 min: 573 ppm
DR: Heat pumps (worst case winter drift)

Footnotes:

Area: 33 m²
No of occupants: 4
Adjacent heated zones: 3 sides
Adjacent unheated zones: 3 sides
Glazing ratio: 33%

Ave: 0.0004K, Max: 1.8K, Min: -1.9K, (Data labels: Median value)
Percentage wintertime (post 1700 hrs) cooling rate exceeding 0.5K per hour: 1.2%
Average temperature drift when exceeding 0.5K: 0.7K
HVAC-enabled thermal recovery rate: greater than 1.23K temperature rise per hour

Positive values indicate falling temperature.
DR: Heat pumps (worst case summer drift)

Ave: 0.0002K, Max: 1.5K, min: -1.4K, (Data labels: Median value)
Percentage summertime (post 1700 hrs) warming rate exceeding 0.5K per hour: 14.5%
Average temperature drift when exceeding 0.5K: 0.72K
HVAC-enabled thermal recovery rate: greater than 1.83K temperature fall per hour

Area: 166 m²
No of seats: 120
Adjacent heated zones: 5 sides
Adjacent unheated zones: 1
DR: total possible response

[a] Deferrable loads (hourly peak > 20 kWh)
Average magnitude of HH deferrable loads during 2018: **109kW**.

- On average deferrable loads form **46.4%** of total building electricity consumption
- Only **0.7%** of the annual aggregate deferrable loads require a 5-minute advanced notice, with **99.3%** of annual deferrable loads available instantly to partake in a DR event.
- A perceptible rise exists in peak summer and pre- and post-Christmas months.
# DR: Power and energy available from VPP

<table>
<thead>
<tr>
<th></th>
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</tr>
</thead>
<tbody>
<tr>
<td>SE (KWh)</td>
<td></td>
<td>SE (KWh)</td>
<td></td>
</tr>
<tr>
<td>min</td>
<td>50 (564 ± 86.4)</td>
<td>28.4 (344.5 ± 13)</td>
<td>28.4 (401 ± 117)</td>
</tr>
<tr>
<td></td>
<td>99.7%</td>
<td>100%</td>
<td>100%</td>
</tr>
<tr>
<td>Mean</td>
<td>141 (640 ± 68)</td>
<td>86.2 (407.2 ± 49.7)</td>
<td>109 (571.2 ± 81.8)</td>
</tr>
<tr>
<td></td>
<td>54.2%</td>
<td>40.40%</td>
<td>41.5</td>
</tr>
<tr>
<td>Q3 [4]</td>
<td>168.4 (684 ± 64.5)</td>
<td>100.2 (445 ± 53)</td>
<td>138 (625.5 ± 17.6)</td>
</tr>
<tr>
<td></td>
<td>27.7%</td>
<td>23%</td>
<td>24.6%</td>
</tr>
</tbody>
</table>

Value of equivalent Li-Ion Battery (no installation cost):
- £473 K
- £751 K
- £844 K

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- For **54.2%** of 2018 annual time USB average office-hour DR capability is **141kW** with (an average of) **640kWh** of stored energy available across the next 4 hrs.
- For **100%** of 2018 cycle USB could be characterised as a VPP with a minimum of **28.4 kW** of initial power with an average of **436kWh** of ensuing stored energy over a 4 hour cycle.

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[1] 08:00–17:00
[2] 17:00–08:00
[3] Percentage of office/non-office/annual time that the stated DR capability can be offered
[4] Upper Quartile (75% percentile) of the data for 2018 deferrable loads
SUMMARY

By virtue of their controllable loads, distributed nature and internal climate inertia, buildings have substantial operational flexibilities that can be exploited to relieve grid constraints and reduce distribution network congestions. Given that well-coordinated DR events have intangible occupant comfort implications, commercial buildings are well-placed to be operated as stationary electrical energy storage assets within a dynamic and interactive energy system.
