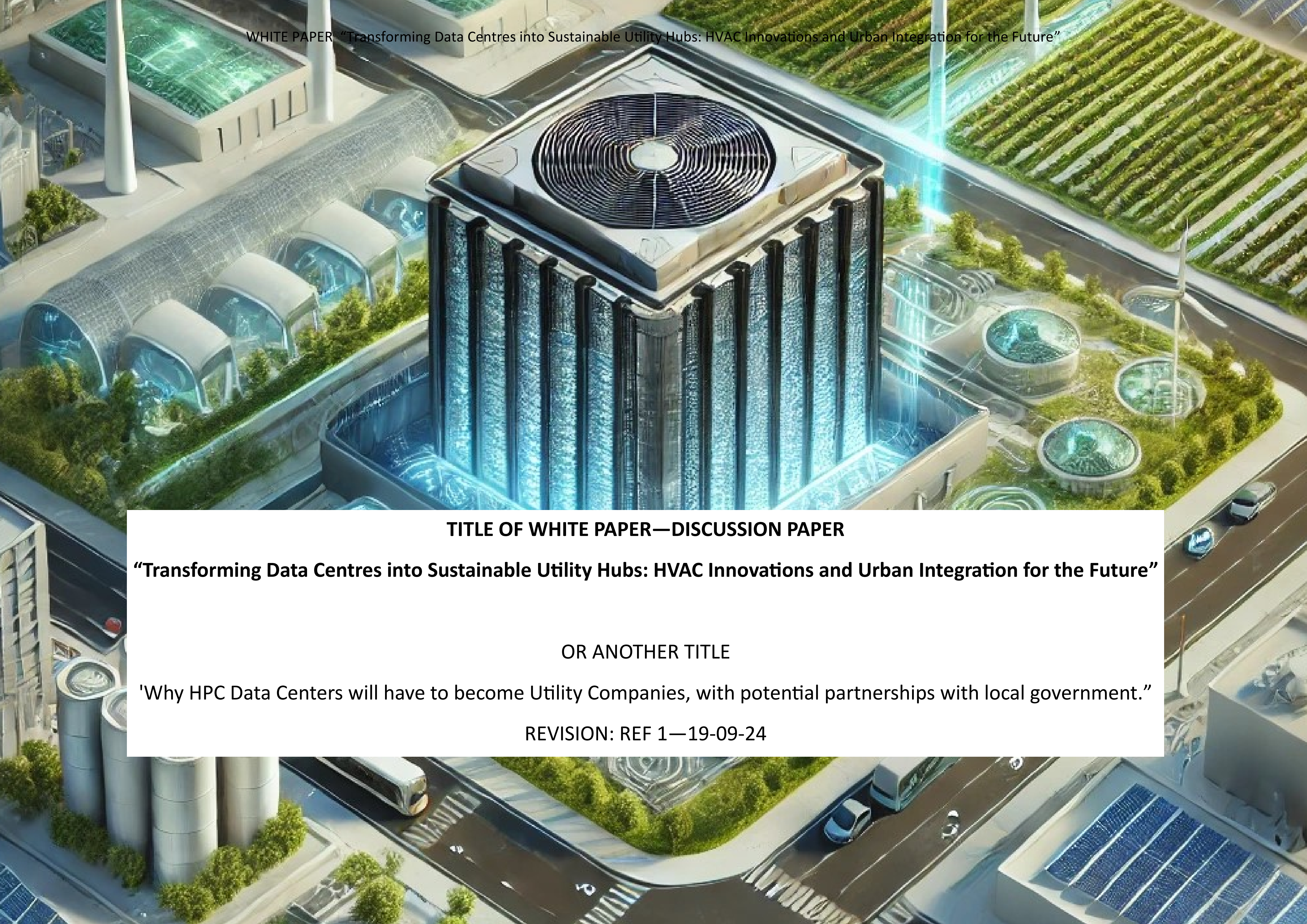


TITLE OF WHITE PAPER—DISCUSSION PAPER

“Transforming Data Centres into Sustainable Utility Hubs: HVAC Innovations and Urban Integration for the Future”

OR ANOTHER TITLE

'Why HPC Data Centers will have to become Utility Companies, with potential partnerships with local government.”

REVISION: REF 1—19-09-24

INTRODUCTION

AI and machine learning are advancing rapidly due to significant investments in technology. The growth of cloud infrastructure, especially among the five major cloud providers, is driving further expansion, as many responsive AI applications operate in the cloud. For example, Phoenix, one of the fastest-growing U.S. hubs for Cloud data centres, is set to increase its cloud capacity by 1.1 GW by 2027, driven by hyperscale providers and favourable conditions such as cheaper land and energy compared to US West Coast markets.

However, as urban centres evolve toward higher productivity, autonomous transportation and robotics, the need for ultra-dense data centres, which enable secure, low-latency AI and machine learning, will become essential. This paper focuses on the development of the 'Data Centre' in how the data centre Facility Services have driven energy consumption, through to the future of high-performance computing (HPC) data centres. Whilst discussing existing HVAC methodologies and potential alternative models, examples have been used based on a 210 MW DC installation planned to be built in London.

As society progresses, the demand for increased productivity through AI and machine learning will necessitate upgrading legacy data centres, especially those reliant on air-based cooling systems. The evolution of HVAC design, in response to rising rack densities—reaching up to 60 kWh per rack or more—requires new strategies to meet the challenges posed by modern ultra-dense facilities.

Energy consumption in these data centres presents both engineering challenges and exciting opportunities. This paper explores how these centres could serve as hubs of utility services for urban communities, while also meeting sustainability goals, such as reducing emissions and efficiently utilizing renewable energy.

Finally, this paper presents technical insights and alternative solutions for transforming data centres into sustainable urban utility hubs, offering guidance for policy makers, engineers, and developers as they plan for the growth of ultra-dense data centres that support modern society without compromising the planet's sustainability.

Graphics have been introduced throughout the discussion paper to simplify the understanding of the technical discussion.

Thank you for taking the time in reading this White Paper, and please share any thoughts or questions you may have

AUTHOR—Neil Turley

contact@neilturley.info
neilturley@netgreensolar.com
neilturley@netgreen.eu

CONTENTS OF WHITE PAPER

SECTION 1 - DATA CENTRES

Decades ago Data Centres used to fall just into two major categories: In-house corporate data centres (CDCs) and Internet data 'Server' centres (IDCs). Both categories of Data Centres were designed using the principles of Legacy Critical HVAC services, that ensured a range of control over the sensible/latent temperatures inside the IT equipment rooms (such as SERs), with different levels of resilience (duplication) of power supplies and certain HVAC systems design, such as heat rejection. Temperature and Humidity within the Data Centres were kept at an optimum condition, with a minimum variation to ensure the IT Server electronic components did not expand or contract, or generate static or condensation.

The Critical Load was made up from: Servers, Routers, Storage Devices, Telecom Equipment, Security and Fire Systems & Monitoring Systems.

The estimation of the HVAC energy usage involved a Rule of Thumb based on a Power Usage Percentage Breakdown of: 36% - Critical Loads, 50% - Cooling/Heat Removal, 11% - UPS Inefficiencies, 3% - Lighting.

IDCs became more powerful over the last two decades as more Internet based applications that have evolved. The power infrastructure designed to provide sufficient redundancy, importance to secure multiple sources of power.

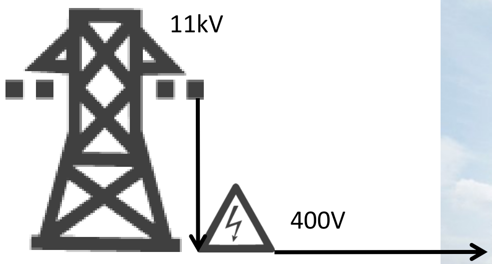
All the typical datacentre Models used some type of Server Rack air-cooling, which accounted for an average of 40% of the datacentre's electricity supply capacity. With the traditional-density, legacy data centres tended to be in the region 1 to 5kW per rack (IT equipment cabinet).

Whatever the Rack air-cooling configeration and supporting HVAC Plant used, the basic principal aim has been to ensure 'without fail' the removal of this IT generated heat to the exterior 24/7, with a minimal of shutdown periods, sometimes with one of more levels of resilience of HVAC Plant and Power Supplies, to minimise risk of cooling system failure.

Levels of Resilience of a Data Centre were defined by:
Tier 1: a single path for power and cooling (the lowest level of resilience).
Tier 2: some level of redundancy, with at least one backup power and cooling source.
Tier 3: multiple sources of power and cooling and designed to allow maintenance or upgrades without disrupting service.
Tier 4: the highest level of redundancy, with multiple sources of power and cooling that are fully fault tolerant.

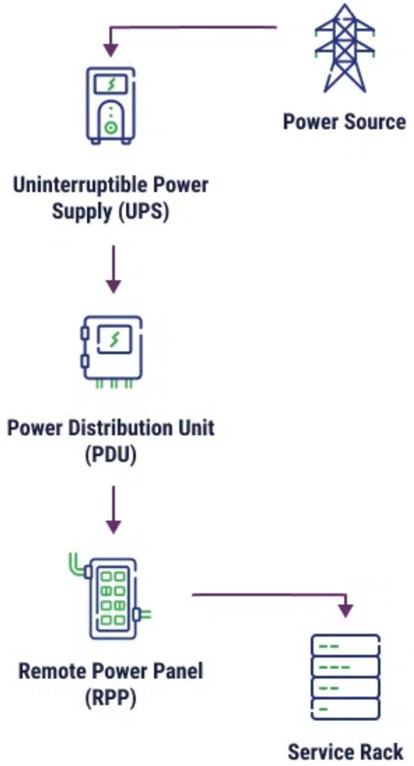
Tier 4 data centres must achieve the following:
2N+1 redundancy. Tier 4 data centres are fully redundant with double the amount of distribution paths needed plus a backup.
96-hour outage protection. Four days of independent power that is not connected to any outside source is required.
No more than 0.5 hours of downtime per year. 26.3 minutes is the maximum amount of downtime allowed in a given year.
99.995% uptime. This is the highest uptime guarantee.
No single points of failure. Since every process is fully redundant, no single outage will shut the entire system down.
All IT equipment follows a fault-tolerant power design. When a piece of equipment fails or there is an interruption, IT operations are not impacted.
Continuous cooling to maintain safe operating environment. The environment is maintained at an ideal temperature to increase efficiency and extend the useful life of hardware.

SECTION 1 - DATA CENTRES (continued)



400V

UP TO 96 HOUR POWER RESILIENCE



Uninterruptible power supply (UPS). These devices offer battery backup to cover the time between the detection of utility issues and a generator starting. (Example Vertiv)

EXAMPLE CONTAINERISED GENERATORS

Using an online uninterruptible power supply (UPS) and a backup power generator provided a good strategy for obtaining an uninterruptible source of power. Also online UPS filters, to condition and regulate the power supply to the IT Equipment, which protected the systems from fluctuating voltages, surges and spikes, as well as noise that may be on the power line. The battery backup for the UPS should be capable of maintaining the critical load of the data centre for a minimum of 15 minutes of autonomy during a power failure. This is typically sufficient time to transfer power to an alternate Utility feed or to the power generator.

SECTION 2 - COLOCATION DATA CENTRES

As the usage of on-line IT software and Internet Application software outgrew the capacity of the corporate in-house server Data Centre – whether in terms of available Resource budgets, space, power, cooling requirements and the necessity of ensuring an 99.9% uptime 24/365, and alternative expansion Data Centre Capacity options became available.

Expansion Capacity Models such as Cloud Services or Colocation Data Centres (that rents out remote 'rack space' without the need to maintain the data centre Critical Services), which provided lower corporate running costs and improved operating flexibility.

The costs to construct, maintain and provide service resilience Capacity for a +2 Tier Data Centre requires a large investment.

The minimal service resilient characteristics will need to include for:

- Dual power feeds from separate power grids or power substations to ensure that power is available even if one feed fails.
- Backup generators to provide power in the event of a power outage.
- A Uninterruptible Power Supply (UPS) system to provide immediate backup power in the event of a power outage, allowing critical systems to remain operational until backup generators can be activated.
- Redundant cooling systems such as backup air conditioning units or chillers, to ensure that the temperature remains within acceptable limits in the event of a cooling system failure.
- Hot aisle/cold aisle design to optimise airflow and cooling efficiency. This design separates hot and cold airflows and directs cool air to the front of the racks where the servers draw in air.
- Environmental monitoring to detect and alert staff to potential cooling or power issues.

Therefore a Model of providing a colocation data centre, is any large data centre facility that rents out rack space to third parties for their servers or other network equipment.

This has become a very popular service that is used by businesses that may not have the resources needed to maintain their own data centre, but still want to use the High reliability of Data Centre Facility Services such as Power and Cooling, with the option of Expandability of the Rack Services when needed and Costs directly related to bandwidth consumed.

Therefore provided a concept that a company could have their equipment located in multiple places. They may have servers, for example, in three or four different colocation data centres. This is important for companies that have large geographic footprints, and they want to make sure their computer systems are located near their physical offices/clients.

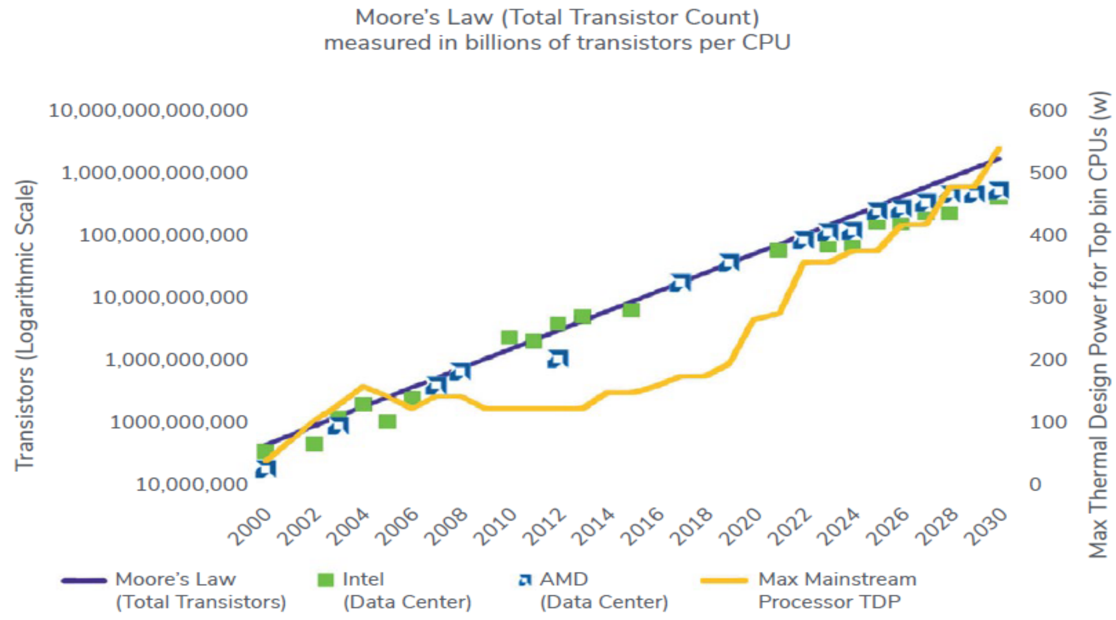
SECTION 3 - CHANGES DUE TO THE INCREASE OF RACK DENSITY WITHIN DATA CENTRES

Chip performance have risen in all three decades since the 1990's (that’s Moore’s Law) but the impact on power consumption has varied. Since about 2018, the number of transistors on a substrate and therefore the computations that can be done continued to double, but computations per watt did not.

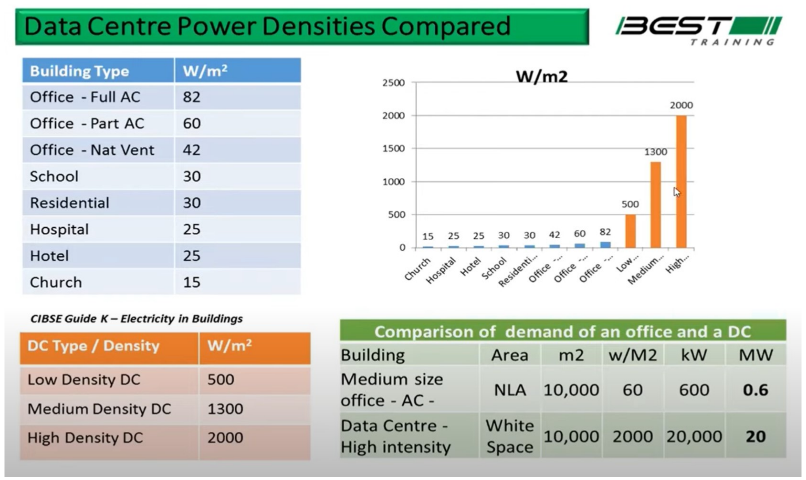
The adjacent Graph does not take into consideration the effect of the maximum power consumption of NVIDIA’s latest GPU which is 160% higher than that of the company’s previous generation chips.

Gone are the days where increased performance came without increasing power demand. Now, more computation requires more watts.

These power wars are driven by the increasingly widespread adoption of power-intensive workloads, which is driven by exponentially rising demand for more data, real-time data consumption, and real-time analytics—particularly as organisations and every day Users embrace Artificial Intelligence (AI) and Machine Learning (ML) for an increasingly wide range of applications.



Source: Omdia research commissioned by Stream Data Centers



To provide some idea of the density of energy required by Data Centres, it is best to make a comparison of Electrical Power Consumption of other Building Types, based on floor area.

Again this graphical illustration was generated before Artificial Intelligence (AI) and Machine Learning (ML) was considered.

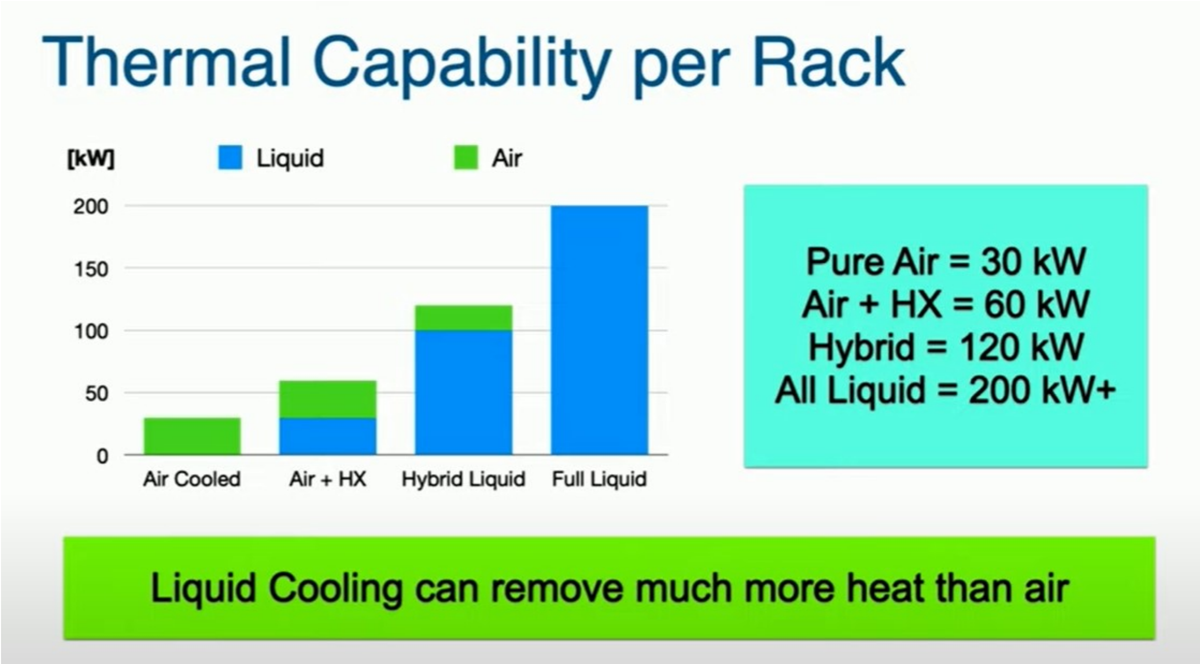
SECTION 3 - CHANGES DUE TO THE INCREASE OF RACK DENSITY WITHIN DATA CENTRES (continued)

While AI has been around in one form or another for quite some time, OpenAI LLC's ChatGPT and other generative AI services sparked a new interest in the technology, which seems to be fuelling a new era for growth along the entire supporting infrastructure chain. From a datacentre infrastructure perspective, the industry is seeing new and interesting growth in some markets. It is worth pointing out that the current growth wave in the US started in 2021, nearly a year before anyone had heard of ChatGPT and the AI rush. Building on the back of the increased demand brought on by COVID, cloud service providers have already started ramping up deployments. Taking into account all the investments in the latest CPUs and (mostly) graphics processing units (GPUs) by cloud service providers, it would seem we can expect further changes for the datacentre industry.

A recent Survey (Ref. 2) found that average rack densities in 2023 were less than 6kW per rack, this is expected to grow in conjunction with the increased use of AI, ML, and HPC solutions. The typical Colocation high-density data centre has gradually increased to a present average of 10 kW per rack, with different configurations of Rack air-cooling being applied.

Racks come in various densities, ranging from standard to ultra high-density, each with distinct averages for power consumption:

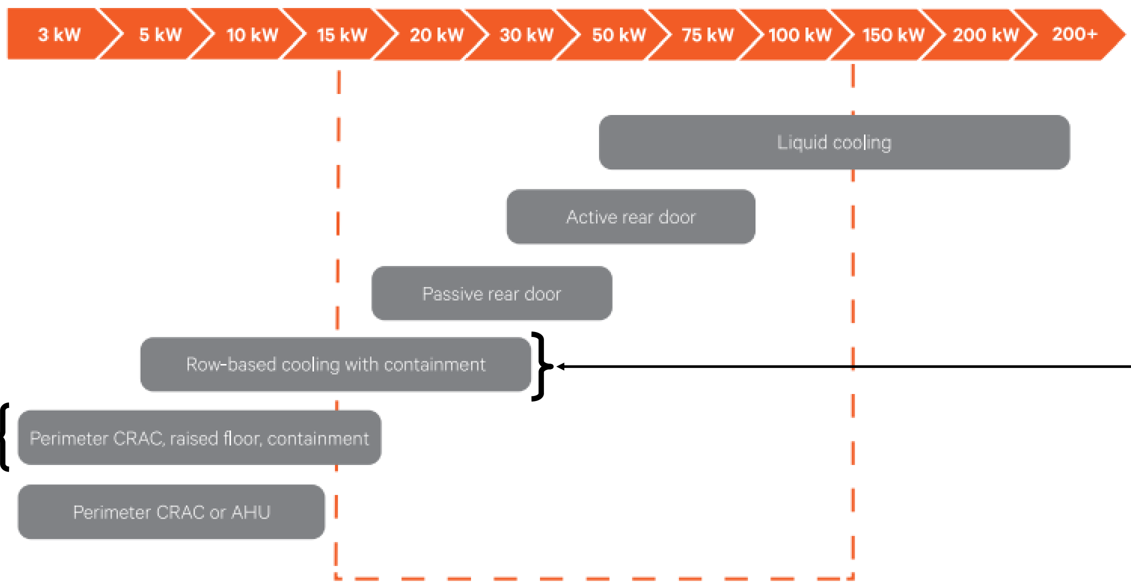
Standard density racks can consume up to 10kW of power per cabinet.
High-density racks have cabinets that can consume 10kW to 30kW of power.
Ultra high-density racks can consume anywhere from 30kW to 85kW of power per cabinet.



SECTION 4 - THE CHANGES IN METHODOLOGIES OF HEAT REJECTION FROM THE DATA HALL

In a typical air-cooling Data Centre the Heat Rejection HVAC would account for roughly 40% of an average Data Centre's electricity use. Air-cooling solutions such as in-row or overhead cooling units were used, that could precisely target and remove heat generated by high-density servers. These systems offered greater control and efficiency compared to traditional perimeter cooling methods used for lower heat rejection temperatures, when the previous standard working temperature of a Data Centre white space was approximately 24 degrees Celsius.

At present, it isn't unusual to have Data Centre's running between 24 and 25 C in front of the servers, with return air to the indoor cooling units at 36 to 37 C. (Ref 3.). As the Data Hall interior temperature have risen, particularly in hyperscale IT Installations, there has been a gradual shift from traditional air-based cooling methods to liquid cooling and rear-door heat exchangers.



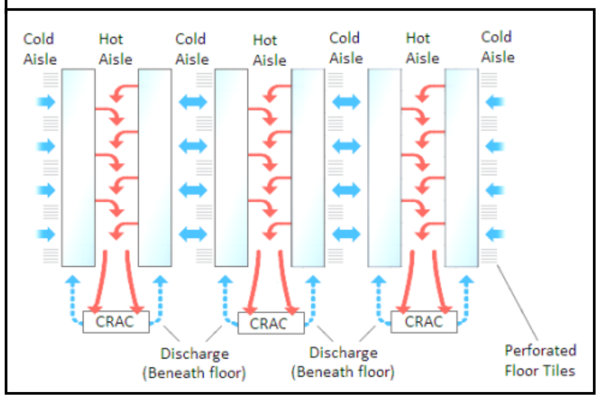
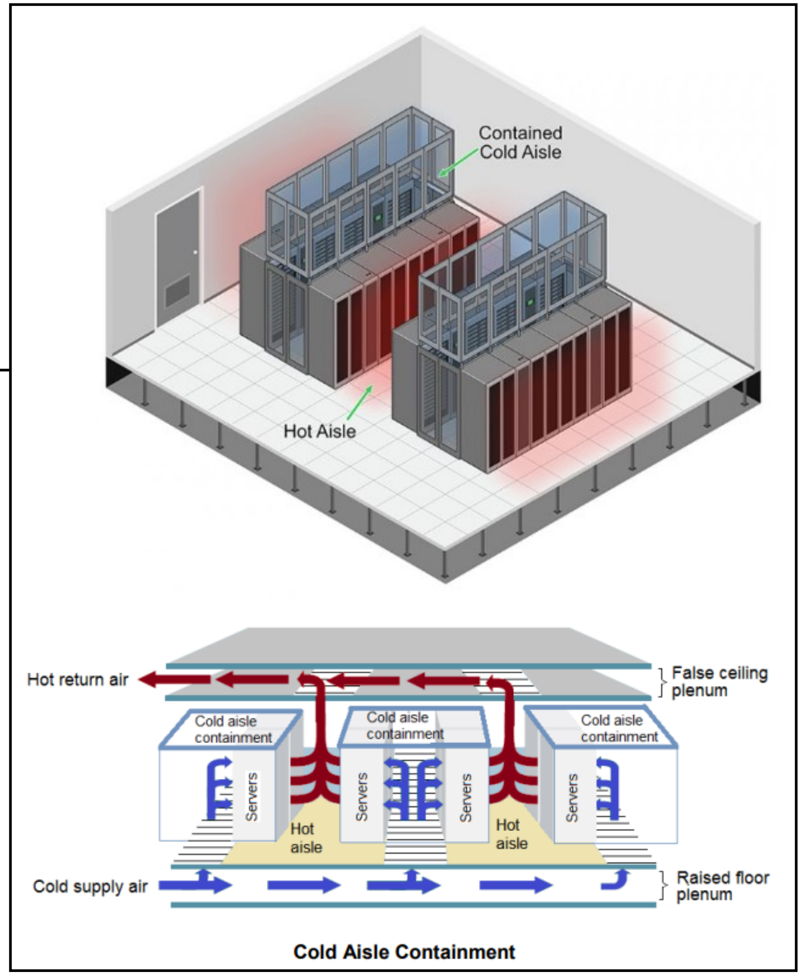


Figure 1. Air-based cooling systems lose their effectiveness when rack densities exceed 20 kW, at which point liquid cooling becomes the viable approach



SECTION 4 - THE CHANGES IN METHODOLOGIES OF HEAT REJECTION FROM THE DATA HALL (continued)

Initially Data Centre developers and HVAC Designers believed racks/cabinets approaching 20 to 30kW load were at the ceiling of air-cooling capability for maintaining component temperatures within industry specifications. Air cooling systems have continually evolved to address higher densities with greater efficiency, with some air-cooled server products achieving rack/cabinet heat loads upwards of 40 to 50kW thanks to advances in air moving technology within the server and Data Centre.
But there is a point at which air simply does not have the thermal transfer properties required to provide sufficient cooling to high-density racks in an efficient manner. This can reduce the performance and reliability of specialized servers and becomes less energy efficient as rack power increases. As more high-power racks are deployed, air cooling becomes untenable from an economic and sustainability perspective. The ability to move additional airflow and enabling higher rack heat loads is not without cost, as it has been shown that increasing air cooling density not only increases the amount of power used to move that air, but also reduces cooling efficiency.

Heat Rejection is one of the biggest challenges that high-density Data Centres have had to contend with. Using systems like liquid cooling or liquid-air hybrid cooling technology can lower operating temperatures and keep system performance high. Water has a specific heat capacity that is 4 times greater than air; in other words, water can 'absorb' about 4 times as much heat as air can, for a given unit mass. Case studies have shown that liquid cooling offers significant power reductions, as high as 90%, while improving capability and allowing more densely packed systems that, in turn, increase rack power usage.

In the case of air-cooled IT equipment operating at the upper limit of the ASHRAE recommended range of 27°C, and maximum recommended dew point of 15°C with a rack ΔT of 15°C, moderate work requires a 30 minute break every hour and a prescribed minimum amount of water intake to avoid heat stress. Liquid cooling to the rack can result in a more human friendly data hall environment, with less noise and movements of surrounding air, resulting in happier Data Centre staff.

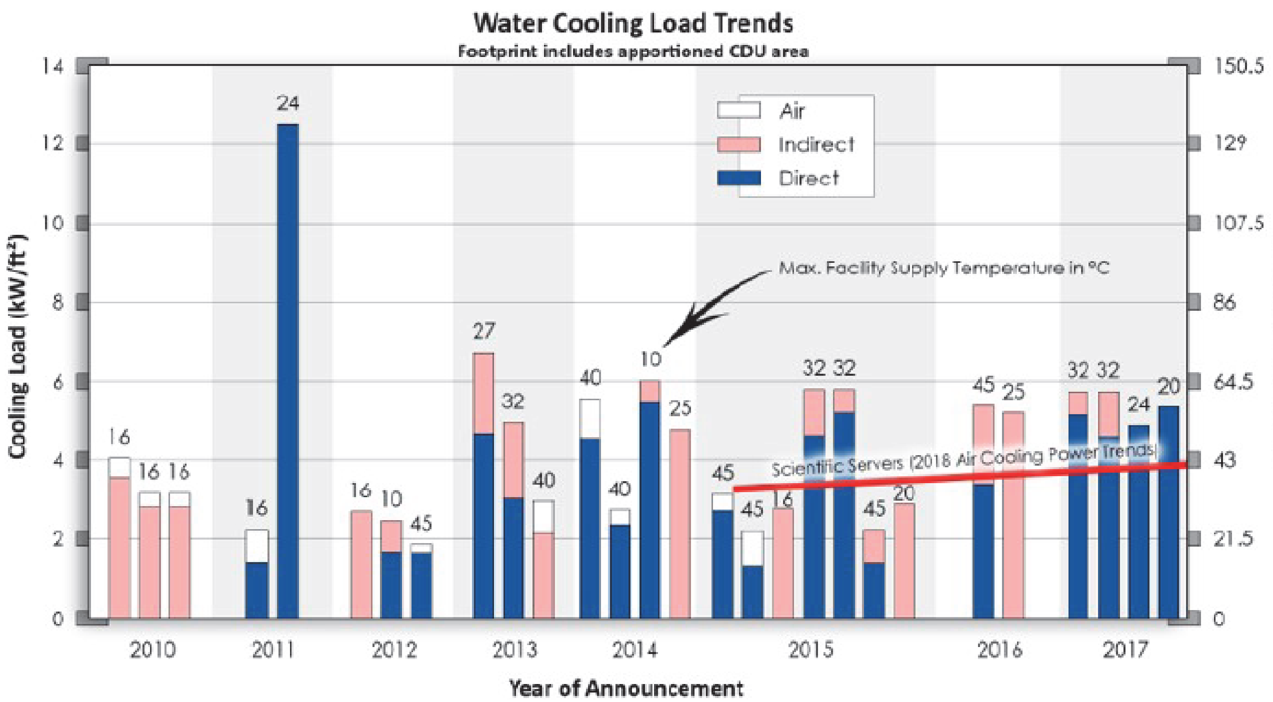


Figure 1 Water cooling load trends from 2010 to 2017. - Ref: White Paper Developed by ASHRA E technical Committee 9.9 (Ref. 4)

The Graph illustrates the historical changes of water cooling trends, from IT Equipment Venders that provide water cooling Solutions (data from 28 water-cooled products), relating to the maximum facility supply Temperatures. Information from the Vendors also indicated that some of the water-cooled products were equal to or slightly lower power than the air-cooled products.

- Air cooled —power that is transferred directly to the room air and cooled via traditional data centre cooling
- Indirect water-cooled —power that is transferred indirectly to water through an air-to-water heat exchanger located within or on the rack (could be a rear door heat exchanger)
- Direct water-cooled —power that is transferred directly to an attached heat transfer component such as a cold plate

SECTION 4 - THE CHANGES IN METHODOLOGIES OF HEAT REJECTION FROM THE DATA HALL (continued)

Server makers like Dell and HP are producing liquid-cooled versions of their hardware, and are predicting that in 10 years' time Data Centres will be 50 percent liquid-cooled. Not every application has such high demands for cooling, and this means that half the servers can still be air-cooled.

A key factor in maximising the heat rejection system (with chilled water) efficiency is minimising the heat rejection unit approach temperature i.e. the difference between

ASHRAE water cooling classes (W17-17°C to W+>45°C) of the maximum facility water temperatures indicate that the supply/return CHW water temperatures will be increasing to levels above viable removal by air movement through the Data Halls.

The continuation of the general Trend in Data Centre Cooling from the time of the data to the present time indicates;

Increased Cooling Loads:

- The cooling loads in Data Centres have been increasing due to higher server densities and the growth of high-performance computing (HPC) workloads.
- This has led to greater demand for efficient cooling solutions, particularly those capable of handling high thermal loads.

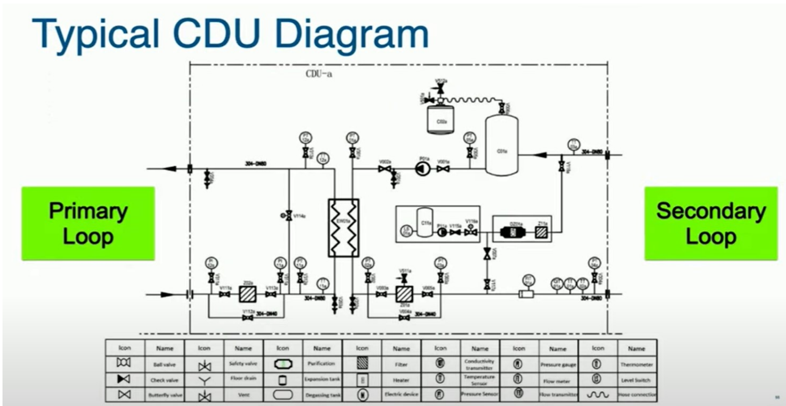
Maximum Facility Temperature:

- Data Centres have been pushing the boundaries of maximum allowable temperatures to reduce cooling costs and energy consumption.
- ASHRAE (American Society of Heating, Refrigerating and Air-Conditioning Engineers) guidelines suggest that modern Data Centres can operate efficiently at higher temperatures than before, up to around 27°C under certain conditions.

Cooling Strategies:

- Air-Cooled Solutions: Still widely used, especially in traditional Data centres. However, these solutions are less efficient for high-density racks.
- Indirect Water Cooling: More common in facilities looking to balance efficiency and cost. It uses a heat exchanger to transfer heat from the Data Centre to an external cooling source.
- Direct Liquid Cooling: Gaining popularity, particularly for HPC and Edge Data centres. Direct cooling, where coolant is delivered directly to the heat sources (e.g., servers), is considered more efficient, especially for high-density environments.

The most common systems installed in data centres use Chilled Water (CHW) as the medium between the internal and external units. Chilled water systems offer significant flexibility in Data Hall Configeration removing heat using Coolant Distribution units (CDUs) connected to the Heat Rejection Plant on the Primary Loop to multiple options of Heat Rejection methodologies, such as dry cooling, dry cooling with partial evaporative assist, and full direct adiabatic cooling.



SECTION 5 - ULTRA DENSITY HIGH PERFORMANCE COMPUTING (HPC) DATA CENTRES

What is “big” in big data as it continues to expand. It is estimated that by 2025, we will globally create 180 zettabytes of data, tripled from 64.2 zettabytes in 2020. To put that in perspective, one zettabyte is 1 trillion gigabytes, or 1 billion terabytes. (Ref. 5)

With the power consumption of CPU and GPU increases of Power and speed of processing, requiring the chip substrate to be manufactured from diamond rather than copper, will combine to generate a considerable amount of heat in a relatively small area. With more and more processing power being packed into servers supporting artificial intelligence and other processor-intensive applications, rack power requirements are exceeding 20 kilowatts (kW) in a growing number of facilities, and many organizations are now looking to deploy racks with requirements of 50 kW or more.

NVIDIA Corp. noted in its second-quarter 2023 earnings call that Data Centre compute revenue had almost tripled year over year, and this was primarily being driven by an accelerating demand from the cloud service providers and internet content companies. Also NVIDIA CEO Jensen Huang's comments during his keynote speech at SIGGRAPH 2023, indicated to him that it seemed a foregone conclusion to him that AI workloads would ultimately live in the cloud. So at present…. AI is being mainly applied in US based Cloud based HPC Data Centres.

High-performance computing (HPC) is quickly evolving. What used to be reserved for highly technical companies is now being more widely used by the average consumer, thanks to artificial intelligence (AI) applications and large language models. This sudden burst in popularity is also significantly impacting the strain on Data Centres, making high-density facilities more important.

The processing power inherent in an HPC system makes it suitable to a variety of industries and institutions, whether governments, financial services, natural resources, manufacturing, or media and entertainment. Engineers, for example, can use HPC to verify structural designs, test prototypes or perform simulations. When you add in future technologies such as autonomous Transport systems and improved Productivity such as AI, with their requirements of low Latency, these HPC Resources will be located in the vicinity of the Urbanisations served.

An HPC data centre doesn't come cheap. An organisation must acquire and manage the hardware, but also have the facilities to house the equipment. To reign in Facility costs, some organisations are turning to colocation Data Centres that provide leasable space for housing IT equipment, which can lower costs and reduce operational overhead. Providers did note that the hyperscale cloud providers were wanting to chart out a plan to accommodate over 50 kW per rack in future Data Centres; likely within the next five years. In response, these same providers are currently working with liquid and other cooling technologies in order to best accommodate these requests.

Many colocation Data Centres can now accommodate HPC systems, support denser rack spaces and offer more power per rack, up to 50 kW in some cases. They also provide ventilation and cooling systems to support the high-density equipment, along with security and power backups. Though future planning will be required for ultra high -density that can average around 85kW.

Extensive development work has already been conducted across Data Centre equipment and infrastructure suppliers to support liquid cooling, and multiple solutions are available today to cool servers through rear door heat exchangers, conductive cold plates, and immersion. Modifications will require the elimination of air-cooled heat sinks replaced by cold plates mounted to processors and the possible elimination of some and possibly all server fans. Approximately 90% of the Rack Heat can be removed via the direct Heat Exchanger, to the water heat rejection circuit. The residual 10% of heat will require to be removed using air-cooling.

SECTION 5 - ULTRA DENSITY HIGH PERFORMANCE COMPUTING (HPC) DATA CENTRES (Continued)

HPC Data Centres will require Variable Design features, such as variable flowrate primary chilled water loops, coupled to a configurable mix of fan coil walls and/or CDUs that are piped to a technology cooling system to support any mix of air cooled and liquid cooled IT in the same environment. These features should ‘future proof’ the data centre, ensuring its usability for many years to come even as the requirements of the customers whose workloads run on the IT equipment inside the data centre varies, therefore extending the useful life of data centre MEP infrastructure,

With hundreds of Megawatts of heat to be rejected, when large number of Chillers are placed on the roof of the building, and this means they are packed together tighter, causing a “heat island” problem. If indirect Adiabatic Coolers are used then at high ambient Temperature conditions the Data Centre locality may be affected by generating local tropical weather conditions…..

As Facility working temperatures increase, using water as the cooling medium will allow the delta T (difference between Flow and Return temperatures) to increase therefore reducing the costly upgrade of the cooling water pipework infrastructure, of an existing Data Centre. The higher the return water temperature the more efficient and opportunity for productive use of waste heat.

At this time, supply conditions to the external Heat Rejection HVAC Plant is usually between 27°C and 35°C with a ΔT of 10°C are most common. Raising facility water temperatures means our chillers don’t have to work as hard and we can economize (use just the outdoor ambient lower temperature difference to reject heat) many more hours of the year for a given location.

An example of higher the facility water temperatures being suitable for Heat Recovery and Reuse of the Rejected Heat Energy for other purposes (as illustrated in Section 11).

SECTION 6 - SO HOW MUCH ENERGY WILL A HPC DATA CENTRE USE - USING A 100 MW MODEL?

Using a Model of a 100 MW Data Centre which is on the low side of the Electrical Consumption, when compared to the potential of future AI/Machine learning HPC Data Centres. This Model has been used to enable the possibility of comparing different HVAC strategies available for a Chilled Water (CHW) methodology of providing Cooling, as illustrated in the following Section.

DATA CENTRE PHYSICAL ASSUMPTIONS

BUILDING USAGE Space Proportion **2.92 kW/m2**

GROSS INTERNAL AREA	34,290	m2	NET TECHNICAL AREA	18,000	m2	DATA HALL AREAS EAC	1,500	m2 (EXCLUDES FALLOW SPACE 300m

BUILD FLOOR AREA USAGE - 16,290m2 SERVICES & ADMIN AREAS + 19,000m2 IT AREAS - 0.86:1 RATIO OF USAGE A (Therefore Grey Zones approx. 52% of Gross);

2	BLOCKS	8,250	m2 of Data Halls per Block	16,500	m2 of Data Halls for both Blocks
6	IT DATA HALLS per BLOCK	1,500	m2 Area each Data Hall - 57 x 26n	1,375	m2 per IT equiped Data Hall
448	Racks per Hall	2,688	Racks per Block	5,376	Racks for both Blocks
3.07	m2 - Area per Rack				

IT RACK LOADS - and related Facility HVAC Services

6.07	kW/m2 - IT Load Density	2,300	mm - Rack Height	Using 3.34 m2/ Rack (36 sq.ft/ Rack)
18.62	kW - IT Load per Rack			
8,340	kW - IT Load per Data Hall	50,040	kW - IT Load (Data Hall) per Block	

ESTIMATED LOADS

The energy consumption for HVAC (Heating, Ventilation, and Air Conditioning) in a data centre is a significant portion of the total power usage. For a 100 MW HPC AI data centre certain assumptions can be made to estimate Electrical Loads and Profiles.

1. Power Usage Effectiveness (PUE):
  - PUE is a common metric used to measure the efficiency of a data centre. It is the ratio of the total facility energy to the energy used by the IT equipment.
  - PUE = Total Facility Energy / IT Equipment Energy - Modern, efficient data centres often achieve a PUE between 1.1 and 1.3.
2. Calculation of HVAC Energy Use, using a median value for PUE:
  - If a data centre has a PUE of 1.2, then 20% of the total energy is used for non-IT functions like HVAC - Heat Removal Systems and other non-IT systems (Lighting, Power Distribution, UPS & misc. equipment)
  - For a 100 MW data centre, the energy used for IT equipment is: IT Equipment Energy used = 100 MW / 1.2 = 83.33 MW
  Therefore the remaining energy used for HVAC - Heat Removal Systems and other non-IT systems is = 100 MW - 83.33 MW = 16.67 MW
3. HVAC-Specific Consumption:
  - Typically, HVAC can account for 60-80% of the non-IT energy usage, depending on climate, data centre design, and cooling technology. Assuming a median value of 70% of the non-IT energy allocated to HVAC = 0.7 x 16.67 MW = approx. 11.67 MW

Summary: - For a 100 MW AI data centre, with a PUE of around 1.2, the HVAC system might consume approximately 11.67 MW of power. This is a general estimate, as actual consumption can vary based on factors like climate, data centre design, cooling technologies used and operational practices. The maximum Electrical Load design for Power Equipment & Resilience calculations would be 117 MW, whilst a margin of a 10% Electrical Load would be estimated during a 24 hour period Profile.

SECTION 6 - SO HOW MUCH ENERGY WILL A HPC DATA CENTRE USE - USING A 100 MW MODEL? (continued)

ELECTRICAL CONSUMPTION LOAD PROFILES

An electrical daily load profile graph for an HPC AI data centre typically shows how power consumption fluctuates over a 24-hour period. The profile can vary depending on factors such as the workload, data centre design, cooling requirements, and the time of day. The Key Features of the Load Profile:

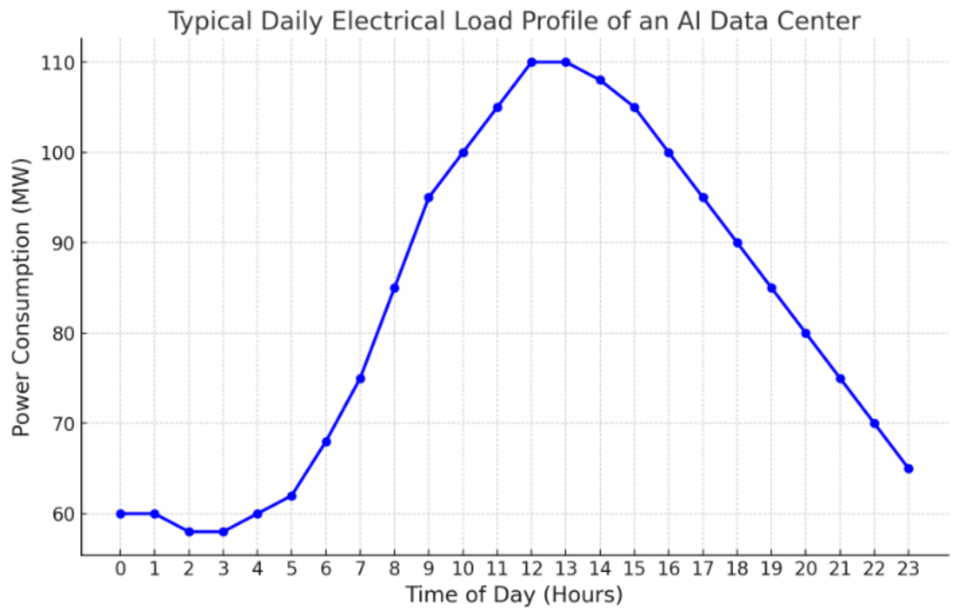
Base Load:
The base load is the minimum power consumption level that the data centre maintains, even during low activity periods. This includes essential services such as cooling, lighting, and servers running background tasks.
Peak Load:
Peak load occurs during periods of high computational demand, often coinciding with peak business hours when AI models are heavily used for training or inference tasks.

Nighttime Load:
During nighttime, the load may slightly decrease due to reduced human activity and possibly fewer jobs being processed, but AI workloads can still be significant, especially if global operations are involved.

HVAC Influence: The HVAC system's load can fluctuate depending on external temperatures and the heat generated by servers. During the hottest parts of the day, cooling demands can increase, adding to the overall load.

Example Load Profile (Hypothetical):

00:00 - 06:00 AM: Moderate load as AI jobs continue processing, but slightly reduced from peak hours.
06:00 - 09:00 AM: Increase in load as employees begin work and new tasks are queued.
09:00 AM - 06:00 PM: Peak load during business hours with maximum power consumption due to heavy AI workloads, cooling demands, and operational activities.
06:00 - 10:00 PM: Gradual decline as operations slow down, but still maintaining a high base load.
10:00 PM - 00:00 AM: Stabilization at a slightly lower load compared to peak periods.



GRAPHIC - DC 24 HOUR ELECTRICAL PROFILE - FIGURE 2

SECTION 7 - THE TYPICAL HVAC HEAT REJECTION DESIGN MODEL FOR A 100 MW DATA CENTRE - USING DIFFERENT COOLING HVAC STRATEGIES

As discussed in the previous sections the Rack Density of 20 kWh would be the limit of using an air methodology of cooling the IT Equipment within the Data Halls, due to potential high Static pressures, noise and inefficiencies when compared to a liquid cooling methodology, using a Chilled Water (CHW) Infrastructure. Therefore we will assume that CHW will be used to reject heat via external HVAC Plant, where the increases in heat rejection efficiencies have improved.

Improvements of Data centres operating within ASHRAE A1 Allowance temperature and located in colder/dryer climates, such as direct evaporative coolers (DEC) provide a highly efficient solution, however, they utilise a larger footprint on the site. These systems can potentially operate in free cooling mode year-round, leveraging both dry and adiabatic cooling based on external conditions. This can translate to low reliance on mechanical cooling and potentially exceptional PUE values. Compared to free cooling, mechanical heat rejection requires substantial electrical input, which ultimately contributes to more heat being rejected. This can further increase water consumption if the heat rejection plant utilises adiabatic cooling

Adiabatic cooling has the advantage of using a high level of latent heat rejection by changing the physical state of the cooling water to a water vapour. The down-side of this high efficient process of cooling is the high consumption of water when the data centre overall energy consumption increases. As Colocation high-density data centre have been increasing in Rack load (Cooling) Density, there has been the necessity to apply direct and in-direct adiabatic water cooling to aid the removal of the heat from the Data Centre interior to the Ambient.

Adiabatic Cooling will result in a reduction of the PUE ratio by transferring some of the heat rejection load to use the physical energy phase change of water from liquid to vapour, therefore leading to the evaporation of water to the ambient. Therefore there will be a requirement to measure the Water Consumption efficiency (WUE), another ratio between the use of water in Data Centre systems (water loops, adiabatic towers, humidification, etc.) and the energy consumption of the IT equipment. The lower a Data Centre's WUE ratio is, the more efficient it's use of water resources is. The average Data Centre has a WUE of 1.8L per 1kWh, at peak IT Loads.

DIFFERENT OPTIONS OF COOLING STRATEGIES TO INCREASE ELECTRICAL ENERGY EFFICIENCY AND REDUCE PUE (AND USE OF WUE)

Vertiv published in an interesting White Paper (Ref. 6), the analysis of several optimisations of Heat Rejection strategies for chilled water systems to demonstrate the impact on the PUE and WUE (also further analysis in the comparison of different locations, of the identical Data Centre). Using the data results for the IT load of 15 MW Data Centre Model, and using data from a DC located in London, has enabled this white paper to further demonstrate different CHW conditions and external Plant performance, by using the analysis proportionally to a large sized HPC Data Centre.

On the assumption of the location of a 100 MW Model DC being in London UK, it is possible to compare the HVAC Peak Loads using different liquid (CHW) cooling methodologies, which also illustrates a similar 24 hour Load Profile as Figure 2. (on the previous page). The Annual 24 hour Load Profile graphs (on the next page) give a good indication of what options are available for Cooling Strategies using the medium of CHW, and the changes to the PUE ration of the Electrical Power efficiency of the Data Centre Model.

The following Analysis Calculations have been used to clarify the performance of the different Scenarios, in the comparison of how a Heat Rejection Load Profile is achieved, using different Cooling Strategies. NOTE: All values of Energy MW defined below in the five DC Heat Rejection Scenarios concern Electrical Input Energy, not Heat Energy valuations. Load Calculation assumptions are continued from the previous Section 6.

SECTION 7 - THE TYPICAL HVAC HEAT REJECTION DESIGN MODEL FOR A 100 MW DATA CENTRE - USING DIFFERENT COOLING HVAC STRATEGIES (continued)

DEFINITIONS USED FOR ANALYSIS

Number of Hours for one Year, as used in the Profile Graphs for different Scenarios: 8,760 hours

IT Peak Loads: defined as the energy required by servers, storage systems, network equipment, and other hardware that performs computing and data processing. Note these Loads stay constant when comparing the different Scenarios.

Peak HVAC Cooling Loads: defined as the energy required for Heat Rejection from IT Equipment and the general Data Hall environment. Note: This variable has different values when comparing the different Scenarios, as the Primary CHW external plant and CHW working conditions are variables.

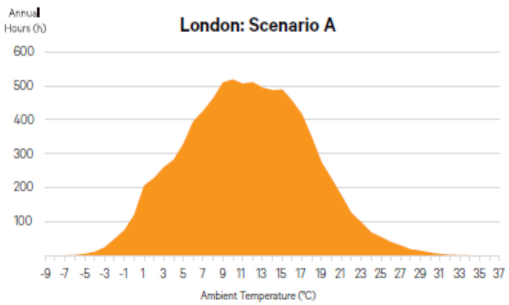


Figure 3. Traditional Chilled Water System: Working at a temperature of 10 to 15 °C, composed of standard chillers and CRAH units, resulting in a PUE value of 1.212.

Coolant Distribution units (CDUs) located on each row of IT Racks, within the Data Halls, to provide seperation of the Primary and Secondary liquid cooling circuits between the Chiller Plant and the IT Equipment. Approximately 90% of the heat will be removed from the Racks using cold plate heat exchangers mounted to processors, remainder removed using CRAH/Powerwall units.

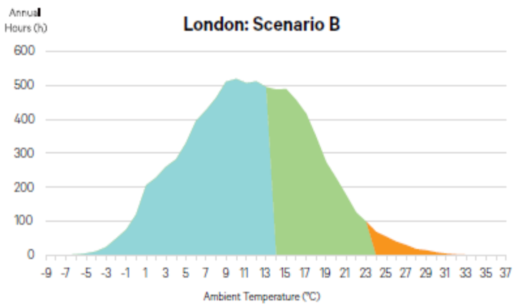


Figure 4.With increased air and water temperatures: Working from 10 to 15 °C to 20 to 28 C, and the return air/liquid temperature from 26 to 36 °C provides a supply air/liquid temperature to the server below 25 °C.

Introducing a free-cooling chiller instead of

a standard chiller reduces the PUE value from 1.212 to 1.114.

ASHRAE Water Cooling Class & Maximum Facility Water Temperature between Class W27 (27 °C) and Class W32 (32 °C) due to the Return Temperature of 28 °C, for the Primary CHW (Facility Services).

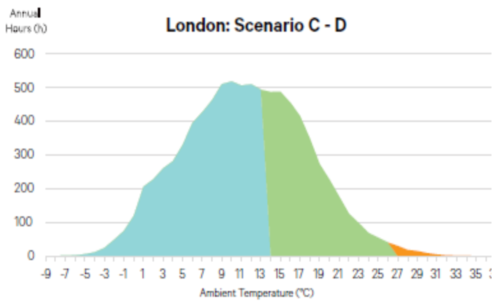


Figure 5. With optimized chilled water system control & improved compressor technology and low-GWP refrigerant: Additional controls integrated to optimize the water flow control and leverage the dynamic water control system reducing the PUE value even further, from 1.114 to 1.100.

Improving Chiller Technology, with free-cooling and inverter driven compressors and low-GWP Refrigerant (such as R290 or Ammonia). Energy consumption reducing the aforementioned PUE value from 1.114 to 1.094.

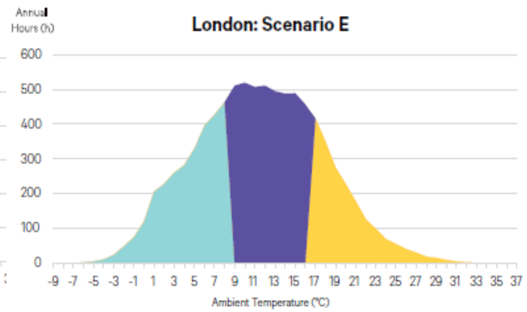


Figure 6. Including the adiabatic system: Illustrates that with the adiabatic system (using water for evaporative cooling) the chilled water system never fully works in direct expansion mode but is able to in free-cooling or mixed mode, thus improving overall efficiency and reducing costs.

By adding an adiabatic configuration to the chillers, the system can reach a PUE of 1.082.

The adiabatic component would generate indirect evaporative cooling by spraying water of the Chiller condenser Coils. WUE ratio will provide a maximum water consumption during peak IT Loads. A reservoir of water storage should be provided to provide Resilience.

SECTION 7 - THE TYPICAL HVAC HEAT REJECTION DESIGN MODEL FOR A 100 MW DATA CENTRE - USING DIFFERENT COOLING HVAC STRATEGIES (continued)

Aim to calculate the reduction of Total Peak Electrical Energy and HVAC non IT Loads required using the different Scenarios.

Scenario A: Traditional CHW Chillers - equates to PUE = 1.212, As PUE = Total Facility Energy / IT Equipment Energy; then total Facility Load will be 21.2% of Total DC Load of 100MW
Figure 3 illustrates no Free cooling - 0 hours [h] during 1 year
Therefore Peak IT energy Load = 100 MW/1.212 = 82.51 MW; therefore Total Facility Peak energy Load = 100 MW - 82.51 MW = 17.49 MW
Assuming 70% HVAC Peak Electrical total Load of Facility = 17.49 MW x 70% = **12.24 MW** and other Electrical Non IT Loads (lighting, Power Distribution, UPS & misc. equipment) equates to 5.25 MW.

FOR Scenarios B, C-D and E assumed:
Equal Data Centre physical characteristics and Facility Equipment/Plant Layout inside Data Centre such as Switch panels/UPS/PDUs/Lighting/Personnel and other Facility Services . Therefore constant values assumed of Peak IT Equipment Load Energy 82.51 MW and Peak Non IT & Non HVAC equipment Energy Load 5.25 MW have been assumed

Scenario B: Increasing ASHRAE water cooling class to W27, with Free Cooling on Chiller Design. Equates to PUE = 1.114
Figure 4 illustrates Free cooling (light blue section) - 5,416 hours [h]
Therefore as PUE = Total Facility Energy / IT Equipment Energy; Therefore 82.51 x 1.114 = Revised Total Facility Load = 91.92 MW
Therefore the improved Peak HVAC energy Load would equal to: Total Facility Load minus Peak IT Equip. Energy = 91.92 - 82.51 = 9.41 MW
ESTIMATED HVAC non IT Loads = 9.41 MW - 5.25 MW = **4.61 MW**

Scenario C: Optimization of the chilled water system control, with Free Cooling on Chiller Design. Equates to PUE = 1.100
Figure 5 illustrates Free cooling (light blue section) - 5,416 hours [h]
Therefore as PUE = Total Facility Energy / IT Equipment Energy; Therefore 82.51 x 1.100 = Revised Total Facility Load = 90.76 MW
Therefore the improved Peak HVAC energy Load would equal to: Total Facility Load minus Peak IT Equip. Energy = 90.76 - 82.51 = 8.25 MW
ESTIMATED HVAC non IT Loads = 8.25 MW - 5.25 MW = **3.00 MW**

Scenario D: Using Inverter Driven Chiller, with Free Cooling on Chiller Design. Equates to PUE = 1.094
Figure 5 illustrates Free cooling (light blue section) - 5,416 hours [h]
Therefore as PUE = Total Facility Energy / IT Equipment Energy; Therefore 82.51 x 1.094 = Revised Total Facility Load = 90.27 MW
Therefore the improved Peak HVAC energy Load would equal to: Total Facility Load minus Peak IT Equip. Energy = 90.27 - 82.51 = 7.76 MW
ESTIMATED HVAC non IT Loads = 7.76 MW - 5.25 MW = **2.51 MW**

Scenario E: Including Adiabatic (water evaporative) Cooling to the Inverter Driven Chiller, with Free Cooling. Equates to PUE = 1.082.
Figure 6 illustrates Free cooling (light &dark blue sections) - 6,849 hours [h] - adiabatic cooling only use water during the hottest part of the day and year
Therefore as PUE = Total Facility Energy / IT Equipment Energy; Therefore 82.51 x 1.082 = Revised Total Facility Load = 89.28 MW
Therefore the improved Peak HVAC energy Load would equal to: Total Facility Load minus Peak IT Equip. Energy = 89.28 - 82.51 = 6.77 MW
ESTIMATED HVAC non IT Loads = 6.77 MW - 5.25 MW = **1.52 MW**

SECTION 7 - THE TYPICAL HVAC HEAT REJECTION DESIGN MODEL FOR A 100 MW DATA CENTRE - USING DIFFERENT COOLING HVAC STRATEGIES (continued)

PLUS WATER CONSUMPTION **Scenario E**: Evaporative Cooling measured by a WUE ratio (dark blue and pale yellow section):

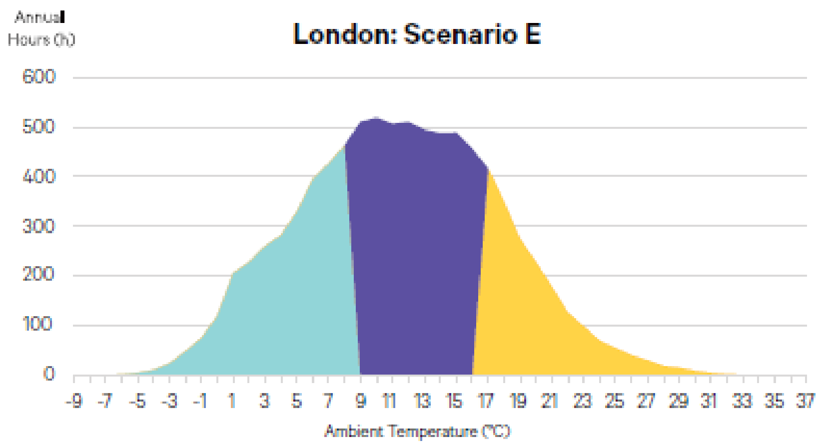
equivalent to maximum Data Centre Water Consumption (in litres) / IT Equipment Energy (in kilowatt hours) = 0.162 L/kWh = 0.162 x (82.51 x1000) = 13.37 m^3 per hour peak water consumption

The water loss rates from reverse osmosis (RO) system, the process to pre-filtrate concentrates from within the supply London Thames Region Utility water (typically hard to very hard, with high levels of calcium and magnesium, TDS (Total Dissolved Solids) levels are moderate, usually ranging from 300 to 600 mg/L and other contaminants such as moderate levels of chlorine & organic matter) would typically range from 20% to 30%, for an data centre indirect adiabatic cooling system. Also an additional consumption rate should be increased by approximately by 2%, to compensate for Evaporative, Blowdown and Drift losses

Therefore total water losses would equate to 30% + 2% = 32% = **17.65 m^3 per hour peak water consumption**

Estimated financial advantages of using Adiabatic Cooling:

Reduction in Total Facility Electrical Peak Load (Ref. 7) of 0.99 MWh (with cost of Electricity £272 /MWh); equivalent saving to £269.28 /hr
Additional Cost of Water Consumption (Ref. 8) of 17.65 m3 (with cost of Water £2.072 /m3); equivalent to an increase of £36.57 /hr



SECTION 8 - ELECTRICAL POWER SUPPLY RESILIENCE - NEAR FUTURE MANDITORY CHANGES AND A LOWER COST OPTION

As already mentioned, there is a need for backup systems in place to protect Critical Facility systems in the event of Supply (Utility) power failures, to provide at least two methods of providing full Electrical Power capacity to the Data Centre. The backup system used most often used are Generators, with totalled Capacity equalling the Utility Power Supply, with redundant equipment such as transfer switches , power distribution units or uninterruptable power supply (UPS) appliances.

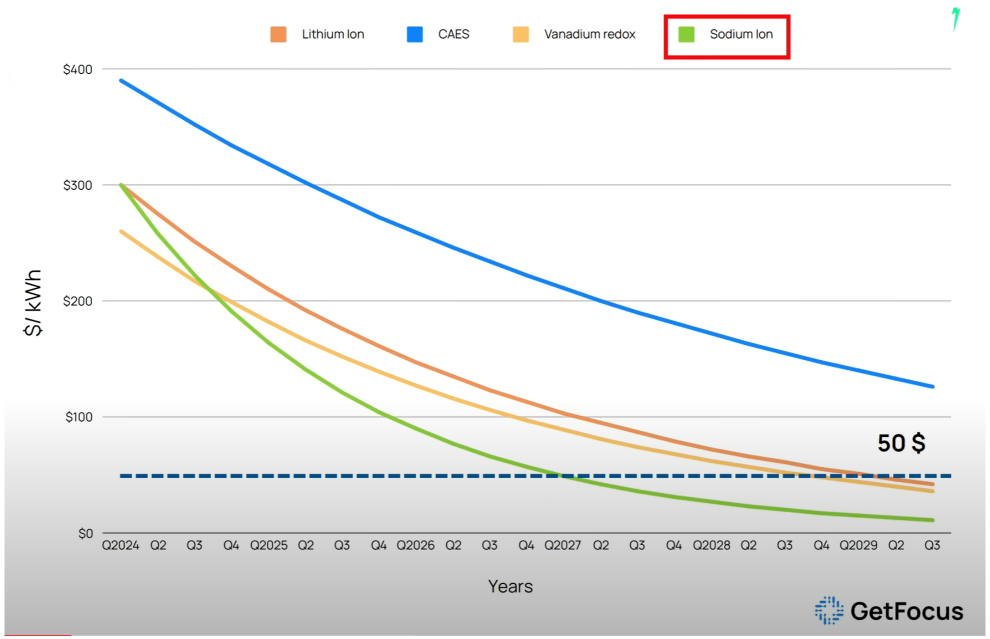
Previously, data centre UPS high rate battery systems were traditionally designed to deliver 10 to 15 minutes of Power Supply autonomy, so that operations were adequately covered, given enough time for back-up generators to be automatically activated. Modern generators have far quicker responsiveness though. All this means UPS autonomy periods could be a lot shorter, with batteries often only needing to support less than 5-minute discharge durations.

The first stage of Power Resilience being the UPS, has been upgraded recently with Li-Ion batteries, which have some operational advantages, when comparing with older traditional valve-regulated lead acid (VRLA) battery technologies, plus higher energy density levels and long service life . Significant reduction in the space required in the Data Centre, now allowing Li-ion batteries to be co-located in the same room that a UPS or IT Equipment.

IT equipment suppliers are now offering integral Power Supplies and UPS Battery Storage into the Rack configeration, with real time monitoring systems included. Lithium-ion battery UPS applications are designed with a greater emphasis on monitoring and safety, with an integral Battery Management system. Battery relative energy densities are increasing, whilst costs are continuing to rapidly reduce, by the end of 2024 the largest Li-ion Battery manufacture (CATL) is projecting a cost of $40/kWh.

The second stage of Power Resilience being the backup power generator Capacity, that should be able to carry all the power requirements of the IT equipment, HVAC and essential auxiliaries. The generator should include dual power distribution switch gear with automatic transfer switching (ATS). Data Centres with +Tier 3 Resilience will also require fuel on Site to provide 36 to 48 hours supply, with the ability to refill the fuel on Site to provide a 72 hour continuous Power Supply. Whilst ensuring resilient infrastructure components, to have no single points of failure, so requiring the duplicate of Systems.

With Gas or Diesel fossil Fuels being the usual options to power these backup Generators, with the need of related fuel storage systems to be configured interlinked or duplicated, and also ensuring the quality of the fuel is maintained to minimise Generator malfunction. The most popular Generator fuel is Deisel, which requires elevated fuel temperature controls within the Day Tanks (located adjacent to the Generator to enable quick start) and Belly Tanks (located below the Generator Container) and Fuel Polishing equipment to ensure consistent fuel density and quality.



Backup systems should also provide enough power to HPC systems to shut them down safely to prevent components from damage and to protect data from loss or corruption, with options to facilitate complete back-up of IT Data to other networked Resilient Data Centres.

SECTION 8 - ELECTRICAL POWER SUPPLY RESILIENCE - NEAR FUTURE MANDITORY CHANGES AND A LOWER COST OPTION (contined)

With HPC Data Centres requiring Utility and Resilient Power Supplies equalling in size to the electrical consumption of a City, the existing aged high voltage (HV) Electrical Grid is under risk from brownouts, especially with greater reliance on renewable sources and nature sometimes being inconsistent (fluctuating wind strength or intermittent cloud cover), will result in urbanisations likely having power outages occurring more often.

As these HV electrical Grid infrastructure systems cover large areas, sometime over national boundaries, certain political aspects have to be considered when planning for the construction of a HPC Data Centre.

Several examples can be provided, from European wide regulations starting to be published or individual countries designating conditions. For instance, being reported during the last few years from Republic of Ireland, can illustrate the mounting issues. (Ref. 9)

- In 2022 EirGrid placed a moratorium on construction of new Data Centres in the Dublin area that is set to last until 2028.
- Planning permission objections pushed back the construction of a 200MW Data Centre in County Clare by five years, due to environmental concerns, from valid concerns that the development would generate 657,000 tonnes of CO_2 each year due to its high power requirements.
- Ireland’s Environmental Protection Agency made an agreement with Meta, that the Power Backup Deisel Generators will not be just used as a DC Power Resilience, but designed to be the Primary Power sources if the HV Grid requires to Load Shed the Data Centre, receiving a special license to run 90 diesel generators on the DC site in Clonee. They will provide up to 734MW of power in the event of an emergency, and the license allows Meta to run the generators for up to 500 hours a year, which would generate an estimated 72,177 tonnes of CO_2 each year, and undermine the original DC Power Resilience Strategy.

Also with the Mandatory phasing out of fossil fuelled engines throughout Europe, such as diesel generators, will require a revised Solution to provision of Resilient Critical Power Supplies.

Luckily for the foreseen timeline growth of HPC Data Centres, coincides with the rapid development of large scaled grid Electrical Storage Technology, and the decrease in relative manufacturing costs of Lithium (and future Sodium) ion Batteries and other large scaled battery Solutions.

Large scaled grid electrical Storage batteries are being rapidly installed with HV Grid infrastructures throughout the Globe, to primarily reduce Load Shedding risks but also taking advantage of basic financial investment incentive from a profit model of taking advantage of lower day-to-day Energy costs is by utilizing Battery Storage for peak shaving purposes.

Presently Lithium Ion and Redox type battery Solutions are being used for Storage Buildout, but other multiple chemical Battery Solutions are being planned, especially Sodium (Salt) based batteries with lower Power Density characteristics, when compared with Lithium based, but with a potential large reduced cost advantage.

SECTION 8 - ELECTRICAL POWER SUPPLY RESILIENCE - NEAR FUTURE MANDITORY CHANGES AND A LOWER COST OPTION (contined)

Some Data Centre operators are considering the potential to draw electricity from their battery resources when costs are high, before subsequently recharging them when electricity costs are at their lowest. Another strategy that operators are starting to experiment with is to become net producers - generating money by supplying electricity back to the grid, as part of grid frequency response.

Battery Storage systems capacities are increasing rapidly with sizes of 3GWh / 750MW (Ref 19) being reported. As battery prices decreases these capacities will increase because of their financial viability.

Example of 200 MWh Battery Storage

Below in Section 12 it has been demonstrated, with an installation of a large scaled Battery Storage system to provide the basis of providing both the linkage to Power Utility Supply and provide the Critical Resilient Supply, therefore a replacement of the Deisel Generators, Deisel Tanks and all the other supporting peripheral system.

Also by taking advantage of the comparison with Residential and Data Centre Load Profiles, the example Section 12 Model, can provide a Battery System for a 210 MW Data Centre that can provide full Capacity with over 6,000 cycles, with Grid Load shedding capacity and opportunity of purchasing from the Grid at low tariff rates, to be sold onto the End User (Residential Household Clients) to provide additional Revenues.

Alternative Solutions are also being explored, such as a collaboration with Microsoft and Ballard demonstrates the potential of hydrogen fuel cells to help data centres address their critical power needs while reducing their emissions," said Jaime Mineart, senior vice president of Caterpillar Electric Power. The project simulated a 48-hour backup power event at Microsoft's data centre in Cheyenne, where a hydrogen fuel cell was integrated into a data centre electrical plant to support its critical load. (Ref. 10). The only issue with this Solutions is a source of sufficient Green Hydrogen, as of yet it is not financially viable when comparing with Electrical Storage.

SECTION 9 - CONSIDERING HIGH ELECTRICAL CONSUMPTION AND LIMITED RENEWBLE ENERGY GENERATION CAPACITY AVAILABLE. - ALTERNATIVE HVAC MODEL

Even though there has been a significant growth of Renewable Energy (RE), we are well short of the capacity that will be needed over the next two decades, to fulfil the Net Zero Targets of 100% RE for all of our Building Stock, Industries and our Transportation (with the continuous growth of EVs and manditory phase out of Fossil fuelled vehicles by 2035).

With the challenging Net Zero targets aiming for 50% completion by 2030 and 100% by 2050, the prospective of expanding Nuclear Power Generation, has become politically acceptable, even with related higher long term costs (and risks) of waste processing and decommissioning.

As described in the earlier Sections of this White Paper, the decades evolvement of Data Centre Design Engineering has ensured the improvement of HVAC Facility Design for Data Centres. By increasing the overall efficiency of the removal of heat to the environment, therefore improving the PUE ratio from over a ratio of over 2 to just over 1, by higher HVAC Plant overall efficiencies and increased operating temperatures of IT Equipment used with the Data Halls.

HPC Data Centres will be located in the vicinity of Urbanisations, to ensure AI applications have the low latency requirement to function inside the related Urbanisation. With potential AI and Machine Learning applications being expansively being used, within the Server Data Halls the GPU & CPU electrical consumption will reach in excess of 50 kWh per Rack, with expected increase of energy consumption expected, as IT evolves in our future. Design Responsibilities should be considered but also the potential opportunities of adapting the present HVAC Design Model.

Using this methodology of designing the Facility Services of the HPC Data Centre, ensuring the continuation of the requirements of Power and Cooling resilience, will require a fundamental changes in the overall strategies of Data Centre Design.
Otherwise blockages will occur to the progress of HPC Data Centre build-out, from the tightening of political Mandatory Regulations, reacting to offsetting potential political back-lash against the accusations of proliferate energy consumption. Also promoting the idea that increased Data Centres could potentially derail the continuation of the Social transition expected by the Green Deal/ Net Zero aspirations.

By increasing the challenge increasing RE Capacity to the scales required within the targets of just decades, and including of the need of constructing buildings that consume Megawatts/Gigawatts of electricity, will require a revision to the DC Design strategies to reduce the impact of HPC Data Centres, that enables the electrical energy capacity to be shared/re-cycled/re-used by the Urbanisation it is located within.

The suggested HVAC Design Models illustrated in the following Sections of this Paper, not only will fulfil the Sustainability obligation of an AI Service provider, but potentially provide an additional Revenue Model, as fulfilling the Role of an Urbanisation “Utility Provider”…..whilst ensuring the continuation of the Critical Infrastructure methodology of providing heat rejection and power to the Data Centre.

SECTION 10 - THE NEED FOR ADDITIONAL HOUSING CONSTRUCTION IS AN OPPORTUNITY

Throughout the world there is a need for affordable housing. This fact has been recognised by the majority of the world's Democracies and politically there is ongoing policy being enacted aiming to provide this need. As this White Paper is focusing on providing an alternative Model within the UK, a study was made of the potential new house distribution through the UK.

The UK government’s housebuilding target of 1,500,000 additional homes will likely be distributed across different regions based on various factors, including population growth, housing demand, economic development, and local planning strategies.

EXAMPLE BEING USED FOR ILLUSTRATION OF ALTERNATIVE MODELS - FUTURE 210 MW HPC DATA CENTRE COMPLEX -located in the Royal Docks, East London UK (Ref. 11)

With London being the UK's most populous city and has the highest housing demand. The city faces a significant housing shortage, with affordability being a critical issue. The government and London Mayor's office have ambitious plans to building 300,000 to 400,000 new homes, especially in areas undergoing regeneration.

The potential number of new houses that can be built in the East side of Central London depends on several factors, including available land, planning permissions, infrastructure capacity, and the specifics of regeneration projects. East London has been a focal point for regeneration efforts over the past few decades, driven by projects like the Olympic Legacy in Stratford, the redevelopment of Docklands, and new transport links like Crossrail (the Elizabeth Line). Total Potential New Housing in East Central London: Estimate: 53,000 - 85,000 new homes

The Royal Docks are a waterfront area that was once a gateway to world trade. Today, it's a growing hub for business and culture, and is a major riverside destination in East London. The Royal Docks include Silvertown, North Woolwich, Custom House, London City Airport, and part of Beckton. The Newham Council and the Mayor of London are working together to restore the Royal Docks to its former glory.

The plan is to build more than 36,000 new homes and create 55,000 new jobs in the area.

SECTION 11 - AN ALTERNATIVE HVAC MODEL - RE-USE OF DATA CENTRE HEAT REJECTION FOR USAGE BY RESIDENTIAL HOUSING - UTILITY SERVICES

Using the Facility Design requirements to provide an Alternative Model to support a Tier +3 HPC Data Centre, plus the utilisation of the 100 MW Model initiated in Section 7, they were combined and upscaled to the indicate the requirements of the East London 210 MW Data Centre.

Continuing the Analysis made in Section 7, the Electrical Peak Consumption will be approximately double the Capacity of the same HVAC Systems applied, the Traditional 210 MW Electrical Data Centre Loads applied will be based on: **Scenario E**: Including Adiabatic (water evaporative) Cooling to the Inverter Driven Chiller, with Free Cooling. Equates to PUE = 1.082. Facility CHW Temperatures 30/20 °C.
Free cooling - 6,849 hours [h] - adiabatic cooling only use water during the hottest part of the day and year
As PUE = Total Facility Energy / IT Equipment Energy; Therefore 210 MW x 1.082 = Revised Total Facility Load = 194 MW
The Peak HVAC energy Load would equal to: Total Facility Load minus Peak IT Equip. Energy = 210 - 194 = 16 MW
ESTIMATED HVAC (non IT) Load = 16 MW - 11 MW = **5 MW HVAC Electrical Load** (principally used for Pump circulation).
With an estimated **Peak water consumption = 42 m³ per hour.**

DESCRIPTION OF STRATEGY OF RE-USE OF HEAT REJECTION FROM DATA CENTRE FOR SPACE HEATING (Heating) AND DOMESTIC HOT WATER (DHW)
FOR 36,000 RESIDENTIAL HOUSEHOLDS

Even though the HVAC electrical Load is very efficient when compared to total Heat Rejection Load of approximately 202 MW, the heat energy is literally thrown away to the exterior, with the potential of changing weather conditions in the immediate locality, that may turn the Royal Docks in East London into a tropical environment.

The Alternative strategy will be use the heat rejection (Facility CHW Temperatures 30/20 °C.) from the Data Centre for the planned new residential housing (of 36,000 units), but using only 25% of the heat rejected from the Data Centre at Peak Load. The remaining 75% (157 MW) could be used by retrofitting existing housing, but would be more problematic and require longer lead times, though possible once the existing residents become aware of the potential advantages of being engaged, and the infrastructure built.

It should be noted that the assumed Space Heating Load, for a typical Residential household has been assumed at 12,000 kWh/year, and used for the Alternative Heat Rejection Model calculations (in Appendix Section 16.) This Load should be significantly less for housing constructed after 2025, due to the greatly improved Building Regulations.
From a following White Paper (hopefully to be published during October/November) indicates an approximate x6 reduction of required space heating capacity, if compared with an equally size pre-1945 residential house.

Aim of the Heat Rejection Model Illustration - provide a Model of the scale of the proposed system, based on Peak Loads. Subsequent stages would involve Modelling of all the variables, variables such as Ambient conditions, Household Loads, Data Centre Loading, Period of Time/Season, District Heating Infrastructure…..and so on. It would also be assumed that Real Time data (using IoT Strategies) would enable the overall constructed system to optimise and monitor performance, enabling Maintenance and Fault Finding Response.

Facility CHW Temperatures from Data Centre - Facility CHW Temperatures 30/20 °C - As mentioned in Section 5, depending on the IT equipment used within the HPC Data Centre, there is a good chance that Facility CHW temperatures may well be at an even higher temperature, which will be benifical to the overall Alternative Model operating conditions. The CHW flowrate will be variable due the IT Electrical Load expecting to range from 60% to the Peak Load during a 24 hour period.

SECTION 11 - ALTERNATIVE HVAC MODEL - RE-USE OF DATA CENTRE HEAT REJECTION FOR USAGE BY RESIDENTIAL HOUSING (continued)

Water / Water Heat Pumps are used to upgrade the Facility CHW Temperatures (30/20 °C) to a higher temperature that is suitable for a Heat Network (DHS), such as 70/50 °C - A Low GWP refrigerant Ammonia 1.74 MW Water/Water Heat Pump (SABROE Dual PAC 716-W) was selected to upgrade the temperature of the CHW 30/20 °C to 70/50°C. Estimated Peak Loads indicate the requirement of 38 Heat Pump units to generate sufficient grade of heat for 36,000 low temperature residential heating systems (for example hydraulic underfloor radiant heating) and provide Domestic Hot Water (DHW).

Summer Load - For approximately 4 months of the year during the summer months it has been assumed that there would not be the requirement for Space heating, just Domestic Hot Water (DHW). Therefore the average daily hot water consumption has been reduced to an estimated 432 MW (from 1,584 MW during Space Heating periods).

Two separate Storage systems are to be applied, each with 2 Tanks containing 5 million litres of water (total 10,000 m3), for storage of CHW (30/20 °C) & HW (70/50 ° C).

- Two Buffer CHW Storage Tanks (2N) - Each Thermally Insulated Tank would and would act as Data Centre cooling thermal storage, with a turnover/reserve of approximately 4 hours. - Source for Heat for Household Heating using Water/Water Heat Pump to upgrade the Temperature - and contribute to a Power Resilience Strategy (see following Section 12).

- Two Buffer HW Storage Tanks (2N) - Each Thermally Insulated Tank would and would act as Residential thermal storage, with a turnover/reserve of approximately 7 hours. The temperature difference between top and bottom of the Tanks would be expected to 70/50 °C, though the Heat Network (District Heating system) load over a 24 hour period may vary the return temperature of the Heat Network / Low temperature District Heating system .

Thermal buffer vessels - simply act as an oversized header and are used to link various energy sources, or multiple Heat Pump pipework Circuits, help control and manage those energy sources, increases peak performance and helps to improve the turn-down and the reaction time of the heat source technology in line with the fluctuating demands of the Heat network.

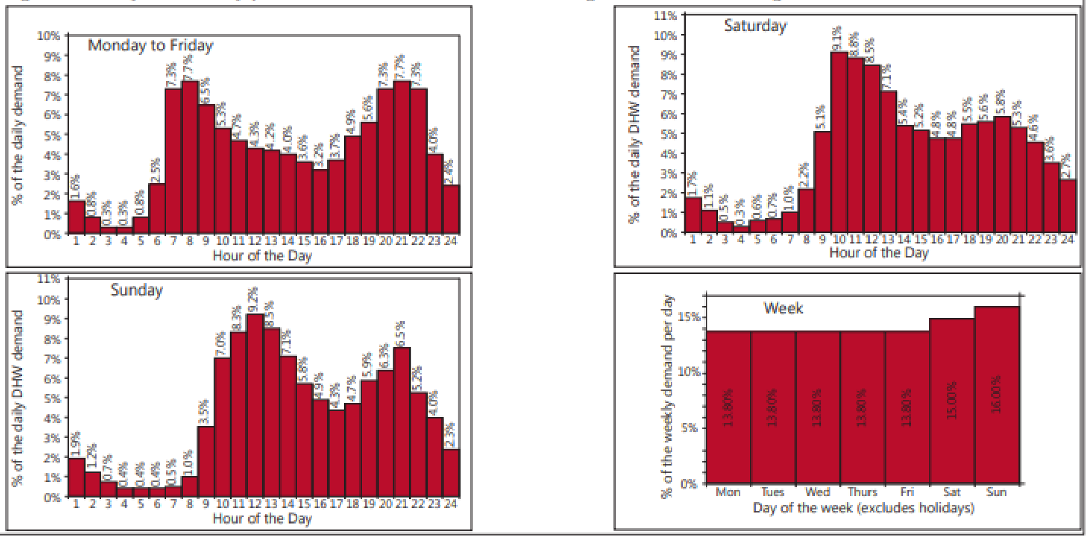
Thermal storage vessels - In contrast thermal storage vessels acts as an energy bank, where Plant are able to run and charge the vessels over extended periods. A thermal store will enhance the output of the heat source to cope with peak demands and allow the heat source to top the thermal store back up during periods when demand is low. Thus providing a load levelling effect to a systems fluctuating energy demands. They tend to be much larger in size than a thermal buffer allowing them to be charged both during times of high and low demand.

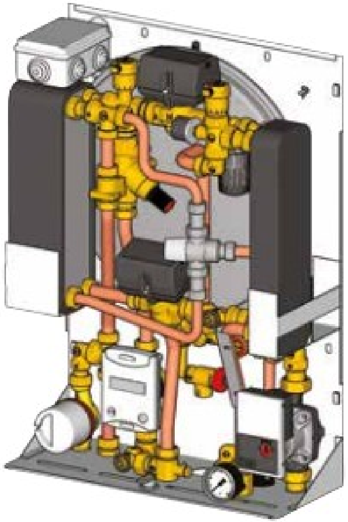
SECTION 11 - ALTERNATIVE HVAC MODEL - RE-USE OF DATA CENTRE HEAT REJECTION FOR USAGE BY RESIDENTIAL HOUSING (continued)

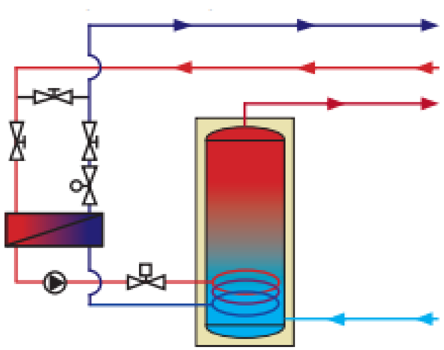
The Residential Household Hot Water (HW) Load will vary during the Annual/Seasonal and 24 hour periods, therefore variable flowrates and variable return temperature will be controlled to the HW Load. - Peak HW Loads during the Space Heating period would be expected to be in Winter when the combination of Space Heating (32 kWh/day) and Domestic Hot Water (DHW 12 kWh/day), to Summer when it would just be DHW.

Therefore the re-use of the DC Heat Rejection would reduce from 25% to 7%, if applying the HW Loads to a community usage size of 36,000 residential units. It would be assumed that the Data Centre would need the Adiabatic and Chiller Heat Rejection Plant to reject heat from the Data Centre during the Summer period, though there would be a small reduction in Electrical power and Water Consumption.

Figure 2 - Daily and weekly profile of the hot water demand in large residential buildings







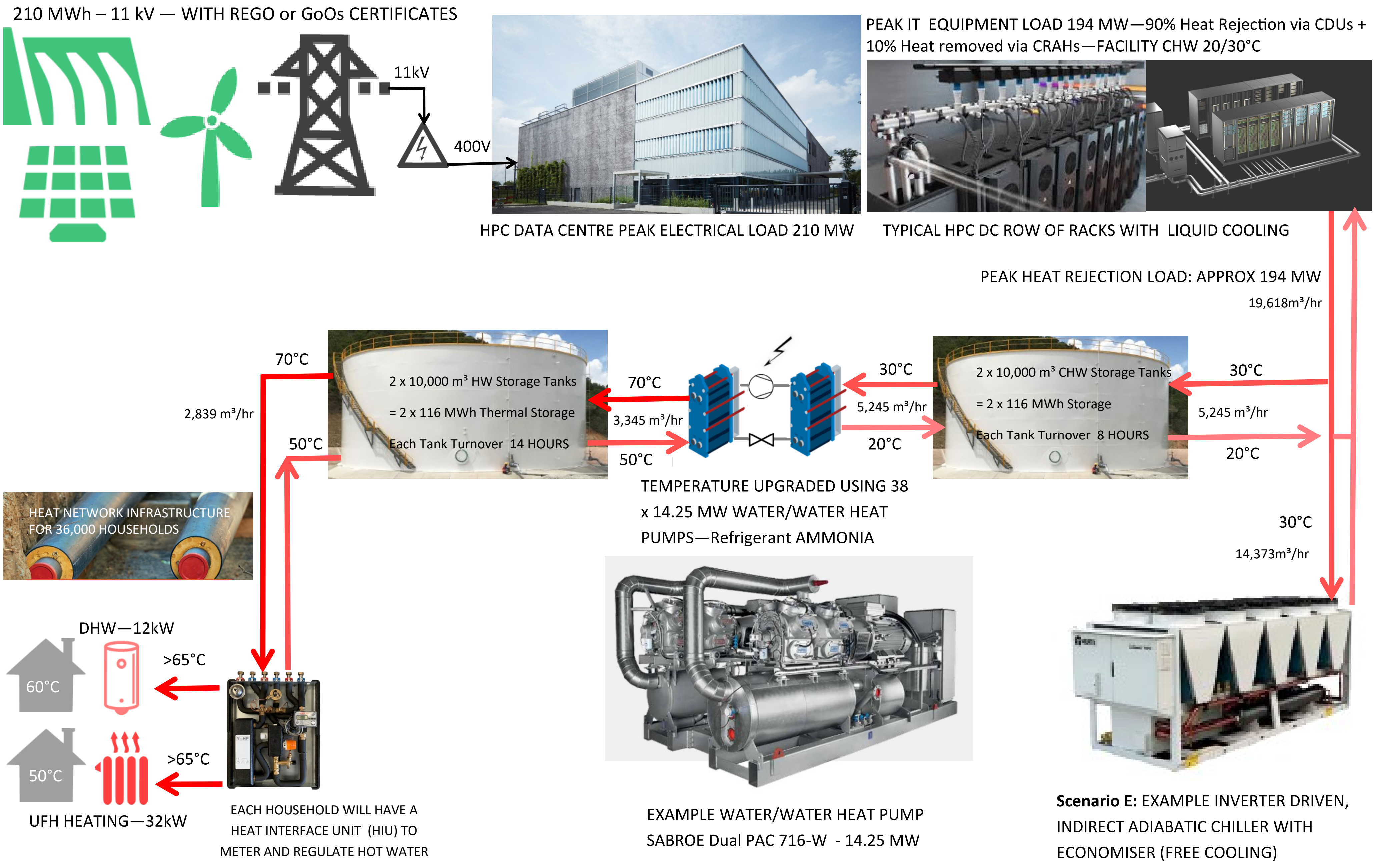
Each Residential Unit will have a Heat Interface Unit (HIU) which will allow a physical seperation (using Plate Heat Exchanger) between the District Heating infrastructure and the Household, which will allow for additional Control by the Energy User and enable Metering of Energy consumed.

Existing buildings can also integrate a HIU into the existing Boiler Space Heating/DHW system, which would significant reduce running costs, if the radiators were replaced with wall mounted fan convector units, though potential consumers would require education and the Heat Network (District Heating) infrastructure installed in the adjacent street.

Also each Residential Unit would have a Buffer Cylinder (for UFH Space Heating) and a DHW Storage Cylinder to reduce Instantaneous Loads on the Heat Network, therefore allowing longer recovery rates to recharge Buffer/Storage. Though the Heat Network would need to be sized to cope with the peak demands in the depths of winter.

These low grade heat District Heating systems, called 'Heat Networks' are starting to be designed for and be constructed in Urban areas. Heat Networks / Low Temperature District Heating (DH) have not been really used in UK up to now, unlike mainland European countries such as Germany.

It will become common practice for these Heat Networks systems to be rolled out throughout Communities worldwide, to take advantage of low grade Energy sources, including Community Renewable Energy Systems.



PEAK WINTER SPACE HEATING & DHW LOAD FOR 36,000 RESIDENTIAL HOUSEHOLDS (APPROX. 27% OF 210MW DATA CENTRE HEAT REJECTION)

SECTION 11 - ALTERNATIVE HVAC MODEL - RE-USE OF DATA CENTRE HEAT REJECTION FOR USAGE BY RESIDENTIAL HOUSING (continued)

ANALYSIS OF DATA FROM MODEL OF USE OF DC HEAT REJECTION FOR 36,000 HOUSEHOLDS (Space Heating & DHW)

NOTE: No Diversity or Modelling has been used to generate this data from Calculations. Also data used assumed Peak Loads and average consumption over a time certain period, has been a derivative from Peak Loads. The aim of the calculations is provide a scale of the Solution and provide guidance on the viability of the proposed Model.

The Overall COP of 4.6.

Providing Space Heating and DHW to 36,000 Residential units for Peak Heat Pump Load (66 MW) over 24h average flowrate. Assuming that Total Circulation losses (circulation Pumps) would be under 1% of Total Heat Pumps electrical consumption.

Peak consumption of Data Centre heat recovery would be 66 MW, during Winter loading of space heating & DHW, which would equate to 27% of available Heat Rejection.

Summer daily average consumption (over 24h) would be 17 MW

Water/Water Heat Pumps selected for calculations were 1.74 MW SABROE DualPAC 716-W, using ammonia for Refrigerant. Winter Load 38 units required; Summer Load 10 units required

Calculations for reuse of DC Heat Rejection can be seen in the Appendix (Section 16a)

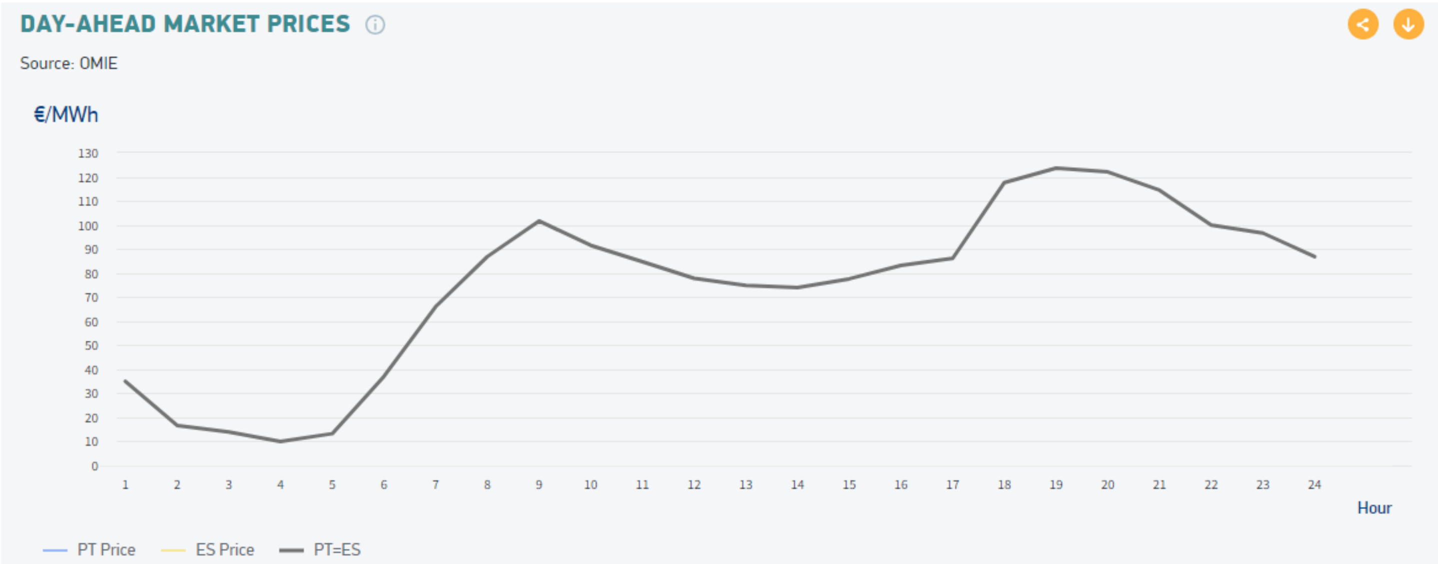
SECTION 12 - ALTERNATIVE DATA CENTRE RESILIENT POWER SUPPLY STRATEGY

As already stated earlier, the traditional method of providing 72 hours of Resilience to the Data Centre Power Supply is the usage of Diesel Generators, equal to the total capacity of the Peak Total Electrical Load of the Data Centre. To provide further Resilience of the number of Generators, to minimise the risk of any potential Generator failures, there would be a requirement to install 6 Generators for every 5 based on the DC Load. Therefore in the case of the 210 MW Data Centre there would be the requirement of installing 84 x 3 MW Generators (70 Generators to function for 72 hours) with sufficient fuel capacity and infrastructure. During 72 hours the Generators would consume an estimated 1,108,800 litres of Diesel, which would release an estimated 3 tons of $C0^2$ Emissions.

As discussed in Section 8, the existing strategy of providing Data Centre Power Supply Resilience using fossil fuelled generators has a limited time line for further usage, and potentially compromises the overall Green Deal or Net Zero political and social objectives. Another point already been considered was the use of large Battery Storage systems to provide Electrical Energy resilience to the Data Centre, due rapid capital cost reductions.

It must be concluded, from the discussion in Section 8, that in the future construction of HPC Data Centre Installations, that there will be a large Battery Storage system in between the Utility 400v HV Grid and the HPC Data Centre, sized multiple times to the Peak IT Electrical Load of the Data Centre. The large Battery Storage system would be sized and designed to function as a 'Battery energy storage system (BESS)'. A BESS is a system that stores electricity in batteries for later use. They also help to improve the efficiency of electricity grids by preventing brownouts and providing back-up power during blackouts. BESS systems will become common place on national Electrical Grid infrastructure with capacities ranging into GWh capacities (Ref. 13). Growth of BESS application due Battery price reductions and from immediate financial returns due to extreme price differentials during a 24 hour period, on the Wholesale Electrical Market (see graphic below).

The MWh price can fluctuate significantly over a 24 hour period on the Electrical Market. As demonstrated on a day in March 2024 the price ranged from €10 MWh to 115 MWh



It will also become normal practice for IT equipment suppliers to provide integral Power Supplies and UPS Lithium-ion Battery Storage into the Data Hall Rack configeration (potentially providing more than 15 minutes of Electrical power Resilience, as the power density of the Battery Technology improves).

SECTION 12 - ALTERNATIVE DATA CENTRE RESILIENT POWER SUPPLY STRATEGY (continued)

With +3 Tier Data Centre requirement of a secondary 72 hour Power Supply Resilience, this will be made up from different strategies:
UPS Integral Installation in the Data Halls + BESS System providing 24 hours of Energy Storage + CHW Storage at lower temperatures less than the Facility CHW temperatures, to reduce the need of using Chillers during high ambient Temperatures + Alternative Fuel Source to generate Electrical Power with sufficient capacity to make up any short-fall from the previous itemised Strategies.

Continuing the example of the future 210 MW HPC Data Centre complex to be constructed in East London, which will also provide Utility Services to the surrounding Residential Community, at this stage of analysis sized at 36,000 households. Taking the maximum Peak Electric Load of the DC being 210 MW and expanding the Utility Services to provide Electrical 230v to 36,000 households (Average consumption 13 kWh/day per household), taking into the consideration the 24 hour profiles of building types (DC average - est. 154 MWh per hour) and the opportunity of reducing the Electrical Wholesale price, the number of hours storage within the BESS can be calculated. Without modelling, it can be estimated at 24 hours of charge therefore 24 x 154 MWh + 36,000 x 13 kWh = Total BESS Storage 4.2 GWh Capacity with maximum hourly discharge of 250 MW.

Continuing these assumptions, there will be an additional need of an equivalent of a minimum of 48 hours of additional Energy Storage to Power the HPC Data Centre, (estimated at 48 x 154 MWh = 7.4 GWh of Energy/Fuel requirement (plus Transformation Inefficiencies) for a 48 hour period, with maximum hourly generation capacity of 250 MWh over that period, without the Utility 400v HV Grid being connected.

GENERATION CAPACITY OF 7.4 GWh FROM NON FOSSIL ENERGY/FUEL - TO BE SUPPLIED OVER A 48 HOUR PERIOD

Albert Einstein is credited with the quote, *"Energy cannot be created or destroyed; it can only be changed from one form to another".* This is also known as the Law of Conservation of Energy, which is the first law of thermodynamics. So when we come to our consumption in our homes, why do we consume energy and then just throw away the bi product - though we are starting to separate our household waste for recycling.

Taking this thought further, and considering the waste streams that residential household generate, have a considerable amount of embodied energy, which is usually just discarded, with a additional financial costs. As our previous Solution of re-using Heat Rejection from the Data Centre to be used by nearby Residential Household, using a District Heating Infrastructure, it is proposed to continue this association for the Data Centre, to re-use Waste Energy from the residential households, after processing.

DESCRIPTION OF TYPES, REASONS AND STRATEGIES OF RE-USE OF HOUSEHOLD WASTE ENERGY STREAMS

- Solid Combustible Waste - The quantity of solid incinerated waste per household in the UK varies depending on the specific area and year. However, as of recent data: Total Incinerated Waste: The UK incinerates around 11-12 million tonnes of waste annually. Household Contribution:
- Approximately 50-60% of this waste comes from households. Given the UK has around 27 million households, the average household contribution to incinerated waste would be: Per Household: Approximately 200-300 kg of waste per year is incinerated.
  The calorific value of household waste varies depending on its composition, but a typical value is around 7-11 MJ/kg (megajoules per kilogram).

SECTION 12 - ALTERNATIVE DATA CENTRE RESILIENT POWER SUPPLY STRATEGY (continued)

- Black Water Sewage Waste - An average person generates around 70-90 grams of volatile solids per day in the sewage system(taking into account both faecal matter and other organic inputs like kitchen waste, where applicable). Let's assume 80 grams (0.08 kg) of volatile solids per person per day. Therefore 0.08 kg/day × 365days = 29.2kg. Biogas Yield: The biogas yield from sewage sludge typically ranges from 0.6 to 0.8 cubic meters (m^3) per kilogram of volatile solids (VS) destroyed, containing about 60-65% methane. Methane Yield: The methane yield from sewage sludge digestion is generally about 0.025 cubic meters (m^3) of methane per kilogram of volatile solids (VS) destroyed. Methane production: About 0.22 cubic meters (m^3) of methane per kilogram of volatile solids destroyed. $0.025 m^3/kg$ VS × 29.2kg = 0.73 m^3/year. So, each person could be expected to generate approximately 0.7 cubic meters (m^3) of methane per year through the anaerobic digestion of sewage sludge. Each m^3 of methane has an energy content of approximately 35.8 megajoules (MJ).

- Household Food Organic Waste - volume of waste that could be collected at a municipal scale for anaerobic digestion (AD). Municipal food waste generation can vary but typically ranges from 0.3 to 0.7 kg per person per day. Assuming 0.5 kg per person per day. Not all waste is suitable for anaerobic digestion. Usually Organic waste (food waste, garden waste, etc.) typically makes up around 40-50% of municipal waste. Methane Yield: The methane yield from organic waste is typically around 0.2 cubic meters (m^3) of methane per kg of volatile solids (VS). Assuming 0.2 m^3/kg. This Waste stream would be combined with Sewage Waste anaerobic digestion process. So, each person could be expected to generate approximately 36.5 cubic meters (m^3) of methane per year through the anaerobic digestion of household food waste. Each m^3 of methane has an energy content of approximately 35.8 megajoules (MJ).

- If an anaerobic digestion (AD) plant is operated at 55°C, within the thermophilic range (50–60°C), the methane biogas output from sewage sludge and food waste is likely to increase. Thermophilic conditions enhance the rate of organic matter breakdown, which can lead to faster digestion and higher methane yields compared to mesophilic conditions (35–40°C). Under thermophilic conditions, methane production from sewage sludge can increase by about 20–30% compared to mesophilic digestion.
  Using waste heat from the HW Storage Tanks (from CHP return or DC upgraded Heat Rejection) the above Methane generated per m3 will increase to:
  Black Water Sewage Waste: Improved Yield - 0.033 m3/kg Methane Biogas
  Household Food Organic Waste: - 0.26 m3/kg Methane Biogas

Above there are two types of Waste Streams and different processes to transform the embodied Energy into Heat and Electrical Energies

- a Solid Waste that is compacted and Incinerated to produce steam and to produce hot water above 90° C (60% output) and Electrical Power (25% output) using a CHP Engine/Turbine.
- a Liquid Waste stream anaerobic digested to a methane gas of energy content of approximately 35.8 megajoules/m^3 (MJ), compressed to fuel directly a CHP Engine/Turbine to produce hot water above 90° C (41% output) and Electrical Power (45% output).

- The Electric Power outputs from the CHP Turbines are used to recharge the Large Battery Storage, whilst the Hot water (above 90° C) outputs is transformed into Chilled Water, using Absorption Chillers, to reduce HVAC Heat Rejection DC Electrical & Water Consumption, by the Chillers and Adiabatic Primary CHW Plant Systems.
- It must be assumed that sufficient compacted Solid combustible household waste and compressed (300 bar) methane gas will be stored, with the CHP output capacity, to fulfil 48 hour Power Supply of the Peak Load of the HPC Data Centre.

SECTION 12 - ALTERNATIVE DATA CENTRE RESILIENT POWER SUPPLY STRATEGY (continued)

210 MW HPC Data Centre Example - ALERNATIVE SOURCE OF ENERGY TO FULFILL DATA CENTRE 72 HOURS OF PEAK POWER SUPPLY - POWER SOURCE RESILIENCE

One the assumptions made, that the BESS Battery Storage would provide 24 hours Resilient Power Capacity. The outstanding 48 hours of Resilient Electrical Power to the Data Centre, with a maximum peak of 210 MWh and an estimated average 24 hour consumption of 153 MWh, would equate to a total requirement of 7.4 GWh of Electrical Power, to be generated from Household Waste.

Continuing the assumption of the number of 36,000 Residential households connected to the HPC Data Centre (average: 3 occupants/ house), generating the quantities of Waste described in the previous paragraphs have been estimated to:

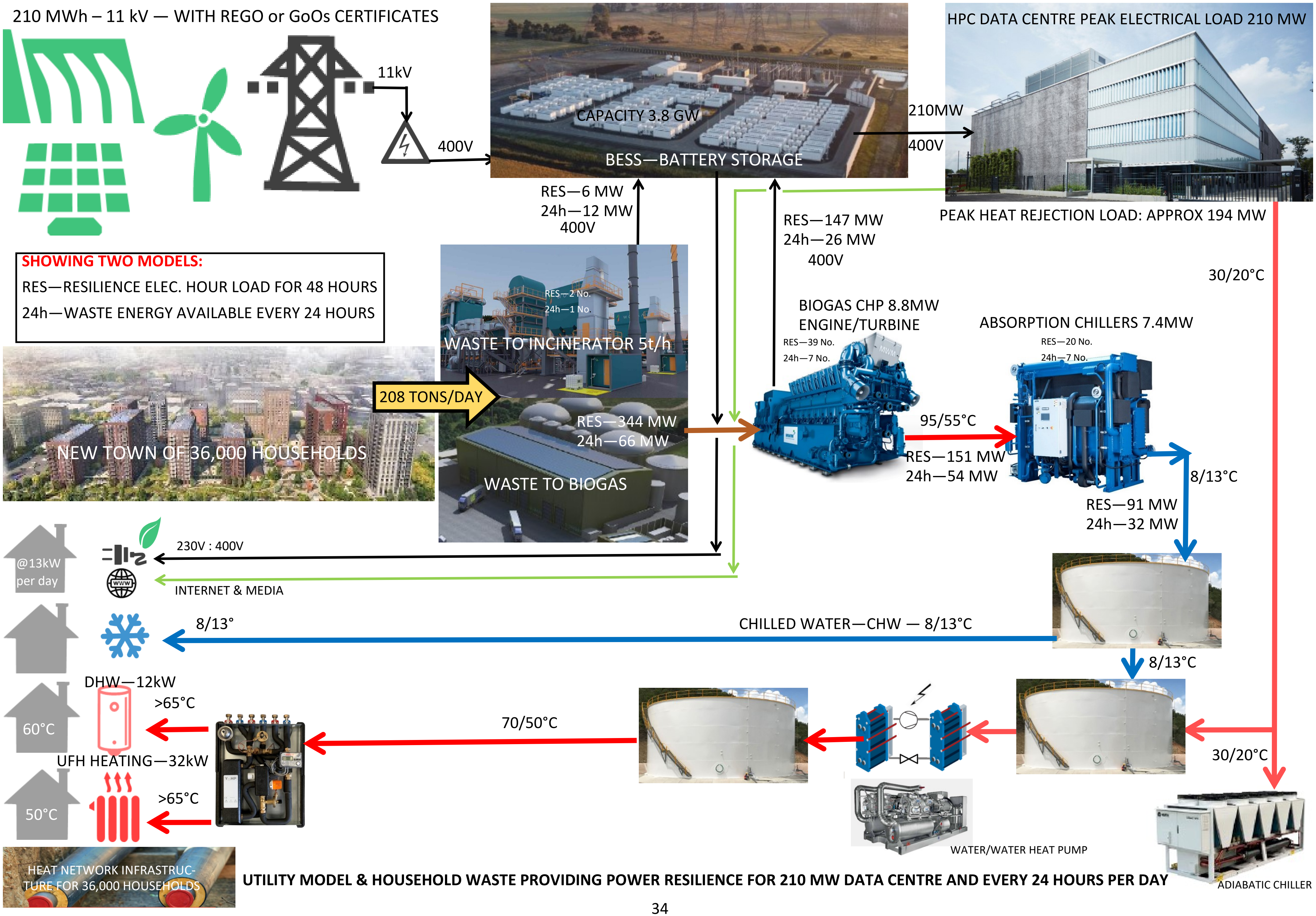
- Waste Energy generated annually - Anaerobic Digestion - 24 GWh; Combustible Waste - 18 GWh; Note: In this example Agricultural Waste has not been included due the location of the proposed Data Centre, but in a smaller City Urbanisation this would probably not be the case, therefore potentially adding a large additional Energy stream of a similar scale demonstrated.

- Outstanding 48 Hour Data Centre Electrical Power Resilience Requirement - From the Annual Waste Energy outputs it has been calculated that a combination of using of both Energy Waste Streams can generate 153 MW of Electrical Power, for 48 consecutive hours, in addition also 91 MW of 13/8 °C Chilled Water (CHW) (for 48 hours) that can be used to reduce the Data Centre Heat Rejection Load/ Adiabatic Water Consumption. There is also sufficient Electrical Power and Chilled Water capacity to provide Utility Services to the Household Infrastructure, capacity depending on the time of day and requirements from the Data Centre.
- It was calculated that to fulfil the 48 hours Data Centre Power Supply Resilience requirement would require to store Household waste in reserve: 7% of annual Household output of Combustible Waste (compressed and bailed; volume 800 m3) and 69% of the annual Household output of Anaerobic Digested Methane Gas (compressed to 300 bar pressure; volume 115m^3).

- The daily output of Energy from the Household waste streams, that can be consumed by the Data Centre and/or to the Household Utility Services has been estimated to 54 MW of Electrical Power (Households average daily Electricity requirement of 468 MW) and 23 MWh of 13/8 °C Chilled Water (CHW). Obviously both Energy outputs can be stored to be consumed when the Loads dictate during the 24 hour period.

- The Performance of the Plant, in the configeration demonstrated in the Schematic below, to enable these transformation of Energy can be listed as:
- 48 hours of Resilient Power for the Data Centre: Waste Energy used per hour: 379MW (Solid 25MW, Liquid 344MW) providing Output per hour - Electrical Power 153MW & CHW(8/13) 91MW

Daily output (during 24 hours) from the Household Waste: Input 115MW (Solid 12MW, Liquid 66MW) providing Output per 24 hours - Electrical Power 38MW & CHW (8/13) 32MW


210 MWh – 11 kV — WITH REGO or GoOs CERTIFICATES
11kV
400V
CAPACITY 3.8 GW
BESS—BATTERY STORAGE
210MW
400V
HPC DATA CENTRE PEAK ELECTRICAL LOAD 210 MW
PEAK HEAT REJECTION LOAD: APPROX 194 MW
RES—6 MW
24h—12 MW
400V
RES—147 MW
24h—26 MW
400V
30/20°C
SHOWING TWO MODELS:
RES—RESILIENCE ELEC. HOUR LOAD FOR 48 HOURS
24h—WASTE ENERGY AVAILABLE EVERY 24 HOURS
RES—2 No.
24h—1 No.
WASTE TO INCINERATOR 5t/h
BIOGAS CHP 8.8MW
ENGINE/TURBINE
RES—39 No.
24h—7 No.
ABSORPTION CHILLERS 7.4MW
RES—20 No.
24h—7 No.
208 TONS/DAY
NEW TOWN OF 36,000 HOUSEHOLDS
RES—344 MW
24h—66 MW
WASTE TO BIOGAS
95/55°C
RES—151 MW
24h—54 MW
8/13°C
RES—91 MW
24h—32 MW
@13kW per day
230V : 400V
INTERNET & MEDIA
8/13°
CHILLED WATER—CHW — 8/13°C
8/13°C
DHW—12kW
>65°C
60°C
70/50°C
30/20°C
UFH HEATING—32kW
>65°C
50°C
WATER/WATER HEAT PUMP
HEAT NETWORK INFRASTRUCTURE FOR 36,000 HOUSEHOLDS
UTILITY MODEL & HOUSEHOLD WASTE PROVIDING POWER RESILIENCE FOR 210 MW DATA CENTRE AND EVERY 24 HOURS PER DAY
ADIABATIC CHILLER

SECTION 12 - ALTERNATIVE DATA CENTRE RESILIENT POWER SUPPLY STRATEGY (continued)

ANALYSIS OF DATA FROM A MODEL OF PROVIDING AND RESOURCING DC POWER SUPPLY RESILIENCE, BY UTILISATION OF WASTE STREAMS FROM 36,0000 HOUSEHOLDS

NOTE: No Diversity or Modelling has been used to generate this data from Calculations. Also data used assumed Peak Loads and average consumption over a time certain period, has been a derivative from Peak Loads. The aim of the calculations is provide a scale of the Solution and provide guidance on the viability of the proposed Model.

Annual output from 36,000 Households has been estimated to total 52 GWh, which would be used as storage capacity dictates. Liquid Waste Digester output (Methane/ Biogas) has the advantage of being able to be compressed to reduce storage Volume. Therefore the majority (97%) of the 24 hours of Data Centre Power Resilience Load (151 MW/hour) was generated by Methane/Biogas to generate 400v Electricity, from a storage of 155 m3, compressed to a pressure of 300 bar. It would be assummed that this fuel would turned over regularly, but always ensuring this capacity is available if the HV Grid has to be disconnected from the DC Systems.

The Solid Waste has the disadvantage of requiring significant storage, even if compacted down to 600 kg/m3 bails, when compared with Energy density of Liquid waste compressed gaseous output. Therefore Solid Waste would be consistently burnt, whenever enough material had been collected to ensure the efficient use of the 5 ton per hour Incinerator. The CHP Turbine section of the Incinerator has the option of only producing Electrical Power (at a lower efficiency) or a combination of Electrical Power and Hot Water above 95 °C. The optimum output makeup would have to be modelled.

Hot Water (above 95 °C) generation from both Solid and Liquid CHP Plants, would primarily be used for the generation of Chilled Water CHW 8/13 °C, via the use of Absorption Chillers. Though there may be the requirement to raise the Flow temperature (<70 °C) of the Space Heating/DHW Heat Network when ambient temperature drops to extremely low temperatures or a sudden peak load occurs.

As the principal CHW load will be required during high ambient temperatures, to reduce the need of using the DC Chiller Plant or Household/Building air conditioning requirements, there will be a need to store Waste to model the CHW Load.

The continuous final product from the Anaerobic Liquid Digester, after harvesting the biogas biproduct for compression, will be an odourless solid digestate but potentially high in Nutrients , suitable for soil amendment.

Plant Selected to illustrate Model:

Biogas CHP Engine/Turbine selected for calculations were 8.8 MW MSM TCG 2032 V16, providing 3.8 MW Electricity (400v) & 3.5 MW Hot Water (>95 °C). DC Power Resilience (for 24 hours) 39 units required; Household Waste Generation per day 7 units required. (Ref. 15)

Absorption Chiller selected for calculations were 7.4 MW World Energy Model:2AB1300, providing 4.6 MW Chilled Water CHW (8/13 °C). DC Power Resilience for Heat Rejection Load (for 24 hours) 20 units required; Household Waste Generation per day 7 units required. (Ref. 16)

Incinerator CHP selected for calculations were 5 ton/hour Sumitomo Modular Waste-to-Energy , providing 3.7 MW of electricity OR 2 MW of electricity and 10 MW (>95 °C). DC Power Resilience for Heat Rejection Load (for 24 hours) 2 units required; Household Waste Generation per day 1 unit required. (Ref. 17)

SECTION 12 - ALTERNATIVE DATA CENTRE RESILIENT POWER SUPPLY STRATEGY (continued)

REMOVAL OF C0² EMMISSIONS FROM CHP EXHAUST—DURING COMBUSTION OF METHANE GAS & SOLID WASTE

Main Processes for CO2 Removal:
Post-combustion Capture:
How it works: In this method, CO2 is captured after the fuel has been burned. The exhaust gases from the CHP unit are passed through a solvent (commonly amine-based solutions) that absorbs the CO2. The solvent is then heated to release the captured CO2, which can be compressed for storage or utilization.
Effectiveness: Post-combustion capture can remove up to 85-95% of CO2 from the flue gas, depending on the technology used. This method is widely used due to its adaptability to existing CHP systems.

Oxy-fuel Combustion:
How it works: This method burns fuel in pure oxygen instead of air, which results in a flue gas composed mainly of water vapor and CO2. The water vapor is condensed out, leaving concentrated CO2, which can be captured more easily.
Effectiveness: Oxy-fuel combustion can capture up to 95-98% of CO2. However, this technology is more complex and expensive due to the need for an oxygen production unit.

HYDROGEN GAS PRODUCTION AS AN ALTERNATIVE

- It should be noted that the CHP (Combined Heat & Power) Engine would require a C0² Scrubber (and removal of other gases) on the Exhaust to minimise the Carbon Emissions. This technology is approximately 85% efficient, if a use for all the low grade heat can be found from the combustion process. In the near future inefficient combustion could be replaced by using a transformation of energy using chemical reaction, promoted by the use of Fuel Cells.

- Anaerobic Digested Methane Gas production should be improved by using waste heat, such as from the CHP Engine (55 °C), to generate a Thermophilic process, which is a biotechnology process that invigorates the microorganisms to break down organic waste more efficiently. Not only does it increase the Biogas yield (higher methane content), but also reduces the risk of pathogens in the final solid, odourless residue, the digestate, enabling the nutrient content to be used as fertilizer.

- Thermophilic conditions (55°C) can also enhance hydrogen yields, by the adaption of the process to accelerate the suppression of Methane-producing microbes (methanogens) through process conditions or by using specific microbial inhibitors. This Photo fermentation process or After dark fermentation, allows certain bacteria to use light to further convert VFAs into additional hydrogen, which would ensures that hydrogen-producing bacteria would dominate the system.

- Hydrogen production has significant advantage of not producing C02 during the process of generating electrical power - hydrogen is an efficient energy storage system (10.8 MJ/m3) and hydrogen produced can be used in fuel cells (50%-60% efficient process), to generate electricity. One ton of Anaerobic Digestion can be estimated to generate 60 to 120 m3 of Hydrogen equating after passing through a Fuel Cell into 324 MJ (90 kWh) to 778 MJ (216 kWh) of Electrical Power.

- The principal disadvantage is that hydrogen has a lower energy density by volume compared to methane (biogas), but a higher energy density by mass. i.e. One m³ of methane has an energy content of approximately 35.8 megajoules (MJ).

Calculations of Resilient Power Supply can be seen in the Appendix (Section 16b)

SECTION 13. OTHER INFRASTRUCTION CONSIDERATIONS TO ENABLE THE ALTERNATIVE MODELS TO FUNCTION EFFICIENTLY

The great majority of Urbanisation practices within Developed countries, and probably being copied by Developing countries, were constructed from centuries ago. The most illogical urban waste infrastructure in these times of gradual insecure fresh water supplies due to Climate change, is the thought of using large quantities of potable water to remove our liquid based waste from our Households (and all buildings for that matter).

Sewer drainage infrastructure, sometimes with an inclination of a couple of degrees, will be prone to blockages, and high pumping costs to ensure the waste reaches the Waste disposal plants. At the Sewage Waste Plants more resources are used to dewater the sludge (Rule of Thumb: 0.5 kWh to treat 1m3 of Sewage), or depending on the Environmental guidelines drain it away in Rivers. Gravity Sewer systems that are aged, as a significant percentage in the UK, will result in rainwater and groundwater entering into the sewer network, leading to further inefficiencies.

As the above Model illustrated in Section 12 was proposing use an urbanisation output of sewage and food waste, to fuel Electrical Production (and CHW). A more efficient methodology should be used to reduce collection costs. On the assumption that food waste can use Macerators to liquify the waste (even though Regulations want to ban these in March 2026, to continue manual collections of food waste in little green bags from every household), all the liquid waste can use a vacuum sewage/waste system, to increase efficiencies of collection and processing.

Most people would have experienced a vacuum waste system when flying in an aircraft, but there are a growing number of urbanisations using this infrastructure (Ref. 18)

CONTINUING WITH THE EXAMPLE OF 36,000 HOUSEHOLDS WITH SUBTERRANEAN UTILITIES

Using a vacuum sewer system instead of a traditional gravity drainage system for a large-scale urbanization (such as one with 36,000 households) can lead to substantial benefits in both electrical energy savings and water reduction. Here's an analysis based on typical values:

1. Electrical Energy Savings

Gravity Sewer System: Pumping Requirements: Gravity systems in urban areas often require extensive pumping stations to move wastewater across different elevations. The energy used depends on the topography, distance, and volume of wastewater. For a large urbanization, electricity use for pumping can reach 60-120 kWh per household per year. For 36,000 households, this is around 2.16 million to 4.32 million kWh/year.

Vacuum Sewer System: Lower Energy Consumption: Vacuum systems rely on a few centralized vacuum stations, which are more energy-efficient than multiple scattered pump stations. Vacuum sewer systems can use 40-60% less electricity compared to gravity systems due to the reduced need for continuous pumping over long distances. For 36,000 households, electricity consumption for vacuum systems could be reduced to around 1.3 million to 2.6 million kWh/year.

Annual Electrical Savings: Energy savings: Around 0.86 to 1.72 GWh/year.

2. Water Savings

Gravity Sewer System: Infiltration and Inflow (I&I): Gravity sewer systems are prone to infiltration (groundwater entering through cracks) and inflow (rainwater entering through illegal connections or manholes). This can increase the volume of wastewater, leading to higher water use for flushing and treatment. In urban settings, it's estimated that inflow and infiltration can increase the total volume of wastewater by 20-40%. If each household uses around 150 litres of water per day, this results in about 5,400 cubic meters per day for 36,000 households. With a 20-40% increase due to I&I, the total wastewater volume increases by 1,080 to 2,160 cubic meters per day, which requires treatment and additional energy.

Vacuum Sewer System: Minimal Infiltration and Inflow: Vacuum systems are sealed, reducing inflow and infiltration significantly. Estimates suggest a 90% reduction in I&I with vacuum systems. Water use for vacuum systems is much lower since vacuum pressure is used for movement, not additional water.

Annual Water Savings: Inflow and infiltration reduction: For 36,000 households, the savings could be 394,200 to 788,400 cubic meters of water per year.

3. Additional Environmental and Financial Benefits:

Lower Water Treatment Costs: Reducing the water volume that enters the sewer system reduces the load on treatment plants. With less wastewater, treatment facilities consume less energy and chemicals. Operational Efficiency: Vacuum systems are generally more reliable, with fewer blockages and maintenance needs, contributing to long-term cost savings. These savings not only translate to lower operational costs but also contribute to a more sustainable and efficient urban sewer system,.

SECTION 14 - A POTENTIAL REVENUE MODEL FOR A LOCAL GOVERNMENT & DATA CENTRE PARTNERSHIP

As of recent data, internet purchasing in the UK accounts for a significant portion of overall retail sales, particularly when compared to high street purchases.
In 2023:

- Online sales accounted for approximately 25-30% of total retail sales in the UK.
- The remaining 70-75% of sales were made in physical stores, primarily on the high street.

This shift towards online shopping has been influenced by the growth of e-commerce platforms and changing consumer habits, with the pandemic accelerating the trend. However, physical stores still make up a larger portion of overall retail, though the gap continues to close. These percentages can fluctuate depending on the time of year (e.g., holiday seasons), specific sectors (like electronics vs. groceries), and broader economic conditions.

Local Authorities/Government are presently under financial stress with a large part of their revenue Model disappearing, from a reduced local taxation from the local commerce on the High Street, due to changes of purchasing using the Internet (via Data Centres), via on-line commerce providers such as Amazon. With the decrease of Revenue there is an expectation from the Local Residents for additional support Services expenditure, a good example being the combination of demographics with generations of improved health care, generating a larger proportion of elderly Pensioners requiring Local Services. With the additional requirement of providing low cost housing already mentioned in Section 10.

Therefore there is the requirement for Local Government in finding other sources of Revenue. The requirement of Distributing Infrastructure with the layout of the Local Governments area of responsibility, will need a significant input from them to enable both Models illustrated above to come into fruition.
If both Models (from Sections 10 & 11) were put into effect the Local Government/Data Centre Partnership would provide a wide selection of Utility Services to the connected Households. The utility Services provided: Hot Water (Space Heating & DHW), Electrical 230v Power, Internet/Media Services, Waste Services (Black Water & Household Waste) and potentially CHW for A/C. If Serving a Household a Community of 36,000 households, would generate revenues, plus more importunately a sustainable lifestyle to the Community served.

Combined utilities costs (electricity, gas, and internet/media) during 2024 in the UK for an average household is £125 - £180 per month. Therefore providing Utility Services indicated for 36,000 households could generate an average Revenue Stream of £5.5 Million per month, which is a benifical starting point for any partnership.

Just some of the potential Partner Services and inputs a Local Authorities/Government would contribute, to enable the Models to come into effect:

Provide planning guidance & information that incentivise the investment of a HPC Data Centre and provide a structured Contract to allow long term collaboration and partnership with Local Authorities/Government.
Provide planning guidance to undertake and promote a Residential House Construction Programme, in the locality of the proposed HPC Data Centre
Provide guidance and mandatory Regulation for residential house construction, to Design and Construct the building services to use the Utility Services (Hot Water, 230v/240v Electricity, Cooling, and Internet). Provide a Provide and administer a Metering system to monetise the Utility Services, with subsidies on local taxes to provide incentives for Engagement.
Provide the planning guidance and Investment mechanisms for the installation and maintenance of a district subterranean trench systems, via communication routes of the Urbanisation, to distribute the Utility Services.
Provide the planning guidance and administrative structures to manage the transition of improved utilisation of Residential/Commercial Waste streams (Food & Agricultural Waste, Combustible Waste and revised Sewage treatment Processes).

SECTION 14 - A POTENTIAL REVENUE MODEL FOR A LOCAL GOVERNMENT & DATA CENTRE PARTNERSHIP (continued)

MODERNISING OF EXISTING URBANISATIONS

The majority of the Urbanisations built in Developed Countries have evolved from historical and cultural heritage, which should be protected and cherished. With the threat of Global Warming, the Building Regulations and Building practices are becoming more extreem to try and reduce the risks to the populations and societies in those countries. It should be also one of the principle guidelines for Local Authorities/Government to ensure they respect these risks will occur to their communities, and prepare for these threats.

Modernising Infrastructure and Practices definitely fall within the remit of Local Authorities/Government, especially when the changes can be financed by a Revenue Model. Therefore it would be expected that older more established parts of Urbanisations could take advantages from the proposed Models.

SECTION 15 - SUMMARY & CONCLUSIONS

As the demand for data centres continues to surge, especially in response to the rise of AI, machine learning, and high-performance computing, the need for efficient and sustainable solutions becomes critical. The concept of Ultra-Density Data Centres pushes the boundaries of power and cooling demands, forcing a revaluation of traditional methodologies. This white paper presents a future-focused vision where data centres can not only meet their own operational needs but also contribute to broader urban sustainability goals by acting as utility providers.

Through innovative HVAC strategies such as liquid cooling, adiabatic systems, and the integration of data centre heat rejection for residential heating, there is an opportunity to turn data centres into energy hubs for local communities. These advanced cooling techniques not only improve the efficiency of high-density data centres but also provide a secondary benefit—turning heat waste into valuable resources for residential areas. This dual-purpose approach aligns with global sustainability goals, particularly in urban environments like London, where data centres can play a key role in achieving Net Zero targets.

Moreover, by exploring resilient power supply models, including the shift from traditional diesel generators to battery storage and alternative fuel sources, the data centre industry can significantly reduce its carbon footprint. These alternative models offer long-term resilience while contributing to local grid stability, enhancing both economic and environmental outcomes.

In conclusion, the future of data centres lies in their potential to evolve beyond traditional infrastructure, becoming integral components of urban eco-systems. By adopting sustainable cooling technologies, leveraging renewable energy sources, and integrating heat recovery systems, data centres can shift from being energy consumers to energy providers—supercharging societal progress while supporting critical environmental commitments. This holistic approach not only addresses the technical challenges of the future but also positions data centres as vital players in the push toward a sustainable, resilient, and digitally empowered world.

REASONING WHY THE AUTHOR COMPILED THIS PAPER:

With +30 Years experience of Consultancy in Mechanical Engineering HVAC Design, with R&D&I in the application of Renewable Energy Solutions within Buildings, has allowed the understanding of how Data Centres have evolved, and the potential limitations and risks that could rerail the HPC DC growth, as AI and machine learning applications advance. Whilst waiting for the UK’s economy to initiate further Investments, and provide me with a new challenging Project, has provided me with the time to research and compile this White Paper.
https://www.linkedin.com/in/neil-turley-17651613/

SECTION 16a & 16b - APPENDIX - ALTERNATIVE MODEL CALCULATIONS - Indication of Assumptions made to illustrate a Scale of the Model.

Obviously additional Modelling of multiple Variables and Assumptions will be required to develop a Stage 2 (RIBA) Project

Calculations for reuse of DC Heat Rejection can be seen in the Appendix (Section 16a)

HOUSING OUTPUTS

HEATING - 8 Months

	PER HOUSE	**AVERAGE MAX DAILY LOAD kW**
DHW	250l/day	12
HEATING	8 months/y	32
		44
ELECTRIC	EQUAL/DAY	**13**

SUMMER - 4 Months

	PER HOUSE	**AVERAGE MIN DAILY LOAD kW**
DHW	250l/day	12
HEATING	SUMMER	0
		12
ELECTRIC	EQUAL/DAY	**13**

HEATING LOAD PER YEAR/ HOUSE

12,000 kW

ELECTRIC LOAD per YEAR / HOUSE

13 kW/day

HOUSES ASSUMED

36,000 HOUSES 3 Persons/H

HEATING TOTAL LOAD/ year

432,000,000 kW

65,929 kW - Average per hour over 24h Load

DHW TOTAL LOAD/ year - SUMMER

418,000 kW

17,417 kW - Average per hour over 24h Load

ELECTRIC LOAD / year

170,820,000 kW

19,500 kW - Average per hour

SECTION 16a & 16b - APPENDIX - ALTERNATIVE MODEL CALCULATIONS - Indication of Assumptions made to illustrate a Scale of the Model.

Calculations for reuse of DC Heat Rejection can be seen in the Appendix (Section 16a) CONTINUED

MODEL 1 - 210 MW DATA CENRE HEAT REJECTION LOAD UPGRADED AMMONIA HEAT PUMPS TO PROVIDE HEATING/DHW TO RESIDENTIAL HOUSES

100MW DATA CENTRE - SUSTAINABLE MODEL ASSUMPTIONS Specific Heat Water SpW - kJ/kg.°C - Glycol 20% - 3.56 kJ/kg.°C , Tank stored water Glycol 0% - 4.18 kJ/kg.°C

									DATA CENTRE TOTAL
	CHW °OUT	CHW IN	KW input	FLOWRATE(m³/h)	AV. SpW	FLOWRATE(kg/s) x 6	**HEAT REJECT. MW**		IT PEAK LOAD MW
DATA CENTRE CHW COOLING (PART OF)	30	20		5,245	3.56	242.8	51.87		**194**
							27%		19,618
	STORAGE (m³)	CHW °C OUT	CHW ° C IN	STORAGE CAP (hours)	AV. SpW	ENERGY STORED MJ	NO DIVERSITY incl.		FLOWRATE(m³/h)
MILLION LTR CHW STORAGE TANKS x 2	20,000	20	30	3.81	4.18	836,000			
							Ammonia Refrigerant		
							No. HPs	COP	Elec MW - hourly
DC COOLING & HOT WATER UPGRADE - WATER/WATER HEAT PUMP SABROE DualPAC 716-W					**38 UNITS**		38	4.6	14.25
	CAPACITY (MW)	CHW OUT	CHW IN	FLOWRATE(m³/h)	AV. SpW	INPUT(MW)	FLOWRATE(kg/s) x 2		
EVAPORATOR SIDE	1.365	20	30	5,245	3.56	51.87	728.5		
	CAPACITY (MW)	CHW OUT	CHW IN	FLOWRATE(m³/h)	AV. SpW	OUTPUT(MW)	FLOWRATE(kg/s) x 2		
CONDENSER SIDE	1.74	70	50	3,343	3.56	66.12	464.3		
				PEAK WINTER UTILITY					
	STORAGE (m³)	CHW °C OUT	CHW ° C IN	STORAGE CAP (hours)	AV. SpW	ENERGY STORED MJ			
MILLION LTR HEATING STORAGE TANKS x 2	20,000	50	70	7.04	4.18	1,672,000			
							FLOWRATE(m³/h)	FLOWRATE(kg/s) x 4	
FLOW OUT TO HOUSING HEATING - DISTRICT HEATNG/ HEAT NETWORK							2,839	197.2	
WASTE HEAT IN SUMMER (only DHW Load) - Required to be rejected				Av 24h.DHW LOAD MWl	**No.Heat Pumps**	HEAT REJECTION MWh	Elec MWh - hourl	COP	
				17.42	10	13.70	3.75	4.6	
ELECTRICAL STORAGE RESILIENCE			HEAT GENERATED		COP				
DC PEAK FACILITY LOAD REDUCTION	During Summer	MW		MW	4.58				
AMMONIA HEAT PUMP PEAK LOAD	14.25	MW	66	MW					

SECTION 16a & 16b - APPENDIX - ALTERNATIVE MODEL CALCULATIONS - Indication of Assumptions made to illustrate a Scale of the Model. (continued)

Calculations of Resilient Power Supply can be seen in the Appendix (Section 16b)

ANEROBIC DIGESTION OF DOMESTIC ORGANIC AND LIQUID WASTE

ANAEROBIC DIGESTION - Based on 3 x Waste Streams - Food Waste, Black Waste Water & Animal Waste

DOMESTIC (HOUSEHOLD) FOOD WASTE

Assume a municipal population of 1 million people.(AI Output) 182.5 kg/year/person with 45% organic waste **82.13** Organic Waste Volume kg/ year / person

0.26 m³ generated thermophilic methane /kg **21.35** m³ - Volume Methane /year /person 35.8 Methane Energy megajoules (MJ) per m³

https://www.eufic.org/en/food-safety/article/food-waste-in-europe-statistics-and-facts-about-the-problem Therefore = **212.34 kWh per person/year**

https://www.eu-fusions.org/phocadownload/Publications/Estimates%20of%20European%20food%20waste%20levels.pdf

https://www.gov.uk/government/statistics/united-kingdom-food-security-report-2021/united-kingdom-food-security-report-2021-theme-2-uk-food-supply-sources

DOMESTIC (HOUSEHOLD) SEWAGE PROCESSING **Note:** ENERGY CONSUMPTION BY PRESENT SEWAGE PROCESSING MODEL - i.e. ONLY To treat waste water -

Assume 80 grams (0.08 kg) of volatile solids generated and disposed per person per day. **29.20** Sewage Sludge Waste Volume kg/ year / person

Sewage Sludge Processing: 0.08 kg/day × 365days = 29.2kg/person per year 0.033 m³/kg - Methane yield from thermophilic sewage sludge digestion about 0.033 cubic m³/ kg of volatile solids (VS) destroyed.

Methane Production per person/ year (m3/year) **0.96** m³ of methane has an energy content of approximately 35.8 megajoules (MJ) Therefore = **9.58 kWh per person/year**

FEASIBILITY STUDY IN SEWAGE TREATMENT PLANT PROJECT, UTILIZATION OF BIOGAS PRODUCED IN AN ANAEROBIC DIGESTER - Konstantinos Stavridis - Tech Library© 2004

If an anaerobic digestion (AD) plant is operated at 55°C, within the thermophilic range (50–60°C), the methane biogas output from sewage sludge and food waste is likely to increase.

Thermophilic conditions enhance the rate of organic matter breakdown, which can lead to faster digestion and higher methane yields compared to mesophilic conditions (35–40°C).

Under thermophilic conditions, methane production from sewage sludge can increase by about 20–30% compared to mesophilic digestion.

Improved Food Waste Methane Production From: 200 m3/ton Average To: 260 m3/ton Improved Sewage Waste Methane Production From: 25m3/ton Average To: 33 m3/ton

36,000 RESIDENTIAL HOUSES - SEWAGE & BIOGRADABLE WASTE EQUIVALENT ENERGY/YEAR 23,967 MWh per year

Methane - Food Waste volume / year	2,306,070 m3	FROM	8,869,500	kg - original feedstock / year
Methane - Sewage Sludge volume / year	104,069 m3	FROM	3,153,600	kg - original feedstock / year
(at atmospheric Pressure)	**2,410,139 m3**		**12,023,100**	**kg**

Small to Medium-Sized Plant: Serves a population of around 50,000 to 100,000 people.

32,940 kg Capacity: Typically processes around 50 to 150 tons (50,000 to 150,000 kg) of combined sludge and food waste per day.

Retention Time (Hydraulic Retention Time - HRT) - Digstion Processing Time

Total Volume = Daily Volume × Retention Time (HRT) using 30 day Retention Time

Total Volume processed = 6,603 m3/day × 30 days HRT = 198,094 m3

Typical Densities after Digestion Process:

Sewage Sludge: The density of dewatered sewage sludge typically ranges from 600 to **1,200 kg/m³.**

Organic Food Waste: The density of food waste typically ranges from 500 to **800 kg/m³.**

DAILY HOUSEHOLD GENERATION TOWARDS UTILITY POWER SUPPLY - Biogas/Methane to Multiple CHP Engines

32.94 tons - Original Feedstock - sewage and food waste

66 MWh Methane/Biogas Energy to be used over a 24 hour period

6,603 m3 - Stored area

BioGas (Methane) for DC Resilience would be reduced in Volume to

RESILIENCE POWER SUPPLY - Biogas/Methane to Multiple CHP Engines

70 HOURS- Yearly Production if Consumed over number of hours & Stored

172 tons used per Hour - Original Feedstock - sewage and food waste

16,435 MW/h to be used over an hour period (for 48 hours)

115 m3 (compressed to 300 Bar Pressure)

SECTION 16a & 16b - APPENDIX - ALTERNATIVE MODEL CALCULATIONS - Indication of Assumptions made to illustrate a Scale of the Model. (continued)

Calculations of Resilient Power Supply can be seen in the Appendix (Section 16b) (continued)

SOLID COMBUSTABLE WASTE

Per Household: Approximately **200**-300 kg of waste per year is incinerated. Therefore Total weight of waste per year for all Households 7,200 ton/ year

The calorific value of household waste varies depending on its composition, but a typical value is around 7-12 MJ/kg (megajoules per kilogram) for mixed municipal solid waste.

Using a midpoint value of 9 MJ/kg - Total Energy Content: Calorific value 1,800 MJ (500 kWh) into heat and electrical energy output in kWh:

36,000 HOUSEHOLDS - COMBUSTABLE WASTE EQUIVALENT ENERGY/YEAR 18,000 MWh per year — EQUIV. ELECTRIC DAILY OUTPUT - MWh 12

Heat Output: Typically, incinerators can achieve efficiencies of 70% for heat.

Electrical Output: For electrical generation, efficiencies are generally lower, around 20-30%.

If we assume 85% efficiency for heat Recovery.

Assume 25% efficiency for electricity: Electrical Energy Output = 500 kWh × 0.25 = 150 kWh

Assume Heat Energy Output HW above 90°C = 500 kWh × 0.6 = 300 kWh

19.7 tons - Average Incinerator consumption per day

ANNUAL BREAKDOWN OF ENERGY TYPES GENERATED FROM INCINERATORS

Therefore Electrical Energy Output	**4,500 MWh/year**
Heat Energy Output over 90°C / year	**10,800 MWh /year**

DAILY HOUSEHOLD GENERATION TOWARDS UTILITY POWER SUPPLY - Incinerators

19.73 tons - Compressed Feedstock - Combustible Household Waste

29.59 **MWh Heat Energy (over 90°C) to be used over a 24 hour period**

12.33 **MWh Electrical Energy to be used over a 24 hour period**

RESILIENCE POWER SUPPLY - Based on Incinerator Waste Processing Rate - ton/hour

Processing for 48hr period	10 **tons/ hour**
Electrical Output	6 **MW/hr per hour for 48 hours**
Heat Output over 90°C	15 **MW/hr per hour for 48 hours**

equivalent to average 720 HOURS - Yearly Production if Consumed over a number of hours & Stored

30 days

Minimum Storage (to cover DC 48 hour Resilience) 800 **m3 of ventilated storage**

STORAGE OF WASTE - **Compacted MSW (600 kg/m³)**: Loose MSW: The density typically ranges from 100 to 300 kg/m³ (kilograms per cubic meter).

ANEROBIC DIGESTION OF DOMESTIC ORGANIC AND LIQUID WASTE

ANAEROBIC DIGESTION - Based on 3 x Waste Streams - Food Waste, Black Waste Water & Animal Waste

(NOT INCLUDED AS URBAN AREA BASED IN EAST LONDON MAY NOT HAVE ANY NEARBY FARMS)

ANIMAL & AGRICULTURAL WASTE - Additional Waste Energy Resource

UK Farm Primary Production Food Waste - 2020	7,200,000 tonnes
UK Cow Population - 2022 - Production waste	1,850,000 population

https://www.gov.uk/government/statistics/united-kingdom-food-security-report-2021/united-kingdom-food-security-report-2021-theme-2-uk-food-supply-sources

TYPICAL OUTPUTS - Average CHP Elec outputs - Lansing. Et al 2019 Bioresource Technology

Cow - 3.5 kWh/day

Dairy Manure - CH_4 220L/kg

Dairy Manure (stored) - CH_4 100L/kg

Food Waste (Heated) - CH_4 500L/kg

Grass/Corn Silage - CH_4 300L/kg

METHANE

Methane(CH_4) 55% to 75% -	35.8 MJ/m3
Scrub C02 - to 99% -	9.94 kWh/m3

80 Cow (5m3 manure) + Energy Crops (5.5t corn silage/day) + Food waste (10t /day) = 1,200 m3 CH_4/day = 200 kWh/day (Elec), which = 11,933 kWh /day

SECTION 16a & 16b - APPENDIX - ALTERNATIVE MODEL CALCULATIONS - Indication of Assumptions made to illustrate a Scale of the Model. (continued)

Calculations of Resilient Power Supply can be seen in the Appendix (Section 16b) (continued)

SUMMARY - ENERGY/FUEL GENERATED FROM 36,000 HOUSEHOLDS WASTE STREAMS - TO COVER RESLIENCE LOAD OF DATA CENTRE - EVERY HOUR FOR 48 HOURS PRODUCTION USAGE

24 HOUR CHW & ELECTRICAL CAPACITY GENERATED FOR DATA CENTRE / HOUSEHOLD DAY LOAD - TO PART RECHARGE BATTERY STORAGE & PROVIDE CHW TO DC OR HOUSEHOLDS

24 hr 13/8 °C CHW Capacity	31.94	MW per hour (from Absorption Chiller)
24 hr Electrical Capacity generated	38.68	MW per hour (from CHP & Incinerators)

HOURLY GENERATION OF CHW & ELECTRICAL POWER FOR DATA CENTRE RESILIENCE LOAD - FOR 48 HOURS - RECHARGE BATTERY STORAGE & LOWER TEMPERATURE OF CHW DC STORAGE TANK

RESILIENCE 13/8 °C CHW Capacity	91	MW per hour (from Absorption Chiller) - TO BE USED FOR: CHW to reduce need for Chiller usage & Residential A/C
RESILIENCE Electrical Capacity generated	153	MW per hour (from CHP Turbine) - TO BE USED FOR: Recharging 4.2GWh BESS Battary Storage - DC Resilience & Residential 230v Utility

FUEL/ENERGY USED OVER 48 HOURS TO GENERATE RESILIENT CHW & ELECTRICAL CAPACITY FOR DATA CENTRE RESILIENCE LOAD - REQUIRE 7.4 GWh for minimum 250 MWh per hour

ANEROBIC DIGESTION OF LIQUID WASTE	16.43	GWh (processed by CHP)	STORAGE REQ'D	115	m3 -EQUIV. % OF ANNUAL OUTPUT	**69%**
SOLID BURNABLE WASTE	1.20	GWh (processed by INCINERATOR/CHP)	STORAGE REQ'D	800	m3 -EQUIV. % OF ANNUAL OUTPUT	**7%**
	17.63	**GWh**				

DATA CENTRE POWER RESILIENCE 48 HOUR LOAD - CHP & ABSORTION CHILLER PLANT TO PROCESS ANEROBIC DIGESTION OF DOMESIC OGANIC AND LIQUID WASTE

ABSOPTION CHILLER -	CAPACITY (kW)	HW OUT	HW IN	FLOWRATE(m³/h)	AV. SpW	Each OUTPUT(kW)	NUMBER OF	**NET OUTPUT - hourly**	
World Energy	7,431	55	95	3,200	4.18	7,431	CHILLERS	148,622	kW
Model:2AB1300		COOL ING IN	COOLING OUT	FLOWRATE(m³/h)	AV. SpW		20		
		31	36.5	36,840	4.18	11,763		235,264	kW
	USED ELEC (kW)	CHW OUT	CHW IN	FLOWRATE(m³/h)	AV. SpW				
	196	8	13	15,720	4.18	4,563	CHW (7/12)	91,263	kW

CHP OUTPUT -		CAPACITY (kW)	HW OUT	HW IN	FLOWRATE(m³/h)	AV. SpW	OUTPUT(kW)	NUMBER OF	**NET OUTPUT - hourly**	
MSM		7,582	93	80	3,434	3.56	3,484	CHP UNITS	135,863	kW
TCG 2032 V16	**BIOGAS USED (kW) per hour**			39.70%				39		
		8,775	ELEC	EFFICIENCY	USED ELEC kVA					
	Overall Efficiency	86.40%	400v	42.90%	585		3,764	ELEC (400v)	146,815	kW

SECTION 17 - APPENDIX - WHITE PAPER REFERENCESAND LINKS TO INFORMATION USED

(Ref 1) 5 Principle cloud service providers and internet content companies, of Amazon Web Services Inc., Google Cloud, Meta Platforms Inc., Microsoft Corp. (Azure) and Oracle Corp. (Oracle Cloud)

(Ref 2.) 2023 Uptime Institute Global Data Centre Survey Report - https://uptimeinstitute.com/about-ui/press-releases/uptimes-13th-annual-global-data-center-survey-shows-widening-range-of-challenges

(Ref. 3) https://www.vertiv.com/4a0316/globalassets/products/thermal-management/thermal-control-and-monitoring/lieber-icom-cwm---the-advanced-chilled-water-plant-manager-control/vertiv-chilled-water-solutions-wp-en-emea-web.pdf

(Ref. 4) - Figure XXX Water cooling load trends from 2010 to 2017. - Ref: White Paper Developed by ASHRA E technical Committee 9.9
(Ref. 5) https://datacentercatalog.com/news/2024/navigating-data-center-power-density-in-the-age-of-hpc-and-ai

(Ref. 6) VERTIV WHITE PAPER - https://www.vertiv.com/49d8ee/globalassets/documents/white-papers/vertiv-liquid-cooling-wp-en-na-sl-70807-web_332687_0.pdf

(Ref. 7) Commercial Electricity Price per kWh LONDON - 27.3p/kWh - https://www.uswitch.com/gas-electricity/studies/business-energy-statistics/

(Ref. 8) Commercial Water Price per m3 LONDON - £2.0722/m3 - https://www.aquaswitch.co.uk/business-water-rates/#:~:text=Volumetric%20water%20charge%20%E2%80%93%20%C2%A3207.22%2C%20calculated%20by,per%20cubic%20meter%20(default%20tariff%20volumetric%20rate)

(Ref. 9) https://www.datacenterdynamics.com/en/news/aws-restricts-data-center-access-in-ireland-amid-power-concerns-report/

(Ref. 10) hydrogen fuel cells to help data centers address their critical power needs - https://www.datacenterfrontier.com/energy/article/33019254/microsoft-knows-future-of-data-center-power-will-be-everything-everywhere-all-at-once

(Ref. 11) - 210MW The 210-megawatt (MW) Docklands AI data centre campus - https://www.romfordrecorder.co.uk/news/24439978.royal-docks-host-one-londons-largest-data-centres/

(Ref. 12) - Hot water Profiles Residential - Daily & Weekly - Hot water Association - www.hotwater.org.uk

(Ref. 13) Example of 450MWh BESS - https://victorianbigbattery.com.au/our-battery/

(Ref. 14) - Large BESS Examples - https://www.quantistry.com/blog/the-largest-batteries-in-the-world

(Ref. 15) - CHP - MSM-TCG 2032-V16 - https://www.mwm.net/en/gas-engines-gensets/gas-engine-tcg-2032/

(Ref. 16) - Absorption Chiller - Model:2AB1300 - https://worldenergy.co.kr/en/portfolio-item/2ab-2/

SECTION 17 - APPENDIX - WHITE PAPER REFERENCESAND LINKS TO INFORMATION USED (continued)

(Ref. 17) - 5 ton/h Incinerator Selection example - https://www.shi-fw.com/our-solutions/energy-from-waste/modular-waste-to-energy-plants/

(Ref. 18) - Small list of example Urbanisations using Vacuum Sewage systems - Almere, Netherlands, Stockholm Archipelago, Sweden, Disney World, Florida, USA, Skelmersdale, UK, Floriade Expo Grounds, Netherlands, The Palm Jumeirah, Dubai, UAE, Sea Ranch, California, USA, Village of Taos Ski Valley, New Mexico, USA, Jubail Industrial City, Saudi Arabia, Ørestad, Copenhagen, Denmark

(Ref. 19) —3 GWh/750 MW BESS— https://www.ctif.org/news/despite-fire-hazards-lithium-ion-battery-energy-storage-systems-are-getting-larger-and-larger

(Ref. Fig 1) Estimate the typical household in England, Scotland and Wales uses 2,700 kWh of electricity and 11,500 kWh of gas in a year.
From <https://www.ofgem.gov.uk/average-gas-and-electricity-usage>

Office Electrical Profile graph - https://www.sciencedirect.com/science/article/pii/S0378778814001224

Residential Space heating, DHW and Electrical profile - 24 hours - https://www.researchgate.net/publication/339670029_Design_of_Heat-Pump_Systems_for_Single-_and_Multi-Family_Houses_Using_a_Heuristic_Scheduling_for_the_Optimization_of_PV_Self-Consumption#pf5

RESIDENTIAL ELEC LOAD PROFILES - https://www.researchgate.net/figure/Typical-residential-house-daily-electricity-load-profile_fig4_343181343