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MSc Energy Systems and the Environment

# *'An investigation into using free cooling and community heating to reduce data centre energy consumption'*

**Submitted in partial fulfilment with the requirements of the degree:**

**MSc in Sustainable Engineering - Energy Systems & the Environment**

**Department of Mechanical Engineering**

**Energy Systems Research Unit (ESRU)**

**Strathclyde University**

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## Declaration of Author's Rights

# Acknowledgements

I would like to thank the WSP Group and Mr Ken McLean for providing me with the opportunity to examine the energy use of the data centre case study investigated in this project. I would also like to thank them for the support they gave me throughout the course of the project.

I would also like to extend my thanks to Dr Michael Kummert for supervising this study. His support and instruction were invaluable. In particular, when learning to use TRNSYS 16, and when debugging the models, without his expertise, this project would not have been possible.

## Abstract

As computer technology becomes more prevalent in businesses of all shapes and sizes, the need for data storage increases. In many cases, data is stored on servers stacked from floor to ceiling, and in rows from wall to wall in buildings called data centres. To keep these servers running, the energy required is enormous, and the energy used to run the computers is emitted from them in the form of heat. So, in addition to the energy needed to keep the data centre running, additional energy is needed to cool the servers to prevent them from over heating. As the need for data centres continues to grow, and as energy resources become both more expensive, and more rare, data centre developers are exploring new ways to energy and cool data centres.

In this project, an eight story data centre in central London will be used as a case study to model the use of waste heat in a community heating scheme for a nearby residential area. This project will determine how much energy is saved by reusing the waste heat, and as a result, by how much the carbon dioxide emissions are reduced. This project will also explore the different ways in which waste heat can be taken from the cooling system to determine the most energy efficient method of cooling the data centre and heating the residential building.

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# Introduction

Climate Change. Global Warming. Green Living. Sustainability. These are the buzzwords of the 21st century. As the public perception of environmentalism is shifting to not only a more acceptable notion, but also a popular one, it is hard to escape the messages that pervade the media and everyday conversation about how to live a more energy efficient life. Individuals are becoming more environmentally conscious with their choices from light bulbs to clothing to fuel efficient cars, but the carbon footprints of industry dwarf an individual's carbon footprint. In particular, data centres.

Data centres are large buildings full of electronic equipment that is operating 24 hours per day. These buildings can require as much electrical power as 1.5 kW per square meter of space for the IT equipment, and new data centres are being built all the time. Engineers have been researching ways to make data centres more energy efficient from both an information technology (IT) and a heating, ventilation, and air conditioning (HVAC) perspective. **The purpose of this report is to identify the most feasible method of saving energy from an HVAC perspective for a data centre case study in London**.

The main body of the report consists of eight sections that cover three broad topics: *Literature Review*, *Methodology*, and *Design Analysis*. The first section covers data centres, and why they are important. This section includes information about a data centre’s electricity load, how that load is allocated, and how that load can be reduced. The second section covers the components likely to be found in a data centre’s cooling system. This section explores the way in which both a chiller and a dry cooler function. From here, the ways in which energy can be saved in a data centre cooling system are explained, since now the reader has an understanding of how the components work. Section three covers one such energy savings method in detail: the community heating scheme. The definition of community heating, the necessities for both the producer and the consumer, and the equipment used in a community heating scheme are all reported in this section. Additionally, this last section of background information covers the building requirements specific to the case study explored in this report.

The methodology section of the report consists of sections four, five, and six. Section four ventures to explain the modelling program, TRNSYS, used in this study. It describes the TRNSYS user interface, and the range of components the program can simulate. Finally, section four describes the TRNSYS components used to model the data centre in this case study. From here, section five details the specifications of the case study HVAC components. Then, this section explains any assumptions made to simulate the data centre, and to modify the data to a presentable form. Lastly, section six explains each of the six case study simulations in detail: the base case, free cooling, and implementing community heating from two places within the cooling system both with and without free cooling. This section's purpose is to create an understanding of the components that were used, the way in which they were modelled, and the purpose of the simulations.

Sections seven and eight cover the *Design Analysis* part of the report. Section seven covers the six simulations, and the results garnered from each one. This section delves into the energy use of each data centre case study option; it explores where the electricity use is going, and where savings, if any, are coming from. Section seven also compares each of the six sections to determine which case provides the most energy savings to the data centre. Finally, section eight will summarise the findings from the study. This section will provide more complete insight into the way in which a data centre works, why it uses the amount of energy it does, and how data centre owners can do their part to reduce their electricity consumption.

# 1. Literature Review

## 1.1. Data Centres

### *What are Data Centres?*

A data centre (also known as a server farm, computer centre, or a data storage and hosting facility) is a building specifically designed to house electrical equipment such as computers, routers, servers, and related computing equipment. These buildings are used to manage digital data and information (Lawrence Berkeley National Laboratory (LBNL), 2008). Many times, the data centre space is rented out to clients in need of a place to house their data equipment, or to act as a hub for their data exchange and processing. Unlike normal office buildings, the primary use of data centres is not to house the employees, but to house the equipment. Office buildings also use computers, servers, routers, and other related computer equipment, but the amount of equipment per square meter of office space is not nearly as large as that of a data centre, and much of the electronic equipment in a standard office building can be, and is, shut off at the end of the regular office day. This cannot be said for data centres — digital information does not sleep, especially in an international market, so data centres run continuously. Additionally, office buildings tend to have a higher employee to equipment ratio than data centres do.

### *Data Centre Energy Use*

According to the US EPA, annually, the average office building annual energy consumption is 166.8 kWh of electricity per square meter, and 2.9 therms of natural gas per square meter (EPA, 2007). Office buildings are usually between 93 and 4,645 square feet, so their average annual energy consumption is between 15.5 and 775 MWh. With a 1,375 square meter average office size, the typical American office building uses 229.4 MWh (U.S. DOE, 2006). To put that into perspective, according to the UK Department for Business, Enterprise, and Regulatory Reform (BERR), the average annual domestic energy consumption per household in 2004 was between 20 MWh and 28 MWh (2008). A data centre uses significantly more energy.

In a typical office building, energy used to power office equipment makes up 20 percent of the total, while 23 percent of the energy goes towards cooling the building. A data centre, on the other hand, uses 10 to 100 times more energy per square foot than a typical office building (US DOE, 2006). This is partially due to the density of equipment in the building, and it is partially due to the fact that the data centre runs continuously. A typical rack of new servers draws approximately 20 kilowatts of power alone, and a data centre houses hundreds of these racks (Greenberg et al, 2006). Running all day every day, one 20 kilowatt rack alone uses over 170,000 kWh annually. That's over ten times the amount of energy the average UK resident uses in a year (BERR, 2008).

According to the US Department of Energy, the US data centre industry's electricity consumption accounted for 1.5 percent of the entire country's electricity use in 2006, using 61 TWh of electricity. This figure is expected to rise by 12 percent each year. According to the EPA, a ten percent energy savings by all US data centres would save 10.7 billion kWh annually — enough energy to power one million US households (U.S. DOE and EPA, 2008). By reducing the energy consumption of data centres worldwide by even ten percent, global energy consumption would be reduced significantly, and, as a result, carbon dioxide emissions would be cut also. In the US alone, reducing the data centre energy by 10.7 billion kWh annually is the same as cutting 5.6 metric tons of $CO_2$ emissions, or taking just over one million cars off the road (EPA, 2000).

The massive amount of energy used by data centres has not been lost on industry professionals. In fact, the U.S. data centre industry has been aware of the need for energy efficient measures for some time. In the fall of 2006, Hewlett-Packard came out with an energy management system to save 20 to 45 percent cooling cost savings. Around the same time, California's Pacific Gas and Electric Company started a rebate program for data centres that were using software to minimize their server use. Also, the American Society of Heating, Refrigerating, and Air-Conditioning Engineers released liquid cooling guidelines for data centres. Then, on December 20, 2006, President George W. Bush signed a bill that required the U.S. Environmental Protection Agency to study the growth and energy consumption of data centres with the intention to determine best practices for not only data centre energy efficiency, but also for cost efficiency (US DOE, 2007). Since that time, the Lawrence Berkeley National Laboratory has developed a list of 67 best practices for optimal data centre design. They are broken up into the following categories: Mechanical, IT equipment, Electrical Infrastructure, Lighting, and Commissioning and Retrocommissioning. This study focuses on the best practices for the mechanical systems.

### *Saving Energy in a Data Centre*

When determining how to save energy in a data centre, a few useful metrics can be used for benchmarking purposes. One metric is the Computer Power Consumption Index, and it is used to ascertain the data centre's energy efficiency. The CPCI is the ratio of the total data centre power to the power used by the computers alone. The higher the number, the better, since the computer use is the primary function of the data centre. A high number means the other energy uses (HVAC, lighting, etc.) are working efficiently. A low number means the other systems are working inefficiently, or the majority of the energy use is not going toward the data centre's primary purpose: the computers. A similar benchmark that focuses on the HVAC system specifically is the HVAC Effectiveness Index. This benchmark is the ratio of computer power to HVAC power. Again, a higher number indicates good energy efficiency in the data centre (Greenberg et al, 2006).

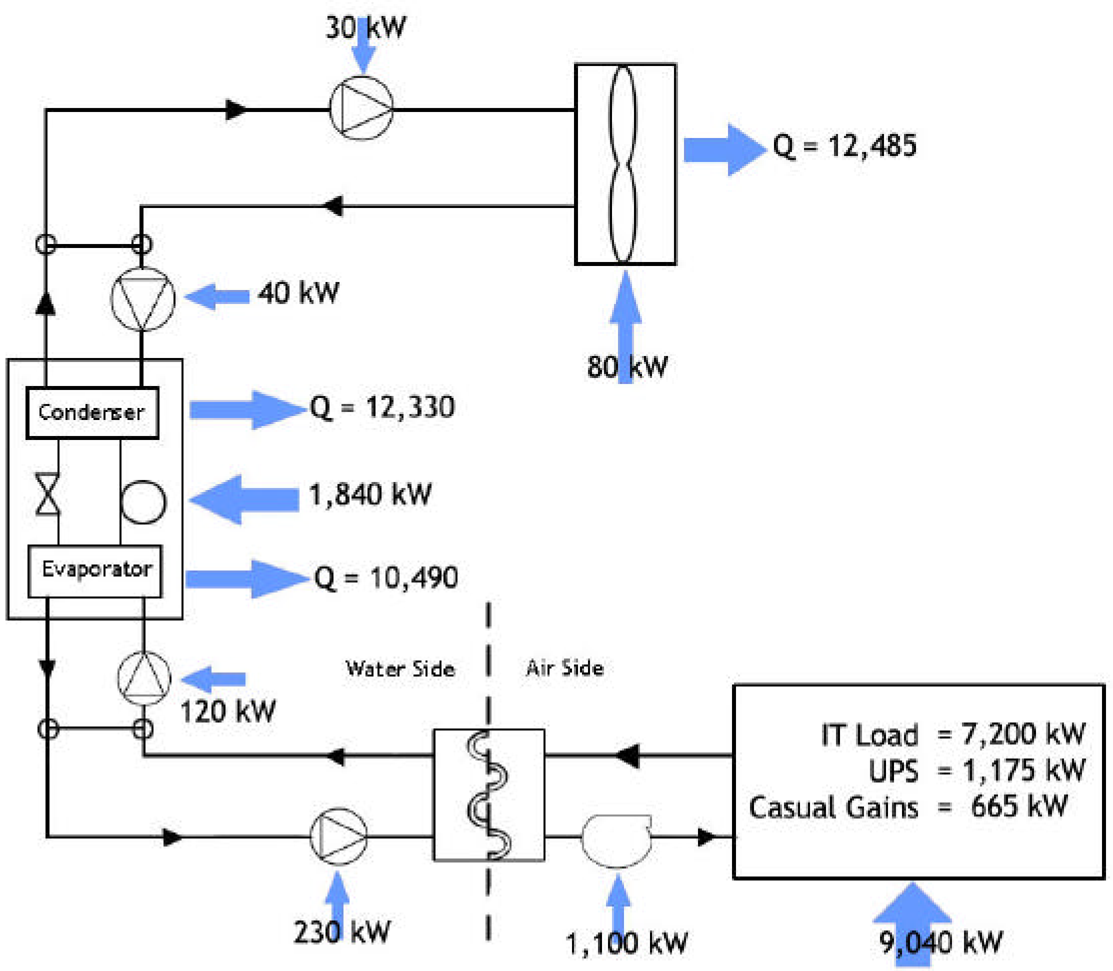


*Figure 1 Energy Flow in a sample Data Centre*

Figure 1 shows the energy flow in a sample data centre. As shown in the figure, the largest amount of energy use comes from the IT load, UPS, and casual gains inside the data centre. Since this energy used by the computers in a data centre is converted into heat, the cooling system plays a major role in a data centre's ability to run continuously. The efficiency of the HVAC system, therefore, is key to the overall energy efficiency of the data centre. As shown in Figure 1, the chiller uses the most energy in the HVAC system, followed by the RACU fans. There are a number of ways to improve a data centre's HVAC system, and many techniques to improve HVAC efficiency are considered "best practice" when designing a data centre. One such practice is the "hot aisle" and "cold aisle" arrangement — an arrangement that improves both RACU and chiller efficiency. Racks of computers are arranged so that the hot discharge from the equipment is expelled into one aisle from racks on either side of the aisle, and similarly, the cold inlet sides of the racks face each other into a cold aisle. This arrangement is shown below.

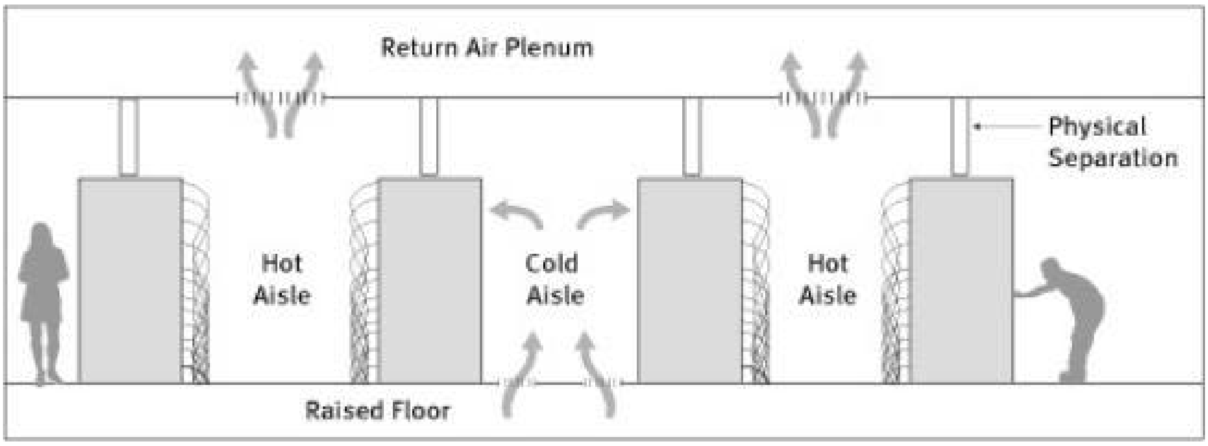


*Figure 2: Typical Hot Aisle/Cold Aisle Data Centre Arrangement*

*Source: Greenberg et al, 2006*

By separating the hot and cold air, mixing of the cold inlet and hot discharge air is kept to a minimum, improving the overall efficiency of the cooling system. Preventing the cold air from mixing with the hot discharge air reduces the amount of work the chillers have to do to produce cold air. As shown in the figure, the cold air enters through vents in the floor tiles of the cold aisles while the hot air returns to the cooling system through vents in the ceiling of the hot aisles. These vents need to be placed strategically to avoid producing "hot spots" in the racks, leading to equipment overheating. The data centre designer also needs to be careful that the space below the racks is large enough for the electrical wiring without blocking the flow of the cooling air (MacKay, 2007). In addition to the hot and cold aisle arrangement, data centre designers can improve air circulation by ensuring that racks are ventilated properly, and by blocking off unused space between the racks to avoid hot and cold air mixing.

After optimizing the air circulation, the cooling system equipment itself can be optimized. Designing the equipment to serve the correct size data centre is important to optimization. One challenge to choosing the right size equipment is predicting the amount of cooling that will be needed in the future as the IT needs increase. In addition to the sizing, the operation of the HVAC system requires optimization. By running the chilled water at a medium temperature — ideally at the maximum temperature it can be while still meeting the cooling load — between 10 and 16 °C, the temperature difference between the chilled water and condenser water is minimized. As a result, the chiller runs with a higher efficiency (Greenberg et al, 2006).

In the HVAC system, the liquid chiller uses the most energy. To minimize the amount of work the chiller has to do, free cooling can be implemented. Free cooling takes advantage of cool outside air temperatures in the evenings and during cool months. When the outside air is cold enough to employ free cooling, the dry liquid coolers or cooling towers can lower the water temperature before it enters the chillers on the evaporator side, or it can cool the water enough to bypass the chillers completely. According to the Lawrence Berkeley National Laboratory, free cooling is well suited for climates with outside wet bulb temperatures below 12.8 °C for at least 3,000 hours (or 4 months) of the year. In the case study, the outside wet bulb temperatures were below 12.8 °C for over 7100 hours of the year. Free cooling is a good alternative to air-side economizers in areas with both cool climates and concerns about particulates or other air pollution (Greenberg et al, 2006). Free cooling is explored as a method of improving energy efficiency in the case study shown.

One energy saving technique not used in this case study is to use liquid cooling instead of air cooling. Since water has higher heat transfer coefficients than air does, placing liquid cooling coils throughout the racks can improve the overall efficiency of the system. Rather than mixing a small amount of hot air from the equipment with a large amount of cool air, and then cooling the entire mixture, the heat is transferred directly from the equipment to the cool water circulating through the cooling coils. This water is at a medium temperature to begin with (10 - 15 °C), so the chiller load is minimized. Also, the RACU fan size and power consumption is reduced, since their primary purpose is no longer cooling the equipment, but instead it is cooling the remaining data centre space (Greenberg et al, 2006).

## 1.2. Typical HVAC Components in a Data Centre

The IT equipment in a data centre is constantly emitting heat; making the cooling system in the building essential to keep the data centre functioning properly. Because of the constant heat production, a data centre HVAC system typically only needs the cooling system, and not any heating equipment. The figure below shows a schematic for a typical data centre cooling system.

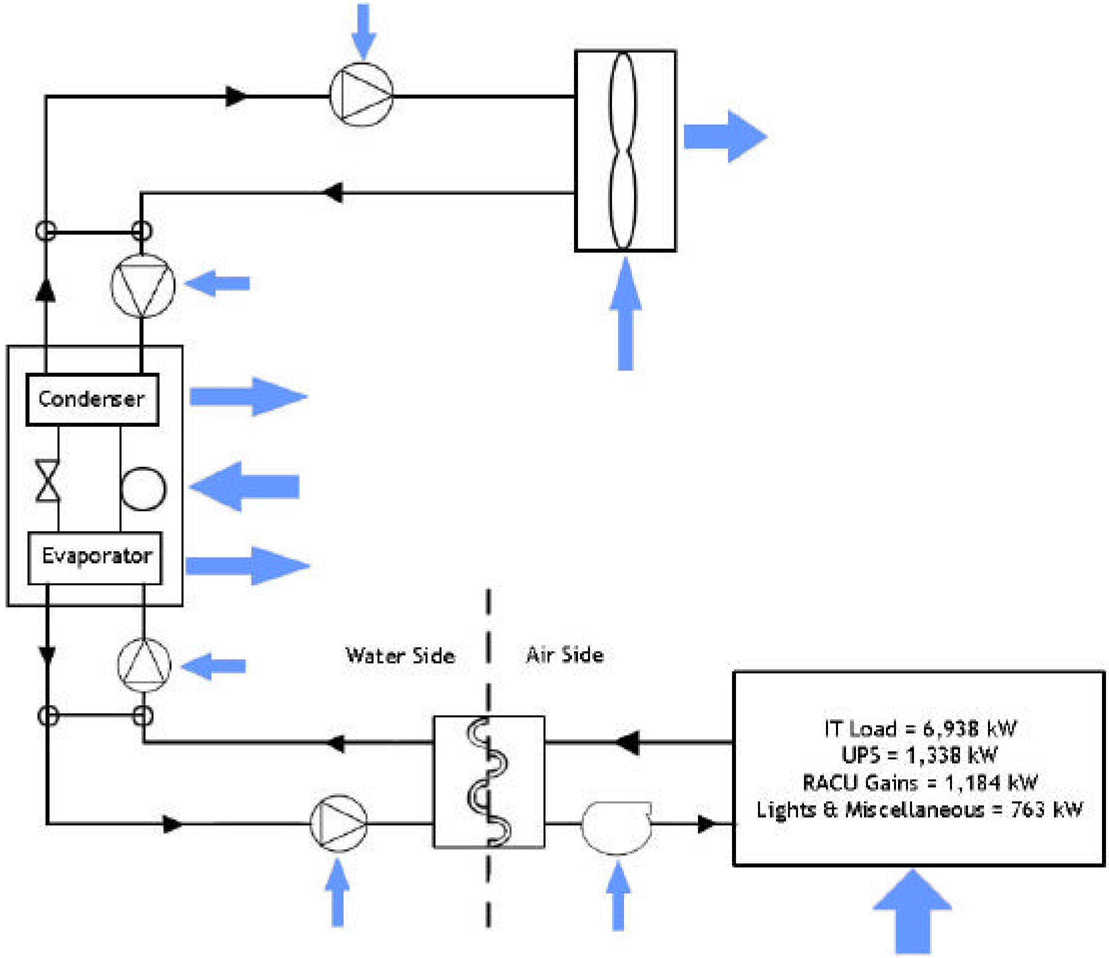


*Figure 3: Typical Data Centre HVAC schematic with energy flow*

The main components in a data centre cooling system are the computer room air conditioning units (RACUs), the chillers, and the dry liquid coolers. Each of these components is described briefly below.

***Chillers***

A liquid chiller, also known as a mechanical refrigeration compressor, is used to cool any refrigeration liquid for air-conditioning or refrigeration needs. The figure below shows the main components of a liquid chiller: a compressor, a cooler/evaporator, a condenser, and an expansion valve.

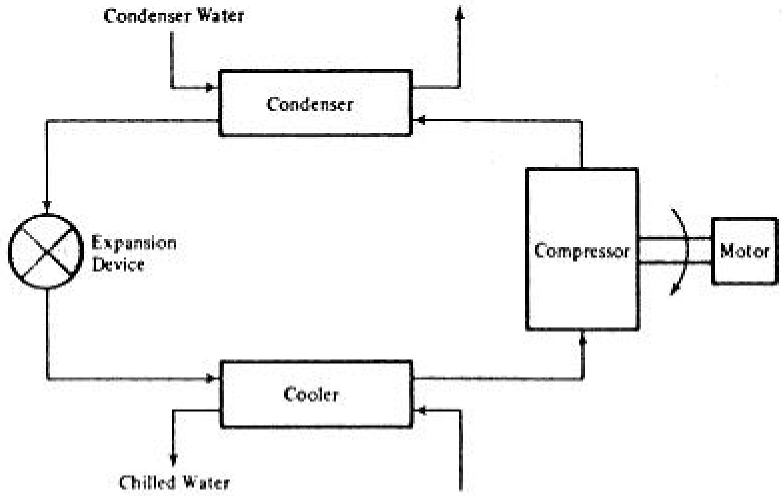


*Figure 4: Liquid Chiller Diagram*

*Source: Thumann, 1997*

The main loop in a liquid chiller is filled with a refrigerant that is pressurized to the point that its boiling point is lower than the temperature of the water in the chilled water loop entering the chiller/evaporator. In the evaporator, the refrigerant is heated to its saturation point, using the heat from the water in the chilled water loop and the surroundings in the evaporator. This cools the water in the chilled water loop as it exits the chiller. The refrigerant then needs to return to its liquid form to be reused, since the refrigerant can only absorb the maximum amount of heat from the chilled water loop through vaporization. This process is done in the condenser by cooling the refrigerant with the water in the condenser water loop. Unfortunately, the chiller is not as simple as just an evaporator and condenser. Since the refrigerant is at a lower temperature, even in its saturated vapour state, than the condenser water used to cool it, the refrigerant temperature needs to be raised. To accomplish this, the vapour is pressurized further in the compressor. As shown in Figure 5, as the pressure of the refrigerant is raised, the temperature increases accordingly (Ananthanarayanan, 2005).

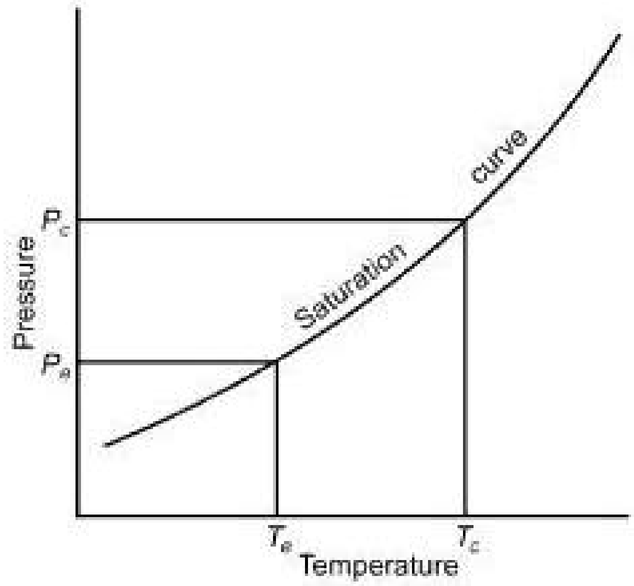


*Figure 5: Expansion and compression of a fluid*

*Source: Trott, 1999*

The condenser then removes both the superheat and latent heat from the refrigerant, returning it to its liquid form. This heat can be summarized as the heat taken in by the evaporator plus the heat of compression (Trott, 1999). At this point in the refrigeration cycle, the refrigerant is liquid, but it is not ready to return to the evaporator until it expands to the correct pressure to allow for vaporization at the temperature of the cooling water loop. The refrigerant, therefore, goes through a throttling process by way of an expansion valve or similar device, and it returns to the evaporator where the process starts again.

The coefficient of performance (COP) is used to rate the performance of the refrigeration system. For the chiller, the COP is determined by the following equation:

$$\text{COP (Cooling)} = \frac{\text{Rate of Net Heat Removal}}{\text{Total Energy Input}}$$

*Equation 1: Chiller Coefficient of Performance*

*Source: Thumann, 1997*

The inverse of this equation is known as the efficiency. In this case study, the chiller used has a COP of 4.83, and a primary efficiency of 0.207.

### *RACUs*

A room air conditioning unit, or RACU, is used to blow cold air into the space that needs cooling. The warm air from the space is circulated through the RACU where it is cooled by a stream of cold water. This now cooled air is then blown back into the room. In a complete HVAC system, the air will be filtered before being re-circulated. For modelling purposes, a RACU can be thought of as a heat exchanger and a fan in series. The heat exchanger circulates water that has been cooled in the chiller through one side, and it circulates the hot air from the computer room through the other side.

### *Dry Liquid Coolers*

In the chiller, the refrigerant is cooled in the condenser by the condenser water loop, but something also needs to cool that condenser water after it has done its job. In many large cooling applications, like a data centre, a wet-cooling tower is used for this purpose. A cooling tower uses evaporation as the primary method of heat rejection. Ambient, dry air is drawn past a flow of water where it absorbs water vapour — cooling the water remaining in the flow (Kubba, 2008). The downside to wet-cooling towers is their exposing the water flow to the outside environment. The temperature at which the cooling tower operates can promote the growth of the bacterium *Legionella pnumophila*: the cause of Legionnaires' disease. *Legionellae* are bacterium that live in water and soil, and the bacteria affects humans only when the infected water vapour is inhaled. The resulting disease is a form of pneumonia, and the fatality rate is approximately 20% (Clay, 2004). While proper water treatment can prevent the growth of such bacterium, outbreaks are still possible with the use of cooling towers.

That is where the dry liquid coolers come in. Dry coolers rely on convection heat transfer between the condenser water, enclosed in a cooler coil, or tube, and the outside air. Fans are used to blow the air onto the condenser water coils, and thus, heat is expelled. Since the cooling water is enclosed, the exposure to the environment is eliminated, and the risk of a Legionnaires' disease outbreak is gone.

## 1.3. Why District Heating?

While data centres are an important facet of modern day technological growth, the servers, computers, and other IT equipment require a great deal of fossil fuelled energy to run 24 hours per day, seven days per week. The data centre equipment uses its required electrical energy, and then it is released as heat. This heat needs to be dissipated to prevent the equipment in the data centre from over-heating, and to keep the data centre operations running smoothly. So, in addition to the energy needed to run the equipment, more energy is needed to run the ventilation and air conditioning systems.

The heat being generated by the IT equipment and being dissipated by the HVAC system is considered "low temperature waste heat." It is considered "waste heat" because while it is being cast-off into the surrounding environment, it could be reused in a functional and economic fashion. This waste heat is considered "low temperature," because it is below 450 °F (232.2 °C) (Thumann, 1997). In this project, the low temperature waste heat is being used in a district heating scheme — the heat is being used to heat nearby residential buildings. The low-temperature water flow then returns to the data centre HVAC system, cooler than it started. This reduces the amount of energy needed by the data centre for cooling, and, with typical a heat pump coefficient of performance (COP) above 3, it reduces the amount of energy needed by the nearby residents for heating purposes compared to the energy needed when using gas boilers. In this study, the amount by which the energy load is reduced is estimated for the data centre side.

### *What is District Energy/Community Heating?*

District energy refers to a scheme in which a small producer provides both heat and power to a community. The power could be generated with a diesel generator, a biomass boiler, or any other combined heat and power (CHP) source. In combined heat and power district energy schemes, the heat is distributed using the hot water or steam that remains after it has been used to generate electricity.

Community heating, while it can provide power in some cases, can also refer to a scheme in which a central source provides the heat only, and not the power to any number of buildings or residences. The heat could come from a number of sources: combined heat and power, like in a district energy scheme, a centralized boiler, renewable heat sources, or industrialized waste heat. In the case study explored here, the waste heat from the cooling system of a large data centre provides the heating. Like district heating schemes, community heating is typically distributed via hot water (Energy Saving Trust).

***How does it work?***

From the perspective of a tenant, the heating system seems virtually the same. Radiators still distribute the heat, and residents can control the amount of heat they get with the same controllers they are used to. However, instead of a having a boiler provide the heat, a "hydraulic interface unit" is used to transfer the heat from the community heating source to the tenant's home. Additionally, a heat exchanger can be included to provide "instantaneous" hot water to the tenants (Energy Savings Trust). Meters can still be used to measure how much heat each tenant is using, and billing can continue in the same way. The difference is that the heat will cost less than it would in a traditional heating arrangement.

As a building owner, either on the producer or the consumer side, the differences between the community heating and traditional heating system are more noticeable. First, a heat distribution network must be put in place for the hot water to get from its source (whether it be a large boiler, industrial waste heat, or a renewable heat source) to the community of consumers. Depending on the size of the community heating scheme, this distribution network could be as simple as a pump with conventional valves and insulated pipes much like those in a home central heating system, or it could be as complex as installing a large heat main with variable speed pumps, and leak detection systems. These heat mains are installed the same way as any other mains — buried in the ground (Energy Savings Trust). In this study, a heat main leading to the residential building would need to be installed as part of the construction of the data centre. This study also explores the best place from which to take the waste heat as part of the cooling system cycle.

***What are the main benefits of community heating?***

Community heating offers a number of benefits not only to the tenants of the building taking advantage of the heat, but also, in many cases, to the producers of the heat, not to mention the environment.

***Cost Reduction:***

For the tenants, using heat from a community heating scheme will reduce their overall costs for heating. The heat in a community heating scheme is usually much less expensive than heat from traditional heat sources, such as natural gas. In this case study, the heat comes from "waste heat", so it is "free heating," since it would need to be dissipated in any case. Additionally, if designed to do so, community heating schemes can take advantage of a number of heat sources: changing the source of the heat based upon availability and price. In areas with multiple community heating schemes close together, the communities can link up with one another, providing back-up heat sources for one another should one system fail. Linking heating schemes can also improve the overall efficiency of the system.

For the landlords of the buildings using the community heating, maintenance costs are reduced. By having a centralized heating source, there is no need for individual maintenance checks in each dwelling. The space needed by a boiler in each dwelling is also freed up for the tenants, making each dwelling more attractive to potential tenants — potentially making each dwelling worth more.

In some cases, implementing community heating can also be cost effective for the producers. When the heat used is "waste heat" from industrial processes, the heat is free for the consumers, and the useful application of that heat provides a savings for the producers. This is because the industrial buildings providing the waste heat would be expelling the heat to the atmosphere in any case. By providing the heat to a community for a useful purpose, the amount of heat needed to be cooled in these industrial buildings is reduced, thus reducing the cooling load on the producer side. The amount of savings accrued by the producer by implementing community heating is modelled in this study.

***Environmental Benefits***

Community heating is a scheme that is beneficial for the environment from both the producer and the consumer sides. The producer, especially in the case that uses either CHP or waste heat as the community heating source, reduces $CO_2$ emissions from their own building. In the case with waste heat, the cooling load is reduced on the producer's side, reducing the electricity demand in the building. The residential building is also reducing their electricity demand for heating purposes, and, as a result, cutting $CO_2$ emissions.

## 1.4. Efficient Building Requirements

With growing concerns about global climate change, greenhouse gas emissions, and energy efficiency, cities around the world are developing more stringent requirements for building development. Energy efficiency measures that were once considered "cutting edge" are now considered "best practice, and in many cities, energy efficiency is a required part of a new building's plans in order to get a building permit. In these new planning requirements, exemptions for "industrial processes" are becoming more difficult to obtain. The case study modelled is a new data centre being built in London: one of the many cities in the UK where energy efficiency is a requirement.

The Greater London Authority (GLA) has instated a plan to reduce energy use, supply energy efficiently, and to use renewable energy. As part of this "Energy Strategy," the GLA have implemented guidelines for new building projects. These guidelines state that developments will reduce their carbon dioxide emissions by 20 percent from on-site renewable energy generation. The guidelines state that this provision may be bypassed if it is shown to be infeasible. The renewable energy technology allowed includes: biomass fuelled heating, cooling and electricity generating plant, biomass heating, combined heat and energy and cooling, communal heating, cooling and energy, renewable energy from waste, photovoltaics, solar water heating, wind, hydrogen fuel cells, and ground-coupled heating and cooling (GLA, 2008).

For each proposed major development, an assessment of energy demand and carbon dioxide emissions is required. This assessment will provide a basis for the GLA to measure energy and carbon dioxide emissions savings after the implementation of energy efficient and renewable technology. In the case of the data centre modelled in this study, multiple technologies will need to be put into place to attempt to meet the energy efficiency requirements of the GLA, and even then, the 20 percent reduction in emissions may not be possible. The planners for the data centre in question have considered a number of technologies approved by the GLA for emission reduction purposes (WSP Group, 2008).

The first of these technologies is combined cooling, heat and power (CCHP). This system uses gas fired CCHP engines to provide the primary power to the data centre. Absorption chillers are linked to the CHP engines to provide the primary cooling to the data centre. In the case of a loss of gas supply for the CHP engines, the data centre would require a back-up electrical source in the form of an electrical grid connection. In this same case in which the CHP engines cannot run, the primary cooling would also be unable to cool the data centre, so the data centre would require a second chiller system. WSP determined that the energy consumption by the CHP engines would produce more $CO_2$ emissions than the case without CCHP. In addition to the increase in emissions, the full back-up HVAC plant would be an impractical installation.

The second technology explored by the data centre planners was renewable energy generation. Unfortunately, the location of the data centre does not allow for the practical implementation of many technologies. The data centre is located in a busy urban area, so the installation of wind turbines, for example, would not be feasible. Small turbines, while installable on the roof of the building, would not be ineffectual because of the urban landscape. Since the data centre does not need to produce heat, solar thermal panels are unnecessary, and the available area would be too small to power a significant absorption cooling plant. Photovoltaics (PV) are a possibility, but the roof space for their installation is limited by the installation of dry liquid coolers on the roof. If the roof space were available, and even if the whole roof was covered, the PV output would be dwarfed by the electricity use of a data centre.

The third strategy explored by the data centre planners was to use the waste heat from the cooling system for a useful purpose in the community.

The location of the data centre makes this option the most ideal of the three, since residential buildings are nearby for community heating purposes, and more than one building could take advantage of the heat provided by the data centre. While this strategy does not reduce the carbon emissions of the data centre itself by 20 percent, it is the plan that creates the biggest emissions reduction of the three at the community level.

# 2. Methodology

In this case study, the data centre will be modelled in a comprehensive energy systems simulation software package called TRNSYS (Klein et al, 2004). The following section describes the modelling program: its uses, its components, and how the case study data centre was modelled using the program.

## 2.5. TRNSYS Basics

### *What is it used for?*

In this project, the model of the heating and cooling systems will be completed on TRNSYS, which stands for Transient System Simulation. TRNSYS is a program used for “transient simulation of thermal systems” through a modular interface. The program is used to help researchers and professionals alike in determining the validity and workability of new energy concepts.

### *How it works*

By linking together pieces of a thermal system, the user can simulate an existing system, or he or she can model a new system to determine how it will work. Altering the input, output, and parameters according to the user's specifications can modify TRNSYS components, called "Types". Each Type is modelled by a set of mathematical equations in the TRNSYS “simulation engine.” Standard TRNSYS components include, but are not limited to, thermal storage, solar collectors, building loads, heat exchangers, HVAC components, controllers, hydronics, electrical components, and physical phenomena such as temperature and psychometrics.

## 2.6. Data centre Model

### *TRNSYS Model — Components used*

In this project, TRNSYS is used to model the data centre and its heating, ventilation, and air conditioning (HVAC) systems. The data centre is modelled as a single zone building with a heating output equal to the electrical load the servers and computers require. The hot air in the data centre travels up through air vents to the room air conditioning units (RACUs) where it is cooled and re-circulated. The RACU is modelled as a basic heat exchanger with air on one side and water on the other. On the liquid side of the RACU, a variable speed pump is used to ensure the air is cooled enough to keep the data centre fully functional. In the model, a PID controller is used to regulate the flow rate of the chilled water into the RACU so that the internal temperature of the data centre does not exceed 24° C. Once the chilled water has been used in the RACU to cool the circulating air, it is pumped into the chiller. The RACU model uses a curve fit equation to model the overall UA value of the heat exchanger for different water flow rates (the air flow rate is fixed in this configuration).

The condenser water from the chiller is pumped to the dry fluid coolers. A flow diverter and mixer are used to circulate any water returning to the chiller above or below 20 °C. If the water is above 20 °C, it will flow to the dry fluid cooler, and if it is below, it will circulate until it is mixed with the warm condenser water, and it reaches 20 °C. Two PID controllers control the temperature of the condenser water returning to the chiller — one controlling the temperature to which the dry fluid coolers cool the condenser water, and one controlling the amount of water going to the dry fluid coolers as opposed to circulating back through the chiller.

In the simulations that implement community heating, an approximation of a residential heating load is used. The file simulates the peak heating demands of the morning and evening hours as well as the reduction of heating demands in the afternoon and overnight.

In the free cooling simulations, an additional heat exchanger is used. Unlike the RACU heat exchanger, the free cooling heat exchanger is modelled as a constant effectiveness heat exchanger. This was selected for the sake of simplicity, as it assumes the free cooling heat exchanger is correctly sized to operate at the design effectiveness.

### *Chiller Specifications*

The chillers used in the case study are Trane CVGF 1000 water-cooled centrifugal compressor chillers. Each chiller has a cooling capacity of 2750 kW for a total building cooling capacity of 16500 kW. The chillers are rated at 572.9 kW (compressor power) each, and they have COP of 4.81.

### *Room Air Conditioning Unit Specifications*

The RACUs used in the case study are Liebert Hiross HPM model L12UC units. The case study design calls for 20 RACUs per floor, but only 15 are needed on each floor to meet the load. Each RACU fan can blow 26,500 cubic metres per hour with a total fan power per unit of 7.98 kW. The RACUs also have a 90.6 kW net cooling capacity.

### *Dry Fluid Cooler Specifications*

In the case study modelled, 40 dry fluid coolers are in use on the roof of the data centre. Each unit has a capacity of 337.50 kW. There are 14 fans in each unit, each with an 800 mm diameter. This array of dry fluid coolers is designed to keep the noise levels to a minimum since the case study data centre is in a highly populated area.

### *Simulation assumptions*

The case study data centre modelled in this project is designed with 138 RACUs, six chillers, and 42 dry coolers to effectively cool the building. However, the simulation uses only one of each of these components in the model. By programming each component to represent the total energy, flow rate, and effectiveness of all the parts, only one TRNSYS component is needed to effectively, and accurately model the actual data centre.

The kilograms of carbon dioxide emissions produced by the data centre's electricity load were determined using DEFRA's guidelines to greenhouse gas conversion factors (DEFRA, 2007). According to the 13 July 2007 guidelines for company reporting, the conversion factor for electricity is 0.4300 kg of $CO_2$ per kWh of electricity use. For this case study, the longterm marginal factor is used to assess energy savings measures.

To model the residential heating load for the community heating cases, a typical heating load for a residential building was scaled up to a level near that of the data centre's IT load. The community heating scheme uses a heat pump and the exact amount of heat that is drawn from the data centre depends on the heat pump COP. In this project, the heat pump COP was simply estimated by a linear function of the inlet temperature:

$$\text{COP} = 2.55 + 0.045 \times T_{\text{in}},$$

*Equation 2: COP for Community Heating Heat Pump*

where $T_{in}$ is the temperature of the water entering the community heating system.

## 2.7. Description of all cases modelled:

### *No Free-Cooling*

#### *Base Case*

The figure below shows a simplified schematic of the base case model. In the figure, and in the schematics of the subsequent cases, not every component is shown. In all six cases, on either side of the chiller, a low-loss header is used to maintain a constant flow rate to the chiller, while allowing the variable speed pump to adjust its flow rate to the RACU or to the dry fluid cooler to meet the system’s temperature requirements. Additionally, the controllers on the dry fluid cooler fans, and the variable speed pumps are not shown.

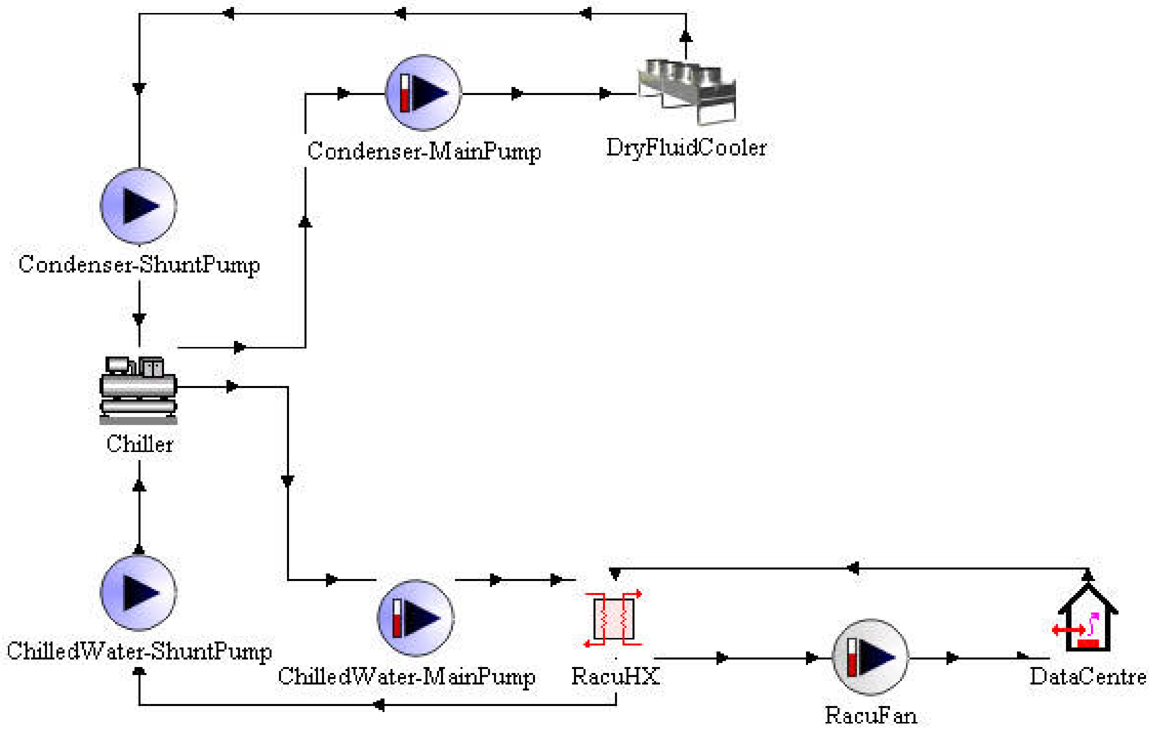


*Figure 6: Simplified model of the base case*

In the base case, the data centre HVAC system uses three main components: the RACUs, the chiller, and the dry cooler. In this system, the hot air pumped through the ceiling air vents of the data centre is cooled in the room air conditioning units (RACUs) and the cold air is pumped back into the data centre through vents in the floor. The RACUs act like a heat exchanger, with air on one side, and water on the other. The cold water used to cool the hot air from the data centre is pumped through a chiller to be cooled before returning to the RACU. The flow rate of the water running from the chiller to the RACU is controlled to maintain an internal temperature of 24 °C inside the data centre. In the chiller, the condenser water is pumped out to the liquid dry cooler to be air cooled before returning to the chiller. This condenser water returning to the chiller is maintained at 20 °C to keep the chiller running efficiently. To do this, a controller adjusts the flow rate of the variable speed pump leading to the dry coolers. A flow diverter is used to loop the condenser water that does not need cooling by the dry coolers back to the chiller.

***RACU Side Community Heating***

The figure below shows a simplified model of the case in which community heating is utilised using the hot water returning from the RACU to the chiller.

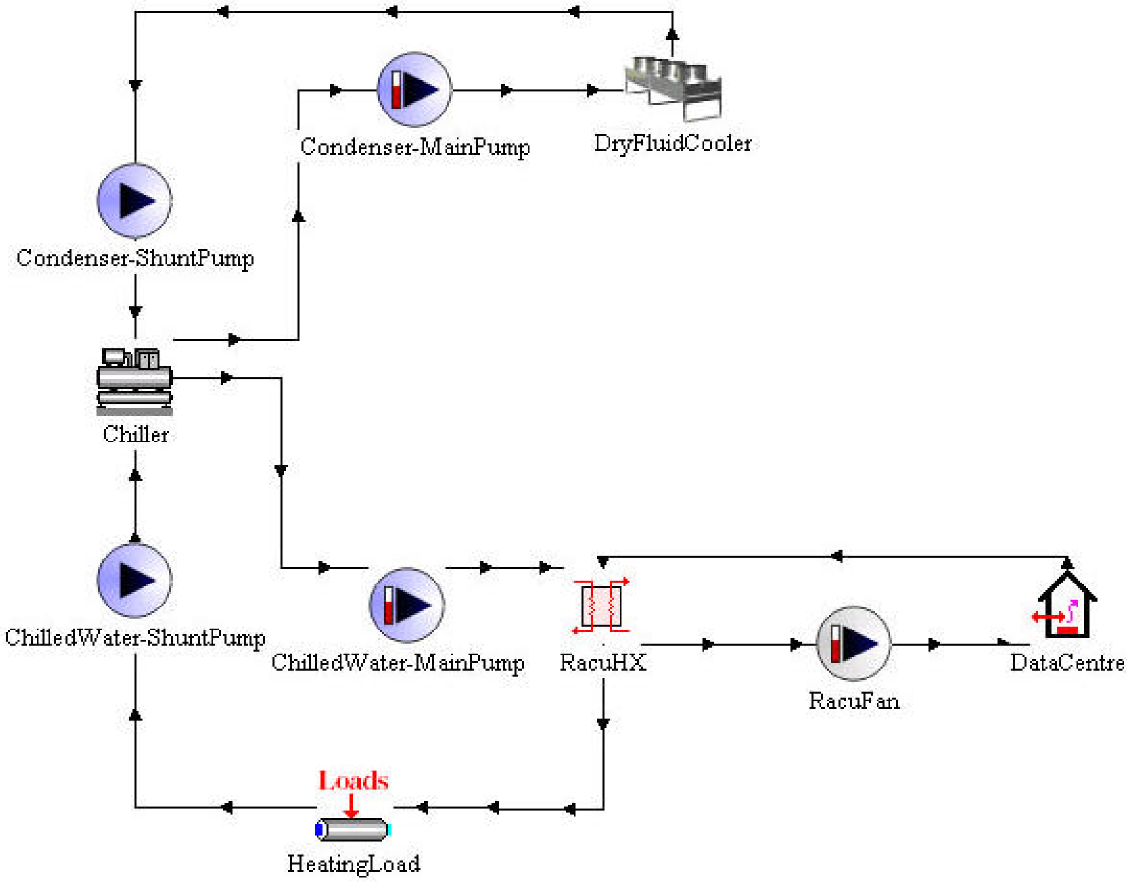


*Figure 7: Simplified Model — Residential Heating Load on Chilled Water Side*

In the cases that implement community heating, hot water is pumped from the cooling loop to the nearby residential building. There, the heat is transferred through a heat exchanger and used in a variety of ways — for what ever the residential user's heating needs require. Then, after the residential building has taken their required heat from the water, it is pumped back to the data centre cooling system, a few degrees cooler than when it left. In this first case, the hot water for the community heating is taken from the system between the RACU and the Chiller. In this study, the water reaches the heating load at a temperature of 19 °C, and returns to the HVAC system at a temperature anywhere from 16.1 °C (a 3 °C difference) in January and December to 18.4 °C (a 0.6 °C difference) in July and August. By lowering the temperature of the water entering the chiller, the chiller does not need to work as hard, and therefore, the system saves energy. Since the chiller is operating at a lower temperature, the dry cooler should also not need to work as hard.

***Condenser Side Community Heating***

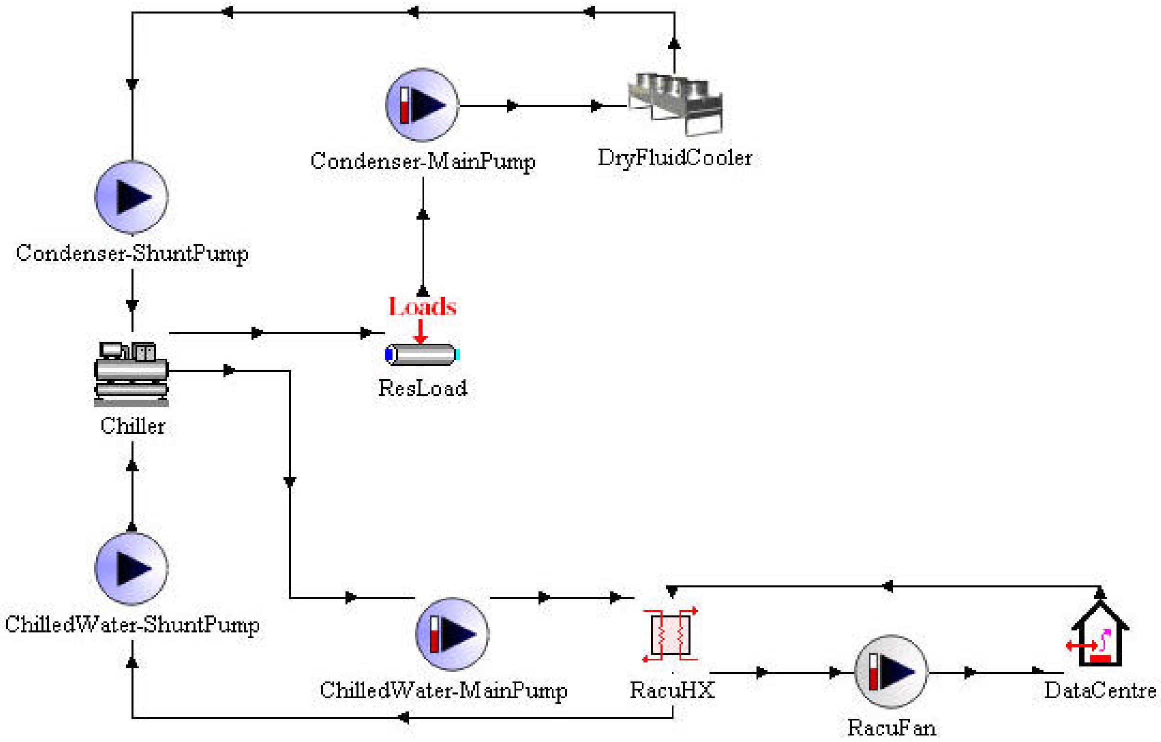


*Figure 8: Simplified Model — Residential Heating Load on Condenser Side*

As seen in figure 3, in the second case in which the hot water is used for a nearby residential heating load, the hot water is taken from the system between the chiller and the dry cooler. The water reaches the heating load at an average temperature of 24.8 °C, and it returns to the system at an average temperature of 24.2 °C. This 0.6 °C average reduction of the condenser water temperature going to the dry coolers means the fans do not need to work as hard to cool the condenser water as they would otherwise. The system is still controlled to return the water to the chillers at 20 °C. This means the chiller energy use is relatively unaffected by the residential heating load.

### *Free-Cooling*

#### *Base Case*

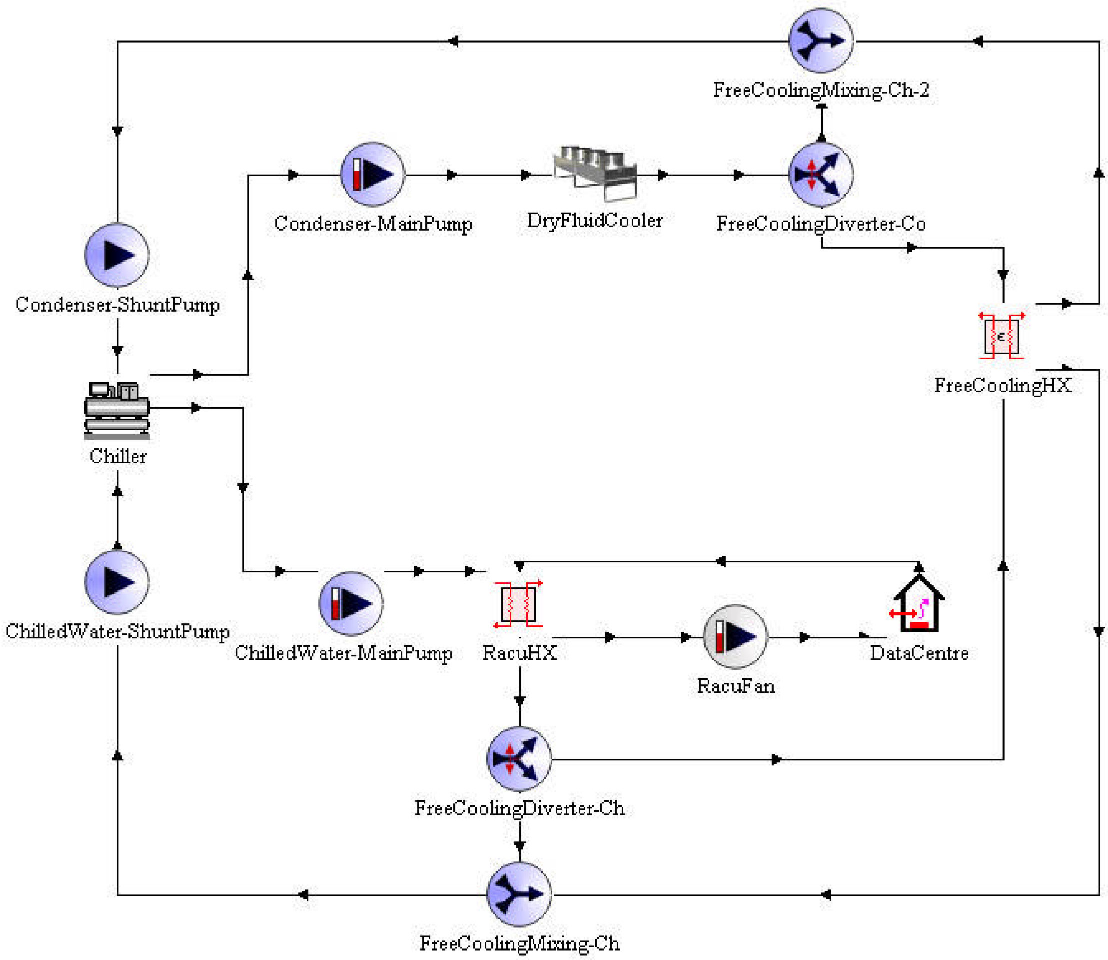


*Figure 9: Simplified Model — Base Case with Free Cooling*

In the case that implements free cooling, the data centre HVAC system works almost identically to the base case, with one difference. During colder months, the hot water returning from the RACUs bypasses the chillers, and instead is cooled directly by the outside air, using the dry coolers. This is called "free cooling," because in essence, the cooling is done for free by the environment. In reality, the free part of the free cooling only refers to the chiller which uses far less energy in free cooling mode, shutting down completely at times, than in the standard HVAC cycle. The dry coolers, on the other hand, have to work harder. Rather than cooling the condenser water to 20 °C, the dry coolers are working to cool the circulating hot water all the way to 8 °C. However, since the chillers use around ten times as much energy as the dry coolers, an increase in the dry cooler use does not affect the overall energy use as much as the decrease in the chiller use does. The chillers are virtually unused on cold days.

The free cooling is most useful in the winter months, and it can also be utilized at night during the cooler spring and autumn months. In this simulation, free cooling is put into effect any time the outside temperature drops below 8 degrees centigrade. If the target temperature for the chilled water was much higher than 8 degrees centigrade, the free cooling could be put into effect at a higher temperature. In this simulation, however, the target chilled water temperature is 10 °C.

***RACU Side Community Heating***

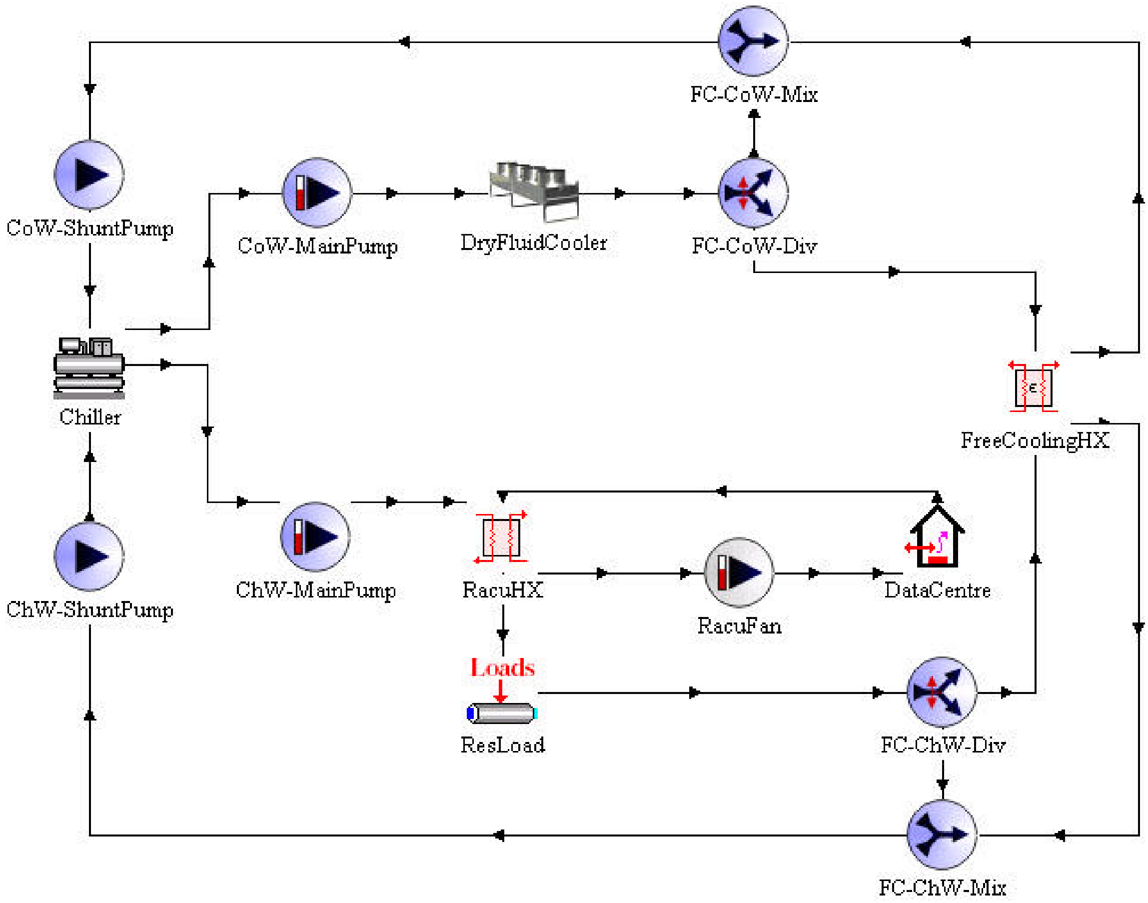


*Figure 10: Simplified Model — Free Cooling with Load on Chilled Water Side*

In the case that combines free cooling and community heating on the RACU side, the system grows slightly more complex. During times in which free cooling is not in effect, the system runs identically to the RACU Side community heating case without free cooling. However, with free cooling in effect, the hot water returning from the residential load is pumped through the free cooling heat exchanger, bypassing the chiller. This is in contrast to the free cooling case without residential heating, in which the water returning from the RACU was pumped through the free cooling heat exchanger directly.

In this study, the water reaches the heating load at a temperature of 19 °C. The hot water returns to the HVAC system at a temperature anywhere from 16.1 °C (a 3 °C difference) in January and December to 18.4 °C (a 0.6 °C difference) in July and August. Since free cooling does not affect the cooling system until after the hot water returns from the residential heating load, this temperature difference stays the same in both cases with and without free cooling.

***Condenser Side Community Heating***

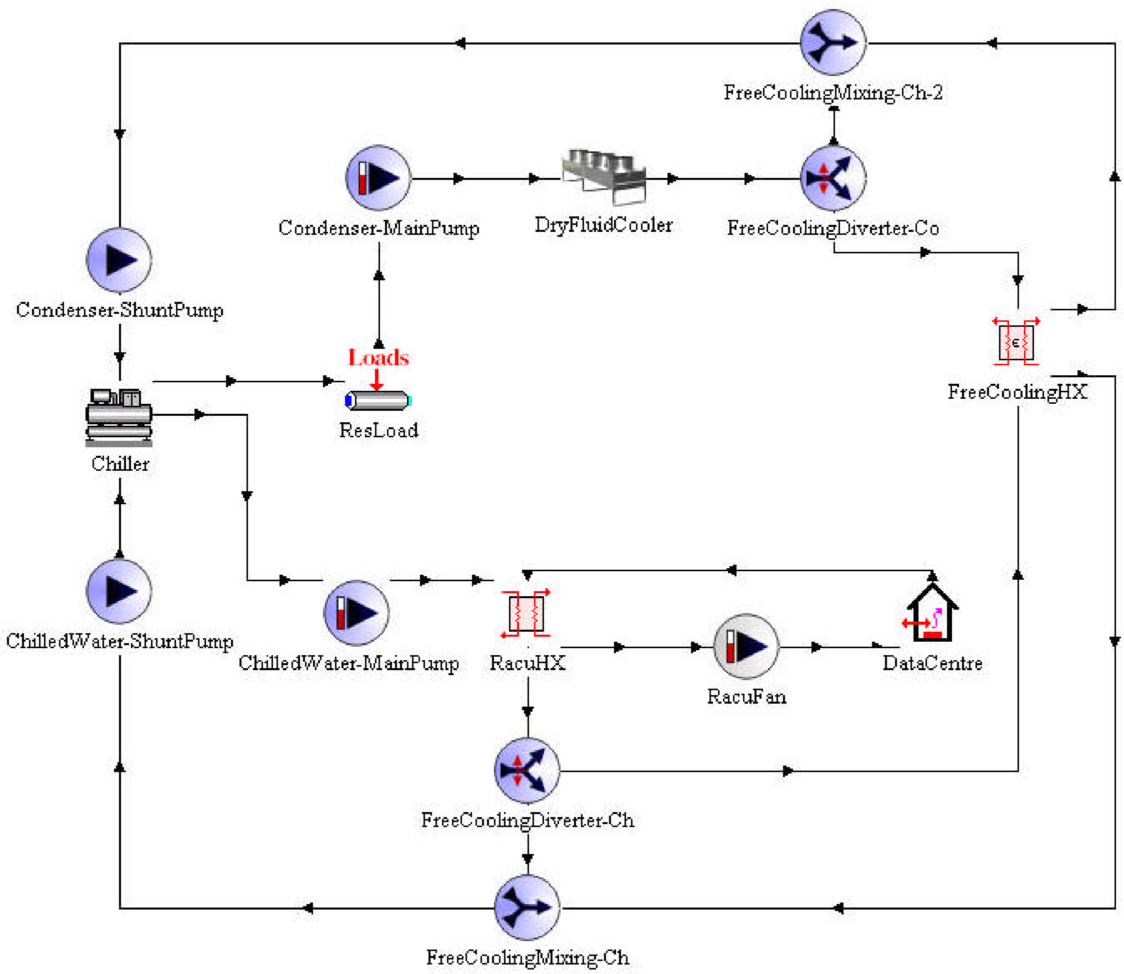


*Figure 11: Simplified Model — Free Cooling with Load on Condenser Water Side*

In this case, the model combines the free cooling model with the condenser side community heating model. This model works the same way as the condenser side community heating model without free cooling when the free cooling is not in effect. When the free cooling is in effect, the only difference between it and the standard free cooling model is that the condenser water leaving the chiller is pumped to the residential heating load prior to reaching the dry coolers.

# 3. Data Analysis

## 3.8. Results

In the following section, six scenarios are modelled to determine the following:

the amount of electrical energy used by the data centre

the breakdown of that energy use by data centre component

the amount of carbon dioxide emissions created by the data centre.

The first scenario is considered the "Base Case" because it does not include any energy savings measures. The results of this base case are used for comparison purposes for the other five scenarios to determine how much, if any, energy was saved.

For all six cases, the total energy used by the HVAC system, or the "Total HVAC load" refers to the sum of the energy used by the RACU fans, the chillers, the dry coolers, and all the pumps needed to keep the cooling system running. The total heat emitted by the IT equipment, the uninterruptible power supply (UPS), and casual gains such as lights and other equipment is often referred to as the "IT Load." This load remains constant for all six simulations at 10.2 MW, or 89.6 GWh over the course of the year.

### *Standard Cooling System*

#### *Base Case*

In the base case of the data centre, the total yearly energy used for the HVAC system is 32.5 GWh. The components that make up that total energy use are the chiller, the RACU fan, the dry cooler fan, and the pumps. The components that change the most from case to case are the chiller and the dry cooler fan.

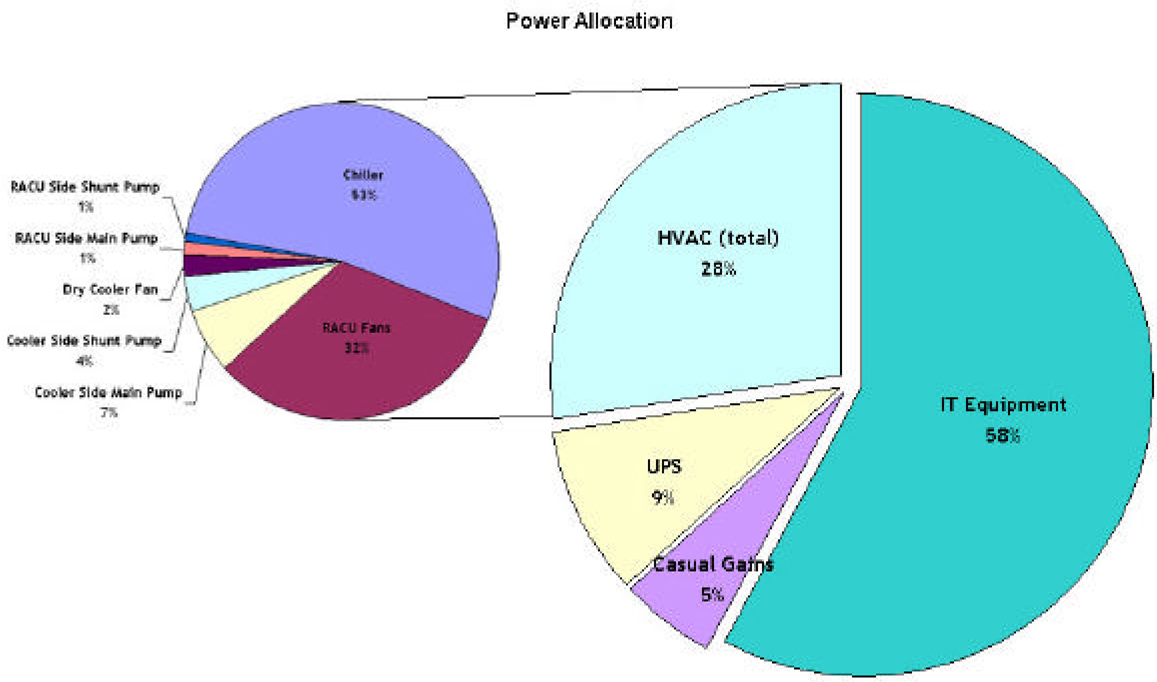


*Figure 12: Allocation of Energy Use in a Data Centre*

The figure above shows the breakdown of the data centre energy consumption by type. Over half of the energy is used by computer equipment, and almost 30 percent of the electricity goes towards powering the HVAC system. In this base scenario, the chiller makes up 53 percent of the HVAC electricity consumption, using 16.1 GWh over the course of the year, while the dry cooler fans use 0.7 GWh — only 2.3 percent of the HVAC system. 32 percent of the HVAC energy use goes towards the RACU fans. Their use of 9.6 GWh of energy remains constant across all six scenarios. In combination with the IT load, the base case uses 109 GWh of electrical energy in a year.

In total, the HVAC system of the base case data centre with no free cooling or community heating produces 12,978 tonnes of $CO_2$ emissions. According to the Energy Saving Trust, each UK household produces approximately 6 tonnes of $CO_2$ emissions annually. The data centre modelled in this study emits as much $CO_2$ as nearly 2,200 households. With the IT load, UPS, and casual gains (referred to hereafter as simply the IT load) included, the base case emits 47 thousand tonnes of $CO_2$, or enough to account for 7,800 UK households.

### *RACU Side Community Heating*

In the case in which the hot water was taken from the RACU side of the data centre HVAC system, the data centre used 26.2 GWh of energy in total for the entire year. On average, the energy used for the HVAC system in this case is 86.7 percent of the energy used in the case without any community heating. Monthly, January showed the biggest energy savings — the community heating scheme saved 20.12 percent — or a total savings of 507 MWh.

Figure 13, below, shows the relationship between the temperature difference in the water entering and returning from the residential heating load (the blue line), and the overall energy savings in MWh (the red line) of the data centre by month. So, just as January had the biggest energy savings, it also exhibited the largest change in temperature between going to and returning from the residential building for community heating purposes.

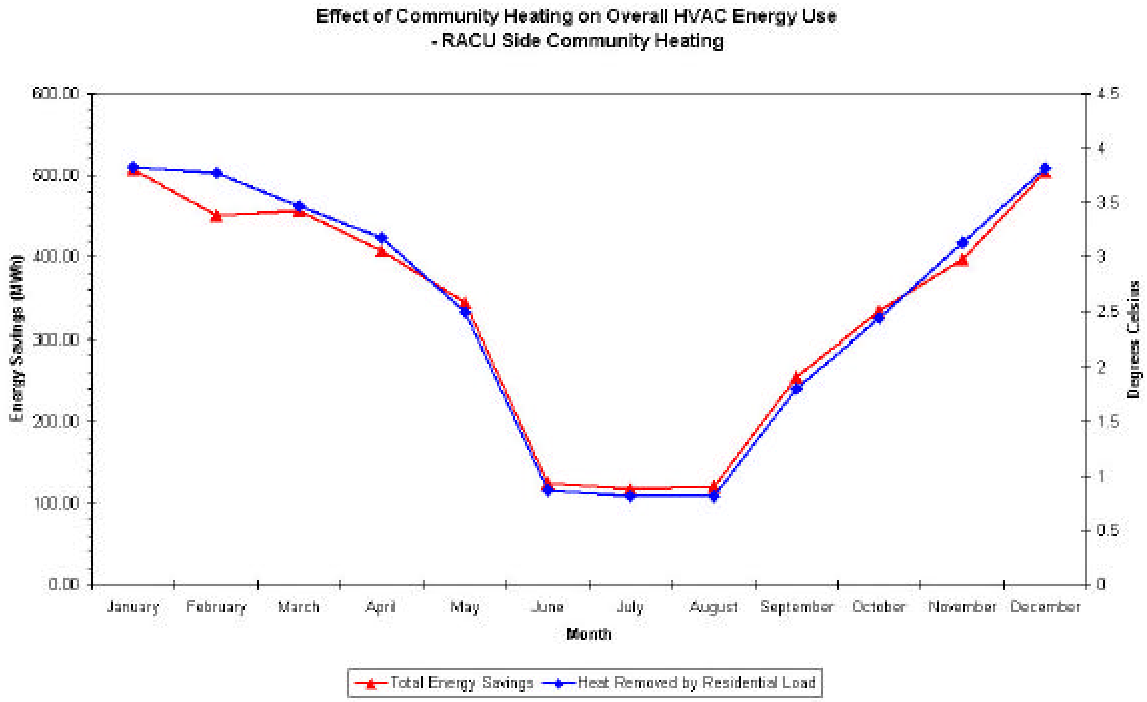


*Figure 13: HVAC Energy Use as affected by Community Heating from the chilled water loop*

As shown in Figure 13, over the course of the month, the residential heating load reduced the water temperature by an average of 3.83 °C. Conversely, July modelled the least energy savings — only 4.37 percent lower than the case with no community heating, or 117.8 MWh of energy savings. July was also the month that produced the least change in hot water temperature from the residential heating load, reducing the hot water temperature by an average of only 0.81 °C throughout the month.

In total, the data centre with no free cooling and community heating from the chilled water side of the cooling system produces 11,250 tonnes of $CO_2$ emissions with the HVAC system alone, and emits approximately 45,300 tonnes of $CO_2$ with the IT load. By removing some heat from the data centre to provide free heating to nearby residential buildings, this system configuration reduces the data centre emissions by 1,728 tonnes of $CO_2$. That savings accounts for about 288 average UK homes.

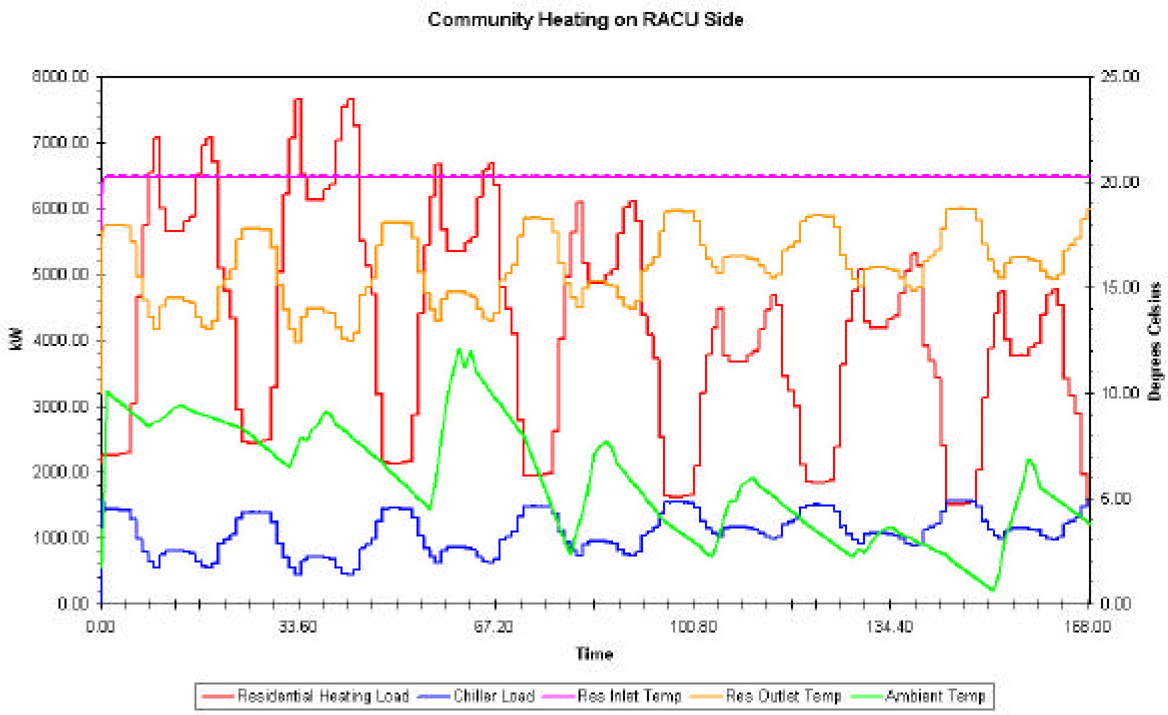


*Figure 14: Week 1 Results — RACU Side Community Heating*

As seen in Figure 14, the temperature of the hot water going to the residential heating load from the RACU (the fuchsia line) stays relatively constant around 20.3 °C. The temperature of the hot water leaving the residential heating load, entering the chiller (the orange line) is dependent on the actual load (the red line) of the residential building. As the heating load increases, the temperature of the hot water returning to the cooling system decreases, and as the heating load decreases (like in the middle of the day when the tenants are at work or at school), the hot water returning to the cooling system is hotter. The blue line in Figure 14 is the power used by the chiller, in kJ. The chiller power follows the same trend as the hot water returning from the residential heating load, since the chiller is cooling that water. When the water returning from the community heating load is high, the chiller has to work harder to cool it, whereas, when the temperature of the water is cooler, when the residents are using more heat, the chiller does not need to work as hard since the community heating scheme has already cooled the hot water in the chilled water loop. The green line represents the outside air temperature. Since this sample week is in January, the temperatures are consistently below 12 °C.

### *Condenser Side Community Heating*

In the case in which the hot water was taken from the condenser water leaving the chiller to heat the residential building nearby, the savings was insignificant in comparison to the previous case. As explained in the methodology section, the water returning to the cooler is controlled to stay at 20 °C to keep the chiller running at its best efficiency. Because of this temperature control, providing free heating to the nearby residential building has no effect on the chiller performance. The temperature difference in the condenser water caused by the residential heating load will affect the dry coolers, however. In this case, the dry coolers use less energy than in the base case — providing a 14.4 percent savings in the dry cooler energy use. However, since the dry coolers do not constitute the majority of the data centre's load, the savings is minimal. In fact, the 14.4 percent savings in the dry coolers only accounts for 100.9 MWh of the entire savings. In total, this case uses 99.7 percent of the total HVAC energy used in the base case, or 99.9 percent of the total energy including the IT load.

Despite having an overall low energy savings in this case with community heating on the condenser water side, the savings still change significantly from month to month. Figure 15, below, shows the relationship between the temperature difference in the water entering and returning from the residential heating load (the blue line), and the overall energy savings in MWh (the red line) of the data centre by month. However, unlike in the previous case with free cooling on the RACU side of the HVAC system, the monthly savings do not show a correlation to the temperature difference in the water going to and coming from the residential heating load. When analysing the savings by month, the smallest HVAC energy savings occurred in December, and both March and November showed an increase in energy use from the base case. In December, this scenario used 0.01 percent less than in the base case — a total savings of only 140 kWh. In November, the case with community heating on the condenser side used nearly 2 MWh more than the base case did.

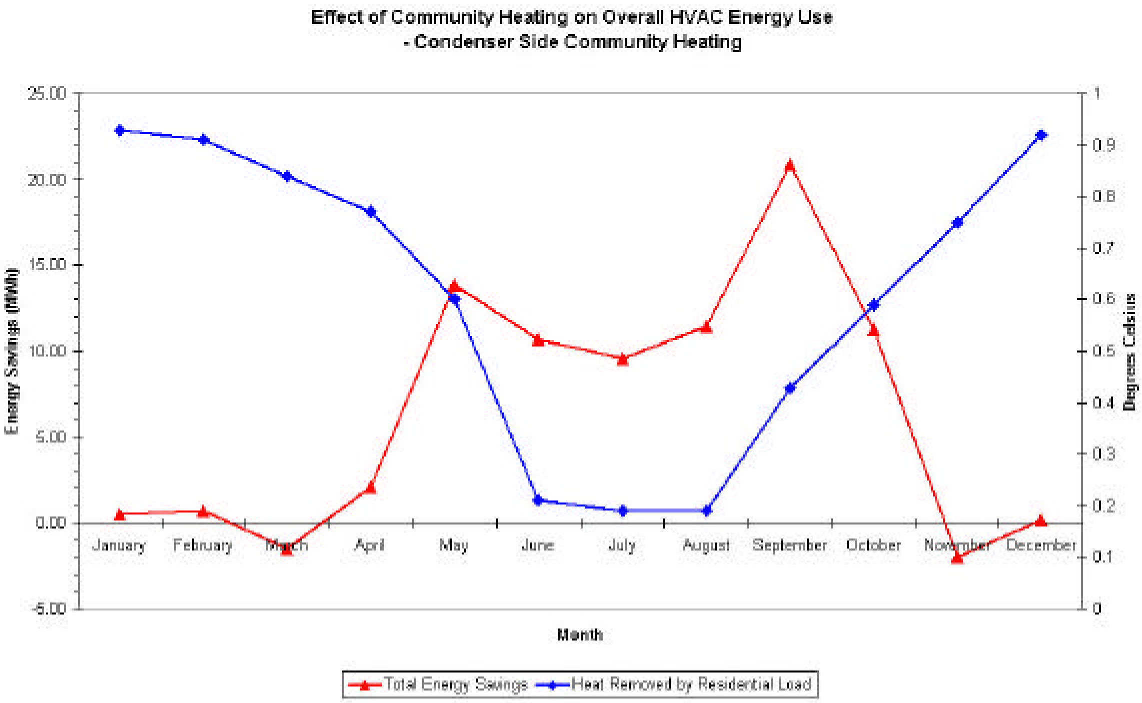


*Figure 15: HVAC Energy Use as affected by Community Heating from the condenser water loop*

As shown in Figure 15, September was the month with the highest percentage of savings at 0.82% — the equivalent of 20.9 MWh. Over the course of that month, the community heating load reduced the water temperature by an average of 0.43 °C.

In total, the data centre with no free cooling and community heating from the condenser water side of the cooling system produces 12,944 tonnes of $CO_2$ emissions from the HVAC components. By providing free heating to nearby residential buildings, this data centre model saves 33 tonnes of $CO_2$ from being produced. That accounts for just over five average UK homes.

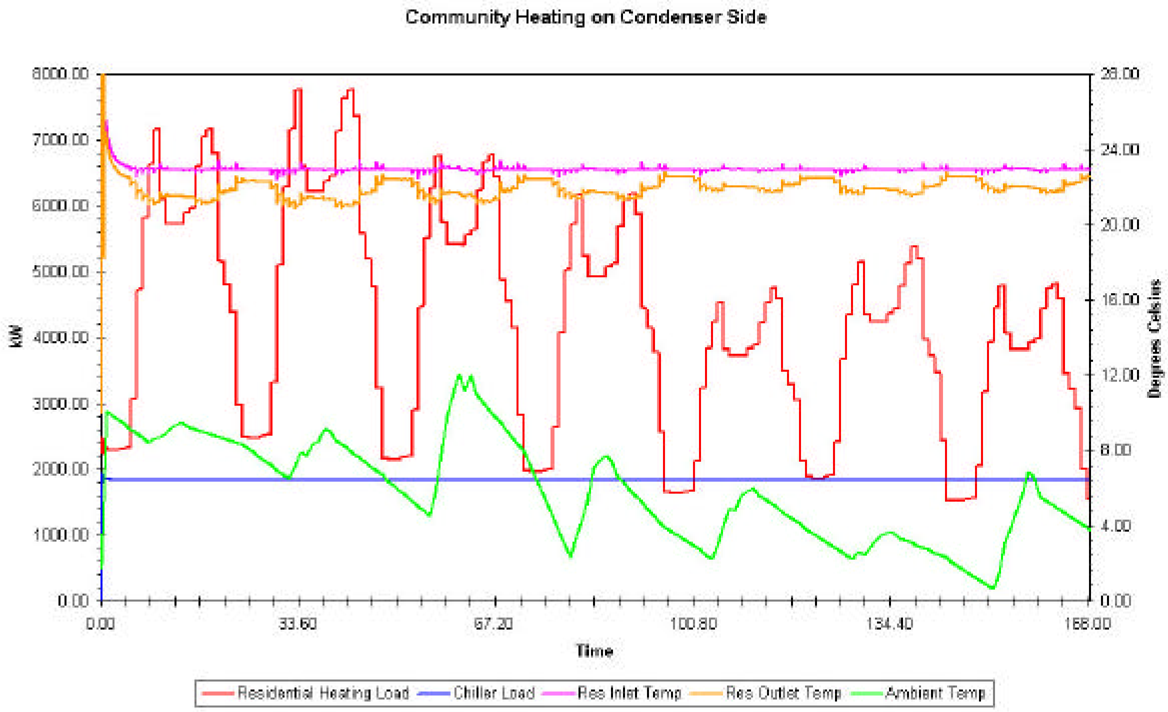


*Figure 16: Week 1 Results — Condenser Side Community Heating*

As seen in Figure 16, the temperature of the hot water going to the residential heating load from the chiller (the fuchsia line) is not as constant as it is in the case with community heating on the RACU side of the cooling system. In this case, rather than staying constant at 20.3 °C, the condenser water entering the residential load oscillates around 23 °C. The temperature of the hot water leaving the residential heating load, and returning to the flow diverter (the orange line) is dependent on the actual load (the red line) of the residential building, much like in the last case. However, in this case, the amount by which the temperature changes isn't as great. As the residential heating load increases, the temperature of the condenser water returning to the cooling system decreases slightly, and as the heating load decreases, the temperature of the condenser loop water returning to the cooling system is increases. The blue line in Figure 16 is the power used by the chiller, in kJ.

Unlike the previous case, the chiller power remains constant despite the temperature of the water returning from the residential heating load. Since the water returning to the chiller is maintained at 20 °C by a PID controller, the residential heating load has no effect on the chiller power.

### Free-Cooling

#### Base Case

In total, free cooling reduces the energy consumption of the standard cooling system by 19.9 percent, or 6.0 GWh. Most of the savings comes from the chiller — with the chiller using 32 percent less energy than the chiller in the case without free cooling. The dry coolers require 1.46 times as much energy in the free cooling case than in the standard cooling set-up, but the savings from the chiller is large enough to make the extra dry cooler use a non-issue. To illustrate, the 32 percent savings in the chiller consumption accounts for 5.1 GWh of the total savings, while the increase in the dry cooler use is only 323 MWh. Including the IT load, the total savings accounts for 5.5 percent of the entire electricity load.

The base case data centre with free cooling or community heating produces 10,397 tonnes of $CO_2$ emissions from the HVAC system: enough to account for just over 1,700 homes. By implementing free cooling, this data centre model saves 2,580 tonnes of $CO_2$ from being produced. That accounts for the emissions of 430 average UK homes each year.

#### RACU Side Community Heating

By implementing free cooling and the residential heating load on the chilled water side of the cooling system, the total energy saved is 26.3 percent of the original cooling system without free cooling. That makes the total HVAC savings 7.9 GWh of energy. In addition to the 5.1 GWh of energy saved by the chiller from free cooling, the community heating reduces the chiller energy by an additional 1.5 GWh. The dry coolers, in this case, do not need as much additional energy to cool the condenser water as in the free cooling case without the community heating. With free cooling and the residential heating load removing heat from the system, the dry coolers save 17.4 percent of the energy used for the dry cooler fans in the standard cooling base case, saving 52.2 MWh. This is an increase in the energy use by the dry coolers in the case with community heating on the RACU side without free cooling, but not by much.

Figure 17, below, shows the relationship between the temperature difference in the water entering and returning from the residential heating load, and the overall energy savings in MWh of the data centre by month. Like the case with RACU side community heating without free cooling, the total energy saved by the data centre by month follows the same curve as the temperature difference in the water going to and coming from the residential building for community heating purposes. Monthly, January showed the biggest energy savings. The combination of free cooling and community heating on the RACU side of the cooling loop saved 43.8 percent of the HVAC load in January — or a total savings of 1,103 MWh.

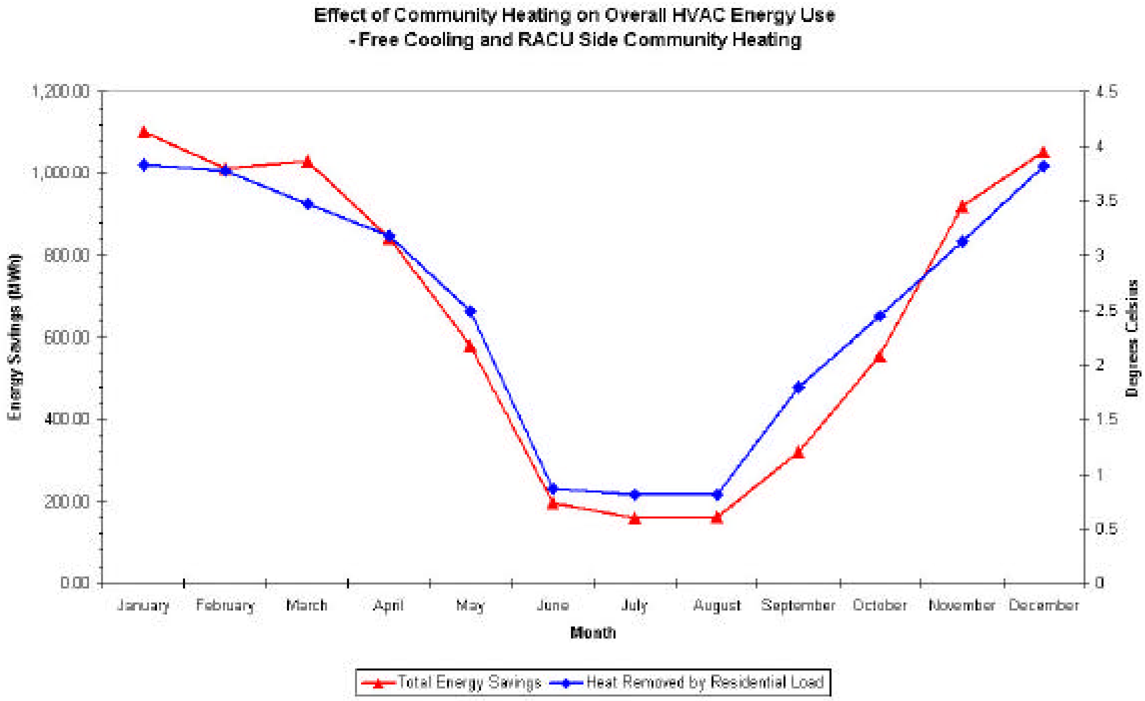


*Figure 17: HVAC Energy Use as affected by Free Cooling and Community Heating from the chilled water loop*

Accordingly, as shown in the figure above, January showed the biggest reduction in temperatures between the hot water entering and exiting the residential heating load. Over the course of the month, the load reduced the water temperature by an average of 3.83 °C. July, once again modelled the least HVAC system energy savings — only 5.9 percent lower than the case with no community heating, or 159 MWh of energy savings. July was also the month that produced the least change in hot water temperature from the residential heating load, reducing the hot water temperature by an average of only 0.81 °C throughout the month.

In total, the data centre with free cooling and community heating from the chilled water side of the cooling system produces 9,565 tonnes of $CO_2$ emissions. By not only implementing free cooling, but also providing free heating to nearby residential buildings, this data centre model saves 3,410 tonnes of $CO_2$ from being expelled into the environment. That accounts for the emissions of just over 560 average UK homes.

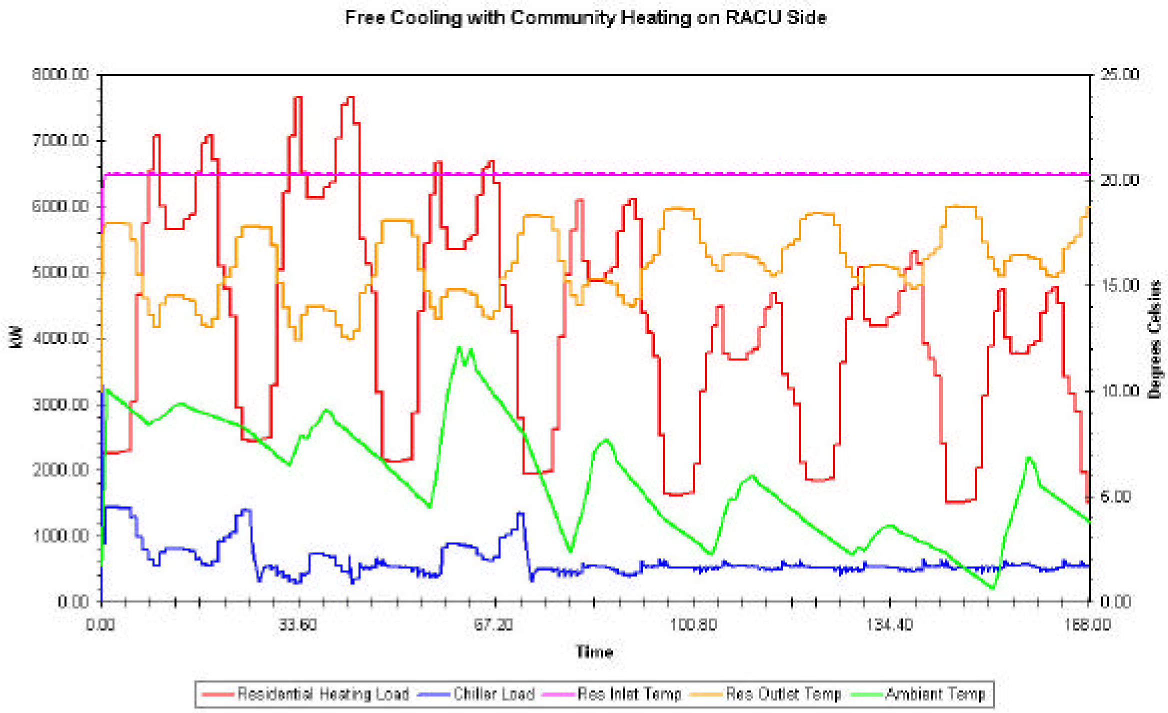


*Figure 18: Week 1 Results — RACU Side Community Heating with Free Cooling*

As seen in Figure 18, just like in the RACU Side Community Heating case without free cooling, the temperature of the hot water going to the residential heating load from the RACU (the fuchsia line) stays constant around 20.3 °C. The temperature of the hot water returning to the chiller from the community heating load (the orange line), again, has an inverse relationship to the actual heating load (the red line) of the residential building. As the heating load increases, the temperature of the hot water returning to the cooling system decreases, and as the heating load decreases, the hot water temperature returning to the cooling system increases. The blue line in Figure 18 is the power used by the chiller, in kJ. Unlike the case without free cooling, the chiller power does not exactly follow the same trend as the hot water returning to the chilled water loop. In this case, the chiller power is dependent not only on the temperature of the water returning from the residential load, but also it is dependent on the outside air temperature. The green line represents the outside air temperature. Since this sample week is in January, the temperatures are consistently below 12 °C, and often times, the temperature is below 8 °C. When the outside air temperature is below 8 °C, free cooling is put into effect, so the chiller is bypassed, as the water returning from the community heating scheme is cooled by the outside air via the dry coolers. For the last four days of this sample week, free cooling is in effect almost all the time, so the chiller is doing very little work. At the beginning of the week, however, when the temperature is above 8 °C, the chiller will still follow the same trend as in the case without free cooling: when the water returning from the community heating load is high, the chiller has to work harder to cool it, whereas, when the temperature of the water is cooler, when the residents are using more heat, the chiller does not need to work as hard since the community heating scheme has already cooled the hot water in the chilled water loop.

### *Condenser Side Community Heating*

By implementing free cooling and the residential heating load on the condenser water side of the cooling system, the total energy saved is 17.4 percent of the original cooling system with no free cooling. That makes the total energy saved less than in the free cooling case without any residential heating load. The total HVAC system savings are 5.3 GWh of energy, with the chiller saving 3.9 GWh of energy, and the dry cooler fan uses 17.2 MWh of energy less than the base case.

In the following figure, the data centre energy savings by month are compared with the reduction in temperature in the condenser water loop caused by the community heating scheme. Monthly, January showed the biggest energy savings — the community heating scheme combined with free cooling saved 32.8 percent from the HVAC load— or a total savings of 825 MWh.

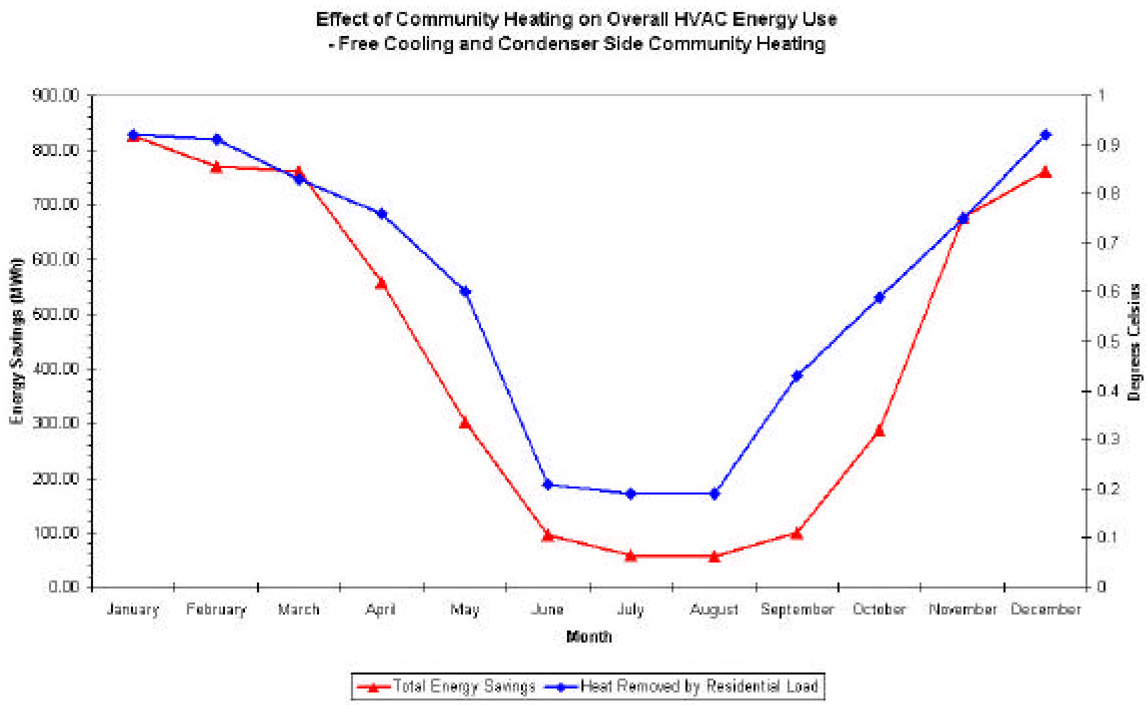


*Figure 19: HVAC Energy Use as affected by Free Cooling and Community Heating from the condenser water loop*

As Figure 19 shows, the monthly energy savings correlate closely with the amount of heat removed from the condenser water loop by the residential heating load. Accordingly, as shown in the figure above, January showed the biggest reduction in temperatures between the hot water entering and exiting the residential heating load. Over the course of the month, the load reduced the water temperature by an average of 0.92 °C. July modelled the least energy savings — only 2.1 percent lower than the base case, or 57.3 MWh of energy savings. July was also the month that produced the least change in hot water temperature from the residential heating load, reducing the hot water temperature by an average of only 0.2 °C throughout the month.

In total, the data centre with free cooling and community heating from the condenser water side of the cooling system produces 10,718 tonnes of $CO_2$ emissions. By providing free heating to nearby residential buildings, and by implementing free cooling, this data centre model saves 2,259 tonnes of $CO_2$ from being produced. That $CO_2$ savings accounts for the emissions of about 376.5 average UK homes.

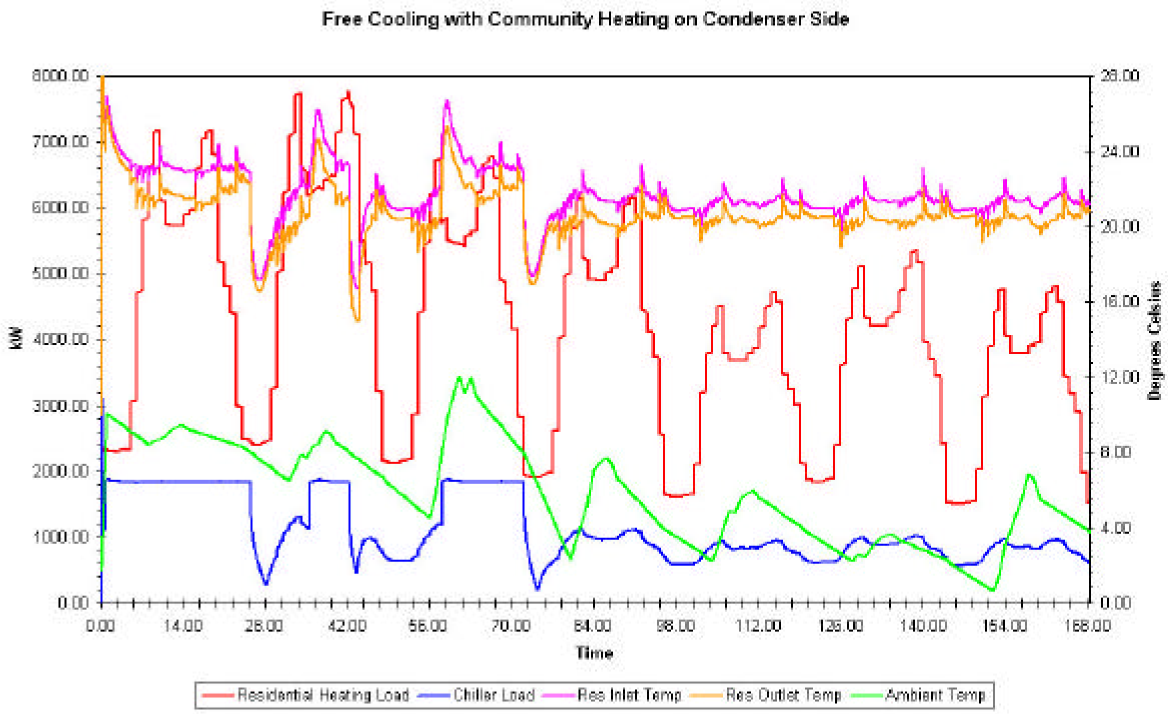


*Figure 20: Week 1 Results — Condenser Side Community Heating with Free Cooling*

As seen in Figure 20, the temperature of the hot water going to the residential heating load from the chiller (the fuchsia line) acts unlike any other case. The changes in the temperature of the condenser water follow most closely to the shape of the chiller power curve (the blue line). Like in the case with the community heating on the condenser water side, the temperature is around 23 °C, but unlike in that case, the temperature in this case fluctuates significantly more. The temperature of the hot water returning to the dry coolers from the community heating load (the orange line), as a result, follows a similar curve. The temperature curve of the water returning from the residential load is not identical in shape to the curve of the water going to the residential load, since it is also affected by the magnitude of that heating load. As the heating load increases, the temperature of the hot water returning to the cooling system decreases, and as the heating load decreases, the hot water temperature returning to the cooling system increases. The power used by the chiller, in kJ, also takes on a different shape than it did in the case with the residential heating load on the condenser side but without free cooling. Unlike the case without free cooling, the chiller power does not stay constant throughout the week. In this simulation, the chiller power is dependent on the outside air temperature, represented by the green line. Since this sample week is in January, the temperatures are consistently below 12 °C, and often times, the temperature is below 8 °C. When the outside air temperature is below 8 °C, free cooling is put into effect, so the chiller is bypassed, as the water returning from the RACUs is cooled by the outside air via the dry coolers. For the last four days of this sample week, free cooling is in effect almost all the time, so the chiller is doing very little work. At the beginning of the week, however, when the temperature is above 8 °C, the chiller will still follow the same trend as in the case without free cooling: a constant output near 2 MW.

## 3.9. Discussion

### *Case Study Comparison*

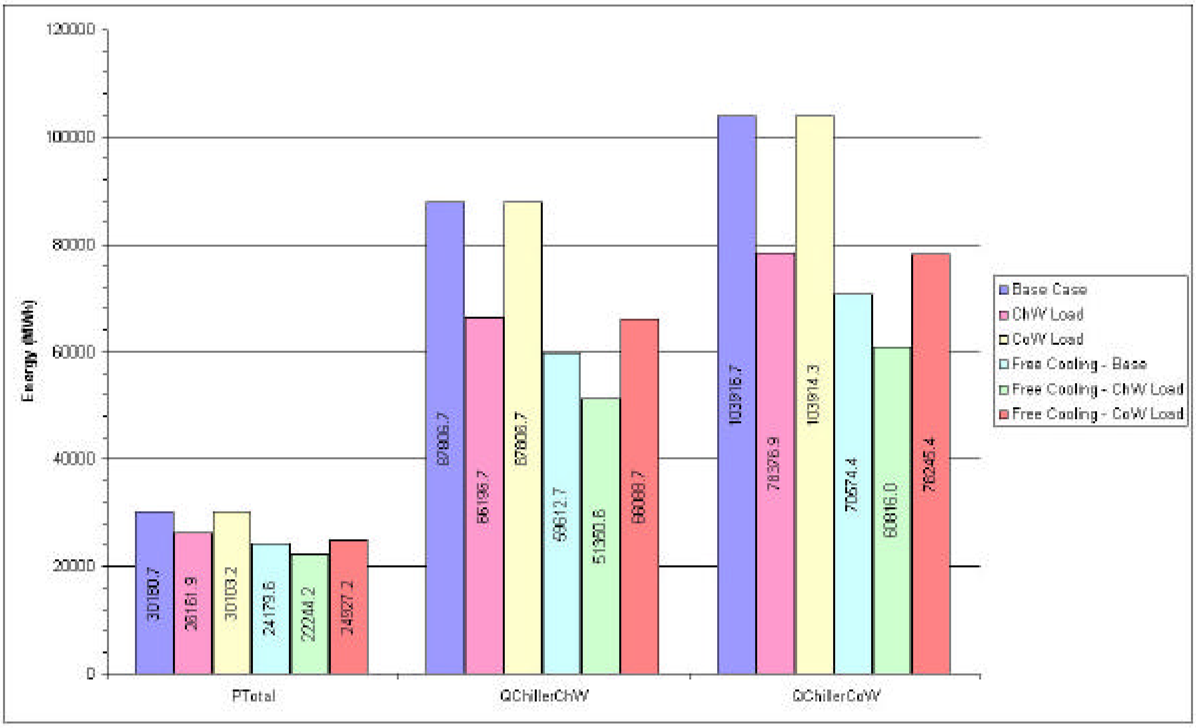


*Figure 21: Comparison of total power and work done by the chiller*

Figure 21, above, compares the total HVAC power for all six data centre models. On the left hand side of the figure, the six columns represent the total energy consumed by the HVAC system in the six cases. From left to right, it is easy to see that the base case uses the most energy, and the free cooling case that implements community heating in the chilled water loop uses the least amount of energy.

The biggest component of the HVAC load is the chiller load, and the right two sets of columns show the heat transfer that occurs in the chiller. The middle set of columns is the heat transfer value in the evaporator (chilled water side) for each of the cases. This is the amount of heat transfer that occurs when the refrigerant in the chiller evaporates as a result of coming in contact with the hot water returning from the RACU. The far right set of columns is the heat transfer value in the condenser for each of the six cases. This is the amount of heat transfer that occurs when the refrigerant in the chiller condenses back to a liquid when, in the condenser of the chiller, it comes into contact with the cool water returning from the dry coolers. The difference between the columns (QChillerCoW - QChillerChW) is the amount of work done by the compressor, or the energy needed by the chiller to do its job. The bigger the difference between the columns, the more energy is needed by the chiller. For example, the base case shows a large difference between the QChillerChW and the QChillerCoW values, while the case with free cooling and community heating on the chilled water side shows a much smaller difference. The value of the heat transfer that occurs in the condenser is also a good indicator of how much power the dry cooler will need to expel the heat from the condensing refrigerant. So, as that number decreases, the amount of power needed by the dry cooler will also decrease.

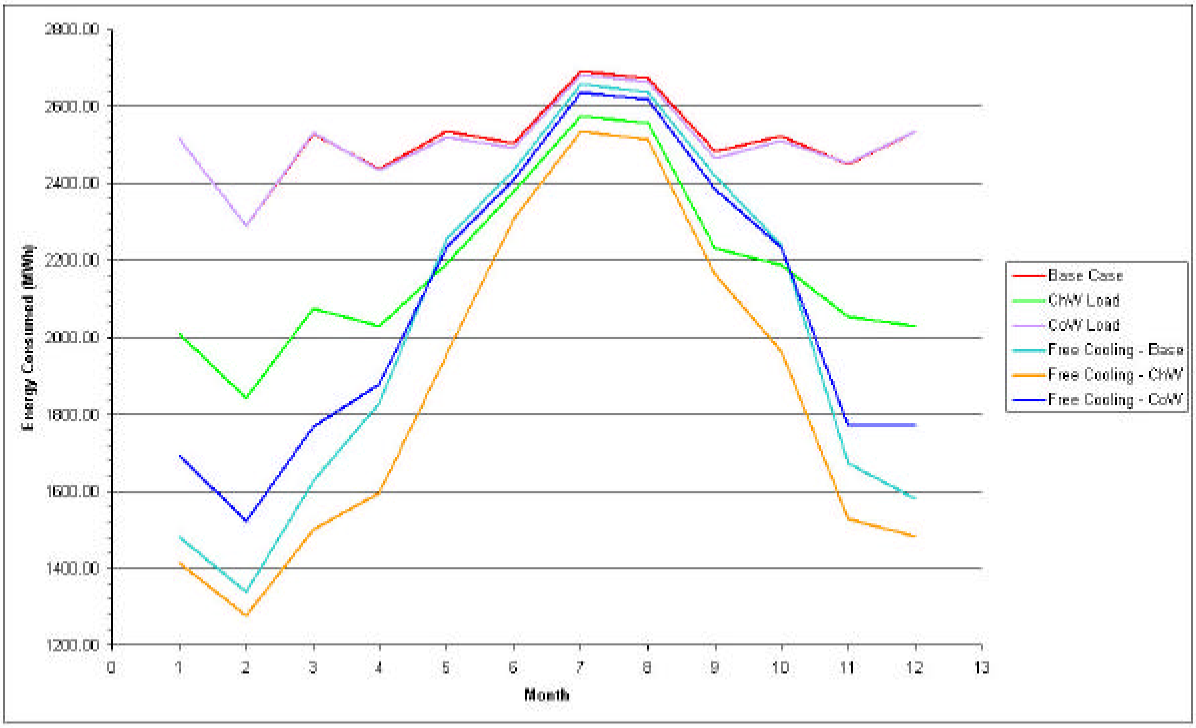


*Figure 22: Monthly energy consumption for all six scenarios*

Figure 22 shows the monthly energy consumption for the HVAC system in the data centre for all six cases. The base case (the red line) is relatively high for all twelve months, with an increase in consumption during the summer months. Since in the summer months the ambient air temperature is higher, the dry cooler fans are running at a higher speed than in the winter months. As a result, the chillers are working harder.

Just below the base case is the case with community heating on the condenser water loop. This case shows the opposite trend as the other five cases. In this simulation, the residential heating load cools the water going to the dry cooler. The condenser water is controlled to stay at 20 °C when returning to the chiller, so the chillers do not work less than in the base case. In the summer months, however, the return temperature to the condenser is sometimes higher than 20 °C even when the dry cooler fans are running at full speed. In these cases, the residential heating load helps to reduce the dry cooler load, thus making the summer months save more energy in comparison to the base case than the winter months do.

The green line on the graph is the case in which waste heat for the community heating scheme is taken from the chilled water loop after the RACU but before the water is returned to the chiller. This scenario reduces the temperature of the water entering the chiller, so the chiller does not need as much energy to cool the water. This, in turn, keeps the condenser water loop at a slightly lower temperature than in the base case, reducing the dry cooler fan load, as well. The savings in this case are dependent primarily on the amount of heat the community heating scheme removes from the chilled water loop. As a result, the majority of the savings occur in the winter months when the heat demand is high, and fewer savings occur in the summer months when there is less of a demand for heat.

The free cooling base case is represented in Figure 22 by the light blue line. The savings in this case are based on the ambient temperature. When the temperature drops below 8 °C, free cooling goes into effect. Free cooling works by using the outside air to cool the water returning from the RACUs by using the dry liquid chillers. When free cooling is in effect, the chillers are bypassed. Since the chillers make up 56 percent of the HVAC load in the base case, bypassing the chillers any time the temperature is below 8 °C can have a large impact on the energy use of the data centre. As evidenced by the graph, free cooling affects the energy consumption the most during the winter months, and it has very little impact during the summer months.

The case in which free cooling is combined with a residential heating load on the condenser water loop is marked on the graph by the dark blue line. Unlike in the cases without free cooling in which the residential heating saved energy in comparison to the base case, this scenario with residential heating uses more energy than the base case with free cooling. This may be because while free cooling is in effect, less water is flowing through the chiller to the residential heating load, so the system is affected less by the effects of the reduced water temperature due to the community heating load. Also, the dry cooler, in this case is working harder because of the free cooling.

The case that uses the least amount of energy is the case that combines the community heating scheme from the chilled water loop and free cooling. It is represented by the orange line in Figure 22. This case saves energy in comparison to the base case for a number of reasons. First, the residential heating load reduces the temperature of the water needing to be cooled in the chiller, thus reducing the chiller's load. Secondly, the free cooling allows the chilled water to bypass the chiller and be cooled by the ambient air via the dry liquid coolers any time the ambient temperature is below 8 °C. Finally, these two aspects can be combined. Since the residential heating load lowers the temperature going to the chiller, when free cooling is not in effect, the residential heating load also lowers the temperature going to the free cooling heat exchanger when the ambient temperature is low enough for free cooling to be implemented. This reduces the power needed by the dry cooler fans to cool the water to the chilled water set point. Like both the free cooling base case, and the case with only community heating on the chilled water side, this scenario saves more energy in the winter months than in the summer months.

### *Implications of Results*

While this study determined that free-cooling and community heating both have a positive impact on the $CO_2$ emissions of a data centre, the exact impact could be explored further. With additional information regarding the actual heating requirements of the consumers in a community heating scheme, an accurate emissions reduction calculation could be undertaken to determine the total reduction in emissions for the producer and consumer of the heat. For a community heating scheme to be effective, the producer has to be sure the heat provided is enough for the consumer's needs. Should a consumer in a community heating scheme require more heat than the producer can provide, the results could be devastating. In the case study presented in this report, additional research could be done to determine the exact amount of heat transfer that can occur before the chilled water loop returns from the residential load at a temperature that is too low to be usable. Knowing that would allow the data centre planners to negotiate community heating systems with multiple customers.

In this case study, a number of assumptions were made to allow the modelling of the data centre. By modelling the large numbers of individual components (RACUs, chillers, and dry coolers) as single, large components, the modelling program assumed the components would work as efficiently as group as they do as single components. This assumption has its limitations. For example, in the actual data centre upon which the case study is based, the roof is filled with 40 dry coolers. For simplicity's sake, the modelling program assumes each of the 40 components will act identically, and therefore, the 40 components will act like one component scaled up 40 times. In reality, however, because of fluid dynamics, the air flow near a dry cooler on the edge of the roof will be much different than the air flow near a dry cooler in the middle of the array. As a result, the dry cooler on the edge of the roof will perform with a different efficiency than the dry cooler in the middle. If a study which required more precision were to be undertaken, a computational fluid dynamics analysis of the roof and the dry coolers would need to be completed first. The same could be said for the complexity of pipe flow within the large HVAC system, and the effects it has on chiller, RACU, or pump efficiency.

# 4. Conclusions

### ***Fundamental Aim***

Data centres use massive amounts of energy all day, every day. One average data centre can use anywhere from 155 to 620 kWh per square foot, annually. In other words, in only 30 to 180 square feet of space, a data centre uses enough electricity to power an average UK home (BERR). With the constant growth of information technology, new data centres are being built, while old data centres are increasing the amount of IT power they can provide without increasing the building's footprint. Reducing the amount of energy used in data centres worldwide would make a significant impact in the global effort to reduce carbon emissions.

This case study was designed to determine the best way to reduce energy use, and the resulting $CO_2$ emissions. It aimed to give a solid base of information about data centres and the methods used to save energy within them. This study also explored six variations on the design of a data centre and determined which design saved the most energy from the HVAC system.

### ***Background Information***

Using an extensive literature review, this section aimed to define data centres, and explain their use, and why they use a large amount of energy.

This section reviewed the components of an HVAC system likely to be found in a data centre. The concepts of free cooling and community heating were introduced in this section, also. By presenting an overview of the components in a data centre, and the methods that can be used to save energy, this section paved the way for the more technical discussion of how such a large data centre would be modelled and analysed.

### *Methodology*

In the second section, this study explained the modelling systems that were to be used in the data analysis. This section also explained the assumptions that were made for the purpose of simplicity in the modelling program. In addition, the methodology section explained how each of the HVAC components worked together in each of the six cases to be modelled for the case study data centre.

### *Data Analysis*

In the case study presented, the data centre uses 30.2 GWh of energy annually at standard operating mode — without free cooling or district heating. By adding free cooling, the data centre reduced its energy use by 19.9 percent, or 6 GWh. That savings alone is enough to supply energy to 250 average UK homes using 24,000 kWh annually. In areas with cool climates, free cooling is an easy way for data centre operators to not only reduce energy use, but also cut utility costs. Free cooling should be implemented in all new data centre builds in areas that can support it as best practice for energy efficiency. Free cooling could also be implemented as a retrofit in data centres in cool climates.

Community heating schemes are the other energy savings method explored in this study. Reusing the data centre's waste heat in a nearby high rise residential building for free heating benefits both the data centre and the residential building's owners. Unfortunately, this set-up is only feasible in situations in which the data centre is built close to a building that could use the free heating provided by the data centre. Should a data centre be built as part of an office complex, ideally, the waste heat from cooling the data centre would be used to heat the other buildings. District heating schemes are most viable in situations in which both buildings (the data centre and the building taking advantage of the free heating) are owned by the same company or individual. In the case study, the data centre and the residential building are not owned by the same company, and the set up could be compromised should the owner of the residential building decide not to use the free heating, or if the building changed ownership. However, in a situation in which both the provider and user of the heating are happy with the system, district heating can save energy for both parties. In this case study, adding district heating without free cooling saved the data centre 13.3 percent of their base case energy load. With district heating in addition to free cooling, the data centre saved 26.3 percent of the original load.

### *Data Centre Energy Savings*

Free cooling and district heating are both worthwhile energy savings methods for data centre use — each saving over ten percent of the base energy load in the case study. However, both methods are contingent on conditions, such as climate and proximity to surrounding buildings, which are not always within the data centre owner's control. Climate plays a crucial role in free cooling. If the data centre is located in a warm climate with fewer than 3,000 hours of wet-bulb temperatures below 12.4 °C, free cooling is not a feasible source of energy savings. Also, if a data centre is located in an area far away from other buildings, the use of the data centre's waste heat for a community heating scheme may be out of the question. In all cases, whether or not they can implement additional energy savings methods, data centres should implement best practice designs for both IT and HVAC energy efficiency.

# References

Ananthanarayanan, P.N., 2005. *Basic Refrigeration and Air Conditioning*. 3rd ed. New York: McGraw-Hill Education, pp. 16-18.

Andrepont, J. S., 2004. Distributed Generation Benefits and Barriers -- The Perspective of Combined Heat & Power/District Energy Developer. In: D. Sioros, ed. 2004. *Building for the 21st Century : Energy and the Environment*. New York: Fairmont P, Incorporated, pp. 305-11. Available at: NetLibrary, University of Strathclyde e-collection, <http://www.netlibrary.com>. [Accessed June 2008].

BERR, 2008. *Annual Average Total Domestic Energy Consumption per Capita in 2004 (kWh).* UK. Department for Business Enterprise & Regulatory Reform. 12 Jan. 2008. Available at: <http://www.berr.gov.uk/files/file41497.pdf>. [Accessed 4 Sept. 2008].

Birkeland, J, 2002. *Design for Sustainability : A Sourcebook of Integrated, Ecological Solutions*. Detroit: Earthscan/James & James. Available at: NetLibrary, University of Strathclyde e-collection, <http://www.netlibrary.com>. [Accessed June 2008].

Clay, H, H., & Bassett, W. H., 2004. *Clay's Handbook of Environmental Health*. New York: Taylor & Francis Group. Available at: NetLibrary, University of Strathclyde e-collection, <http://www.netlibrary.com>. [Accessed September 2008].

"Definition of Data Center: Data Center Energy Management." Data Center Energy Management. 13 Mar. 2008. Lawrence Berkeley National Laboratory. <http://hightech.lbl.gov/dctraining/definitions.html>.

DEFRA, 2008. *Guidelines to Defra's Greenhouse Gas (GHG) Conversion Factors for Company Reporting - Annexes, July 2007*. Department for

Environment, Food, and Rural Affairs, London, UK. Available at: <http://www.defra.gov.uk/environment/business/envrp/conversion-factors.htm>.

Elliott, J. A., 2006. *An Introduction to Sustainable Development*. 3rd ed. New York: Routledge, 2006. Available at: NetLibrary, University of Strathclyde e-collection, <http://www.netlibrary.com>. [Accessed June 2008].

Energy Saving Trust. *Community Heating and Combined Heat and Power.* Available at: <http://www.energysavingtrust.org.uk/uploads/documents/housingbuildings/10_community_heating_s.pdf> [Accessed June 2008].

Greater London Authority, 2008. *The London Plan – Climate change – Sustainable energy – 4A.7 Renewable energy* [Online]. Available at: <http://www.london.gov.uk/thelondonplan/policies/4a-07.jsp> [Accessed June 2008].

Greenberg, S., Tschudi, B., & Rumsey, P., 2006. Commercial Buildings: Technologies, Design, Performance Analysis, and Building Industry Trends. In: American Council for an Energy-Efficient Economy, *ACEEE Summer Study on Energy Efficiency in Buildings*, Pacific Grove, CA, 14 Aug. 2006. [Online] Lawrence Berkeley National Laboratory. *Environmental Energy Technologies Division*. (Updated 30 Jan. 2007). Available at: <http://eetd.lbl.gov/emills/pubs/pdf/aceee-datacenters.pdf> [Accessed September 2008].

H.R. Res. H.R. 5646, 109th Cong., 152 Congressional Record 2920-21 (2006) (enacted).

Jones, W. P., 2000. *Air Conditioning Engineering*. Chicago: Butterworth-Heinemann Limited.

Klein, S. A., W. A. Beckman, J. W. Mitchell, J. A. Duffle, N. A. Duffie, T. L.

Freeman, J. C. Mitchell, J. E. Braun, B. L. Evans, J. P. Kummer, R. E. Urban, A. Fiksel, J. W. Thornton, N. J. Blair, P. M. Williams, D. E. Bradley, T. P. McDowell, M. Kummert. 2004. *TRNSYS 16 -- A TRaNsient SYstem Simulation program, User manual*. Solar Energy Laboratory, University of Wisconsin-Madison. Madison.

Kubba, S. A., 2008. *Architectural Forensics*. New York: McGraw-Hill Professional.

Lawrence Berkeley National Laboratory, 2008. *Data Center Energy Management, Best Practices Checklist.* [Online] (Updated 23 June 2008). Available at: <http://hightech.lbl.gov/dctraining/best-practices.html>.

Lawrence Berkeley National Laboratory, 2008. *Data Center Energy Management.* [Online] (Updated 23 June 2008). Available at: <http://hightech.lbl.gov/dctraining/dc.html> [Accessed June 2008].

MacKay, K., 2007. *Energy Efficient Cooling Solutions for Data Centres*. [Online] Available at: <http://www.esru.strath.ac.uk/Documents/MSc_2007/Mackay.pdf> [Accessed June 2008].

Scheihing, P., 2007. *Creating Energy Efficient Data Centers*. [Online] U.S. Department of Energy. Energy Efficiency and Renewable Energy. Available at: <http://www1.eere.energy.gov/industry/saveenergynow/docs/doe_data_centers_presentation.ppt> [Accessed 4 Sept. 2008].

Thumann, A., & Mehta, D. P., 1997. *Handbook of Energy Engineering*. 4th ed. New York: Fairmont P, Incorporated. Available at: NetLibrary. University of Strathclyde e-collection. <http://www.netlibrary.com> [Accessed June 2008].

Trott, A. R., & Welch, T. C., 1999. *Refrigeration and Air Conditioning*. Chicago: Butterworth-Heinemann Limited.

Tschudi, W., Mills, E. & Greenberg, S., 2006. Measuring and Managing Data-Center Energy Use. *HPAC Engineering,* [Online] Mar. 2006, pp. 45-51. Available at: *Data Center Energy Management*. Lawrence Berkeley National Laboratory. <http://hightech.lbl.gov/documents/data_centers/hpac_dc_bestprac.pdf> [Accessed 4 Sept. 2008].

U.S. Department of Energy, 2006. *2003 Commercial Buildings Energy Consumption Survey Overview of Commercial Buildings Characteristics*. Energy Information Administration. [Online] (Updated 24 Mar. 2006). Available at: <http://www.eia.doe.gov/emeu/cbecs/cbecs2003/introduction.html> [Accessed 11 Sept. 2008].

U.S. Department of Energy, 2007. "Green Grid" Consortium Takes Aim on Data Center Energy Use. *EERE Network News*. [Online] 28 Feb. 2007. *EERE News*. Available at: <http://apps1.eere.energy.gov/news/news_detail.cfm/news_id=10598> [Accessed 11 Sept. 2008].

U.S. Department of Energy, 2007. President Bush Signs Data Center Energy Efficiency Bill. *EERE Network News*. [Online] 4 Jan. 2007. *EERE News*. Available at: <http://apps1.eere.energy.gov/news/news_detail.cfm/news_id=10493> [Accessed 11 Sept. 2008].

U.S. Department of Energy, 2008. *U.S. DOE Energy Efficiency and Renewable Energy Home Page.* Available at: <http://www.eere.energy.gov>. [Accessed July 2008].

U.S. Department of Energy and Environmental Protection Agency, 2008. *Fact Sheet on National Data Center Energy Efficiency Information Program*. [Online] U.S. Department of Energy: Energy Efficiency and Renewable Energy. *Industrial Technologies Program: Save Energy Now.* (Updated 18 Mar. 2008). Available at:

<http://www1.eere.energy.gov/industry/saveenergynow/pdfs/national_data_center_fact_sheet.pdf> [Accessed 4 Sept. 2008].

U.S. Environmental Protection Agency, 2000. *Emission Facts: Average Annual Emissions and Fuel Consumption for Passenger Cars and Light Trucks*. Available at: <http://www.epa.gov/oms/consumer/f00013.htm> [Accessed 11 Sept. 2008].

U.S. Environmental Protection Agency, 2007. *Office Building Energy Use Profile*. [Online] U.S. Environmental Protection Agency: Clean Energy. 10 July 2007. National Action Plan for Energy Efficiency. Available at: <http://www.epa.gov/cleanenergy/documents/sector-meeting/4bi_officebuilding.pdf> [Accessed 4 Sept. 2008].

WSP Group, 2008. *080813 Planning Energy Strategy Report.* [Report] 13 August 2008.

# Appendices

## 1. SIMULATION DATA

*Table 1: Summary of results for Base Case*

| Monthly Analysis | Base Case | | | |
|---|---|---|---|---|
| | Load (MWh) | Total Load (MWh) (HVAC + IT + Misc) | $CO_2$ Emissions (tonnes) | $CO_2$ Emissions + IT (tonnes) |
| January | 2,519.00 | 9,244.01 | 1,083.17 | 3,974.93 |
| February | 2,291.17 | 8,365.38 | 985.20 | 3,597.11 |
| March | 2,531.00 | 9,256.02 | 1,088.33 | 3,980.09 |
| April | 2,436.67 | 8,944.75 | 1,047.77 | 3,846.24 |
| May | 2,535.58 | 9,260.60 | 1,090.30 | 3,982.06 |
| June | 2,504.57 | 9,012.65 | 1,076.96 | 3,875.44 |
| July | 2,693.96 | 9,418.98 | 1,158.40 | 4,050.16 |
| August | 2,675.38 | 9,400.40 | 1,150.42 | 4,042.17 |
| September | 2,485.13 | 8,993.21 | 1,068.61 | 3,867.08 |
| October | 2,523.01 | 9,248.03 | 1,084.89 | 3,976.65 |
| November | 2,450.11 | 8,958.19 | 1,053.55 | 3,852.02 |
| December | 2,535.14 | 9,260.15 | 1,090.11 | 3,981.87 |
| Total | 30,180.73 | 109,362.37 | 12,977.71 | 47,025.82 |

*Table 2: Summary of Results for RACU side Community Heating Case*

| Monthly Analysis | Chilled Water Community Heating | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Load (MWh) | Total Load (MWh) (HVAC + IT + Misc) | MWh Saved | % Saved | Temp Difference (C) | $CO_2$ Savings (tonnes) | $CO_2$ Emissions (tonnes) | $CO_2$ Emissions + IT (tonnes) |
| January | 2,012.16 | 8,737.18 | 506.84 | 20.12% | 3.83 | 217.94 | 865.23 | 3,756.99 |
| February | 1,840.49 | 7,914.70 | 450.68 | 19.67% | 3.77 | 193.79 | 791.41 | 3,403.32 |
| March | 2,074.60 | 8,799.61 | 456.41 | 18.03% | 3.47 | 196.26 | 892.08 | 3,783.83 |
| April | 2,028.80 | 8,536.88 | 407.87 | 16.74% | 3.18 | 175.38 | 872.39 | 3,670.86 |
| May | 2,191.80 | 8,916.81 | 343.78 | 13.56% | 2.49 | 147.83 | 942.47 | 3,834.23 |
| June | 2,380.06 | 8,888.14 | 124.51 | 4.97% | 0.87 | 53.54 | 1,023.43 | 3,821.90 |
| July | 2,576.14 | 9,301.16 | 117.82 | 4.37% | 0.81 | 50.66 | 1,107.74 | 3,999.50 |
| August | 2,555.90 | 9,280.92 | 119.48 | 4.47% | 0.81 | 51.38 | 1,099.04 | 3,990.79 |
| September | 2,230.55 | 8,738.63 | 254.58 | 10.24% | 1.8 | 109.47 | 959.14 | 3,757.61 |
| October | 2,188.80 | 8,913.81 | 334.21 | 13.25% | 2.44 | 143.71 | 941.18 | 3,832.94 |
| November | 2,052.77 | 8,560.85 | 397.34 | 16.22% | 3.13 | 170.86 | 882.69 | 3,681.16 |
| December | 2,029.86 | 8,754.88 | 505.28 | 19.93% | 3.82 | 217.27 | 872.84 | 3,764.60 |
| Total | 26,161.93 | 105,343.57 | 4,018.80 | 13.32% | | 1,728.08 | 11,249.63 | 45,297.73 |

*Table 3: Summary of Results for Cooler side Community Heating Case*

| Monthly Analysis | Condenser Water Community Heating | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Load (MWh) | Total Load (MWh) (HVAC + IT + Misc) | MWh Saved | % Saved | Temp Difference (C) | $CO_2$ Savings (tonnes) | $CO_2$ Emissions (tonnes) | $CO_2$ Emissions + IT (tonnes) |
| January | 2,518.48 | 9,243.49 | 0.52 | 0.02% | 0.93 | 0.22 | 1,082.94 | 3,974.70 |
| February | 2,290.47 | 8,364.68 | 0.70 | 0.03% | 0.91 | 0.30 | 984.90 | 3,596.81 |
| March | 2,532.51 | 9,257.53 | -1.51 | -0.06% | 0.84 | -0.65 | 1,088.98 | 3,980.74 |
| April | 2,434.58 | 8,942.66 | 2.09 | 0.09% | 0.77 | 0.90 | 1,046.87 | 3,845.34 |
| May | 2,521.76 | 9,246.78 | 13.82 | 0.55% | 0.6 | 5.94 | 1,084.36 | 3,976.11 |
| June | 2,493.89 | 9,001.97 | 10.68 | 0.43% | 0.21 | 4.59 | 1,072.37 | 3,870.85 |
| July | 2,684.40 | 9,409.42 | 9.56 | 0.35% | 0.19 | 4.11 | 1,154.29 | 4,046.05 |
| August | 2,663.96 | 9,388.98 | 11.42 | 0.43% | 0.19 | 4.91 | 1,145.50 | 4,037.26 |
| September | 2,464.28 | 8,972.36 | 20.85 | 0.84% | 0.43 | 8.96 | 1,059.64 | 3,858.12 |
| October | 2,511.81 | 9,236.82 | 11.21 | 0.44% | 0.59 | 4.82 | 1,080.08 | 3,971.83 |
| November | 2,452.09 | 8,960.17 | -1.98 | -0.08% | 0.75 | -0.85 | 1,054.40 | 3,852.87 |
| December | 2,535.00 | 9,260.01 | 0.14 | 0.01% | 0.92 | 0.06 | 1,090.05 | 3,981.81 |
| Total | 30,103.22 | 109,284.86 | 77.50 | 0.26% | | 33.33 | 12,944.39 | 46,992.49 |

*Table 4: Summary of Results for Free Cooling base case*

| Monthly Analysis | Free Cooling | | | | | | |
|---|---|---|---|---|---|---|---|
| | Load (MWh) | Total Load (MWh) (HVAC + IT + Misc) | MWh Saved | % Saved | $CO_2$ Savings (tonnes) | $CO_2$ Emissions (tonnes) | $CO_2$ Emissions + IT (tonnes) |
| January | 1,482.79 | 8,207.81 | 1,036.20 | 41.14% | 445.57 | 637.60 | 3,529.36 |
| February | 1,337.60 | 7,411.80 | 953.58 | 41.62% | 410.04 | 575.17 | 3,187.08 |
| March | 1,626.48 | 8,351.49 | 904.53 | 35.74% | 388.95 | 699.39 | 3,591.14 |
| April | 1,828.90 | 8,336.98 | 607.77 | 24.94% | 261.34 | 786.43 | 3,584.90 |
| May | 2,257.01 | 8,982.02 | 278.57 | 10.99% | 119.79 | 970.51 | 3,862.27 |
| June | 2,433.70 | 8,941.78 | 70.86 | 2.83% | 30.47 | 1,046.49 | 3,844.97 |
| July | 2,658.36 | 9,383.37 | 35.61 | 1.32% | 15.31 | 1,143.09 | 4,034.85 |
| August | 2,638.41 | 9,363.43 | 36.97 | 1.38% | 15.90 | 1,134.52 | 4,026.27 |
| September | 2,419.21 | 8,927.29 | 65.92 | 2.65% | 28.34 | 1,040.26 | 3,838.74 |
| October | 2,241.73 | 8,966.75 | 281.28 | 11.15% | 120.95 | 963.95 | 3,855.70 |
| November | 1,674.05 | 8,182.13 | 776.06 | 31.67% | 333.70 | 719.84 | 3,518.32 |
| December | 1,581.35 | 8,306.37 | 953.78 | 37.62% | 410.13 | 679.98 | 3,571.74 |
| Total | 24,179.60 | 103,361.24 | 6,001.13 | 19.88% | 2,580.49 | 10,397.23 | 44,445.33 |

*Table 5: Summary of Results for RACU side Community Heating Case with Free Cooling*

| Monthly Analysis | Chilled Water Community Heating + Free Cooling | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Load (MWh) | Total Load (MWh) (HVAC + IT + Misc) | MWh Saved | % Saved | Temp Difference (C) | $CO_2$ Savings (tonnes) | $CO_2$ Emissions (tonnes) | $CO_2$ Emissions + IT (tonnes) |
| January | 1,415.84 | 8,140.86 | 1,103.16 | 43.79% | 3.83 | 474.36 | 608.81 | 608.81 |
| February | 1,278.24 | 7,352.45 | 1,012.93 | 44.21% | 3.77 | 435.56 | 549.64 | 549.64 |
| March | 1,501.87 | 8,226.88 | 1,029.14 | 40.66% | 3.47 | 442.53 | 645.80 | 645.80 |
| April | 1,594.84 | 8,102.92 | 841.83 | 34.55% | 3.18 | 361.99 | 685.78 | 685.78 |
| May | 1,955.16 | 8,680.18 | 580.42 | 22.89% | 2.49 | 249.58 | 840.72 | 840.72 |
| June | 2,308.90 | 8,816.98 | 195.67 | 7.81% | 0.87 | 84.14 | 992.83 | 992.83 |
| July | 2,534.69 | 9,259.70 | 159.28 | 5.91% | 0.81 | 68.49 | 1,089.92 | 1,089.92 |
| August | 2,514.37 | 9,239.38 | 161.02 | 6.02% | 0.81 | 69.24 | 1,081.18 | 1,081.18 |
| September | 2,164.23 | 8,672.31 | 320.90 | 12.91% | 1.8 | 137.99 | 930.62 | 930.62 |
| October | 1,965.96 | 8,690.97 | 557.05 | 22.08% | 2.44 | 239.53 | 845.36 | 845.36 |
| November | 1,529.06 | 8,037.14 | 921.05 | 37.59% | 3.13 | 396.05 | 657.50 | 657.50 |
| December | 1,481.02 | 8,206.03 | 1,054.12 | 41.58% | 3.82 | 453.27 | 636.84 | 636.84 |
| Total | 22,244.17 | 101,425.81 | 7,936.55 | 26.30% | | 3,412.72 | 9,564.99 | 9,564.99 |

*Table 6: Summary of Results for Cooler side Community Heating Case with Free Cooling*

| Monthly Analysis | Condenser Community Heating + Free Cooling | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Load (MWh) | Total Load (MWh) (HVAC + IT + Misc) | MWh Saved | % Saved | Temp Difference (C) | $CO_2$ Savings (tonnes) | $CO_2$ Emissions (tonnes) | $CO_2$ Emissions + IT (tonnes) |
| January | 1,693.45 | 8,418.47 | 825.54 | 32.77% | 0.92 | 354.98 | 728.19 | 728.19 |
| February | 1,521.60 | 7,595.80 | 769.58 | 33.59% | 0.91 | 330.92 | 654.29 | 654.29 |
| March | 1,768.65 | 8,493.66 | 762.35 | 30.12% | 0.83 | 327.81 | 760.52 | 760.52 |
| April | 1,878.51 | 8,386.59 | 558.17 | 22.91% | 0.76 | 240.01 | 807.76 | 807.76 |
| May | 2,233.48 | 8,958.50 | 302.10 | 11.91% | 0.6 | 129.90 | 960.40 | 960.40 |
| June | 2,410.34 | 8,918.42 | 94.22 | 3.76% | 0.21 | 40.52 | 1,036.45 | 1,036.45 |
| July | 2,636.56 | 9,361.58 | 57.40 | 2.13% | 0.19 | 24.68 | 1,133.72 | 1,133.72 |
| August | 2,618.09 | 9,343.10 | 57.30 | 2.14% | 0.19 | 24.64 | 1,125.78 | 1,125.78 |
| September | 2,385.29 | 8,893.37 | 99.84 | 4.02% | 0.43 | 42.93 | 1,025.67 | 1,025.67 |
| October | 2,235.72 | 8,960.73 | 287.29 | 11.39% | 0.59 | 123.54 | 961.36 | 961.36 |
| November | 1,772.66 | 8,280.74 | 677.45 | 27.65% | 0.75 | 291.31 | 762.24 | 762.24 |
| December | 1,772.90 | 8,497.92 | 762.23 | 30.07% | 0.92 | 327.76 | 762.35 | 762.35 |
| Total | 24,927.25 | 104,108.89 | 5,253.48 | 17.41% | | 2,259.00 | 10,718.72 | 10,718.72 |

*Table 7: Comparison of all six case study simulation results*

| Data Centre Case Study Simulation -- Energy Comparison (MWh) | Component Energy Use (MWh) | | | | | | | Total HVAC | HVAC + IT Load | Total HVAC CO2 (tonnes) |
|---|---|---|---|---|---|---|---|---|---|---|
| | Chiller | Chilled Water Shunt Pump | Chilled Water Main Pump | RACU Fan | Dry Cooler Fan | Condenser Water Shunt Pump | Condenser Water Main Pump | | | |
| Base Case | 16,109.93 | 275.09 | 371.97 | 9,646.86 | 701.44 | 1,067.07 | 2,008.36 | 30,180.73 | 109,362.37 | 12,977.71 |
| Chilled Water Side Community Heating | 12,180.23 | 275.09 | 371.97 | 9,646.86 | 585.43 | 1,067.07 | 2,035.27 | 26,161.93 | 105,343.57 | 11,249.63 |
| Condenser Water Side Community Heating | 16,107.53 | 275.09 | 371.97 | 9,646.86 | 600.53 | 1,067.07 | 2,034.16 | 30,103.22 | 109,284.86 | 12,944.39 |
| Free Cooling | 10,961.67 | 275.09 | 371.97 | 9,646.86 | 1,024.85 | 1,067.07 | 832.08 | 24,179.60 | 103,361.24 | 10,397.23 |
| Free Cooling + Chilled Water Side Community Heating | 9,465.42 | 275.09 | 371.99 | 9,646.86 | 649.28 | 1,067.07 | 768.45 | 22,244.17 | 101,425.81 | 9,564.99 |
| Free Cooling + Condenser Water Side Community Heating | 12,156.69 | 275.09 | 371.99 | 9,646.86 | 684.23 | 1,067.07 | 725.30 | 24,927.25 | 104,108.89 | 10,718.72 |

*Table 8: Percentage energy savings with respect to Base Case simulation*

| Data Centre Case Study Simulation -- Energy Comparison with Base Case | Component Energy Use (MWh) | | | | | | | Total HVAC | HVAC + IT Load |
|---|---|---|---|---|---|---|---|---|---|
| | Chiller | Chilled Water Shunt Pump | Chilled Water Main Pump | RACU Fan | Dry Cooler Fan | Condenser Water Shunt Pump | Condenser Water Main Pump | | |
| Chilled Water Side Community Heating | 75.6% | 100.0% | 100.0% | 100.0% | 83.5% | 100.0% | 101.3% | 86.7% | 96.3% |
| Condenser Water Side Community Heating | 100.0% | 100.0% | 100.0% | 100.0% | 85.6% | 100.0% | 101.3% | 99.7% | 99.9% |
| Free Cooling | 68.0% | 100.0% | 100.0% | 100.0% | 146.1% | 100.0% | 41.4% | 80.1% | 94.5% |
| Free Cooling + Chilled Water Side Community Heating | 58.8% | 100.0% | 100.0% | 100.0% | 92.6% | 100.0% | 38.3% | 73.7% | 92.7% |
| Free Cooling + Condenser Water Side Community Heating | 75.5% | 100.0% | 100.0% | 100.0% | 97.5% | 100.0% | 36.1% | 82.6% | 95.2% |

## 2. DESIGN PARAMETERS USED IN TRNSYS 16

The design parameters for the simulations are: -

Data Centre:

Volume = 19,200 $m^3$

Building surface area = 4,800 $m^2$

Building capacitance = 50,000 kJ/K

Internal heat gains, excluding RACU fan power = All IT lighting + lighting + miscellaneous = 9,039 kW (32,540,398 kJ/hr).

Building loss coefficient is negligible, i.e., loads such, as solar gains, and losses, through fabric etc are taken as negligible in TRNSYS program.

Room Air Conditioning Units (RACUs)

Rated fan power = 3,964,464 kJ/hr = 1,100 kW

Rated flow rate = 4,461,540 kg/hr = 1,240 kg/s

Design temperatures are: 24ºC returning from the data centre.

In TRNSYS 16, only one RACU is modelled, but in reality 138 RACUs would be used.

For the water side, the equivalent UA of the RACU is calculated using a regression on the water flow rate:

$$UA\ [kW/K] = -12.444438 + 34.3267977*x - 15.3908699*x^2 + 3.27705672*x^3 - 0.26623961*x^4$$

Where x is the chilled water flow rate in kg/s. The equation above is for one RACU with a design load of 76.5 kW so it is scaled up to model a series of parallel RACUs matching the total load of 9,039 kW.

The water flow rate is set by a PID controller that keeps the return air (or the data centre room temperature in the model) constant at 24 °C.

## 3. NOMENCLATURE

| | |
|---|---|
| BERR | Department of Business Enterprise and Regulatory Reform |
| CCHP | Combined Cooling, Heating and Power |
| $CO_2$ | Carbon Dioxide |
| COP | Coefficient of Performance |
| DOE | Department of Energy |
| EPA | Environmental Protection Agency |
| GHG | Green House Gas |
| GW | Gigawatt |
| GWh | Gigawatt hours |
| HVAC | Heating Ventilation and Air Conditioning |
| IT | Information Technology |
| kW | Kilowatts |
| kWh | Kilowatt hours |
| LBNL | Lawrence Berkeley National Laboratory |
| MW | Megawatt |
| MWh | Megawatt hours |
| UPS | Uninterruptible Power Supply |
| UK | United Kingdom |
| US | United States of America |