Investigation of techniques for energy-efficient new-build data centres

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Contents

Preface

Data centres are a fast growing and increasingly important sector of the Dutch economy. Parallel with the economic importance, also the energy use of the sector is growing fast, and the sector contributes substantially to the Dutch total consumption of electricity.

In recent years diverse technical options have been developed, that provide opportunities for large increases in the energy efficiency. Within the framework of environmental permits local authorities ask data centres to implement such measures. In this context there is a need for an objective overview of options that limit energy use, and that are economically and technically feasible. The purpose of this report to provide such an overview for new-build data centres.

In preparing this study, a range of suppliers of energy-efficient techniques was willing to share detailed information on the performance of energy-efficient techniques. Also diverse operators of data centres were willing to compare modelled results with their experiences. It is only due to this cooperation that we have been able to prepare this report. Especially, we would like to thank the following companies: APC, Atos, Boersema Installatie Adviseurs, DataCenter Infra Solutions, Equinix, Holland Ventilatie Groep, Jaeggi, Kyoto Cooling, Nebiprofa, Optigroen, Piller, RecAir, Recool, Rotterdam Internet Exchange, Stulz, TCN Data Hotels, Tenzon, The Datacenter Group and Ziggo. Also the consultancies EnergyGo and KWA delivered valuable data. In addition we would like to thank the members of the Expert Advisory Group for their open and constructive contributions. Last but not least, the steering group, guided by NL Agency's Frank Hartkamp, has helped the project team with valuable discussions and made contacts within a broad network possible.

We hope this report can serve as a means for both data centres and government authorities in assessing effective and feasible options for a new generation of energy-efficient data centres.

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Summary

In today's society, immense volumes of electronic data need to be stored and the data centre industry that has emerged to cater for this need consumes a vast amount of energy: at present 1.6 TWh. A substantial fraction of this energy is used for cooling applications (typically 23%) and for the supply of electricity (typically 7%). The use for other equipment such as offices and lighting is generally small (typically < 1%).

This report assesses the potential impacts of (combinations of) various measures to improve energy efficiency in this sector. In recent years a range of energy-efficient technologies have been developed for both cooling and power supply and this study evaluates combinations of these for three typical data centres: small (0.25 MW), medium (3 MW) and large (8 MW). The research is based on an extensive literature study, interviews with suppliers, model calculations and validation among data centre operators.

Combinations of techniques (variants)

Based on the literature research, five combinations of energy-efficient cooling techniques were distinguished (Table 1). In general, these techniques are based on maximum utilization of the cold available in the outside air, thus to avoid the use of electricity for compression cooling. The variants are based on the energy-efficient techniques currently available from suppliers and have all been implemented in recently built centres. They comprise such techniques as air filters, fans, dry coolers, wet coolers, hybrid coolers, heat exchangers and cooling units.

Table 1 Variants for energy-efficient new-build data centres

General concept	Variant
1 Open cooling systems	1a Supported by adiabatic cooling
	1b Supported by phase change heat/cold storage
2 Closed cooling systems, air/air	2a Supported by adiabatic cooling
	2b Supported by compression cooling
3 Closed cooling systems, air/fluid	3 Supported by hybrid cooling

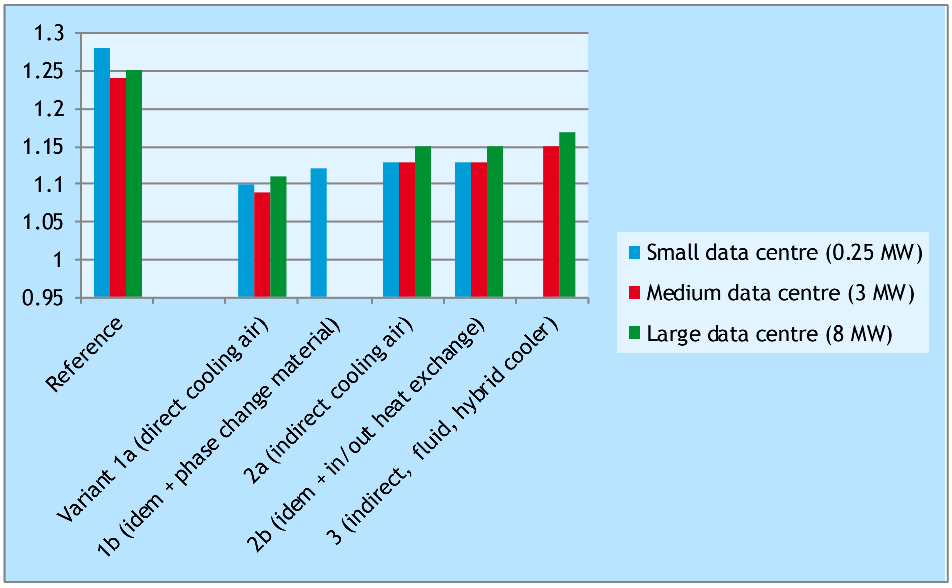
With a view to energy-efficient operation, these variants all share the following characteristics:
- maximum use of free cooling ('natural' sources of cold);
- full separation of warm and cold air streams;
- variable-speed drives on fans, and pressure control wherever possible;
- temperature and humidity ranges in line with the ASHREA US industrial standard (max. temperature: 27˚C).

Supplier data, model calculations and validation

Suppliers of these technologies were contacted for specific data on investments and energy performance. Model calculations were then carried out to calculate typical values for investments, energy performance and pay-back time for the three 'typical' data centres distinguished. Thereafter, the results were checked with data centre operators applying the specific techniques concerned. Given the uncertainties in the data, a sensitivity analysis was carried out, and the pay-back times presented reflect the results of that analysis.

The main results are summarized in Figure 1 and Table 2 below.
In Figure 1 energy performance is measured as Energy Usage Effectiveness (EUE), the ratio between the total amount of energy supplied to a data centre and the amount actually used for the computing equipment. It thus provides a measure of the amount of energy used for cooling and other ancillary systems. The method used for calculating the EUE is comparable to the SMK standard and excludes transformers.

Figure 1 **Performance of energy-efficient variants for new-build data centres measured as EUE**



The figure shows that while the reference cases have a EUE below 1.3, the various energy-efficient variants can score well below 1.2. The differences between the variants are relatively small.

The pay-back times are presented in Table 2. For all three sizes of data centre Variant 2a is profitable. This is due to the relatively limited investments involved, since in this variant no compression cooling is applied. The economic performance of Variant 3b may be similar to the reference, depending on the specific investments required. This is also the case for Variant 2b in a large data centre.

Table 2 **Pay-back times for energy-efficient cooling variants (per year)**

Cooling variants	Small (0.25 MW)	Medium (3 MW)	Large (8 MW)
Variant 1a	> 10	>= 0	> 10
Variant 1b	> 10		
Variant 2a	< 0	< 0	< 0
Variant 2b	> 10	> 10	>= 0*
Variant 3b		>= 0*	>= 0*

* Results for these variants vary under sensitivity analysis testing.

Furthermore, in the model analysis not all technological details and cost advantages or disadvantages are included. Three examples of design aspects that were not quantified are data centre raised floor, costs of electricity cabling and mains voltage transformers and costs for separated hot/cold alleys. In design choices for the efficient cooling technology employed, actual additional installation costs may be limited.

Conclusions

The results show that a high degree of energy efficiency can be achieved, with various combinations of techniques available to this end. A crucial factor in all variants is substantial use of 'free cooling'. As the energy used for cooling purposes reaches even lower levels, that used for power supply becomes increasingly important, and in this respect modular construction is then a pivotal factor. To give an indication for the modular building: for a 2 MW data centre of which the power supply must be N+1 redundant: modular build should be in increments of 250 kVA or less.

For maximum energy efficiency the following measures should be implemented:
- data centre temperatures an humidities, as per ASHREA recommended values, temperatures max. 27˚C;
- continuous monitoring of energy use per system and function;
- maximum use of 'free cooling', typically > 98%;
- cooling air inlet on a cool part of the building (e.g. not on a dark roof);
- fully segregated cold and warm aisles;
- modular building of the uninterruptible power supply (UPS) systems;
- use of a UPS that provides high energy efficiencies across a broad range.

1 Introduction

1.1 Background and objective

As the need in society for storage of electronic data is rapidly growing, the data centre sector shows a fast grow in the Dutch economy. Because data centres are usually large consumers of electricity the total use by the sector is substantial. According to a recent study of CE Delft for Hivos this amounts to around 1.6 TWh, or 1,5% of the total consumption of electricity in the Netherlands (CE Delft, 2012). The members of the trade organization Nederland ICT have a combined energy consumption of 15.6 PJ/year, and projections for a business-as-usual (BAU) scenario indicate a growth in the energy consumption to 39 PJ/year in 2030 (ICT Office, 2012).
A substantial part of the energy use of data centres is not used for the IT equipment itself, but for the cooling and electricity supply, these aspects can account for up to 50% of the total energy use of a data centre. For these aspects measures in recent years diverse measures have been developed that can substantially reduce the energy use. In the framework of environmental legislation local government authorities can oblige data centres to implement energy efficiency measures, under the condition that measures have a pay-back time smaller than five years. In this context local government authorities and data centres are looking for an actual and objective overview of possible energy-efficient techniques or combination of techniques.
This report gives presents this overview. It is directed at possible energy-efficient techniques for new-build data centres, and focusses on measures for cooling and electricity supply. Parallel a study is being conducted focussing at existing data centres. The study is conducted on behalf of NL Agency, an agency of the Ministry of Economic Affairs. It has been guided by a steering group with representatives of NL Agency, the Ministries of Economic Affairs and Infrastructure and Environment, the environmental offices of Amsterdam-Noordzeekanaalgebied and Rotterdam-Rijnmond and the sector organisation Nederland-ICT. During the process (intermediate) results have been exchanged with a counseling group of data centres. Annex A gives an overview of participants of steering and counseling group.
The study is based on an exhaustive research of available national and international literature, interviews with suppliers of energy-efficient techniques, model calculations and validation of results with users of data centres. The results of the study will serve as basis for the preparation of a guide to the competent local authorities in assessing plans to build new data centres and server rooms. Key points from this study relevant for this guide are summarized in Annex D (in Dutch).

1.2 Objective

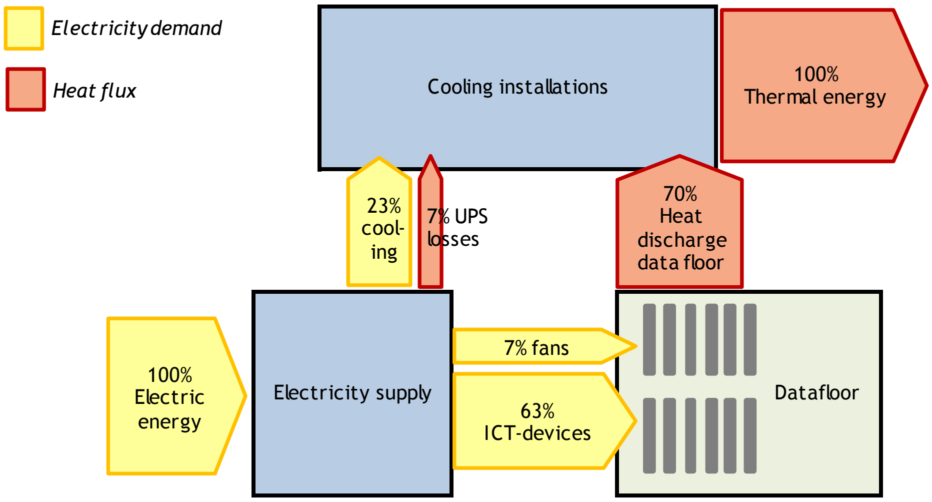
The objective of this study is to investigate the best available techniques for energy efficiency for new-build data centres.
The study answers the following questions:
- What possible energy saving techniques can be applied?
- What combinations of techniques are possible?
- What are the costs and energy use of these combinations of techniques?
- To what extent are these combinations of techniques technically and economically feasible?

1.3 Scope

Energy use for cooling and electricity supply

Conventionally, approximately 70% of the energy supply of a data centre is used for the ICT. The other parts of the energy supply is mainly used for cooling (23% in this case) and the electricity supply, or UPS (Uninterupted Power Supply) (7% in this case). The last two subjects are part of this study, the energy use by the ICT itself is not part of this study. Within the subject of cooling, also the energy use for humidification and the aspect of limiting heat-influx from outside is included.
Furthermore, a minor part of the energy use in a data centre is for other applications, such as the use of energy for lighting, office equipment and the climate control of offices. This energy use is also excluded from this study. Figure 2 gives an overview of the major energy flows in a data centre.

Figure 2 **Overview of major energy flows in a data centre**



Investments and energy use of energy-efficient technique-combinations

A critical factor in this study are data on investments and energy use of energy-efficient techniques. These are the basis for model calculations on typical investments and energy use of technique-combinations ('variants' in the terminology of the report). These data are based on information received from a large number of suppliers of energy-efficient techniques, mainly located in the Netherlands. Afterwards suppliers and users have been asked to check the data used in the model calculations. Apart from these suppliers no other suppliers have been approached.

Calculation of pay-back times

This report gives pay-back times of several energy-efficient combinations of techniques. These pay-back times are based on a 1st order calculation from investments and energy costs. Other cost factors (for instance for other related operational costs or savings) are not taken into account in the calculation. This is in accordance with the standard calculation method of pay-back times in the Dutch environmental protection law.

1.4 Definition of energy efficiency:

Energy efficiency is a key word in this report. In the data centre world two terms are being used to address this aspect: the Power Usage Efficiency (PUE) and Energy Usage Efficiency (EUE). Currently both EUE and EUE are defined in the same way:

$$EUE = PUE = \frac{\textit{the total yearly averaged energy use of a data centre}}{\textit{the yearly average energy used by the ICT equipment}}$$

The certification scheme '*Milieukeur Klimaatbeheersing bij datacenters*' (SMK, 2012) gives a standard for measuring the EUE. The model analysis conducted in this study (Chapter 4) is comparable to this definition.
As a difference, the energy use for 'other' equipment such as offices and lighting is not included.
Sometimes data centres report incorrect values for EUE values, for instance when the reported value is calculated on the basis of energy numbers over a shorter period of time, or when the energy use of significant energy consuming equipment is subtracted.

1.5 Structure of the report

The first part of this report (Chapter 2) presents a concise overview of available information in literature on energy-efficient techniques for data centres. Based on these findings logical combinations of techniques (variants) for energy-efficient cooling are defined (Chapter 3). In the next step (Chapter 4) these variants are quantitatively evaluated. This evaluation is based on costs and energy performance of specified energy-efficient techniques, as provided by suppliers of these techniques and validated by users of data centres. These data have been put into a technical-economical model, resulting in specific data for investments, energy performance and pay-back times of variants. Chapter 5 evaluates the most important findings for energy-efficient cooling. In Chapter 6 the findings for other aspects are discussed. The main conclusions are presented in Chapter 7.

2 Results of desk study

2.1 Introduction

This chapter provides an overview of the literature sources with relevance for new-build data centres, viz. government white papers, information brochures and studies commissioned by governments, technical reports, and product information from suppliers and others. At the core of the desk study undertaken are several recent reports by Dutch government agencies, supplemented by information from foreign reports and supplier information.

Section 2.2 summarizes the main content of the respective documents, while Section 2.3 presents our main findings for each individual class of techniques considered.

In the present study the following literature sources were investigated:

Dutch government agencies

- Sustainable cooling of data centres (in Dutch: *Duurzaam koelen van datacenters*) (NL Agency, 2012).
- Energy saving in data centres (*Energiebesparing in datahotels*) (ECN, 2008).
- List of measures from the Dutch Multi-YearAgreement for the ICT sector (MJA-3) (*Maatregelenlijst voor de MJA-3 van de ICT sector*).
- Cloud computing: grey or green (*Cloud computing: Grijs of Groen*) (TNO, 2012).
- Energy advice for Amsterdam: from insulation to city heating (*9 Energie-adviezen aan Amsterdam, bundeling van ECN-notities van isolatie tot stadsverwarming door F.A.T.M. Ligthart*) (ECN, 2004).

European Union

- The Code of Conduct for Data Centres - participant guidelines.
- The Code of Conduct for UPS systems.

Industry associations

- The Green Grid white papers.
- Dutch Code of Practice NPR 5313 (*NEN Praktijkrichtlijn 5313*,under development).
- ASHRAE, The American society for Heating, Refrigerating and Air-conditioning Engineers.

Product information from suppliers

- APC whitepapers on power supply and cooling.
- ADC whitepapers.
- TE Connectivity.
- Kyoto Cooling.
- GE Digital Energy.
- Eaton.
- Solartech.

Academia
- Lawrence Berkley National Laboratory (LBNL).
- Specific sources: Moehle 2011, Ashrae Transactions 2012, ASU, 2012.
- Free University of Amsterdam: Online library of Green ICT Practices.

Other
- Energy efficiency measures in existing data centres (EnergyGo, ongoing research for GreenIT Amsterdam).
- Certificatieschema Milieukeur klimaatbeheersing bij data centres (SMK, 2012).
- Memo Witte daken, toepassing bij datacentra (Arcadis, 2012).
- BREEAM Data centres.
- Proceedings of Symposium ICT 4EE, Brussels, 2011.

2.2 Brief outline of documents

In the following subsections the scope of the literature sources investigated are briefly outlined.

2.2.1 Reports by Dutch government agencies

Sustainable cooling of data centres (NL Agency, 2012)
This report provides qualitative information on different types of energy-efficient cooling of data centres. The underlying sources are not explicitly specified, but are probably mainly interviews with data centre managers and information provided by cooling system suppliers.
Ten recently developed technical concepts are described, for most of which a concrete example is given of a data centre where it is already implemented. Effects on energy use are presented as typical values for EUE.

Energy saving in data centres (ECN, 2008)
This report for the Municipality of Amsterdam investigates potential techniques for new and existing data centres, and the effects of these techniques on EUE. The study is based on scientific reports and information from the Green Grid. The descriptions of the techniques vary widely in degree of elaboration.

List of measures for the ICT sector (MJA-3)
This overview of potential measures for energy saving in the ICT sector comprises a total of 93 measures, technical as well as organisational.
Each of these is extensively described and for a limited number the pay-back time is indicated. The main technical measures are listed below (Table 3).

Table 3 Main technical measures in 'List of measures for the ICT sector (MJS-3)'

Serial no.	Type	Measure
1522	Limit heat-influx from outside	Avoid direct heat-influx from outside
2128	Cooling/air distribution in data centre	Frequency-regulated fans
2129	Cooling/air distribution in data centre	Frequency-regulated pumps
1527	Cooling/air distribution in data centre	Physical separation of heat and cold streams
1530	Cooling/air distribution in data centre	Cooling of processor
1531	Cooling/air distribution in data centre	In rack cooling
2131	Cooling/air distribution in data centre	Obstructions and leaks

Serial no.	Type	Measure
1547	Cooling/air distribution in data centre	Cooling of processor
1528	Efficient discharge of heat	Free cooling with additional active cooling
1502	Efficient discharge of heat	Absorption cooling
2132	Efficient discharge of heat	Adiabatic cooling
1503	Efficient discharge of heat	Absorptioin cooling in combination with CHP
2130	Humidification	Ultrasone humidification
1548	Delivery of heat to external consumer	Reuse of waste heat of data centres
1549	Delivery of heat to external consumer	Storage of heat/cold in the underground
2134	Electricity supply	High efficient UPS systems
1505	Electricity supply	Battery free UPS systems
1521	Electricity supply	Reduction of stationary heat from generator
1540	Electricity supply	Conversion of high voltage at a late stage in the process
2158	Design criteria ICT	Use of ICT equipment with higher tolerances for use
2142	Design criteria ICT	Broad margins for relative air humidity

2.2.2 European Union documents

European Code of Conduct on Energy Efficiency (2011)
The Code of Conduct for Data Centres Energy Efficiency, version 2.0: Participant guidelines and registration form. Valid as from 1.1.2010:
This document, issued by the European Commission, sets out the procedures to be followed and measuring equipment to be used by data centres wishing to sign up for the code of conduct. The document specifies no particular level of energy efficiency to be achieved.

European Code of Conduct on UPS (2011)
The Code of Conduct on Energy Efficiency and Quality of AC Uninterruptible Power Systems (UPS), final version with new target values for 2011-2014. Version 2.0 dated 16 March 2011.
This document describes, for different types of power system and different power levels, the targets and time schedules for meeting the 25, 50, 75 and 100% nominal power targets in the period from 2011 to 2014 for data centres seeking to join the Code of Conduct on AC UPS Systems.

2.2.3 Industry associations

The Green Grid (www.thegreengrid.org)
The Green Grid is a global consortium of companies, government agencies and educational institutions dedicated to advancing resource efficiency in data centres and business computing ecosystems.

Relevant reports

1. Breaking New Ground on Data Centre Efficiency, Feb 2012.
   Case study of measures taken to improve efficiency of an existing data centre. Particular emphasis on temperature set points and free cooling.
2. Case study: The ROI of cooling system energy efficiency upgrades, 2011.
   Case study of measures taken to improve the efficiency of an existing data centre. Particular emphasis on variable-speed drive efficiency.
3. Fundamentals of data centre power and cooling efficiency zones, 2009.
   Analysis of various efficiency gains, including temperature setpoints and air flow patterns, efficiency of drive motors and electrical installations, etc.
4. White Paper 30, Qualitative analysis of cooling architectures for data centres, 2011. An analysis of the efficiency of various cooling architectures.
5. White Paper 29: ERE, a metric for measuring the benefit of reuse energy from a data centre.

Dutch Code of Practice NPR 5313 (under development)

Dutch Code of Practice NPR 5313, 3-3 Computer Rooms and Data Centre Requirements and Classification of Energy Efficiency (under development)
This part of the cited code of practice is concerned mainly with explaining the abbreviations and terms used to describe the energy efficiency of a given data centre. It is proposed to categorize data centres according to five energy efficiency classes: A to E, based on the achieved EUE and referred to as 'observation levels', as follows:

A: EUE <= 1.1, observation level 3 (outstanding)
B: EUE <= 1.25, observation level 2 (excellent)
C: EUE <= 1.5, observation level 2 (good)
D: EUE <= 2, observation level 1 (average)
E: EUE > 2, observation level 1 (can be greatly improved)

Note: In this classification, efficiency is not affected by data centre availability.

The document does not describe specific techniques for improving energy efficiency.

Dutch Code of Practice NPR 5313, 3-1, Computer Rooms and Data centres Requirements and Classification of Availability (under development)
In the context of determining so-called classes of availability, the Dutch Standards Committee 381 888 has studied several existing standards, thereby opting for the BICSI classes F1 to F4, which are well defined and immediately applicable for characterizing existing data centres. As in NPR5313, 3-3 (see above), no techniques are discussed. Furthermore, energy efficiency is beyond the scope of this part of the code of practice.

Rich Miller: Data centre energy efficiency guide (2011)

This source contains several case studies for reuse of data centre. heat. http://www.data centreknowledge.com/archives/2011/03/04/data-center-energy-efficiency-guide/

Ziggo press release (2011)

This source considers the use of phase-change materials for the purpose of cold storage. www.ziggo.com/nl/pers/persberichten/60,450/bouw-nieuwe-generatie-data centres/

2.2.4 Information from suppliers

APC whitepapers

APC is part of the Schneider Electric company. The APC 'whitepapers' describe various aspects of energy efficiency in data centres. Although the papers are undated, it can be assumed that most of them (up to no. 137) were published before 2009. The source has a good reputation for accuracy and the whitepapers are regularly reviewed.

Power best practices

WP 28, WP 29, WP 92, WP 127, WP 128, WP 129, WP 157.

- WP 127 shows that the most efficient AC systems (2012) in 'eco-mode' are 0.99% more efficient than the most efficient DC systems. If the 'eco-mode' is not applied, the DC system is 1.05% more efficient. A 1% improvement in power system efficiency translates to about 0.13% of the total data centre energy use.
- WP 128 applies only to the USA according to the authors.
- WP 129 applies only to existing data centres.
- WP 157 describes the risks of 'eco-mode' for UPS systems

Cooling best practices

WP 49, WP 68,WP 130, WP 132, WP 134, WP 135, WP 137, WP 139.

- WP 49 is about correcting faulty installation of cooling equipment.
- WP 130 describes the differences between rack, row and room cooling systems.
- WP 132 is about economizer modes on cooling systems.
- WP 134 advocates concentrating high-density racks in specialised high-density pods with their own cooling system. The most efficient way to organise such pods is by way of hot aisle containment or rack air containment.
- WP 135 is about air containment.
- WP 68 provides insight into the cooling of wire closets. It provides charts of temperature vs. IT equipment load figures, showing the critical values for conduction, passive ventilation, fan-assisted ventilation and dedicated cooling.[1]
- WP 137, published in the ASHRAE Journal (October 2008), advocates the complete separation of cold and hot aisles in the form of row-based cooling as a standard practice in 'new' data centres.
- WP 139 uses computational fluid dynamics (CFD) to illustrate that row coolers are on their own sufficient for cooling an entire data centre and that cooling based solely on row coolers has lower costs and higher efficiency and permits elimination of raised floors.

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1 This explains:

- why larger closets require less cooling (higher conduction capacity);
- why wire closet temperature rises with increasing thermal resistance of walls, ceiling and floor (assuming the closet surroundings are cooler, see next point) and thus the need for ventilation/air conditioning;
- why rising outside temperature of closet walls (e.g. due to sun exposure) increases closet temperature and thus the need for ventilation/air conditioning.

Energy efficiency
WP 66, WP 92, WP 114, WP 126, WP 154, WP 158, WP 161.

- WP 92 compares static and dynamic UPS systems. The former appear to be significantly more efficient at loading values of up to 60%.
- WP 154 explains how EUE should be measured and how loading may effect it. Measures to decrease it are not discussed.
- WP 161 describes how energy costs and CO_2 emissions should be allocated to IT users.
- WP 158 shows that overhead cabling decreases leakage of cold air and thus reduces energy use compared to other cabling modes.
- WP 66, WP 114 and WP 126 are outdated.

TE Connectivity, formerly ADC Krone

TE is a commercial company that plays an important role in the power, data and signal connectivity of industry as a whole. Their expertise includes data centre infrastructure, with two relevant publications on this issue:

1. Designing an Optimised Data Centre, 2007
   Amongst other things, this whitepaper describes cabling strategies to achieve maximum airflow in the data centre.
2. TrueNet® Data Centres, The complete Data Centre solution, 2007
   This is a brochure describing the various 'uptime' TIER-level requirements in relation to cabling infrastructure.

Emerson

Emerson is a diversified global manufacturing and technology company providing a broad range of products for data centre infrastructure, including power and cooling equipment. Their product documentation provides valuable insight into modern techniques. The source has a good reputation for accuracy and their whitepapers are regularly reviewed.

1. White paper: Evaluating the Opportunity for DC Power in the Data Centre, 2010.
   Paper showing the need to limit powerline length by placing 48VDC conversion close to the point of use.
2. White paper: Recycling Ratios: The Next Step for Data Centre Sustainability, 2011.
   Examination of the recyclability of infrastructure elements like batteries and airconditioning equipment.
3. White paper: Energy-efficient Cooling Solutions for Data Centres.
   Report on the economization modes on all Liebert-branded cooling equipment and their effectiveness.
4. Data Centre Users' Group Special Report: Energy efficiency and capacity concerns increase, fall 2012.
   This report provides a good overview of the size distribution of members' data centres and their primary concerns. The study underlines that electrical power is the primary operational constraint and therefore the parameter of choice for determining data centre load percentages.

Stulz, 2008

White paper: Data Centre Cooling Best Practice (2008)
Multiple recommendations on airflow management in data centres, including recommendation for pressure-controlled ventilation.

Kyoto Cooling

Product information from the supplier of the Kyoto Wheel, a type of rotary heat exchanger used for cooling, including PPT-presentations on its operation and descriptions of 24 locations where it is installed. www.kyotocooling.com

Solartech, 2012
Product information on the Energiedak® technology, a means of cooling air using the roof as a heat exchanger. www.energiedak.nl

2.2.5 Academia

Lawrence Berkley National Laboratory (LBNL): Technical Best Practices checklist
A comprehensive list of possible best practices for data centre efficiency. http://hightech.lbl.gov/dctraining/about.html

Nicholas Moehle: Advanced control for data centre cooling
A research proposal for superior control algorithms for data centre cooling, including heightened awareness of the physical state of the data centres, (particularly airflow and pressure).
http://www.stanford.edu/class/ee392n/lecture/jun11/nm.pdf

David Moss: ASHRAE Transactions, Jan. 2012. Under-floor pressure control: a superior method of controlling data centre cooling.
Academic discussion, including test results in a live data centre for pressure-controlled ventilation.

Anna Haywood, Jon Sherbeck, Patrick Phelan, Georgios Varsamopoulos, Sandeep K.S. Gupta (2012)
Thermodynamic feasibility of harvesting data centre waste heat to drive an absorption chiller.
http://impact.asu.edu/publication/Haywood2012-feasibility.pdf

T. Takakura, S Kitadeb, E Gotob (2000). Cooling effect of greenery cover over a building
Elsevier Energy and Buildings, Volume 31, Issue 1, Jan. 2000, p. 1-6
Peer-reviewed scientific article presenting the cooling effect of various kinds of greenery cover(bare concrete, soil layer, soil layer with turf and soil layer with ivy), investigated by both experimental construction and computer simulation. To calculate the cooling effect, temperature profiles, including air temperature under the roof, were measured along with other environmental parameters.

Free University of Amsterdam: Online library of Green ICT Practices, on-going
In the context of a collaborative project between the Free University of Amsterdam (Software and Services Research Group) and SURFNet, the former is developing an online library of 'Green ICT Practices', which currently has 258 entries elicited from both industrial practice and academic publications.

2.2.6 Other sources

EnergyGo, 2012
Niels Sijpheer, Marcel Elswijk and Bart Roossien, presentation of intermediate results of a study on energy efficiency improvements in existing data centres within the Amsterdam region. This study is part of the City of Amsterdam's GreenIT programme.

SMK, 2012
Certificatieschema Milieukeur klimaatbeheersing bij data centres.
Certification scheme for data centre climate control published by a Dutch NGO. Part of this certification scheme is a definition of the EUE. In the definition the EUEtotaal is the ratio between the energy use for the climate system (electricity and gas), UPS systems and other (offices and lighting), and the energy use for the ICT/server racks.

ICT4EE, 2010
Proceedings of second High Level Event on ICT for Energy Efficiency, Brussels, 2010.
The focus of this ICT 4EESymposium, organised by the European Commission's Information Society and Media Directorate-General, was on the enabling of energy efficiency through ICT, and as such the proceedings are of little relevance to the present study. The ICT4EE Forum, announced at this event, is active but has no activities relevant to the present study.

University of Twente
A paper on the use of cold water storage to bridge warm weather periods.
http://www.utwente.nl/fb/vastgoed/archief/nieuwsarchief/symposiumkoudecirkel.doc

ASHRAE, 2011
White paper on Thermal Guidelines for Data Processing Environments – Expanded Data Centre Classes and Usage Guidance, ASHRAE Technical Committee, 2011.
ASHRAE stands for the American Society for Heating, Refrigerating and Air-conditioning Engineers.

Arcadis, 2012
Witte daken; toepassing bij datacentra, Luc Cartigny, Arcadis Divisie Gebouwen Maastricht, 27 September 2012.
Short literature study confirming that white roofs improve the capacity of data centres to convey excess heat to the outside due to a lower roof temperature.

Optigroen, 2012
Assessment of information on ‘green roofs’ on Optigroen website (www.optigroen.nl) and by Rob Steltenpöhl, technical adviser at Optigroen.

CRRC, 2012
Information assessed at www.coolroofs.org by the Cool Roof Rating Council, created in 1998 to develop accurate and credible methods for evaluating and labelling the solar reflectance and thermal emittance (radiative properties) of roofing products and disseminate the information to all interested parties.

BREEAM, 2012
BREEAM-NL Data centres, keurmerk voor duurzame vastgoedobjecten.
Beoordelingsrichtlijn Nieuwbouw-Data centres, version 1.0, February 2012.
BREEAM is an international benchmark for the sustainability of buildings, judging the design and realisation of a new building on the following categories: Building and construction management, Health & Comfort, Energy, Transport, Water, Materials, Waste, Landuse & Ecology, and Pollution.
In each category points are awarded for preventing negative environmental effects. The more points, the higher the rating.

2.3 Temperature and humidity regulation within data centres

In this paragraph we discuss the regulation of temperature and humidity within data centres. The temperature and humidity settings selected by operators play a crucial role in controlling the data centre environment and therefore overall energy consumption.

ASHRAE recommendations

Recommended temperature and humidity settings are provided in an ASHRAE publication on electronic equipment[2]. The values are shown in Figure 3 and in Figure 14[3]. For the classes A1 to A4, a dry-bulb temperature of 18-27˚C is recommended . The recommended humidity range is, in a temperature independent representation, a dew point between 5.5 and 15˚C. Maximum allowable values are broader, as shown in Figure 3.

Figure 3 ASHREA guidelines for temperature and humidity

Classes (a)	Equipment Environmental Specifications							
	Product Operations (b)(c)					Product Power Off (c) (d)		
	Dry-Bulb Temperature (˚C) (e) (g)	Humidity Range, non-Condensing (h) (i)	Maximum Dew Point (˚C)	Maximum Elevation (m)	Maximum Rate of Change(˚C/hr) (f)	Dry-Bulb Temperature (˚C)	Relative Humidity (%)	Maximum Dew Point (˚C)
Recommended (Applies to all A classes; individual data centers can choose to expand this range based upon the analysis described in this document)								
A1 to A4	18 to 27	5.5ºC DP to 60% RH and 15ºC DP						
Allowable								
A1	15 to 32	20% to 80% RH	17	3050	5/20	5 to 45	8 to 80	27
A2	10 to 35	20% to 80% RH	21	3050	5/20	5 to 45	8 to 80	27
A3	5 to 40	-12˚C DP & 8% RH to 85% RH	24	3050	5/20	5 to 45	8 to 85	27
A4	5 to 45	-12˚C DP & 8% RH to 90% RH	24	3050	5/20	5 to 45	8 to 90	27
B	5 to 35	8% RH to 80% RH	28	3050	NA	5 to 45	8 to 80	29
C	5 to 40	8% RH to 80% RH	28	3050	NA	5 to 45	8 to 80	29

Source: ASHRAE, 2011.

2 American Society of Heating, Refrigerating and Air-Conditioning Engineers, 2011: ASHRAE TC 9.9 2011 Thermal Guidelines for Data Processing Environments – Expanded Data Center Classes and Usage Guidance.

3 Suppliers of electronic equipment indicate for a product supplied the according ASHREA-class.

Figure 4 ASHRAE-recommended and allowable envelope, presented as a psychometric chart

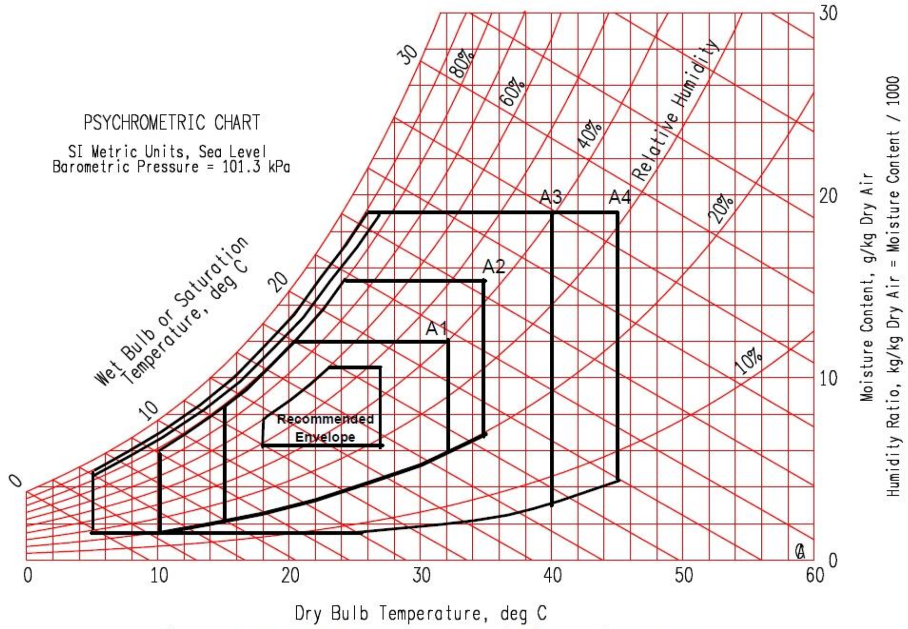


Figure 2. ASHRAE Environmental Classes for Data Centers

Flexible temperature operation

Green Grid White Paper 50 (Data centre efficiency and IT equipment reliability at wider operating temperature and humidity ranges, October 2012) treats the subject of data centre internal environment control.

In many data centres, temperature set points are generally static over the course of the year. White Paper 50 discusses the implications of a variable setpoint, chosen at values lying within the ASHRAE-allowed range for type A1 equipment. Choosing a value within the allowable envelope greatly extends the period of full free cooling. A particular peculiarity of the Dutch climate is that relative humidity at these high temperature extremes is invariably low, making adiabatic cooling very effective in this range.

While running at 29˚C or even higher may fall within manufacturer-allowable values and allow for free cooling, the adaptive fans inside the IT equipment will spin faster, leading to higher IT equipment energy consumption.

As a result, overall energy use would be much higher than running the same data centre well within the ‘ASHRAE-recommended’ range.

The solution proposed is to keep well within the allowable envelope and allow the data centre setpoint to fluctuate, following the general trend of the outdoor temperature. This means that the setpoint may drop to as low as 15˚C during the winter but be allowed to reach 32˚C on hot summer afternoons. Interestingly, the EUE of a data centre running this kind of flexible regime would not be as low as would be obtained with a fixed high setpoint of, say, 25˚C. Total energy consumption, would be the lowest obtainable, however!

It is important to note that this form of operation is currently untried and raises the complexity for both operator and regulator because of the fluctuations in setpoints. The promise of improved operation and energy efficiency is a strong argument in favour of this method, though.

2.4 Efficient air transport

Most ICT equipment requires air at a temperature within the limits defined by the ASHRAE temperature envelope for cooling. However, this temperature is only required at the air inlet.

This topic is discussed in multiple sources, but the GreenGrid Whitepaper 39, (Case study: the ROI of Cooling System Energy Efficiency Upgrades) provides a prime example. According to this paper, three types of measures should be taken:
- air separation (hot and cold aisles);
- frequency control of fans/natural air movement;
- prevention of high air speeds and long distances in air transport.

Air separation (hot and cold aisles)

Data centre cooling systems will operate more efficiently when the hot and cold air streams remain fully separated (see also the calculations in APC Whitepaper 130, Choosing Between Room, Row and Rack-based Cooling for Data Centres) (Figure 5 and Figure 6). According to a study conducted by EnergyGo (EnergyGo, 2012) on existing data centres, typical investments for creation of hot and cold aisles are in the range of < € 1,500/kW.

Figure 5 **Example of separation of hot and cold air streams in a data centre. In this example cold air is blown in and hot air discharged from the sides of the alleys**

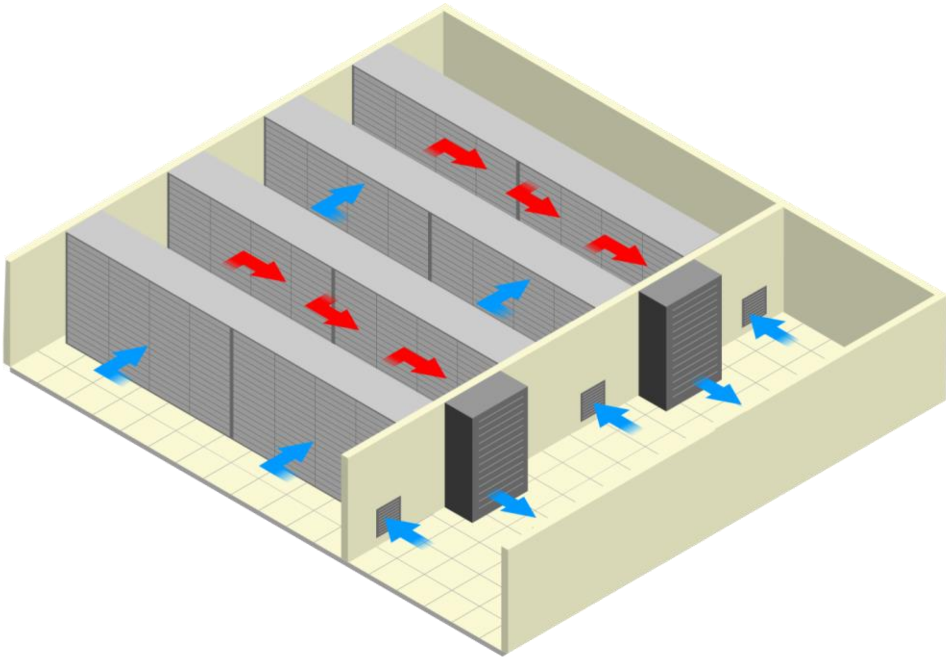


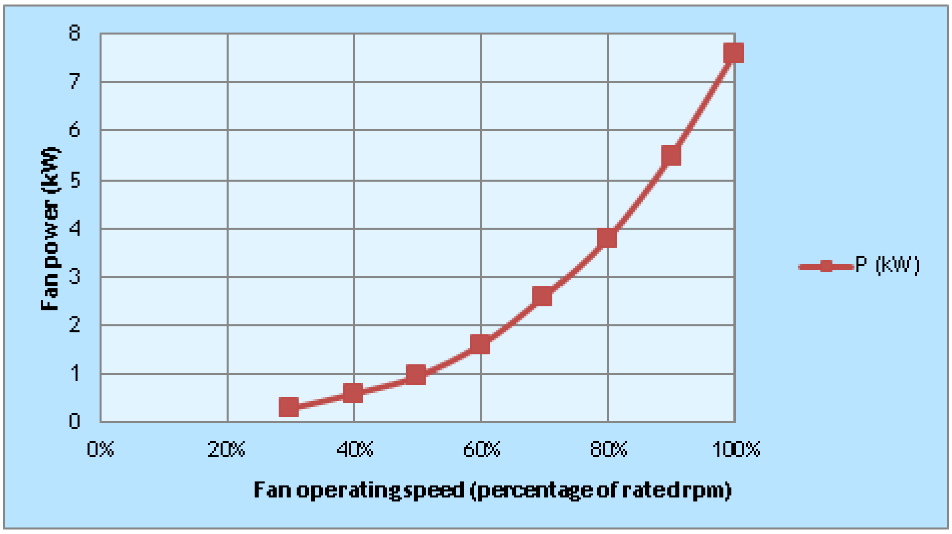
Figure 6 Example of full separation of cold and heat air streams in data centre. The photo shows a cold alley, with influx of cold air via the bottom

Frequency control of fans/natural air movement

In cases where a traditional Computer Room Air Handling (CRAH) system is based on static speed fans, the need for variable-speed fans is apparent. This is currently the standard in modern installations (Moehle, 2011; Stulz, 2008). With these variable-speed drives, the lower the fan (air) speeds, the more efficient these fans become.

This mechanism is illustrated in Figure 7, which plots the relationship between the fan speed and power usage for CRAH fans. At 60% speed the 7.6 kW nominal power engine only uses 1.4 kW. The cooling capacity at nominal power is 105 kW, while at 60% of fan speed the cooling capacity is 60 kW. The related performance coefficient (COP) improves from 13.8 to 43.

Figure 7 Relationship between CRAH fan speed and power usage



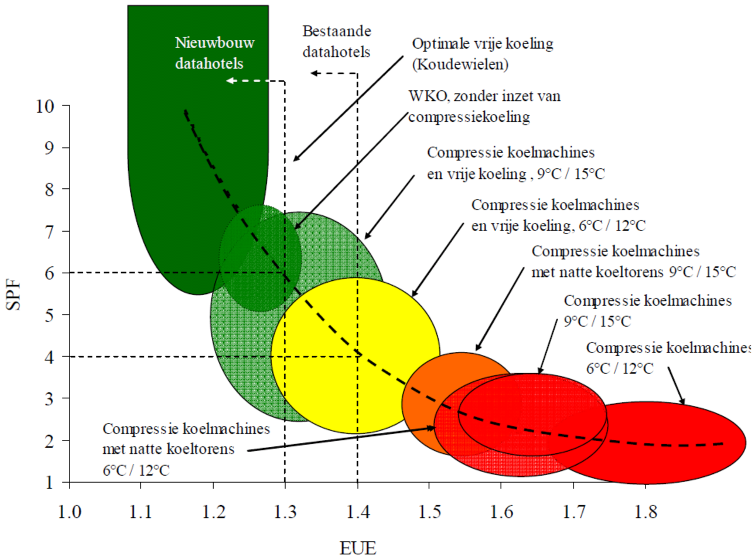
A reduction of airspeeds has a substantial effect on required fan power: as a general rule, a reduction of airspeed by a factor 2 results in a reduction of required power by a factor 8 (EnergyGo, 2012). This can be further improved by combining the above insights: the amount of cooling air needs to be regulated to match demand exactly, and airspeeds should remain low and distances short. Part of this can be achieved by means of full aisle containment (i.e. completely separated hot and cold aisles) using pressure sensors. The temperature of the cold air and its volume are then separated quantities that can be independently controlled (ASHRAE Transactions, 2012).

2.5 Efficient discharge of heat

2.5.1 Compression and free cooling

Efficient heat discharge is key to high energy efficiency. To obtain a sufficiently low EUE, naturally cold sources for air or water need to form the pivotal element of the heat discharge system. As an illustration, an ECN study of 2008 reports the effects of different cooling systems, with and without 'free cooling' (cold from a natural source) on the overall EUE (ECN, 2008).

Figure 8 **Technical concepts and corresponding effects on EUE** [4]



Source: ECN, 2008.

There are many different devices and technologies available for cooling data centres. However, each comprises the following elements:
- *Heat transport:* fans and/or pumps moving fluid (such as air or water) to transfer heat energy from the data centre to the outdoor environment.
- *Heat exchange:* coils or vents that transfer heat energy from one heat stream to the next. In all cases, there is a final heat exchanger to the outdoor environment or heat harvesting stream.
- *Source of cold:* this can be a natural source, but also cold from a compressor system.

[4] SPF (seasonal performance factor) is a measure of the energetic performance of the cooling system.

2.5.2 Technical options

There will always be a range of solutions providing the optimum cooling system. For the system to be energy-efficient, the cold from the cold medium must derive as far as possible from a natural source. In the data centre world, cooling using cold from a natural source is called '*free cooling*'.
Energy-efficient cooling systems can be divided into several categories, in all of which free cooling plays a key role.

1. Open cooling systems: data centre air supplemented directly with filtered outside air
   In open cooling systems, the cold outside air is directly vented to the data centre through a microfilter without any intermediate heat transfer medium.
2. Closed cooling system: indirect free cooling with an outside air/inside air heat exchanger
   In these variants, the cooling is indirect, i.e. there is heat exchange between different air streams. This can be done using a rotating 'heat wheel' heat exchanger, or using cross-flow or counter-current air/air heat exchangers. The 'Kyoto Wheel' is one example of a heat wheel, and according to the product information this provides energy savings of 85% compared with conventional design, or 400 k€/MW IT-load/year.
   This results in $EUE_{cooling}$-levels of 1.05-1.15 (Kyotocooling, 2012).
   According to the EnergyGo study on existing data centres, typical investments for adding 'free cooling with outside air' are in the range of < € 1,600/kW, yielding typical energy savings in the range of € 430/yr/kW.
3. Closed cooling system: indirect free cooling with fluid-based thermal transport.
   In this variant, a fluid cold transport medium is used to transfer cold from the outside to air-handling units that are placed close to the IT equipment/heat loads. The warm air in the computer room is vented along a heat exchanger where 'cold' air is made using a chilled water stream. The warmed-up water then goes to a cold water plant where the heat is vented off to the air. Traditionally, compression cooling technology was used to make the chilled water in a cold water plant. According to the EnergyGo study, typical investments for adding 'indirect free cooling' are in the range of < € 1,000/kW and typical energy savings in the range of € 430/yr/kW.
   If a data centre is able to use groundwater as a source of cold water, the cold can be derived solely from a heat exchanger. Alternatively, instead of cold water storage tanks or other means, cold storage in phase change materials (PCMs) may be used to bridge those periods in which fully economized mode (full free cooling) are unfeasible.
4. Heat/cold storage.
   Another option is underground heat storage. In the Netherlands, ground conditions are favourable for such storage. In this approach, the data centre can draw groundwater for economized cooling and store the resulting warm water underground. In order to maintain the energy balance for underground water reservoirs, the warm water can be pumped up by third parties for use in low-temperature heating systems, or if necessary by the data centre operator during cold spells for cooling. Equinix AM3 in Amsterdam is an example of such an installation (Agentschap NL, 2011). Techniques like these do not generally improve data centre efficiency as expressed in PUE (or EUE). Free cooling, for instance, is mostly incompatible with heat recovery. To assess efficiency for these installations, the energy use of all affected parties must be added and compared with a reference situation. Since the entire concept of 'delivering heat to the neighbourhood' depends on having a neighbourhood with both a need for heating and the ability to use the

temperature range provided by the data centre, this technique is almost exclusively used in new-build data centres where location selection can take possible customers for waste heat in account.

5. Heat delivery to a neighbourhood.
   The waste heat of a data centre is in most cases so called ‘low-quality heat’, meaning that the temperatures are lower than are generally useful for use by third parties.
   However, there are possible exceptions that do allow the waste heat to be used for heating or even cooling purposes (ASU, 2012). The Dutch university hospital VUMC employs such a system, for example, although it should be noted that this data centre’s energy use is small compared to the total energy use of the hospital (VU, 2012).
   For a typical case of heat delivery to a neighbour, the EnergyGo study indicates that investments are < 1,000 €/kW_{ict}, with annual savings of 580 €/kW_{ict}. This results in a reduction of 3 tonne CO_2/kW_{ict}/year.

2.5.3 Experience in existing data centres

Table 4 shows the main technical concepts, data centres and EUEs reported in the document ‘Sustainable cooling of data centres’ (Agentschap NL, 2011).
It should be noted that in this study the methods used for calculating PUEs are not specified and the values are therefore tentative.

Table 4 Energy-efficient heat removal concepts reported in 'Sustainable cooling of data centres’

Concept	Technology name	Data centre	Reported PUE[5] (indicative values)
Direct free cooling with filtered outside air	DataCenterCooling; Air@work	Smart DC, Rotterdam; ColoCenter, Zoetermeer; eQuest Helmond	< 1.15 (‘mostly’) (Smart DC)
Indirect free cooling with an outside/inside air heat exchanger	Kyoto Wheel	Rotterdam Internet Exchange (R-IX)	1.19 (‘snapshot value’)
Indirect free cooling with an outside/inside air heat exchanger, supported with evaporative assist	The Datacenter Group	The Datacenter Group, Amsterdam and Delft	1.16 (existing) 1.13 (Delft)
Heat-cold storage		Equinix AM3, Amsterdam	1.1-1.2 (‘typically possible’)
Hybrid direct/indirect free cooling with an outside/inside air heat exchanger, supported with evaporative assist	Menerga system	EvoSwitch, Haarlem	1.05 (PUE cooling only, theoretical); < 1.2 (EvoSwitch)
Indirect free cooling with fluid-based thermal transport	Jaeggi, Rital (hybrid wet/dry cooler)		
Humidity control	Dry to cool: energy-efficient drying of air	Van Dam Group, Rijssen/ Rosmalen	
Natural cold source	Lake source cooling	Examples of projects: Eesermeer, Nieuwe Meer, Oudekerkerplas	

5 The reported PUE/EUE values are not substantiated and it is sometimes unclear what aspects are incorporated.

Compression-less cooling

Some of the data centres mentioned above have eliminated the compression cooling machine by reverting to evaporative assist technology with good results to date. The cited study (Agentschap NL, 2012) reports a number of data centre cooling technologies that work compression-less.

2.6 Energy efficiency in electricity supply (UPS)

Much of the material presented in this section is based on the whitepapers published by APC and Emerson, information sources with a good reputation for accuracy and viewed, reviewed and quoted by a very wide readership all over the globe.
Power distribution within data centres comprises three major components: UPS, distribution system (bus-bar and/or wire) and IT power supplies, the first two of which form part of the present study.

UPS, Uninterrupted Power Supply

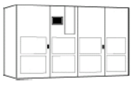
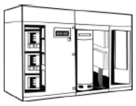
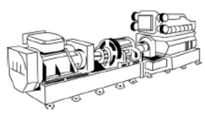
A UPS system combines electronics for power quality control with a source of stored energy to override any period of grid failure. In addition, many data centres are equipped with a diesel generator to overcome longer periods of grid failure, when the amount of energy stored would be insufficient.

There are two basic kinds of UPS layout: static (Figure 9) and rotary (Figure 10). A rotary UPS is coupled to the motor/generator and generally combines a flywheel. A static UPS is not attached to the generator system and may consist of battery storage (with either double or delta power conversion electronics) or flywheel energy storage.

Figure 9 Examples of static UPS systems

Figure 10 A rotary UPS (engine-coupled)

Figure 11 Types of UPS systems

Static	Key differentiators	Rotary	Key differentiators
Double-conversion UPS 	•Represents > 90% of 3- phase UPS installed base •Supports wide load range (10 kW – 1.6 MW) •Typical runtimes 5 to 15 minutes	Motor-generator / battery UPS 	•Compact vertical motor / generator design •Outputs power through motor / generator •Mechanical components / higher maintenance
Delta conversion UPS 	•Highest Efficiency •Modular/ scalable •Electrical components / lower maintenance	Engine coupled UPS 	•Attached / integrated diesel generator •Mechanical components / higher maintenance •Single unit supports largest load blocks (1 MW +)
Flywheel UPS 	•Battery free •Typical runtimes 15 - 30 secs •Represents < 3% of 3-phase UPS installed base •Outputs power through inverter		

Source: APC (WP 92).

APC White Paper 127 ‘A Quantitative Comparison of High Efficiency AC vs. DC Power Distribution for Data Centres’ provides useful graphs and numbers on the efficiency of typical modern static UPS systems: efficiency at 50% load: 96.3%, in eco-mode efficiency at 50% load = 98.5%, this is best in class, DC UPS: efficiency at 50% load = 96.5%, this is best in class.

APC White Paper 92 ‘Comparison of Static and Rotary UPS’ provides a typical efficiency curve of a rotary (dynamic) UPS system, from which it can be concluded that an average rotary UPS at 50% load has an efficiency of approximately 93%. At much higher utilization rates, the rotary UPS is more efficient then a modern double conversion UPS. Depending on the system, this crossover may occur at 65% load or higher with the optimal efficiency of the rotary system at 100% load beating even the eco-mode in the static UPS.

Combining typical efficiency (at 50% or lower load) with the fact that the modularity of a static UPS is smaller, the static UPS is the method of choice for all but the largest data centre builds. Also, note that 50% load is typically too high for the higher redundancy levels. At 2N redundancy the load is often 35%. In this case the average rotary UPS is 90% efficient according to APC, and the static UPS is 95% efficient.
In all cases, the efficiency of UPS systems starts to drop significantly below 25% load. The static UPS systems perform notably better at lower load.

Eco-mode

'Eco-mode' is an operational mode that reflects operation in bypass mode, where the double conversion (AC->DC->AC) is bypassed. This greatly saves on conversion losses. Most modern static battery UPSs are equipped with this mode. For a typical case of replacement of an existing low-efficient UPS system with a 50% more energy-efficient UPS system, the EnergyGo study indicates that investments amount to approximately 1,500 €/kW_{ict}, with energy savings larger than 50 €/kW_{ict}/year and a reduction of CO_2 emissions by 0.3 tonne/kW_{ict}/year.

Distribution wiring

Distribution wiring has a linear load to loss ratio, with 99% efficiency at 100% load and 99.5% efficiency at 50% load. Since many data centres operate with redundant power distribution and below full load, typical loads on both UPS and wiring are below 50% during normal operation.

2.7 Energy efficiency in humidification

Over the past few years, humidity control conditions have been relaxed in line with the aforementioned ASHRAE publication on the recommended environmental conditions for Class A1 electronic equipment[6].

Even at these conditions, introduction and/or removal of moisture from the data centre will sometimes be needed. Traditionally steam generators have been used for moisture introduction and the cooling system for moisture removal.

Humidification can be more efficiently accomplished, however, through evaporation of small water droplets in the airstream. These droplets can be created by high-pressure spray systems or ultrasonic humidifiers.
The evaporation process will, as an added bonus, cool the air, but this effect on overall data centre efficiency is in general too small to be noticeable.

Drying (moisture removal) is an energy-intensive operation because the latent heat stored in water vapour is released upon condensation and adds to the overall heat load of a data centre. In general, moisture deficiency as well as overabundance are a result of moisture migrating from the surrounding environment. The most efficient form of humidity control is therefore bound up with **insulation** of the data centre.

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[6] American Society of Heating, Refrigerating and Air-Conditioning Engineers, 2011: ASHRAE TC 9.9 2011 Thermal Guidelines for Data Processing Environments – Expanded Data Center Classes and Usage Guidance.

As described in APC WP 58, intelligent ventilation might prove to be a useful component of humidity control. Introduction of fresh air in greater quantities under favourable conditions and minimal quantities under adverse conditions provides an easy way to improve overall data centre efficiency.

2.8 Limitation of heat-influx from outside

Obviously, heat that has not entered the building does not need to be removed by a cooling installation. Therefore it is important to avoid heat-influx as far as possible.

Two types of heat-influx from the outside environment can be distinguished:
1. Directly, through (walls and) roof.
2. Increased air intake temperature due to elevated roof temperature.

Reduction of heat-influx from the outside environment therefore merits due attention, generally by one of three methods:
– increased reflectance of sunlight;
– green roofs and shading;
– increased insulation.

These aspects are further discussed in Section 6.3.

3 Variants for energy-efficient cooling

Based on the results of the literature study in the preceding chapter, in this chapter a number of energy-efficient variants are presented for three typical data centre size classes. In addition to the energy-efficient variants, a reference design for each DC size class has also been composed, reflecting state-of-the-art conventional data centre design. The energy efficiency and financial performance of the variants are compared with the references.

3.1 Variants considered

We discern four groups of energy efficient cooling variants.

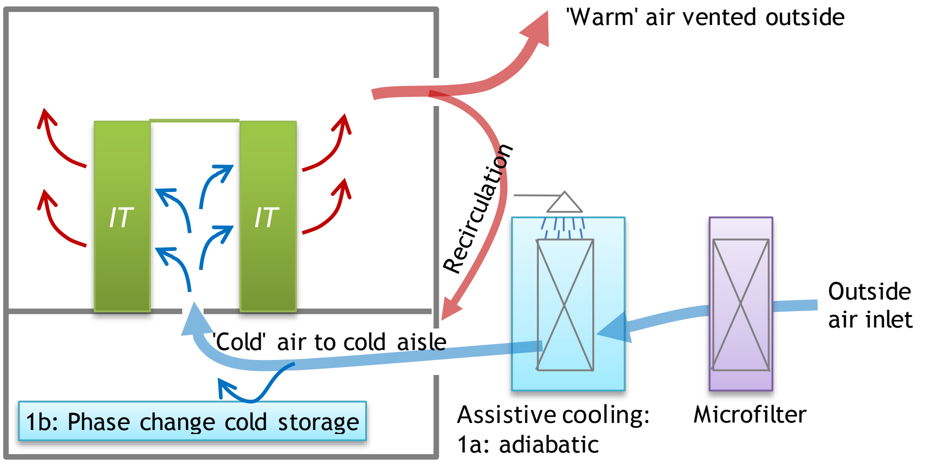
3.1.1 Variant 1: Open cooling systems: supplemented directly with filtered outside air

In open cooling systems, the cold outside air is directly vented to the data centre through a microfilter without any intermediate heat transfer medium. This results in the lowest air speeds and makes optimum use of natural convection. It also allows a large share of free cooling.
The disadvantages are that moisture control is difficult and that there is a direct impact on fire extinguishing systems. Also, if the outside air is polluted, cooling may be impacted. These variants are therefore not necessarily usable for the higher-TIER classifications.

There are two subvariants:
1a: Supported partially with adiabatic cooling or other evaporative assisted techniques.
1b: Supported partially with phase change cooling/heat storage (PCM).

A key aspect of these designs is that the hot air section is on the outside walls/roof, limiting the impact of hot roofs.

Figure 12 Schematic depiction of heat flows in the direct cooling variants



Examples of Subvariant 1a include: Smart DC Rotterdam and ColoCenter Zoetermeer (Agentschap NL, 2011).

Variants 1a:
Open cooling system, supplemented directly with filtered outside air, supported partially with evaporative assist/adiabatic. This system is a total cooling solution including:
- air treatment with air filters;
- air transport with direct application of air to cold alleys
- fans are frequency regulated; low-speed ventilation concept; fan speed can be reduced to 15% of rated rpm;
- adiabatic cooling system as additional cooling system for hot periods, OR the system includes a full backup compression cooling system that can also be partially utilized (latter part not in cost figures).

In one variant, the system is a complete cooling solution, includes the cost of compartmented alleys.

Variants 1b:
Generally the same as 1a, but expanded with PCM cold storage as an extra assurance for bridging unexceptionally hot and humid days.
This variant includes:
- air treatment with air filters;
- air transport with direct application of air to cold alleys;
- fans are frequency regulated; low-speed ventilation concept; fan speed can be reduced to 40% of rated rpm;
- adiabatic cooling system as additional cooling system for hot periods, AND phase change cold storage material that can bridge the hottest periods.

3.1.2 Variant 2: Closed cooling systems: indirect free cooling with an outside air/inside air heat exchanger

In these variants the cooling is indirect, i.e. there is heat exchange between different air streams. This can be achieved using a rotating 'heat wheel' heat exchanger, or using cross-flow or counter-current air/air heat exchangers.

The advantage is that there is no intermediate heat transfer medium (fluid) and thus no leaks or other complexities. The disadvantage is that the air speeds through the air-air heat exchangers are comparatively high and thus involve energy losses.

There are two subvariants:
2a: Air/air heat exchange, supported partially with adiabatic cooling or other evaporative techniques on the outside (see Figure 13).
2b: Air/air heat exchanger, supported partially with compression cooling in the inside air section (see Figure 14).

Examples include The Datacenter Group in Amsterdam and Delft (Subvariant 1a) and Rotterdam Internet Exchange in Rotterdam (Subvariant 2b) (Agentschap NL, 2011).

Figure 13 Schematic depiction of heat flows in Subvariant 2a with adiabatic cooling on the outside

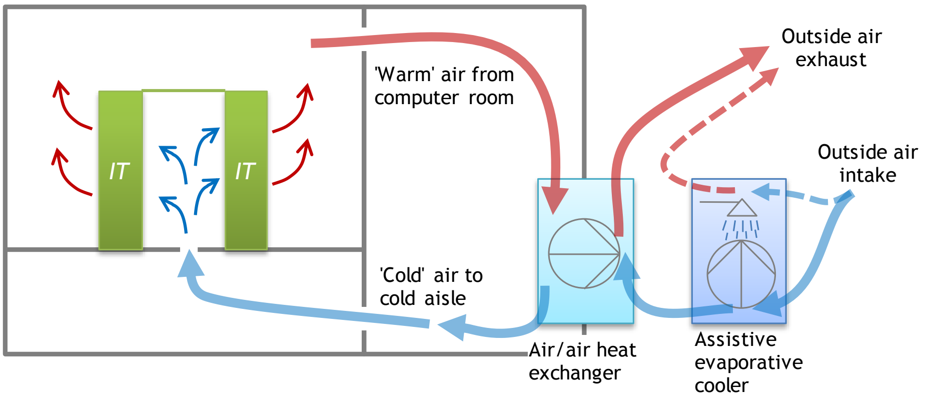
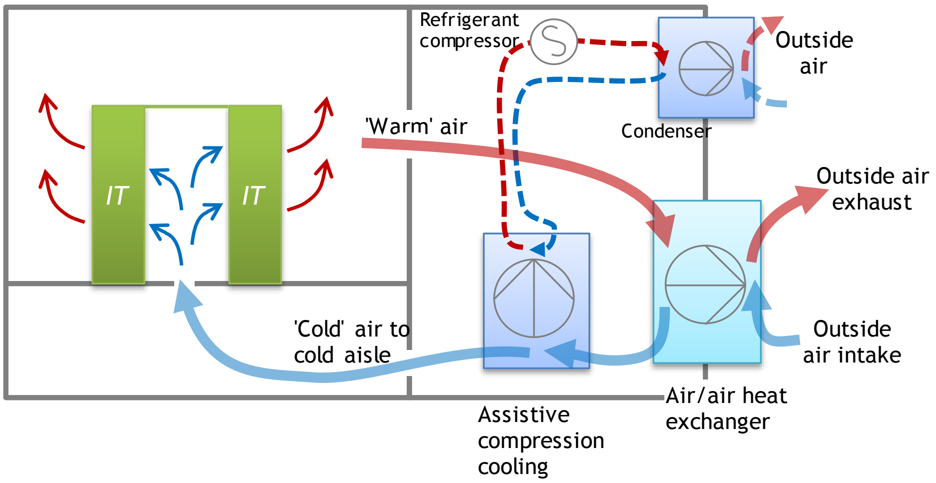


Figure 14 Heat flows and cooling layout of Subvariant 2b with assistive compression cooling in the inside air section



Variants 2a:
With outside/inside fixed air/air cross flow heat exchangers:
- air treatment with air filters;
- air transport with direct application of air to cold alleys; hot air containment;
- fans are frequency regulated; low-speed ventilation concept with pressure control over hot/cold alleys;
- adiabatic cooling system as additional cooling system for hot periods, designed to comply to 20-year extremes for temperature and humidity, based on KNMI data for the Amsterdam location.

Variants 2b:
With outside/inside air/air rotating heat transfer medium, supplemented by backup/additional compression cooling:
- Air treatment with air filters.
- Air transport with direct application of air to cold alleys; hot air containment.
- Fans, motors and pumps are frequency regulated; low-speed ventilation.
- Compression cooling system as additional cooling for the hot periods. The compression cooling system is sized to be able to fully cool the data centre at the given level of redundancy.

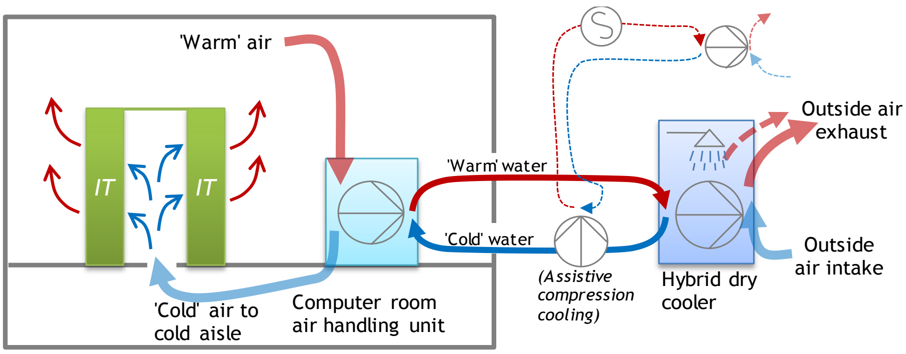
3.1.3 Variant 3: Closed cooling systems; indirect free cooling with fluid-based thermal transport

In this variant, illustrated in Figure 15, a fluid cold transport medium is used to transfer cold from the outside to air handling units installed close to the IT equipment/heat loads. The warm air in the computer room is vented along a heat exchanger where 'cold' air is made using a chilled water stream. The warmed up water then goes to a cold water plant where the heat is vented to the air.

Various sources of cold can be used to make the chilled water: a wet cooler, a hybrid dry cooler or a natural source of cold (deep lake or groundwater). The cooling lay-out is depicted schematically in Figure 15 for the case of the hybrid dry cooler.

All these options are highly efficient provided large shares of free cooling are used. Additional cooling, using a compression cooling unit, for example, can be limited to several dozen hours a year.
In this study the option with a hybrid cooling tower has been investigated in further detail. This variant is very well comparable to the reference, only the free cooling system is different. The compression cooling system acts as additional cooling system for the hot periods. In the variant fans, motors and pumps are frequency regulated.

Figure 15 Heat flows and cooling layout of Variant 3



3.1.4 Variant 4: Making use of waste heat

The above variants are focused exclusively on the most energy-efficient cooling systems, making maximum use of free cooling. However, these are essentially systems designed to throw away the heat energy as efficiently as possible. We now consider several variants in which this heat is usefully recovered so that primary heating energy is saved.

In these designs the main aim is to capture as much useful heat as possible and then cool the remainder as efficiently as possible. The captured heat can be supplied to other users; if no such users are available nearby, these variants will not be feasible.

There are two subvariants:
4a: Direct or indirect use of warm air.
4b: Cooling with a heat/cold storage buffer, using a heat pump to create sufficient heat and cold quality.

The first Subvariant, 4a, can be either a closed or an open system; the closed system is depicted in Figure 16.
The second Subvariant, 4b, is a closed cooling system using cold from a heat/cold storage buffer. This variant is depicted in Figure 17. For small environments this can be a couple of water tanks, while for larger variants this will generally be two underground water bodies containing the hot and cold water. A heat pump is used to increase the quality of the heat.

Two examples of Subvariant 4b are already operational in the Netherlands:
- With permanent heat recovery (University of Groningen);
- With partial heat recovery and free cooling the rest of the year (e.g. Equinix AMS3 and Triodos). In wintertime the data centre operates using free cooling and the utility building (where there is a demand for heat) is heated using the heat/cold storage buffer. In summertime, the heat/cold storage is regenerated using the data centre heat.

Figure 16 Heat flows and cooling layout of Subvariant 4a for an open system. When heat demand is low, heat is vented to atmosphere

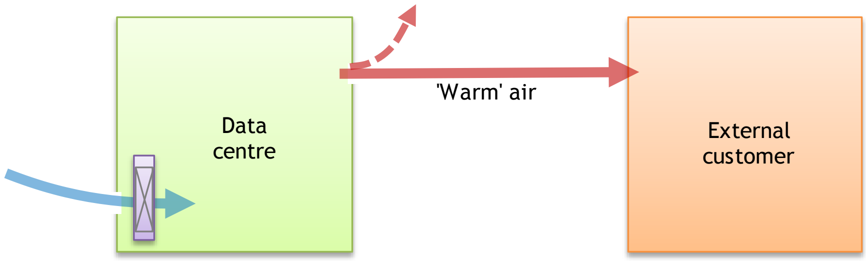
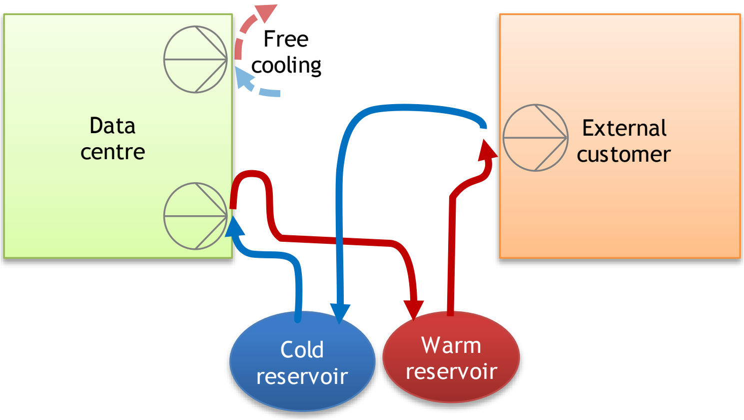


Figure 17 Heat flows of Subvariant 4b. In wintertime the data centre is cooled with free cooling via the atmosphere and the cold reservoir is regenerated



The feasibility of the last three Subvariants, 3c, 4a and 4b, depends very much on the surroundings. Both the geological situation (for hot/cold storage) and the existence of substantial heat demand are requirements.

3.2 References

The performance of the variants is compared to three references, representing a typical small, medium-sized and large data centre. For small data centres: 0.25 MW, for medium-sized centres (0.5-5 MW): 3 MW, and for large centres (> 5 MW): 8 MW. These references are based on the state-of-the-art of recently built centres and in all cases use free cooling supported by compression cooling. The reference cooling variants include a total cooling concept consisting of chiller plants with a compression cooling system, heat is given of by dry cooling towers.

Figure 18 Dry cooler

Cold is transported with a water/glycol mixture and delivery of cold to cooling alleys via air handling units. All the references have the following measures in place:
- separation of warm and cold air streams;
- variable-speed drives on fans, with pressure control wherever possible;
- temperature and humidity ranges as per ASHRAE, tending towards the warmer range (up to 27˚C);
- all designs suitable for modular build;
- diesel generators electrically heated (1 kW per 50kVA).

The main energy consuming devices are:
- computer room air conditioning unit: fans, compressor (reference I);
- air handling units: fans (reference 2, 3);
- chiller plants: compressors (reference 2, 3);
- cooling towers: fans;
- water pumps.

The key data for the references are shown in Table 5.

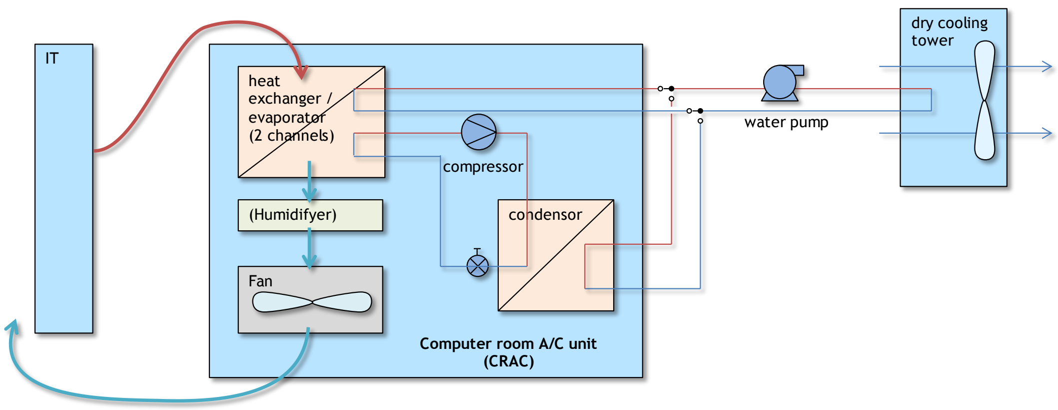
Table 5 **Typical data for references**

Class	Class I (0.1-0.5 MW)	Class II (0.5-5 MW)	Class III (> 5 MW)
User specifications			
Electric power (maximum ICT load, at the UPS, at the required level of redundancy), in MW	0.25	3	8
Floor area available for IT, in m^2 (white space)	300	2,000	4,000
TIER level	1	2	3
Redundancy	N+1	N+1 (E and C)	2N; 90% max(E) N+1 (C)
Degree of loading	70%	70%	50%
Technical specifications:			
Discharge of heat	Compression cooling system, dry cooler (2 channel), either free or active cooling	Dry cooler, free cooling gradually possible	Dry cooler, free cooling gradually possible
% of the year free cooling	70%	90%	95%
UPS	Static	Static	Dynamic

References

Reference 1: Small data centre (250 kW)

Figure 19 **Reference 1: Small data centre (250 kW)**



In this reference the cooling is based on direct expansion downflow units (split units), with water-cooled condensers and a dual-channel heat exchanger for free cooling. The degree of free cooling is 70% of the year, corresponding with those hours in the year when the temperature is below 15˚C (at De Bilt, the Netherlands).

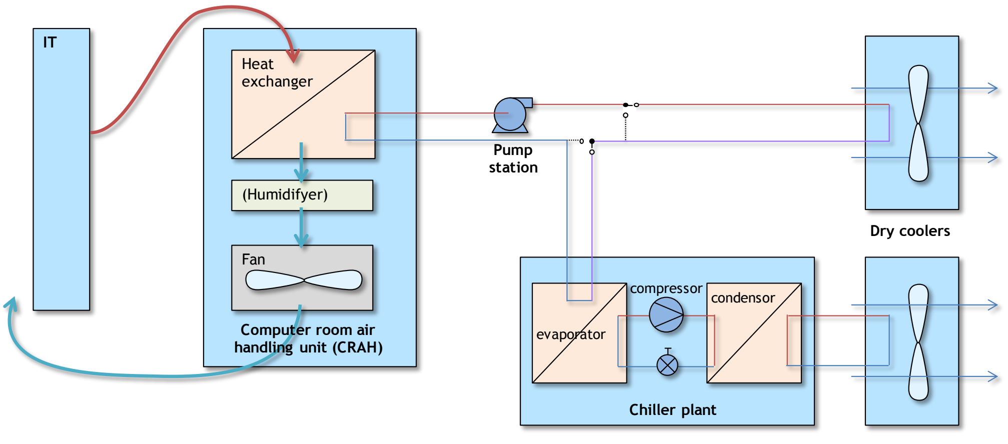
The system in question can be in either free cooling or in mechanical cooling mode, but is not capable of mixed mode operation.

The 15˚C outside temperature will result in a cold water temperature no lower than 18-20˚C, which can then be used to create the 25˚C airflow needed inside the data centre.

Reference 2: Medium-sized data centre (3 MW)
In this reference the cooling is supplied by chiller plant equipped with dry coolers for (partial) free cooling. Cold air is generated with water-cooled downflow units. The degree of free cooling is 90% of the year, corresponding with those hours in the year when the temperature is below 20˚C (at De Bilt, the Netherlands). The system in question can be in (partial) free cooling and mechanical cooling mode simultaneously. The 25˚C inside temperature will result in a water return temperature above 20˚C, which can then be reduced by the dry cooler and lowered further with the aid of mechanical cooling. Humidity is controlled with mechanical (ultrasonic) evaporators.

Reference 3: Large data centre (8 MW)
Also in this reference the cooling is supplied by a chiller plant equipped with dry cooling towers for (partial) free cooling. Cold air is generated with water-cooled downflow units. The degree of free cooling is 95% of the year, corresponding with those hours in the year when the temperature is below 22˚C (at De Bilt, the Netherlands). The system in question can be in (partial) free cooling and mechanical cooling mode simultaneously. The 25˚C inside temperature will result in a water return temperature above 20˚C, which can then be reduced by the dry cooler and lowered further with the aid of mechanical cooling. Humidity is controlled with mechanical (spray) evaporators.

Figure 20 Reference 2 and 3: medium and large size data centre (3 and 8 MW)



4 Model analysis of cooling variants

4.1 Introduction

Of the possible cooling variants described in the previous chapter, five were evaluated quantitatively: 1a, 1b, 2a, 2b, 3. The main focus of this evaluation was on investments and impact on energy consumption for three size classes of data centres. The quantitative evaluation of energy performance included such aspects as energy used for the cooling system and energy lost in power conversion. The results were compared with those for the reference designs, one for each data centre size class.

4.2 Approach

For this assessment the following approach was adopted:
1. As a first step, a selection of suppliers of technologies and solutions were contacted to provide relevant data. The suppliers providing information are listed in Table 6.

Table 6 Suppliers providing data on energy efficiency

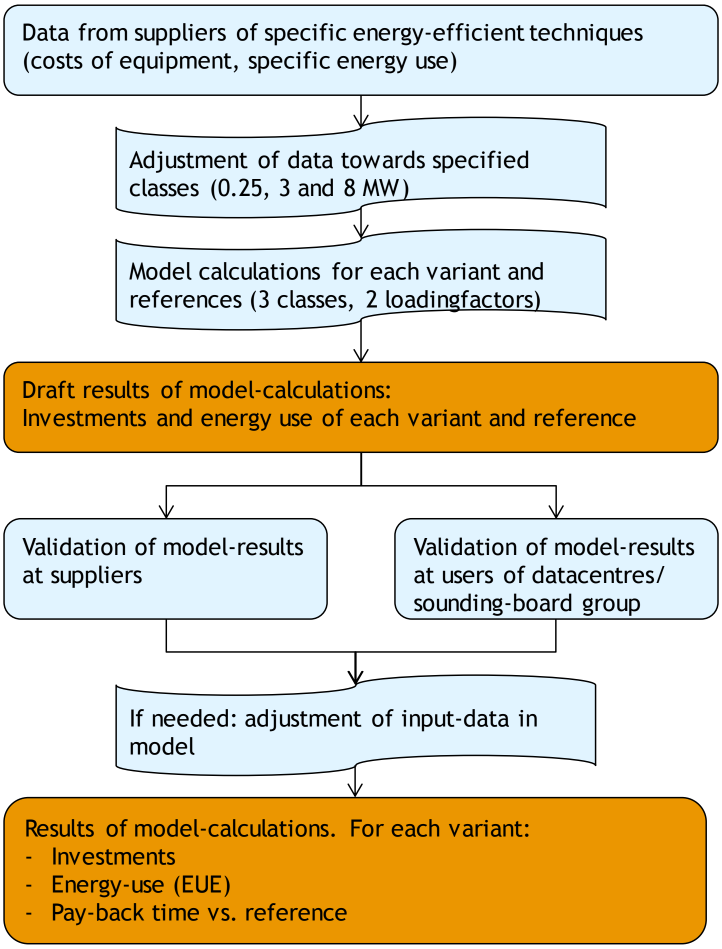
Aspect	Supplier
Air ventilation within data centre	DataCenter Infra Solutions, Holland Ventilatie Groep, APC, Stulz, Low Speed Ventilation Datacentres
Efficient heat discharge from data centre	DataCenter Infra Solutions; Ziggo (Tenzon); Kyoto Cooling; RecAir; Jaeggi; APC; Stulz
Humidity control	Recool
Efficient power supply (UPS)	Piller, APC
Limiting heat-influx	Nebiprofa, Optigroen

The suppliers were approached by means of a questionnaire followed by a telephone interview. A wealth of information was received for the cooling variants 1a, 1b, 2a, 2b and 3. In some cases certain data from the EnergyGo study could also be used. From the interviews with the suppliers new insights emerged. Where relevant, these insights will be detailed later in this report (Section 4.3).
1. Based on the interviews, the specific data provided by suppliers were adjusted to match the three classes in the model.
2. Using the model, the total investments and energy use of each of the variants as well as the references were calculated. This was carried out for two loading factors (average and maximum). Further information on the model is provided in Section 4.4.

3. Validation of calculation model results was carried out by sending the results to suppliers as well as data centre operators, asking for feedback. For each variant and reference, appropriate operators were approached. Results were also checked by data centres participating in the expert advisory group ('klankbordgroep'). Certain data centres were unwilling to validate data, mainly because of time constraints and concerns regarding confidentiality. However, five data centres did respond. In general, the response showed that experiences at data centres were in line with the modelled results reported, with centres indicating that calculated values for investments in cooling matched their own experience within a range of 10%. For the UPS larger differences were reported. However, these did not impact on the modelling results, as the model used largely the same UPS configurations for both the reference and variants.
4. Depending on the information received in the validation step, the calculation model was adjusted accordingly. This 'tweaked' model yielded the data on investments and energy use reported below. Based on the differences in investments and energy use between the variants and the references, the pay-back times of the variants were calculated. These modelling results are reported in Section 4.5.

The steps are illustrated in Figure 21.

Figure 21 Approach for quantitative evaluation of variants



4.3 Insights from suppliers and data centre operators

Cooling

For the five cooling variants the suppliers were asked to detail their solutions in terms of energy performance and purchase costs. From the material provided, subsequent discussions and the information offered by data centre operators a number of key conclusions and surprising results emerge.
In this section these are described.

Key insights for cooling systems:
- a number of excellent energy-efficient cooling options exist, both compressor-less and with assistive compressor cooling;
- a number of suppliers are able to supply both efficient and non-efficient products;
- direct air/air heat exchange configurations are cheap to purchase and very energy-efficient.

Power supply (UPS)

The design variants considered in this study employ both static and dynamic UPS systems. In both cases high-efficiency models are today available. Specific information was received from two of the main suppliers: Piller, APC.

Our calculation model uses efficiencies typical for state-of-the-art equipment. These are further outlined in Section 6.1.3. In Section 4.4.5 we report the loading factors used in the model. We have not calculated with 'eco-mode operation' but with real 'double conversion' efficiency values at the load values used in the study, according to the discussion in Section 6.1.3.

4.4 Calculation model of techniques

To evaluate the energetic performance of the energy-efficient data centre variants compared with the references, a modelling approach was adopted, with performance and efficiency being modelled under different degrees of data centre loading using the technical parameters of the respective references and variants. The latter are related to the installation cost of the variants and references.

4.4.1 Modelling energetic aspects of data centre efficiency

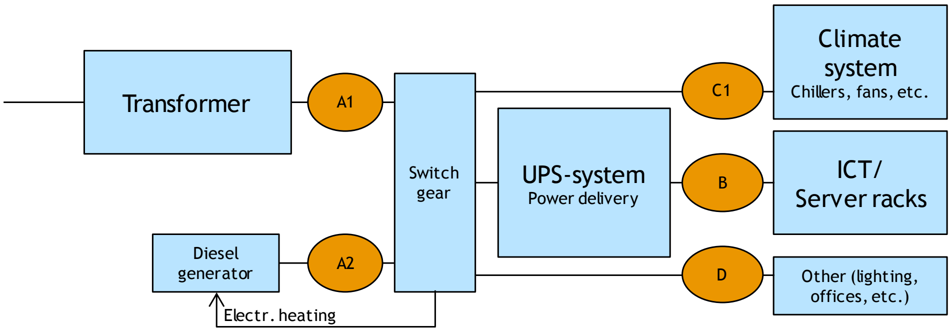
Aggregate data centre energetic performance depends on the following factors:
- loading of fans and air handling units: energetic efficiency generally improves strongly as loading declines;
- loading of pumps and certain motors: energetic efficiency is generally constant, with power uptake responding linearly to load;
- power supply systems: energetic efficiency decreases with lower loading (different efficiency curves for different systems).

To calculate overall data centre energy efficiency, the performance coefficients were varied per unit depending on loading. To establish the loadings of individual units in the model, the total data centre loading was used.

EUE

Energy efficiency was calculated as an annual average EUE incorporating both cooling and power supply systems. The energy use by 'other' equipment (offices, lighting) was not included[7, 8]. This is illustrated in Figure 22.
In the model, the EUE is the total energy use for UPS system, climate system and ICT divided by the energy use for the ICT, (A1 + A2[9] - D)/ B.

Figure 22 **Calculation of the EUE. In the model the EUE is calculated as (A1 + A2 – D)/ B**



As already mentioned, suppliers were contacted to provide the technical details required and the results validated with both suppliers and operators.

Aspects not included in the model

The following aspects were *not* included in the model:
- any data centre power use unrelated to ICT or temperature control systems, e.g. power for lighting, powering office spaces, smoke detection systems, other control systems on generator/UPS output, etc.;
- water use;
- diesel fuel use for aggregate.

Inclusion of the energy use by these other energy consumers would result in slightly higher EUEs. Assuming that the share of 'other equipment' in the total energy consumption is less than 1%, the effect on the EUE will be less than 0.02.

Two scenarios for loading degree

The data centre variants were evaluated for two scenarios of loading degrees: average and maximum.
- Average loading: This represents a realistically high degree of data centre loading: 70% of power draw for class I and II and 50% for class III.
Taking into account the redundancies in the different classes, this results in a loading of the UPS system 47, 56 and 22%, respectively for class I, II and III. Note that for size class III (8 MW), the TIER-3 classification requires a sizing of the UPS so that at 100% power drawn there is still 10% headroom to draw extra power. This means that with this size class, UPSs are generally at a somewhat lower loading than for size classes I and II.
For the cooling the resulting loading degree is 58% for class I and II, and 42% for class III.

[7] In comparison, the definition by Stichting Milieukeur (SMK, 2012) includes the energy use for 'other equipment' in the calculation of the EUE.

[8] The same applies for the use of diesel for the aggregate.

[9] Minus the energy-use for the diesel.

– Maximum loading: This represents 100% power draw of nominal rated UPS output (at given redundancy levels).
This results in a loading degree of the UPS system of 67, 80 and 44% for respectively class I, II and III.
For the cooling system the loading degree is 83% in all classes.

The degrees are summarized in Table 7.

Table 7 **Loading degrees for scenario of average and maximum loading**

	Size class of Data centre		
	I (250 kW)	II (3 MW)	III (8 MW)
UPS (electricity supply)			
Reduncancy	N+1	N+1	2N
Maximum load	0.67	0.80	0.44
Average load	0.47	0.56	0.22
Cooling			
Reduncancy	N+1	N+1	N+1
Maximum load	0.83	0.83	0.83
Average load	0.58	0.58	0.42

4.4.2 Investment costs

The model includes the installation costs of the heat removal/cooling systems and the power supply (UPS) systems. The model covers all key costs that differ between the references and the energy-efficient variants.

For the references, the investments costs covered include the cost of UPS systems, air handling units, chiller plants (compression cooling system), cooling towers, water pumps and piping.
For the energy-efficient variants, we asked the suppliers to supply complete cost estimates covering the equivalent cooling function. In many cases they responded with complete overviews of costs. Sometimes the data provided by suppliers even included an assessment of the relative return on investment vis-à-vis a reference lay-out.

Not incorporated in the calculations are investments cost components that will be shared in all cases (variants and references). These include such cost components as the data centre building, mains/medium-voltage transformer, power delivery units, electrical cabling and wiring, fire extinguishing systems and so on. These costs are not anticipated to differ significantly between the references and energy-efficient variants[10].

The cost figures employed are based on supplier figures that were cross-checked with both data centre operators and the expert advisory group. Where new information was received from operators or experts, this was used to update the cost-figure input to the model. The procedure adopted was that if two or more data sources contradicted, the average was input to the model.

10 In the absence of a back-up compression cooling system, a number of electrical components can be sized smaller. These include the transformer and power delivery system, and in the case of rotary UPS, also the UPS. This can entail a cost advantage for the compression-free variants. We have not quantified these aspects, so in this study identical electrical layouts are assumed.

Two cost components are of particular note:

- The cost of creating separate hot and cold aisles. These costs are not included in any of the designs. However, one cooling variant (1a) is a ‘total solution’ in which these costs are already included. To account for this, in this variant, a cost figure of 160 €/rack was subtracted from the overall installation cost of this variant.
- The cost of a raised floor configuration. In all the energy-efficient cooling variants (1a-b, 2a-b) the cooling solution has no need for a raised floor, which can therefore in theory be omitted. However, as there may be other reasons for installing a raised floor (equipment access, cabling, etc.), we introduced no cost deductions for raised floors (typically € 80-100 per square metre) in any of the variants.

Some of the cooling variants already incorporate costs for components (such as closed compartments for hot/cold aisles) that would be required in other variants. In these cases, the supplier figures were adjusted accordingly.

4.4.3 Power supply system

Within each size class, the same power supply system is used in all the variants as well as the reference. For size classes I and II the designs use a static UPS, while for the largest of the size classes, III, a dynamic UPS is used. Parameters for the power draw in the configurations, the lay-out of the power supply system and the modularity are indicated in Table 8.

Table 8 Parameters of power supply systems, including modularity and installation costs

Used for		Class I References and variants	Class II References and variants	Class III References and variants
For IT output level at required redundancy level	kW	250	3,000	8,000
Dynamic UPS also drives air handling units, additional power requirement	kW			1,338
Total required apparent power	kVA	310	3,750	11,700
Unit size (modularity)	kVA	200	300	1,600
Type of UPS		Static	Static	Dynamic
Number of units non-redundant		2	13	8
Number of units redundant		1	4	9
Total number of units		3	17	17
Total non-redundant capacity	kVa	600	5,100	27,000
Cost price of all units (excl. diesel generators)	€	165,000	1,296,000	9,193,000

4.4.4 Cooling system

The investment costs of the cooling system are indicated in Table 9, first for the reference designs and then for the variants.

Table 9 **Installation costs of cooling systems in reference designs and variants**

	Size class	Installation costs, cooling and heat removal (x 1,000 €)	Difference from reference (x 1,000 €)
Reference design I	I	300	-
Reference design II	II	3,650	-
Reference design III	III	8,630	-
Open cooling system, supplemented directly with filtered outside air, supported partially with evaporative assist/adiabatic	I	500	200
	II	4,690	1,040
	III	12,280	3,650
Idem, supported partially with PCM cold storage	I	840	540
Closed cooling system, outside > inside air/air heat exchange, supported partially with evaporative assist	I	180	-120
	II	2,050	-1,600
	III	5,550	-3,080
Closed cooling system, rotating air/air heat transfer, supported partially with compression cooling	I	680	380
	II	5,430	1,780
	III	10,620	1,990
Closed cooling system, fluid based thermal transport, hybrid cooling towers	II	4,010	360
	III	10,070	1,440

4.4.5 Energetic performance

Power supply

TIER classifications impose requirements for redundancy on the power supply system that translate into different loading degrees of the individual UPS.
An individual UPS can have a loading degree that is significantly lower than the total data centre degree of loading, due to the redundancy requirements.

TIER classifications impose redundancy requirements on the power supply system, which translate to different loading degrees of the individual UPSs. Because of these redundancy requirements, an individual UPS can have a loading degree that is significantly lower than that of the total data centre.

Based on the efficiency figures detailed in Section 6.1.3, the efficiency figures used in the model are indicated in Table 10. These efficiencies are appropriate for state-of-the-art UPS systems. For the dynamic UPS, efficiency figures for *isolated parallel bus operation* are also given. In this case, the number of redundant units is significantly lowered to achieve better UPS utilization.
In the model calculations, for both the reference designs and the energy-efficient variants, the standard (2N+1) operation was taken (for both installation costs and energy performance).

Table 10 Efficiency parameters of UPS systems

Size class			Class I	Class II	Class III	
Average Loading degree IT			70%	70%	50%	50%
Redundancy power supply (and nominal max.)			N+1, N=2	N+1, N=4	2N+1, N=8 max=90%	N+2, N=8 Isolated parallel bus, 2N equiv.
Used for			References, variants	References, variants	References, variants	Variants
Loading degree of UPS systems at redundancy		Assumed	47%	56%	22%	40%
		Maximum	67%	80%	44%	80%
Efficiency figures						
Static UPS	Unit size	KVA	200	400		
		Assumed loading degree	**94.4%**	**94.5%**		
		Maximum loading degree	**94.6%**	**94.6%**		
Dynamic UPS	Unit size	KVA			1,600	
		Assumed loading degree			**88.3%**	91%
		Maximum loading degree			**93.0%**	95%

Degrees of loading of fans and pumps

The model permits assessment of the energetic performance of the different components at various loading degrees. In the model the following assumptions were used:

- the energy consumption of compressors and CW pumps varies linearly with loading degree;
- the energy consumption of air transport (fans) varies quadratically with loading degree (the theoretic efficiency responds to the third power of the load, but the quadratic model is more in accordance with what is observed in practice).

For total cooling concepts where air transport is dominant, not all power consumption conforms to quadratic decrease with declining load, with some fraction of energy consumption (10-20% across the variants) either fixed or varying linearly with load.

4.5 Results of model calculations

4.5.1 Investments

Table 11 shows the investments (in M€) for the variants, for the three size classes of data centres studied. The investments for the largest class are relatively high, due to the assumed high TIER class of this type of data centre. This results in high degree of redundancy for cooling equipment and electricity supply, and thus higher investment costs. Variant 2a has relatively low investments because of the abundance of compression cooling.

Table 11 Investments for variants and references

	Data centre size class		
	0.25 MW	3 MW	8 MW
Reference 1	0.47		
Reference 2		4.9	
Reference 3			17.8
Variant 1a	0.67	6.0	21.5
Variant 1b	1.0		
Variant 2a	0.35	3.3	14.7
Variant 2b	0.84	6.7	19.8
Variant 3		5.3	19.3

4.5.2 Energy efficiency

Table 12 and Table 13 show the energy efficiency of the variants relative to the references for scenarios of average and maximum loading. The efficiencies are expressed as EUE.

Table 12 Energy efficiency of variants at average loading degree, expressed as EUE

Average load	Data centre size class		
	Class I	Class II	Class III
Reference 1	1.25		
Reference 2		1.21	
Reference 3			1.25
Variant 1a	1.09	1.09	1.16
Variant 1b	1.11		
Variant 2a	1.11	1.11	1.17
Variant 2b	1.12	1.11	1.17
Variant 3		1.13	1.19

Table 13 Energy efficiency of variants at maximum loading degree, expressed as EUE

Max. load	Data centre size class		
	Class I	Class II	Class III
Reference 1	1.28		
Reference 2		1.24	
Reference 3			1.25
Variant 1a	1.10	1.09	1.11
Variant 1b	1.12		
Variant 2a	1.13	1.13	1.15
Variant 2b	1.13	1.13	1.15
Variant 3		1.15	1.17

The results for average and maximum loading degree are comparable, with a slightly lower EUE for the average case. This is due to the relatively lower energy use of fans (as discussed in Section 5.4).
In all variants, and for each of the three size classes, the EUE is in a range between 1.1 and 1.2. For the variants without compression cooling (1a, 1b and 2b) the EUE is slightly lower than for the variants with assisted compression cooling (2b and 3). These differences are small, however. This is discussed further in Section 5.3.

It may be noted, furthermore, that the energy use increases with data centre size class. This is due to increased energy use for the electricity supply (UPS). In the model the higher classes have a higher TIER level, which imposes greater redundancy on the electricity supply. As a consequence the UPS has a lower loading degree, resulting in a lower energy efficiency (see Section 6.1.3).

4.5.3 Pay-back times

Calculation

The pay-back times of the variants have been calculated relative to the reference data centres. This was done using data on investments and annual energy costs, using the following formula:

$$Payback\ time = \frac{Investment\ of\ variant - Investment\ of\ reference}{Annual\ energy\ costs\ of\ reference - annual\ energy\ costs\ of\ variant}$$

In the calculations an electricity price of 10 €ct/kWhe was assumed for the small data centre (0.25 MW) and 7 €ct/kWhe for the middle-class (3 MW) and large (8 MW) data centres.

The results show that pay-back times can be very long. This is due to the fact that the investment costs are in most cases substantially greater than the annual energy costs. In addition, the savings in annual energy costs are relatively small since differences in EUEs between variants and references are relatively small. For example: in the case of a EUE in the reference of 1.2 and 1.15 in the variant, the difference in total energy costs is only 4%. Also, the energy prices are relatively low, especially for the two higher classes (7 €ct/kWhe).

Sensitivity analysis

While pay-back times can vary widely, it should be noted that uncertainty ranges must be taken into account for both investments and energy use. Both are based on data for techniques used in variants and references. In practice these will vary depending on the data centre configuration in a specific case. For this reason calculations have been carried out with a margin of uncertainty of +/- 10% for both the variants and the references. The combined effect is a +/- 20% variation for the difference in costs between variant and reference. This variation reflects the uncertainties in investments and energy use[11].

Specific design aspects

Furthermore, in a model analysis such as the one performed for this research, it is not possible to include all technological details of all energy-efficient options. Therefore, certain specific cost advantages or disadvantages of variants vis-à-vis the references are not included (see also Section 4.4.2).

[11] In the validation among suppliers and users of data centres the differences between proposed EUE values and investment costs and responses were at most 10%.

We will give three examples of design aspects that were not quantified because they are too specific.

- Data centre raised floor. The model calculations are done without the costs of raised floor, which is a necessary ingredient in cooling systems with a liquid heat transfer step. In direct or indirect air/air cooling variants, the raised floor is not required. In practice, data centres of these layouts are observed which do have and which do not have the raised floor configuration. We have not subtracted the cost of the raised floor in these cases, as the raised floor may be desired for other reasons (e.g. cabling). Typical amounts for this cost point are € 30,000/200,000/400,000 for the three data centre size classes.
- Compressor-free cooling variants (1a, 1b, 2a) impose lower power draw. This could mean a saving on cost of electricity cabling, mains voltage transformers, or in case of dynamic UPS also UPS systems. This is very specific to actual data centre layout, but it could be up to 15%.
- Costs of providing for separated hot/cold alleys. One supplier of Variant 1a technology has a solution that already includes this cost component. Because this cost component is not included in the other variants nor in the references, in this case an adjustment was made to the cost figures: the installation costs of this variant were reduced (with 163 €/rack, or € 20,000/130,000/260,000 for the three data centre size classes).

When deciding on data centre cooling technologies, detailed profitability analysis of an energy-efficient design must be performed on a location specific basis, involving the suppliers of energy-efficient technologies in the design. The suppliers can in many cases give information which will enable very good energy efficiency to be combined with low installation costs.
From the information received from the suppliers, it is expected that by making actual design choices that are optimal for the efficient cooling technology employed, actual additional installation costs may be limited to only a couple of percentage points in the overall costs. Therefore, optimally integrating technologies in the data centre design, the differences between options can become small.

Detailed results

Table 14 summarizes the calculated results. This table shows:

- Energy prices used in the model, € 0.10/kWhe for class I, and € 0.07/ kWhe for class II and III.
- Investment costs:
  Investments (in € 1,000) for both references and variants are shown, with a specification for UPS and cooling systems, and the resulting total costs.
  For the variants the extra costs relative to the reference are indicated.
  It should be noted that in several cases (Variant 2a) extra costs are negative, due to the fact that investment costs for the variant are lower than for the reference.
- Energy costs:
  The yearly energy costs (in € 1,000) are given for both references and variants. The costs are specified for the scenarios of average and maximum loading, as described in Section 4.4.1.
  For the variants the savings in energy costs relative to the reference are indicated. In all cases the energy costs of the variants are lower than for the reference. However, in most cases the savings in energy costs, are relatively small compared to the extra investment costs.

- Pay-back times:
  From the investments and energy costs, simple pay-back times (in year) are calculated, respectively for a scenario of average and maximum loading.
  In many cases the calculated pay-back times are very large, >> 10 years. This is due to the large amount of extra investment costs vs. the savings in yearly energy costs. For Variant 2a, the calculated pay-back time is 0, indicating that compared to the reference, this variant is profitable from the start of the operation of activities. This is due to the fact that both investment costs and yearly energy costs of this variant are lower than for the reference.
- Sensitivity analysis:
  The last column shows the results of the sensitivity analysis for the calculated pay-back times.
  The results show that also the uncertainties of the calculated pay-back times are in many cases very large, >> 10 years. The presented results are based on a variation of investments of both references and variants with +/- 10%. This reflects the strong dependence of the calculated pay-back times on investment costs.

Table 14 Full calculation model results. Investment costs, yearly energy costs, and pay-back times

Design variant, size class	Electricity costs	Investment costs			Operational cost, yearly				Simple pay-back time		
		Inv. costs UPS system	Inv. costs cooling system	Extra cost compared to reference	Energy costs: max load	Energy costs: normal load	Savings energy costs: max load	Savings energy costs: normal load	Normal load	Max. load	Uncertainty in sensitivity analysis testing (+/- amount)
	€/MWh	x1,000 €			x1,000 €/year				Years		
Reference 1	*10*	*165*	*302*		*6*	*4*	*0*	*0*			
Reference 2	*10*	*1,300*	*3,650*		*64*	*39*	*0*	*0*			
Reference 3	*7*	*9,190*	*8,630*		*121*	*61*	*0*	*0*			
Var 1a Class I	10	165	501	199	2	1	4	2	82	50	± 25
Var 1a Class II	10	1,300	4,690	1,040	25	17	39	21	49	27	± 30
Var 1a Class III	7	9,190	12,280	3,650	56	40	64	20	179	57	± 70
Var 1b Class I	10	165	840	538	3	2	3	2	242	158	± 40
Var 2a Class I	10	165	180	-122	3	2	3	2	0	0	± 40
Var 2a Class II	10	1,300	2,050	-1,602	33	20	30	18	0	0	± 40
Var 2a Class III	7	9,190	5,550	-3,078	73	43	48	18	0	0	± 75
Var 2b Class I	10	165	678	376	3	2	3	2	180	120	± 30
Var 2b Class II	10	1,300	5,430	1,770	35	21	29	18	99	61	± 75
Var 2b Class III	7	9,190	10,620	2,000	75	42	45	18	109	44	± 25
Var 3 Class II	10	1,300	4,010	358	38	23	25	16	23	14	± 30
Var 3 Class III	7	9,190	10,070	1,440	82	45	38	15	95	38	± 70

Aggregated results
Taking into account the results of the sensitivity analysis, the aggregated results are presented in Table 15 and Table 16. These show respectively the results for a scenario of average and maximum loading.
This presentation of results in classes of pay-back times represents the uncertainties in the model calculations.

Table 15 Aggregate results for pay-back times, for average loading (years)

Average load	Data centre size class		
	Class I	Class II	Class III
Reference 1	-		
Reference 2		-	
Reference 3			-
Variant 1a	> 10	> 5 **	> 10
Variant 1b	> 10		
Variant 2a	< 0	< 0	< 0
Variant 2b	> 10	> 10	>= 0 *
Variant 3		>= 0 *	>= 0 *

* Results for these variants vary under sensitivity analysis testing.
** These variants can become < 10 under sensitivity analysis testing.

Table 16 Aggregate results for pay-back times, for maximum loading (years)

Max. load	Data centre size class		
	Class I	Class II	Class III
Reference 1	-		
Reference 2		-	
Reference 3			-
Variant 1a	> 10	> =10	> 10
Variant 1b	> 10		
Variant 2a	< 0	< 0	< 0
Variant 2b	> 10	> 10	>= 0 *
Variant 3		>= 0 *	>= 0 *

* Results for these variants vary under sensitivity analysis testing.
** These variants can become < 10 under sensitivity analysis testing.

For all size classes, Variant 2a has a pay-back time of 0, meaning that it is profitable, compared to the reference. This is due to the fact that in this variant both investments and energy use are lower than in the reference cases.

Within the uncertainty margins, Variants 1a (middle class), 2b (large class) and 3 (middle and large class) may also have a pay-back time of less than five years.

5 Evaluation of energy-efficient cooling techniques

5.1 General principles

This study has shown that with proper application of modern techniques highly efficient data centres can be built and run. Achievement of this result in practice, however, is highly contingent on observance of two basic operating principles and a single guiding principle.

Operating principle 1: Utilize the entire ASHRAE allowed temperature and humidity ranges
Every one of the techniques discussed above for cooling, direct and indirect air cooling and free cooling operation of chiller plants can only be efficient as long as the period available for free cooling use is close to 100%. To satisfy this requirement, full use of the allowed temperature range is needed.
As discussed earlier, to prevent excessive energy use by IT equipment the period of time at the highest temperatures should be minimized.

Operating principle 2: Right sizing and modular building
Every effort should be made to avoid very low utilization percentages in critical components of the data centre facility infrastructure. In cooling equipment, moderate underutilization leads to efficiency gains, a direct result of the use of variable-speed drives. Care should be taken, however, to prevent utilization percentages below the minimum drive speed of these components. For UPS systems high utilization is to be preferred, and the data centre build should accommodate for the possibility of modular energy infrastructure components.

Guiding principle: Minimize total energy use
Minimizing total energy use would seem to be an open door when discussing efficient data centres, but a danger lurks in the use of a single value, like EUE or EUE , for characterizing data centre efficiency. Minimizing the data centre's energy use does not necessarily equal the pursuit of the lowest possible EUE value.
Operating an energy-efficient data centre requires intimate knowledge of the infrastructure and the skill to interpret the data obtained from meters located at significant points in that infrastructure. In addition, the operational boundaries of the equipment should be leading in determining the environmental boundaries maintained inside the centre. Knowing these boundaries, it is up to the data centre's operator to find the most efficient operating parameters within them. Contractual agreements with data centre users stipulating temperature and humidity setpoints can severely hinder efficient operation stipulating actual values in contracts is not only an obstacle in current operation, it is also a handicap in maintaining or increasing current efficiency, as operational boundaries for ICT equipment might change for future generations of ICT products.
Whereas the model results show really good energy efficiencies for all variants, true efficient performance has much to do with operational aspects: choices made during day-to-day operation. Data centres operators that show excellent understanding of the issues involved and take care in these matters can achieve the high energy efficiencies in this study.

However, operation of data centres at low temperatures, high air speeds, low utilization of UPS systems, mixing of heat/cold air due to insufficient segregation of hot/cold air streams are issues that may cause worse EUE's than observed in this study, also for the most energy-efficient variants.

5.2 Operation within ASHRAE-recommended temperature range

The temperature and humidity settings chosen by operators play a crucial role in controlling the data centre environment and therefore overall energy consumption.
Traditionally (pre-2010) these settings where around 20˚C (measured in front of the IT racks) combined with a humidity centred at 50% RH with a fairly narrow margin of 10%. Maintaining these low temperatures requires substantial cooling and results in a high energy use.[12]

According to the ASHRAE recommendations, temperatures should be in the range of 18-27˚C and within a certain humidity range. These values are shown in Figure 23. Operating a data centre within these limits creates considerably greater scope for using 'free cooling' and more energy-efficient operation.

[12] Several factors are cited as reasons for maintaining low temperatures:
1. Raising the temperature inside the cold corridor results in high temperatures in the hot corridors. Based on a delta T over the IT equipment of 12˚C, the high point in the recommended range of 27˚C results in a hot aisle temperature of 39˚C. Prolonged exposure to these temperatures is considered unpleasant.
2. Reliability of ICT equipment. In theory, higher temperatures can increase the risk of equipment failure; in practice, however, the increase in component temperatures is small and is, furthermore, largely compensated by the fans inside modern ICT equipment, which increase (and decrease) the airflow to maintain critical component temperatures at a fixed level. Modern ICT equipment carries a manufacturer's warranty that remains valid for cold aisle temperatures of up to 35˚C.
3. Energy use of ICT equipment at higher temperatures. Given variable fan speeds, the energy consumption of the ICT equipment (and subsequently data centre heat load) will in fact rise at elevated temperatures. The difference in energy use can be as great as 20%.

Figure 23 ASHRAE-recommended and allowable envelope

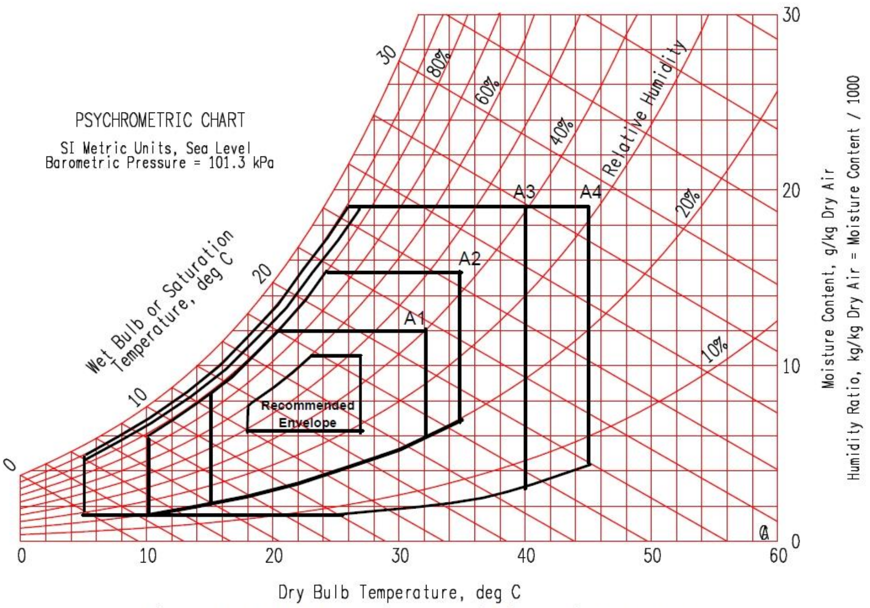


Figure 2. ASHRAE Environmental Classes for Data Centers

5.3 Free cooling

Operating a data centre within the broad range of temperatures and humidity recommended by ASHREA is a critical factor in achieving a high degree of free cooling. This applies to all the variants investigated.
Several variants described operate with 100% free cooling, without additional compression cooling, while other variants are based on very limited use of compression cooling. The critical factors in the operation of these variants are described below.

5.3.1 Options without back-up compression cooling

In the energy-efficient variants, a number of options have no compression cooling system as a back-up. This holds for Variants 1a, 1b[13] and 2a.

These variants rely on adiabatic assistive cooling for the hottest moments of the year. Adiabatic cooling is effective as long as the humidity of the air is sufficiently low. The main risk involved in these variants is that the temperature and humidity may at some point in time reach levels at which adiabatic cooling is insufficient to achieve data centre cold alley setpoints.

The magnitude of this risk will need to be duly assessed, given the data centre operating envelope and location.

Although in the Netherlands the common perception is that the air is very humid on hot days, technically speaking this is not true. In this country, too, as the temperature rises, the relative humidity drops, so there is scope for adiabatic cooling.

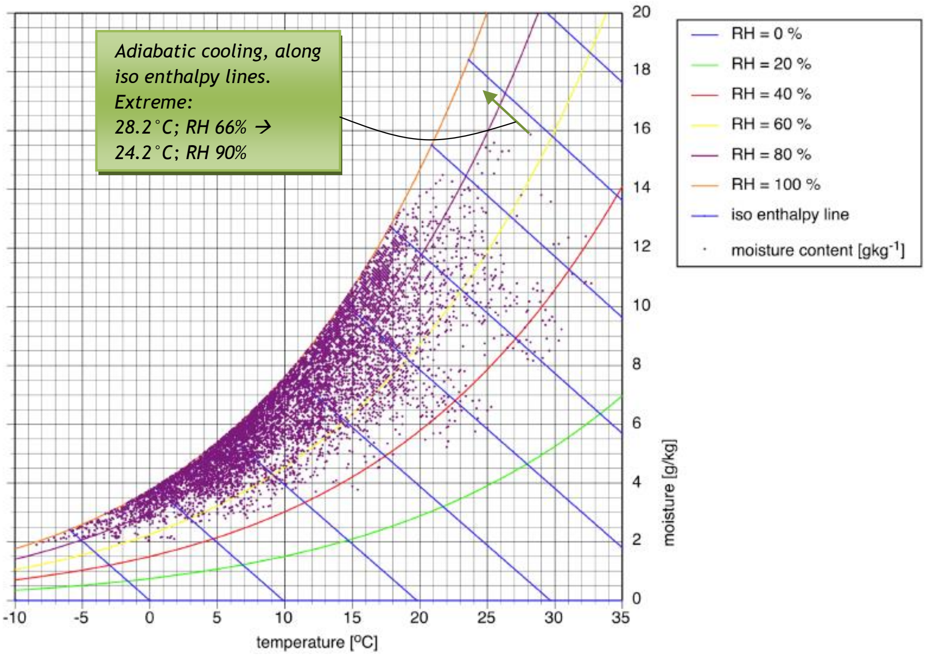
13 This variant has a phase change cold storage medium as an extra assurance for temperature/humidity extremes.

Figure 24 is a temperature-humidity diagram showing the average annual Amsterdam climate plotted on an hourly basis. From the figure it can be observed that at high temperatures the relative humidity is always low (see e.g. the data points in excess of 30˚C): the relative humidity remains below 50%. At this low relative humidity, adiabatic cooling is very effective and there is plenty of room for manoeuvre.

Adiabatic cooling works by the evaporation of water, which requires energy, supplied by lowering the temperature of the ambient air. As no external energy is added to or removed from the air, the enthalpy remains the same. During adiabatic cooling, temperature and relative humidity follow the so-called iso-enthalpylines, directed towards the upper left in Figure 12. As the absolute amount of vapour and the relative humidity increase, the temperature drops.

The point with the highest enthalpy, the uppermost data point on the right, is the 'hardest hour' for adiabatic cooling. The hardest hour for Amsterdam has a temperature of 28.2˚C and 66% RH. As an example, the arrow in the figure indicates the degree of cooling that can be achieved with one type of adiabatic cooler from one supplier.

Figure 24 Amsterdam climate: temperature versus humidity per hour (8,760 data points)



Source: Supplier, based on KNMI data.

Suppliers of compressor-less data centre designs can supply tailor-made calculations indicating the temperature and humidity ranges within which their cooling solutions are effective. These calculations, combined with a temperature-humidity diagram for the data centre location, will establish whether compressor-less operation is possible for all the hours of the year and what cold-alley temperatures are achievable.
Key to operating efficiency is that during the hottest and most humid hours of the year the cold alleys are allowed to be at the upper end of the ASHRAE-recommended envelope (i.e. 24-27˚C).

Suppliers indicate that the nearer the location is to the North Sea coast or the great lakes, the higher the relative humidity on hot days typically is relative to more inland locations. Adiabatic-only variants are never a problem in the eastern parts of the Netherlands, whereas in the western part the 10-year extremes from the KNMI may show temperature and humidity extremes requiring careful design choices and sizing of components. At a particular location, the heat exchanger contact areas need to be dimensioned bigger to be able to deal with temperature extremes compared to the case in the eastern part of the country.
It is up to the customer and the supplier to negotiate a system tailor-made to the particular location and cooling demand.
For this study, we asked suppliers to design systems that are able to function in the Amsterdam location, where on hot days the temperature may approach the upper range of the ASHRAE-recommended envelope (27˚C). The suppliers contacted performed calculations for these parameters. One supplier responded with a number of detailed design options, one suitable for the eastern part, one for the western part of the Netherlands.

While (compressor-less) adiabatic cooling can be expected to be an effective route at more inland European locations as well, this needs to be researched for individual sites. Generally, the following rule of thumb holds: the higher the temperature, the lower the relative humidity becomes, as the air can contain more moisture in kg/m^3. This leaves scope for adiabatic cooling.

5.3.2 Options with compression cooling

Several variants, including 2b and 3, feature a compression cooling system as a ‘bridge’ for hotter moments. In these variants the compression cooling system serves as a reassurance to customers that the temperature can be controlled to any level, regardless of outside air temperature, including traditional operating ranges such as 20˚C. Furthermore, variants with a liquid heat transfer medium require assistive cooling earlier than open cooling variants or indirect air/air heat exchanger variants.

The variants equipped with assistive/back-up compression cooling can be operated in a very energy-efficient manner, though, if the number of hours of operation of the compression cooling system is kept very low. If the temperature in the cold alleys may rise to the higher end of the ASHRAE-recommended envelope of 27˚C, the use of compression cooling systems can be kept low, e.g. less than 100 per year for all Dutch locations.

A disadvantage of compression cooling layouts is installation cost. A full backup cooling system needs to be installed with cabling, piping and maintenance costs.

Variants equipped with compression cooling systems may have external chiller plants and cooling towers and use a fluid heat transfer medium (water/glycol). This adds up to a doubling of heat exchange steps compared with indirect air/air cooling. The double heat exchange step means that, if the free cooling needs to be achieved using the fluid system, the amount of free cooling in the year is lower compared with alternatives.

ICT equipment energy use

A disadvantage of being in the upper part of the ASHRAE operating envelope is that the power consumption of the ICT equipment itself increases.
It is therefore not recommended to operate a data centre year-round at e.g. 24-27˚C; to economize on compressor use this should be done only on the hottest hours of hot days. See also Section 5.1.

5.4 Efficient air transport within the data centre

Air separation (hot and cold aisles)

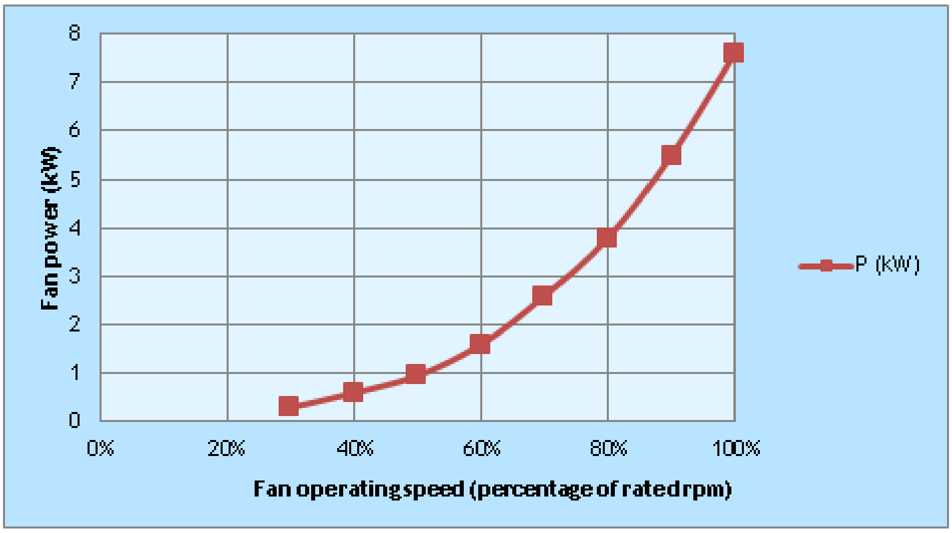
Data centre cooling systems will operate more efficiently and longer in economized mode when the hot and cold air streams remain fully separated (see also the calculations in APC Whitepaper 130, Choosing Between Room, Row and Rack-based Cooling for Data Centres).According to the EnergyGo study on existing data centres, typical investments for creation of hot and cold aisles are in the range of < € 1,500/kW.

Frequency control of fans/natural air movement

In cases where a traditional Computer Room Air Handling (CRAH) system is based on static speed fans, the need for variable-speed fans is apparent. This is currently the standard in modern installations (Moehle, 2011; Stulz, 2008). With these variable-speed drives, the lower the fan (air) speeds, the more efficient these fans become.

This mechanism is illustrated in Figure 25, which plots the relationship between the fan speed and power usage for CRAH fans. At 60% speed the 7.6 kW nominal power engine only uses 1.4 kW. The cooling capacity at nominal power is 105 kW, while at 60% of fan speed the cooling capacity is 60 kW. The related performance coefficient (COP) improves from 13.8 to 43.

Figure 25 Relationship between CRAH fan speed and power usage



A reduction of airspeeds has a substantial effect on required fan power: as a general rule, a reduction of airspeed by a factor 2 results in a reduction of required power by a factor 8 (EnergyGo, Energy savings in existing data centres). This can be further improved by combining the above insights: the amount of cooling air needs to be regulated to match demand exactly, and airspeeds should remain low and distances short. Part of this can be achieved by means of full aisle containment (i.e. completely separated hot and cold aisles) using pressure sensors. The temperature of the cold air and its volume are then separated quantities that can be independently controlled (ASHRAE Transactions, 2012).

6 Evaluation of other aspects of energy-efficient operation

6.1 Electricity supply (UPS)

A data centre's energy supply system can be a substantial source of energy loss. The main element of this system that determines the energetic performance is the Uninterruptable Power Supply (UPS).

6.1.1 Components of power distribution systems

The power distribution system of a data centre has three major components: the UPS, the distribution system (bus-bar and/or wire) and the IT power supply. The IT power supply falls outside the scope of this study.

UPS (Uninterruptible Power Supply)

A UPS combines electronics for power quality control with a source of stored energy to override any period of grid failure. In addition, many data centres are equipped with a diesel generator to overcome longer periods of grid failure, when the amount of energy stored would be insufficient.

Distribution wiring

Distribution wiring has a linear load-to-loss ratio; efficiency at 100% load = 99%, efficiency at 50% load = 99.5%. Since many data centres operate with redundant power distribution and below full load, typical loads on both UPS and wiring are below 50% during normal operation.

Power supply in ICT equipment

Although beyond the scope of the present study, it is interesting to note that the power supplies in IT equipment have improved dramatically in recent last years and now typically have approximately 93% efficiency at 50% load. Again, these efficiencies drop under low load conditions, which are not uncommon in modern IT systems, which therefore have oversized, redundant power supplies.

6.1.2 Static and dynamic UPS systems

There are two basic kinds of UPS layout: static and rotary (Section 2.6). A rotary UPS is coupled to the motor/generator and generally combines a flywheel. A static UPS is not attached to the generator system and may consist of battery storage (with either double or delta power conversion electronics) or flywheel energy storage.

6.1.3 Energy efficiency and loading factors

Both types of UPS systems are a source of considerable losses when significantly underutilized. Table 17 and Table 18 show typical efficiency values for both static and rotary UPS at different loading degrees.
From these tables it can be seen that the conversion efficiency is strongly dependent on the load factor, the share of rated UPS power output that is actually drawn. Especially with dynamic UPS systems, when the load declines to below 50%, the energy efficiency suffers.

Table 17 Typical data for static UPS efficiency (as used in the model), based on supplier information

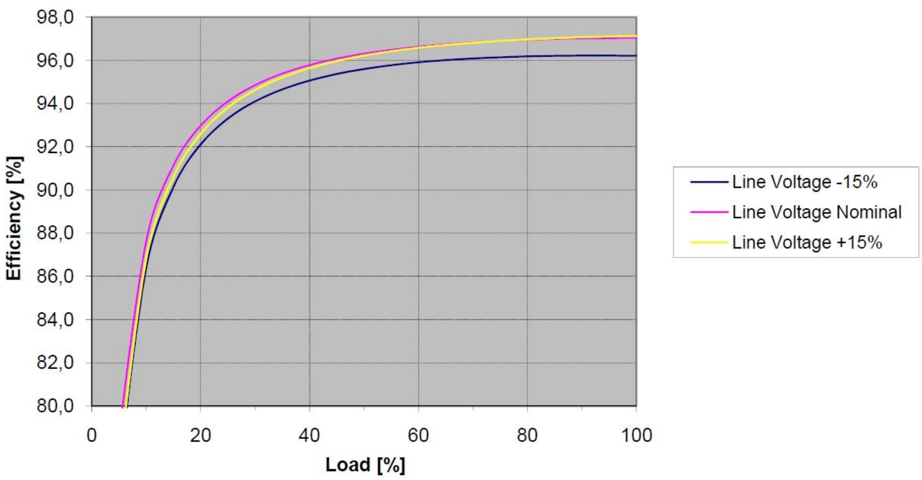
Loading degree	125 kVA	200 kVA	300 kVA	400 kVA
25%	90.6%	92.6%	92.5%	94.2%
50%	93.7%	94.4%	94.4%	94.5%
75%	94.6%	94.6%	94.6%	94.6%
100%	94.7%	94.8%	94.8%	95.2%

Table 18 Typical data for dynamic UPS efficiency (as used in the model), based on supplier information

Loading degree	625 kVA	800 kVA	1,100 kVA	1,670 kVA	2,000 kVA	2,500 kVA
25%	82.1%	85.0%	86.6%	87.1%	87.6%	90.5%
50%	90.3%	91.8%	92.8%	93.0%	92.8%	94.5%
75%	93.0%	93.8%	94.5%	94.8%	94.3%	96.0%
100%	94.4%	94.6%	95.1%	95.7%	95.0%	96.4%

The effect of loading factors is further illustrated in Figure 26, which shows the typical efficiency of a static UPS system.

Figure 26 Efficiency of UPS systems as a function of loading degree



Efficiencies are clearly low at low load levels. This situation is most acute in high TIER level data centres where UPS systems are employed in a 2N configuration with a limited maximum loading, even in a failure situation. In these situations the maximum normal operation would lead to a 45% load on any UPS, with loads below 25% very common in practice.

Static UPS systems - eco-mode

A static UPS typically offers ‘eco-mode operation’. In this mode the double conversion is bypassed, giving very high efficiency (about 99.5%). According to the information provided by data centre operators, however, this mode has practical limitations, and is not therefore used.

6.1.4 Achieving high efficiencies in UPS: the importance of modular building

The efficiency of a UPS improves substantially with higher unit loading, which can be increased by a higher overall loading degree, diminishing the number of redundant units. However, the data centre loading degree and the redundancy requirements imposed by the TIER classification have consequences for the efficiency figures with which the static and dynamic UPS systems are operated.
The unit loading degree can also be improved by matching the number of operational units to the data centre's overall filling degree, by adopting a modular building design. In practice, such modular building is crucial for achieving high-efficiency UPS systems, allowing equipment to function at good utilization rates using individual UPS units.

Modern static UPS systems are often composed of modules representing 20 to 25% of the maximum capacity of the complete system. Care should however be taken in employing the modular functionality of the systems. Since the power distribution system that delivers the electrical power from the UPS to the data centre floor is designed with a series of breakers that are designed for full-load operations, the less than fully configured UPS system must be able to deliver enough amperage in a short-circuit condition to be able to trip these critical breakers.
For dynamic UPS systems a different solution is needed, because these systems cannot be of modular build. The modularity in these cases must be provided by the number of active units that supply power to the internal data centre grid. Fortunately, dynamic UPS systems can be configured in a set-up known as 'isolated parallel'. In this set-up true load-sharing and 2N-like redundancy is obtained with less then 2N UPS systems.

6.2 Humidity control

Humidification can be a relevant source of energy use in a data centre.
The amount of humidification needed depends strongly on the ranges of humidity accepted at the centre.

Over the past few years humidity control conditions have been relaxed in line with publication of ASHRAE's recommended environmental conditions for Class A1 electronic equipment[14].
The recommended humidity range is now 30 to 60% RH at 24˚C, or a in an alternative, temperature-independent representation, a dew point between 5.5 and 15˚C. The range of recommended and maximum allowable values is shown in Figure 3.

Humidification is a substantial design aspect and source of energy/water use for open cooling configurations (Variants 1a and 1b). This is because in wintertime the cold outside air contains less moisture.
All open cooling configurations have systems in place to recirculate as much inside air as possible, limiting the amount of dry outside air that is let in to the data centre. In the case of open cooling systems, the energy requirement of humidification is incorporated in the energy figures supplied by the suppliers.

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14 American Society of Heating, Refrigerating and Air-Conditioning Engineers, 2011: ASHRAE TC 9.9 2011 Thermal Guidelines for Data Processing Environments – Expanded Data Center Classes and Usage Guidance.

In none of the closed cooling systems is humidification a substantial source of data centre energy use. Although steam humidification is more energy-intensive than mechanical (ultrafine spray) humidification, average annual energy use is still very low because energy-efficient closed configurations require very little humidification, given that no moisture is removed from the data centre (no condensation air-handling units)

The most common method used for increasing humidity levels is to introduce steam into the airflow. Steam generation is very energy-intensive, however, and for this reason mechanical humidifiers, spray and ultrasonic, have been introduced. At first glance, mechanical humidification appears to be almost energy-free, but large-scale systems need rigorous water treatment, reverse osmosis filter and UV irradiation to prevent the possibility of legionella contamination. *Drying (moisture removal)* is an energy-intensive operation because the latent heat stored in water vapour is released upon condensation and adds to the data centre's overall heat load.

Steam humidification can be simple and energy-effective on condition that steam generation is kept to a minimum. This can be achieved by adopting broad humidity ranges and flexible temperature settings inside the data centre.

6.3 Limitation of heat-influx

6.3.1 Increasing reflectance of sunlight

To assess the effect of direct influx we here assume a roof temperature of 70˚C and an inside temperature of 28˚C. At a roof insulation degree of Rc=3.5 m^2K/W (the standard under Dutch building regulations since April 2012) heat-influx will be 11.5 W/m^2. This heat is additional to the heat produced by the IT equipment.
A cool roof needs not be white. The two basic characteristics that determine the 'coolness' of a roof are solar reflectance (SR) and thermal emittance (TE). Both properties are rated on a scale from 0 to 1, where 1 is the most reflective or emissive (CRRC, 2012). A wide variety of colours is therefore available that still maintain a high solar reflectance (www.coolroof.org).

If a roof reflects the sun's heat and emits absorbed radiation back into the atmosphere, it stays cooler and reduces the amount of heat transferred to the building below, keeping the building at a cooler and more constant temperature. According to a short literature study by Arcadis this can be realised by painting the roof with a reflective white paint (Arcadis, 2012).
The main findings of the cited literature are as follows:
- White roofs can reflect up to 85% of the sunlight falling on them and as a result have lower average and lower peak temperatures.
- Actual measured rooftop temperature values reported over different periods in the year showed that during summer months the average temperature remained 8˚C below the average temperature of dark roofs. The maximum temperature of a dark roof exceeded 55˚C and the maximum temperature of the white roof remained below 33˚C (on a roof in June).

– The effect of the white paint decreases over time due to pollution of the roof (up to 20% decrease in effect per year).
– In the first year the effect on the roof temperature is significant. The effect in the longer term is disputed.

Roof temperature can thus be significantly lowered. A decrease in peak roof temperature from 70 to 40˚C will reduce the additional heat load on the data centre floor beneath that roof from 11.5 W/m^2 to 3.3 W/m^2.

However, the most important effect is the lowering of the temperature at the air inlet of the coolers positioned on the roof. As mentioned above, on a sunny day in June the temperature of a black roof exceeded 55˚C,while the neighbouring white roof remained below 33˚C. This means that the air at the air inlet on the black roof may have become too hot for use for free cooling (even with evaporation assist), while the air at an air inlet on the white roof would still be cool enough.

This information has been confirmed by experience with painting a data centre roof with a reflecting paint, which resulted in a lower temperature at the air inlet of the chillers 2 metres above the roof. The white paint led to an 8˚C lower air temperature (Bonke, 2013). At this data centre this meant that existing peak capacity was suddenly more than sufficient.

The additional costs of reflective roofing are 9-10 €/m^2 for similar-quality roofing. Placement of the material takes no longer; on the contrary, some types of reflective roofing are even less laborious than conventional black roofing. Besides reducing peak temperatures, reflective roofing has the additional advantage that of reducing temperature differences over time. This increases the life expectancy of the roofing material (IKO, 2013), although it is not specified by how much longer.

6.3.2 Green roofs

If the case of a so-called 'green roof', the vegetation is applied on top of a regular roof. Today there are various different types of vegetation roofs on the Dutch market. In the simplest category we can distinct two types:
– economical roofs that can be applied on roofs that can bear 100 kg/m^2 static weight;
– light-weight roofs that that can be applied on roofs that can bear 50 kg/m^2 static weight.

Some suppliers offer even lighter constructions, but there is then a risk of the vegetation requiring additional irrigation during longer dry periods (Optigroen, 2012).

These roofs have a water retention value of around 20 l/m^2. Because of the evaporation of water by the plants, temperatures on the roof remain under 30˚C in the temperate Dutch climate (Optigroen , 2013)[15]. Although this figure derives from tests elsewhere and has not yet been scientifically confirmed for the Dutch situation, it is consistent with experiments carried out in Japan under far more severe circumstances (Takakura et al., 2000).

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[15] This value is from the practice of 'roof vegetation gardeners' (in Dutch: 'Groendak hoveniers'). The precise values and the dependence on type of roof is currently being studied at the University of Wageningen as part of a project entitled: 'Begroeide daken classificatie implementatie technische eigenschappen', Weblink: http://www.innovatie-alliantie.nl/projectenbank/raak-project/981.html. In Germany there is also a very large-scale research programme underway at the Frauernhofen Institute to investigate the effect of vegetated roofs on indoor temperatures and dew points of the construction below.

This means that in the case of a green roof with water retention and an insulation value of Rc =3.5 m^2K/W there is no direct heat-influx and no significant temperature increase of the air inlet. This means that free cooling is possible during the whole year.

Another possibility is to combine a lighter type of green roof with solar panels: the so-called Solar Greenroof. This combination brings out the best of both types of system: solar panels work better on an cool roof, and roof vegetation retains more water due to the shading provided by the solar panels (optigroen.nl).

Financial aspects

The financial aspects are determined by the ratio between costs and benefits. The benefits of a green roof are high if the air intake of the free cooling system is on the roof, for in that case a year-round roof temperature of below 30˚C is guaranteed, allowing for 100% free air cooling.
To quantify this benefit requires calculation of the cost of the additional cooling system that would otherwise be required during periods when the roof temperature is too high – for example, when the outside temperature exceeds 25˚C (158 hours per year in the Netherlands).

In the case of a flat roof surface of over 300 m^2 the additional cost is around 25 €/$m^2$for the economic roof and 30 €/m^2 for the light-weight roof (optigroen.nl). In addition, roof maintenance costs of 1.50-2.00 €/m^2 per year should be factored in, for:
– cleaning the rainwater drain (should be done with normal types of roofs, too);
– removing weeds;
– adding (specially coated) fertilizer.

The following aspects should be taken into account when assessing these costs:
– the green roof has the advantage that it protects the roofing material against UV radiation and temperature swings, extending the lifetime to double the life expectancy without roof vegetation;
– the water retention capacity[16] may be of interest both to meet eventual water retention requirements and because some city councils offer subsidies in support of green roofs;
– to prevent leaks, checking the rainwater drains should be done on a regular basis on roofs with or without vegetation.

6.3.3 Insulation

Insulation helps retain heat. Given the very considerable heat excess in data centres, the amount of heat that needs to be removed from the building will rise with the degree of insulation. At the same time, too little insulation brings the risk of condensation inside the centre. When the temperature difference between the inside walls and the ambient air temperature is large, only very dry air will not condensate.

[16] Water retention capacity is the delay in rainwater drainage after heavy showers. Roof gardeners express this capacity as the 'drainage coefficient', the ratio between the amount of rainwater drained within 15 minutes of an extreme shower (27 l/hour) and the amount of water retained within the green roof. This value is 0.5 for the economic roof and 0.65 for the light-weight roof. The latter cannot retain as much water, since the sediment layer is much less thick. The Dutch water authorities (W*aterschappen*) use different parameters, however, and a study is therefore currently underway to align these different ways of expressing water retention capacities.

In 1995 the minimum standard for roof insulation was set at Rc = 2.5 m^2K/W. In April 2012 this value was raised to 3.5 m^2K/W and it is expected to raise to 5 m^2K/W in 2015.

Roof insulation decreases the effect of direct heat-influx. For example, the heat-influx at a roof temperature of 70˚C is 11.5 W/m^2 at Rc = 3.5 m^2K/W and 8.55 W/m^2 at Rc = 5 m^2K/W. With a roof temperature of 40˚C the heat-influx becomes 3.3W/m^2 and 2.3 W/m^2, respectively.
This does not prevent a temperature increase of the air intake due to elevated roof temperature, however, and is therefore much less effective than the other two measures.

6.4 Other energy use: lighting, offices, etc.

Apart from the main elements of energy consumption discussed above, data centres will usually also consume minor quantities of energy for other purposes, more or less typical for offices. Among other things these will includes office lighting, heating and cooling as well as office equipment (computers, copiers, etc.). According to a study by ECN (2008), the total energy consumption of these sources can amount to 2% of total data centre energy consumption.
For these applications a broad range of energy-efficient techniques exist. These are listed in the NL Agency database 'Energiebesparing en Winst' http://www.infomil.nl/onderwerpen/duurzame/energie/energiebesparing (sector 'offices'). This database describes the main measures available, including technical feasibility and typical pay-back times. The database is intended for use by local governments in the context of environmental inspections and permitting procedures.
These techniques are not further described in the present report.

7 Conclusions

General conclusions

1. The results of this study show that in new-build data centres a high level of energy efficiency can be achieved, with EUEs lower than 1.2. Different combinations of techniques are available for achieving these efficiencies. A crucial factor in all variants is that a large amount of 'free cooling' is used. As energy use for cooling purposes falls to low levels, energy use for electricity supply becomes increasingly important. For this aspect a modular building design is a crucial factor.

2. These high levels of energy efficiency can be achieved by implementing the following measures:
   - data centre temperature levels according to the ASHRAE-recommended maximum value of 27˚C;
   - maximum use of 'free cooling', typically > 98%;
   - cooling air inlet on a cool location of the building (i.e. not on a dark roof);
   - segregated aisles within the building;
   - modular building of the data centre;
   - use of a UPS that allows for high energy efficiencies over a broad range.

Cooling variants for energy-efficient data centres

3. Based on literature research, five combinations of energy-efficient cooling techniques have been distinguished (Table 19). In general, these techniques are based on making maximum use of the cold available in the outside air, thereby avoiding the use of electricity for compression cooling. Apart from these options, other options might also be possible.

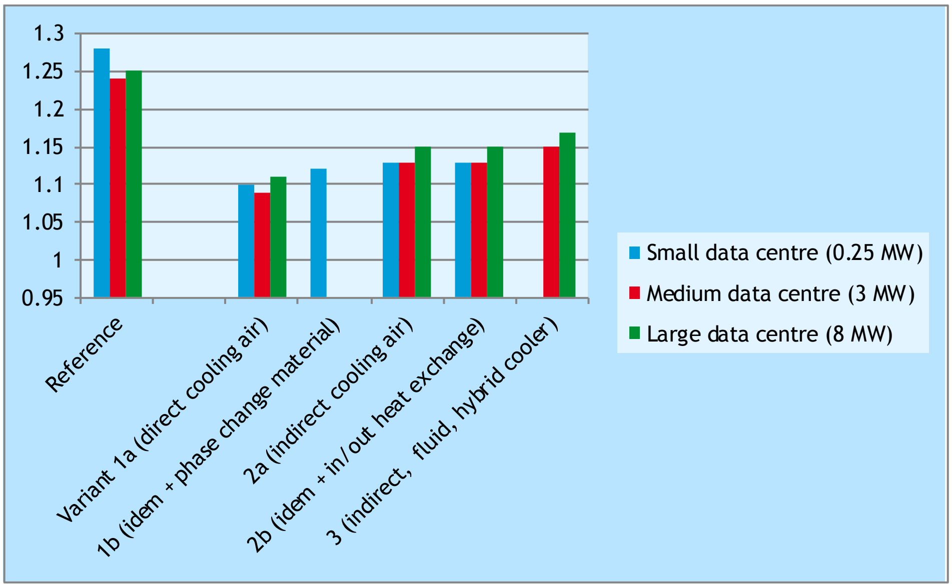
Table 19 Variants for energy-efficient new-build data centres

	General concept	Variant
1	Open cooling systems	1a Supported by adiabatic cooling
		1b Supported by phase change heat/cold storage
2	Closed cooling systems, air/air	2a Supported by adiabatic cooling
		2b Supported by compression cooling
3	Closed cooling systems, air/fluid	3 Supported by hybrid cooling

4. In addition to these routes, which improve the energy efficiency of the data centre itself, it is also possible to supply excess heat to external consumers. This can be realised by direct use of warm air, or via a heat/cold storage buffer.

5. With the various variants *high levels of energy efficiency* can be achieved, with EUEs in a range between 1.1 and 1.15, as shown in Figure 27. For all classes and with all variants EUEs remain well below 1.2. The results shown apply for ‘average’ data centre loading. In the case of ‘maximum’ loading the figures are comparable, with slightly higher EUEs. The differences between the variants are relatively small. In comparison, the energy efficiency of references are about 1.25.The references are based on recently built data centres, with 70, 90 and 95% free cooling for the small, medium and large data centre, respectively. The difference between the variants and the references means that the non-IT energy consumption in the variants is almost 50% lower than in the reference cases. The method used for calculating the EUE is comparable to the SMK standard and excludes the transformers.

Figure 27 Performance of energy-efficient variants for new-build data centres



6. The *pay-back times* of the variants (compared with the references) are shown in Table 20. In all cases Variant 2a is profitable. This is due to the relatively limited investments of this variant, which employs no compression cooling. The economic performance of Variant 3b can be similar to the reference, depending on the investments required for a specific situation. This is also the case for Variant 2b in a large data centre.

Table 20 **Pay-back times for energy-efficient cooling variants**

Average load	Data centre size class		
	Class I	Class II	Class III
Reference 1	-		
Reference 2		-	
Reference 3			-
Variant 1a	> 10	>= 5 *	> 10
Variant 1b	> 10		
Variant 2a	< 0	< 0	< 0
Variant 2b	> 10	> 10	>= 0 *
Variant 3		>= 0 *	>= 0 *

* Results for these variants vary under sensitivity analysis testing.

It should be noted that in the model analysis not all technological details are included. Examples are data centre raised floor, costs of electricity cabling and mains voltage transformers lower and costs for separated hot/cold alleys. By including these aspects in design choices actual additional installation costs may be limited.

Temperature and humidity regulation: ASHRAE-recommended values

7. Operating a data centre within a broad range of temperatures and humidity is a critical factor in achieving a high degree of free cooling. This applies to all the variants investigated. The standard for applicable temperatures and humidities was published in 2011 by ASHRAE (American Society of Heating, Refrigerating and Air Conditioning Engineers). According to this standard, temperatures should preferably lie between 18 and 27˚C, although the permissible range is even substantially larger. The recommended and permissible values are shown in Figure 28. Operating a data centre within the recommended limits considerably enlarges the scope for use of 'free cooling' and energy-efficient operation.

Figure 28 **ASHRAE-recommended and allowable envelope**

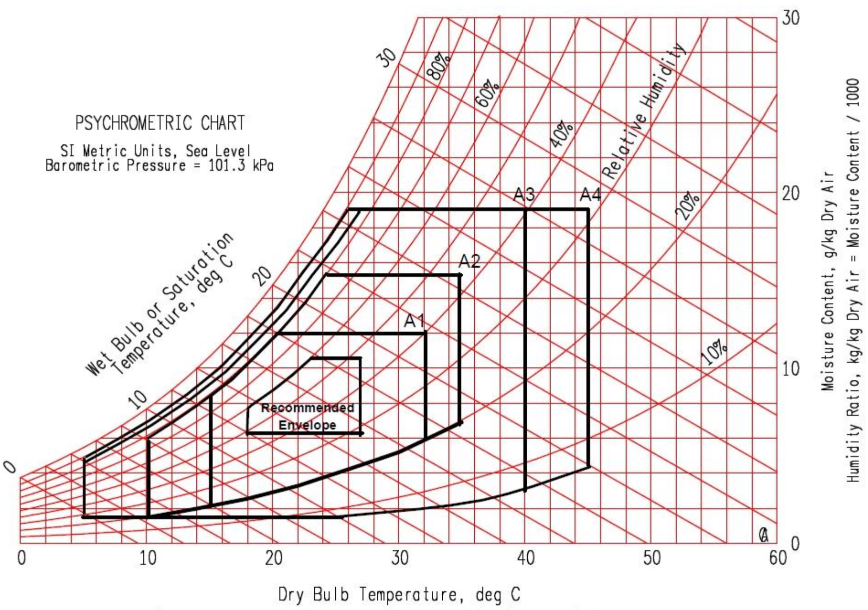


Figure 2. ASHRAE Environmental Classes for Data Centers

Variants without back-up compression cooling

8. Several variants studied (1a, 1b, 2b) rely on adiabatic assistive cooling for the hottest moments in the year and are not supported by compression cooling. The main risk involved in these variants is that the temperature and humidity will at some point in time be such that adiabatic cooling is insufficient for achieving cold alley setpoints. Suppliers of data centre designs that work compressor-less can supply tailor-made calculations indicating the temperature and humidity ranges within which their solutions are effective in data centre cooling. This, combined with a temperature-humidity diagram for the specific location of the data centre, will establish whether compressor-less operation is possible for all of the hours of the year.

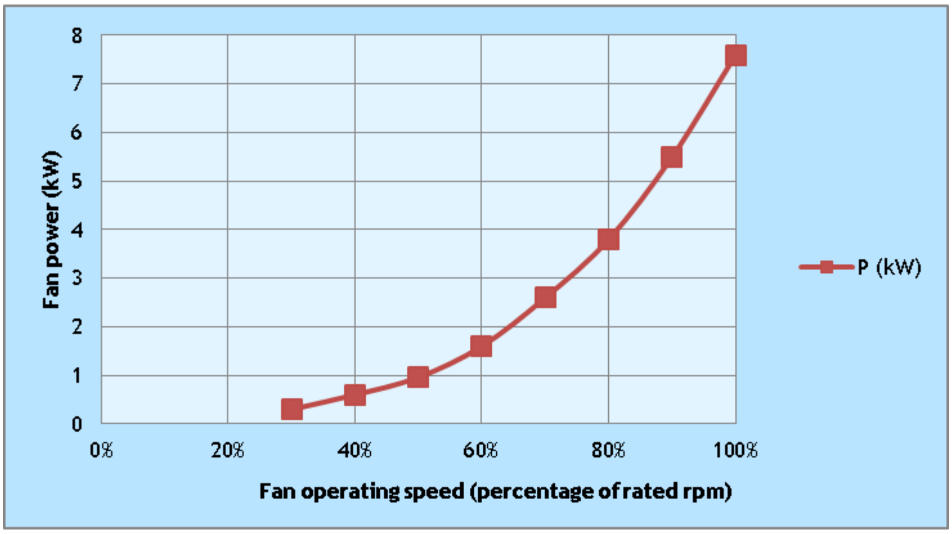
Variants with back-up compression cooling

9. The variants equipped with assistive/back-up compression cooling can also be operated in a very energy-efficient manner, though, if the number of hours of operation of the compression cooling system is kept very low. If the temperature at which the cold alleys are allowed to move to the higher part of the ASHRAE-recommended operating envelope of 27˚C, then the need for compression cooling can be kept low. A typical value is 100 hours per year for all Dutch locations.

Efficient air transport within data centre

10. In addition to a large degree of ‘free cooling’, efficient air transport within the data centre is another important factor in energy-efficient cooling. The two main factors are:
    - Full air separation between hot and cold aisles
      The cooling system of a data centre can operate more efficiently and longer with ‘free cooling’ when hot and cold air streams in the data centre remain fully separated.
    - Use of variable-speed fans
      Variable-speed fans are currently the standard in modern installations. With these fans, the lower the fan (air) speeds, the more efficient these fans become. This mechanism is illustrated in Figure 29, showing a typical relationship between fan power and speed.

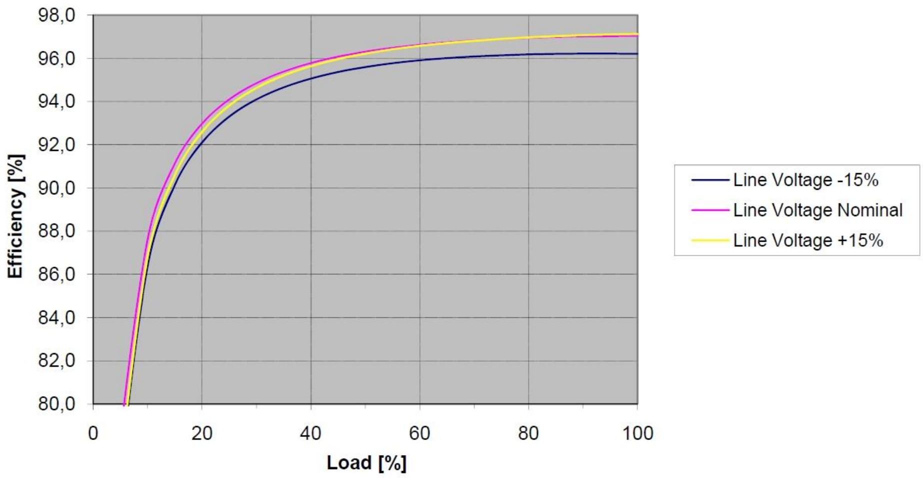
Figure 29 Relationship between CRAH fan speed and power usage



Electricity supply (UPS)

11. The efficiency of a UPS (uninterrupted power supply) improves substantially with higher unit loading, which can be increased by a higher overall loading degree. This effect is illustrated in Figure 30 for a static UPS.

Figure 30 Efficiency of UPS systems as a function of loading degree



12. However, the TIER classification imposes redundancy requirements for the electricity supply, with major consequences for the loading degree of UPS systems. The unit loading degree can be improved by attuning the number of operational units, by adopting a modular building practice. Such modular building is crucial for high-efficiency UPS systems. A rule of thumb is that utilization per individual UPS should be between 50 and 90%. As an indication for the modular building: for a 2 MW data centre for which the power supply must be N +1 redundant: modular build should be in increments of 250 kVA or less. If this is done, with a fill factor of 50% the load of the UPSs will already be 80%. A precondition to the modular design of the power supply is protect circuits. The data provided by the installed 'short circuit' current must be large enough to allow switching existing securities.

13. A static UPS typically offers 'eco-mode operation'. In this mode, the double conversion is bypassed, giving very high efficiency (of about 99.5%). However, this mode appears to have important practical limitations, because in this mode the inverter is switched off and will only be active when the normal power supply from the grid fails. This ensures that the ICT equipment has no power for at least one cycle. This mode is not therefore advised by suppliers and operators of data centres.

Humidification

14. The energy required for humidification (and related energy use) can be reduced substantially by operating within sufficiently broad ranges of temperatures and humidity, as recommended by ASHRAE. If data centres are operated within these ranges, energy use for humidification remains limited. In that case, replacing steam generators by more energy-efficient mechanical humidification units adds little additional effect on overall energy efficiency.

Limiting heat-influx from outside

15. To secure a maximum amount of free cooling, the cooling air inlet should be located at a cool location on the data centre building. As an example, on a sunny summer day the temperature of a black roof can exceed 55˚C, which means the air at the roof air inlet will become too hot for use for free cooling (even with evaporation assist). Options for maintaining low temperatures on roofs of data centres include:
    - Painting the roof with a reflective paint. This results in a lower temperature at the air inlet. At one data centre a temperature decrease of 8˚C was reported.
    - 'Green roofs'. A vegetated roof guarantees a year-round roof temperature below 30˚C, substantially increasing the scope for 100% free air cooling.

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Annex A Steering group and consultancy group

A.1 Participants of the steering group

Cynthia Bosman, Ministerie van Economische Zaken
Bouke Bussemaker, Ministerie van Economische Zaken
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Rice van Gompel, Interxion
Gerwalt Harmsen, UPC
Frank Hartkamp, Agentschap NL
Kees de Klein, Atos
Kees Loer, TCN
Joost Nuse, CapGemini
Fons Pennartz, KWA Bedrijfsadviseurs
Ronald van Veen, KPN
Bert Zijderhand, Verizon Terremark

Annex B Questionnaire for suppliers of energy-efficient techniques

Vragenlijst Leveranciers energie-efficiënte technieken datacenters

Koelinstallaties
Gesproken met: ……………………… Bedrijf:………………… Datum:…………………………

Omschrijving systeem: werkingsprincipe/categorie

Onderwerp		Antwoord
Omschrijving systeem: werkingsprincipe/categorie		
Typerende Investeringskosten per benodigd koelvermogen		
-	Wat zijn de investeringskosten in euro/MW koelcapaciteit bij een koelinstallatie Let op: duidelijk vragen naar welke MW stroom: afgevoerde warmte bijvoorbeeld	-
-	Is deze onafhankelijk van koelvermogen of zijn er bepaalde klassen te onderscheiden	-
Typerend energiegebruik per koelvermogen		
-	bijv. kWh/MW koelcapaciteit/jaar bij een koelinstallatie?	-
-	Hoe hangt dit af van de belastingen: bij 50%, 70% van de belasting?	-
-	Hoe hangt dit af van de omvang van het geïnstalleerde koel-vermogen? Zijn daar klassen in te onderscheiden?	-
Levensduur		
-	Wat is de typische levensduur? (afwijking van NEN norm 2767)	
Modulair bouwen, cascaderegeling		
-	Hoe kun je modulair bouwen met deze techniek?	-
-	Is de techniek geschikt voor een cascaderegeling, zo ja, hoe dan, wat zijn de gevolgen voor de efficiëntie?	-
Wat zijn andere operationele kosten:		
-	Watergebruik	-
-	Arbeid voor onderhoud en bediening	-
-	Overige operationele zaken: bijv. blusgas, legionellabestrijding, wieren/algen, etc.	-
Randvoorwaarden:		
-	Wat zijn de voorwaarden om de techniek toe te passen?	-
-	Wanneer kan het niet?	-
Neveneffecten: wat zijn gevolgen van toepassen voor andere aspecten datacenterontwerp?		
-	Hoeveel dagen per jaar is de koelmethode niet voldoende	-
-	Hoe gericht kun je koude brengen naar bepaalde plaatsen in DC, bijv. als er podkoeling nodig is	-
-	Welke technieken zijn onverenigbaar met deze koelmethode? Of verlagen de performance?	-
-	Welke technieken verbeteren de totale prestaties van het DC in combinatie met deze koeltechniek?	-
-	Overige?	-
Hoeveel installaties van dit type al operationeel?		
Welke datacenters kunnen we hierover benaderen?		

Stroomvoorziening

Gesproken met: ………………………. Bedrijf:………………… Datum:…………………………

Omschrijving systeem werkingsprincipe/categorie

Typerende Investeringskosten per benodigd IT uitgangsvermogen

- Bijv. Euro/MWe uitgangsvermogen.
- Is deze onafhankelijk van uitgangsvermogen of zijn er bepaalde klassen te onderscheiden?

Typerende omzettingsefficiëntie?

- Als percentage bijv. 97%
- Hoe hangt dit af van de belastingen: bij 25, 50, 75 en 100% van de belasting?
- Hoe hangt dit af van de omvang van het geïnstalleerde UPS-vermogen? Zijn daar klassen in te onderscheiden?

Modulair bouwen, cascaderegeling

- Hoe kun je modulair bouwen met deze techniek?
- Is de techniek geschikt voor een cascaderegeling, zo ja, hoe dan, wat zijn de gevolgen voor de efficiëntie?

Wat zijn andere operationele kosten:

- Arbeid voor onderhoud en bediening
- Overige operationele zaken: bijv. blusgas, vervangen batterijen, smeerolie, etc.

Randvoorwaarden:

- Wat zijn de voorwaarden om de techniek toe te passen?
- Wanneer kan het niet?

Neveneffecten : Wat zijn gevolgen van toepassen voor andere aspecten datacenterontwerp?

- Hoe gericht kun je apparatuur aansluiten? In de zin van sommige apparaten op het UPS en andere niet.
- Kun je ook sommige apparaten een grotere redundantie geven?
- Welke technieken zijn onverenigbaar met deze stroomvoorziening? Of verlagen de performance?
- Welke technieken verbeteren de totale prestaties van het DC in combinatie met deze stroomvoorziening?
- Overige?

Hoeveel installaties van dit type al operationeel?

Welke datacenters kunnen we hierover benaderen?

Annex C Questionnaire validation of investments and energy efficiency

Vragenlijst energie-efficiënte technieken in datacenters

Techniek-combinatie:
Deze vragenlijst is opgesteld in het kader van het project ‘energie-efficiënte technieken voor nieuwe datacenters’ van Agentschap NL, in samenwerking met onder andere Nederland ICT. Dit project wordt uitgevoerd door Mansystems en CE Delft, en brengt energie-efficiënte technieken voor nieuw te bouwen datacenters in kaart.
Eén van de techniekcombinaties die in dit project in kaart is gebracht is [……].
Hiervoor hebben wij gegevens verzameld ten aanzien van investeringen en energiegebruik. Met deze vragenlijst vragen wij u om aan te geven in hoeverre deze ramingen overeenstemmen met de ervaringen van uw bedrijf.
Respons zal in geanonimiseerde vorm, dus zonder vermelding van bedrijfs-naam, worden verwerkt.

Datum:	…………		
Bedrijf:	…………	Contactpersoon:	…………
Telefoon:	…………	E-mail:	…………

Wilt u de ingevulde vragenlijst terugsturen aan: …………

In het onderzoek brengen we investeringen en energiegebruik in kaart van het koelsysteem en de stroomverzorging van drie typerende grootteklassen datacenters. De parameters zijn:

Klasse	Maximaal opgesteld vermogen[17] in kW	Vloer-oppervlak IT (m^2)	TIER-klasse	UPS	Koeling
‘Klein’	250	300	1	Statisch, 200 kVA UPSen N+1, N=2	N.v.t.
‘Middel’	3.000	2.000	2	Statisch, 400 kVA UPS, N+1, N=4	Totaalkoelconcept voorzien van indirecte koeling. Het systeem is minimaal N+1 redundant uitgevoerd qua dimensionering (aantallen luchtbehandelings-kasten; ventilatoren pompen en regelingen) en voorzien van back-up compressie cooling.
‘Groot’	8.000	4.000	3	Rotary, 1.600 kVA N+2, N=8 (2N equiv.)	Idem

[17] Nominale output UPS-systeem.

Vraag 1: Raming investeringskosten
Van de totale investeringskosten van het datacenter hebben we de volgende zaken in de studie meegenomen:
- stroomvoorziening: UPS-systeem; echter NIET de dieselgeneratoren;
- koelconcept omvat:
  - luchtbehandeling, luchttransport;
  - ventilatoren, motoren, pompen toerentalgereguleerd;
  - compressiekoelsysteem als hulp/back-up koeling.

In hoeverre stemmen deze ramingen overeen met uw ervaringen?

Klasse	Raming investering (M€ 2013)	Te laag	Klopt ongeveer	Te hoog	Mate van overeenstemming (% te hoog of te laag)
'Klein'	......				
'Middel'	......				
'Groot'	......				

Opmerking: …………………………………………………….

Vraag 2: Energie-efficiency (EUE)
De EUE (Energy Use Efficiency) is berekend op basis van een datacenter dat werkt binnen de grenzen van de ASHREA-recommended envelope (temperatuur koude gang kan oplopen tot maximaal 27˚C) en maximaal vrije koeling toepast, waardoor de draaiuren van compressiekoeling beperkt zijn.

De ΔT over de ICT-equipment bedraagt 12˚C. De EUE betreft hierbij de verhouding tussen het totale energiegebruik, en het gebruik voor de ICT-toepassing.

Van het energiegebruik van de stroomvoorziening en luchtbehandeling is het volgende meegenomen:
- elektrische verwarming dieselgeneratoren;
- energieverbruik (verliezen) van UPSen bij gegeven redundantie en belastingsgraden;
- energiegebruik van luchttransport (fans) bij gegeven redundantie en belastingsgraden, bij Nederlandse 20-jaars klimaatgemiddelden voor temperatuur en vochtigheid (de Bilt/Amsterdam);
- waarden gaan uit van een vullingsgraad van 70% (klasse 'klein' en 'middel') resp. 50% (klasse 'groot'), gedefinieerd op het ICT-uitgangsvermogen van de UPS.

In hoeverre stemmen deze ramingen overeen met uw ervaringen?

Klasse	EUE bij gegeven vullingsgraad	Te laag	Klopt ongeveer	Te hoog	Mate van overeenstemming (% te hoog of te laag)
'Klein'	......				
'Middel'	......				
'Groot'	......				

Opmerking: …………………………………………………….

Binnen welke temperatuurgrenzen opereert uw datacenter? …˚C - …˚C.

Annex D Key results for Dutch guideline for local governments (in Dutch)

Er zijn veel alternatieven voorhanden om zeer energie-efficiënte datacenters te bouwen. Dat is de hoofdconclusie van dit rapport, dat verschillende combinaties van technieken onderzoekt om energie-efficiëntie in datacenters te verbeteren.
Datacenters hebben een substantieel energiegebruik: nu ongeveer op 1,6 TWhe ofwel 1,5% van het Nederlandse nationale elektriciteitsverbruik. Binnen de datacenters wordt een groot deel van het energiegebruik gebruikt door de ICT-applicaties. Typerend ligt dit op ca. 70%. Daarnaast zijn koeling en de ononderbroken stroomvoorziening aanzienlijke gebruikers van elektriciteit, in de orde van resp. 23 en 7%. Energiegebruik voor andere toepassingen (zoals voor verlichting en kantoorinrichting) is beperkt (ordegrootte 1%).
Er bestaan diverse energie-efficiënte technieken waarmee het energiegebruik van koeling en stroomvoorziening kan worden gereduceerd. Dit onderzoek geeft een overzicht van die technieken. Het is daarbij gericht op nieuwbouw van datacenters.

Onderzoek
Het onderzoek is uitgevoerd door een combinatie van een uitgebreide literatuurstudie, interviews met leveranciers van energie-efficiënte technieken en een model-analyses. Resultaten zijn daarna gevalideerd bij leveranciers en gebruikers van datacenters.
Het onderzoek richt zich op drie typerende grootteklassen datacenters: klein (0,25 MW), medium (3 MW) en groot (8 MW). Voor deze typen zijn varianten uitgewerkt, dit zijn combinaties van energie-efficiënte technieken voor koeling en stroomvoorziening. Voor de varianten hebben leveranciers specifieke gegevens over investeringskosten en energieprestaties gegeven, welke de basis vormen voor de modelberekeningen. Op deze basis zijn typerende waarden voor investeringskosten, energieprestaties en terug-verdientijden bepaald.
Modelresultaten zijn bij verschillende benuttingsgraden van het datacenter berekend en aan gebruikers uit de praktijk voorgelegd ter validatie. Informatie uit de validatie is gebruikt om de modelberekeningen aan te passen.

Combinaties van energiezuinige koeltechnieken
Het onderzoek leert dat er verschillende varianten mogelijk zijn om energie-zuinige koeling in datacenters te realiseren. Deze varianten bestaan uit combinaties van technieken, zoals luchtfilters, ventilatoren, droge koelers, natte koelers, hybride droge koelers, warmtewisselaars en koelmachines. Van een achttal opgestelde koelvarianten zijn vijf varianten verder kwantitatief onderzocht.

Voor al de varianten geldt dat ze in één of meer recent gebouwde datacenters in Nederland worden toegepast:

1a: Open koelsystemen ondersteund door adiabatische koeling.

1b: Open koelsystemen ondersteund door adiabatische koeling, én een faseovergang koudeopslagmiddel.

2a: Gesloten koelsystemen met lucht-lucht warmtewisselaars, ondersteund door adiabatische koeling.

2b: Gesloten koelsystemen met lucht-lucht warmtewisselaars, ondersteund door compressiekoeling.

3: Gesloten koelsystemen via vloeistof warmteafvoer met hybride droge koelers, ondersteund met compressiekoeling.

Deze varianten hebben de volgende gemeenschappelijke kenmerken:

- Temperatuur en vochtigheid binnen het datacenter zijn voldoende ruim, de volledige ruimte binnen de door ASHRAE aangeraden grenzen mag worden gebruikt. Dit betekent dat de temperatuur aan de ingang van de ICT zo nodig mag oplopen tot 27˚C.
- Maximaal gebruik van vrije koeling ('natuurlijke' bronnen van koude).
- Volledige scheiding van warme en koude luchtstromen.
- Toerentalgeregelde ventilatoren met luchtdrukregeling over de ICT.
- Zo laag mogelijke luchtsnelheden.

Modelberekeningen

Met een model zijn voor de vijf varianten investeringskosten en jaarlijks energiegebruik berekend. Er is hierbij een onderscheid gemaakt naar drie grootteklasses van datacenters, een klein datacenter (0,25 MW), een middelgroot (3 MW) en een groot datacenter (8 MW). De berekeningen zijn uitgevoerd voor twee situaties van belading van het datacenter: 'gemiddelde' en 'maximale' belading. De beladingsgraad is een graadmeter voor het % van het opgestelde vermogen voor stroomvoorziening en koeling dat daadwerkelijk wordt benut.

Voor de drie grootteklasses zijn ook referenties opgesteld. Deze referenties zijn gebaseerd op recent gebouwde state-of-the-art datacenters, met een meer conventioneel koelsysteem.

Op basis van verschillen in kosten tussen varianten en referenties, is berekend welke terugverdientijd de varianten hebben ten opzichte van de referentie.

Voor de terugverdientijden is een gevoeligheidsanalyse uitgevoerd. In deze analyse is op basis van de onzekerheden in investeringsramingen berekend in hoeverre resultaten veranderen als investeringen variëren.

Energiegebruik

Uit de modelberekeningen volgt dat met de verschillende varianten een hoge graad van energie-efficiency is te realiseren.

Een graadmeter hiervoor is de EUE, dit is de verhouding tussen het totale energiegebruik in een datacenter en het energiegebruik voor de ICT-systemen zelf[18]. Voor alle grootteklassen zijn EUE's haalbaar ruim beneden 1,2.

Dit betekent dat het totale energiegebruik voor koeling en stroomvoorziening lager ligt dan 20% van het totale energiegebruik voor de ICT-toepassingen zelf.

De berekende EUE's zijn weergegeven in Figuur 1. De verschillen tussen de varianten zijn relatief klein.

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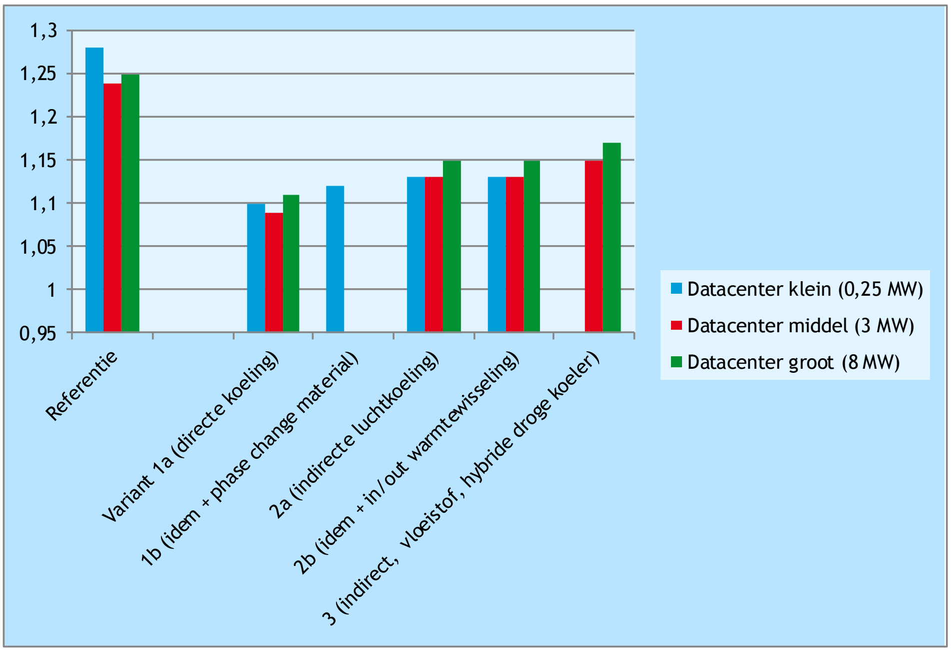
[18] In het onderzoek is in de EUE niet het energiegebruik voor 'overige toepassingen (verlichting, kantoortoepassingen, etc.) meegenomen. Deze hebben doorgaans een beperkt energiegebruik, en het effect op de EUE is verwaarloosbaar.

De gebruikte methode voor het berekenen van de EUE is vergelijkbaar met de SMK (Stichting Milieukeur) standaard en omvat niet het energiegebruik van transformatoren.

Figuur 1 **Prestatie van energie-efficiënte varianten voor nieuwbouw datacenter, ten opzichte van de referentie**



Figuur 1 toont ook de EUE's voor de referenties. De referenties hebben een gesloten koelsysteem met warmtetransport middels een vloeistofsysteem en droge koelers, een hoge graad van vrije koeling en worden ondersteund door compressiekoeling. De referenties zijn in verhouding tot het gemiddelde bestaande datacenter ook zeer efficiënt: voor de referenties ligt de berekende EUE in de range tussen 1,2 en 1,3.

Terugverdientijden

Van een terugverdientijd is sprake als een investering in efficiëntie door de bereikte besparing aan energiekosten terugverdiend kan worden. De terugverdientijd is een belangrijk criterium in het Activiteitenbesluit, omdat volgens dit besluit bedrijven energiebesparende maatregelen die zich binnen vijf jaar terugverdienen moeten treffen.
In de modelanalyse zijn de terugverdientijden van de varianten berekend door de investeringen en jaarlijkse energiekosten van de varianten te vergelijken met die van de referenties.
De resultaten van deze berekening zijn weergegeven in Tabel 1. De weergegeven resultaten hebben betrekking op de situatie van gemiddelde belasting, resultaten bij maximum belasting zijn vergelijkbaar.

Tabel 1 **Berekende terugverdientijden (in jaren) (scenario gemiddelde belading)**

	Grootteklasse datacenter		
	Klasse I	Klasse II	Klasse III
Referentie 1	-		
Referentie 2		-	
Referentie 3			-
Variant 1a	> 10	>= 5 *	> 10
Variant 1b	> 10		
Variant 2a	< 0	< 0	< 0
Variant 2b	> 10	> 10	>= 0 *
Variant 3		>= 0 *	>= 0 *

* Resultaten voor deze varianten verschillen bij gevoeligheidsanalysetests.

** Deze varianten kunnen < 10 scoren bij gevoeligheidsanalysetests.

In veel gevallen zijn de terugverdientijden hoog. Dit komt doordat de omvang van investeringen vaak een ordegrootte groter is dan de jaarlijkse besparingen op energiekosten door toepassing van een energiezuiniger variant. Dit is in Tabel 1 weergegeven met > 10 jaar. Hierbij speelt ook dat de referenties al een hoge energie-efficiëntie kennen.
Bij de variant ‘indirecte lucht/lucht koeling met adiabatische ondersteuning (Variant 2a)’ zijn de investeringskosten beperkter dan in de referenties.
Dit leidt tot een terugverdientijd van 0 jaar: in vergelijking tot de referentie is de variant vanaf het begin rendabel. Dit komt doordat voor deze variant zowel de investeringskosten als de kosten voor energiegebruik lager zijn dan bij de referentie. De lage investeringskosten hangen er mee samen dat in deze variant geen compressiekoeling wordt toegepast, waardoor kosten voor compressiekoeling ontbreken.
Uit de modelberekeningen blijkt dat onder bepaalde condities soms ook andere varianten redelijk geringe terugverdientijden hebben. Dit kan echter van geval tot geval verschillen, en hangt af van de kosten en investeringen die in een investeringsbeslissing worden meegenomen, en daarnaast van niet gekwantificeerde overige operationele verschillen in kosten.

In dit verband is ook van belang dat in de modelanalyse niet alle technische details zijn opgenomen. Voorbeelden zijn datacenter verhoogde vloer, bekabeling en transformatoren en gescheiden warme/koude gangen.
Door deze aspecten in ontwerpkeuzes mee te nemen worden extra installatiekosten beperkt.

Koeling

De resultaten tonen aan dat met energie-efficiënte koelmethoden een hoge graad van energie-efficiëntie kan worden bereikt. Hiervoor zijn verschillende combinaties van technieken beschikbaar.
Cruciaal in alle varianten is dat een grote hoeveelheid ‘vrije koeling’ wordt toegepast.
Verschillende varianten zijn gebaseerd op adiabatische ondersteunende koeling, en worden niet ondersteund door compressie koeling.
Voor compressieloze systemen kan worden berekend binnen welke temperatuur en vochtigheid de systemen effectief zijn. Samen met een locatie-specifiek temperatuurvochtigheid diagram kan dan worden vastgesteld of dit voldoende koeling levert voor alle uren in het jaar. Ook varianten met back-up compressiekoeling kunnen een hoge graad van energie-efficiëntie leveren, mits het aantal bedrijfsuren van de compressie koelsysteem zeer laag wordt gehouden.

Met voldoende ruime temperatuurranges, conform de aanbevelingen van ASHRAE, geldt dat voor alle Nederlandse locaties minder dan 100 uur per jaar compressiekoeling nodig is.

Stroomvoorziening (UPS)

Met het verlagen van het energiegebruik van de koeling worden de conversieverliezen van de stroomvoorziening relatief belangrijker. Voor de omzettingsefficiëntie van de UPS (*Uninterruptable Power Supply*) is de beladingsgraad een belangrijke factor. De energieprestaties van een UPS dalen namelijk sterk bij een lage beladingsgraad. Een vuistregel is dat een individueel UPS minstens voor 50% moet worden benut om een redelijke efficiëntie te bereiken. Om een hoge beladingsgraad te realiseren is het zaak dat het UPS-systeem modulair wordt gebouwd, dan kunnen de eenheden bijgeplaatst worden als de toename van het aantal ICT-systemen daar om vraagt.

Mogelijke maatregelen

Voor het realiseren van een hoge graad van energie-efficiency in een datacenter zijn de volgende maatregelen van belang:

Algemeen

- Het realiseren van een lage EUE voor nieuwbouw datacenters.
  Met alle onderzochte energie-efficiënte koelvarianten en de efficiënte UPS-systemen kan een EUE van minder dan 1,2 worden gehaald.

Verbeterde bedrijfsvoering

- Het aanhouden van voldoende ruime grenzen voor temperatuur en vochtigheid.
  De ASHREA (American Society of Heating, Refrigerating and Air-Conditioning Engineers) geeft standaarden die grenzen omvat onder meer t.a.v. de toelaatbare temperatuur en luchtvochtigheid voor in bedrijf zijnde klasse A1 elektronische apparatuur, waaronder de typische datacenter ICT vaak valt. De temperatuur wordt gemeten bij de luchtingang van de apparaten. Als het datacenter zich houdt aan de maximum aangeraden grenzen volgens ASHRAE, dan moet de temperatuur binnen de koude gangen tussen de 18-27˚C blijven. Dit is nog ruim binnen de maximum toelaatbare bedrijfstemperaturen voor klasse A1 elektronische apparatuur.
  De compressieloze en adiabatisch ondersteunde varianten werken het beste als het hele regelbereik van de ASHRAE aanbeveling wordt benut. Dit betekent dat tijdens warme en vochtige buiten condities de bovengrens van het aanbevolen bereik worden aangehouden, maar ook dat tijdens periodes met lage buitentemperatuur de setpoints meer naar de ondergrens worden gebracht. Bij deze wisselingen dient niet de maximale verandersnelheid die door ASHRAE wordt vermeld te worden overschreden.
- Continue monitoring van energiegebruik per systeem en functie.
  Door op continue basis het energiegebruik per systeem of toepassing (ICT-apparatuur klanten, koeling, bevochtiging, stroomvoorziening, overige energiegebruikers, ..) te meten ontstaat niet alleen inzicht in bijvoorbeeld de EUE, maar door gedetailleerde gegevens vast te leggen, maar ontstaat ook een basis om de prestaties te verbeteren. Gegevens kunnen al dan niet geanonimiseerd onderling tussen datacenteraanbieders uitgewisseld worden om van elkaar te leren.
  Bij de nieuwbouw van een datacenter kunnen de monitoringsystemen aangeschaft en ingeregeld worden.

Koeling en afvoer van warme lucht

- Het realiseren van een hoog aandeel ‘vrije koeling’.
  Uit het onderzoek volgt dat het met de Nederlandse klimaat-omstandigheden mogelijk is om in tenminste 98% van de tijd gebruik te maken van vrije koeling. Compressiekoeling is hooguit 100 uur per jaar nodig. Dit geldt voor alle locaties in Nederland.
- Het gebruik maken van een techniek-combinatie die het mogelijk maakt om een hoog aandeel vrije koeling te gebruiken.
- Volledig gescheiden ‘koude’ en ‘warme’ gangen.
  Het koelsysteem van een datacenter werkt efficiënter als voorkomen wordt dat warme en koude luchtstromen mengen. Daarom dienen warme en koude luchtstromen in het datacenter volledig gescheiden zijn, en niet gebruikte openingen in racks voorzien van blindplaten.
- Toepassing van toerentalgeregelde ventilatoren en pompen.
  Toerentalgeregelde ventilatoren zijn op dit moment leverbaar door alle leveranciers en in de efficiënte koelvarianten worden deze standaard gebruikt. Voor luchttransport geldt dat naarmate de koelbehoefte afneemt, dat het elektrisch vermogen dat door de ventilatoren opgenomen wordt met de tweede macht kan afnemen als gebruik gemaakt wordt van toerentalregeling. Dit komt omdat naarmate de luchtsnelheid lager is, ventilatoren efficiënter werken. Voor vloeistofpompen volgt het energie-gebruik meer lineair met de belasting.
- Toevoer van koellucht op een koele locatie van het gebouw.
  Externe warmtewisselaars en toevoersystemen van koellucht dienen bij voorkeur gelokaliseerd te zijn op een koele locatie. Dit maakt het mogelijk om langer in het jaar gebruik te maken van vrije koeling. Opties zijn om de luchttoevoer te plaatsen op een schaduwlocatie. Als de koeling op het dak is gelokaliseerd verdient het aanbeveling dat dit een reflecterende kleur heeft. Een vegetatiedak is een andere optie. Een ongunstige keuze (bijvoorbeeld een dakkoeler die op een zwart dak is geplaatst) kan betekenen dat het aantal uren dat de vrije koeling faalt significant hoger is (bijvoorbeeld verdubbelt).

Electriciteitsvoorziening (UPS)

- Modulaire bouw van het UPS-systeem (afzonderlijke UPS-eenheid per ICT-eenheid van het datacenter).
  De efficiëntie van een UPS verbetert sterk als de belastinggraad hoger is. Door de hoeveelheid geïnstalleerde UPS systemen precies af te stemmen op de stroomvraag en de redundantievereisten, kan de beladingsgraad per UPS-eenheid geoptimaliseerd worden. Een vuistregel is dat als men altijd voor benutting tussen de 50 en 90% per individuele UPS moet zitten.
  Als indicatie: bij een 2 MW datacenter, waarbij de stroomvoorziening N+1 redundant moet zijn, dan dient men bijvoorbeeld modulair te bouwen in stapgrootten van 250 kVA of kleiner. Doet men dit, dan kan men bij een vullingsgraad van 50% ervoor zorgen dat de belasting van de UPSen toch al 80% is. Een randvoorwaarde in de modulaire opbouw van de stroom-voorziening is beveiliging van de circuits. De door de geïnstalleerde apparatuur te leveren ‘kortsluit stroom’ moet groot genoeg zijn om de aanwezige beveiligingen te laten afschakelen.
- Keuze voor een type UPS dat bij een breed scala van mogelijke belasting-graden een hoog rendement heeft.