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02

WHITE PAPER

New dimensions in Data Centre design

Professionalising the Data Centre by striving for Operational Excellence

By Patrick Timmer

I: Summary:

The increasing demand and dependency on data and IT is gradually changing the world we live in. As with many fields of industry Data Centres have reached the state where it's crucial to further professionalise and take responsibility for its impact. This can be achieved by further creating a common language by which Data Centre experts communicate. The PUE has done a lot of good already but is just a start. The next important definition that will help Data Centres further professionalise is Operational Excellence. In the Data Centre context Operational Excellence strives for optimising the total cost and quality model of delivering IT-services. The initial design is considered of crucial importance for Data Centre owners to meet business goals and remain competitive throughout the whole lifetime. A poorly chosen initial design creates a difficult lifetime with many unnecessary challenges. A bad start is no start. Data Centre designers therefore play an important role.

During the design, acknowledging the presence of several stakeholders can help understand the several perspectives and therefore the underlying drivers. Since the reality is unruly when it comes to creating solutions for Data Centres, it is believed that no matter the type of Data Centre involved, commercial or corporate, large or small, an optimal and reliable solution can be found as long as some guiding principles are kept in mind. The 'New Dimensions' complement existing design tools:

1. The volumetric dimension: Instead of thinking in m^2 a DC designer should think in m^3.

2. Reducing complexity of the design will pay-off from an energy consumption and manageability point of view.

3. Integration[3]: Three levels of integration must be accomplished as part of creating an Operational Excellent design.

    - Physical Integration
    - Control Integration
    - Knowledge Integration

These three main guidelines result in a Data Centre which is able to deliver IT-services which are qualitative and market competitive. The 'Volumetric' dimension can further help Data Centre owners understand the metrics and choices that are involved in creating a successful DC. Hopefully it will inspire Data Centre designers to document their solutions complementing to a widespread overview of available solutions for each type of Data Centre.

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Chapter 1: Introduction

Today's Data Centres face many challenges. The continuously growing need for IT-services world wide creates opportunities but at the same time increases the level of complexity in many fields related to Data Centre design. This calls for a more professional and dedicated approach towards Data Centre design and the solutions that will be implemented.

Due to the large market potential many solutions arise for each aspect of Data Centre design: Cooling, Power, Management and Infrastructure, resulting in a large range of solutions. This creates another issue: When to select what kind of products in what type of situation suitable for what type of Data Centre, commercial, corporate, small or large? This paper provides important tools/guidelines which can help anyone involved in the design of a Data Centre, whether it concerns an upgrade or a Green field situation, to improve its decision making and reach an optimal performing Data Centre. Following fundamental principles, especially during the design, will create a solution that pays-off during the whole lifetime of a Data Centre. In terms of energy efficiency and the way it complies to its function and/or business goals. An optimal performing Data Centre will create a stronger position in the market or within the company. How can this be achieved?

In a business that is professionalising not only the products and solutions dedicated to a Data Centre are important. More-over creating a common language and tools which will help us evaluate and reflect upon designs and solutions is important as well. One striking example of the creation of this common language is the PUE value. Although there is some debate on how to use it exactly it nevertheless has shown to have an enormous impact on the DC thinking in general. It has created a drive and set goals for development. This paper provides additional design tools to support the professionalising Data Centre Industry.

Chapter 2: Vision: Operational Excellence

Predicting the future can sometimes feel like looking into a crystal ball. Anyone involved in upgrading or designing a new Data Centre is faced with questions related to what type of technologies to incorporate in order to make the Data Centre future proof meeting functional, sustainable, technical and financial requirements and certainly last but not least, how to create an environment in which the Data Centre employees can work optimally?

In today's world where information is shared easily new determining factors for future developments are all around, one only needs to be aware of them and have the right mind set to detect them. Minkels believes that the Data Centre Industry will have to professionalise even more. Due to its growing importance to society, it's impact to a sustainable society should result, eventually, in Optimally Performing Data Centres no matter the size and type of Data Centre, corporate or commercial. Just like other types of Industry have evolved to a mature state, the Data Centre industry will have to do so as well. Think for example of the Energy Industry. IT just like energy is becoming a basic need to society and therefore will have to evolve in a similar way. The question however is, how can this process of professionalisation be achieved and supported?

Key aspects in enabling the Data Centre Industry to become more professional are:

1. Creating metrics and a common language through which experts can measure improvements and exchange thoughts.

2. Applying a professional process towards designing, engineering and building a Data Centre.

3. Having a supply industry that is able to create industry specific innovative solutions and is technologically ahead of the industry to which it supplies.

2.1 Operational Excellence:

Next to PUE, which is an energy efficiency metric, it is believed that other, more business related definitions, need to be added. One definition considered of great importance, when bringing Data Centre development to the next level, is 'Operational Excellence'.

Operational Excellence is a definition that enables one to focus on achieving ones business goals in an integrated approach. Not just only focus on one aspect, like the PUE, but take into account the complete operation required to successfully do business or fulfil a function. Whether the Data Centre is small or large, commercial or corporate, Operational Excellence helps to professionalise because it challenges to analyze the Data Centre activities in a process like way.

Operational Excellence from the point of view of Data Centres Operators means:

1. Optimise the quality of Data Centre products and services towards (internal) IT-customers, know their demands.

2. Optimise processes and effectively use resources to decrease the total cost or impact of an operation.

3. Create a flexible business process which can adapt to varying market demands.

The supply industry needs to come up with solutions which support the Data Centre operator in achieving Operational Excellence. The table below compares the different requirements between the perspectives.

Data Centre Operator perspective	Data Centre Supply Industry perspective
Delivery of a quality IT-product at a reasonable price	Provide energy efficient solutions that are also reliable
A business strategy that fits (changing) market opportunities	Incorporate the right level of modularity and flexibility into the solutions provided.
A continuous process of innovation to stay competitive and maintain quality.	Provide intelligent solutions which give the DC manager sufficient control over his processes
Improve process and risk controls	Create a transparent design to keep good overall control

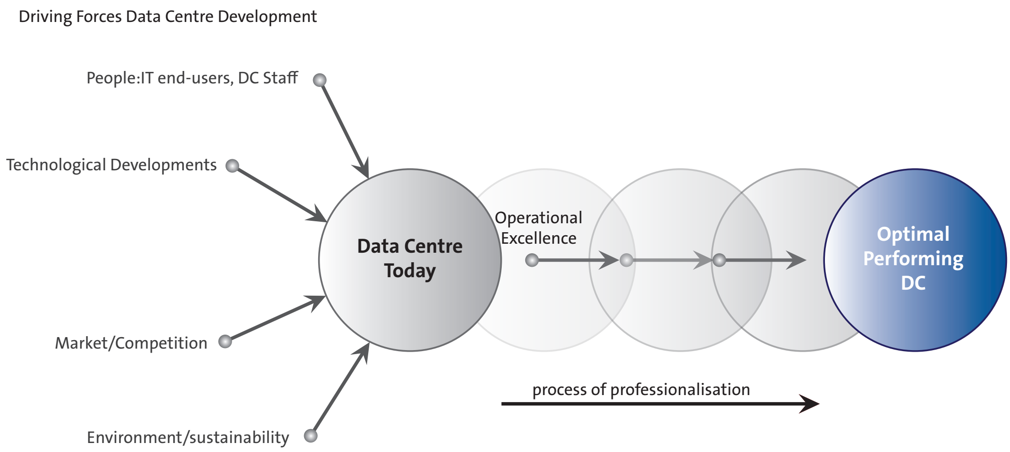
Keep up to date with legislation and standards.	Solutions should resemble the latest insights
Streamline processes to reduce costs.	Provide integrated solutions which are dedicated and optimised
Keep focusing on core activities, specialise.	Ability to customise solutions

Decisions made during the initial design are of crucial importance to the quality of the operating Data Centre. Restoring bad designs afterwards is accompanied with higher risks and higher costs leading to a lower quality of Data Centre services. The Data Centre designer's main goal is to find the best solution given a certain situation, to obtain an Operational Excellent Data Centre. How can this be accomplished?

2.2 Indicators for Operational Excellence

The illustration below summarises the Minkels vision and shows the process required towards an 'Optimally Performing Data Centre'.

Figure 1: Vision



There are strong indicators which support the need for Operational Excellence as a stepping stone in reaching Optimally Operating Data Centres. A few indicators behind the driving forces in figure 1, are mentioned below:

1. People: IT users:

- Increasing demand for data: Developments like Youtube and the social media, twitter, facebook, etc. have resulted in people using more data and becoming more reliant on availability of data anywhere at any time.

- New markets: Beside the growing applications, there is a potential large 'new' consumer market waiting to profit from all the benefits the digital era has to offer. China and India form a market of more then 2 billion potential users.

2.. Technological Developments:

- Miniaturisation of electronics: Moore's Law still holds and the further decreasing size and costs of electronics creates new product opportunities. This can only lead to more data being used. Think of all the mobile applications for example.

- Cloud computing and virtualisation: These trends result in the decoupling between hardware and software. It's no longer about ownership but about availability.

3. Market / Competition:

- Insourcing versus Outsourcing: Many companies re-evaluate what services, for example email, should be outsourced and what products should be kept within the company. It's all about what belongs to the core competence of ones business and what IT-competences available in-house versus what common IT-goods can be better handled by specialised commercial Data Centres.

- Energy costs: The continuously rising energy prices together with the increasing energy consumption makes the costs related to energy form a big portion of the total Operational Expenses (OPEX) which is passed on to the costs of IT-services.

4. Environment / sustainability:

- Legislation and awareness: Governments and organisations become more aware of their responsibility towards the environment and want to act in a proper way. In the UK the CRC (Carbon Reduction Commitment) sets up a whole system of legislation in order to stimulate companies to reduce their energy consumption. Also the Dutch government has adopted a sustainable purchase policy.

2.3 Solutions and Operational Excellence

The Data Centre supply industry should provide solutions which are:

1. Manageable: the many changes taking place during the lifetime of a DC should not have an impact on the quality and availability of a product. Solutions should be simple yet effective.

2. Modular: To minimize the financial impact the investments (CAPEX) and operational expenses (OPEX) should be matched with the specific Data Centre budgets.

3. Flexible: The right level of modularity increases the flexibility. This is required to be responsive towards market developments. A tool will given later on in this paper.

4. Energy efficient: Both for the sake of lowering the Operational Expenses (OPEX) as well as reducing the carbon footprint from an environmental responsibility point of view.

Predicting the future for a new build or upgradable Data Centre, with a potential lifetime of 10-15 years, does not need to feel like a free fall into the dark. The ultimate goal is to create an Optimally Performing Data Centre. Operational Excellence can help to achieve that. This paper will present design tools that enables to create Future Proof and Operational Excellent Data Centres.

Chapter 3: The unruly reality

The gradually professionalising Data Centre Industry reveals itself through the emergence of total integrated concepts like the Google Containerized Data Centre, the Microsoft Next Generation Data Centre, the HP Butterfly and many more. The question however is, do these concepts contribute to the overall professionalising of the Data Centre Industry?

The answer is yes and no. Yes because these integrated concepts resemble great features like modularity, flexibility, on-demand, all-in-one solutions. No because the reality is unruly and the variety of Data Centre requirements cannot be captured or covered by only a few designs. So a couple of downfalls of these concepts:

- The size of the building block is quite capital intensive and not suitable for smaller Data Centres.
- The designs particularly aim at new build/green field environments.
- Despite fast deployment possibilities, scalability and flexibility there needs to be a certain site with infrastructure, water, power, network available This requires a large initial investment nevertheless. So it's modularity and flexibility at a coarse level.

Figure 2: Modular solutions

Google, Containerized DC's | HP, Butterfly design | Microsoft Generation 4, Modular DC plan

The reality is unruly because:

- There are companies who have an existing Data Centre which needs upgrading but are restricted for the moment to their initial location.
- The Data Centre's position inside the building does not always offer a large degree of freedom to adopt the latest type of technology. A specially engineered solution must be provided.

- The size of the Data Centre is too small to allow for capital intensive 'green' solutions.

The challenge for anyone involved in the initial design of a Data Centre is to make to the latest technologies and insights available for each type of 'unruly' Data Centre. To achieve that there needs to a profound understanding about the variety of situations in which Data Centres operate:

- Who are the stakeholders?
- What perspectives are involved?
- How to shape the Data Centre design process in a way that makes the best solutions fit the right customer?

The following chapters will deal with these subjects.

Chapter 4: Perspectives and Stakeholders

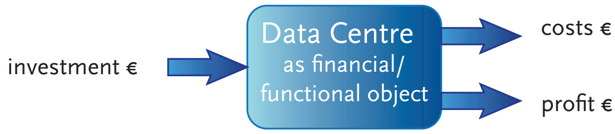
In order to identify the underlying causes of the unruly reality its fundamental forces need to be exposed. Roughly there are five main perspectives that will somehow play a role in the design of a Data Centre:

- Business / Financial perspective
- Commercial / IT perspective
- Technical Perspective
- Sustainable perspective
- Peoples perspective

1. **Business/Financial perspective:** The Data Centre is regarded as a financial asset or seen as a business unit serving the organisation from which it is part of. In commercial Data Centres the costs and profits can be more easily subscribed to the Data Centre operation. In a corporate environment the costs and profits cannot only be expressed in financial parameters only. Due to its supporting function IT is an enabler of business. Nevertheless budget regimes and business goals can be determined for the Data Centre. Typical stakeholders in this perspective are CEO, CFO.

Questions	Parameters
How can IT support the business?	Strategic fit
How to maximise profit?	€ : cost vs. earnings in general
What is the ROI of my Data Centre?	TCO (Total cost of ownership): What are during the lifetime the overall costs involved.
What market/customers do we need to approach?	ROI (Return on investment): When do certain investments payback?

What technologies do we require?	CAPEX (Capital Expenses): What is the initial budget?
What is our environmental impact?	OPEX (Operational Expenses): What does it cost to keep the DC running?



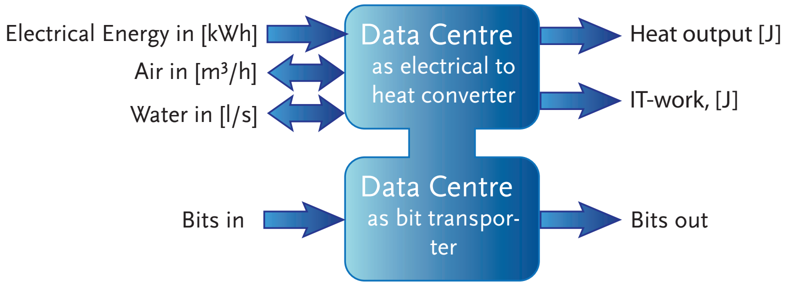
2. **The commercial/IT perspective:** Whether the IT-services provided are meant for inter-company or external end-users, in any case there should exist a balance between demand and supply of IT-services. From this perspective the Data Centre its main function is to translate desires/demands into functionality/services. The commercial perspective raises the question; What should this Data Centre do for my (internal) customer?

Questions	Parameters
Which customers should we focus on?	Market segments
What services should be provided?	Type of Applications
Enough IT capacity/resources?	GB/s: What is the amount of input that can be handled and transferred to output.
Availability of service/product?	Uptime guarantees: At what level of redundancy should the services be provided.
How to cope with growing future demands?	Flexibility of operation
Impact of growing dependency towards IT services?	Uptime

3. **The technical perspective:** Computers can only operate if there is enough power, cooling, network and presence of infrastructure components available. Almost all electrical energy is converted into heat. The technical infrastructure is basically there to keep the computers running safely under the right conditions. Nothing more and nothing less. The IT-infrastructure has a facilitating nevertheless important role. Beside electrical energy, air and, in some situations, water is required to be able to remove the heat to the outdoor environment.

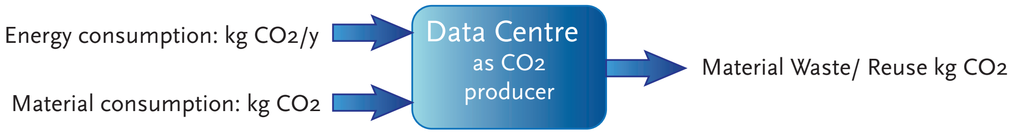
Questions	Parameters
How to create an energy efficient Data Centre?	PUE: What part of the total energy consumption is truly utilised by the IT-services.
How to create a resilient Data Centre?	Tier level: What are the uptime guarantees

How to create cost-effective IT-services?	€/GB/s: What does it cost to deliver a certain IT-service?



4. **The sustainable perspective:** As part of the Corporate Social Responsibility (CSR) it is the duty of each company to operate in a way that minimises its environmental impact. Using materials, consuming energy and wasting heat to the environment produces CO_2 as by product.

Questions	Parameters
How to do business without harming our environment?	kg CO_2: What is environmental impact of running the Data Centre?



5. **The people's perspective:** Another aspect of the CSR is the social context in which or by which a Data Centre operates. In all fore mentioned perspectives people are involved. Beside work related drivers people always have personal drivers as well. For any business to be successful it is necessary to know the personal drivers of it's (internal) people.

Questions	Parameters
How to combine personal motivation with business responsibilities?	Skills, passion, fun

For anyone involved in Data Centre design it is crucial to be aware of these perspectives and understand the business related and personal drivers of the stakeholders involved. Finding the right balance between all these perspectives, stakeholders and parameters is key in finding the best solution for the situation at hand.

A successful Data Centre cannot only be measured by a single metric if the context in which it operates is multi-dimensional. It might give a distorted view and incorrect conclusions. This is why it is so important to not only evaluate the performance of a Data Centre on a single metric only, like the PUE, but make it part of a larger set of tools to deal with this complex scheme of interests. This multilevel approach is exactly what 'Operational Excellence' is all about.

Below is a comprehensive illustration of the several stakeholders and their span of concerns. The better this picture can be filled in the better the DC solution in the middle will be.

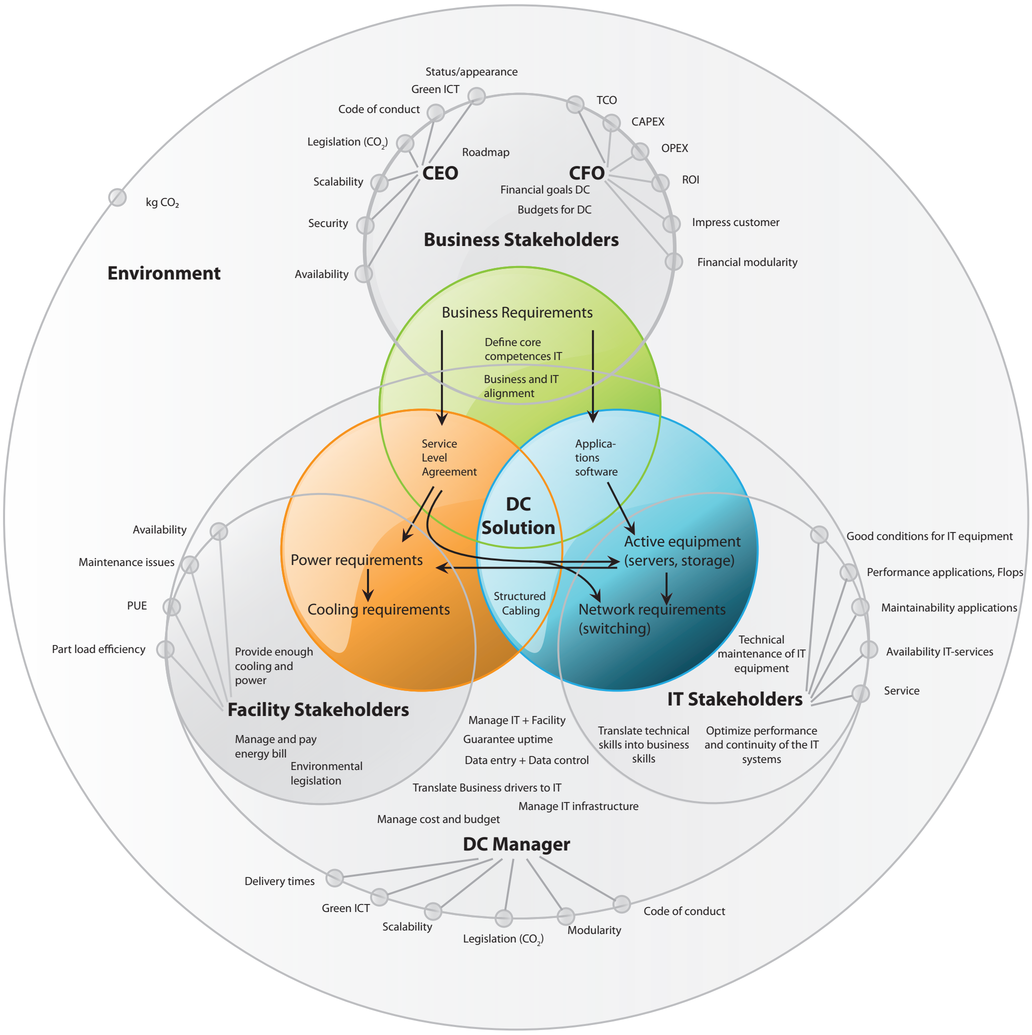


Figure 3: Overview stakeholders and parameters.

Chapter 5: The right solution for the right business

Once the 'unruly reality' has been identified and business goals and physical situations are clear, a set of tools is required to select and couple the right solution to the right Data Centre business. In order to determine what's 'right' the following approach is presented:

5.1 Strategy:

It all starts with following a strategic design approach, similar to that of product design, including the following phases (see table below). The reasons for following a strategic approach is to be sure that no opportunities are missed and that the best possible design is implemented. Meeting, for example, your CSR (Corporate Social Responsibilities) can easily be incorporated in the initial design. Taking into account a pleasant working environment and conditions in terms of temperature etc. is easy to do in the beginning. Making adjustments later on is difficult. It's merely about making the correct choices instead of doing extra work. The table below roughly describes such an approach and is in fact basic and is used in all sorts of design processes.

Strategic Design Process
1. Analysis phase: The most important one: a. Explore the challenges, the needs and the possibilities b. Explore the latest technology that might be useful c. Use theoretical knowledge beside practical knowledge to understand some of the fundamentals in data centre functioning.
2. Set up a solid program of demands which is parameterised, so using above mentioned parameters (chapter 5)
3. Creativity sessions should lead to minimal three equivalent concepts to choose from. There are always multiple solutions to be found.
4. Choosing the best design based on the program of demands.
5. After finalising the design stage the engineering project starts and the design will be fixed. Once this phase is passed changes are difficult to make.

5.2 Select type of business:

Before the design of a Data Centre starts it's important to establish and understand the type of business the Data Centre is going to serve. Does it involve a corporate and or commercial Data Centre and what is the exact nature of the services that will be provided. It sounds obvious but reality has shown that this is not always performed correctly. In the following chapters it will become clear why there exists a relation between the nature of the Data Centre and it's design. Roughly there is the following widely accepted segmentation:

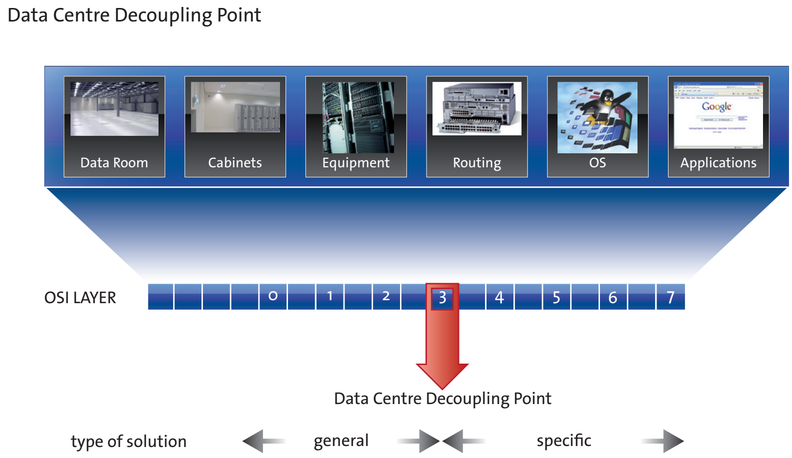
Type of business	Description
Operator	Operates the entire data centre from the physical building through to the consumption of the IT services delivered.
Colo Room provider	Operates the data centre for the primary purpose of selling space, power and cooling capacity to customers who will install and manage racks and IT hardware.
Colo provider	Operates the data centre for the primary purpose of selling space, power and cooling capacity to customers who will install and manage IT hardware.
Colo customer	Owns and manages IT equipment located in a data centre in which they purchase managed space, power and cooling capacity.
Managed service provider (MSP)	Owns and manages the data centre space, power, cooling, IT equipment and some level of software for the purpose of delivering IT services to customers. This would include traditional IT outsourcing.
Managed service provider in Colo	A managed service provider which purchases space, power or cooling in this data centre.

5.3 Determine DC decoupling point:

A new definition is introduced to better understand the relation between type of Data Centre and type of solution provided. It is called the 'Data Centre Decoupling Point' or DCDP. It's very similar to the definition used in logistics, which is the customer decoupling point. The Data Centre Decoupling Point is the point from which the Data Centre operator has no more influence on the resulting outcome of his IT-services towards the end user, so in fact the digital output of his Data Centre. The location of this point greatly determines the type of infrastructure solution that can be offered to the Data Centre. The further this point lies to the left, see figure 4, the more generic the solutions will have to be. In other words a high level of flexibility is to be incorporated in the design to meet many unknown and unforeseen applications. The further the decoupling point lies to the right the more influence the Data Centre operator has on the final outcome of his Data Centre operations. For example a Colocator does not know exactly the type of equipment his customers will install nor the exact amount of power to be consumed. Therefore he has to provide a certain infrastructure solution that is able to deal within a certain range on power, cooling, management etc. On the other end of the spectrum there are, for example, the large corporate companies like Google, which control the whole chain. Google designs its own servers and even its own applications. For that reason their decoupling point lies completely to the right. This enables them to build a very customised and specific infrastructure. Since the whole chain can more easily be optimised in that way 'Operational Excellence' can more easily be accomplished. Small and medium corporate companies are somewhere in between. The OSI Layer model is used as ruler to pinpoint the location and make it widely understandable.

Determining the DCDP is a first step in understanding the level of influence a Data Centre operator has on the final IT-output. Understanding the range of variability the Data centre design has to comply to gives an indication on how general or specific a design needs to be.

Figure 4: Data Centre Decoupling Point

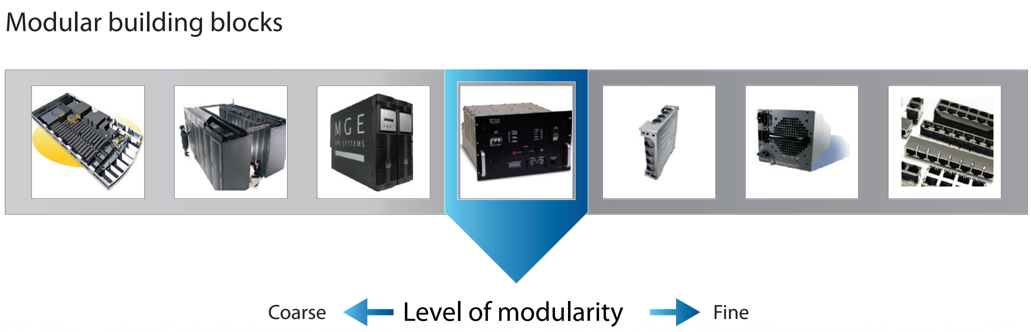


5.4 Determine level of modularity:

The term 'a modular solution' is often claimed but in many times it's unclear what is meant by it. Probably the only thing it says is that the entity of the solution is standardised and therefore allows for easy assembly, repair and building up and can be applied in multiple arrangements thereby providing flexibility. The problem is however that the size of modularity is never mentioned. In fact all products are modular to some extend. However what level of 'modularity' makes sense to what type of Data Centre?

There is a strong correlation between the level of modularity and the Data Centre Decoupling point. The level of modularity implies the size or granularity of a modular building block which is part of a bigger composition. For example a rack is a modular product, but the rack can also be part of a corridor, a corridor can be part of an IT-room and an IT-room can be part of a Data Centre etc. On each level there can be modularity. However it depends on the size and the type of the Data Centre operations which level is appropriate. Meaning what level of modularity provides that flexibility, scalability and gradual investments that is needed for a specific Data Centre to successfully do business. For example, Microsoft finds a fully stacked container datacenter a modular solution, and in some respect it is. But the reality is unruly and for Small and Medium Enterprises (SME) this level of modularity is too coarse and brings along disproportional investments. For each Data Centre the right level of modularity needs to be determined.

Figure 5: Level of Modularity



5.5 Knowledge organizations:

There are many organisations that contribute to the knowledge required to successfully design, operate and build Data Centres. It's recommended to participate or at least follow the output of these organisations closely and implement their 'Best Practises'. A selection of the most important ones are mentioned below:

- ASHRAE, TC 9.9: Especially dedicated to specifying the allowable and recommended air conditions under which servers can operate safely.

- The Green Grid: Especially dedicated to designing metrics and tools for Data Centre evaluation.

- CENELEC TC 215/WG3 is developing a new standard EN 50600-1 'Facilities and Infrastructures'. A large input has been provided by the NEN, the Dutch standardisation committee which is working on the NPR 5313. Minkels is an active participant in the NEN.

- Code of Conduct: Setting the industries 'Best Practices' to optimise a DC's energy efficiency on a European level. Minkels is an active participant of the Code of Conduct and implements its best practises in each design.

- BICSI: An US based organization for the IT supporting industry. BICSI recently launched a well documented and very complete handbook for Data Centres design,

5.6 Investment model:

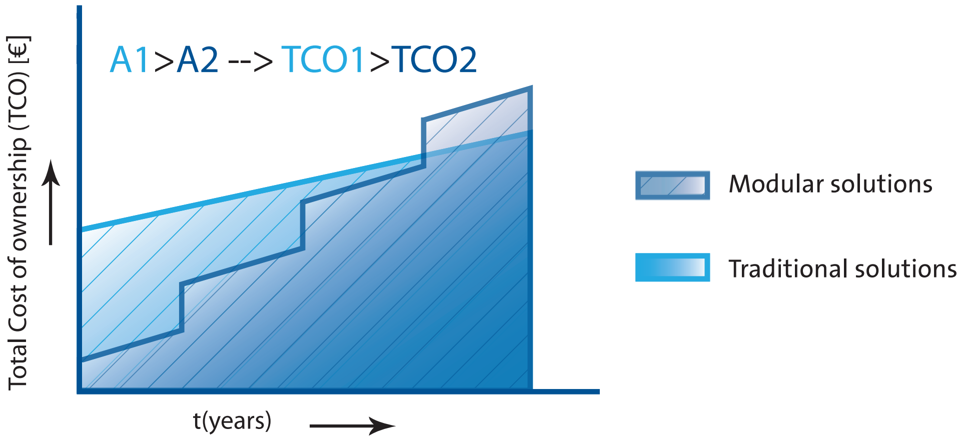
Making a design as scalable and flexible as possible by using the fore mentioned principles allows for incorporating a gradual investment model. Since pay back periods need to be short, 3-5 years and for some companies even shorter periods, 1-2 years, this gradual investment model allows for minimising the financial impact and risks involved. Although there is a widespread recognition on this phenomena it is not always successfully implemented simply because:

- The design does not allow for a gradual build up. Especially in the field of electronic and hydraulic installations the modular building blocks are still too large, a typical indicator of the unruly reality.

- The way budgets are allocated demand for spending it all at once.

The illustration below shows the financial advantages when choosing for the right size of modularity. The area under the graph displays the financial impact and risks involved. Minimising those risks by better fitting the costs versus functionality is one of the key aspects of Operational Excellence.

Figure 6: Financial benefits of modular solutions



Chapter 6: New dimensions in DC Design

In order to zoom into the process of achieving the best solution for the Data Centre at hand three key dimensions are presented. These dimensions have proven their success in daily practice and are therefore explained in more detail:

1. The 'Volumetric Dimension'
2. Reducing complexity
3. Integration³

These guidelines are called dimensions because they will show how easy it can be to come up with a good design by just looking at the design challenges from a new perspective. The dimensions presented here are mainly related to cooling and integration since together they are considered to contribute most in becoming Operational Excellent.

Cooling because:

- It plays a big part of the total energy consumption of a DC. Thereby contributing heavily to the total operation costs.
- Cooling is a fundamental ingredient in a reliable and successful operation of IT-equipment.
- Cooling equipment technology is not yet fully optimised for DC operation. There is still much to be gained in improving cooling components and architectures.

Integration because:

- It can increase the effectiveness and efficiency of the IT-infrastructure components considerably when the individual components work together as one entity.

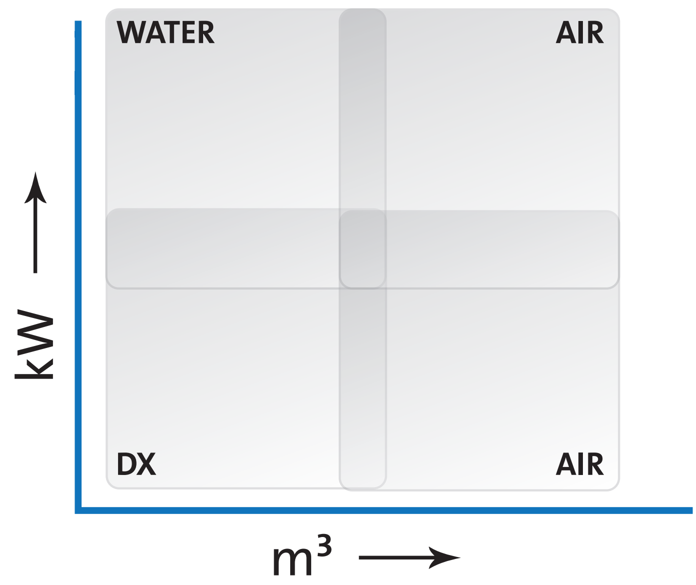
- A good integration facilitates future growth and expansion by telling exactly the current state of a DC at any given time. It therefore allows to be well managed.
- A good integration platform/system goes even further by showing how the Data Centre operation can be improved and thereby relieves some of the tasks from the Data Centre manager.

6.1 The volumetric dimension:

Selecting the best cooling infrastructure is key in saving money, providing a reliable and resilient environment, minimise the carbon footprint and providing good working conditions for people working in the Data Centre environment. So key for Operational Excellence.

When a DC is characterised the amount of square meters [m^2] is mentioned in relation to its designed power consumption [kW]. This relation is referred to as the heat density in kW/m^2. Although the m^2 parameter is relevant in understanding the site's size and therefore the amount of racks and servers that can be housed, it's considered not to be the best parameter for judging what type of cooling system should be applied. Another more valuable parameter in designing a cooling system is the available m^3. If the cubic meters are positioned against the required cooling capacity a new dimension reveals, the 'Volumetric Dimension.

Figure 7: The 'Volumetric Dimension'



Minkels is using this new dimension for quite some time and this metric still seems to hold and proves to be viable. The reason for this is not so strange. Namely the metric is based on a physical law which is the formula of Bernoulli. It states that the total amount of pressure remains the same on a streamline from one point to the other.

The Bernoulli formula for processes is:

[1] $$p_a + \tfrac{1}{2}\rho v_a^{\,2} + \rho g z_a = p_b + \tfrac{1}{2}\rho v_b^{\,2} + \rho g z_b + \Delta p$$

[2] $$\Delta p = \underbrace{\sum_{n=1}^{i} \left(\lambda \cdot \frac{L}{D_h} \cdot \tfrac{1}{2}\rho v^2\right)_n}_{\text{straight ducts}} + \underbrace{\sum_{n=1}^{j} \left(\zeta \cdot \tfrac{1}{2}\rho v^2\right)_n}_{\text{corners, devices, hydraulic components}}$$

[3] $$D_h = 4 \cdot \frac{A}{O}$$

$p =$ static pressure [Pa]	$O =$ circumference [m]
$\rho =$ density [kg/m^3]	$A =$ surface [m^2]
$\lambda =$ friction factor [..]	$\zeta =$ resistance coëfficiënt [..]
$D_h =$ hydraulic diameter [m]	$v =$ velocity [m/s]
L = length of hydraulic path [m]	z = height difference [m]

Formula [1] shows that along a streamline from A to B the total pressure remains equal. However there is a static component (pi), a dynamic component ($\frac{1}{2}\rho v^2$), a height different component ($\rho g z$) and a friction/resistance component (Δp). Together these components change in composition when traveling from one location to the other.

Formula [2] shows that the total friction component (Δp) is depending on the total sum of friction that it faces during it's path from point A to B. This friction can exist in straight ducts due to wall resistances, or due to path direction changes, bends, narrowing, obstructions etc. This total amount of friction along the air path results in a pressure drop (Δp) since the airflow has to be kept at a certain level [m^3/h]. The only way to compensate for this loss is to increase the static and dynamic pressure. This is in fact the fundamental property of a fan unit. Creating a static pressure directly resulting into a dynamic pressure, air speed. The more resistance along the air path, the harder the fan has to work, the more energy it consumes. This is the relation, formula [4], derived from the fan formulas [5,6,7]:

[4] $$\left(\frac{P_2}{P_1}\right) = k \cdot \sqrt[3]{\left(\frac{p_2}{p_1}\right)^2}$$

Derived from [5,6,7]

[5] $$\left(\frac{\dot{V}_2}{\dot{V}_1}\right) = \left(\frac{n_2}{n_1}\right)$$ [6] $$\left(\frac{p_{s2}}{p_{s1}}\right) = \left(\frac{n_2}{n_1}\right)^2$$ [7] $$\left(\frac{P_2}{P_1}\right) = \left(\frac{n_2}{n_1}\right)^3$$

$k =$ total fan efficiency (fan+motor)

n=rotational speed (min^{-1})

P= Power [W]

$\dot{V}$= volume flow [m^3/hour]

p=static pressure/dynamic pressure or Δp [Pa]

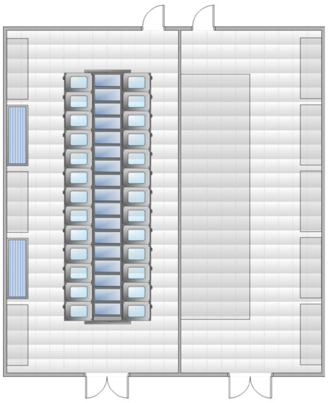
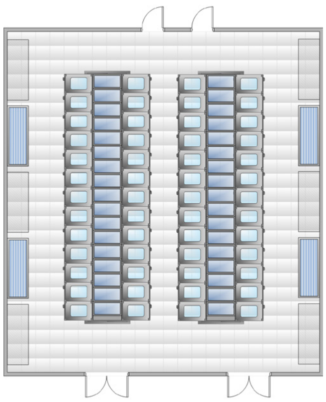
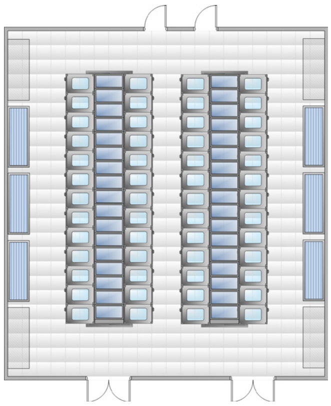
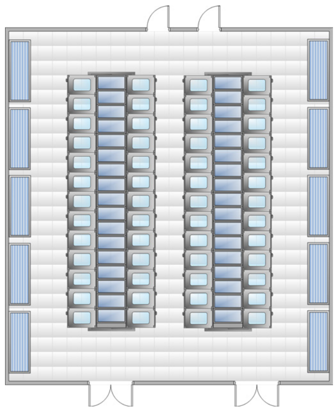
Each time the air goes round in a cooling system, from heat source to cooling source, this energy loss needs to be compensated for by the fan. Formula [2] shows which parameters determine this loss. Therefore the following fundamental guidelines should be followed during the design.

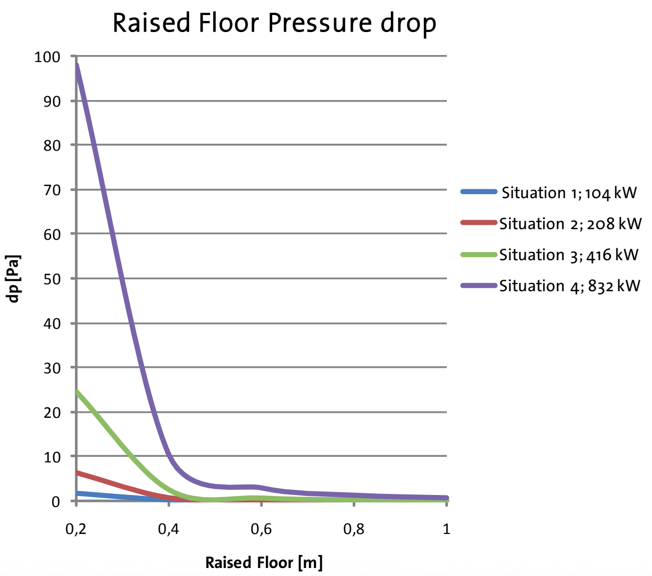
- Reduce the sum of air path lengths [L]
- Reduce the number of obstructions and air path changes, [ζi]
- Increase your hydraulic diameter [Dh]
- Reduce air speed [v]
- Determine optimal working point of fans. [kW vs. m³/h]

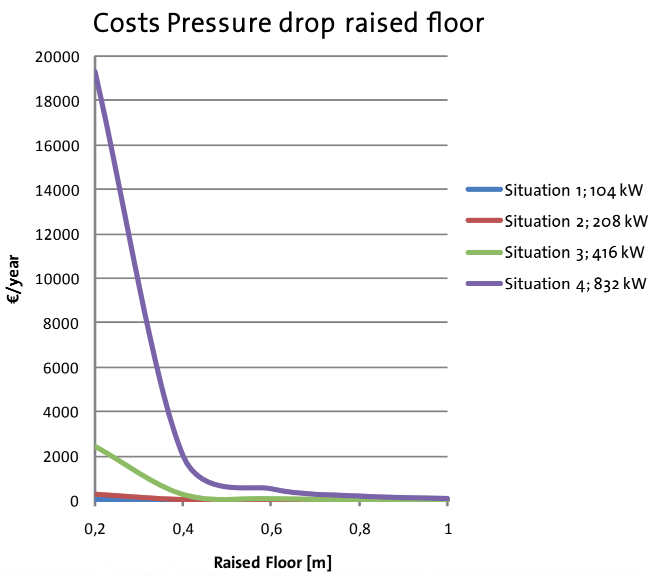
Calculation example: Raised floor related energy costs

Description: A DC owner requests to justify which raised floor should be taken. The choices are between using 20, 40, 60, 80 or 100 cm in height. The width of his room is 14,4 m and the average length from the CRAC to the Cold corridor is 3,6 m. The room is going to expanded gradually in the future from 4 kW/rack to finally 16 kW/rack.

Using the Coolebrook-White approximation formula for the friction factor the following results are given:

			
Situation 1: Corridor 1, 4 kW/rack, N+1	Situation 2: Corridor 1+2, 4 kW/rack, N+2	Situation 3: Corridor 1+2, 8 kW/rack, N+2	Situation 4: Corridor 1+2, 16 kW/rack, N+2





Speed v and throughput area A are coupled to provide enough air volume [m^3/s]. Combining formula [2] and [3], for the straight duct part gives:

$$[8] \qquad \Delta p = \tfrac{1}{8}\lambda\rho\frac{OL}{A^3}\cdot\dot{V}^2$$

$$\text{whereby } \dot{V} = vA \text{ (volume flow) } [m^3/s]$$

Formula [3] shows the 'almost' third power relation between pressure drop and cross sectional area for air transport. 'Almost' because an increment of A changes the circumference O and the friction factor λ as well. Since an extensive elaboration into the formulas of determining friction factors is beyond the scope of this document the importance of increasing the cross-sectional area A and therefore the dedicated volume for air transport is illustrated by an example on the previous page.

The calculation example on page 22 shows that especially choosing a raised floor lower then 60 cm creates an inefficient situation with difficult control parameters. Subsequently the graph on the right shows the yearly energy costs of the fan power consumption related to the raised floor pressure drop based. The power consumption is based on the data provided by the CRAH manufacturer

These cost differences are not extremely high but they are only related to the raised floor friction. Imagine what it would cost yearly when a poor initial design of the whole room is delivered, so a badly chosen return air plenum, a cold corridor which is too small, leakage etc. Beside the additional operational cost involved with a poor design, there is an issue of controllability and thereby availability. If one is not bothered by the additional costs of a poor design, one should be bothered by the lack of controllability. That truly endangers the quality of the IT- services and has a negative influence on the Operational Excellence.

Although the example above is only one aspect in evaluating the cooling design it shows that a good design can save quite a bit of money and therefore pays an important role in becoming Operationally Excellent. These and other tools should be part of the Data Centre designer's way of analyzing in order to come up with the best solution given the restrictions of the Data Centre owner.

6.2 Reducing complexity

Cooling basically is about three things:

1. Providing enough cooling medium: [m^3/h]
2. Provide it at the right location: [x,y,z]
3. Provide it with the right conditions [°C, RH%, ppm] (according to ASHRAE recommended, Class 1)

These principles however can be applied in many configurations. In DC's there is a tendency to make cooling and control mechanisms too complex. Complexity can endanger Operational Excellence because it creates an environment which requires more effort to control, more equipment involved etc. Often this complexity is the result of using machines which have not been designed specifically for Data Centres and therefore possess functions which are not necessarily required for the DC situation. A lot of effort will have to be put in to compensate for this. The reason for using non-optimised solutions is due to the following aspects:

1. There is a large knowledge and install base with cooling equipment used in other fields of industry, like the Food industry or the Petrochemical industry. So the risks are lower in applying existing technologies.

2. The energy efficiency debate arose during the last decennium. Former concerns were more related to the controllability of the whole system.

3. Physical limitations of each DC can be different. Therefore limiting the possibilities to using optimised solutions.

4. Formerly the conditions which were recommended for the IT-server equipment were very tight. Due to increasing knowledge on the impact of temperature, humidity and pollution levels this range has been extended facilitating energy efficiency measures.

5. Over-designing which is very much related to not knowing your heat load.

The aforementioned factors have resulted in cooling systems which have many heat transferring moments. Figure 8 denotes the relation between energy efficiency [PUE] and the number of heat transfers [n]. In each picture on the very left there is the heat source and on the very right there is the outside air which eventually removes the heat from the Data Centre. The heat can be transported in a maximum number of ways via the following steps:

1. Heat coming from the IT-server components is transported onto the air which is forced through the servers.

2. The heat transported by the air of the server equipment is transferred via a heat exchanger to a secondary water circuit located in the IT-room.

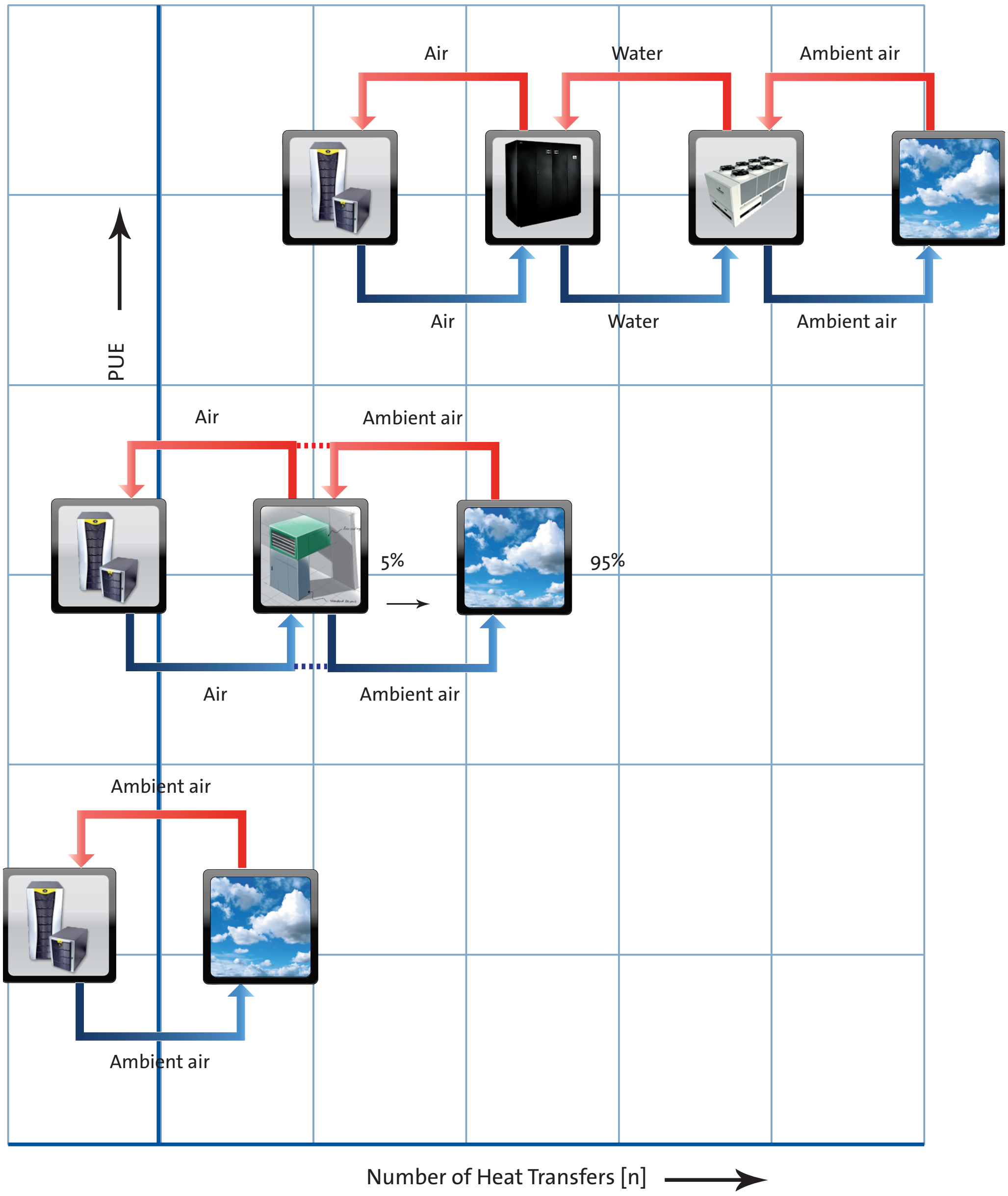
3. The heat removed by the secondary water circuit is transferred to a primary water circuit which goes to the outdoor environment.

4. If the outdoor temperature is too high the primary water circuit needs to be cooled through an additional compressor circuit or via evaporative cooling.

The upper cooling infrastructure in figure 8 is the most extensive application in this comparison. Unfortunately in some Data Centres the complexity goes even further due to reasons mentioned in the earlier chapter about the unruly reality. The goal is to reduce the number of heat transfers because each heat transfer is accompanied with losses ranging between 1-5 K. This eventually reduces the outdoor cooling capacity requiring more work to be done by the compressors.

A more ideal situation would be to directly utilise the outdoor conditions by allowing outside air to enter the Data Centre directly when conditions are within range, see middle picture figure 8. The most ideal situation would contain no cooling at all, see lower left picture figure 8. However, this would require servers designed to withstand such conditions.

Figure 8: Reducing complexity

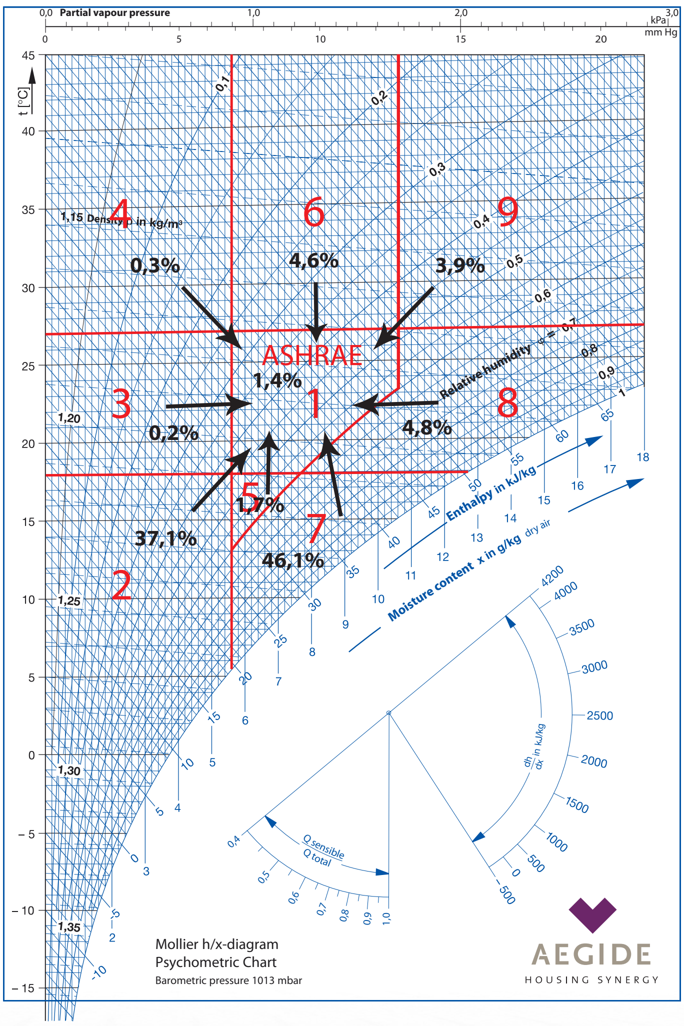


Yet there is some reluctance towards using outside air for the relatively unknown consequences on the IT-server equipment. ASHRAE has done some research to it but the amount of experimental data remains limited. One of the main reasons is that server manufacturer's have never really felt the need to explore this field or at least are very cautious in expanding their guarantee conditions.

In order to prevent ending up in a situation where there is no longer a choice but to go complex in terms of sensors and control mechanisms, the design needs to be simplified as much as possible. This can be achieved in the following way:

1. Analyse outside air conditions over the whole year.
2. Determine max and minimum situations that have occurred in the last 20 years.
3. Set Area 1, figure 9, by analyzing requirements from the server equipment (for example ASHRAE recommended, Class 1)
4. Put the average data into the mollier diagram shown in figure 9
5. Determine for each area how the cooling solution should behave.
6. Select the minimum amount of equipment to achieve this.

Figure 9: Example approach in defining a suitable climate control strategy



Beside potential energy savings a simplified design allows for better manageability and scalability. Simplifying a design does not involve reducing functionality or intelligence. It involves better thinking in the design stage how conflicting interests can be solved in another, maybe less conventional, way. For the Data Centre designer it involves going very much into depth and detail on the challenges, for example contamination problems in Free cooling solutions, in order to come up with a solution that is both energy efficient as well as reliable.

6.3 Integration[3]

A major contributor towards being Operationally Excellent is to know exactly the processes that take place in the Data Centre. In order to be able to control one has to measure and know about the desired situation, so the set points. This has been common practice in many fields of industry for decades. It's no surprise, and very natural, that there's an increasing awareness now in the Data Centre's as well because IT-processes have become more and more complex. Integration should be implemented at three levels to meet Operational Excellence goals:

Integration^1:= Physical Integration: A good integrated design starts with a well-aligned physical integration that shows a consistent set up of physical components. For example the Cold Corridor®, which creates a consequent separation of hot and cold air throughout the whole room and therefore creates a better more predictable environment which allows for setting up control mechanisms that work predictably. Physical integration should solves questions like:

- How should new racks be implemented in the existing cooling design?
- How to replace or reposition future cabling. Is there still a clear overview on the cabling structure?
- Is it possible to expand power and cooling without harming the redundancy of the initial design?

Integration^2:=Control Integration: Upon this solid physical infrastructure layer a layer of control mechanisms consisting of sensors, actuators and controllers can successfully be applied. Since the physical models are put into place in a consequent way the control mechanism is able to predict the response mechanism of the physical environment and therefore is able to apply it's control algorithm successfully with a minimum of disturbances. Minimising the number of disturbances decreases the need for highly complex control algorithms and therefore pays an important contribution to reducing the complexity in Data Centres. Control integration solves questions like:

- My heat load in rack number *x* is *y*?. How does my cooling system has to respond?
- My power consumption in rack *x* is reaching it's maximum!

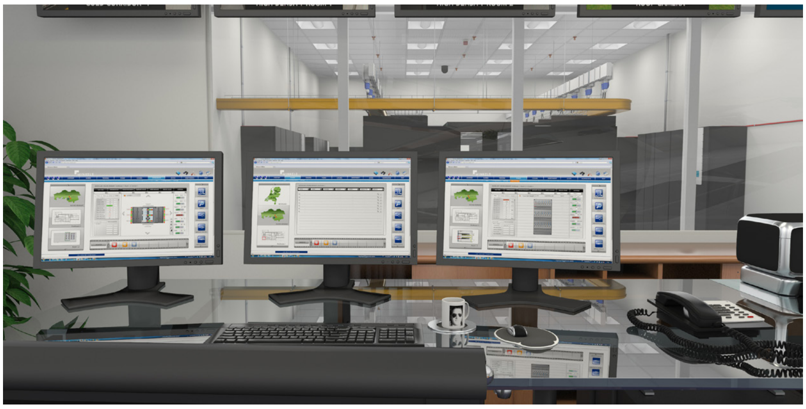
Integration3:=Knowledge Integration: Above the control level is the knowledge level. This is the place where true data centre expertise can be implemented and will help the Data Centre owner to optimise his Data Centre. This is at the same time the most difficult aspect to get a grasp on and will be very Data Centre specific and more difficult to implement at this moment. Knowledge integration might solve questions like:

- The PUE value is too high? How can, based on the existing installed cooling equipment, this PUE value be improved?

- A hot spot is located! How should the IT-load be diverted to mitigate the hotspots?

The monitoring system becomes a sparring partner in solving Data Centre issues, like hot spots or power restrictions, and proposes ways to solve them. Once certain procedures have proven successful they can be hard-coded in the software and become part of the customised intelligent system. In other words there are some self-learning possibilities.

Figure 10: Control Room

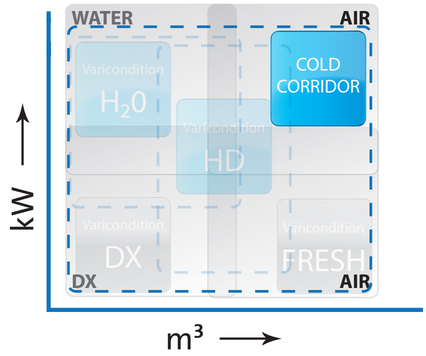


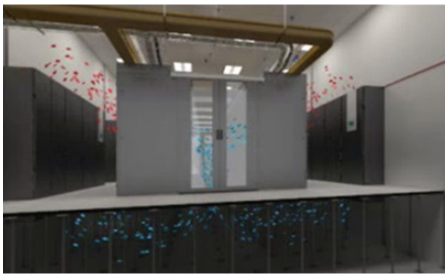
Chapter 7: Successfull implementation of new dimensions

For each segment there are a multitude of products available. However the question is where do certain solutions fit best. Due to the availability of real projects being done at the Minkels organisations, this metric has been filled in for the Minkels solutions. In fact many more specific solutions can be adapted. It would make sense to put in solutions from the industry to complement this metric for their specific cooling solutions once the project data has become available. This overview will clarify to new DC owners what are the possibilities are given a certain situation.

Varicondition Cold Corridor

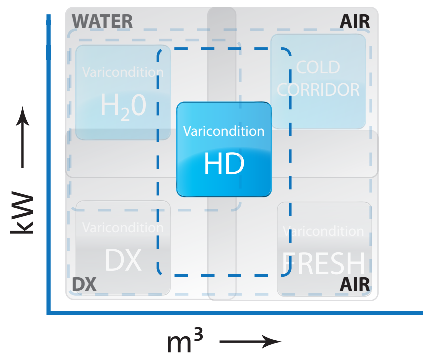
Typical Application:	Working principle:	PROS:
Many, can be used complementary to any cooling solution/architecture	Separating Hot and Cold air	- Low cost energy efficiency enabler - Creating a stable more controllable environment **CONS:** - None

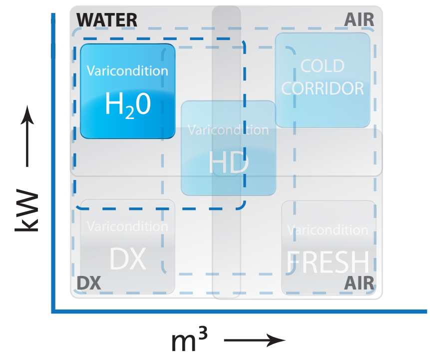




Varicondition HD

Typical Application:	Working principle:	PROS:
In rooms with slab height> 4,5 m. due to needing a return air plenum and possibly also a raised floor. In very scalable heat density requirements.	1. Rack individual return air extraction 2. Balancing sum of rack flow vs. CRAC flow 3. Hot and Cold air ducting	1. Increased energy efficiency due to airflow balancing and hot and cold air separation 2. Rack specific cooling due rack individual control. 3. Pleasant working environment for staff, there is only a 'cold' working environment. 4. Flexible cooling range **CONS:** 1. Requiring a considerable slab height due to supply and return air ducting



Varicondition H2O		
Typical Application: In rooms with limited slag height <3,5 mtr. High density computing	**Working principle:** 1. Close control cooling with an air-to-water heat exchanger 2. Reduction of air flow path which allows for compact building.	**PROS:** 1. High heat densities, 24 kW per cabinet 2. Close control per rack possible 3. No raised floor required 4. Flexible cooling range **CONS:** 1. More complex cooling architecture, involving higher initial costs.
 		

Chapter 8: New concepts for Operational Excellence

Not only does the 'Volumetric Dimension' provide a tool for placing existing solutions in. It also makes clear where there are gaps in solutions available to the market which are in particular energy efficient. The 'Compact' and 'Volumetric' area shows great opportunities for optimising the energy efficiency and thereby contributing to becoming more 'Operationally Excellent'.

'Volumetric'solution: Fresh Air Cooling

Typical Application:

A large range of cooling capacity is possible as long as there is sufficient volume for air transport.

Working principle:

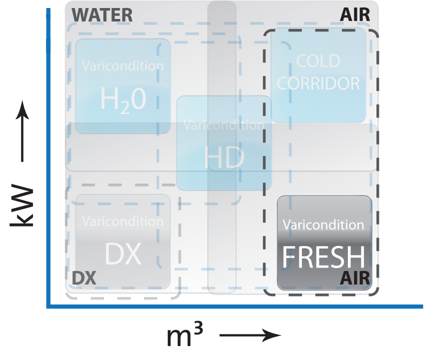
Outside air is directly provided for cooling. There is a minum number of heat transfer steps involved in providing the right conditions to the IT-equipment

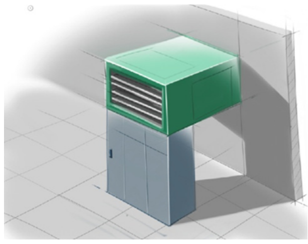
PROS:

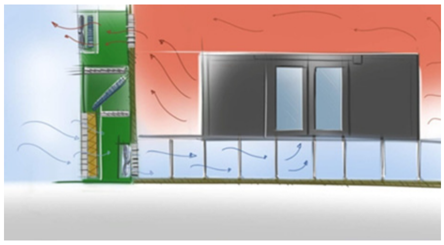
1. Energy efficient way of cooling
2. Simple architecture allowing for a scalable and flexible DC.

CONS:

1. Requires specific knowledge on how to condition the outside air to meet proper conditions for IT-equipment.







'Compact' Direct Expansion solutions

Typical Application:

SME with a need for reliable environment conditions.

Working principle:

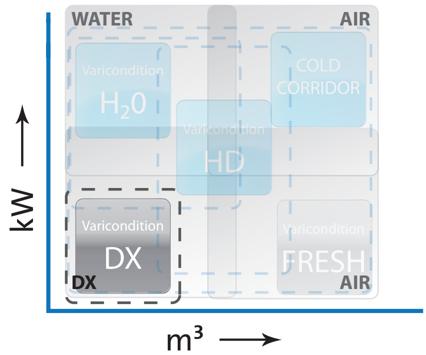
A rack or corridor dedicated cooling solution based on vapor compression cycle directly cooling the IT-cabinets

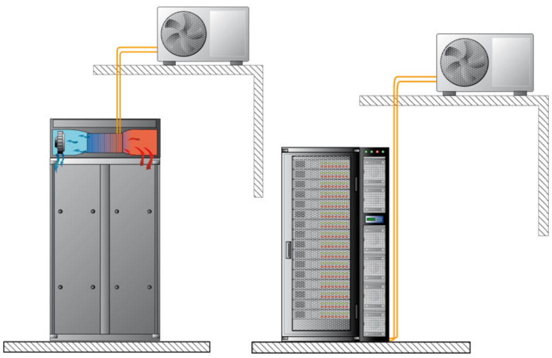
PROS:

1. Rack dedicated cooling solution
2. Independent of environmental conditions
3. Low CAPEX due to a minimum of infrastructural costs.
4. Easy to install.
5. Ideal for small environments

CONS:

1. Not so energy efficient technology





The above mentioned concepts are derived from the intrinsic belief that dedicated Data Centre products, especially related to cooling, will improve the Operational Excellence of Data Centres. There is a need for solutions that are able to meet to the unruly reality for the sake of ending up with Optimal Performing Data Centres in the near future.

Chapter 9: Conclusions:

The digital era is a fact and places an ever increasing demand on our Data Centre's level of professionalism. Each industry that is professionalising requires partners/suppliers that are ahead in this professionalising business and are able to drive this process forwards. The process of professionalising will eventually result in Optimal performing Data Centres. However in order to achieve that a set of parameters, through which Data Centre professionals communicate and operate, needs to be extended. The term 'Operational Excellence is considered to be an important parameter in designing, building and operating a Data Centre. Especially the initial design contributes most in reaching an Operational Excellent Data Centre. No matter whether it involves the design of an upgrade, a green field situation, a small or a large Data Centre, for each type the design can be optimised to reach a Data Centre which is Operational Excellence. Not striving for Operational Excellence might not only create a difficult to control environment which generates disproportional costs, as a result it might even endanger its continuance while others do continue to professionalise.

The tools represented in this paper on the Volumetric Dimension, Reducing complexity and Integration³ represent the latest technologies and insights and are presented in a way that makes this knowledge available to a large range of Data Centres operating in all kind of businesses. The current situation shows that large scaled 'Green Field Concepts' are not sufficient to cover the variety of Data Centres that exist. A more sophisticated approach is required. There is no such thing as 'one size fits all'. The reality is unruly and will continue to be so in the future. Although some technologies will consolidate a Data Centre solution will always be a combination of consolidated general best practises combined with dedicated solutions.

A short summary of the 'New Dimensions' presented in this paper to reach Operational Excellence:

- Treat a Data Centre design process as any other design process is treated. Extensive knowledge is available on this subject. Central in such an approach is the integral view towards all the stakeholders and perspectives involved.

- Don’t just copy a good design from one Data Centre to another. Acknowledge the differences that exist in terms of type of business and physical constraints. Find the right balance between the stakeholders and perspectives involved to end up with the best solution, at the end of the day people are involved. In defining a technical solution combine existing good solutions with required dedicated solutions. The level of modularity and the Data Centre decoupling point need to be determined.

- In executing the technical design use specific analysis tools which help you converge to the right type of solution for the right type of business. A number of new dimensions are introduced:

- The ‘Volumetric’ dimension: Let the basic guidelines for cooling be inspired by laws of physics, especially Bernoulli. This will help save energy throughout the whole lifetime of the DC.
- Reducing complexity: For reasons of saving energy as well as for improving controllability and manageability of a Data Centre, it is important to make the design, especially on cooling, as simple and robust as possible. An IT-infrastructure that is too complex will not contribute to Operational Excellence.
- Integration[3]: Integration in general improves the complete manageability and control of the Data Centre. It helps the DC operator to let his Data Centre meet his business goals. Three levels need to be accounted for:
  - Physical integration
  - Control integration
  - Knowledge integration
- Mapping existing solutions in the ‘Volumetric’ dimension creates an overview of the alternatives a DC owner has in choosing an optimal solution.
- Mapping available solutions in the ‘Volumetric Dimension' at the same reveals gaps and therefore gives an idea where useful solutions can be found.

The tools mentioned have been evaluated throughout many projects and have proven their effectiveness. Nevertheless it doesn’t stop here. Data Centre technologies evolve and the way of designing should evolve as well. Therefore the tools to improve a Data Centre design need continuous improvement and critical evaluations continuously.

It's safe to say that using the presented design tools will improve the 'Operational Excellence' of a Data Centre.