Different Methods of Cooling

Sommerakademie in Leysin
AG 2 – Effizientes Rechnen

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University of Awesomeness

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Studienstiftung des deutschen Volkes

Outline

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General questions

Why schould a computer be cooled at all?

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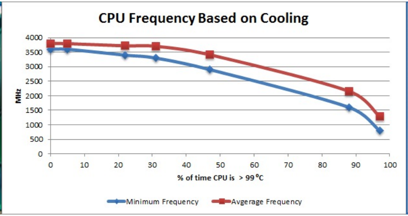
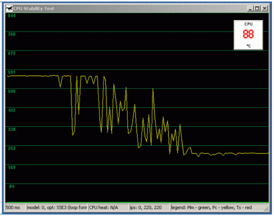
Overheating leads to:

- throttling
- hardware damage





Why do we need different technologies?

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- increasing demand of computing power
- increasing chip density $\implies$ heat density
- up to 10% of electricity consumption: IT equipment & up to 40% for cooling $\implies$ more efficient technologies become interesting

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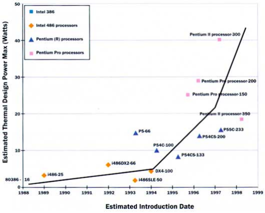

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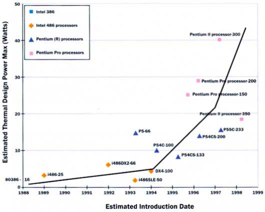

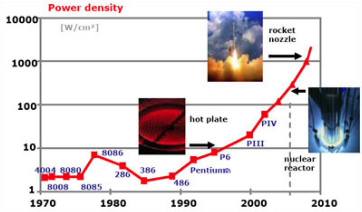

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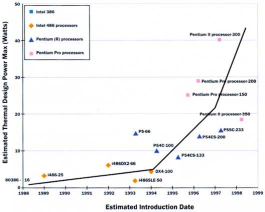
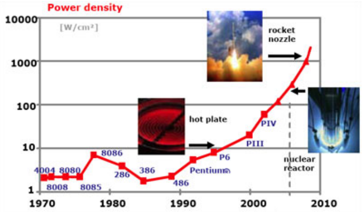




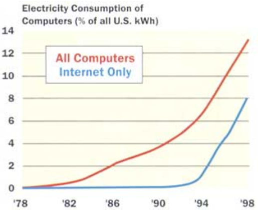


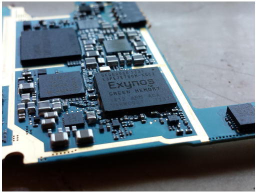
Figure: exaggerated

Outline

What numbers are we talking about?

Overview: Thermal heat output (TDP)

1. SMARTPHONES: 2.5 - 5W size: 10×10mm



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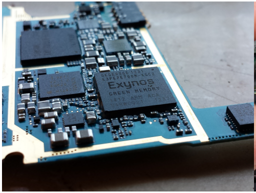

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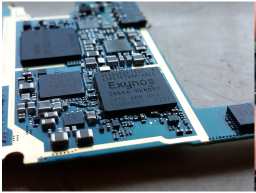
DESKTOP CPU (i7/AMD):	145/220W	$20 \times 20/25 \times 25$mm



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5. SERVER FARM: up to 12.000.000W

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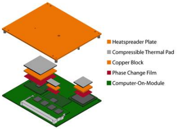
OK, so cooling is important. How does it work?



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Steps of the heat transport

❶ Heat produced by the chip

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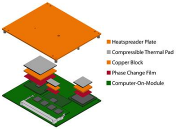

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Steps of the heat transport

1. Heat produced by the chip
2. Heat transfer to the coolant

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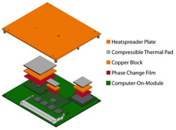

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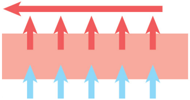

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Steps of the heat transport

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3. Heat transport to the chiller

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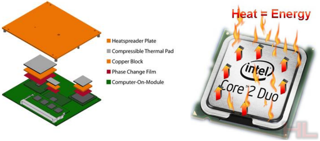

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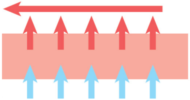

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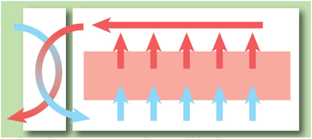

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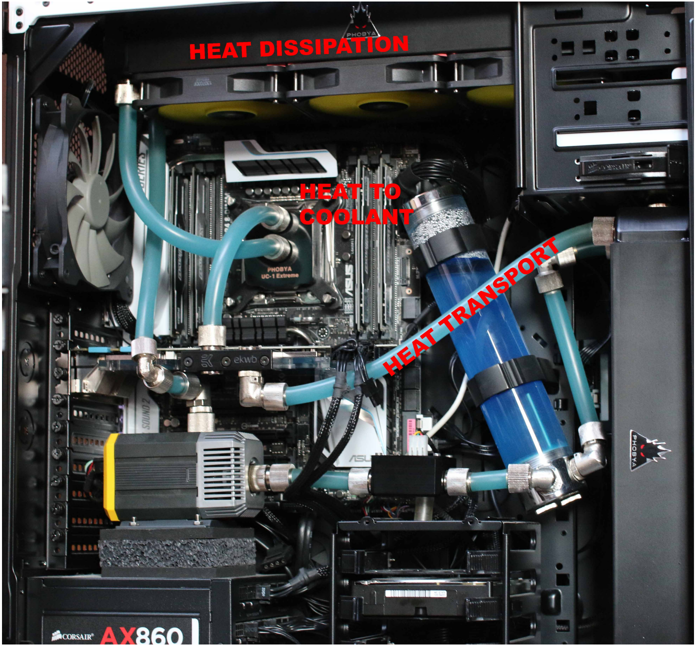
Steps of the heat transport

1. Heat produced by the chip
2. Heat transfer to the coolant
3. Heat transport to the chiller
4. Cooling of the coolant (chiller)


HEAT DISSIPATION
HEAT TO COOLANT
HEAT TRANSPORT
PHOBYA UC-1 Extreme
ekwb
CORSAIR AX860

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Natural convection & conduction + fans

- no additional equipment
- low heatload; 1W/cm^2(usually for everything but cpu)

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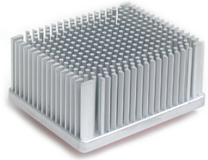
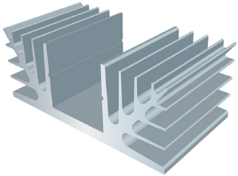
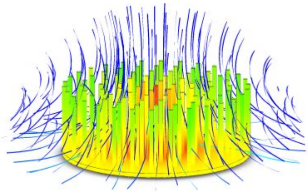
Heat sink

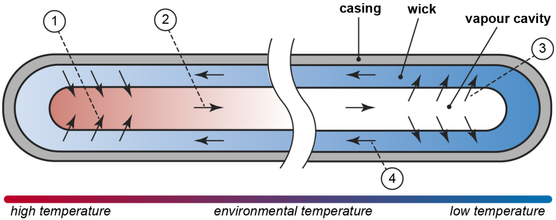
- transport heat via conduction (airflow required)
- bigger surface $\implies$ better dissipation
- affected by: air velocity, material, fin design
- up to 50W/cm^2

Heat pipe

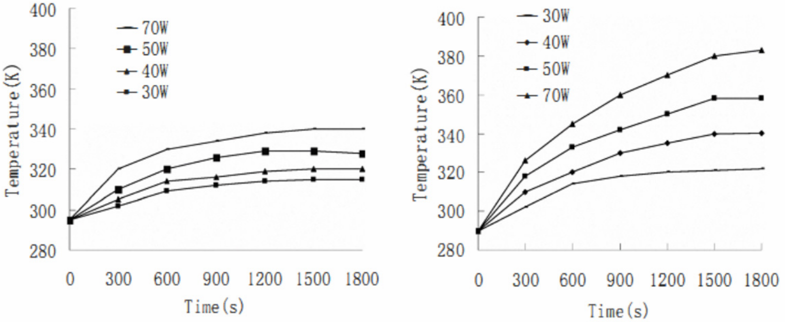
- sealed pipe with working fluid
- higher conductivity
- bigger diameter increases efficiency
- up to $100 W/cm^2$

Heat pipe principle *(source: internet)*



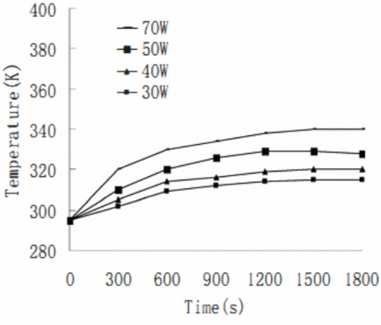
Heat pipe thermal cycle
1) Working fluid evaporates to vapour absorbing thermal energy
2) Vapour migrates along cavity to lower temperature end
3) Vapour condenses back to fluid and is absorbed by the wick, releasing thermal energy
4) Working fluid flows back to higher temperature end

With & without heatpipes

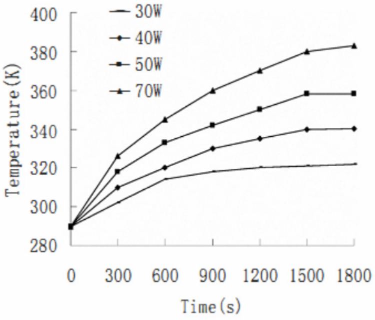


(a) heat pipe radiator (b) finned radiator

With & without heatpipes



(a) heat pipe radiator



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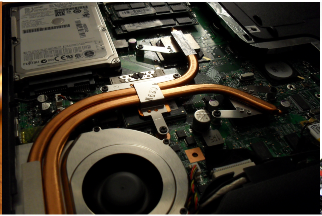
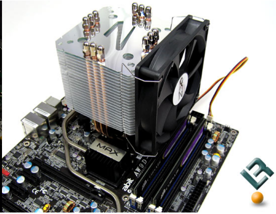
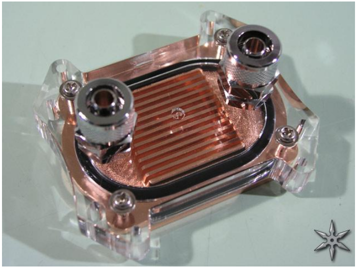
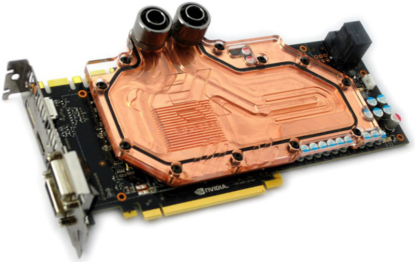




Cooling blocks

- special blocks for every component
- fin design

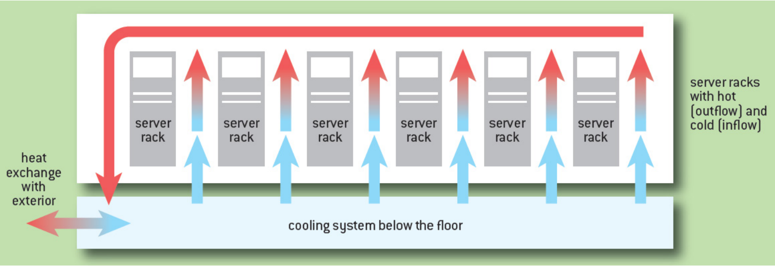




Outline

Room oriented cooling

- traditional approach
- fans push/pull air
- optimized airflow: cold air under the floor



Advantages

+ highly flexible
+ low complexity
+ cheap to buy

Disadvantages

- limited to 10kW/rack
- hotspots
- mixed air $\Longrightarrow$ low (energy)efficiency
- high airflow required

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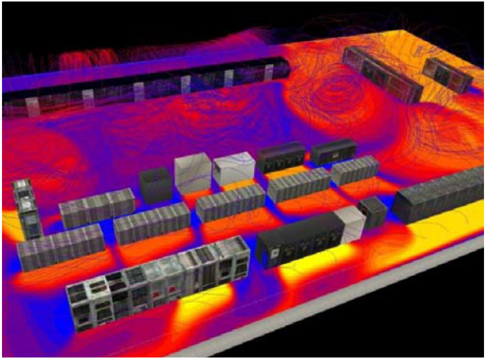

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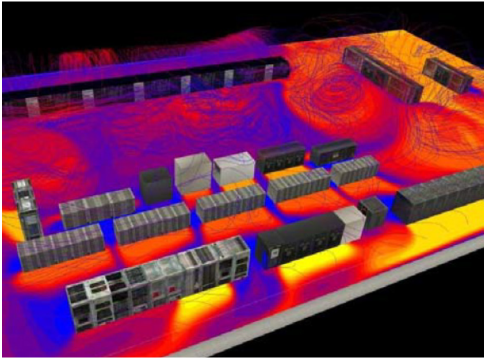
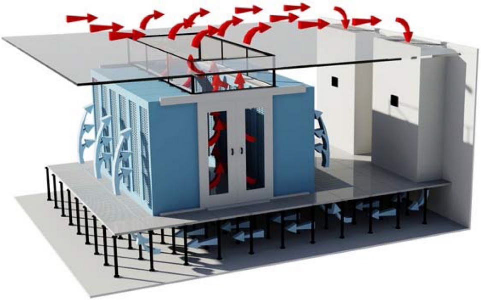
e.g.: 10kW/m^2, $\triangle$T= 15°C $\implies$ requires 1 - 2m^3 per m^2 per second!



Row-oriented cooling

- dropped ceilings/chimneys
- separation of hot & cold air



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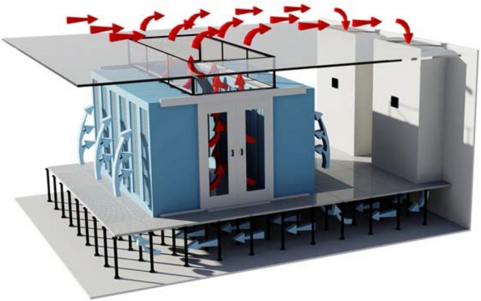


Advantages

+ $\approx$ 30% more energy efficient
+ up to 40kW/rack
+ hotspots less probable

Disadvantages

- more complex (still good)
- lower flexibility (still good)
- pressure has to be identical (overheating) $\Longrightarrow$ difficult calculation of fan power

Rack-oriented cooling

- one chimney per rack
- additional watercooling of the rear doors of the server



Advantages

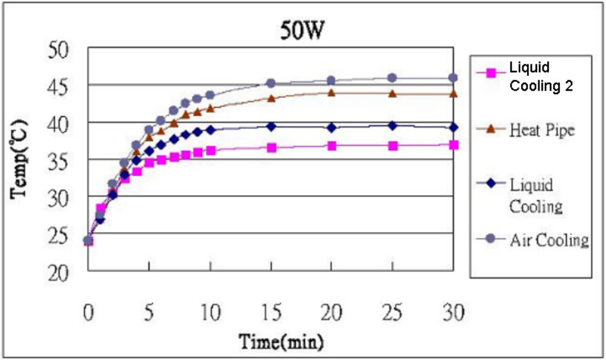
+ air of different racks not mixed $\implies$ less hotspots
+ leads to higher energy efficiency
+ lower temperature of the server room
+ up to 60kW/rack

Disadvantages

- more complex (pipes & connector to rack)
- lower flexibility; if no more space $\implies$ additional infrastructure has to be built
- higher costs (complexity & additional infrastructure at the beginning because later: difficult)
- more items $\implies$ higher probability of drop out
- less air/coolant: fail $\implies$ faster overheating $\implies$ emergency shutdown

Other cooling mediums

- air is a bad thermal conductor: flux water vs air $\triangleq$ 3526:1 (T=25°C)
- replace air by water/ other liquid
- hybrid cooling possible



Advantages

+ more energy efficient (no fans)
+ up to 100kW/rack

Disadvantages

- complex infrastructure (pipes & cooling blocks)
- very low flexibility (different hardware $\Longrightarrow$ different cooling blocks)
- higher costs
- risk of leakage

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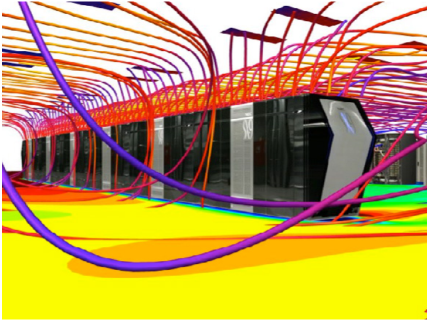
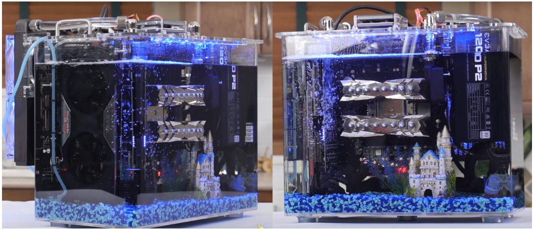


Oil-immersed cooling

- air replaced by oil; fully immersed
- oil is non-conductive
  $\Longrightarrow$ can (un)plug cables



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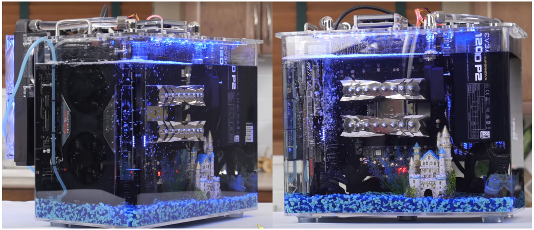


Advantages

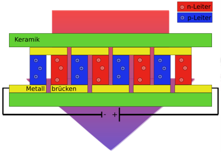
+ higher thermal capacity
  $\Longrightarrow$ low flow rate
+ low noise

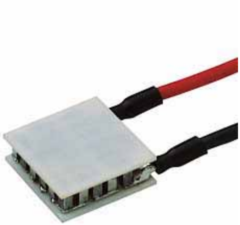
Disadvantages

- extra silicone cases for disk drives
- replacing hardware is difficult
- warranty

Thermoelectric cooling

- consists of n- & p-type semiconductors
- current $\Longrightarrow$ n- to p-type $\Longrightarrow$ heatabsorption





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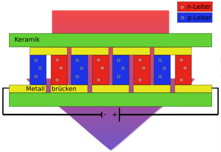
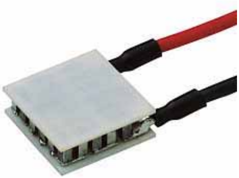




Advantages

+ very small
+ easy to regulate
+ cooling temperature way below ambient
+ no moving parts

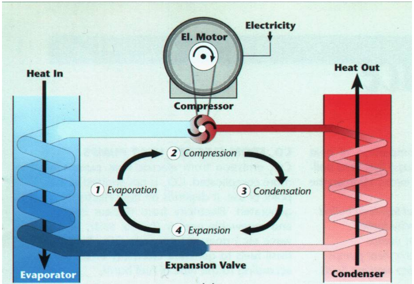
Disadvantages

- generates extra heat
- efficiency only 10% of Carnot
- material with high electrical and low thermal conductivity needed

Outline

Gas based cooling/Thermodynamic cycle

- carnot/stirling process: fridge



(a)

Gas based cooling/Thermodynamic cycle

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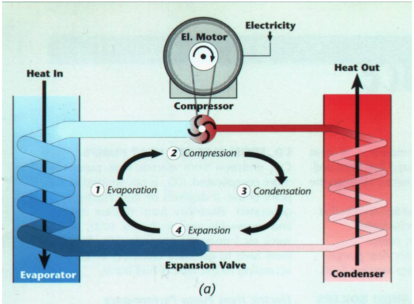


Advantages

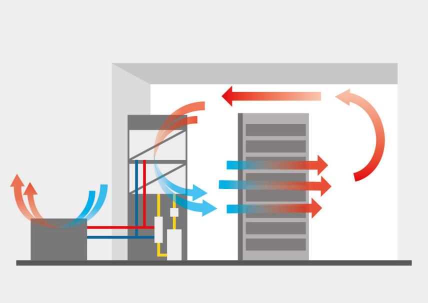
+ handles low grade heat(low Δ)
+ not climate dependent
+ mature and cheap (buying)
+ easy to install

Disadvantages

- needs power
- heat pump alone: 25% of cooling load
- decreased efficiency with higher outside temperature

Indirect free cooling

- outside temperature below 10-15°C $\Longrightarrow$ no compressor needed
- often complementary
- more power if: increasing working temperature/ evaporative assist



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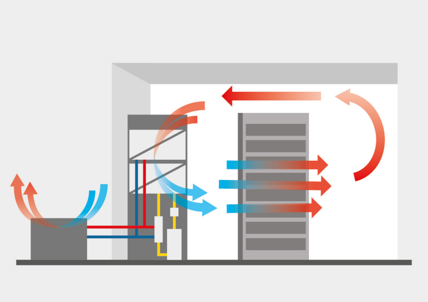
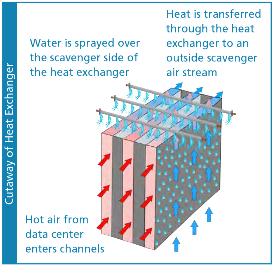
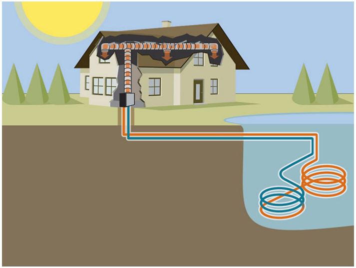






Indirect free cooling

Advantages

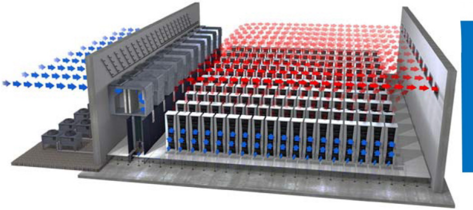
+ total consumption: 10-20% of heatload (friction, fans)
+ low operational costs

Disadvantages

- depends heavily on the climate
- often not suitable for heat dense systems
- requires more space

Direct free cooling

- outside temperature below 15-20°C $\Longrightarrow$ no compressor needed
- similar to IFC but air intake
- evaporative assist can increase performance



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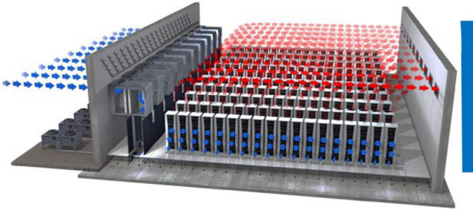


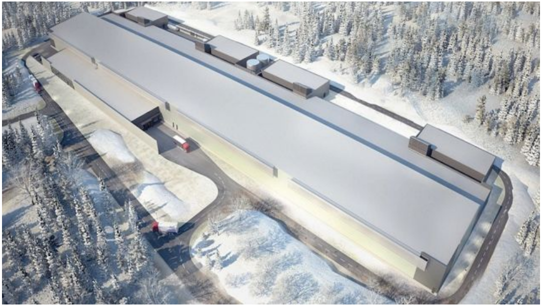
Advantages

+ about 40 % more efficient than CRAC based solution

Disadvantages

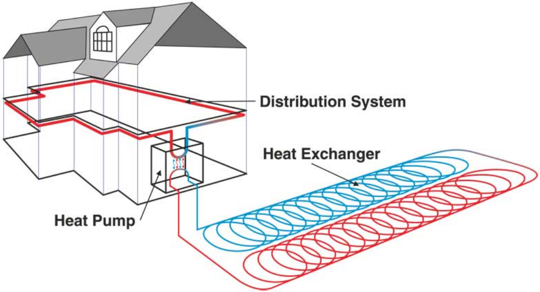
- 50% more space than CRAC based solution

E.g.: facebook server in Sweden



Geothermal exchange

- constant temperature (10-20°C) if below 2m



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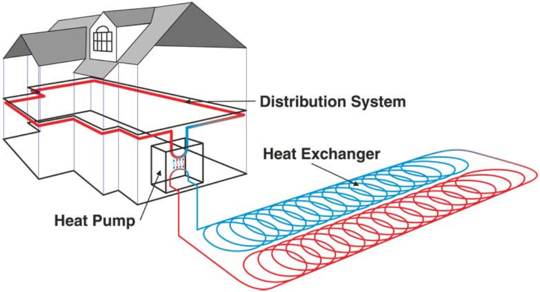


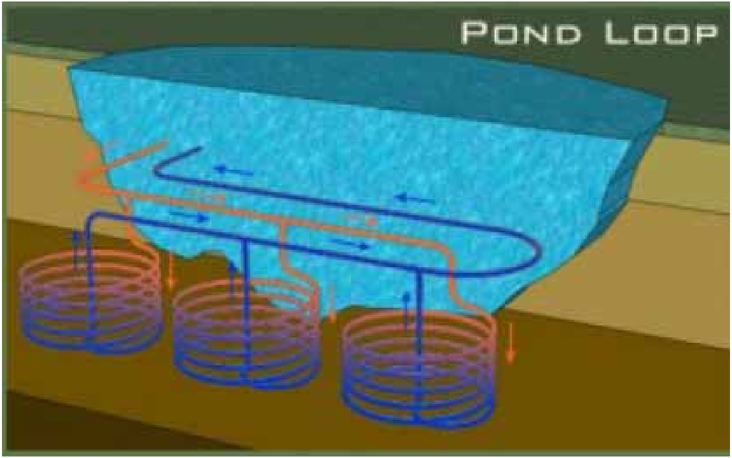
Advantages

+ works in most climates
+ no fluctuations

Disadvantages

- 35-50m needed for 1kW

Combined



Outline

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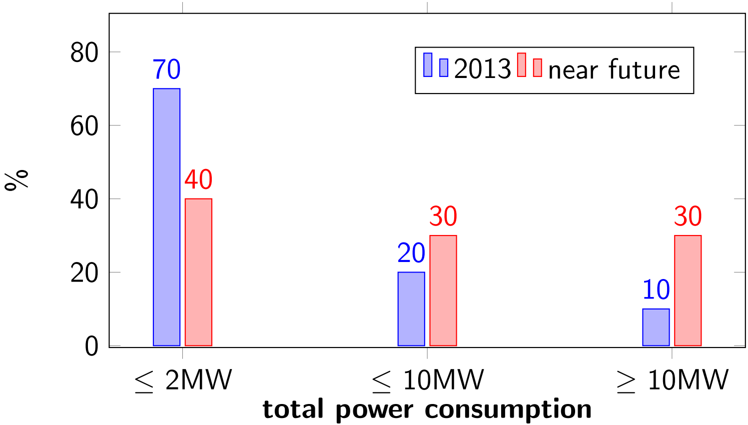
- 

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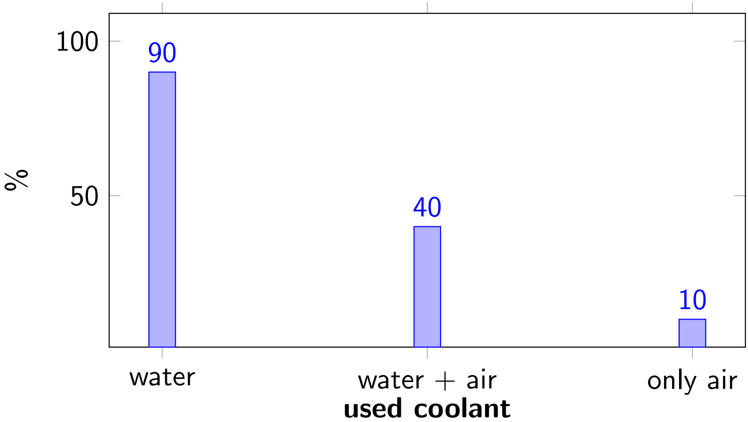
- 

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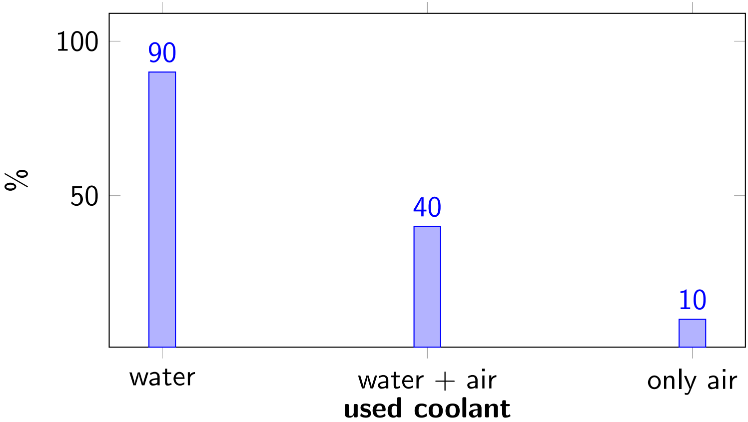
- 

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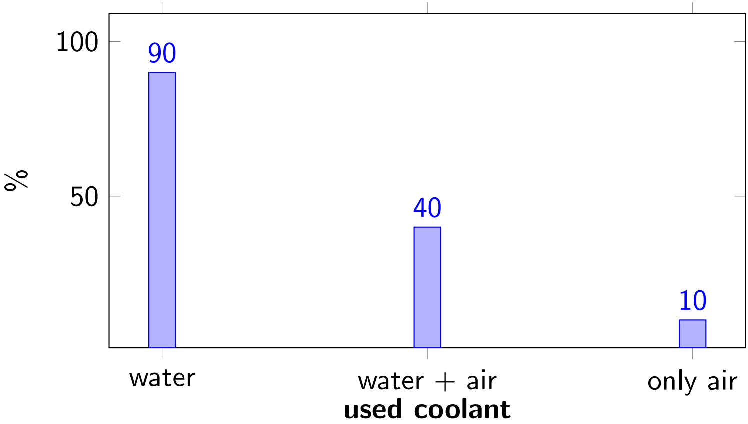
- 

- heat reuse is not too common (low grade)
- heat dissipation is mostly air

- Microsoft puts cloud into the ocean

Thanks for your attention!

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...nope, no potato

Sources

http://large.stanford.edu/courses/2012/ph240/lee1/

https://queue.acm.org/detail.cfm?id=1737963

http://www.electronics-cooling.com/2005/11/advances-in-high-performance-cooling-for-electronics/

http://dsiventures.com/wp-content/uploads/2014/07/CPU-Cooling-Technologies.pdf

http://www.prace-ri.eu/IMG/pdf/hpc-centre-cooling-whitepaper-2.pdf

http://www.notebookcheck.com/fileadmin/_migrated/pics/core_i7_einbau8_01.jpg https://upload.wikimedia.org/wikipedia/commons/c/cc/Samsung-Exynos-4412-Quad_SoC_used_in_I9300.jpg

http://techreport.com/r.x/core-i7-5960x/cpus-top.jpg

http://www.fz-juelich.de/SharedDocs/Bilder/PORTAL/DE/pressebilder/PM2013/13-08-02K-Supercomputer_450.jpg?__blob=poster

http://i.dailymail.co.uk/i/pix/2012/10/17/article-2219188-158CE597000005DC-42_964x507.jpg

http://www.extremetech.com/wp-content/uploads/2012/01/Heatmap-348x196.jpg

http://hardwarelogic.com/articles/reviews/cooling/Thermal_Paste/CPU_2.jpg http://www.congatec.com/fileadmin/_processed_/csm_abbildung1_Aufbau_Heatspreader_56ca5130a2.jpg

http://images.pcworld.com/images/article/2011/12/amd-done-6653394.jpg

http://rakaz.nl/wp-content/uploads/2009/07/20050119-chip.jpg

http://www.ixbt.com/cpu/images/p4-throttling/prescott-06.png

https://www.pugetsystems.com/images/pic_disp.php?id=34612

http://s3.electronics-cooling.com/legacy_images/2000/12/2000_December_figure07.jpg http://s3.electronics-cooling.com/legacy_images/2000/12/2000_December_figure02.jpg

http://www.nanowerk.com/spotlight/id1762_1.jpg

http://www.globalspec.com/ImageRepository/LearnMore/20147/forged-fin234a7de7ea1e437eb2d86dd4b2c2f926.png

http://s3.electronics-cooling.com/wp-content/uploads/2013/03/fig2a.jpg

http://www.frostytech.com/articleimages/200911/sinter-thermolab.jpg

http://www.legitreviews.com/images/reviews/471/vindicator_installed2.jpg http://www.ninjalane.com/images/aquagate/blocktop1.jpg

https://pressdispensary.co.uk/q991404/images/img_8926.jpg

http://www.12v-kuehlgeraete.de/Peltierelement%20Bild.jpg

https://colibris.home.xs4all.nl/bilder/compression_refrigeration_diagram.jpg

https://www.stulz.de/fileadmin/_processed_/csm_FreeCooling_whitepaper-04_62c253d7ba.jpg

http://www.ahumagazine.com/wp-content/uploads/STULZ-IeCE-Cutaway-of-Heat-Exchanger.jpg http://websterandsonswelldrilling.com/geothermal-ground-loop-heat-exchange.jpg

http://ecorenovator.org/forum/attachments/geothermal-heat-pumps/3396d1379184630-heat-pumps-dummies-beginners-guide-gshp_image-jpeg

http://c2109116.myzen.co.uk/wp-content/uploads/2013/03/open_cooling_water_system-1024x365.jpg

http://www.climatemaster.com/residential/wp-content/uploads/2013/09/geothermal-house-pond-lake-loop.jpg