A Heat Re-Use System for the Cray XE6 and Future Systems at PDC, KTH

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***Abstract*—The installation of a 16 cabinet Cray XE6 in 2010 at PDC was expected to increase the total power consumption from around 800 kW to 1300 kW, an increase of 500 kW. The intention was to refund some of the power cost and become more environmentally friendly by re-using the energy from the Cray to heat nearby buildings. The custom made system, which makes it possible to heat nearby buildings at the campus without using heat-pumps, is described in detail. The principle of the system is that hot air from the Cray is sent through industrial heat exchangers placed above the Cray racks. This makes it possible to heat the water to more than 30 °C. The problems encountered and the experiences gained are described as well as projection for the savings. A method of describing a mix of different cooling requirements shows the way for future improvements and addition of future systems.**

Keywords-heat re-use; Cray; cooling; heat exchanger; district cooling; district heating

I. BACKGROUND

PDC Center for High Performance Computing is the major of six academic supercomputer centers in Sweden and is hosted by the Royal Institute of Technology (KTH) in Stockholm. Before the installation of the 16 cabinet Cray XE6 in 2010, we consumed around 800 kW electric power. The Cray was estimated to add 500 kW.

The energy consumption had already increased significantly over the years and this will probably continue in the future. The development of PDC in terms of energy consumption is presented in Fig. 1 where power consumption is plotted against time together with some projections for the future.

In Stockholm, electric energy is still available for around 0.1 €/kWh but rising [6]. The figures show not only the steady increase in demand of electrical power, but also clearly one key factor in the economy of large computer centers: The energy cost.

Cooling of the computer hall was done with a district cooling system, which exists in the Stockholm area. Input temperature is 8 °C to the computer room and outgoing water temperature has to be at least 10 °C higher according to the requirements of the energy company. This is already a quite environmentally friendly method of cooling since the company producing the cooling water produces district

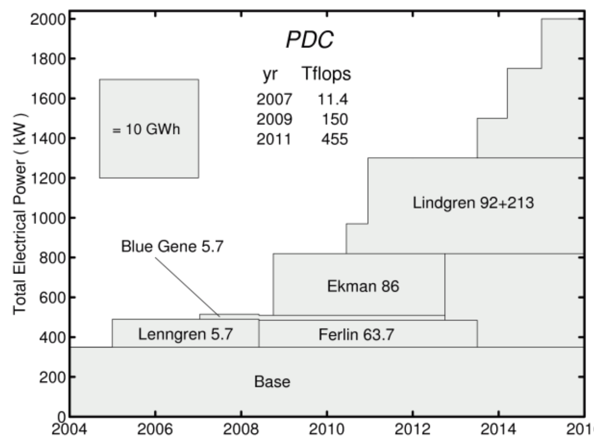

Figure 1. Power consumption at PDC.

heating, with heat pumps, from the returning cooling water. Additional cooling is done by sea water. However, KTH does not get any reimbursement for produced energy but has to pay around 0.06 €/kWh to get rid of the energy. Moreover during the cold season in Stockholm, KTH has to pay for district heating from the same energy company with a rate of 0.06 €/kWh.

Since the distinct cooling is less reliable than what is required for computer operation a method of emergency cooling without using district cooling has to be used as a backup. Locally produced cooling is limited by two factors. In the first place, the current contract with the district cooling company forbids us to produce additional cooling. Secondly the PDC building and parts of the campus area are protected as listed buildings and outdoor equipment must be limited. In our case we use tap water directly or with compressor cooling as emergency cooling.

In the computer room we use two methods of cooling: Low density equipment is cooled by ambient cooling from ordinary Computer Room Air Conditioners (CRAC) units, see Fig. 3. High Density equipment is cooled by hot aisle encapsulated cooling from APC [1], see Fig. 2.

Figure 2. Encapsulated hot aisle in the APC cooling.

Figure 3. Row of computer room air conditioners (CRACs) in the PDC computer hall.

Even if the cooling was quite efficient and environmentally friendly we had the idea to do something even better for the new Cray and possibly future systems. We also liked to save some money; even if district cooling is fairly environmentally friendly it is not free. The present cooling cost is around 60% of the electricity cost. We would rather like to see a solution where we could refund some of the electricity cost.

II. Preliminary Investigations

The idea we had was to heat a nearby building with the energy from the planned Cray installation. Many different methods doing this were investigated by the project group formed by PDC, the owner of the KTH buildings Akademiska Hus and the consulting companies Sweco, Incoord and Hifab.

The current, above mentioned, methods of cooling were producing a coolant temperature of 18 °C which is too low to heat normal buildings. The Cray liquid cooling solution [2] was also found to produce output temperatures of the same range. The temperatures could of course be increased by using heat-pumps. However, this would involve an even further increased use of electricity and calculations showed this to be barely economical.

The Cray system, in its air cooled version [3], takes in cold air (less than 16 °C) from under the raised floor and exhausts the air on the top of the racks with a temperature of 35 – 45 °C in normal operation. This means that useable temperatures exists in the system, the question was just to extract it without losing too much in temperature. Investigating standard industry air – water heat exchangers showed that such units could be used and would produce useful water temperatures.

The next problem to solve was where to place the heat exchangers. Efficient exchangers tend to be large and heavy and contain water with the potential for leakages. Several options were investigated for example to place the units on the side of the Cray but in the same row or to place them in-between the racks. Both options would require considerable amounts of computer room space, something we did not have too much of. The latter solution would also mean that Cray would have to change the cable layout of the system, which was not an option. Placement directly above the computers was considered too risky from a leakage point of view.

As a suitable recipient of the recycled heat, we investigated several alternatives and we found that a nearby building accommodating the Chemistry Laboratory at KTH was a good candidate. First of all the building was undergoing renovation and more over the building required large amounts of air to ventilate the potential dangerous fumes from the laboratories without any recovery of heat to the fresh air in conventional ways.

III. Final Solution

A. In the computer center

The main components of the system in the computer room are large industrial heat exchangers. Considerable planning was spent on placing the heat exchangers due to their large size and risk for water leakages. The final solution was to place the heat exchangers on top of the Cray hanging from the ceiling but slightly displaced so that they are not situated directly on top of the computer racks. This does not eliminate the problem with a leakage completely but will hopefully reduce the consequences of at least a small leakage. Hot air from the top of the Cray is fed to the heat exchangers via chimney-like ducts. The fans in the Cray system were found strong enough since they already were designed for the extra pressure drop of the cooling coils in Cray's liquid cooling solution. Due to the size of the room, it was decided at an early stage to place the sixteen Cray racks in two rows. But even eight racks were too large for one single heat exchanger. Thus, we decided to divide the heat exchanger so that each heat exchanger handles four Cray racks.

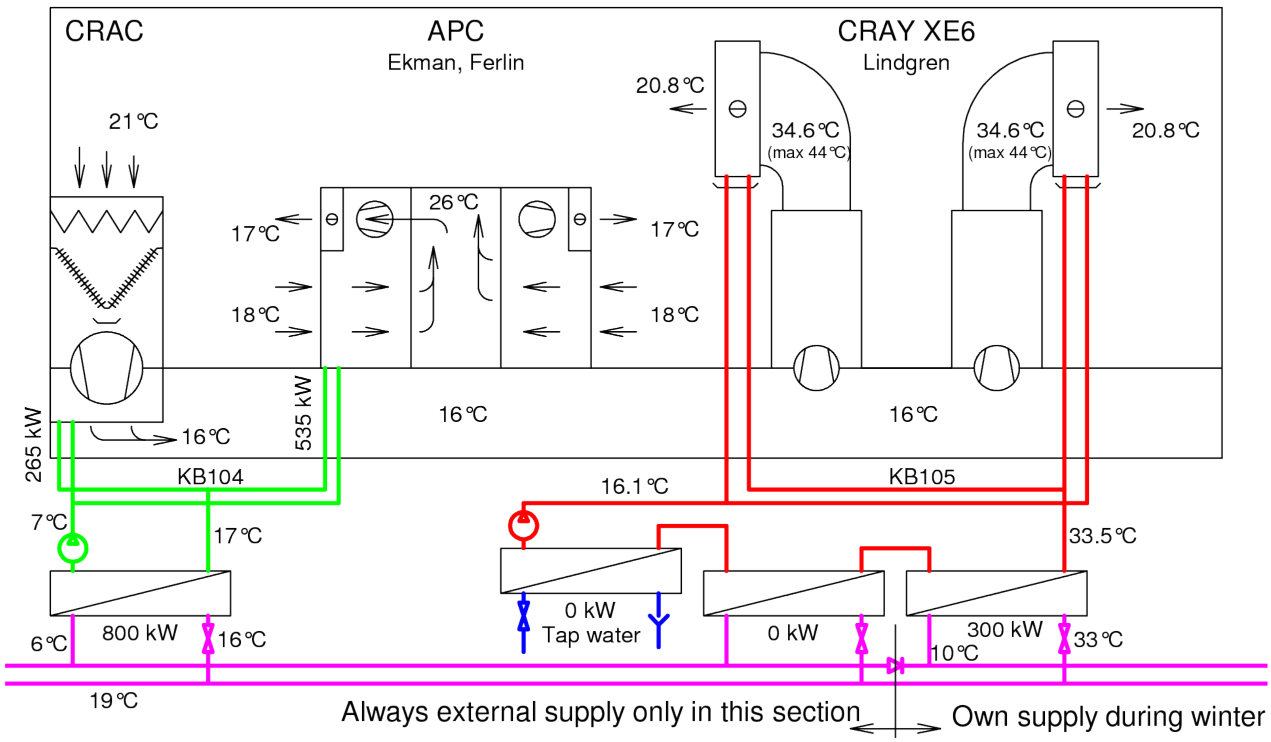

Figure 4. Layout of cooling in PDC: Ambient cooling via CRAC-units (left) and hot aisle APC connected via KB104 to district cooling (with back-up).Also seen is KB105 serving Cray racks with high temperature cooling downstream the check valve backed up by conventional district cooling and tap water cooling.

Fig. 4 and Fig. 5 show the principle solution in the computer room. The Cray requires a temperature below 16 °C under the raised floor. The existing CRAC units in the computer room can handle that if the total heat load is kept within the specification of the units. The Cray takes the 16 °C air under the floor and heats it to 35 – 45 °C in the outlets at the top of the racks from where it is fed via the ducts to the heat exchangers, cooled to around 21 °C and expelled to the room. This heats the water from around 16°C to 30 – 35 °C. The water is circulated in a closed circuit that can be cooled by three different heat exchangers placed outside the computer room: one for heat re-use, one for district cooling and one for ordinary tap water if everything else would fail (Fig. 4). In general, the heat re-use system is controlled by the building control system. The emergency cooling and the valves in the computer room are however handled by a separate control system to keep it completely independent from other parts of the system.

B. Transporting the water

The question now was how to connect to the Chemistry building. Laying down new pipes was assumed to be too expensive. Then the idea to use existing systems to transfer recycled heat came up.

The campus is supplied by district heating and cooling water in one point from where it is distributed to buildings on campus in our own networks. The temperature requirements are higher than 60 °C in the feed line in the heating system and lower than 10 °C in the feed line the cooling system. However, no certain temperature requirements exist for the return lines except that the temperature of the cooling water has to be raised by at least 10 °C in the district cooling circuit. By working within these boundaries, it would be possible to use existing pipes.

Among conventional waste heat sources such as water cooled low temperature chillers, air and helium condensing plants, distillers, compressors and to some extent testing equipment in physics and material science, the super computer center represents the by far the largest single cooling water user on the campus. Of a total of 2,000 kW PDC uses 1,300 kW. This high cooling load requires large amounts of cooling water to be circulated. No further margins existed, and we were requested to utilize the cooling water better.

As the return pipe preferable is kept warm to keep down the flow rate, it at the same time obviously represents a possible source of low grade but for some purposes still usable heat. The higher the return line temperature is kept, the less coolant is used and the more useful for recycling is the heat. Hence a cooling water network may act as a distribution system for waste heat if it is run well enough.

Figure 5. Custom made ducts on top of the Cray lead the air through industrial heat exchangers.

For reliability and capacity reasons the cooling grid on campus is built as a loop network. The computer center is fortunately supplied from the same loop as the Chemistry building. Valves were closed to separate a section of this loop leaving the computer center in the upstream direction. A check valve was put in the feed line outside the computer center as shown in Fig. 4 and Fig. 6.

During the summer, the check valve is open and all cooling demands are supplied from the city. When the system for heat reuse is taken into operation, the flow direction in the intermediate section of the network is shifted as reused heat is taken from water in the return line which is pumped back to the feed line. At outdoor temperatures below 0 °C, all available waste heat is recycled and the check valve closes. The section between the valves is forming an isolated system solely used for transfer of the waste heat, now recycled and with a shifted flow direction. At warmer weather the check valve remains open leaving the flow direction to be only partially shifted.

The outgoing return temperature from the computer center is about 30 – 32 °C but since the system involves a certain amount of intermediate process cooling loads (building 17 and 18), all with significantly lower return temperatures, the temperature of the coolant arriving to the Chemistry building is only about 27 °C. This effect is more pronounced at higher outdoor temperatures when it is

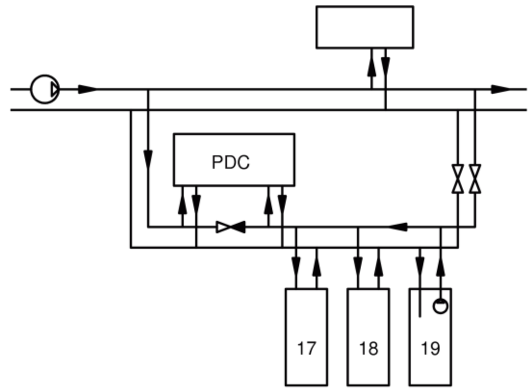

Figure 6. Ring shaped cooling system at the campus. The check valve closes and a self supplying section is formed once building 19 (the Chemistry building) is capable of taking care of all waste heat in the section. This happens at about 0 °C outdoor temperature. PDC uses coolant from both sides of the check valve.

possible to take care of only a minor part of the Cray computer heat, still involving all intermediate cooling loads and the temperature at the Chemistry building may drop to 20 – 23 °C. This is no problem since 18 °C is required as final temperature of the heated air, and the required power at such conditions is low. Instead, the temperature characteristics of the system seem to fit our needs quite well.

C. How the heat is used in the Chemistry building

At an early stage, the Chemistry building was pointed out as a suitable recipient of heat from PDC. Like most buildings of this kind in Stockholm, the house is fitted with a heat recovering ventilation system. However, in this case, the heat recovery suffers from the mismatch in flow caused by the widespread use of separate process ventilation without any heat re-use in the building. The inlet air requires extra heating due to the difference in flow rates of the opposing flows in each air handling unit. However, the temperature requirements on this additional heat are low. A heat source with a temperature as low as 15 – 25 °C is sufficient.

In an unbalanced liquid coupled ventilation heat recovery system like this, the most obvious solution would have been to directly feed the heat recovering loop with the missing amount of heat. To get a better separation in independent systems, another solution was tried where the inlet air is preheated by water side economizers (Fig. 7) in the form of needle heat exchangers mounted in the air intake although it was clear that the already existing heat recovery system would deflect more than 50% of the deposited heat.

The heat is supplied via a secondary system heated by water from the warm return line of the cooling system. Whenever the temperature in this secondary system drops below 10 °C, it becomes possible to maintain the required temperature allowing the water to be pumped back in the feed line of the cooling network.

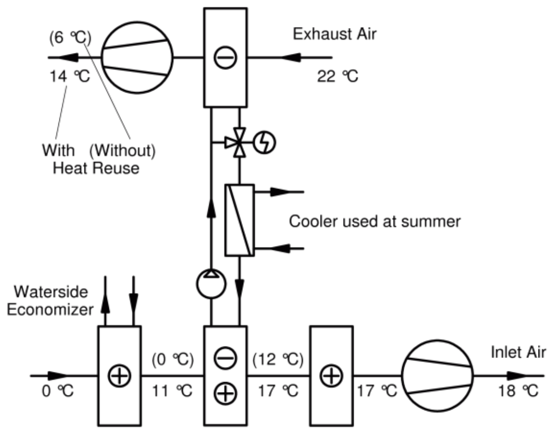

Figure 7. Current design in the chemistry building. Recycled water from the computer center pre-heats incoming air to the building.

IV. Experiences

The designed system is rather complex and there are many different choices to be made and little or no previous experience to refer to. A general problem collaborating with cooling and energy experts is that they generally work with buildings, buildings that may last hundred years and installations which may be functional for 30 years or more. In this case the parts of the system which are close to the computer have to be replaced when the computer gets too old after maybe just four years. Ordering and installation of a supercomputer is also considerable faster than doing anything on the cooling side.

An additional problem was that computer vendors are not normally used to work with custom design installations; it may be hard to get the correct and up-to-date information about details that ordinary customers don't bother with. In our case we had to have exact measurements to fit the hood onto the Cray rack. We visited CSC in Finland just to take measurements and see that everything would fit. Cray was also most helpful to provide information and drawings, but they forgot to tell us about a minor mechanical design change on the top of the rack. Fortunately it was possible to make the required changes of the ducts on site.

Another problem was to understand the over-all control of the system, which is distributed over many independent control systems. One typical example was the control of the under floor temperature in the computer room. This was expected to be handled by the old CRAC units. If they get an intake air temperature of 22 °C they produce just below 16 °C, which is acceptable. However, the measurement is just done in the intake and also controls the start of the emergency cooling in the CRAC units. This means that when a CRAC unit fails the under floor temperature increases and the outgoing temperature from the heat exchangers above the Cray increases. This makes the control system for the heat exchangers to open the valves on the water side somewhat more, and the temperature of the room is brought back to 22 °C. Everything seems normal and the emergency cooling is never started. However, the under-floor temperature is now too high, and the Cray can get damaged or shut down. Obviously the control of the CRAC units had to be changed. This was done by physically moving the temperature sensors to under the floor. In the first attempt the sensors were placed just under the Cray. This didn't work so well because a sensor belonging to one CRAC unit was affected too much by the other units. Therefore, the sensors were moved back to a position fairly close to each unit but still under the floor. This works reasonable well.

After some initial adjustments the system has worked remarkably well, and we haven't had a single interruption caused by the cooling system. Also when the district cooling has failed and the outdoor temperature has been low enough we have been able to cool the Cray with the heat re-use system. Since the cooling system is dimensioned for a forward temperature of around 20 °C when in heat re-use mode, the forward temperature of the district cooling system of normally 8 °C can vary substantially without triggering a start of the emergency cooling. This makes the system highly stable.

The arrangement with air-water heat exchangers on top of the racks hanging from the ceiling but slightly displaced offers a large degree of flexibility considering future installations. As a bonus, the space below the raised floor is left free from bulky tubing.

The use of the cooling network for distribution of recycled heat requires the transfer media to be kept within certain thermal limits but also offers advantages as any interruption in operation of heat consuming systems never affects the waste heat source itself. Thus, instead of making the system more sensitive, recycling obviously rather increases the reliability of the system as was demonstrated in the above mentioned failure in district cooling.

Since the cooling system is used to transport the heat, an additional temperature requirement must be observed: As heat is recovered from the return line water, the water must be cooled down to sufficiently low a temperature to allow the water to be pumped back in the delivery line. This means that the system can only be operated during cold weather, apparently not a big problem since during warm weather no heat is needed in any case. However, the saving in usage of the district cooling as well as the number of annual operational hours would be much greater if the feed line temperature could be allowed to be higher.

We would also strongly recommend a solution directly involving any already existing liquid coupled heat recovery system, see Fig. 8. In many ways, such a system would be simpler and more efficient. This is also the standard configuration when the heat recovery loop is to be used for comfort cooling during the summer. That means that in most common modern liquid coupled heat recovery systems, all necessary heat exchangers and piping already exists, just waiting for the computer heat to be recovered.

The needle heat exchangers have shown to be clearly less temperature efficient than the already existing heat exchangers for ventilation heat recovery. The extra batteries

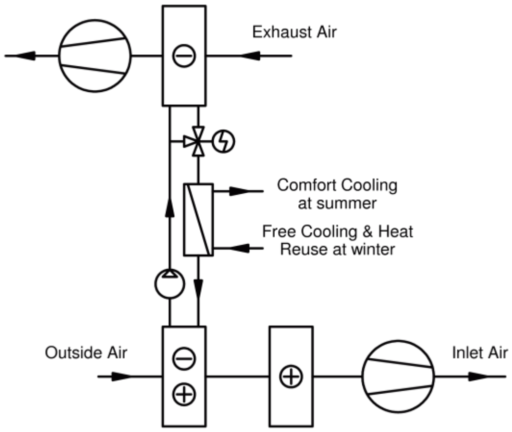

Figure 8. Suggested improved design in the chemistry building. This design doesn't need an additional heat exchanger.

also introduce extra pressure drop in the air stream making the system less energy efficient by somewhat adding to the power consumption of the fan.

Contrary to the massive advertising, our needle heat exchangers mounted before the air filters have shown to be difficult to keep clean which is more important in advanced heat transfer systems with surface loads like this. Together with the single pass cross flow concept, the bad capacity of this kind of heat exchangers makes it necessary to reduce the water flow to extremely low rates if the temperature in the return line is to be kept below a certain limit as in our case. Nothing has been won in simpler control via the solution with economizers independent from the heat recovery system. The bad properties of the needle heat exchangers instead made the control difficult, and we have only barely reached the expected power.

As a result, even with high inlet water temperature it has been impossible to bring up the power enough to reach the desired inlet air temperature if only recycled heat is used: We have to discard high grade heat from the computers at the same time as additional district heat is needed.

V. Expected Cost Savings

The system was taken into ordinary use and full operation during this winter. Some optimizations are still required to reach the set goals. The Cray consumes around 500 kW in normal operation. Of that around 10% is used in the power supplies and other parts cooled by air not captured by the heat re-use system. Moreover, an additional 30% is lost due to the fact that the coils only lower the temperature to around 21 °C and the CRAC units are used for the additional 5 °C required to reach the under floor temperature of 16 °C. The system can be effectively used around 50% of the year, due to the climate in Stockholm. All together this means that PDC can send around 1,300 MWh of energy per year to the Chemistry building. This saves district cooling costs at PDC with an approximative value of 80,000 €. The Chemistry building was already equipped with heat re-use from recycled air. This has an efficiency of around 50%. With the current design this means that in district heating we save correspondingly about 50% of what is received from PDC, in this case giving a saving of 40,000 € per year. Thus, total savings per year are around 120,000 € for a normal year.

VI. Future Development

A. *How much building area can we heat?*[1]

Buildings in Stockholm require 100 – 200 kWh/m^2 [5] per year for heating. The total amount of heat from PDC, 11.4 GWh/year, would be enough for 50,000 – 100,000 m^2 if all heat could be utilized. Even far up in the north, energy for heating is still needed only for a limited part of the year, in Stockholm about 6,400 hours a year [4]. Further, the coldest days during the winter require more than three times as much heat as the average day during the heating season and more than four times the yearly average.

This means that the heat utilization will be very low in a building not larger than that the computers provide all heat needed even the coldest day (see 'A' in Fig. 9 – Fig. 11). Less than 30% of the available heat would actually be used for heating and PDC would not be able to supply more than needed to heat 15 – 25,000 m^2. To reach 50% utilization ('B') the heat source must not exceed 2.0 times the yearly average heat demand, i.e. during in average a little more than 500 hours per year an extra "peak load" supply of heat is needed. If the building is of the size that the yearly average heat demand equals to the available computer heat ('C'), i.e. above mentioned 50,000 – 100,000 m^2, about 70% of the available heat will be utilized and an additional heat supply is needed slightly more than 4,000 hours a year. Due to the limited length of the heating season, even an infinite building ('D') would yield in average no more than 88% utilization of the heat source, see Fig. 10.

The more buildings connected, the better the utilization.

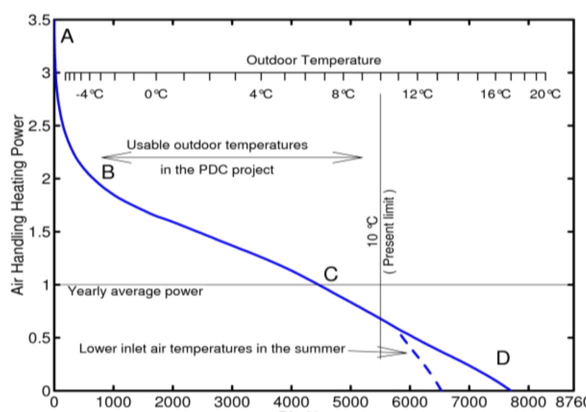

Figure 9. Ventilation power loss in Stockholm (1990-2010) relative to the yearly average vs. given number of hours exception. During the exception additional power is required.

[1] All data in section A and B is based on [4] and [5]

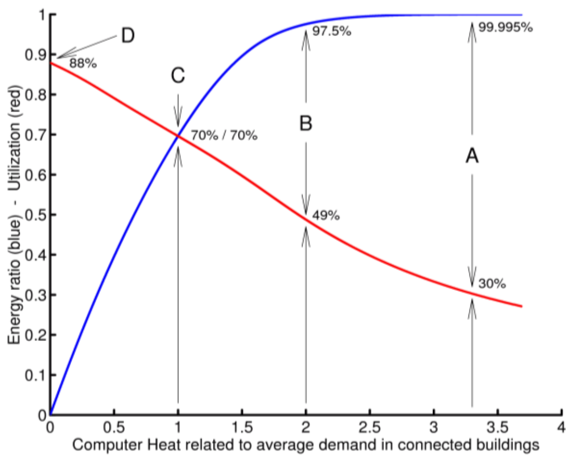

Figure 10. Heat re-use for Stockholm (1990-2010). The figure shows the variation in energy ratio (how much of the needed energy in the building is covered by re-used energy) and utilization (how much of the recovered energy is used in the buildings) depending of the size of the heat source.

However, the peak supply becomes more and more important even in terms of energy. In case ‘B’ still 97.5% of the heat is reused heat (energy ratio 0.975). In ‘C’ the energy ratio is only 70% and with twice as much buildings connected, 50% of the total amount of heat (energy ratio 0.50) comes from the computer center.

As we use a cooling water network to transport the heat, operation is not possible when the outdoor temperature is higher than the maximum allowed return temperature and the relation between receiver energy ratio and utilization of the total amount of heat becomes somewhat more complicated as Fig. 11 shows.

Contrary to the owner of a house who is interested in a high energy ratio to replace as much conventional heat as possible, the owner of the waste heat source is of course interested in getting as much building area connected as possible to get highest possible utilization. If any temperature requirement limiting the operation exists, there is obviously a lower limit in energy ratio below which there is no need to go further (red curve in the figure above). A good balance in energy ratio and heat utilization should therefore not be hard to find in any actual case.

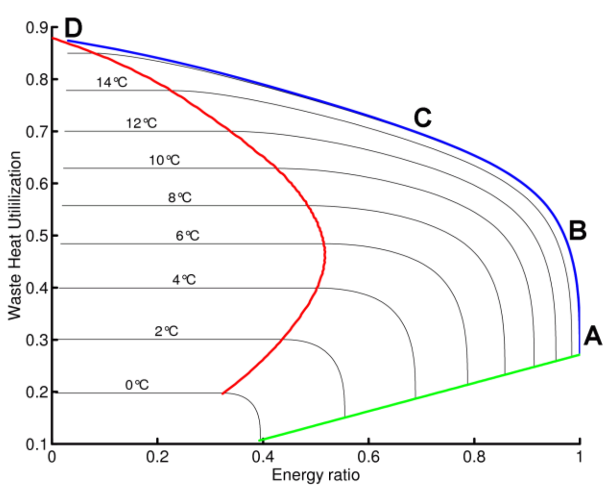

Figure 11. Variation in heat utilization depending on energy ratio when return temperature is limited by a fixed temperature. Blue line represents no limit.

The CRAY and intermediate cooling loads give 350 kW which is 2.5 times the average heat demand (140 kW) of the Chemistry building (12 m^3/s air). Via good heat exchangers it should be possible to supply around 98% of the heat but the utilization would be only around 40%. This means that around 60 % of the heat still must be discarded.

B. Heat and Temperatures

All year around, buildings require some heat for hot water production. At least 10% of this energy is used for keeping the temperature of the system, and the remaining 90% is required for the actual hot water production. The hot water volume varies somewhat over the year. However, varying incoming cold water temperature is the main contribution to yearly variations in heat consumption for hot water production. The temperature of the heat required to produce and keep the hot water warm is in average somewhat above 30 °C. Waste heat at 30 – 35 °C may thus stand for up to half the total amount of energy needed.

Depending on the climate, energy is also needed in the heating system during a shorter or longer period of the year. The temperature of the heat required for this differs a lot depending of the size of the radiators. However, even if heating system temperatures as high as 55 °C may be needed during particularly cold days, the mean temperature over the year is much lower.

Since ventilation contributes to about half the climate depending heat demand, it is actually possible to supply half the total amount of energy via air batteries, often showing remarkably high temperature economy and if not they are easily replaced. Further, it is not a good practice to bring the fresh air to a higher a temperature than 18 °C and one may also not forget that the fan itself heats the air by at least 0.5 °C. Air handling units may thus be constructed in such a way that incoming water of only slightly higher temperature than 20 °C is enough. The return line from an air handling unit is also usually kept colder than 20 °C and may thus function as a useful cooling water source always ready to take care of waste heat.

We have found it useful to present these three heating energy demands of a house by sorting energy by temperature. It becomes clearly visible, that almost half the energy needed for heating a building may be supplied at such a low temperature as 25 °C or below, mainly in air handling units. Some temperature loss occurs and therefore the actual temperature demand on the water is somewhat higher than the theoretical temperature demand of the air. The cumulative energy demand over the year of the building is marked with red in Fig 12.

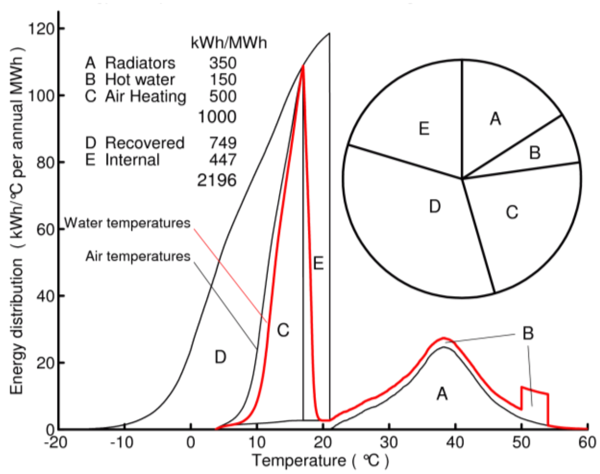

Figure 12. Energy demand with different temperatures in an office building in Stockholm (1990-2010).

Obviously, characteristics of a conventional, old fashion heating system are not as favorable considering operation temperatures as a floor-heating system (maximum 35 °C) would be. Still, over the year temperature requirements should not be difficult to meet via existing high temperature cooling techniques whenever a heat demand like this is to be matched with the waste heat flow from a computer center. However, to start with we decided to focus on the less challenging heat demand of the ventilation air stream, in the actual case corresponding to about 50% of the total energy used in the building.

The relation between total volumes of high and low temperature energy respectively can easily be shifted by altering the inlet air temperature. Besides that, all efforts must be made on maintaining optimum temperature economy in systems for capture and transport of the heat, something that requires careful balancing between heat capacity flow rates as now will be described.

C. *Computer center temperature strategy*

The heat sources in a computer center can be presented in the same way as the various temperature demands of the office building above. Fig. 13 shows cooling systems of the CRAY XE6 and the hot aisle encapsulated cooling (APC) in a diagram accordingly to their requirements on the air temperatures for cooling.

This can be compared to the cooling water system temperatures in Fig. 4 and it is now obvious that a CRAC or an APC unit cannot compete with the temperature economy of our CRAY heat reuse concept as shown in Fig. 14.

At first, the figures seem only to present the different characteristics of the computers at a center in a convenient way. However, a closer look reveals important facts about how an optimal cooling system should be designed and dimensioned. During the project, we have found diagrams like this a useful tool. The vertical axis represents W/°C, i.e. heat capacity flow. Directly from the figure the minimum amount of water required in the primary cooling circuit can be calculated by dividing the heat capacity flow by the heat capacity of the media in kJ/kg K. Optimum design in respect of temperature economy throughout all intermediate stages of heat exchange requires balance between all involved heat capacity flows. Obviously even the required minimum amount of air handled in the last stage of the chain (receiver of the heat) can be read out directly from the same diagram.

As heat capacity of water is about 4.2 kJ/kg K, the non Cray heat load requires a coolant flow around 80/4.2 = 19 kg/s. This amount of water from district cooling is heated from about 7 °C to 17 °C.

Fig. 14 shows that a fraction of this flow, 17/4.2 = 4 kg/s, could be heated further, all the way to 33 °C. The remaining stream, 15 kg/s as directly can be read out from the diagram, would still have to be discarded. However, still substantially more than the collected amount of heat handled by the

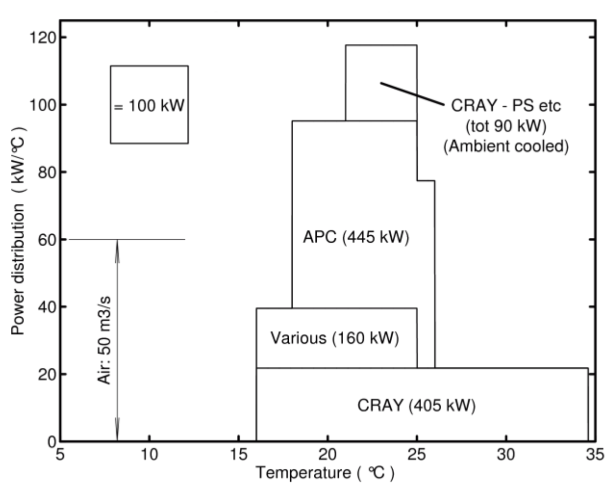

Figure 13. Cooling air temperature characteristics of computers at PDC.

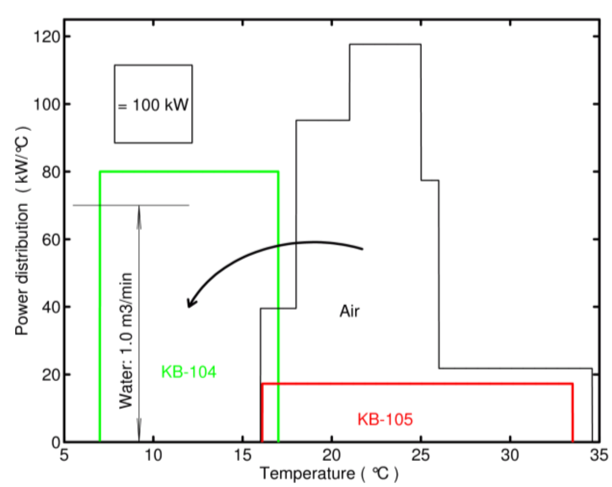

Figure 14. Cooling water temperature characteristics of computers at PDC. KB-104 is the district cooling circuit and KB-105 is the heat re-use circuit.

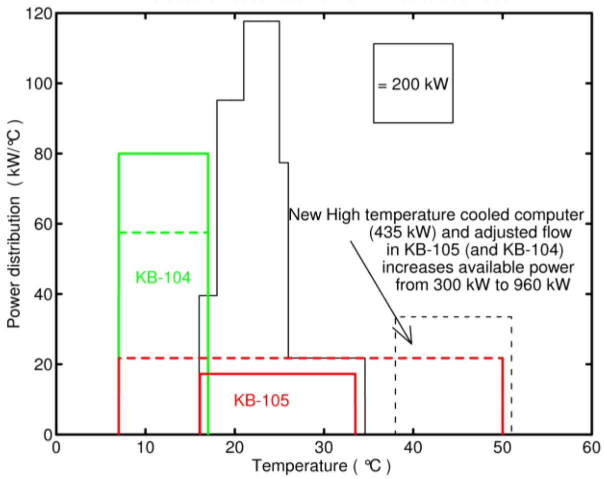

Figure 15. Increasing the amount of saved energy by connecting several computers with different temperature characteristics.

specially designed Cray computer cooling system, theoretically as much as 450 kW would be available for heating. This corresponds to the full amount of heat deposited in the 4 kg/s coolant stream which is heated from 7 to 33 °C. By balancing the flow to 21 kW/°C in the re-use circuit it would be possible to reach 525 kW. Since ventilation of buildings stands for a major part of the heat consumption and the outdoor temperature is lower than 7 °C for about 5,000 hours a year in Stockholm (1990 – 2010) [4] this would enable recycling of as much as 2.5 TWh per year. Fig. 15 shows that adding another high temperature computer (at least 51 °C output) with a power of 435 kW in the same chain would increase the available power for re-use up to 960 kW.

This concludes that a cooling concept does not have to rely on one and only high temperature solution. If only a part of a computer center is designed for the highest temperatures, another part of the center can be allowed to utilize the low temperature end in the same limited coolant stream. Cooling backup resources in the system will ensure that the coolant inlet temperature all the time stays within given limits. A temporary low heat demand or poor temperature economy in the heat distribution system will just reduce the utilization but not affect the computer center. However, all systems receiving the waste heat must be arranged for optimum temperature management to enable highest possible utilization, i.e. the highest temperature loads (hot water and radiator systems) coming first and remaining

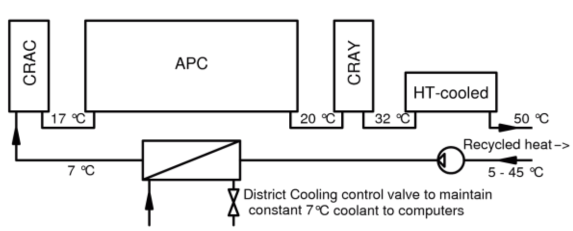

Figure 16. Heat sources at PDC connected in a chain.

heat demands (air handling) in series according to temperature before the water, hopefully at a temperature below 20 °C, returns to the computer center.

In the future we foresee such a mix of different cooling technologies at PDC: A chain (Fig. 16) beginning with Low temperature (20 °C outflow) cooling as the CRAC units and the encapsulated cooling used today will continue with medium temperature cooling (30 – 40 °C) as the current Cray and, finally, high temperature cooling (above 50 °C) with e.g. direct water cooling, submerged oil cooling or direct evaporative cooling, any of which may be used for the future high-end systems.

By connecting the cooling system in series, highest level of temperature efficiency and flow utilization can be obtained as discussed above. The development can continue, a growing fraction of the total heat becomes available for reuse and only the maximum temperature of the high-end system will point out when the coolant stream has to be increased further in heat capacity flow rate to enable the growth of our future, environmental friendly computer center.

VII. Conclusions

We have shown that it is possible to convert an air cooled supercomputer to produce heat by collecting the hot air close to the computer and leading the air through large heat exchangers. This has produced water hot enough, without using heat-pumps, to heat the inflow air into other buildings on the campus. By using an existing ring network for district cooling, it has been possible to avoid laying down new pipes. Several ideas exist to make the system even more useful in the future and also be adapted to other cooling techniques. The project demonstrates how temperature economy all the way from the chip to the final recipient is the key to enhanced energy performance in systems involving super computer centers.

VIII. References

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