EMERGING COOLING REQUIREMENTS & SYSTEMS IN TELECOMMUNICATIONS SPACES

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ABSTRACT

During the last several years, power density trends, and consequently thermal density trends in telecommunications spaces have become topics of increasing interest. This paper will identify several of the underlying drivers of these trends, project possible outcomes, and assess the impact on cooling system design for these spaces.

INTRODUCTION

The installation of Servers, Fiber Optic Switches, and other Internet required and related devices within traditional Central Offices, and the creation of the Internet Data Center as a new communication category, are increasing the power and heat density of these spaces. To illustrate this trend, the microprocessor can be used as one example of the level and direction of power usage. Figure 1 plots the three primary drivers of microprocessor power & density: the number of transistors per processor, the processor clock speed, and track spacing. Transistors turning on and off consume power, speed determines how often they turn on and off, and track spacing establishes the transistor density. Since 1975 transistors per processor have increased by approximately a factor of 4,000, clock frequency by a factor of 600, and spacing has decreased by a factor of 50. Note that the vertical scale is logarithmic. Plotting these curves on a linear scale, Figure 2, shows more dramatically the recent increases. The Pentium 4 microprocessor now has 42,000,000 transistors, is approaching 2GHz in speed, has a track spacing of 0.12 micron, and consumes approximately 50 watts at full power. Recent statements from Intel such as “The number of transistors on our processors should pass 200 million by 2005, and reach well in excess of 1 billion by the end of the decade”, and recent announcements by Sandia Labs of success in achieving a track spacing of 0.07 micron using Extreme Ultraviolet Lithography (EUVL), give a high degree of probability that these trends will continue in the near term. Based on this, Figure 3 shows projected microprocessor power usage. The International Technology Roadmap for Semiconductors projects microprocessor “maximum power” to be 170 watts in 2005.

These, and other trends have prompted a group of computer and communications providers to issue a report entitled “Heat Density Trends in Data Processing Computer Systems, and Telecommunications Equipment”, projecting “Heat Load per Product Footprint” for Communication equipment to be as high as 60,000 watts/m2 in 2005, and Servers to be as high as 15,000. See Figure 4. Heat densities of this magnitude will require substantial changes in the way heat is currently transported out of the space.

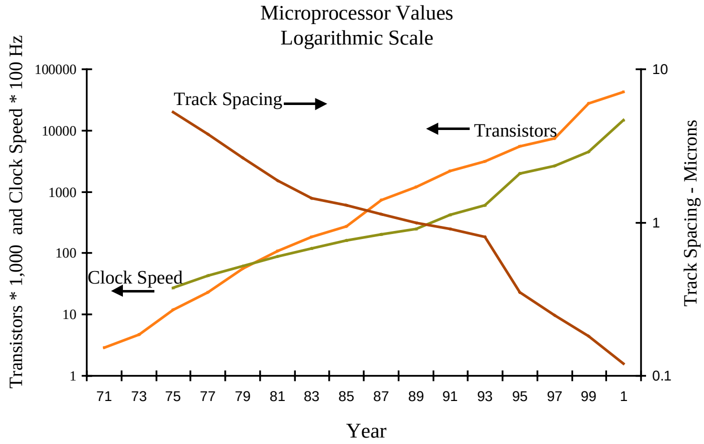

Figure 1

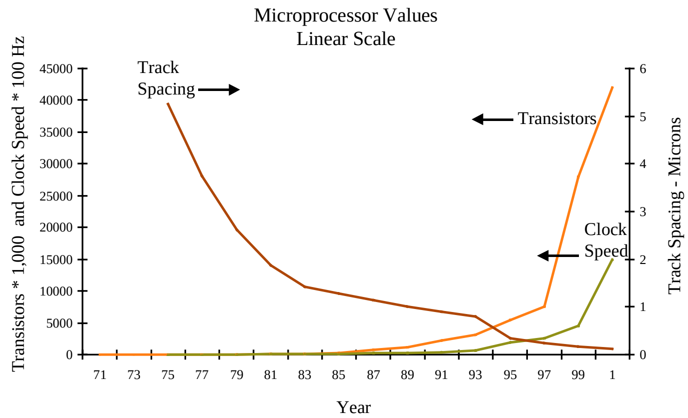

Figure 2

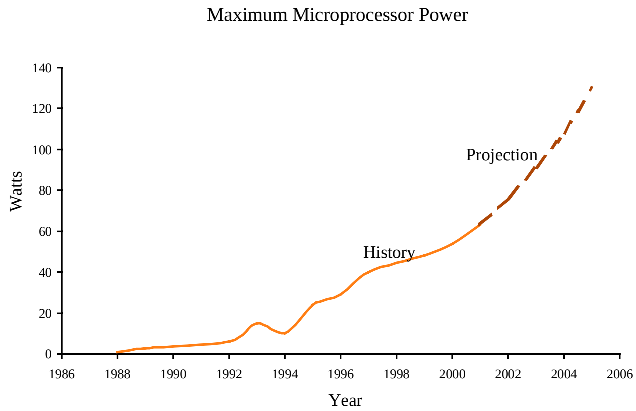

Figure 3

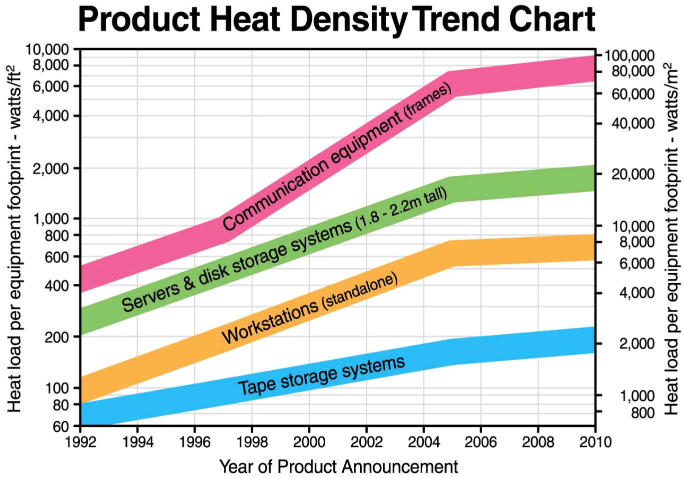

Figure 4

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CURRENT COOLING PRACTICES

The most common current practice for cooling Telecommunications facilities is to use air as the transport medium. This can be done with remote (out of the space) air handling systems utilizing overhead air distribution ducts, or multiple modular systems (in the space) using overhead ducts or mounted on a raised floor supplying air through the under-floor plenum. Common "rules of thumb" for these types of systems are design duct velocity = 5 m/s, airflow = 0.06 m3/s-kW, vertical space for duct = 0.5 m. Modular cooling unit floor space = 0.02 m2/kW, with an additional 0.02 for service. A common design heat density for these spaces has been 500 w/m2. Using these values in a 1,000 m2 facility with a 4-meter slab to slab height as an example, results in duct width, air changes per minute, and air-conditioner floor space values that are rather easy to accommodate.
Heat Density: 500 w/m2
Total Heat = 500 kW
Total Airflow = 500*0.06 = 30 m3/s
Total supply duct cross section = 30/5 = 6.0 m2
Supply duct width = 6 / 0.5 = 12.0 m
Duct Width as a Percent of Room Width = 12.0/31.6 = 38%
Air changes per minute = (30 * 60)/(1000*4) = 0.45
Assuming the need for 15 % of standby capacity, the modular cooling unit footprint would be:
Total Cooling Unit Footprint (with service space) = 500*1.15*0.04 = 23.0 m2
Cooling unit space as a percent of room area = 2.3%

FUTURE COOLING REQUIREMENTS

If heat densities continue to increase as forecast, and design practices do not change, Table 1 summarizes the resulting cooling system values at heat densities up to 5,000 w/m2. Duct dimensions, air changes per minute, and floor space occupied by the cooling system reach generally unacceptable or unachievable levels. Figure 5 demonstrates the floor space occupied by modular cooling equipment at the 5,000-w/m2 point. Since the Duct requirement would be a 2.0-meter high duct occupying 98% of the ceiling space, it is not possible to demonstrate an acceptable duct layout. Smaller duct sizes could be used, with consequently higher air velocities. However, that would result in more expensive duct construction and greater fan power, increasing operating costs and adding more motor heat for the cooling system to absorb. It appears that current system practices reach their limit at approximately 2,000 w/m2. It should be noted that these results apply to any system (such as rooftop air conditioners or central station air handlers) that use ducted air as the heat transport medium.

Up until this point, diversity of heat release has not been discussed. Reviewing the curves in Figure 4, it can be seen that there is a great difference in the heat density of different equipment classes. It is not uncommon, currently, for different zones in a communications facility to vary in density by a factor of five or more. As an example, it would not be unusual in a facility with an average density of 500, to have areas with a density of 833, and areas with a density of 167. If projected heat density trends continue, this diversity factor will increase to eight or more within the next five years. This would mean that a facility with an average density of 3,000 might have zone maximums of 5,336 and minimums of 667, further increasing the difficulty of satisfying local heat releases via traditional techniques. Again referring to Figure 4, localized heat release may be as high as 60,000 w/m2.

Heat Density (w/m2)	500	1000	2000	3000	4000	4500	5000
Total Heat (kW)	500	1000	2000	3000	4000	4500	5000
Room Airflow (m3/s)	30.2	60.4	120.8	181.2	241.6	271.8	302.0
Air Changes per Minute	0.5	0.9	1.8	2.7	3.6	4.1	4.5
Total Duct Area (m2)	6.0	12.1	24.2	36.2	48.3	54.4	60.4
Duct Height (m)	0.5	0.5	1.0	1.5	1.5	1.75	2.0
Total Duct Width (m)	12.1	24.2	24.2	24.2	32.2	31.1	30.2
Duct as a % of Room Width	38%	76%	76%	76%	102%	98%	96%

Table 1

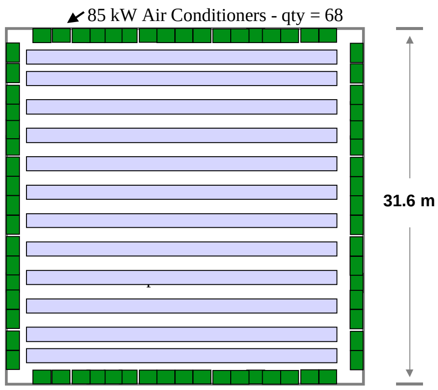

Figure 5

ALTERNATIVE COOLING METHODS

As the average heat release and the diversity of heat release increases a more effective way to absorb this heat may be localized cooling systems. Several system concepts are described below. Also, other materials may be more effective in transporting the heat from the local environment. Fluids and refrigerants are good alternative materials for the absorption and transport of heat. Table 2 compares the volumetric heat transport capacity of air, water, refrigerant R407C, and dielectric fluid HFE 7100.

Material	Air	Water	Refrigerant R407C Liquid	Refrigerant R407C Vapor	Dielectric HFE 7100
Specific Heat J / kg - C	1006	4187	1448	1015	1163
Density kg / m3	1.22	999	1202	32	1543
Enthalpy J / kg			67,498	270,502	
Delta Temp - C	11	6	0	0	6
Volume Heat Capacity – J / m3	13,500	25,096,878	243,955,746	6,552,686	10,767,054
Volume Heat Comparison	1	1,859	18,071	485	797

Table 2

As can be seen, each of these materials has measurably greater heat transport capabilities than air.

Heat densities in communications facilities will very likely increase gradually over time as old equipment is replaced by new, and new product categories are added. Therefore, it can be expected that various products and techniques will be employed at different levels of density and diversity. The following are several possible designs or techniques.

Fan Assisted Enclosure: One method for extending the heat density range of current air cooled environments, particularly those with under-floor air distribution, is shown in Figure 6. This concept draws cold air directly into the enclosure from under-floor (avoiding mixing with warmer air in the aisle) and discharging the heated air out the upper rear (again avoiding mixing with cooler air in the aisle, and returning warmer air to the air conditioner). This particularly helps with equipment that has a high discharge air temperature, which might affect equipment in adjacent aisles.

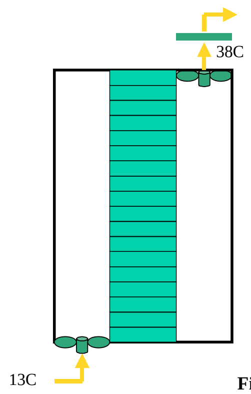

Figure 6

Higher Capacity, Smaller Footprint Air Conditioners: Another method for extending the range of the current air-cooled environment is to increase the cooling capacity per unit, while decreasing the footprint per kW of cooling. Typical Computer Room Air Conditioners, have capacity ratings of 100 – 120 kW, and footprints of 0.02 kw/m2. Manufacturing products with capacity ratings of 200 – 240 kW, while reducing the footprint to 0.015 kw/m2 would reduce the number of units per site by half, and the installation space by 25 %, potentially improving site reliability and saving valuable floor space.

Enclosure Mounted Heat Exchanger: Recent published heat releases for “1U” high servers using dual Pentium III processors, are as high as 292 watts per server. Therefore a “42U” cabinet dedicated to these servers may release as much as 12.2kW of heat. Using a common enclosure footprint of 0.6 m2, this translates to a footprint heat density of 20,333 w/m2. One concept of cooling such a heat release is shown schematically in Figure 7. It consists of a fin and tube coil commonly used in the HVAC industry, mounted on the rear access door of the enclosure. Heat transport is accomplished via water or a dielectric fluid. The intent of this concept is to absorb the heat released by the communication devices as it leaves the equipment and prior to reentering the space, thereby making the cabinet “load neutral” so far as the general air cooling system is concerned.

Laboratory tests have shown that as much as 18kW of heat can be absorbed by such a technique. Supplemental fans are required to pull the server air through the exchanger. Note the nominal air temperatures from entering to leaving the enclosure. Since the air temperature entering the exchanger is approximately 36C, this increases its heat absorption capacity. As service access is required to the rear of the enclosure, the door must remain hinged. This requires that flexible hoses be used with quick connect fittings for easy opening, installation and removal. Advantages of this solution are it can be added or removed as needed, and only installed on those enclosures that have a high heat release.

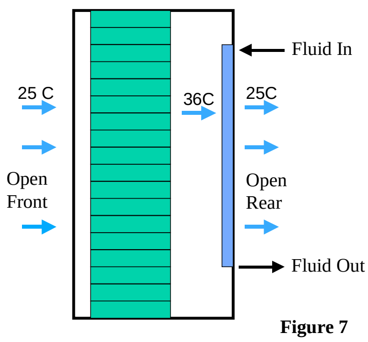

Figure 7

To ensure that no condensation occurs while cooling, the fluid temperature must always be above the dew point of the air. For this reason, and also to ensure proper flow, system pressures, fluid purity, and isolation from the main cooling loop a Coolant Distribution Unit (CDU) should be used, as shown in Figure 8. The CDU contains a fluid to fluid heat exchanger, pumps, control valves, and control. As the CDU provides fluid to multiple exchangers, it would likely have a capacity of between 100 and 200 kW. The power consumption of the fans and CDU pump allocated to the 8 kW model of this enclosure-mounted heat exchanger is 288 watts, or 36 watts/kW. The fan of a traditional cooling system consumes approximately 80 w/kW. This represents a 55 % reduction in power.

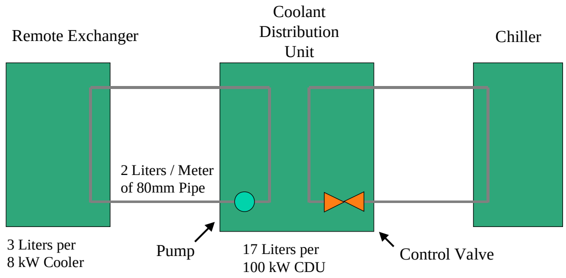

Figure 8

Ceiling Mounted Heat Exchanger: As indicated previously, as heat density increases, it becomes increasing difficult to bring air to the area requiring cooling, using traditional ducting methods. However, a modular ceiling system consisting of a fin & tube coil plus fans, and using a fluid or refrigerant as the heat transport medium, can provide local air movement, and high heat density cooling. One concept for such a device is shown in Figure 9. This concept includes movable fan trays, to optimize the air supply and return path based on the communication equipment beneath it. Laboratory tests have shown that such a system can support heat densities of up to 5,000 w/m2. This system requires a CDU, for the same reasons as mentioned previously, if a fluid is used as the transport medium. If a refrigerant is used as the transport medium, a remote condensing unit is required, and if multiple ceiling units are connected to the same condensing unit, variable capacity is required. Again, the refrigerant temperature must be maintained above the air dew point. The power consumption of the fans and CDU pump allocated to this 20 kW model of the ceiling mounted heat exchanger is 1,020 watts, or 51 watts/kW, representing a 36% reduction in power.

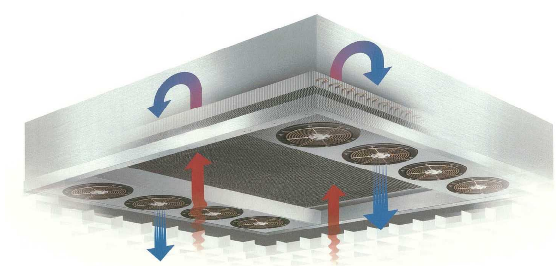
Figure 9

Horizontal Air Displacement Units: Another method of providing local air cooling without extensive ducting, and also cooling in a manner that enhances the natural tendency of warmer air to rise is shown in Figure 10. This concept delivers low velocity cool air at lower levels of the equipment aisle, naturally displacing warmer air as it travels. Heated air exiting the equipment is drawn back to the top of the cooling unit. The sound level of this system tends to be low. This system has been applied with heat densities of up to 1,000 w/m2.

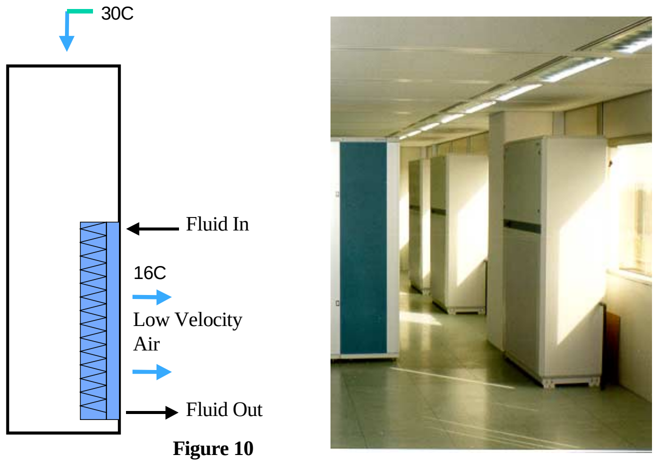

Figure 10

Fluid Assisted Heat Sinks: All of the above systems remove heat from the air that has been heated by the communication equipment. As the packaging density of equipment increases, and the power and power density of the microprocessor increases, it may become necessary for the thermal path to go directly from the processor to a fluid or refrigerant circuit, without air as an intermediary. One concept for such a path is shown in Figure 11. Since conduction is superior to convection in transferring heat, the potential advantages of such a system are: greater heat removal per unit of volume, lower chip operating temperatures, and the ability to support higher equipment footprint heat densities. This solution may be incorporated in a proprietary way by individual manufacturers, or via industry standard construction and dimensions for all manufacturers. The need for this solution may occur as microprocessors approach 150 watts in power consumption and/or 150 watts/cm2 in surface density. Again, a CDU would be necessary for the reasons expressed earlier.

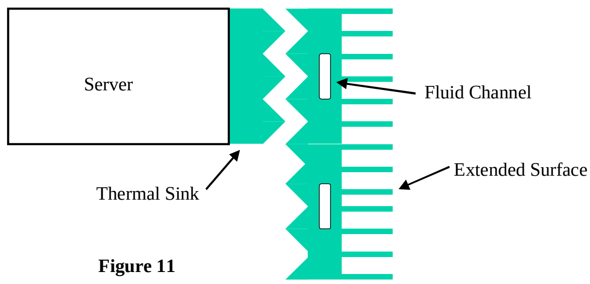

Figure 11

Other Methods: It is not expected or intended that the devices described above are a complete list of all current and future methods of cooling high density heat releases. Spray cooling is an example of a method in use today in Cray computers, thermal conduction modules were employed in previous generations of IBM mainframes, and research is being conducted at the university level on two phase boiling techniques. Each manufacturer may find a unique solution to these challenges.

The Future Cooling System: It is probable that the future complete cooling system for a communications facility will be a combination of many, if not all of the above methods. The thermal demands imposed by increasing average, and increasingly diverse heat densities, will require solutions tailored to these densities. However, it is not expected that the current method of heat absorption via air-cooling will vanish as a primary means of maintaining a suitable environment. Certainly many pieces of communications equipment will continue to be thermally satisfied using current methods of air cooling. General temperature and humidity control are examples of tasks that they will continue to perform.

Thermal Conditions During a Loss of Cooling: While it may be possible to satisfy increasing heat densities with the methods or devices described above, another significant operating condition that must be considered is the temperature and temperature rise of the space in the event of a catastrophic loss of cooling. Examples of a catastrophic cooling loss are, a power failure during which the communications equipment operates on battery power but the cooling system does not, a failure of the cooling system, an inadvertent power disconnect of the cooling system, etc. Figure 12 is actual measured data in a 42 m2 test laboratory, with the walls and ceiling surrounded by a 20 C space temperature. Note that when heat densities approach 4,844 w/m2, the air temperature entering the enclosure remains below 51C for only five minutes. Therefore, either the cooling system has to be restarted, and achieve full capacity in less than five minutes, or some means of thermal "ride through" must be provided. Also note that at 4,844 w/m2 the temperature rise is approximately 5.2C / minute, which far exceeds current test standards for communication equipment, (typically 30C / hour).

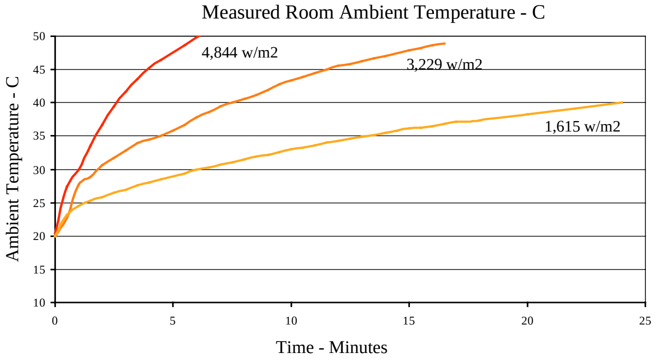

Figure 12

Therefore a combination of both thermal storage for "ride through", (to decrease the temperature rise) and rapid return to full cooling (to reestablish conditions) is an optimal solution, and should be considered in any facility with high heat density. Thermal ride through can be achieved through the use of fluid storage tanks, or other techniques. An analysis of which cooling components, such as pumps, controls, and fans, must be powered by battery power is required for each system configuration. Depending on the degree of ride through that is desired the thermal storage volume may be quite large. Switchover to redundant equipment must be automatic and swift, and the capacity and speed with which standby generation is activated must be assured. Computational Fluid Dynamics (CFD) or other modeling techniques can be employed to create these plots for larger facilities, where temperature gradients may be much greater.

Energy Use, and Potential for Savings: Energy saving techniques applied to the cooling system can achieve substantial reductions in energy use and cost. Assuming a cooling system with the fans consuming 13% of system power, pumps 7%, condenser 17%, and compressor 63%, the following savings are possible. By, applying a variable frequency drive (VFD) to the pumping system it may be possible to achieve a 30% savings in annual pump power consumption, a 2% overall savings. If ceiling or enclosure mounted heat exchangers were employed to absorb half of the heat release, an additional 18 to 28% reduction in fan power could be achieved, a 2 – 4 % overall savings. And if a "free cooling" circuit were used to reduce compressor power in a climate such as Frankfurt's, (see Figure 13), a 40 - 50 % savings in annual compressor power could occur, a 25 - 31 % overall savings. Therefore, attention to system design and product selection could result in 29 – 37 % overall savings in annual cooling power. Assuming a cooling system COP of 2.5, a power cost of 0.10 Br Lbs / kWh, a site size of 1,000 m2, and a heat density of 2,000 w/m2, this would mean an annual savings of between 202,000 and 260,000 Br Lbs / year. To

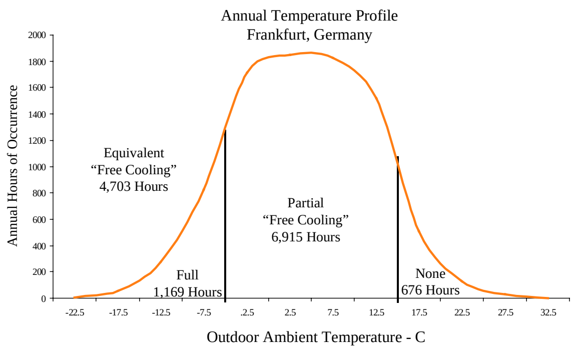

Figure 13

convert these values to Euros, multiply by approximately 1.5.

Summary: Current and projected trends of heat density in telecommunications spaces will result in new cooling solutions to high density heat releases. Product heat density may reach 60,000 w/m2 by the year 2005. These cooling products and systems will likely be modular and local, and may utilize a different heat transport medium than air. This medium may be water, a refrigerant, a dielectric fluid, or other material that has a higher volume heat capacity. Multiple different systems may be employed in the same facility, in order to satisfy diverse densities. Thermal conditions during a loss of cooling will require methods of thermal storage and rapid re-establishment of cooling, in order to avoid equipment shutdown. Energy saving methods can result in substantial operating cost reductions.

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