

Experimental Results for Heat Gain and Radiant/Convective Split from Equipment in Buildings

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ABSTRACT

Measurement of the heat loss from equipment in buildings is necessary in order to make accurate assessments of its impact on cooling loads. Recent advances in the design of buildings and improvement of the thermal characteristics of insulation materials and building envelope systems have significantly reduced the cooling load from external sources; however, the addition of various types of office, laboratory, and hospital equipment to buildings has become a major source of internal cooling load. Unfortunately, accurate information on the total heat gain from equipment is lacking in current handbooks. Some equipment includes a nameplate rating showing total power consumption, while other equipment does not have this. Some manufacturers measure maximum electric power consumption by the equipment and list that as power ratings on the nameplate or in the equipment literature, while some others list the maximum power capacity of the system. Since the manufacturers' power ratings, if reported, are usually based on instantaneous measurement while equipment is working at maximum capacity, use of equipment nameplate values for cooling load calculations may lead to oversizing of air-conditioning equipment, resulting in extra initial cost as well as higher operating costs. On the other hand, underestimating the cooling load may result in insufficient cooling capacity.

Another factor affecting calculation of cooling load is the split between the radiant and convective heat load from the equipment. The convection portion of the heat transferred from the equipment to the surroundings is an instantaneous load, since it is added to room air by natural or forced convection without time delay, whereas the radiation portion is absorbed by the surfaces of the room and then dissipated over time. Accu-

rate determination of cooling load is important in proper sizing of air-conditioning equipment.

This article presents experimental results for the total heat gain and radiant/convective split from equipment in offices, hospitals, and laboratories. The nameplate vs. measured values, peak vs. average values, operational vs. idle values, and radiant vs. convective values are compared and discussed. Furthermore, a brief guideline for use of the experimental results by practicing engineers for estimating equipment cooling load is presented.

INTRODUCTION

Measurement of the heat loss from office equipment and other equipment in buildings is necessary in order to make accurate assessments of its impact on cooling loads. Recent advances in the design of buildings and improvement of the thermal characteristics of insulation materials and building envelope systems have significantly reduced the cooling load from external sources; however, the addition of various types of office, laboratory, and hospital equipment to buildings has become a major source of internal cooling load. Unfortunately, accurate information on the total heat gain of that equipment is lacking in current handbooks. Some equipment includes a nameplate rating showing the total power consumption, while other equipment does not have this. Some manufacturers measure maximum electric power consumption by the equipment and list that as power ratings on the nameplate or in the equipment literature, while some others list the maximum power capacity of the system. Since the manufacturers' power ratings, if reported, are usually based on instantaneous measurement while equipment is working at maximum capacity, use of equipment nameplate values for cooling load calcu-

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Another factor affecting cooling load calculation is the split between the radiant and convective heat load from the equipment. The convection portion of the heat transferred from the equipment to the surroundings is an instantaneous load, since it is added to room air by natural or forced convection without time delay, whereas the radiation portion is absorbed by the surfaces of the room and then dissipated over time.

Recognizing the lack of data on this subject and in order to establish a database of heat gain and split between radiation and convection, the American Society of Heating, Refrigerating and Air-Conditioning Engineers sponsored the research projects RP-822, "Test Method for Measuring the Heat Gain and Radiant/Convective Split from Equipment in Buildings," in 1995 and RP-1055, "Measurement of Heat Gain and Radiant/Convective Split from Equipment in Buildings," in 1998. This paper reports the results of the latter project and includes experimental results from the previous project as well. The main objective of this paper is to present the experimental results for the total heat gain and radiant/convective split from equipment in offices, hospitals, and laboratories. The nameplate vs. measured values, peak vs. average values, operational vs. idle values, and radiant vs. convective values are compared and discussed. Furthermore, a brief guideline for use of the experimental results by practicing engineers for estimating equipment cooling load is presented.

BACKGROUND

Recent advances in calculation methods of solar heat gain and improvements in thermal characteristics of building envelope systems have improved estimation of external cooling loads; however, the addition of various types of office, laboratory, and hospital equipment in buildings has become a major source of building internal cooling loads for which accurate data are not available. The available information on heat gain from office equipment is outdated and does not provide an accurate split between convective and radiant loads. The number of published technical articles related to this topic is limited. Thus, a brief review of available relevant literature is presented here.

Alereza and Breen (1984) reported results of their evaluation of commercial appliances and equipment for heat gain characteristics. Based on appliance manufacturers' input ratings and adjustment factors, they obtained the rates of latent and sensible heat for each item of equipment. They also evaluated an indirect method based on the voltage, amperage, and phase input to determine equipment power rating equivalent to the manufacturers' input rating.

Wilkins et al. (1991) measured the heat generated by various office items and compared the results with the manufacturers' nameplate values and equipment literature to evaluate the accuracy and the relevance of listed power ratings for cooling load calculations. They obtained instantaneous and average power consumption over a time period. They found that the actual power consumption for a desktop computer was 20% to 30% of the rated power (450-900 watts) as reported by the manufacturer. They also found that the usage factors for different types of equipment varied significantly.

Wilkins and McGaffin (1994) presented actual energy consumption data for different computers, monitors, and printers for both idle and operational modes.

Hosni et al. (1998) reported results for total heat gain and split between convection and radiation heat gain for typical office and laboratory equipment, such as desktop computers, monitors, a copier, a laser printer, and a biological incubator. In addition, two standard objects with well-defined radiant heat loss characteristics, a heated flat slab and a heated sphere, were used by the authors to verify the accuracy of their measurement and data reduction procedures. They found that the total heat gain from office equipment tested was significantly less than the nameplate ratings even when being operated continuously. The actual power consumption ranged from 14% to 36% of the nameplate ratings. Thus, they cautioned against the use of equipment nameplate ratings in estimating total heat gain for air-conditioning equipment sizing.

Hosni et al. (1998) reported that the radiant portion of the total heat gain ranged from a minimum of 11% for the laser printer to a maximum of 57% for the incubator. The radiant portion of heat gain from the heated surfaces was higher, at about 60%.

Jones et al. (1998a) presented descriptions of a new method for measuring radiant heat loss from equipment. They reported the proposed measurement method, referred to as the scanning radiometer method, which utilized a relatively inexpensive, off-the-shelf net radiometer to make the measurements. The radiometer scans a hemispherical area about the equipment being evaluated and, by integrating the net radiant flux through this area, the total radiant flux from the equipment to the room is measured. This method automatically compensates for other radiant fluxes in the room. They recommended this method for office equipment radiant heat gain measurement.

Jones et al. (1998b) developed and applied infrared imaging technique for measurement of radiant heat gain from office equipment. The results from this method were compared with those of the scanning radiometer technique. This method was found applicable for radiant heat gain measurements; however, the infrared imaging technique requires a high level of expertise, is much more difficult to use, and the equipment is much more expensive than the net radiometer.

EXPERIMENTAL TEST FACILITY, MEASUREMENT EQUIPMENT, AND PROCEDURES

The radiant/convective split tests for all of the office and laboratory equipment were conducted in an environmental chamber, and the total power consumption measurements for all equipment were conducted in the field. The equipment being tested for radiant/convective split was placed in an environmental chamber with well-controlled temperature (70°F, 21.1°C), relative humidity (50%), and air velocity (60 fpm, 0.3 m/s) conditions.

Under steady-state conditions, with no endothermic or exothermic reactions involved in the equipment, the most accurate method to determine the total heat output is by measuring the total electric power input to the equipment. Based on the conservation of energy principle, at steady-state conditions the total heat output is equal to the total power input. A watt-hour meter was used to measure the total power consumed by the equipment being tested.

For total power consumption measurement, the equipment to be tested was unplugged from the power outlet and plugged into the watt-hour meter power inlet, then the watt-hour meter was plugged into a power receptacle. The output signal from the watt-hour meter corresponding to the equipment power consumption was recorded every 30 seconds for at least 30 minutes. To obtain the peak power consumption, every consecutive six readings (at three-minute intervals) were averaged and recorded. The largest three-minute average was considered as the peak power consumption. Large instantaneous readings that lasted less than three minutes were not considered as peak power since those sudden increases do not contribute to the heat gain in buildings. The average power consumption for each equipment item was obtained by averaging all readings for the entire test period.

The radiant heat loss from the equipment was measured using a net radiometer that was mounted on a scanning arm. This radiometer is accurate for radiation wavelengths from 0.3 to 60 microns and thus is suitable for the long-wave radiation emitted by appliances. The radiometer was systematically moved in a semicircle about the appliance being tested. The appliance was centered on a turntable so that it could be rotated a full 360 degrees. The turntable, which was marked in 10-degree increments from 0 to 180 on its perimeter, was covered by a radiant barrier material (emissivity < 0.05) to ensure the downward radiation was reflected upward and included in the measurement. Since the radiant heat flux from the appliance normally is not uniform with respect to directions, the flux must be integrated over the entire spherical solid angle surrounding the appliance. An accurate integration requires many points. In this research, 51 points were used and proved to provide satisfactory accuracy (Hosni et al. 1996). A stepper motor and a control unit were used to remotely position the net radiometer at various measuring positions. For each equipment item tested, usually three data sets were obtained and an average value was reported. The details of this measurement technique are presented in Jones et al. (1998a).

TEST RESULTS

The total heat gain and radiant/convective split test results for different office, laboratory, and hospital equipment are presented and discussed here. The test results, including description of objects tested, nameplate power rating, peak power consumption, average power consumption, radiant and convective heat gain, and operating mode, as well as usage diversity, are summarized in Tables 1, 2, and 3. For office equipment, the total power consumption and radiant/convective split for both idle and operational modes are presented. However, total power consumption for laboratory and hospital equipment and radiant/convective split for laboratory equipment in only the operational mode are presented since these items are usually turned on and used and not left in the idle mode for extended periods. The radiant/convective split for hospital equipment was not measured due to lack of portability. Detailed discussions of the test results for each office, laboratory, and hospital equipment item are presented in the final research report for this project (Hosni et al. 1999). Space limits prevent inclusion of all of these details in this paper.

SUMMARY AND GENERAL GUIDELINES

The individual data points that resulted from this study should be quite useful for designers. However, equipment changes quickly and the equipment items tested, although extensive in number, are only a tiny fraction of the brands, models, and types that exist. Only in a few special cases will the designer know specifically what brand, make, and model of equipment will be housed in a space. Even if they were so lucky as to know this information and they happen to match items reported in this study, it is likely that these furnishings will change within a few years. For these reasons, the data were assessed to determine if any general guidelines could be developed. Three general questions were addressed.

1. Is it possible to make generalizations about the relationship between nameplate data and actual power consumption?
2. Is it possible to generalize relationships regarding the radiant/convective split of the heat loss from equipment?
3. Can useful ranges of heat load be estimated for categories of equipment (computers in particular)?

Each of these questions is addressed in turn.

Relationship between Nameplate Rating and Actual Power Consumption

In steady state, the total heat load generated is equal to the electrical power consumed for most equipment. The exception is some laboratory equipment in which an endothermic or exothermic reaction takes place. The power consumption for all of the equipment tested is presented as a function of the nameplate rating in Figure 1a. In Figure 1b, more limited ranges of nameplate ratings are included so the individual data points can be viewed more easily. The power consumption data are all for continuous operation. In the case of items such

TABLE 1
Office Equipment

Equipment	Description	Name-plate*** (W)	Idle Mode - Power Consumption (W)				Operational Mode - Power Consumption (W)				Fan	Usage
			Peak	Average	Radiant	Convective	Peak	Average	Radiant	Convective		
Computer and Monitor	Gateway 2000, Pentium-200 Monitor: Gateway 17"	N/A 220	110	51	12 (24%)	39 (76%)	108	98	27 (27%)	71 (73%)	Y N	Continuous
Computer and Monitor**	Pentium-200 17" monitor	575						133	30 (22%)	103 (78%)	Y N	Continuous
Computer and Monitor**	486DX33 15" monitor	420						125	36 (29%)	89 (71%)	Y N	Continuous
Computer and Monitor	Dell Pentium-333 Monitor: Dell 19"	N/A 207	111	110	22 (20%)	88 (80%)	132	130	31 (24%)	99 (76%)	Y N	Continuous
Computer only	Micro Millenia Pentium-200	759	53	35			54	53			Y	Continuous
Computer only	Gateway 4DX2-486	450	54	53			54	53			Y	Continuous
Computer only	Mech Professional Pentium 200	165	39	35			53	52			Y	Continuous
Computer only	Gateway ATX Tower G6-400 Pentium-400	N/A	46	37	6 (15%)	31 (85%)	54	54	5 (10%)	49 (90%)	Y	Continuous
Copy Machine	Canon NP6012 F132500	690	22	22			476	399 85*	16* (19%)	69* (81%)	Y	Intermittent
Copy Machine**		1320						133*	30* (22%)	103* (78%)	Y	Intermittent
Copy Machine	Canon NP6045 F133900	1440	444	247			1140	1076			Y	Intermittent
Copy Machine	Canon NP6545 F137400	1440	463	267			1119	1065			Y	Intermittent
Copy Machine	Canon NP6050	1380	558	354			1223	1167			Y	Intermittent
Electronic Image Scanner	Scan Jet 3C C2520A	90	12	12			35	24			N	Intermittent
Fax Machine	HP Office Jet LX C2890A	110	16	16	6 (38%)	10 (62%)	24	21 19*	6* (33%)	13* (67%)	N	Intermittent
Fax Machine	Sharp F0-215	140	9	9			32	29			N	Intermittent
Fax Machine	Panafax UF-312	72	15	12			32	29			N	Intermittent
Monitor 17"	Acer 56L	340	58	57	25 (44%)	32 (56%)	67	65	27 (41%)	38 (59%)	N	Continuous

TABLE 1 (Continued)
Office Equipment

Monitor 19"	Dell Model D1226H	425	64	64	24 (38%)	40 (62%)					N	Continuous
Monitor 20"	Hitachi Superscan Pro20	565	3	3			86	86	30 (35%)	56 (65%)	N	Continuous
Monitor 14"	1430VTM	168	51	51			53	53			N	Intermittent
Monitor 17"	Gateway 2000 CPD17F23 Resolution 1152 x 864	219					64	64			N	Intermittent
Monitor 17"	Gateway 2000 CPD17F23 Resolution 640 x 480	219	7	7			63	62			N	Intermittent
Monitor 15"***	Energy Saver Monitor	220						80	29 (36%)	51 (64%)	N	Intermittent
Plotter	HP 7586E-size 8 pen type	<182W	86	82			120	112			N	Intermittent
Plotter	HP 7550A-size 8 pen type	<105W	30	30			43	41			N	Intermittent
Dot Printer	KXP 1124	420	16	16	5 (32%)	11 (68%)	56	43 31*	9* (31%)	22* (69%)	N	Intermittent
Dot Printer	Star Gemini-10X	120	16	15			49	44			N	Intermittent
Dot Printer	Okidata Microline 182	48	9	8			31	30			N	Intermittent
Laser Printer	HP Laser Jet III	836						248*	27* (11%)	221* (89%)	Y	Intermittent
Laser Printer	HP Laser Jet 4 C2001A	704	235	79 62*	5* (8%)	5* (92%)	332	208 101*	9* (9%)	92 (91%)	Y	Intermittent
Laser Printer	HP Laser Jet 4P C2005A	242	10	10			180	128 73*	16* (22%)	57* (78%)	Y	Intermittent
Laser Printer	HP Laser Jet 6P C3980A	419	6	6			266	217			Y	Intermittent
Laser Printer	HP Laser Jet 4M C2039A	770	354	68			529	322			Y	Intermittent
Laser Printer	HP Laser Jet 5SiMX C3167A	1448	293	124			617	558			Y	Intermittent
Network Server	Tangent VL 306166	200					126	125			Y	Continuous
Network Server	SUN Sparc Station 10	680					340	336			Y	Continuous

Notes:

* Intermittent printing/copying mode (one page per minute).

** Equipment tested in phase one of this project.

*** If the nameplate rating is given in terms of voltage and amperage, the wattage is listed as the product, i.e., power factor is approximated as unity.

TABLE 2
Laboratory Equipment

Equipment	Description	Name Plate*** (W)	Operational Mode-Power Consumption (W)				Fan	Usage
			Peak	Average	Radiant	Convective		
Analytical Balance	Mettler Toledo, PR 8002	7	7	7			N	Intermittent
Centrifuge	IEC HN-SII Centrifuge	288	136	132 41*	14* (34%)	27* (66%)	N	Intermittent
Centrifuge	International Clinical Centrifuge	138	89	87			N	Intermittent
Centrifuge	IEC B-20A Centrifuge	5500	1176	730			N	Intermittent
Electrochemical Analyzer	Voltammetric Analyzer CV-50W	50	45	44			N	Intermittent
Electrochemical Analyzer	Voltammetric Analyzer BAS 100B	100	85	84			N	Intermittent
Fluorescent Microscope	Leica MZ 12	150	144	143			N	Intermittent
Fluorescent Microscope	Axioplan2	200	205	178			N	Intermittent
Function Generator	Interstate High Voltage Function Generator-F41	58	29	29			N	Intermittent
Incubator**				83	47 (57%)	36 (43%)	N	Intermittent
Incubator	Lab-line Orbit Environ-Shaker No. 3527	600	479	264 220*	68* (31%)	152*(69%)	N	Intermittent
Incubator	Controlled Environment Incubator Shaker G-28	3125	1335	1222			N	Intermittent
Incubator	National Incubator 3321	515	461	451			N	Intermittent
Orbital Shaker	VWR Scientific Orbital Shaker	100	16	16			N	Intermittent
Oscilloscope	BK Precision 20MHZ 2120	72	38	38			N	Intermittent
Oscilloscope	Nicolet Instrument Corp. 201	345	99	97	10 (10%)	87 (90%)	Y	Intermittent
Rotary Evaporator	BUCHI Rotary	75	74	73			N	Intermittent

TABLE 2 (Continued)
Laboratory Equipment

Rotary Evaporator	BUCHI-RE121 Rotavapor	94	29	28			N	Intermittent
Spectronics	Spectronics 20	36	31	31	15 (49%)	16 (51%)	N	Intermittent
Spectrophotometer	Hitachi U-2000	575	106	104			N	Intermittent
Spectrophotometer	Double Beam Spectrophoto-meter Hitachi Perkin-Elmer	200	122	121			N	Intermittent
Spectrophotometer	Infrared Perkin-Elmer 1310	N/A	127	125			N	Intermittent
Flame Photometer	Atomic Absorption Spectrometer 3110	180	107	105			N	Intermittent
Spectro Fluorometer	Spectro Fluorometer Model 430	340	405	395	64 (16%)	331 (84%)	N	Intermittent
Tissue Culture	Fisher Scientific CO ₂ Incubator	475	132	46			N	Intermittent
Tissue Culture	SteriGRAD HOOD VBM-600	2346 Peak & Ave. in Idel mode at 53 W	1178	1146			Y	Intermittent
Thermocycler	Neslab RTE-221	1840	965	641 479	24 (5%)	455 (95%)	Y	Intermittent
Thermocycler	DNA Thermo- cycler 480	N/A	233	198			Y	Intermittent

Notes:

*400 rpm, i.e., 1/4 of the maximum rotation speed for centrifuge (1600 rpm), 200 rpm for shaker (i.e., 1/5 of max speed), and 1/2 max. temperature.

** Equipment tested in phase one of this project.

*** If the nameplate rating is given in terms of voltage and amperage, the wattage is listed as the product, i.e., power factor is approximated as unity.

TABLE 3
Hospital Equipment

Equipment	Description	Nameplate* (W)	Operational Mode-Power Consumption (W)		Fan	Usage
			Peak	Average		
Anesthesia System	Detex Anesthesia System	250	177	166	N	Intermittent
Blood Warmer	Hotline Fluid Warmer	360	204	114	N	Intermittent
Blood Pressure Meter	Critikon Vital Sign Monitor 1846SX	180	33	29	N	Intermittent
Blanket Warmer	Blanket Warmer Model 7923SS	500	504	221	N	Intermittent
Endoscope	Olympus Endoscope	1688	605	596	N	Intermittent
Electrosurgery	Valleylab Force2 Electrosurgical Generator	1000	147	109	N	Intermittent
ECG/RESP	Spacelab ECG/RESP Model 90621	1440	54	50	N	Intermittent
Harmonical Scalpel	Harmonical Scalpel Model G110	230	60	59	Y	Intermittent
Hysteroscopic Pump	Zimmer Controlled Distention Irrigation System	180	35	34	N	Intermittent
Laser Sonics	Laser Sonics Model: Illumina 730	1200	256	229	N	Intermittent
Optical Microscope	Zeiss opMi-1	330	65	63	N	Intermittent
Pulse Oximeter	Nellor Pulse Oximeter, Model N10C	72	21	20	N	Intermittent
Stress Treadmill	EIS PRECOR (walking speed -3 m.p.h.)	N/A	198	173	N	Intermittent
X-ray System	Mobil C-Arm X-Ray Sys, Model 9400 system	1725	534	480	N	Intermittent
X-ray System	Parorex X-ray GX-PAN	968 nominal 110 continuous		82	N	Intermittent
X-ray System	Portable X-ray System Model: 11CE8A	2070 momentary		18	N	Intermittent
Vacuum Suction	Berkeley VC-7 Vacuum Suction	621	337	302	N	Intermittent
Ultrasound System	Ultramark9 Ultrasound system UM9-HDI	1440 continuous 1800 intermittent	1063	1050	N	Intermittent

Note:

* If the nameplate rating is given in terms of voltage and amperage, the wattage is listed as the product, i.e., power factor is approximated as unity.

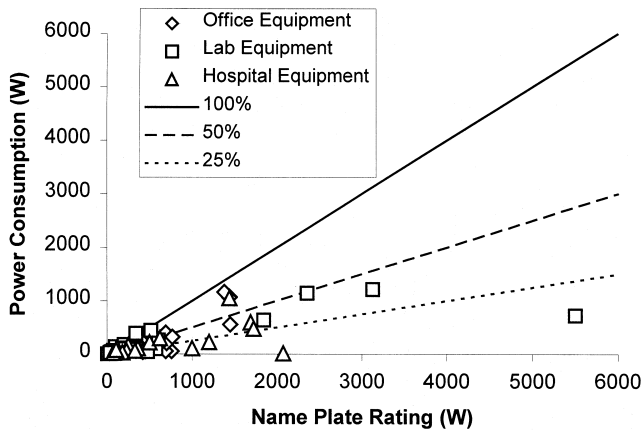


Figure 1a Power consumption with continuous operation, all data.

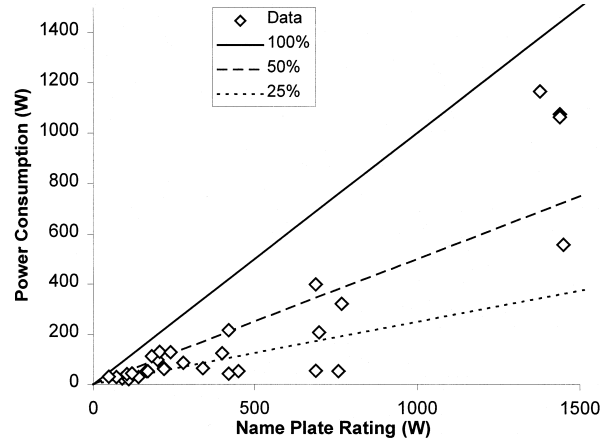


Figure 2a Power consumption with continuous operation, office equipment.

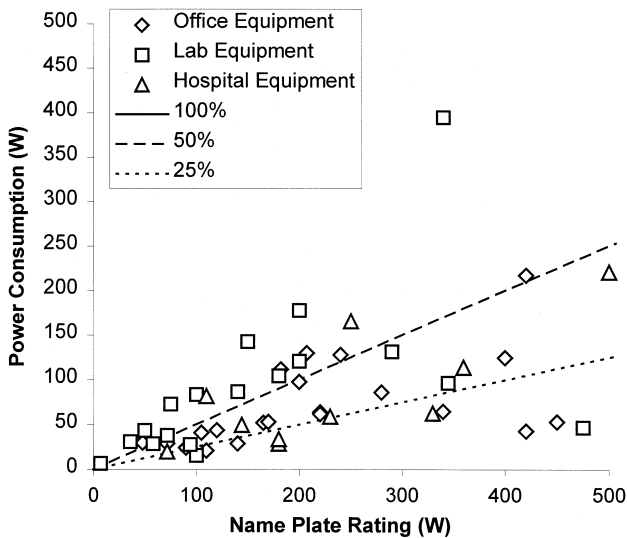


Figure 1b Power consumption with continuous operation, all data.

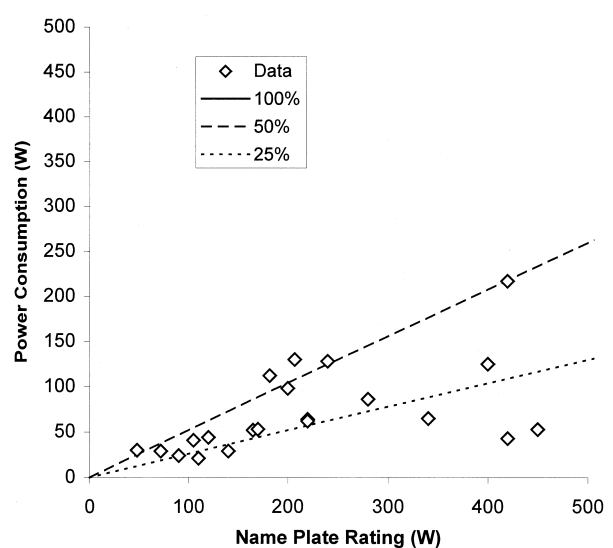


Figure 2b Power consumption with continuous operation, office equipment.

as printers and copiers where the power consumption may depend on the throughput, these data are for the maximum throughput. A substantial majority of the equipment operates at a power level at or below 50% of the nameplate rating.

Figures 2a and 2b present only the office equipment using the same format. Here, some general guidance may be possible. With the exception of some of the higher powered items with nameplate ratings above 1000 watts, the actual power consumption is typically 25% to 50% of the nameplate value. Additionally, much of the equipment does not operate continuously or operates at less than maximum levels. Where no other information is available regarding the actual power consumption of office equipment, the following guideline is recommended:

A conservative estimate for the heat load of a diverse set of office equipment with nameplate ratings less than 1000 W is 50% of the nameplate rating. A “best” estimate for the heat load in such cases is 25% of the nameplate rating.

Note that the guideline is predicated on a diverse set of equipment where no one item dominates. It should not be applied to a room full of identical computers, for example.

Figures 3a and 3b present the data for the laboratory equipment using the same format. The power consumption of the laboratory equipment tends to be much closer to the nameplate rating than does the office equipment. There are a number of exceptions, however. Also, some laboratory items operate a low portion of the time. It is difficult to associate a usage level with a specific piece of equipment. Rather, the usage has much more to do with the nature of the laboratory. An item that is operated essentially continuously in a “production” laboratory may only run infrequently and for short periods of time in a research laboratory. Thus, a designer needs to ascertain, if possible, the nature of the laboratory. While we hesitate to suggest a guideline, it would appear that a reasonable estimate of the heat load for a diverse set of laboratory equipment with nameplate ratings less than 1000 W would be

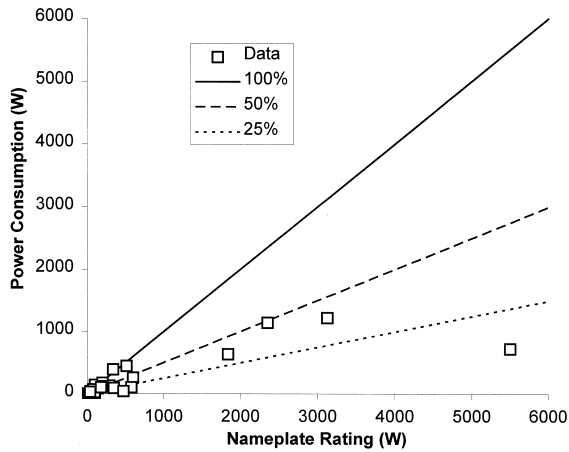


Figure 3a Power consumption with continuous operation, laboratory equipment.

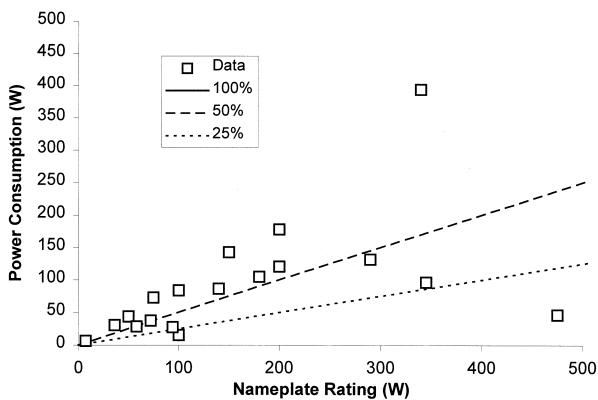


Figure 3b Power consumption with continuous operation, laboratory equipment.

70% of the nameplate. This estimate should only be used if no other information is available. All of the laboratory equipment with nameplate ratings greater than 1000 W consume less than 50% of the name plate rating. However, it would be dangerous to make general conclusions based on four data points.

The data for hospital equipment are shown in Figures 4a and 4b. They appear fairly similar to the office equipment and the same guideline should be satisfactory. Hospital equipment, like laboratory equipment, can vary tremendously in the level of usage and the designer should endeavor to evaluate what usage levels to expect for a given space.

Radiant/Convective Split

The data for the split of the heat loss between radiant and convective modes are shown in Figure 5a. While there is still considerable variation, these data are far more consistent than the data for actual consumption versus nameplate rating and the following guideline is offered:

Where no other information is available, total heat loss can be estimated as 20% by radiation and 80% by convection.

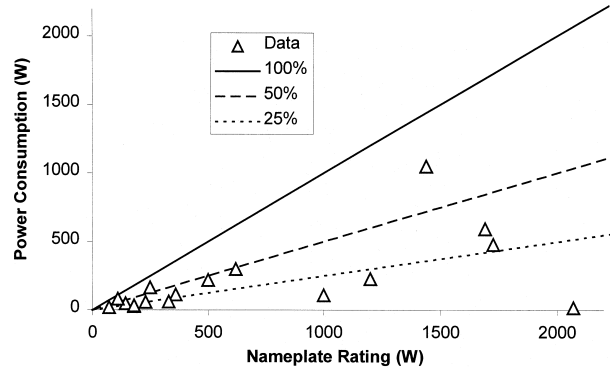


Figure 4a Power consumption with continuous operation, hospital equipment.

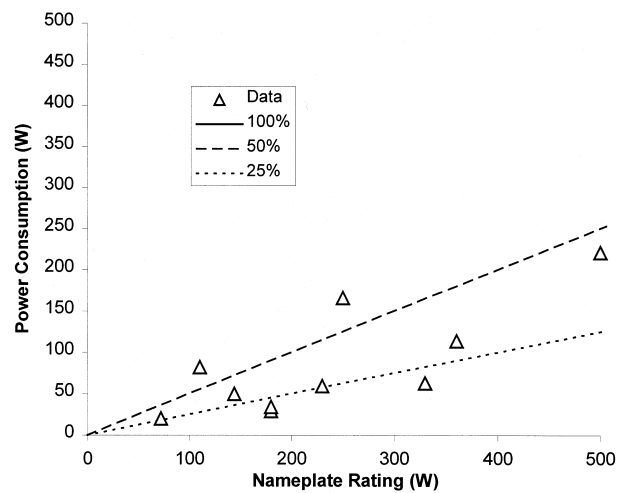


Figure 4b Power consumption with continuous operation, hospital equipment.

The data are divided into two categories in Figures 5b and 5c according to whether or not the primary heat source is cooled by a fan. The presence of a cooling fan would be expected to reduce the radiant portion and increase the convection portion. The data are consistent with this expectation. There is some uncertainty about how computer systems should be classified. Monitors generally do not include a fan, but the central processing units (CPU) do. Where data were collected separately for these components, the results are graphed accordingly. Complete systems, however, have both. Since the monitor typically is the larger power consumer, complete systems are graphed as not having a fan. A second guideline is offered based on the data in Figures 5b and 5c:

For equipment with a cooling fan for the primary heat source, total heat loss can be estimated as 10% by radiation and 90% by convection. For equipment with no cooling fan on the primary heat source, total heat loss can be estimated as 30% by radiation and 70% by convection.

All of the equipment included in this study had no exposed surfaces with highly elevated temperatures. That is, no exposed surfaces would cause significant discomfort upon

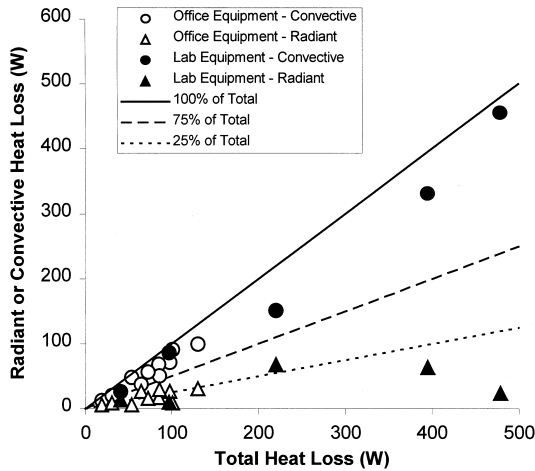


Figure 5a Radiant and convective heat loss in steady-state operation.

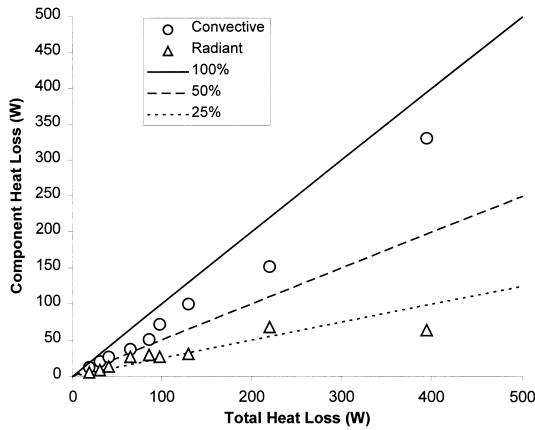


Figure 5b Radiant and convective heat loss, no fan on primary heat source.

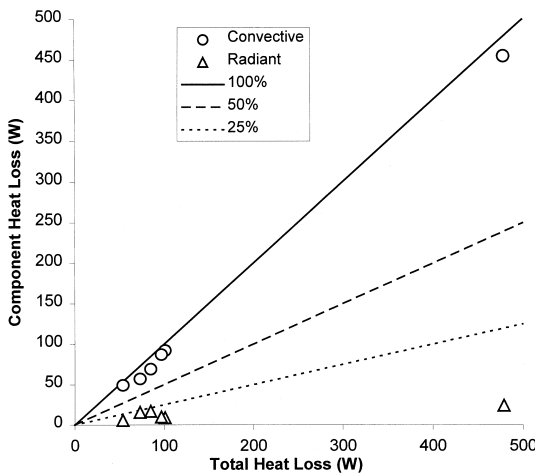


Figure 5c Radiant and convective heat loss, with fan on primary heat source.

direct contact with a person's exposed skin. Essentially all office equipment is purposely designed with this feature and the same is true for the vast majority of laboratory and hospital equipment. It is possible, however, that some special purpose equipment may include surfaces with much higher temperatures. The radiant portion of the heat loss will be higher for such equipment and the above guidelines should not be applied.

Heat Load Estimates by Categories

Ideally, a designer would like to be able to identify a piece of equipment in general terms (office copy machine) and then be able to make a reasonable estimate of the heat load generated by that equipment. The laboratory and hospital equipment items are so diverse and individually so unique that it does not appear possible to derive this level of information from the data set. However, it is possible to draw some general guidance for the office equipment. In particular, we have attempted to develop general guidelines for office computers and printers, copiers, and fax machines. Each will be addressed in turn.

Computers. A desktop computer generally consists of a monitor and central processing unit (CPU). The four CPUs tested ranged from a 4DX2-486 to a Pentium 400 and all consumed essentially the same amount of power during operation (53-54 W). The power required for the pentiums dropped by about 18 W in the idle mode while the 486 did not change. A total of six monitors were tested. The power consumption during operation appears to be strongly influenced by the monitor size, as shown in Figure 6. The power consumption of a monitor can be estimated by the following relationship:

$$P = 5 \times S - 20$$

where P is power in watts and S is the monitor size in inches and the relationship is valid for $14 < S < 20$ inches. Two of the monitors tested were so-called energy-saver monitors. That is, these monitors go into a standby mode if they are not used for a period of time. The power dropped to insignificant levels

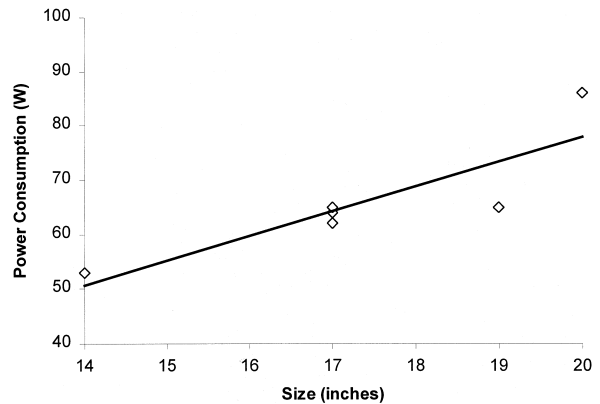


Figure 6 Relationship between monitor size and power consumption.

when in the standby mode. For continuous operation of all desktop computers, the following relation applies where Q is the heat load in watts and S is the monitor size in inches (this relation applies to 486 and standard monitors during idle mode as well):

$$Q = 5 \times S + 35$$

For a pentium computer with a standard monitor in the idle mode,

$$Q = 5 \times S + 15$$

For a pentium computer with an energy-saver monitor in the idle mode,

$$Q = 40$$

Printers. The power consumed by the laser printers tested depends largely on the level of throughput for which the printer is designed. The lower end of the laser printers tested was a minimal desktop unit intended for the individual user. Such a printer is seldom used to run large print jobs and is in the idle mode much of the time. The other end of the spectrum is a high-end printer intended for a computer center or other facility where the printer may run continuously for hours at a time. The table below summarizes the results based on the class of laser printer.

Class	Idle Mode (W)	Continuous Mode (W)
Minimal desktop	10	128
High-grade desktop	6	217
High-grade desktop	79	208
Small office (multiple users)	68	322
Computer center (many users)	124	558

For continuous use, the numbers can be rounded and combined to make a general guideline as follows:

Minimal desktop	130 W
High-grade desktop	215 W
Small office	320 W
Large office/computer center	550 W

It is unrealistic, however, to expect continuous use of at least the first two classes of printers listed above. They simply are not cost-effective at high production rates and would rarely be used in that mode. The power consumption for the standby mode ranges from near zero for the so-called energy-saver printers to about one-third of the continuous consumption. A reasonable estimate of the actual heat load for the first two classes is about one-half of the continuous value for the

conventional printer and perhaps about one-fourth of the continuous value for the energy-saver printers. For the office-grade printers, the continuous value is recommended for design calculations. Thus, our final recommendations for printer heat load estimates are as follows:

Minimal desktop	65 W
High-grade desktop	110 W
Small office	320 W
Large office/computer center	550 W

Three dot matrix printers were tested as well. While there are still many of these printers in use, they are generally used for low print volume applications. For these applications, the idle mode will dominate and should be used for heat load estimates. In the idle mode, the dot matrix printers generate little heat and 20 watts is a reasonable estimate that includes the higher power consumption from the occasional use they experience.

Copiers. Of the four copy machines tested, one was a small desktop unit and the other three were typical of copy machines used in larger offices. The results of the tests are summarized below.

Copier	Idle Mode	Continuous Mode
Desktop	20 W	400 W
Large office	300 W	1100 W

The desktop unit would be typical of the type used intermittently, while the larger office machines may well operate at near maximum capacity for hours at a time. All of these copiers are 110 V, single-phase machines and are not representative of very large machines used for production work. The larger machines could result in heat loads several times the amounts listed above. For heat load estimates, it is recommended that the continuous mode value above be used for large office machines. The actual heat load from the desktop unit is unlikely to exceed 100 watts.

Fax Machines. The three fax machines evaluated are all typical of machines that serve a small to medium-sized office. The power consumption of these machines is not large even in continuous operation. A design heat load of 25 watts for these machines is appropriate.

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