CONTINUOUS CONTROLS: LIGHTING ENERGY MANAGEMENT FOR RETROFIT AND NEW CONSTRUCTION PROJECTS

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ABSTRACT

The rising interest of specifiers and end-users in Lighting Energy Management (LEM) control equipment has led to an increased need for further education in the selection, capabilities and applications of such equipment.

This paper addresses these and related points for a particular type of LEM equipment referred to as "continuous controls." More specifically, the need for such equipment and its performance are reviewed. The remainder of the paper discusses the capabilities and applications of continuous control equipment for retrofit and new construction projects. Particular attention is drawn to the need for specifiers and end-users to become more control conscious as continuous controls become more fully integrated into building design.

INTRODUCTION

Lighting is responsible for a significant portion of the total energy bill for an office building, typically constituting thirty five to sixty percent of the electrical load. Lighting costs will continue to rise as electrical rates and demand charges escalate. A recent survey of energy users revealed an expected average electricity rate increase of 6% for the next year. (1) This is consistent with data from previous years; since 1969, electricity costs on a national average basis have always increased from year-to-year, peaking in 1974 and 1979 with 29.9% and 20.5% increases respectively. (2)

From a building owner's point of view, Lighting Energy Management (LEM) equipment is necessary in order to control present and future energy expenditures as well as to minimize the sudden damaging effects of a dramatic price increase; those which occurred in 1974 and 1979 are good examples. Specifiers then, must become proficient at understanding the capabilities and applications of LEM equipment. They must gain the attention of building owners who expect energy-efficient buildings and realize that properly designed, high-quality LEM equipment will help ensure long term satisfaction. Conversely, building owners will seek out specifiers with a thorough understanding of LEM as well as a proven track record. It will then be to the advantage of architects, engineers and lighting designers to become knowledgeable about the various LEM controls that are available so that the optimum control system can be selected for each client.

CONTINUOUS CONTROLS

There are several types of LEM control equipment that a specifier can choose from. One of the most technically innovative and economically justifiable of these is "continuous control", often referred to as dimming. In its truest sense, however, dimming involves reducing the light output of a lamp for aesthetic purposes, to modify the ambiance and help define the mood of a space. Dimming fluorescent and HID sources require the use of special dimming ballasts and while energy is saved during the dimming process, it is not the prime consideration.

With continuous controls, the prime motivating factor is proper energy management. Energy consumption is reduced proportionately to lighting levels. As an alternative to using rather expensive dimming ballasts, cost effective continuous control equipment used conventional magnetic core ballasts to reduce the power consumption of fluorescent and HID fixtures. This is quite significant, because one of the primary objectives in any project is to minimize costs while providing maximum benefits. These two important project objectives make <u>every</u> existing or future building an excellent candidate for a continuous control system, since it will be shown that tremendous energy savings and other associated benefits will result. Costs will also be minimized because the first half of the system, conventional ballasted luminaires, is already in place or soon will be.

EQUIPMENT

The other half of a continuous control system is the equipment itself. There are four major classifications of continuous control equipment by capacity: sub-circuit, circuit, multi-circuit and panel control.

SUB-CIRCUIT

Sub-circuit control is used when the lighting level requirements or working schedules vary within a small area, typically less that 1,000 square feet. Sub-circuit control would be considered for areas less than 500 square feet for some older buildings with 120 volt lighting systems. The equipment is generally located above the ceiling in the plenum or in the fixture itself.

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CIRCUIT

Circuit control is the most common strategy in an office building whereby a continuous control unit adjusts the lighting consumption of an entire circuit of lighting. The control equipment typically is mounted in or near the electrical closet.

MULTI-CIRCUIT

Multi-circuit control involves combining several lighting circuits on the same lighting phase to one control unit. The unit is fed with a higher amperage breaker, typically 30 or 40 amp, and the load is then reduced to 20 amp lighting circuits (15 amp in some cities) via secondary breakers on the equipment. Multi-circuit control equipment is used in larger areas where lighting level requirements and schedules are similar. The control equipment again is installed typically in or near the electrical closet.

PANEL

Panel control involves controlling all the lighting on a distribution panel as one zone (a zone of lighting being defined as a group of luminaires which are controlled simultaneously and identically). The control equipment is of high amperage capacity and installs between the main distribution panel and the lighting distribution panel, either in the electrical closet or where the main feeders enter the building.

There are trade-offs between the different control capacities; for example, as the equipment size increases, the installed cost per watt controlled decreases, but so does the flexibility and with it the potential to maximize energy savings. Careful consideration must be given to the proper sizing of the control equipment for each project. Manufacturers are usually willing to provide applications assistance; however, it may be best to work with the manufacturers that offer a wide choice of equipment sizes to ensure that the client's needs are best met and not the manufacturer's.

PERFORMANCE

A properly designed continuous control system that performs well is an invaluable asset to a building owner; the equipment will provide tremendous energy savings while creating an extremely flexible lighting system. On the other hand, a continuous control lighting system which performs poorly will result in lower energy savings, negative employee/worker reations and an extremely unsatisfied building owner. All of the following performance specifications should be given due consideration for any continuous control system and can be met with high-quality equipment from a reputable manufacturer.

Control Range. Minimum control range should be 100% to 50% for both energy saving and standard lamps. Obviously the greater the control range, the greater the potential energy savings and system flexibility. Systems with ranges in excess of 100% to 50% are available; one manufacturer has a proven system with a range of 100% to 22% using a specific energy saving lamp/ballast combination.

Lamp Aesthetics. Two considerations are important from an appearance point of view.

1. Lamps should not flicker throughout the entire control range.

2. Lamp to lamp uniformity should be maintained; in other words, at any point in the control range there should not be a visible differential in light output throughout a controlled area if similar lamps and ballasts are employed.

Control Technology. The technology and the control circuitry employed by the manufacturer should be such that no degradation to the lighting system (lamps, ballasts, wiring, etc.) could occur over any portion of the control range. Otherwise, the economic justification of a control system may no longer apply and the specifier will end up with a potentially unhappy client.

A high quality continuous control lighting system will provide a wide control range, excellent lamp aesthetics and uphold the integrity of the lighting system. It is the responsibility of the specifier to seek out such control systems, verify that all performance criteria are met as well as the client's short and long-term needs.

APPLICATIONS AND DESIGN CONSIDERATION

There are three continuous control strategies which may be employed, either independently or in combinations with each other, in order to maximize savings. Lighting energy savings are possible by: 1. Maintaining a given light level using photosensor control. 2. Eliminating lighting energy wastes when and where appropriate. 3. Reducing lighting peak demand usage.

PHOTOSENSOR CONTROL

Two options are possible using photosensor control.

Daylighting - DAC*. Daylight Automatic Compensation control is probably the easiest control strategy to understand as well as justify. A photosensor is used to monitor daylight levels and interface with continuous control equipment, signaling the equipment to reduce lighting/power levels when any daylight is present in the controlled space. With DAC it is not necessary to reduce the maintained light level to incur savings (figures 1A and 1B). of course, the savings resulting from maintaining 70 footcandles will be greater than a system which maintains 123 FC. Data obtained from detailed analysis, experimentation, and test installations (3, 4, 5) show that DAC can reduce lighting energy costs from 9% to 15% on a building side basis. This is quite substantial when one considers that potential daylight controllable perimeter zones may account for only 15% to 25% of the total floor area; actual annual savings in the controlled zones will range between 35% to 70%. These studies have been further corroborated with post installation monitoring of actual projects which show lighting energy savings of 45%, 51% and 63% respectively. (6, 7, 8) In addition to those points already mentioned, a DAC control system should meet the following performance criteria: 1. Be easy to adjust and calibrate. 2. Utilize an accurate photosensor that does not drift with time or temperature. 3. Provide a slow fade rate (20-30 seconds) between levels to insure that occupants are not subjected to rapidly fluctuating lighting levels, thus minimizing awaremess of a control system.

Sub-circuit and circuit control capacity equipment is generally employed due to the size of the perimeter areas as well as their orientation (maximum savings are achieved if different building facades are controlled independently). Larger perimeter areas or areas that see uniform daylight levels due to skylights or light shelves might utilize multi-circuit or panel control equipment.

Savings associated with reduced peak demand levels and lower cooling loads may be realized as well. The greatest seasonal peak demand period for many commercial buildings occurs in the mid to late afternoon during the summer, primarily due to increased cooling load requirements. Concurrently, with DAC the perimeter lighting load will be substantially reduced providing built-in demand reduction capabilities as the lighting power (KW) decreases in response to daylight. Cooling requirements will also be reduced during these periods, as 0.15 to 0.40 fewer watts of cooling per watt of lighting reduction are required, depending on the total building design and location. The majority of commercial office buildings may be able to translate this into additional peak demand and consumption savings after accounting for all thermal considerations. The same building might also enjoy potential capital savings downsizing the tons of refrigeration required in new construction (a savings of $400 to $800 per KW expected lighting reduction, assuming $1500 to $3000 per ton of refrigeration installed). (9)

Lumen Maintenance - ILC*. Interior Lighting Compensation may be used in any new construction or renovation project, or in retrofit applications where group relamping is practiced. All lighting sources depreciate in light output as the lamps age, necessitating the lighting designers and engineers to provide more light initially than is actually required to ensure that enough light remains at a later date. Luminaires also tend to accumulate dirt and dust, further reducing the efficiency of the lighting system. To compensate for Lamp Lumen Depreciation (LLD) and Luminaire Dirt Depreciation (LDD) as well as other factors, 20% to 35% more light than required will initially be present. ILC uses a photosensor to monitor lighting levels and to "remember" what the desired maintained light level should be. Initial energy savings will be 20% to 35%; savings will decrease with time as additional power is required to maintain the designed light level (figures 2A and 2B). Maximum long term benefits of a ILC system are realized if a group relamping program is implemented; yet, ILC can be combined with other control options to provide an economically justifiable system even if relamping is done on a spot basis in the future.

Even greater savings are possible when employing ILC with lamps with lower LLD factors, such as HO, SHO or VHO fluorescent or HID sources such as mercury vapor and metal halide. Dirtier environments such as industrial and manufacturing facilities where LDD factors will be reduced also provide substantial savings when ILC is employed.

It is very important to note that both DAC and ILC maintain or exceed the desired illumination levels at all times, and that a building owner does not necessarily have to live with lower lighting levels to obtain the benefits resulting from continuous control equipment.

ELIMINATING WASTE

There are two continuous control equipment options that can reduce lighting energy waste by reducing the lighting load and/or the amount of time that lighting is on.

Level Reduction - LEA*. Lighting Energy Adjustment is employed in retrofit or renovation projects where more light than is required is presently being provided. LEA reduces the light/power levels down to the appropriate level. A significant number of existing office buildings are still overlit compared to current design standards; in these buildings LEA provides a means of producing uniform lighting at a lower energy cost.

Another advantage of LEA is "tuning." Tuning represents the ability to finely adjust the lighting system to proper levels. Only after the age of those working in an area and the nature of the task being performed (importance, required accuracy and speed, and other factors) have been considered, can one effectively determine and set the appropriate light level. The value of flexibility is overlooked until one considers a typical office building where a specifier is asked to design a lighting system. In many instances the building owner cannot predict what specific tasks will be performed in any given area of the building, let alone the other factors mentioned. He certainly cannot predict what each area will be used for in two, three or four years.

The ability to fine tune the lighting system over time using continuous controls is one solution to this design dilemma. One study (10) indicated that building owners could have saved an additional 12% on lighting energy costs if the lighting system could have been fine tuned as described. Energy savings might also be realized in areas where constraints due to spacing-to-mounting-height ratios, grid patterns or selected fixture types provide maintained light levels higher than desired. LEA can be used to lower the lighting/power levels to reach the design levels. The "flexibility" feature of continuous controls, both for existing facilities and new construction provides often overlooked, but very important, short and long term benefits for a building owner.

Time of Day Scheduling - TODS*. Time of Day Scheduling is a control option which provides multiple power/light level control as well as on/off capability when used in conjunction with programmable time clocks or energy management equipment. TODS control can provide tremendous building wide energy savings due to the fact that lighting requirements not only change over a long period of time, as already discussed, but in fact change in many instances in a predictable manner within a single day. Take for example a typical workday. If the "official" start of the workday is 8:00 a.m., there will be some workers who will arrive prior to that time to take care of small matters - cleaning up a desk, setting up the day's schedule, etc., in short, preparing for the upcoming day. The majority of these tasks would be classified as non-critical in comparison to those during normal work hours, so it is reasonable to expect that lighting levels might be lowered as much as 60% during these non-critical periods. Once the normal work schedule has been resumed, lighting levels would be brought up to 100% of the desired level. During lunch or other scheduled breaks lighting could once again be lowered or even shut off. Once the cleaning crew has arrived, lighting/power levels could again be reduced and then finally shut off after the cleaning people have left the building (Figure 3).

TODS offers perhaps the greatest building wide energy savings potential of any continuous control option. Previously quoted studies (11, 12, 13) indicate savings in the range of 10% to 40% of the total building lighting consumption. TODS continuous control should be considered for every retrofit or renovation project, since it is not necessary to recircuit or rewire fixtures, add multi-pole wall switches, add relay or contactor panels, or make other expensive changes to the existing lighting system. Similar cost savings (equipment and energy) are available in new construction (Figures 4A and 4B).

There will be instances in some buildings when an employee will choose to work on a weekend or stay late during the weekday, perhaps well into the cleaning period. In these situations, it becomes necessary to provide overrride control capabilities such that proper lighting will be supplied in the employee's work area. Override capabilities should be designed so that: 1. Override controls are easily accessible and usable. 2. Override is for a maximum specified time, then reverts back to the normal operating schedule in order to prevent "permanent" override. 3. Overridden areas are minimized within practical limitations, (i.e., circuit control vs. panel controlled equipment) in order to maximize energy savings.

DEMAND REDUCTION

Peak Demand Reduction (PDR)* is a continuous control strategy which deserves more and more attention as the cost of electrical demand continues to rise. Rather than shutting off or cycling fans, pumps, blowers, chillers, motors or lighting during peak demand intervals PDR involves slightly reducing lighting/power levels during these periods in response to signals from demand sensing equipment (Figure 4). PDR offers several advantages over "conventional" demand limiting techniques.

Increased Occupant Comfort. The skin system in our bodies compensates for rising air temperatures by increasing the amount we sweat or perspire. Our eyes are more sophisticated; the iris expands or contracts as necessary to regulate the amount of light we see. Lighting reductions of up to 15% are not perceivable to the human eye in most commercial office environments if the fade time is long enough for the eye to adapt to the new surroundings. This is not to say that because the changes in the environment are not perceived that there are no effects on the occupants in the space. This is an unknown which is associated with any demand limiting strategy; there are no guarantees that the office environment will be optimum (whatever that may be) 100% of the time.

Ease of Design. PDR does not require that any special circuiting arrangements be made. There is also no real potential for harming any external equipment since there are no minimum "off" times associated with PDR.

Actual Demand Reduction. A 15% decrease in lighting load will generally result in a lower peak demand than a 15% decrease in chiller "on" times. Additionally, lowering the lighting load also will tend to lower the cooling load while the converse is not true.

In facilities where the decision has been made to incorporate demand limiting strategies, PDR should be evaluated as carefully as any other demand control, and will be found to be applicable in many instances.

CONCLUSION

LEM equipment will play an increasingly important role in the design of the total building system. Continuous control is one LEM strategy that when properly integrated into the lighting system can provide building owners high quality lighting, tremendous energy expenditure reductions and unsurpassed lighting system flexibility. Furthermore, associated with these benefits are very attractive payback periods.

Specifiers must take the time to become more knowledgeable about continuous control equipment if they are to successfully market and provide lighting energy management consulting services. Manufacturers, in turn, must be able to provide the technical and sales assistance required by the specifier. This support may take the form of:

- °toll-free technical assistance "hotlines"
- °applications and system lay-out assistance
- °technical and sales presentations
- °free computerized energy analysis

These support services will foster a good working relationship between a control manufacturer and a specifying firm; this can only serve to enhance both the short and long term satisfaction of that firm's clients.

As electrical energy costs escalate, it will become more difficult to hold building operational costs in line. Many owners and specifiers will view this situation as a tremendous problem. Others will translate this problem into an opportunity by using energy management equipment such as continuous controls.

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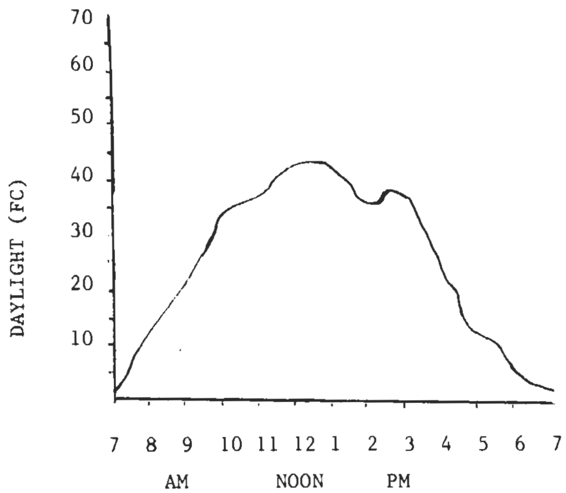


Figure 1A

DAYLIGHT LEVELS 15' FROM WINDOW (TYPICAL) VS. TIME OF DAY.

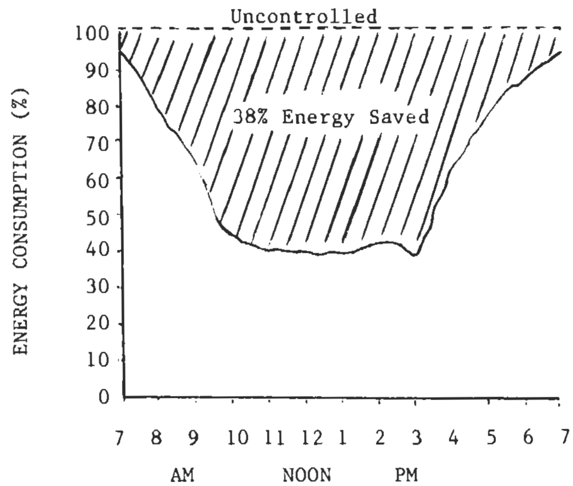


Figure 1B

ENERGY CONSUMPTION VS. TIME USING FIGURE 1A USING CONTINUOUS CONTROL (100%-40% Range, Target Level 50 FC).

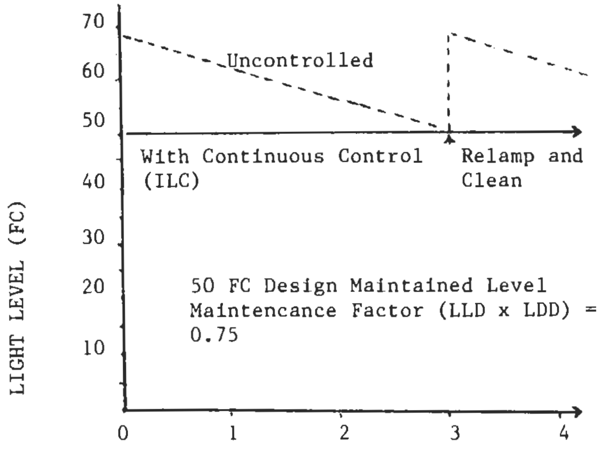


Figure 2A

LIGHT LEVEL IN INTERIOR OFFICE SPACE VS. TIME

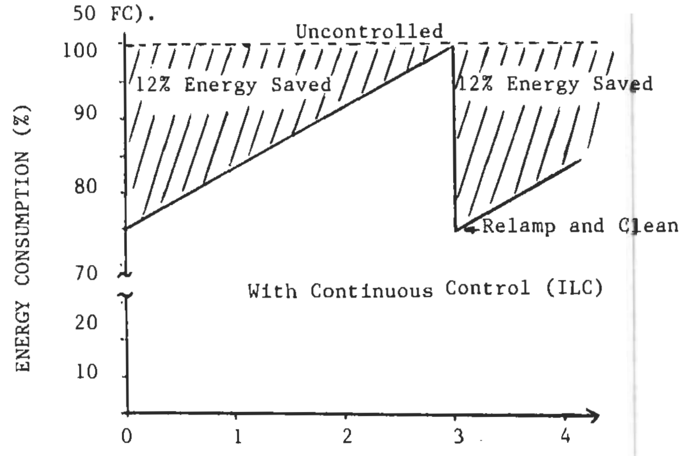


Figure 2B

ENERGY CONSUMPTION VS. TIME USING FIGURE 2A

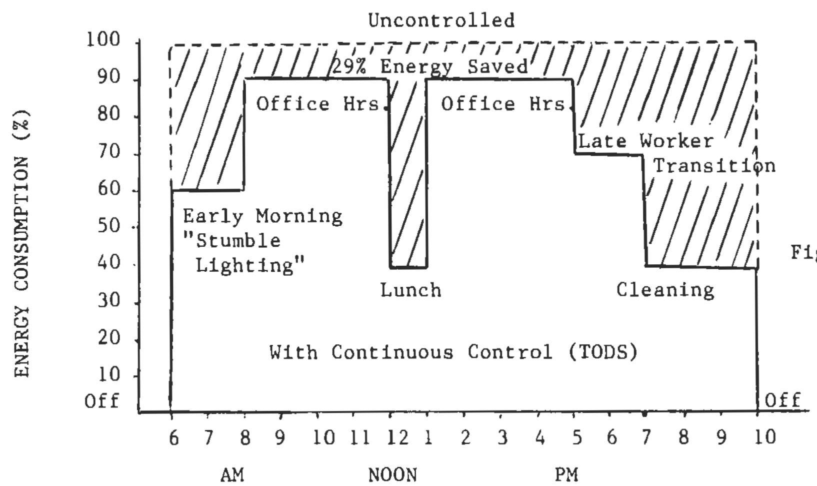


Figure 3

ENERGY CONSUMPTION VS. TIME FOR TYPICAL OFICE AREA

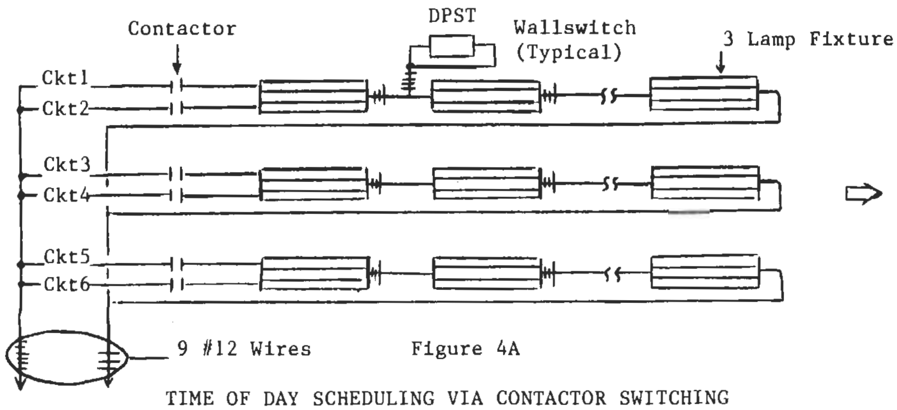


Figure 4A

TIME OF DAY SCHEDULING VIA CONTACTOR SWITCHING

REQUIRES

Contactors

Contactor Panel

2Ø/3W Circuits

More Expensive Localized Switching
- °More wire
- °More switches or
- °More expensive switches (DPST)
- °More backboxes
- °More labor

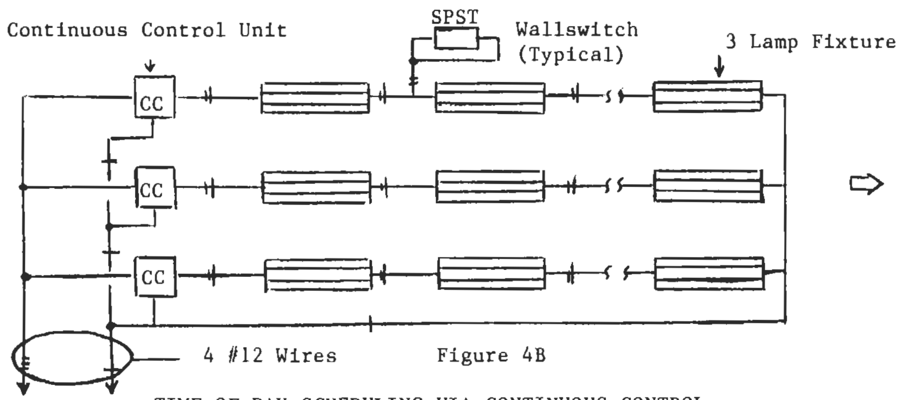


Figure 4B

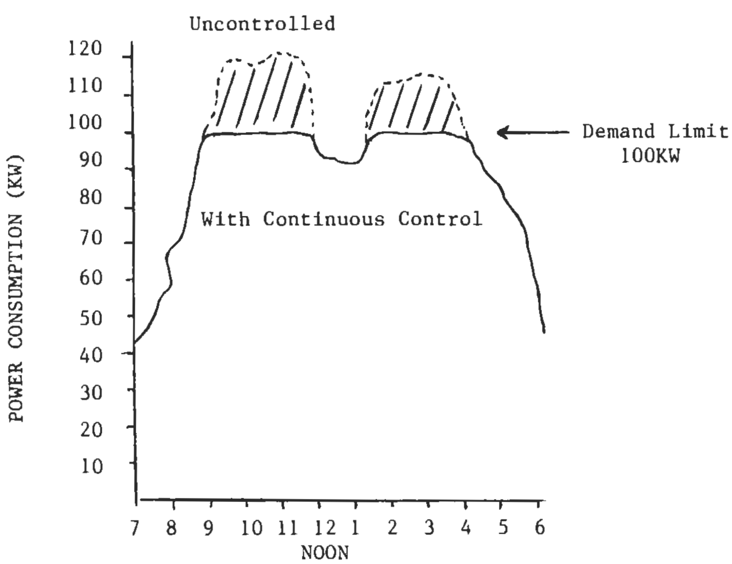
TIME OF DAY SCHEDULING VIA CONTINUOUS CONTROL

REQUIRES

Continuous Control Units

Conventional 3Ø 4W Circuits

Conventional Localized Switching



DEMAND PROFILE FOR TYPICAL OFFICE AREA

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