AN INTRODUCTION TO DIGITAL ADDRESSABLE LIGHTING INTERFACE (DALI) SYSTEMS & STUDY OF A DALI DAYLIGHTING APPLICATION

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B.S., Kansas State University, 2007

A REPORT

submitted in partial fulfillment of the requirements for the degree

MASTER OF SCIENCE

Department of Architectural Engineering and Construction Science
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KANSAS STATE UNIVERSITY
Manhattan, Kansas

2007

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Abstract

The DALI (Digital Addressable Lighting Interface) protocol has set forth the requirements for a digital fluorescent ballast that out performs its predecessors with respect to flexibility and functionality. The advantages of a DALI lighting control system range from advanced dimming capabilities and daylight sensing to saving money in energy and maintenance costs. A DALI lighting control system can also be beneficial to designers when trying to meet the requirements of code or recommended practices.

The information in this report will help designers decide when to consider using a DALI lighting control system. This report covers topics such as the advantages of digitally addressable lighting, the equipment required to make a DALI system work, the limitations and drawbacks of DALI, cost information on installing and using a DALI system, and how DALI can help meet code and recommended practices, and concludes with a case study demonstrating how a DALI system has the potential to save money in energy costs.

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CHAPTER 1 - Introduction

Any new technology is expected to be better than its predecessor in that it should be more flexible and have greater functionality. Digitally Addressable Lighting Controls have been making their way into lighting designs providing increased flexibility and functionality compared to any other dimming system on the market. As an alternative to other dimming systems such as 0-10V systems and DSI (Digital Serial Interface) control systems, they have many advantages that will be discussed in detail in this report.

The purpose of this report is to create a basic understanding for entry-level and experienced engineers of digitally addressable lighting for fluorescent lamps that meets the requirements of the DALI protocol. After reading this report, the engineer should have a good idea of when it would and would not be appropriate to choose a DALI system design. This report covers what DALI is, how it works, the required components, and the advantages and disadvantages of using a DALI system. This report does not cover manufacturer specific products, but does describe some of the products available to consumers. It is assumed that an engineer would consult a manufacturer's representative for specific product options once the decision to design a DALI lighting control system is made. This report also does not go into great depth on how products are designed or specifically how they work since that information is not essential for designing a system. This type of information may be useful for those wishing to create their own products but is beyond the scope of this report.

CHAPTER 2 - Background

DALI is an acronym for Digital Addressable Lighting Interface. The term interface refers to a ballast. This chapter includes a definitions section, an introduction to what DALI systems are, and the history of DALI.

Definitions

This section is intended to explain some of the terminology that is used throughout the paper. The first occurrence of each term defined in this section will be shown in bold as a reference to this section.

0-10V System

A 0-10V system is an analog low voltage lighting control system that uses analog dimming ballasts connected in parallel and controlled simultaneously by changing the voltage from 0V up to 10V with a dimming control unit. The ballasts are not addressable and can not be controlled individually. Hard wiring determines which analog ballasts will be controlled as a group (Ribarich).

Address

An address, when referring to a DALI system, is a series of eight data bits that is unique to each ballast in a DALI loop (Zhang). The address is used to identify a particular ballast when messages are sent from the control unit.

AGI-32

AGI-32 is a lighting calculation software created by Lighting Analysts, Inc. Lighting Analysts, Inc. describes the software as “comprehensive calculations, ease of modeling, and fast, high-quality rendering for any interior or exterior environment, considering electric and/or daylighting sources” (What).

Control Unit

A control unit is the “brain” of a DALI system because it is responsible for telling the ballasts which functions to perform. It can also request information from the ballasts related to ballast/lamp performance. The control unit also creates, stores, and recalls presets when told to do so by the user via a touch button, touch screen signal, or computer software.

DALI Loop

A DALI loop is a group of up to 64 DALI ballasts connected to a control unit or router with low voltage communication wires. A DALI loop can act individually as a system when connected to a control unit, or can be connected to other DALI loops with routers to create a larger DALI network.

DALI Message

A DALI message is a command from a control unit or a response from a ballast. A message command is made up of one start bit, the eight-bit address, an eight-bit command, and two stop bits. A response message consists of one start bit, eight data bits, and two stop bits. Refer to the definition of **Differential Manchester Encoding** for more information on bits.

Daylight Harvesting

Daylight harvesting refers to integrating natural daylight with artificial light to illuminate a space. It is done using lighting controls that sense light levels and respond by dimming or turning off lights to maintain a specified light level.

Differential Manchester Encoding

Differential Manchester encoding is a type of electronic communication using a series of zeros and ones to signify the presence or absence of transitions to indicate logical value (Data). These values make up the bits used in an address and a DALI message.

IEC, International Electrotechnical Commission

The IEC is an international standards organization that sets standards for electrical technology. The standards are based on safety, performance, the environment, and energy efficiency. The American National Standards Institute (ANSI) is a member of the IEC (www.iec.ch).

Preset

A preset may also be referred to as a scene. A preset is a lighting scenario that is stored in the control unit that can be recalled at any time. The preset lighting scenario can be comprised of any combination of ballasts or groups of ballasts, each of which can be set to a different desired dimming level to meet the needs of the space.

Router

A router is used to connect DALI loops to an Ethernet network. This allows more than one DALI loop to be controlled as one system.

Introduction to DALI Systems

A DALI system is a method of controlling light fixtures in a space ranging from single rooms to multiple buildings. Ballasts are connected with the typical hot, neutral, and ground wires to provide power as well as two low-voltage wires. The low-voltage wires act as a means of communication with the **control unit**. The control unit assigns what is referred to as an **address** to each ballast. The address allows the DALI control unit to call on each ballast individually with a **DALI message** and assign it a specific task or receive information from it. The control unit can send/receive ballast information ranging from turn on/off, dim, ballast malfunction, and lamp burn out. Ballasts can also be assigned to groups defined by the user via the control unit. This allows the control unit to send out a group message. Each ballast knows, based on the information stored in the ballast, whether it belongs to that group and if it should perform the given function. The difference between a DALI lighting control system and other lighting control systems with preset functions is that in a DALI system a ballast can be assigned to any group at any time regardless of how the power circuits are wired. Other lighting control systems require groups to be determined during the design phase because they are defined by hard-wired groups.

History of the DALI Protocol

In 1990, European ballast manufacturers such as Philips, Osram, Tridonic, Huco, Trilux, and Vossloh-Schwabe began researching new ballasts that could communicate individually with a control unit. The reason for this research was to explore the possibilities of a lighting control system with greater flexibility than a **0-10V dimming system**. The **IEC** created standard 60929, Annex E: Control Interface for Controllable Ballasts which is known less formally as the DALI protocol, to establish the requirements for the new DALI ballasts. The importance of a standard is that it sets a minimum set of requirements so that components are interchangeable. Many manufacturers have been able to create DALI products since the technology is not patented. Development of commercial DALI products began in 1998. For a ballast to be labeled as a DALI ballast, it must meet the requirements of the DALI protocol. Other DALI equipment such as control units are not defined by the DALI protocol and are labeled as DALI simply because they have the capability of communicating with DALI ballasts. Because the DALI ballasts operate using the same protocol, those manufactured by different companies have the ability to work together. This allows consumers to find more competitive pricing among products. This is also important because ballast replacement does not depend on any one manufacturer’s status as far as discontinued products are concerned. Note that because the DALI protocol only defines the requirements for DALI ballasts, other DALI products such as control units may not be compatible with products from competing manufacturers, but all DALI ballasts will work with any DALI control unit (Technical).

CHAPTER 3 - Advantages of DALI

A DALI lighting control system has the capability of performing a wide variety of tasks beyond those of a typical switch or dimming system. The system can incorporate dimming, daylight sensing, and occupancy sensing, and save energy. This chapter will discuss each of these advantages of DALI systems.

Dimming

The ability to dim lights is essential for many buildings since various daily tasks require dimming. Conference rooms, auditoriums, and classrooms can all benefit from the ability to dim lights. A DALI system makes this task simple. DALI ballasts are capable of dimming down to 1% for linear fluorescent lamps and 3% for compact fluorescent lamps (DaliPro). **Presets** on the control units can be set to tell a certain DALI group to dim to a pre-assigned level. Once the preset is defined within the control unit, only the touch of a button is required to achieve a desired level of dimming. This can save time and allow flexibility for a user. Prior to a meeting or class, users can define presets or use presets already created that meet their needs for specific tasks, such as showing multimedia displays while occupants are taking notes. Owners may also desire various light levels to create different moods for different events such as low light level evening dinners or higher light level conferences. Dimming presets allow the changes to be made instantly at the touch of a button.

According to the DALI protocol, DALI ballasts shall be capable of providing 256 levels of brightness that follow a logarithmic dimming curve. Logarithmic dimming allows for larger increments in brightness at high light levels and smaller increments of brightness at the lower light levels. The result is dimming that appears linear to the human eye (Ribarich).

As it relates to dimming, a DALI lighting control system is different from any other dimming control system because it can be addressed individually and meet the needs of an occupant more flexibly, and the logarithmic dimming capability increases occupant comfort.

Note that some manufacturers are starting to make DALI ballasts that do not have the capability to dim, so it is important to make sure a non-dimming DALI ballast is not specified when dimming is required. Non-dimming DALI ballasts are beneficial because they are more cost effective in areas that do not require dimming such as some restrooms and corridors (Lighting).

Daylight Sensing

Often an owner wants to incorporate daylight into a space for color rendering purposes, to make occupants feel less like they are cooped up indoors, or to save money in energy costs. A DALI system is one of the best ways to integrate daylight with artificial light while maintaining a fairly uniform footcandle level on the workplane. The only time the light level may not remain uniform is when daylight provides a higher footcandle level than that for which the space was designed. In this case, installing blinds or shades on the windows may be beneficial. Since each ballast can be controlled separately in a DALI system, the control unit, after receiving readings from a photosensor, can send individual messages to each ballast about how much they need to dim to keep light levels fairly constant. Refer to Chapter 4 for more information on photosensors, including open-loop versus closed-loop systems. In a typical 0-10V system, where ballasts are grouped based on wiring, the entire group must be dimmed the same amount. This setup requires a careful analysis of daylight levels during the design phase to make sure fixtures are grouped so that dimming requirements are the same for each fixture in a group to allow for a uniform footcandle level on the workplane. In a DALI system, fixtures do not need to be grouped prior to installation, or at all if an open loop photosensor is used. This makes the system easier to design; however, depending on the level of precision desired by the owner, more time will be required for programming. The advantage of a DALI system would be the guarantee of having the capability to provide adequate light levels.

Save Energy

The article “Emerging Trends in Building Lighting Control Systems” by Craig DiLouie states that according to the California Energy Commission (CEC) significant amounts of energy can be saved by controlling lighting. The CEC claims an energy savings of 5-10% can be achieved by automatically shutting off a building’s lights at the end of a workday. Shutting off a portion of a building’s lighting during peak demand loads can save 5-15%. Scheduled dimming of large lighting loads can generate a 2-10% savings (DiLouis, Emerging Trends). A DALI system has the capability to perform each of these functions. It can be programmed to turn lights on/off based on a programmed time schedule, scenes can be set in which some of the fixtures are turned off at a set time of day, and it can dim lights to a desired level. Utilizing a **daylight harvesting** setup has the potential to reduce energy consumption by 30-60% (Advance). See Chapter 9, Daylighting Case Study for an example of how DALI can save energy.

Space Use Flexibility

A DALI control unit has the capability of storing up to 16 preset scenes. A scene refers to a group of ballasts that are told to perform a certain task at the touch of the button on the control panel. Tasks range from turning on/off to dimming to a specified light level. A DALI lighting system creates a space that is flexible for many uses. Presets can be programmed before an event that requires many different light levels or atmospheres. Simply touching the specific preset button on the control panel will change the lighting to the desired scene. One application for which this feature is especially useful is a conference. Part of the day a meeting or classroom light level may be desired for taking notes and later a lower light level may be desired for a dinner function. It is also particularly useful when a stage/speaking area is not clearly defined in a space because it allows the owner to change the lighting to highlight any stage location. The lighting presets can be changed to accommodate any arrangement of furniture or occupants as long as a fixture exists in the desired location. It would still be rather simple to add an additional fixture to a **DALI loop,** provided space is available on the loop. Refer to Chapter 5 for space limitations. The advantage of using a DALI lighting control system in place of another lighting control system with preset capabilities is that DALI groups can be defined/redefined at any time and other system's groups must be determined during the design phase so that they may be hard wired by groups during construction.

Ease of Modification

On occasion the function or layout of a space requires modification. Whether this is a change in furniture layout, new tenant requirements, or simply new task requirements, a DALI lighting system provides the flexibility to adapt the lighting controls to any new space. Because the wiring of the ballasts plays no part in how the fixtures are grouped or controlled, changes can be made whenever the need arises. Fixtures can easily be regrouped and groups can be reprogrammed to fit the needs of the space. Because modification of a DALI system is so simple, it avoids the costly changes associated with a hard-wired system.

Lower Maintenance Costs

Maintenance is often a principal concern for building owners. A DALI system, when used with a computer interface and DALI software, has the ability to provide feedback from the ballasts back to the program. Signals are sent that, for example, report information about failed lamps and ballasts. This information allows maintenance staff to be notified immediately and tells them the exact location where the malfunction has taken place, provided ballast location has been inputted into the computer software. This can reduce the time it takes staff to maintain lamps and allows them to focus on other building issues. This function of a DALI system would be especially beneficial in a large system, maybe even as large as an entire campus because attention can be immediately focused where there is a problem, instead of waiting for a problem to be identified and located.

Individual Control

A DALI system allows occupants individual control of the lighting in their workspace. In an open-office scenario, one employee may desire a higher light level than another. Because each of the ballasts are controlled separately, each fixture can be set to dim to any level desired. One drawback of this feature is that it would be time consuming to change just one fixture in a large loop of fixtures, especially if it were located toward the end of a 64-ballast loop. Programming also requires that all lights are turned off being so that the one fixture specified to be changed can be identified by having that particular ballast turned on, which may be a problem during business hours.

Integration with a Building Management System

A DALI system can be integrated with a building management system (BMS) that controls other systems in a building such as HVAC. This enables an owner to view and change lighting conditions from a computer. From a maintenance perspective, using DALI with a BMS works the same as using DALI with computer software as described in the previous section on maintenance costs. Note that without a DALI system, the ballasts connected to the BMS would not be individually addressable (Advance).

Emergency Lighting Testing

When building standards require each emergency fixture to be tested for its performance and battery condition on a regular basis, time can be saved if a DALI lighting control system in combination with computer software is utilized. Software such as EM winPRO from Tridonic can test the performance of emergency lighting as it relates to lamp and ballast faults and battery status and report their performance back to a computer. The fixtures can be set to be tested periodically or continuously. Because the testing procedure is performed by a computer, testing can be done during off hours without requiring the presence of maintenance staff. After-hours testing is important when productivity issues and potential distractions are a concern to an owner (Hayes).

Installation/Design

A DALI lighting control system is advantageous to any other lighting system requiring dimming or presets in the design phase and installation. Because DALI is individually addressable, the power conductors and low voltage control wires can be installed in any configuration. Other lighting control systems require wiring based on the expected needs of the space at the design phase. DALI offers flexibility in that groups can be assigned at any time regardless of how the fixtures are wired. For example, 0-10V dimming systems require ballasts to be installed in parallel and controlled simultaneously by a single control unit (Ribarich). DALI systems can be installed in series, in a star configuration, or in a combination of the two with the potential of reducing the amount of wiring needed or reducing the maximum distance (Advance). Figure 3-1 (Advance), below, shows the various wiring configurations. See Chapter 5 for more information on distance restrictions.

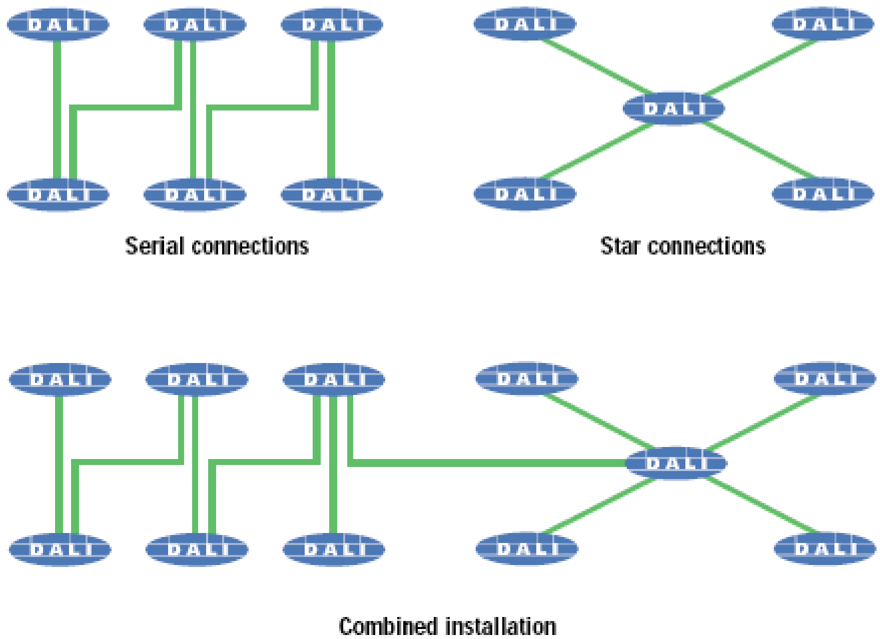

Figure 3-1 Ballast Wiring Configurations for DALI

Ability to Work with Retrofit Designs

A DALI lighting control system can work with a retrofit lighting design. An old control system can be updated by replacing the ballasts in the fixtures with DALI ballasts and providing control wiring to a control unit. If the original system is a 0-10V dimming system, the original control wires can still be used for the new DALI system.

CHAPTER 4 - DALI Equipment

This chapter covers the equipment required to make a DALI lighting control system work. In addition, it covers optional equipment that will upgrade a DALI system to the next level.

Requirements for a Basic DALI System

The most basic DALI system, the system used in a simple single room application, requires light fixtures equipped with DALI ballasts, a DALI control unit, a DALI power supply, and low voltage wires connecting the devices. Even as a basic system, it can still perform essential tasks such as dimming and creating presets. More complex systems, such as those controlling multiple rooms or buildings, require the additional equipment discussed in the Optional DALI Equipment section of this chapter.

DALI Ballasts

When specifying ballasts for a DALI system, designers must make sure the ballasts follow the correct protocol. That protocol, as mentioned earlier, is IEC Standard 60929 which dictates all of the requirements for the ballast so that it will be compatible in any DALI system.

Each ballast within the DALI system is individually addressable. When the system is programmed, each ballast is assigned a unique code, its address, which is used by the control unit to call upon it to perform specific tasks. The ballasts are capable of communicating with the control unit using Differential Manchester encoding.

DALI Control Units

Control units are required in a DALI system to act as the brain of the system. The control unit is responsible for communicating with the ballasts and storing and recalling presets. Because control units are not defined within the requirements of the IEC Standard 60929, control devices from different manufacturers may not work together. They should, however, be able to communicate with any manufacturer’s DALI ballast. A designer would need to check with a manufacturer’s representative to see if two control devices could work together. In a basic DALI system, only one control unit is required, so compatibility is not an issue. Figures 4-1, 4-2, and 4-3 show examples of some DALI control units.

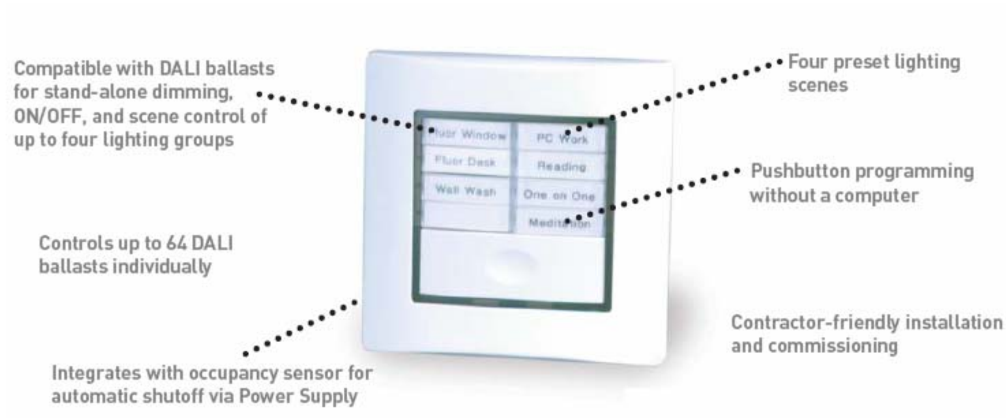

Figure 4-1 Watt Stopper EZ Dali Control Unit

Figure 4-2 Tridonic Control Unit

Figure 4-3 Starfield Control Unit

DALI Power Supply

Because DALI is a low voltage system, a low voltage power supply is required for the system to operate. A DALI power supply steps down a line voltage to the required voltage of 24V DC (An Introduction). The power supply unit has connections to a 120V power supply. The output of the unit is the low voltage wiring that allows for communication between the control unit and each ballast.

Low Voltage Wires

Low voltage wires run between the control unit, power supply, and ballasts. Standard building wire can be used for the low voltage wiring. The low voltage wires can be run in the same conduit as the power conductors as long as local codes allow. The layout of the wires does not affect the performance of the system. They can be designed in a series layout, a star connection, or a combination of the two (Advance).

Optional DALI Equipment

Many options exist for adding equipment to a DALI lighting control system. The additional equipment allows the system to outperform the most basic system's ability to dim lights and set presets. Some other equipment that can be used with a DALI system include occupancy sensors, photosensors, a computer interface, and a Building Management System. Note that this is not an all-inclusive list and that each manufacturer may have its own special DALI equipment.

Occupancy Sensors

Just as with any other application, an occupancy sensor detects occupants in a space and sends the occupancy message to another device that will decide whether the lights need to be turned on or off. An occupancy sensor in a DALI application must be able to communicate the DALI language of Differential Manchester Encoding in order to communicate with the rest of the DALI components. In a DALI system, the control unit can be set to wait a certain period of time once receiving occupancy information from the occupancy sensor before turning the lights on or off. It can also be set to dim the lights for a period of time before they are turned completely off.

Photosensors

Photosensors can be used in a DALI system to sense light and relay the light level message to the control unit, which can then send a message to ballasts to dim. Two types of photosensors will work in a DALI system: a closed-loop photosensor and an open-loop photosensor. Each will perform daylighting functions, but in each case the system will operate a little differently. Another option for sensing daylight is to use light fixtures that have integral photosensors. It is up to designers to choose the best option for a photosensor for a project based on their engineering judgment.

Closed-Loop Photosensors

Closed-loop photosensors are typically mounted on the ceiling within a space. They sense light on the workplane (daylight and lamp light) and report the levels to a control device that can dim fixtures to adjust the light level to a user-defined level. Each sensor controls one zone or, in the case of DALI, one fixture. If it is desired that each DALI equipped fixture is dimmed separately from another, a separate closed-loop photosensor would be required for each. Otherwise, the photosensor would control a group of fixtures that would all have to be dimmed the same amount. Having a separate photosensor for each DALI fixture would be possible, but that would not be a very cost effective solution (Kohnen).

Open-Loop Photosensors

Open-loop photosensors are positioned to only see daylight and no artificial light. They can then report daylight levels and ballasts can be dimmed to a relative percentage based on the sensor reading. As long as a group of fixtures sees the same source of daylight, they can all be connected to one photosensor. One photosensor can be used for an entire façade of a building as long as there are not any other objects, such as other buildings or trees, blocking the sunlight. In a DALI system, each of the ballasts can be set to be dimmed to a different relative percentage based on the photosensor reading (Kohnen).

Fixtures with Integral Photosensors

Another option for daylighting is to use light fixtures with integral photosensors. This eliminates the need to decide whether to use an open-loop or closed-loop photosensor. Because the photosensors are integral, each fixture can be dimmed separately, based on the light level at the nearby workplane.

Routers

Routers are used when more than 64 ballasts are desired on one DALI system. A router connects two DALI loops making it possible to have 128 ballasts controlled by one control unit. If more than 128 ballasts are desired on one DALI system, multiple routers can be connected to an Ethernet network. Figure 4-4 shows an example of a router made by Starfield.

Figure 4-4 Starfield Router

Additional Control Units

By adding control devices, a DALI lighting control system can perform additional functions that the basic DALI system cannot perform by itself. This section covers these additional types of control units and what each can do. Keep in mind that multiple control units can be used in one DALI system, but because control units are not defined within the DALI protocol, different manufacturer's control units may not be able to communicate with another manufacturer's control units.

Touch Button Wall Devices

Touch-button wall control units are the most common type of control device for use in a single DALI loop when 64 or less ballasts are required. The buttons on the unit can create presets, define groups, and recall presets.

Remote touch-button devices are also available. They are typically used as a second switching location and have the ability to recall presets, but not necessarily define them. They are generally used when control is desired in more than one location within a space.

Wall Touch Screens

Another option for individual room control is a wall touch screen. The main difference between a wall touch screen control device and a touch button control device is that touch screen can be used with software to provide the user with additional information. The software allows the user to see digitally what the control device is doing, such as which ballasts are assigned to which groups and what the dimming levels are for each preset. The only way one can tell what the presets are when using the touch-button control device is to actually call up the preset and see if it is desirable.

DALI Software

Computers installed with DALI software can also be used to control DALI systems. This option is generally used when a large space or multiple spaces are being controlled from one location. Many manufacturers of DALI products create software that can be used with a personal computer. When routers are connected to a computer with DALI software, all connected DALI loops can be controlled from one location.

Software is available that is controlled via the internet. This means owners can have access to their system from anywhere in the world with an internet connection. The lighting system can be monitored remotely for light levels, ballast performance, and emergency lighting testing (Lighting).

Personal Digital Assistants (PDA's) can also be used to control a DALI system. They work much like a personal computer since they are simply small computers. The control capabilities are accessed via the internet.

DALI software can also incorporate a DALI system into a building management system. DALI can be integrated with a building management system to any extent desired. The DALI system can act as a stand-alone system by simply reporting to the building management system information such as ballast status and failures. Another option would be to have the DALI system fully integrated with the building management system. In this application, the building management system would be able to control all DALI loops connected to the interface via a translator that would translate the language from the building management system into differential Manchester encoding so that it could be understood by the DALI system. The building management system would be able to send commands to ballasts, change light levels throughout the system, define presets, and query information about ballast or lamp status/failure (Advance).

CHAPTER 5 - Limitations and Drawbacks

As with any new technology, DALI systems do have limitations with respect to the maximum amount of current on a loop, distance and voltage drop, the number of ballasts and groups on a loop, commissioning costs, ballast replacement issues, and energy consumption in off mode. This section will discuss these issues.

Limitations

Loop Current

One limitation on a DALI system is the current allowed to run through each loop. This limit is 250mA with a maximum consumption of 2mA per ballast connected to the loop. This means that the simplest system consisting of one ballast and one control unit can consume a maximum of 2mA. Exceeding the current limitation may result in a reduced signal reliability causing lack of communication or response between the DALI devices. Therefore, designers must keep track of how much power each device requires so that the current limitation is not exceeded (Technical).

Distance/Voltage Drop

As with any wiring project, the voltage drop on a run of wire must be considered as it may affect the performance of the equipment. The maximum voltage drop allowed for a DALI loop to keep a clear message all the way to the end of the loop is 2V. As a rule of thumb for typical wiring and installation, the maximum distance between any devices on the loop should not exceed 984 feet (300m) (Advance; Technical).

Number of Ballasts, Groups, and Presets on a DALI Loop

The maximum number of ballasts allowed on one DALI loop is 64. If the devices chosen draw more power than others, it is possible to have a maximum number of ballasts allowed be less than 64. It is important to check current limitations when ballast quantities are calculated. In most cases, however, 64 ballasts can be used. The maximum number of groups on one DALI loop is 16. One ballast has the ability to belong to each of the 16 groups or as little as no groups. Up to 16 preset scenes can be stored within the control unit on a single DALI loop (Advance).

Drawbacks

Programming

A major issue when a DALI control system is chosen is the time required for programming the system. After the system is installed, ballasts are assigned addresses that are stored in a database with information such as physical locations and which control device operates them. The amount of time required for programming depends on the complexity of the system. It makes sense that a system contained to one small conference room would require much less time for programming than a large exhibition hall. The desired functions and number of presets are also a key factor deciding how much time programming will require. Also keep in mind that future changes in space layout may require re-programming the system. Ballasts may need to be assigned to different groups and presets may need to be re-defined. One way to reduce future costs is to train an in-house staff member during the programming process so that future changes can be made by the in-house staff (DALI Explained).

Ballast Replacement

As the system ages, ballasts may require replacement. In a DSI or 0-10V system, ballast replacement is relatively simple since the ballasts are not individually addressable. Because DALI ballasts are addressable and each has a unique address, replacing a ballast may be challenging. The replacement ballast must be set with the same address as the old ballast. Currently, DALI ballasts can only have their addresses defined and viewed with the use of special equipment. This requires that maintenance staff determine the address of the failed ballast and set the new ballast with the same address. Another option would be to use the default address already stored in the new ballast and program the new ballast to the groups and preset dimming levels of the old ballast (An Introduction).

Ballast Energy Consumption in Off Mode

Another drawback to a DALI system is that the control electronics within the ballasts continue to use energy even when the lamps are off. This is because there is no switch that disconnects power to the devices. They simply receive a message from the control unit telling them to turn off. However, the power consumption is significantly reduced to about one watt per ballast during “off” times as compared to times when the lamps are on (An Introduction). Depending on the system size, one watt per ballast may be significant. One way to address this would be to control the power circuits with a contactor by having the contactor switched to the off position during times when lighting is not required (Koffler).

CHAPTER 6 - Cost Information

An important issue during the design phase of any space is cost. Often owners have specific budgets and must keep spending limits in mind when deciding on a system. The cost of a DALI system really depends on the complexity of the system desired. Systems consisting of only DALI ballasts and a control unit would naturally cost much less than those with DALI ballasts, multiple control units, routers, and occupancy sensors. To gain a more accurate estimate of how much a DALI system will cost, a designer should check with a manufacturer's representative. Having more accurate cost information would allow a designer to perform cost-benefit analyses on various dimming control systems including DALI. Some argue that DALI systems cost less than dimming systems such as 0-10V systems and others say the two systems cost about the same in the end.

When cost-benefit analyses are performed one key issue is the time required for programming each system. Programming times also depend on the level of complexity desired. A DALI system installed in a conference room with only 20 light fixtures would require much less time for programming than a system installed in a large multi-purpose event space with 500 light fixtures.

According to the article "DALI Explained" published in *Buildings Magazine*, Stuart Berjansky from Advance Transformer claims, "if you take a traditional 0-10V system and a DALI system, the installed cost for both will be about the same. Your ballast is going to cost you more, but you'll save in labor because of the lack of lighting circuit requirements. You have less homeruns going back to your electric panels, you have less electric panels" (DALI Explained). Another article, "DALI Takes the Lighting Industry Back to School," discusses the DALI system installed in the lighting lab at Penn State University under the direction of Dr. Martin Moeck. At one point Moeck states, "I was surprised to find out the cost of a conventional 0-10V DC analog fluorescent dimming ballast system was $45,500. The DALI system cost $29,100 to install" (Knisley). This is an installation savings of about 35%. Keep in mind the amount of time required to program a DALI system depends on its complexity. If a staff member can be trained to program the system, that may be more cost effective than hiring a technician to do the programming.

CHAPTER 7 - Installing, Programming, and Using the System

This chapter covers basic information regarding how DALI systems are installed as far as wiring and programming are concerned. It also gives a basic idea about assigning addresses to the ballasts and assigning groups and presets.

Wiring/Communication

The wiring in a DALI lighting control system is rather simple. As mentioned previously, ballasts can be connected to any available unswitched power supply without the need to group fixtures in any way. All components in the system including, but not limited to, ballasts, sensors (occupancy and photocell), switches, and control units can be wired in any way as long as the distance requirements that are listed in Chapter 5: Limitations and Drawbacks are met. Sensors and switches can be connected directly to the control unit or to the wires running between the ballasts; see figures 7-1 (Advance) and 7-2 (Advance). There is no difference in performance for either configuration. As mentioned in Chapter 3, wiring can be installed in series, in a star configuration, or in a combination of the two (Advance). Figure 7-3, on the next page is a sample wiring diagram for a DALI system. Note that each manufacturer will have information specific to wiring and should be consulted in regards to this information, especially when products such as routers and Ethernet connections are used.

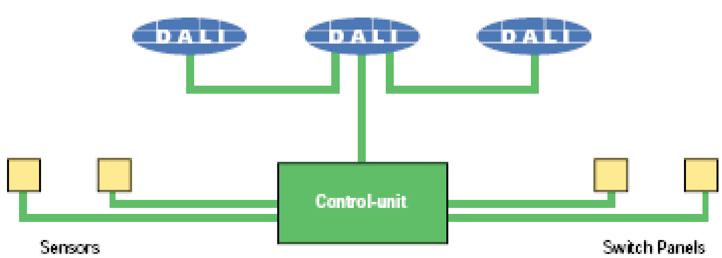

Figure 7-1 Low Voltage Wiring Diagram – Sensors Connected to the Control Unit

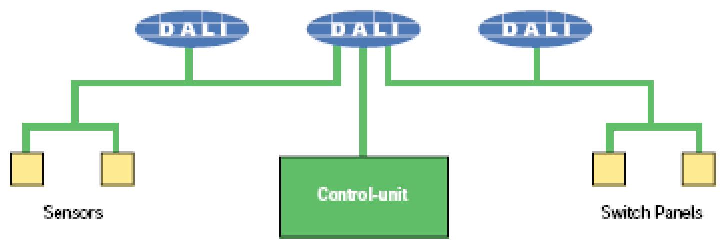

Figure 7-2 Low Voltage Wiring Diagram – Sensors Connected to the Ballast Loop

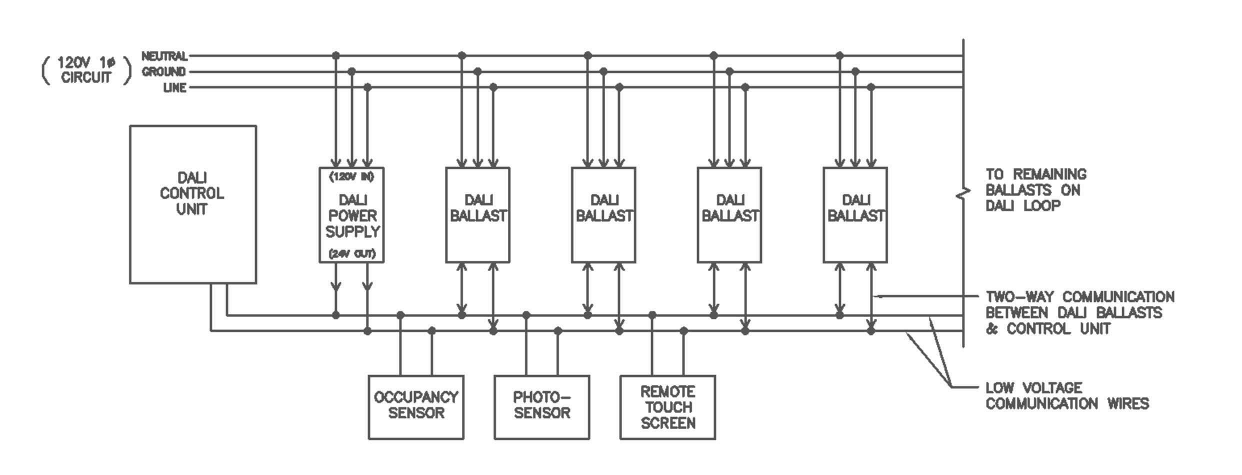

Figure 7-3 Sample System Wiring Diagram

The purpose of the low-voltage control wiring is to allow components in the system to communicate with one another. DALI uses **differential Manchester encoding** to communicate. A DALI message structure is made up of an address and a command. The address corresponds to one of the ballasts in the loop, and the command tells that particular ballast what to do. If a ballast is assigned to a group, it and the other ballasts defined in the group can receive group commands based on a group address stored within the ballast memory (DALI-Lighting). This allows one message to be sent to an entire group of fixtures rather than individual messages being sent to each individual ballast needing to perform a desired function. The method of sending out a group message can be more beneficial than sending out many individual messages because it can prevent what is known as the “Mexican Wave”. The “Mexican Wave” occurs when a large number of ballasts receive individual messages, but not all at exactly the same time. It may become noticeable that a ballast on one end of the room received its message before a ballast on the opposite side of the room when they didn't turn on simultaneously (An Introduction).

Assigning Addresses

The address stored in a DALI ballast can either be programmed before installation or afterwards. Programming addresses prior to installation ensures that each ballast will already have a unique method of identification. When an address is programmed after the installation of the system, the control device can register addresses assigned by the manufacturer into its database. If any addresses are found not to be unique, new addresses are assigned to the ballasts. Each ballast must have its own unique address so that messages from the control unit can be sent to the correct ballast.

Assigning Groups and Presets

This section explains how to use a DALI lighting control system for assigning groups, creating presets, and making changes. Specifics on programming may vary depending on manufacturer; therefore, the manufacturer or manufacturer's representative should be consulted for specifics regarding programming.

Each ballast can be assigned to any number of up to sixteen groups within its loop. The purpose of assigning groups is for ease of creating presets and sending out messages. As mentioned in the wiring/communication section of this chapter, it is more desirable to send out a group message than several messages to several different ballasts.

Once groups are defined, presets can be stored within the control unit. Presets can contain any number of DALI groups. For example, each group within a preset can be set to different dimming levels or fade rates, as desired. The purpose of assigning presets is to recall quickly a lighting scene as required by the event occurring in a space. With presets, a space such as a conference room can be changed quickly from a low light level required for media presentations to a higher light level required for a general meeting.

As the function of a space changes, because of a new tenant or different events for example, changing the system is simple. Groups and presets can be redefined in the same manner they were originally programmed.

Ballast Memory

Ballasts, like control units, have the capability of storing information within their memory. Ballasts store information such as light levels, if their power is on; system failure; fade time and rate; their addresses; and groups to which they are assigned. This function allows for two-way communication between the ballasts and control unit in which the ballasts can send messages back to the control unit or software (Advance).

CHAPTER 8 - Meeting Code/Recommended Practice Requirements

As a result of the nation's concern about energy resources, codes and recommended practice guidelines are requiring greater controllability of lighting in commercial applications. This section discusses how some code requirements and recommended practices can be achieved by utilizing a DALI lighting control system. This section covers topics from the International Energy Conservation Code - 2003 (IECC), ASHRAE/IESNA Standard 90.1-2004, California Title 24, and the Leadership in Energy and Environmental Design (LEED) Rating System. Note that this is not intended to be an all inclusive list of codes/recommended practices to which DALI is applicable. Also keep in mind the importance of checking with the local authority having jurisdiction when applicable codes are determined. This chapter is divided in sections based on various code/recommended practice. Within each section, a code reference will be given, followed by an explanation of how DALI can help meet the requirements. Also, note that this chapter assumes applications with a fluorescent lighting system.

IECC

805.2.2.1 Light Reduction Controls

Each area that is required to have a manual control shall also allow the occupant to reduce the connected lighting load in a reasonably uniform illumination pattern by at least 50 percent. Lighting reduction shall be achieved by one of the following or other approved method:

1. *Controlling all lamps or luminaires;*
2. *Dual switching of alternate rows of luminaires, alternate luminaires or alternate lamps;*
3. *Switching the middle lamp luminaires independently of the outer lamps; or*
4. *Switching each luminaire or each lamp.*

A DALI lighting control system can be used to meet this requirement of the IECC with its capability of dimming fluorescent fixtures. If the building's lighting design contains lamp types other than fluorescent types, technology similar to DALI may still be used, but a DALI control system would work best for a building with a fluorescent design. A building-wide DALI system connected to a BMS or computer software can control all fixtures in the building from one location. If dual switching is desired, it can be set up by creating presets. Switching some lamps in a fixture while leaving others on would be possible if they are controlled by separate ballasts; however, since dimming is available, switching alternate lamps in fixtures would not be necessary.

805.2.2.2 Automatic Lighting Shutoff

Buildings larger than 5,000 square feet (465m^2) shall be equipped with an automatic control device to shut off lighting in those areas. This automatic control device shall function on either.

1. *A scheduled basis, using time-of-day, with an independent program schedule that controls the interior lighting in areas that do not exceed 25,000 square feet (2323 m^2) and are not more than one floor; or*
2. *An unscheduled basis by occupant intervention.*

A DALI lighting control system has the capability of setting times for lights to turn on and off. Occupancy sensors can also be used as a method of turning off the lights when they are not needed.

ASHRAE/IESNA Standard 90.1

9.4.1.1 Automatic Lighting Shutoff

Interior lighting in buildings larger than 5000 ft^2 shall be controlled with an automatic control device to shut off building lighting in all spaces. This automatic control device shall function on either

a. *a scheduled basis using a time-of-day operated control device that turns lighting off at specific programmed times—an independent program schedule shall be provided for areas of no more than 25,000 ft^2 but not more than one floor—or* *b.* *an occupant sensor that shall turn lighting off within 30 minutes of an occupant leaving a space—or*

c. *a signal from another control or alarm system that indicates the area is unoccupied.*

The requirements of this section, much like those in IECC section 805.2.2.2, can also be achieved with a DALI lighting control system.

9.4.1.2 Space Control

Each space enclosed by ceiling height partitions shall have at least one control device to independently control the general lighting within the space. Each manual device shall be readily accessible and located so the occupants can see the controlled lighting.

a. *A control device shall be installed that automatically turns lighting off within 30 minutes of all occupants leaving a space, except spaces with multi-scene control, in: 1. Classrooms (not including shop classrooms, laboratory classrooms, and preschool through 12th grade classrooms), 2. Conference/meeting rooms, 3. Employee lunch and break rooms. These spaces are not required to be connected to other automatic lighting shutoff controls.*

b. *For all other spaces, each control device shall be activated either manually by an occupant or automatically by sensing an occupant. Each control device shall control a maximum of 2500 ft^2 area for a space 10,000 ft^2 or less and a maximum of 10,000 ft^2 area for a space greater than 10,000 ft^2 and be capable of overriding any time-of-day scheduled shutoff control for no more than four hours.*

This space control requirement is feasible with a DALI system. Even if an entire building is controlled by one single DALI system, smaller wall control units can be placed throughout the building for occupant control of individual spaces. The control units in combination with occupancy sensors can be set to turn off lights within 30 minutes of occupants leaving a space.

California Title 24

Section 131 (b) Multi-Level Lighting Controls

The general lighting of any enclosed space 100 square feet or larger in which the connected lighting load exceeds 0.8 watts per square foot, and that has more than one light source (luminaire), shall have multi-level lighting controls. A multi-level lighting control is a lighting control that reduces lighting power by either continuous dimming, stepped dimming, or stepped switching while maintaining a reasonably uniform level of illuminance throughout the area controlled. Multi-level controls shall have at least one control step that is between 50% and 70% of design lighting power and at least one step of minimum light output operating at less than 35% of full rated lighting system power.

DALI's dimming capability will meet this requirement. Presets can be assigned in which light levels can be changed instantly to accommodate the need to save energy in cases such as a brownout or just to help minimize peak loads.

Section 131 (c)(1) Daylit Areas

Daylit areas greater than 250 square feet in any enclosed space shall have at least one lighting control that:

a. Controls at least 50% of the power in the daylit areas separately from other lighting in the enclosed space; and

b. Controls luminaires in vertically daylit areas separately from horizontally daylit areas.

c. Maintains a reasonably uniform level of illuminance in the daylit area using one of the methods specified in section 131 (b) items 1 or 2.

DALI's daylighting capabilities would be especially useful in this case. Uniform light levels could be maintained by dimming each fixture the amount required in each specific location. The only reason ambient design levels would not be maintained would be if the daylight contribution was greater than the design light level. The daylighting capability can be overridden, if necessary, in cases where reducing energy use is a greater priority.

Section 131 (d) Shut-off Controls

For every floor, all indoor lighting systems shall be equipped with a separate automatic control to shut off the lighting. This automatic control shall meet the requirements of Section 119 and may be an occupant sensor, automatic time switch, or other device capable of automatically shutting off the lighting.

A DALI lighting control system can use occupant sensors, timed on/off settings, and manual switching to achieve the requirements for shut-off controls.

LEED

Energy & Atmosphere Credit 1: Optimize Energy Performance

The intent of this credit is "to achieve increasing levels of energy performance above the baseline in the prerequisite standard to reduce environmental and economic impacts associated with excessive energy use."   To obtain this credit a design must demonstrate a percentage of improvement in building energy performance compared to a baseline of ASHRAE/IESNA Standard 90.1-2004. Energy can be saved by utilizing a DALI lighting control system. Energy can be saved by utilizing DALI's daylighting capabilities. See Chapter 9 – Daylighting Case Study for an example of how this can be done.

Indoor Environmental Quality Credit 6.1: Controllability of Systems: Lighting

This credit is intended to "provide a high level of lighting system control by individual occupants or by specific groups in multi-occupant spaces (i.e. classrooms or conference areas) to promote the productivity, comfort, and well-being of building occupants." To obtain the credit, a design must provide individual lighting controls for a minimum of 90% of the building's occupants and controllability for all shared multi-occupant spaces that allow adjustments to meet the needs and preferences of the group.

A DALI lighting control system would be one way to achieve this credit. While it may be easiest to provide individuals with task lighting to fulfill the individual lighting control portion of the credit, DALI can also be used. To provide individual control with a DALI system, there would either need to be individual control units controlling the fixtures in each occupant's space or there could potentially be groups created for occupants' light fixtures in which they could specify their own desired dimming levels/ambient light levels from a more central location. The other half of the credit, controllability of multi-occupant spaces in areas such as a conference room, can be met with a DALI control unit in the specific room being controlled. Occupants would have the option of setting any desired groups and presets to meet their needs.

CHAPTER 9 - Daylighting Case Study

The following case study was performed to show how a DALI lighting control system can save money in energy costs by utilizing daylight sensing in combination with DALI's dimming capabilities. The study was performed using Lighting Analyst's **AGI-32** software.

About the Space

The space chosen for this study is one floor of a multi-story office building located in Littleton, Colorado. The space measures about 23,000 square feet. The space consists primarily of open office space with a core consisting of conference rooms, elevators, restrooms, and mechanical rooms. The core of the building is not included in this daylight case study since that the area does not see significant levels of daylight. The exterior surface consists primarily of floor-to-ceiling diffuse glass windows. For exact locations see the floor plan in Appendix A. Since the building is not neighbored too closely to any other tall buildings, a significant amount of sunlight reaches the working plane throughout the day making it perfect for considering the use of daylight and dimming light fixtures to save money. A DALI lighting control system was chosen to do just that.

AGI-32 Software Calculation

The following sections explain the models that were created to perform the daylighting study. One model was used to calculate the amount of daylight that reaches the workplane at various times of day on various days of the year. Another model was created that does not allow daylight to enter the space, but rather determines the required number of artificial light fixtures to achieve the desired average ambient light level of 50fc on the workplane to simulate times of the day when no daylight is present. AGI-32, created by Lighting Analysts Inc. was chosen for this case study because of its ability to perform daylight studies. The daylighting study function can calculate the footcandle level at any desired point at any specified geographical location based on latitude and longitude. Once the footcandle levels were determined by the program, it was possible to calculate manually what dimming levels were required by each light fixture. This information was used to calculate energy savings compared to a baseline model where all lamps are on 100% during business hours.

Creating the Daylighting Model

The first step of performing the AGI-32 calculation was to build a model that would best match the actual conditions of the space. Since information on reflectances and construction materials were unknown, assumptions were made based on engineering judgment. For example, the average footcandle level was based on IES recommendations and reflectances were chosen based on prior experiences in class and industry. A floor plan of the office was imported from an AutoCAD file as a template for constructing the walls, columns, and cubicles. The outer footprint of the building was constructed as a room with default reflectances of 80/50/20 for ceiling, walls, and floor respectively. Interior walls were constructed as rooms within the outer footprint with similar reflectances. Round floor-to-ceiling columns with a 50% reflectance were constructed since they would play into how much daylight and lamp light would reach the work plane. Cubicle walls were constructed at heights of 5’-0” with a 20% reflectance. The floor-to-ceiling windows were created by modifying the wall type to that of a daylight transition diffuse glass window (surface number 21) with a transparency of 19%. See Appendix F for screen shots of values inputted into AGI-32. The fixtures were not placed in this model since they were not needed for the daylight calculations. Calculation points were placed at the level of the work plane (2’-6” A.F.F.).

Creating the Artificial Daylighting Model

Another model was created for the purpose of determining the number of light fixtures required to provide an average ambient light level of 50fc when no daylight is present. This model was constructed in the same way as the daylighting model, only the daylighting capabilities were disabled. Light fixtures were placed in this model using IES files found on the manufacturer’s website.

The light fixtures were suspended indirect/direct fixtures mounted at 9’-0” above finished floor with a ceiling height of 11’-0”. The fixture was Finelite’s Series 14 (see Appendix B for fixture cut sheet). The low profile fixture measured 8” wide by 4’ long with a thickness of 2”. Two T8 lamps, a white cross blade, and standard anodized aluminum reflectors were chosen.

The fixtures were mounted in a linear pattern end to end at approximately 12'-0" on center between rows. This arrangement provided an average footcandle level of 50 FC on the work plane (2'-6" above finished floor), assuming no daylight was present. Each fixture was equipped with a two-lamp DALI ballast. The ballasts were all connected to a 120V power supply. As mentioned previously, the arrangement of circuits is irrelevant when a DALI control system is used. The ballasts also had two low voltage control wires running to them allowing communication between the ballasts and the DALI control unit. Since there were more than 64 ballasts in this space and control of the space as a whole was desired, routers were used to connect DALI loops. Refer to Chapter 5 for ballast quantity limitations.

Running the Daylighting Model

The next step in AGI-32 was to set up and run a daylight study. Using the Daylight Study Wizard, the following parameters were set. The site location was set as Littleton, Colorado with a latitude of 39.617 degrees North and a longitude of 105.017 degrees West. Sky conditions were set as clear sky. Dates and times were chosen to provide the best data to approximate year-round savings. The dates January 1st, April 1st, July 1st, and October 1st were chosen because they have approximately the same number of days between them. To obtain a good average, it was important to pick dates and times with equal spacing between them. The study was set to calculate light levels at 7:00 am, 10:00 am, 1:00 pm, 4:00 pm, and 7:00 pm on each date chosen. These times were selected because they fell during typical office hours of 7:00 am to 7:00 pm and had the possibility of daylight. January 1st at 7:00 am and 7:00 pm, April 1st at 7:00 pm, and October 1st at 7:00 pm were not calculated in this part of the study since no daylight was present at these times. They were, however, factored into the total average of the study as times when 100% artificial light was required. After setting parameters, the daylight study was set to calculate. AGI-32 calculated footcandle levels for each calculation point for each date and time specified based on the given parameters, reflectances, and construction. Due to the level of detail within the program, each calculation took approximately 45 minutes to complete.

Results of the Daylight Study

The results of the daylight study were then analyzed. Depending on how much daylight could reach a particular area of the work plane, some fixtures could be dimmed. Each fixture was highlighted on the plan according to the level it could be dimmed. Table 9-1 shows how dimming levels were assigned and the corresponding highlighted color. Appendix D contains these data sheets showing highlighted colors corresponding to dimming levels. A table showing the number of fixtures at each dimming level for each time analyzed can be found in Appendix E. These quantities were then used to calculate energy usage as described in the next section.

Table 9-1 Case Study Dimming Levels

Light Level from Daylight (FC)	% Lamps Could be Dimmed to	Light Level from Lamps (FC)	Total Light on the Work Plane	Highlighted Color
≥ 40	0	0	40 +	blue
30-40	25	12	42-52	green
20-30	50	25	45-55	pink
20-Oct	75	37	47-57	orange
≤ 10	100	50	50-60	yellow

Calculations

The quantities from the daylight study were used to calculate the amount of energy consumed at each time on each date chosen for the study. All calculations can be found in Appendix E. The average cost per day utilizing the daylight harvesting capabilities of a DALI system came to $3.27 and a yearly cost of $1,192. For comparison, a baseline calculation was performed in which lights were assumed to be at 100% output for the entire workday (7:00am to 7:00pm). The yearly cost of energy for this scenario came to $2,257. This resulted in a savings of $1,065 for using the daylight harvesting capabilities of a DALI system, compared to not using daylight harvesting. This is a 47% savings.

Keep in mind that several variables in this case study could be different from any other space. The location of the building could have a huge impact on energy savings because of the building's orientation, sunlight availability, and typical sky conditions in the area. Another issue to keep in mind is the difference in energy costs relative to different parts of the country. For example, energy in California costs more than energy in Colorado.

Case Study Conclusion

This case study showed how energy can be saved by utilizing a DALI system's daylight harvesting capabilities. Similar techniques can be used to estimate an energy cost savings for any project and may be beneficial when a cost-benefit analysis like the one mentioned in Chapter 6 is performed.

CHAPTER 10 - Conclusion

In conclusion, DALI lighting control systems have many advantages as well as some disadvantages. A designer should carefully evaluate a project as far as what the owner is looking to obtain from the lighting control system, the budget for the project, and the required functions of the space before considering designing a DALI system. Such spaces as a multi-use convention center or a conference/presentation room may be a good candidates for a DALI system since they often require a wide variety of light levels and lighting atmospheres. As shown for one application with a high level of daylight available, a DALI lighting control system has the potential to save money in energy costs by utilizing daylight harvesting. For some owners, the added flexibility of a DALI system may outweigh added costs of the system over a non-dimming system. For example, a convention hall may be able to book more events if clients know they will be able to get the type of light levels they desire for their function. A non-dimming system only allows for a limited number of options such as turning off every other fixture, which depends on how the system was wired. A 0-10V system can offer dimming options, but fixture grouping also depends on circuiting arrangements. A DALI system can provide the flexibility to control the lighting for any occasion provided fixtures have been designed and installed to accommodate the range of desired results

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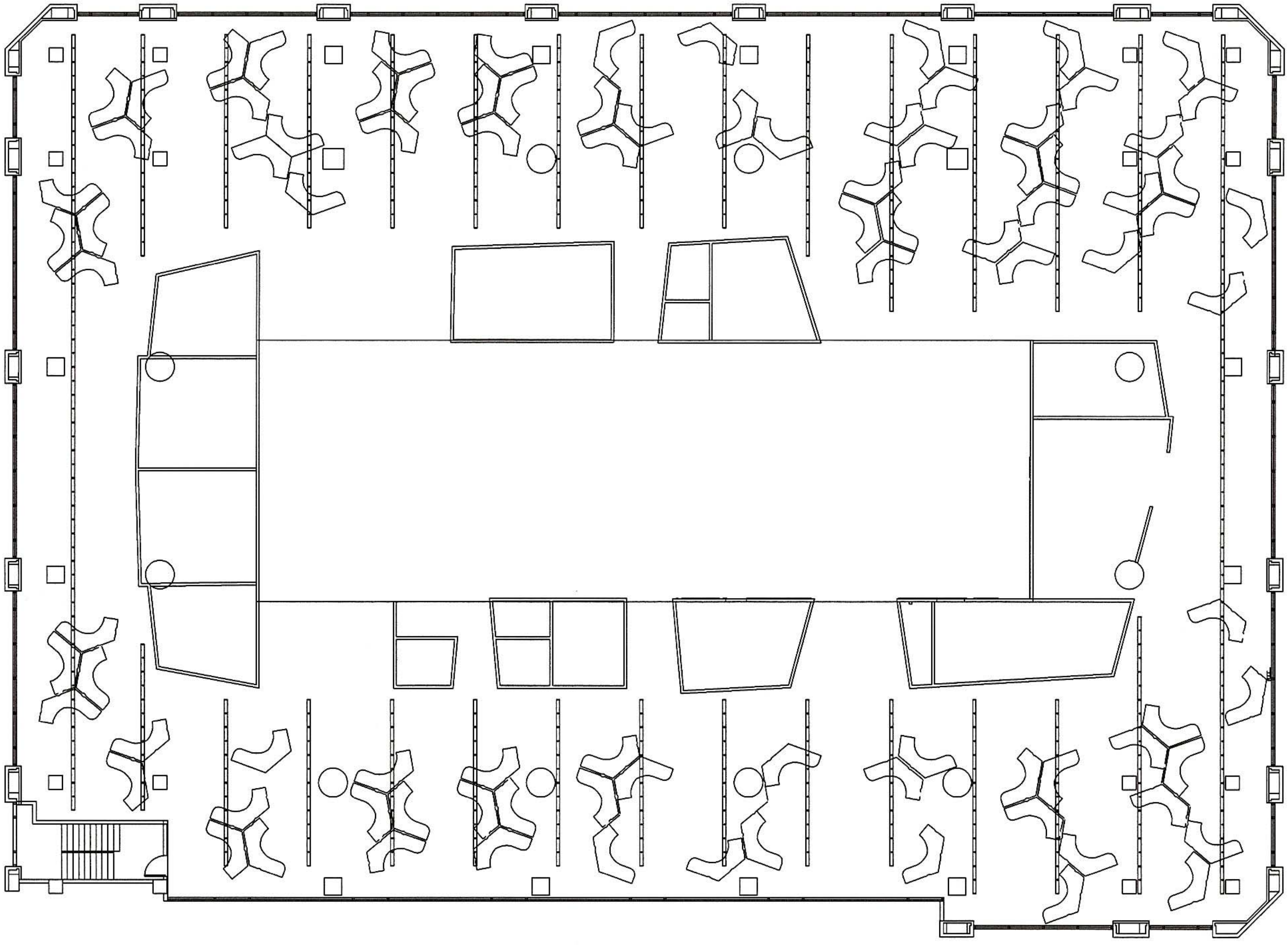
Appendix A - Case Study Floor Plan



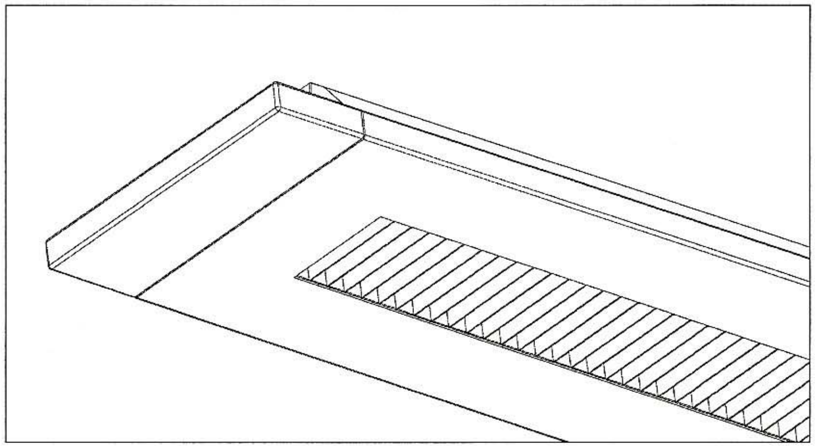
FLOOR PLAN — DAYLIGHTING CASE STUDY

SCALE: NTS

Appendix B - Case Study Light Fixture Cut Sheet

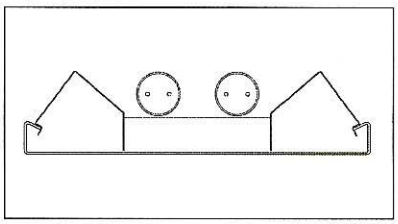
Finelite Series 14 brings new definition to pendant luminaires with a stunning ultra sleek profile. Available in 1 or 2 T8, or 1, 2 or 3 lamp T5 or T5HO cross sections, Series 14 comes in 4′ and 8′ lengths.

Clean, contemporary, standard signal white finish compliments the modern design and brings new elegance to today's contemporary architecture.



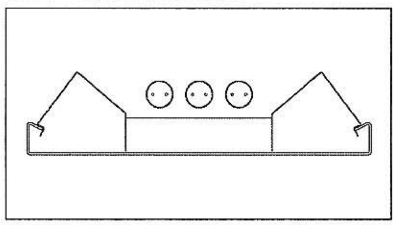
The ultra thin profile of Series 14 adds design and style to any application.

T8 LAMPS



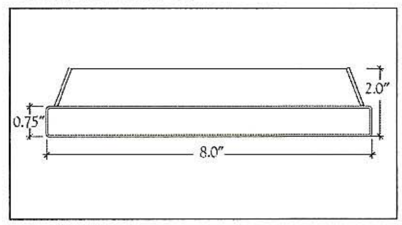
1 or 2 T8 lamps.

T5 / T5HO LAMPS



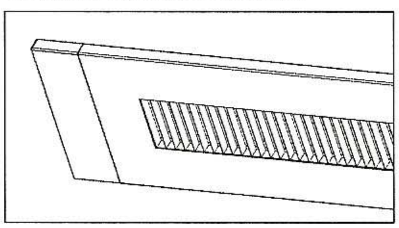
1, 2, or 3 T5 or T5HO lamps.

DIMENSIONS

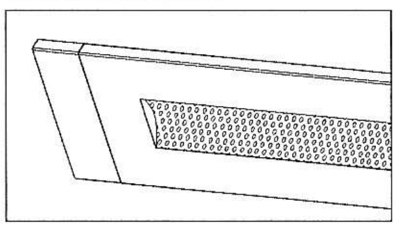


The height of the fixture body is 0.75″, width 8.0″. The overall height to the top of the reflector is 2.0″.

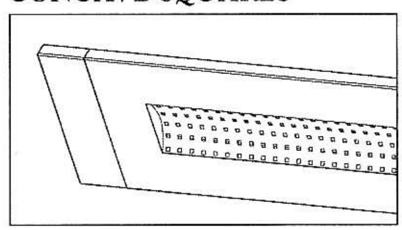
WHITE CROSS BLADE



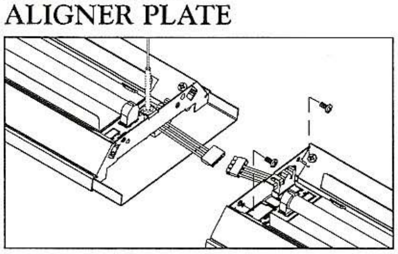
CONCAVE PERF



CONCAVE SQUARES

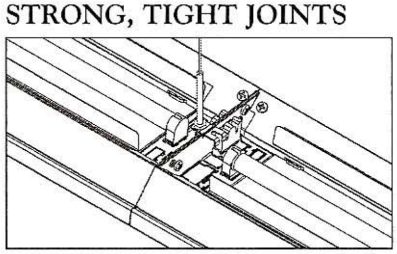


DIE-FORMED ALIGNER PLATE



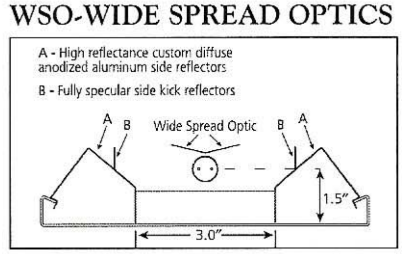
Die-formed aligner plate comes factory installed for smooth joints. Plug-together wiring ensures electrical connections are right every time.

STRONG, TIGHT JOINTS

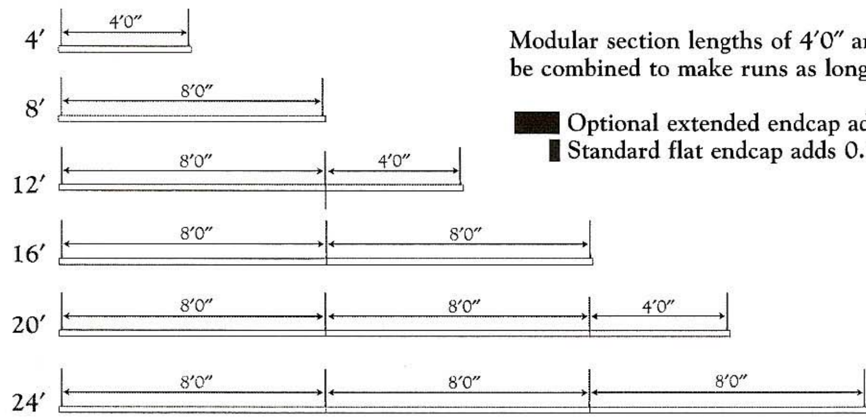


Fixtures slide together tightly and die-formed internal aligner plate ensures strong joints with no light leaks.

WSO-WIDE SPREAD OPTICS



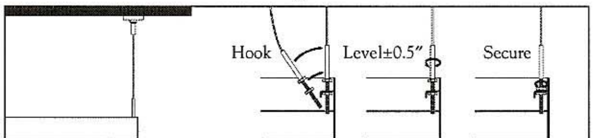
Special wide spread reflector gives extended distribution and is especially effective in low ceiling areas.



Modular section lengths of 4′0″ and 8′0″ can be combined to make runs as long as required.

Optional extended endcap adds 2.5″ at each end.
Standard flat endcap adds 0.1″ at each end.

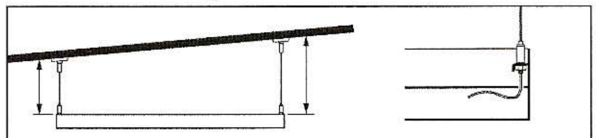
STANDARD SEMI-ADJUSTABLE SUPPORT



Semi-adjustable aircraft cables are available in 8 standard lengths.

Aircraft cables hook into fixture. Turn the support cable to level the fixture. Tighten the top lock nut to complete installation.

OPTIONAL ADJUSTABLE SUPPORT



Fully adjustable aircraft cable simplifies installations on variable ceiling heights. Cable length can vary from 6″ to 150″.

Depress the head of the fitting to allow continuous adjustment of the cable length.

SPECIFICATIONS

CONSTRUCTION: 18 gauge die-formed steel body. All components hard tooled to tolerances of 0.005″.

DOWNLIGHT SHIELDING OPTIONS:
- WCB White cross blade baffles.
- CS Concave shield, square perforations.
- CP Concave shield, round perforations.

ENDCAPS: (FE) Flat Endcap standard *add 0.1″ at each end*. Optional: (EE) Extended Endcap, aluminum die-cast endcap, adds 2.5"at each end. No exposed fasteners, holes or knockouts.

REFLECTORS: (AA) Standard—Anodized Aluminum diffuse high reflectance reflectors. *Optional: (EP) Fully specular side reflectors, (WSO) Wide spread optic system for 1 T5HO. NOTE: EP and WSO reflectors NOT AVAILABLE with emergency battery packs, 347 volt, or dimming ballasts. Consult factory.*

ELECTRICAL: 120 or 277 volt prewired. Fixture and electrical components UL/C-UL listed and fixture will bear UL/ C-UL labels. *Optional Adders: 347 volt prewired, dual circuit, emergency circuits, emergency battery packs.*

LAMPING: 1 or 2 T8 or 1, 2 or 3 lamp T5 or T5HO cross sections. 1 T8 lamp is on angle. UV stabilized lamp diffuser standard for T5HO lamps - 0.100 acrylic. Also available without diffuser (open).

BALLAST: Electronic low profile instant start ballasts <20%THD standard. *Optional Adders: Rapid Start, Dimming ballasts (controls by others). Emergency battery packs, 347 volt, and dimming ballasts require special reflector. Consult factory.*

MOUNTING OPTIONS: Semi-adjustable aircraft cable, (AC) ± 0.5″ in lengths of 12″, 15″, 18″, 21″, 24″, 27″, 30″, 36″. Order length, e.g. AC 18″. *Optional Adders: Fully adjustable aircraft cable (FA) in lengths up to 150″.*

SUPPORT CABLES: Stainless steel with plated hardware.

FEED: 18 gauge straight cord. 14 gauge feed cord used when fixture current exceeds 6 amps. *Optional Adders: Coil Cord Feed.*

FINISHES: Finelite signal white standard. 185 colors available from Tiger Drylac's RAL color chart for a nominal adder.

LENGTHS: 4′ and 8′ section lengths can be combined to make longer runs.

WEIGHT: Fixture weight = 2.0 lb/ft.

ORDERING INFORMATION (2) - S14 - WCB - 32′ - 1T8 - SC - AA - 277 - AC 18″ - EE

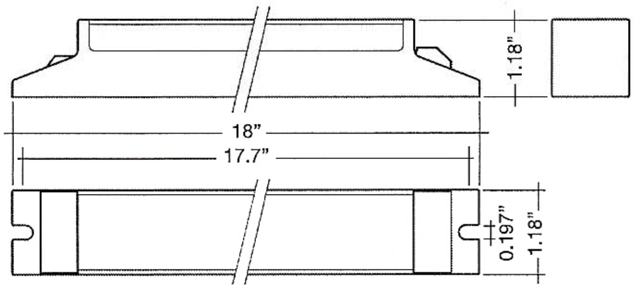
- Quantity
- Finelite **Series 14**
- Shielding (WCB, CS, CP)
- Run length (4′, 8′ multiples standard)
- Number of lamps in cross section (1, 2 T8 or 1, 2, 3 lamp T5, or T5HO)
- Circuiting (SC-single circuit, DC-dual circuit)
- Reflector System (AA, EP, WSO)
- Voltage (120, 277, 347 Volt)
- Mounting (AC/FA)
- Endcap EE (extended), FE (flat)

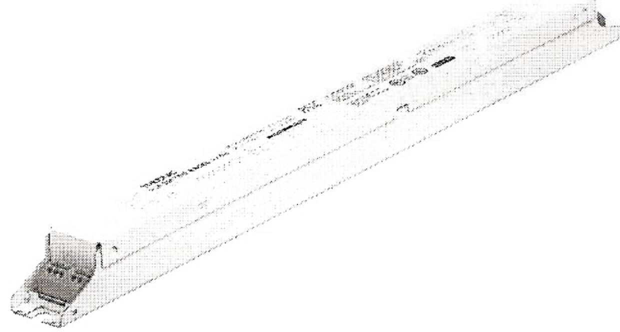
Appendix C - Case Study Ballast Cut Sheet

T8

Electronic digital ballast for dimming 100% to 1%
Fluorescent lamps T8

PCA EXCEL one4all models for 32 W 120–277 V 50/60 Hz, digital dimmable





Features

- Continuous, flicker free dimming from 1 % – 100 %
- Digital bi-directional communication
- Disturbance free precise control with a digital signal (**DSI**), switch**DIM** or **DALI**
  - **DALI** – Digital Addressable Lighting Interface
    64 addresses, 16 groups, 16 light scenes, adjustable fading time
  - **DSI** – Digital Serial Interface
- Return status feedback signal and programmable parameter in DALI and DSI mode
- Polarity free control wiring
- Conventional wire type can be used for control wiring
- Control wiring can be run in same conduits as power wires
- Universal voltage input (UVI) 120–277 V
- Slim profile design – 1.18" H x 1.18" W
- Models for 1- and 2-lamp application
- Quick connectors for wire size 16 – 18 AWG
- End-of-lamp-life protection and inrush current limiting circuitry
- Microcontroller and ASIC (Application Specific Integrated Circuit) technology for optimum dimming performance
- 3 years warranty
- Standby mode

	Ballast	Lamp Information			Ballast Operating Performance								
Order #	Description	No. of Lamps	Lamp Type (Linear only)	Watts (W)	Voltage 50/60Hz (V)	max. Line Current (A) rms 120V	max. Line Current (A) rms 277V	Open Input Power (ANSI) 120V	Open Input Power (ANSI) 277V	Ballast Factor	tc Point * (F / °C)	min. Start Temperature (F / °C)	min. Dimm Temperature (F / °C)
24033592	PCA 1/32 T8 EXCEL one4all	1	T8 32W / 48"	32	120–277	0.31 A	0.13 A	37 W	36 W	1	158 / 70	0 / -18	50 / 10
24033603	PCA 2/32 T8 EXCEL one4all	2	T8 32W / 48"	32	120–277	0.61 A	0.26 A	73 W	70 W	1	167 / 75	0 / -18	50 / 10

* temperature calibration point

LISTED Ballast 54FN

Applications

PCA EXCEL one4all digital dimming ballasts are ideal for executive space applications that require programmable architectural-grade dimming performance or building-wide load control applications that require monitoring and real-time control of lighting loads.
The low profile 1.18" x 1.18" cross section makes these ballasts ideal for architectural fixtures or any application that requires a limited cross sectional area.

Executive Space Applications

- Offices
- Board Rooms
- Conference Rooms
- Training Rooms

Building-Wide Applications

- Open Office Areas
- Private Offices
- Meeting Rooms
- Public Spaces
- Classrooms
- Warehouses

TRIDONIC.ATCO

Description

Tridonic's PCA EXCEL one**4**all T8 digital control dimming ballast sets a new standard for electronic fluorescent dimming. Combining digital**DIM** control technology with true 100 % – 1 % continuous dimming, the PCA EXCEL one4all ballast provides a new level of system performance and flexibility that easily changes to meet present and future lighting needs. Designed with a ballast factor of 1.0, PCA EXCEL one**4**all ballasts provide full rated lumen output to achieve maximum lamp performance and dimming range capabilities. Digital control enables true two-way ballast/control communication that is immune to noise and power disturbances. Control wiring is polarity free and can be run in the same conduits as the power wires. The PCA EXCEL one**4**all universal voltage input capabilities provide added on-site installation flexibility by eliminating the need for multiple single voltage ballast types and also eliminates order errors.

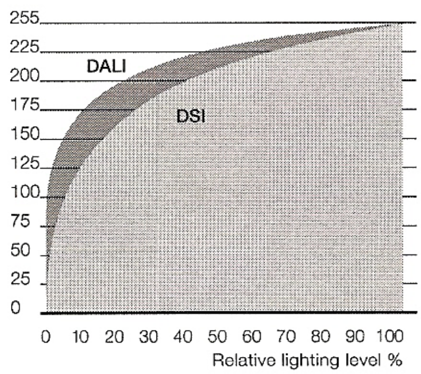
Standards

PCA EXCEL one**4**all complies with
- UL Listed #935
- Suitable for Class I or Class II (control) installations
- Meets ANSI C82.11 Ballast Standard
- Meets FCC 47CFR Part 18 EMI/RFI emission requirements for Class A (non-consumer) equipment
- Meets ANSI C62.41 Category A surge protection standards
- Manufactured in ISO 9001 and 9002-certified facility
- CELMA Energy Classification EEI = A1

Dimming

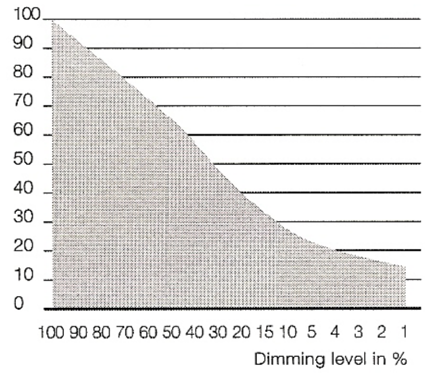
Dimming range 1 % to 100 %
Eye sensitivity optimized dimming curve.
Digital control with:
- DSI signal: 8 bit Code
  Max. fading time 1 % to 100 % 1.4 s
  Status feedback
- DALI signal: 16 bit Code
  Max. fading time 1 % to 100 % 0.5 s
  Individually addressable
  Programmable parameters:
  - minimum dimming level
  - maximum dimming level
  - individual ballast status feedback
  - 64 addresses
  - 16 groups
  - 16 scenes
  - fading time etc.

Dimming characteristics PCA EXCEL



Dimming characteristics
as seen by the human eye

Energy Savings PCA EXCEL



Recommendation

Lamp burn in of 100 hrs. is recommended before dimming!

Performance

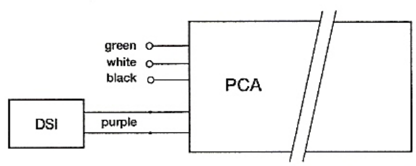
Dimming Range	1 % – 100 %
Ballast Factor	1.0
Power Factor	> 0.98
THD	< 10 %
3rd Harmonic	< 8 %
Inrush Current Peak	< 7 Amps
Lamp Operating Frequency	> 40 kHz
Lamp Current Crest Factor	< 1.7
EMI / RFI	FCC Part 18
Max. Housing Temperature	167 °F / 75 °C
Max. Output Voltage	< 600 rms
Power consumption in sleep mode	< 1 W (120 V) < 2 W (277 V)

Temperature range

Dimming range 1 % to 100 % from 50 °F / 10 °C to maximum permissible ambient temperature.

Control input (DA/purple)

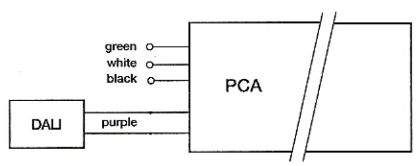
Digital signal can be wired on the ballast terminals DA/purple. These connections are used to use the ballast in DSI or in DALI control mode.



DSI PCA EXCEL one**4**all

Digital signal

The control input is polarity free and protected against accidental connection with mains voltage. Control wires should be installed in accordance to the national and local electrical codes.
Control functions differ depending on capabilities of connected control module.



DALI PCA EXCEL one**4**all

Lamp starting characteristics

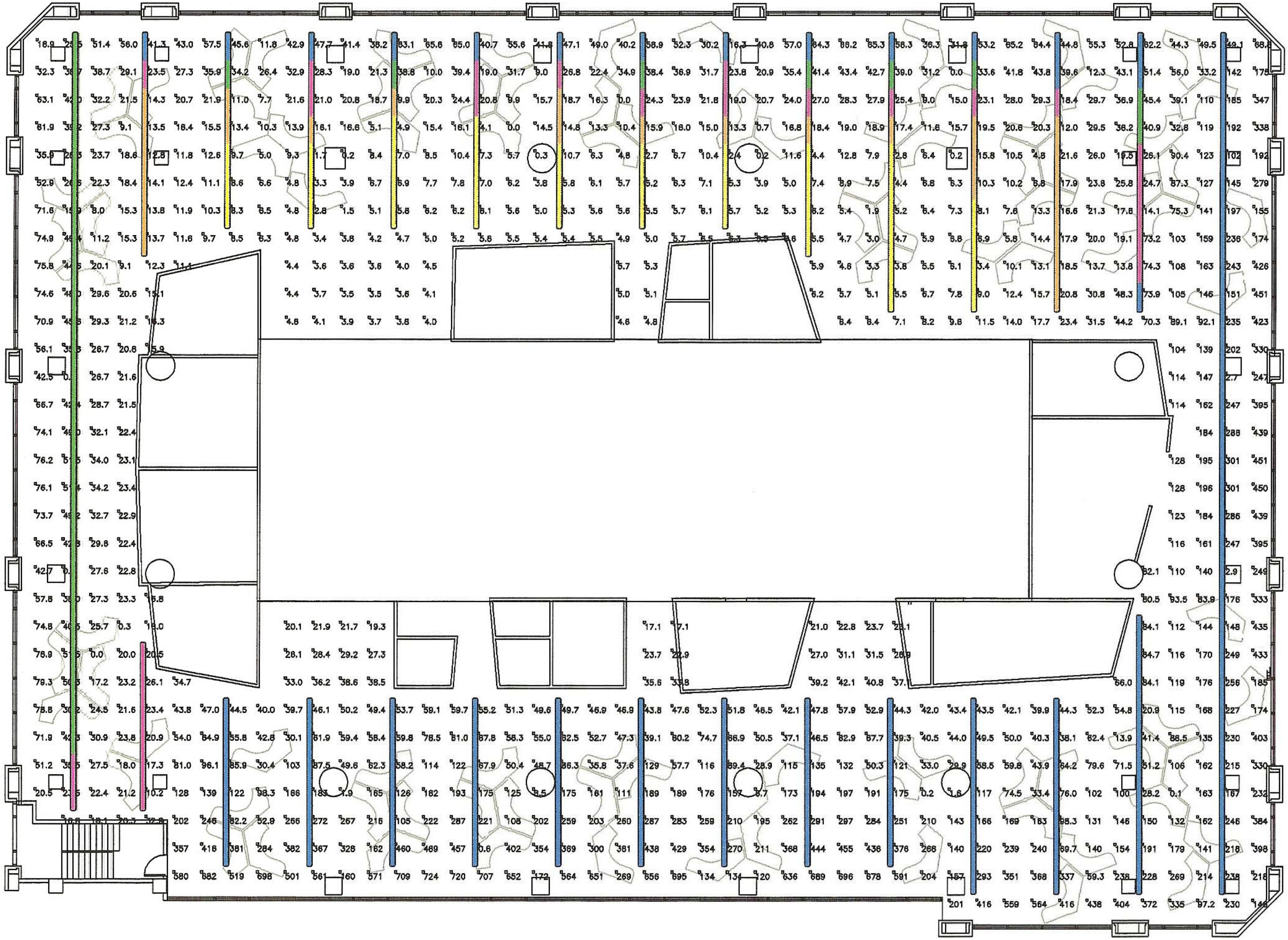
Programmed rapid start
Starting time 1.0 s
Start at any dimming level, without initial flash to higher level.

AC operation

Mains voltage
120–277 V 50/60 Hz

Appendix D - Case Study Daylighting Study Results

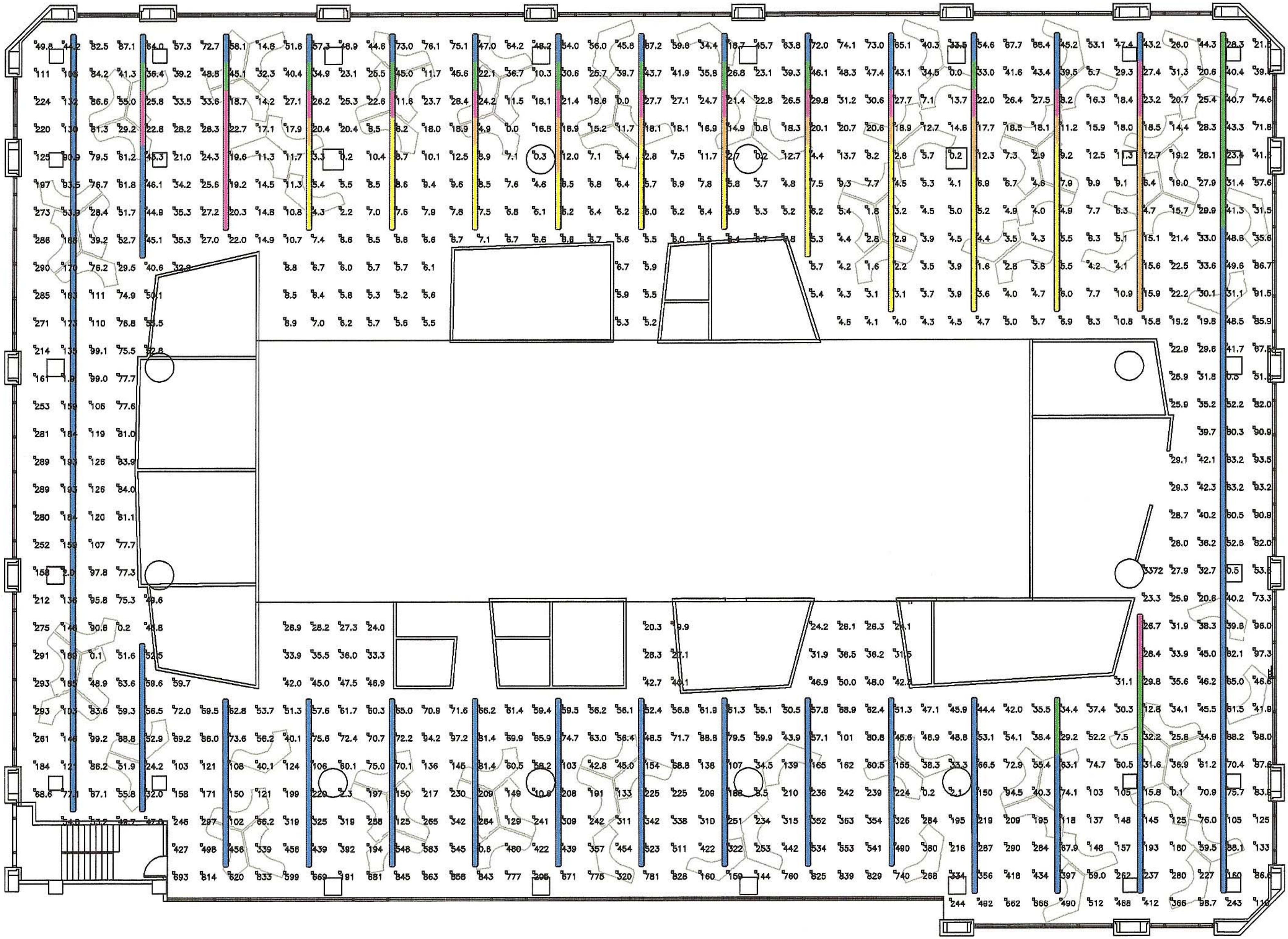
SHEET	DATE	TIME
N/A	JANUARY 1	7:00 AM
S1	JANUARY 1	10:00 AM
S2	JANUARY 1	1:00 PM
S3	JANUARY 1	4:00 PM
N/A	JANUARY 1	7:00 PM
S4	APRIL 1	7:00 AM
S5	APRIL 1	10:00 AM
S6	APRIL 1	1:00 PM
S7	APRIL 1	4:00 PM
N/A	APRIL 1	7:00 PM
S8	JULY 1	7:00 AM
S9	JULY 1	10:00 AM
S10	JULY 1	1:00 PM
S11	JULY 1	4:00 PM
S12	JULY 1	7:00 PM
S13	OCTOBER 1	7:00 AM
S14	OCTOBER 1	10:00 AM
S15	OCTOBER 1	1:00 PM
S16	OCTOBER 1	4:00 PM
N/A	OCTOBER 1	7:00 PM



SHEET S1 – DAYLIGHTING CASE STUDY

SCALE: NTS

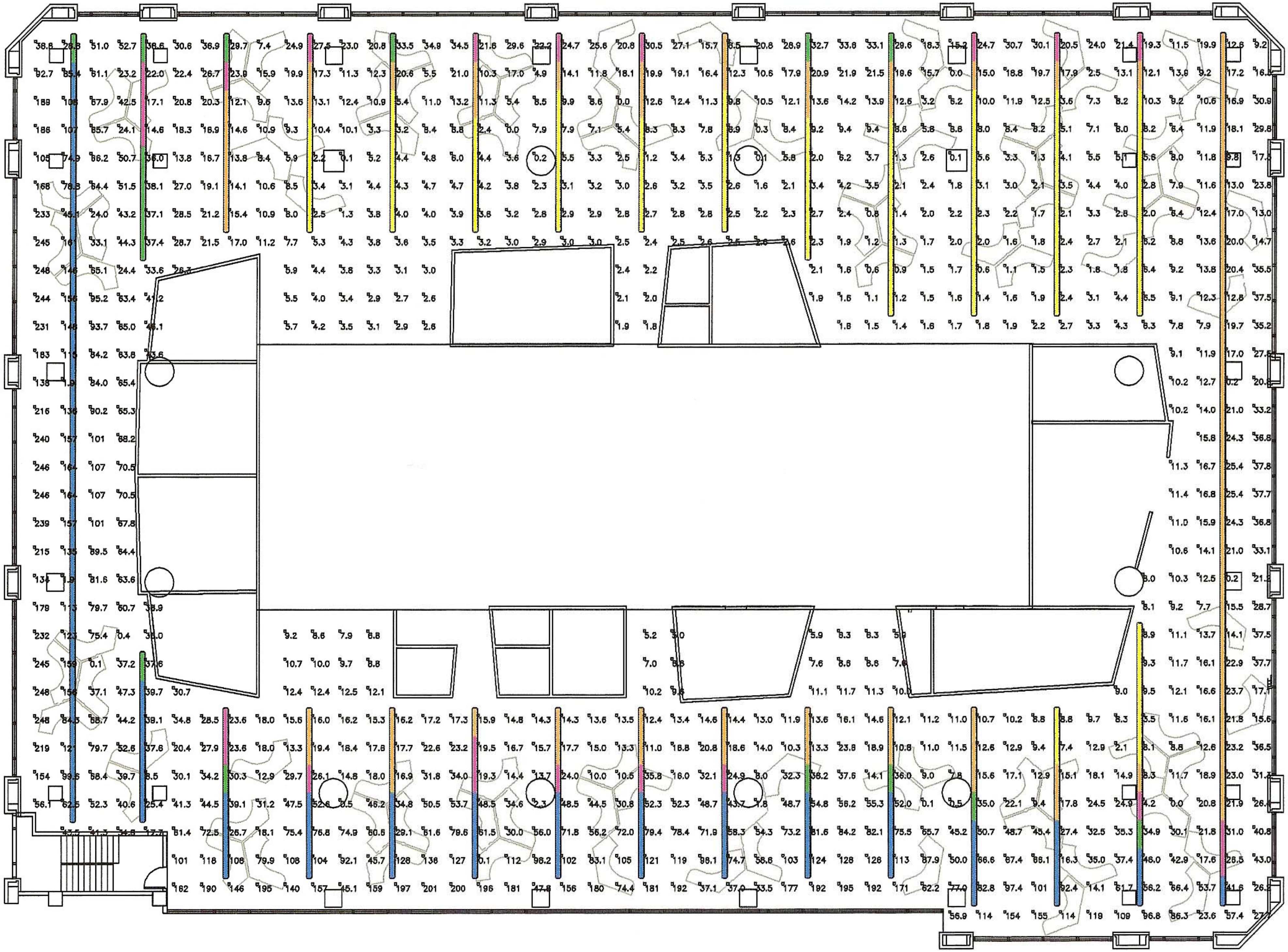
JANUARY 1, 10:00 AM



SHEET S2 – DAYLIGHTING CASE STUDY

SCALE: NTS

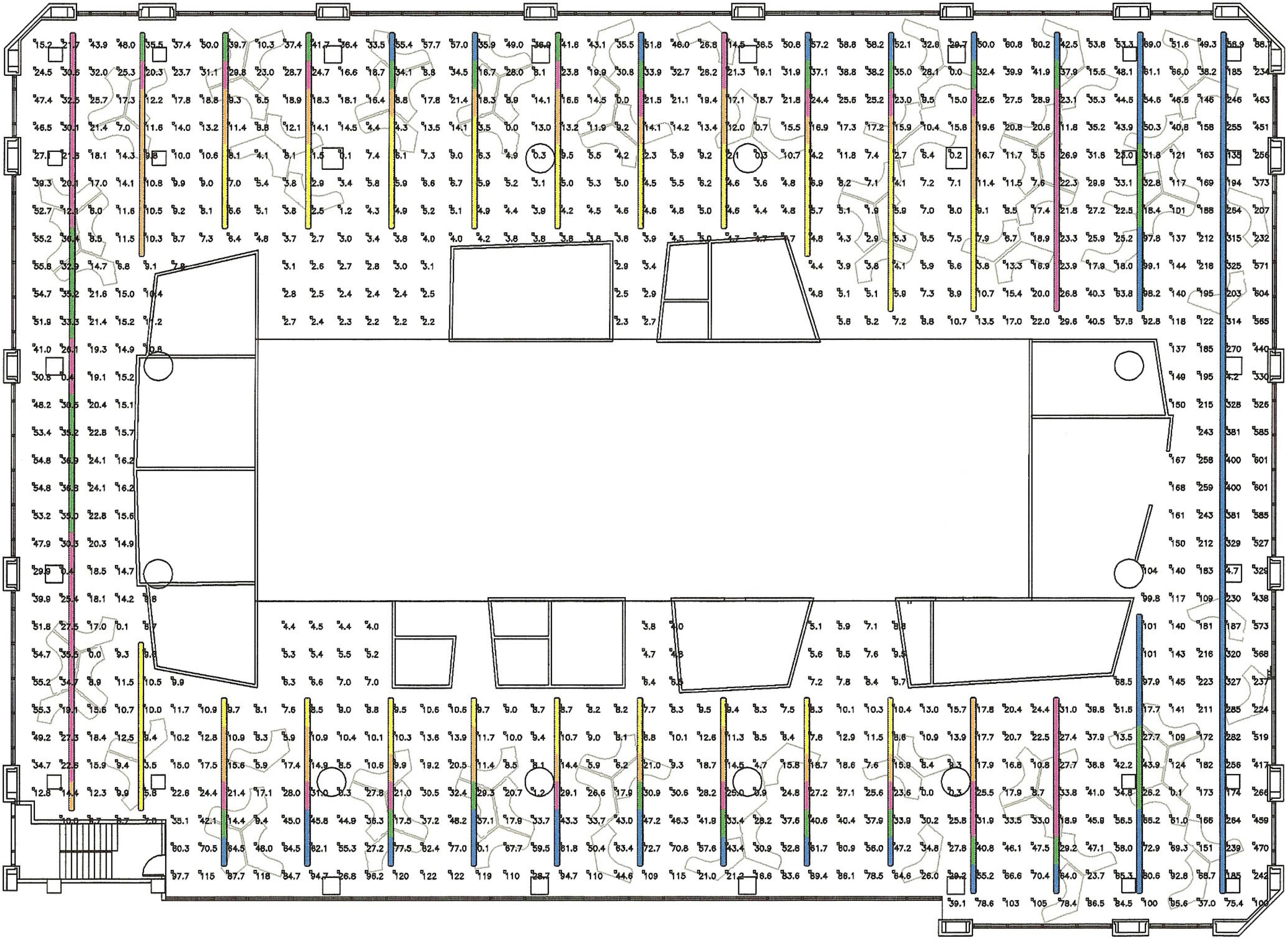
JANUARY 1, 1:00 PM



SHEET S3 – DAYLIGHTING CASE STUDY

SCALE: NTS

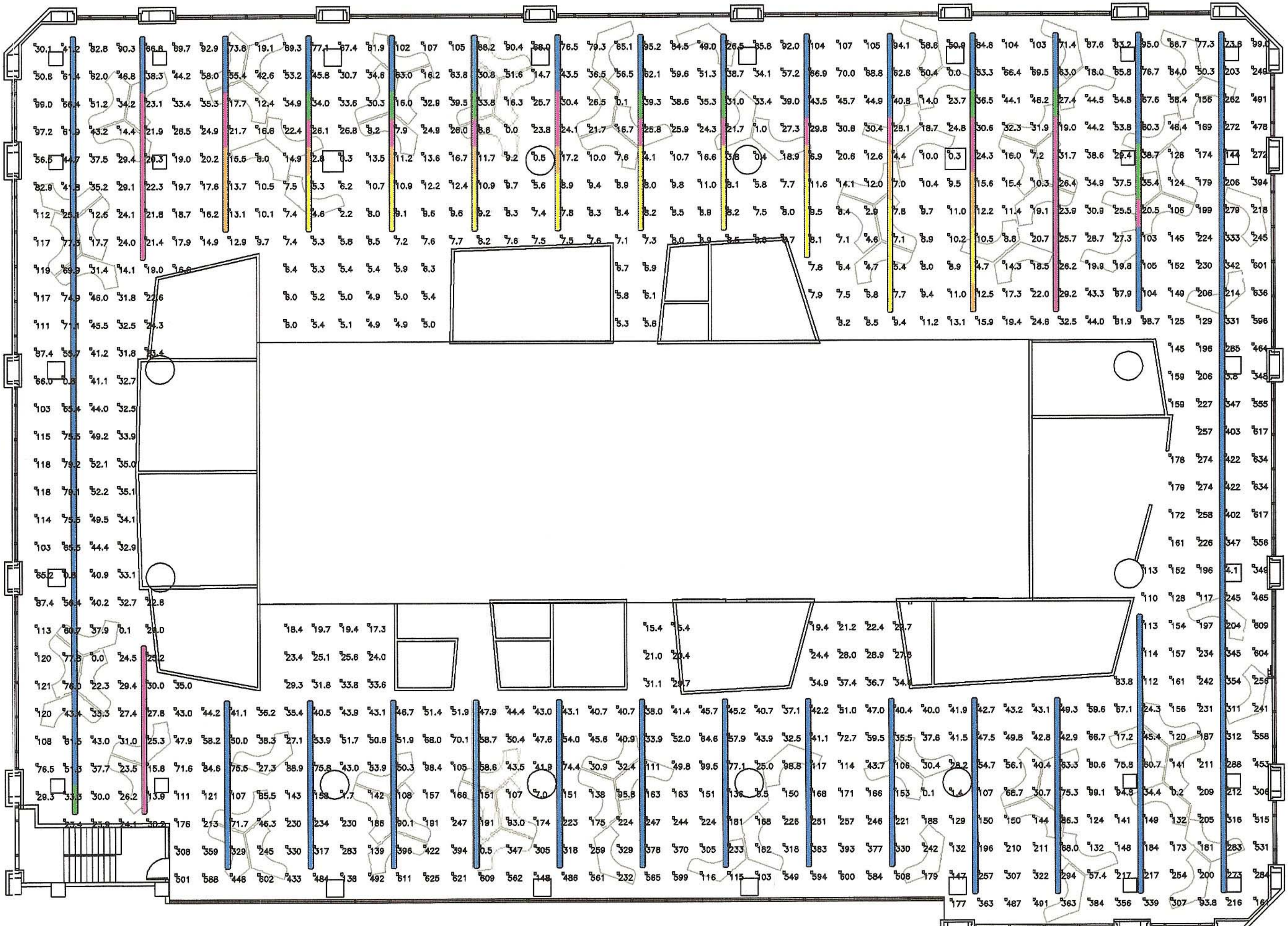
JANUARY 1, 4:00 PM



SHEET S4 – DAYLIGHTING CASE STUDY

SCALE: NTS

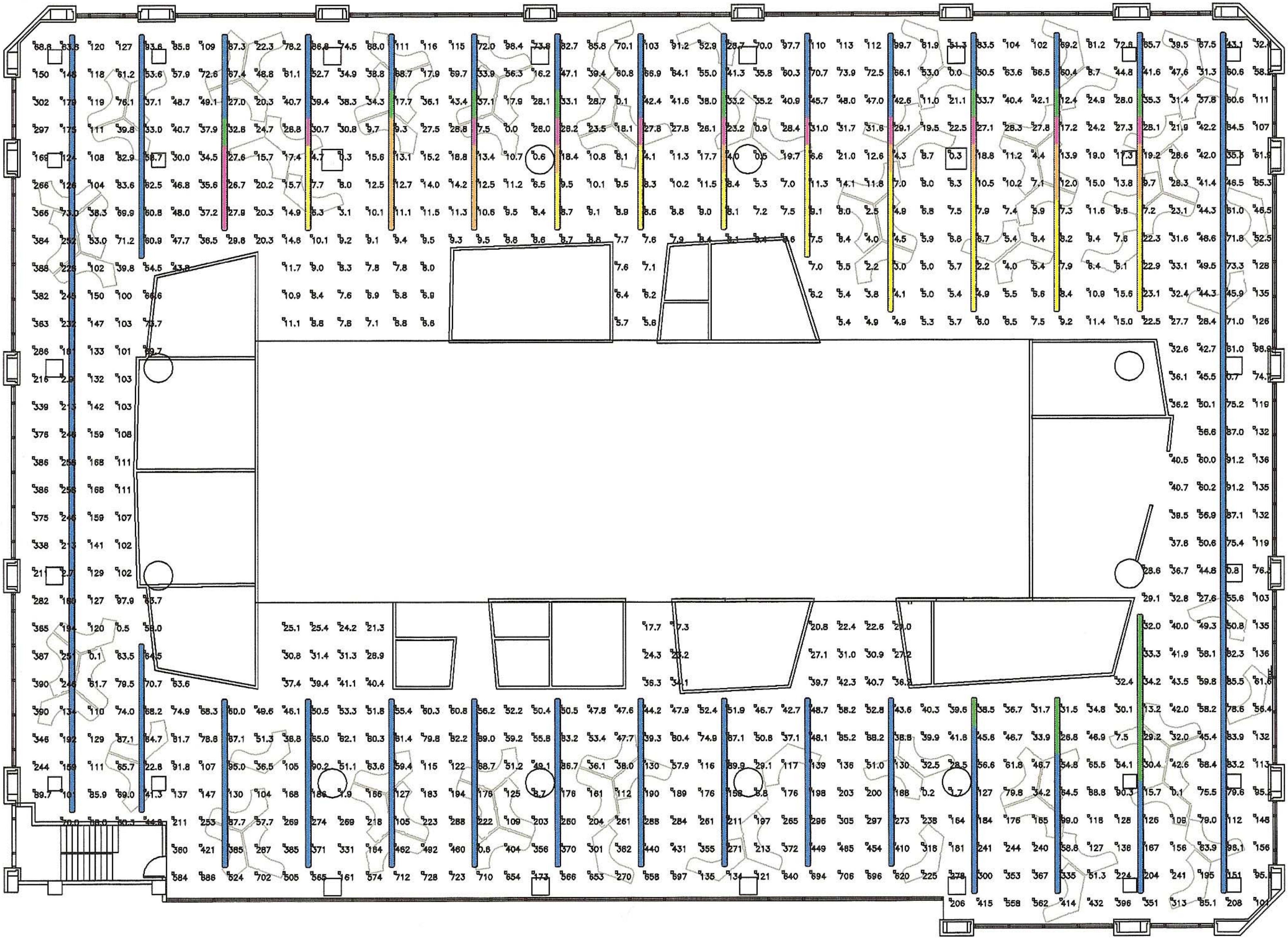
APRIL 1, 7:00 AM



SHEET S5 – DAYLIGHTING CASE STUDY

SCALE: NTS

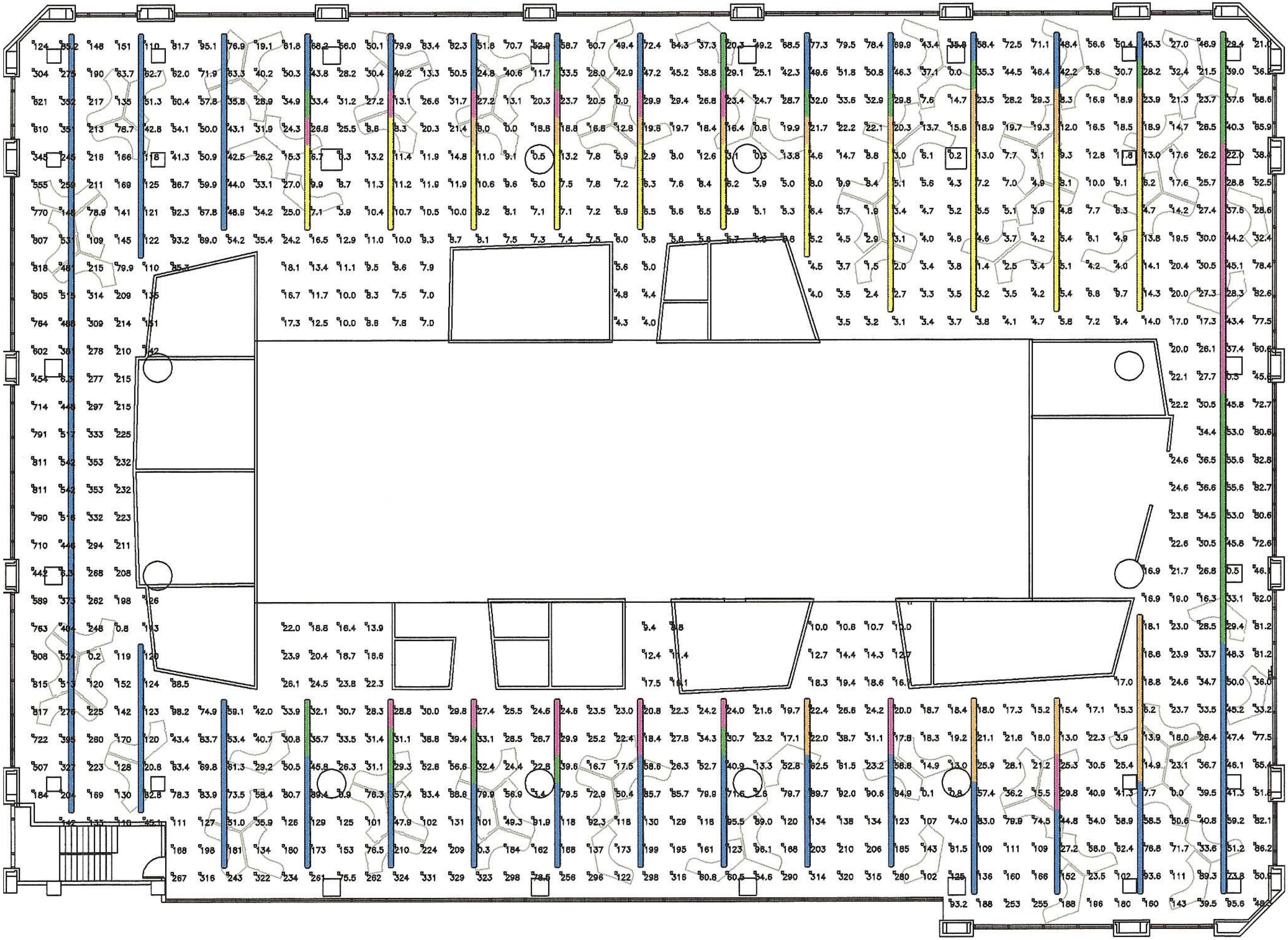
APRIL 1, 10:00 AM



SHEET S6 — DAYLIGHTING CASE STUDY

SCALE: NTS

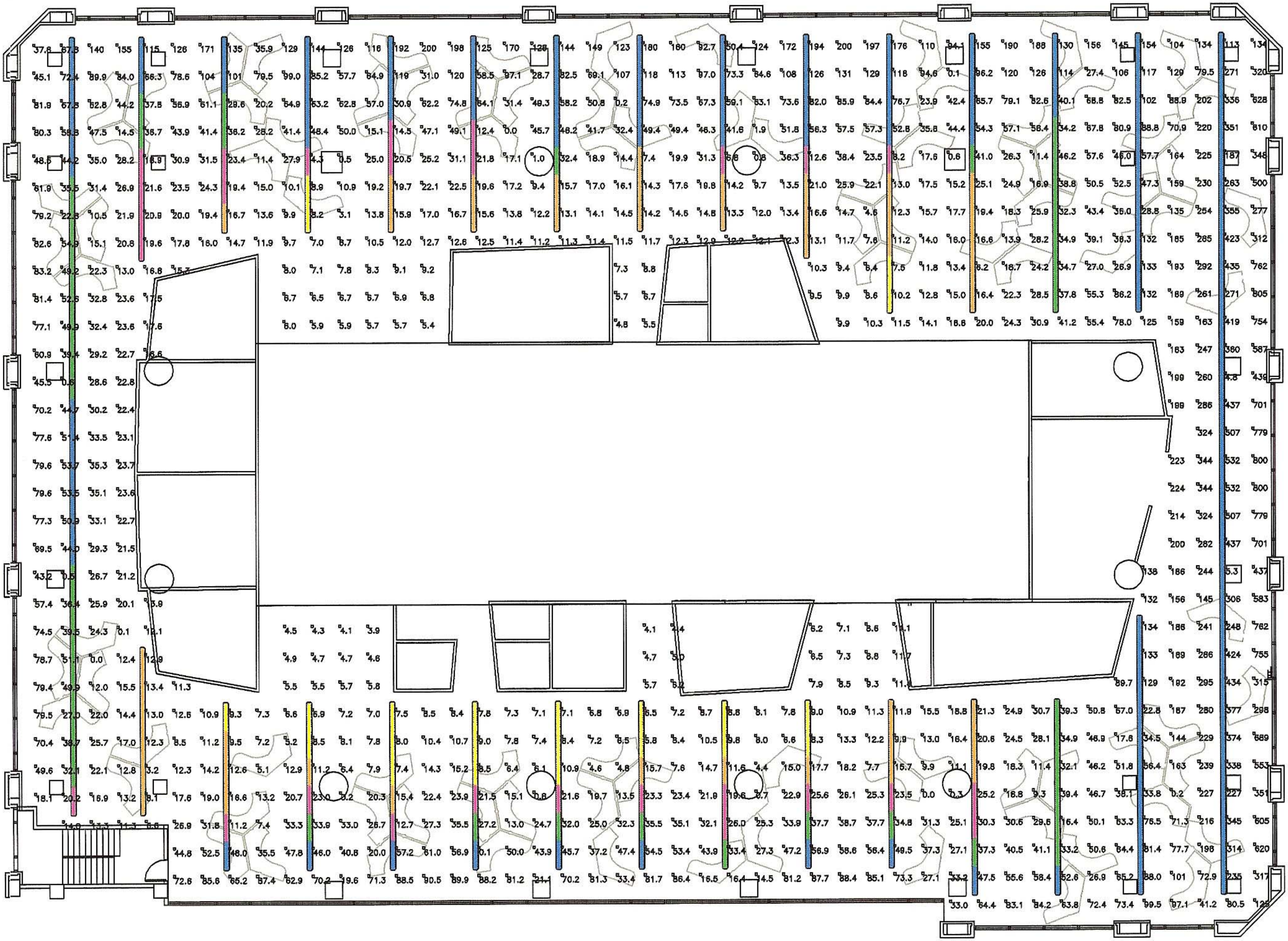
APRIL 1, 1:00 PM



SHEET S7 – DAYLIGHTING CASE STUDY

SCALE: NTS

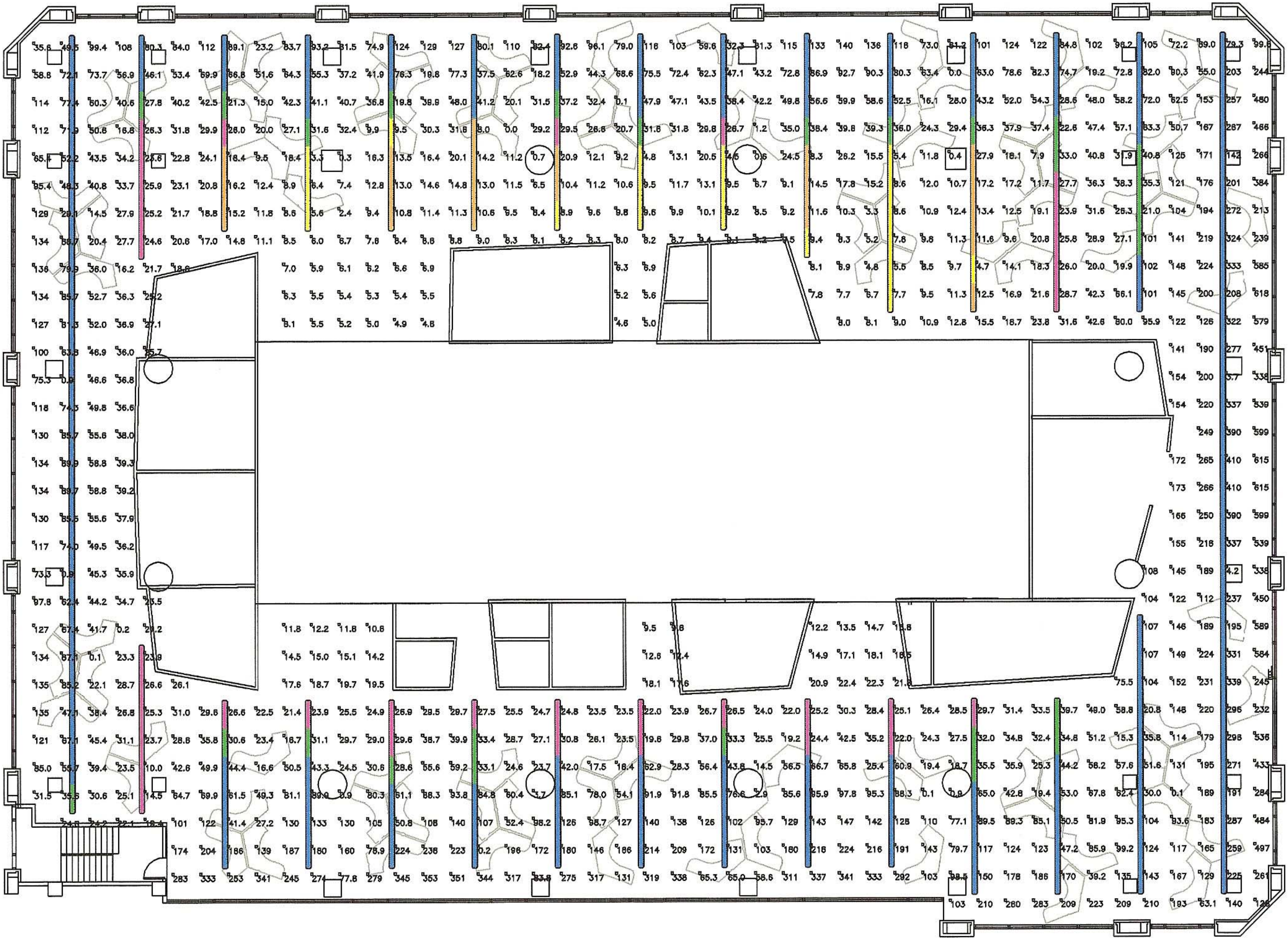
APRIL 1, 4:00 PM



SHEET S8 – DAYLIGHTING CASE STUDY

SCALE: NTS

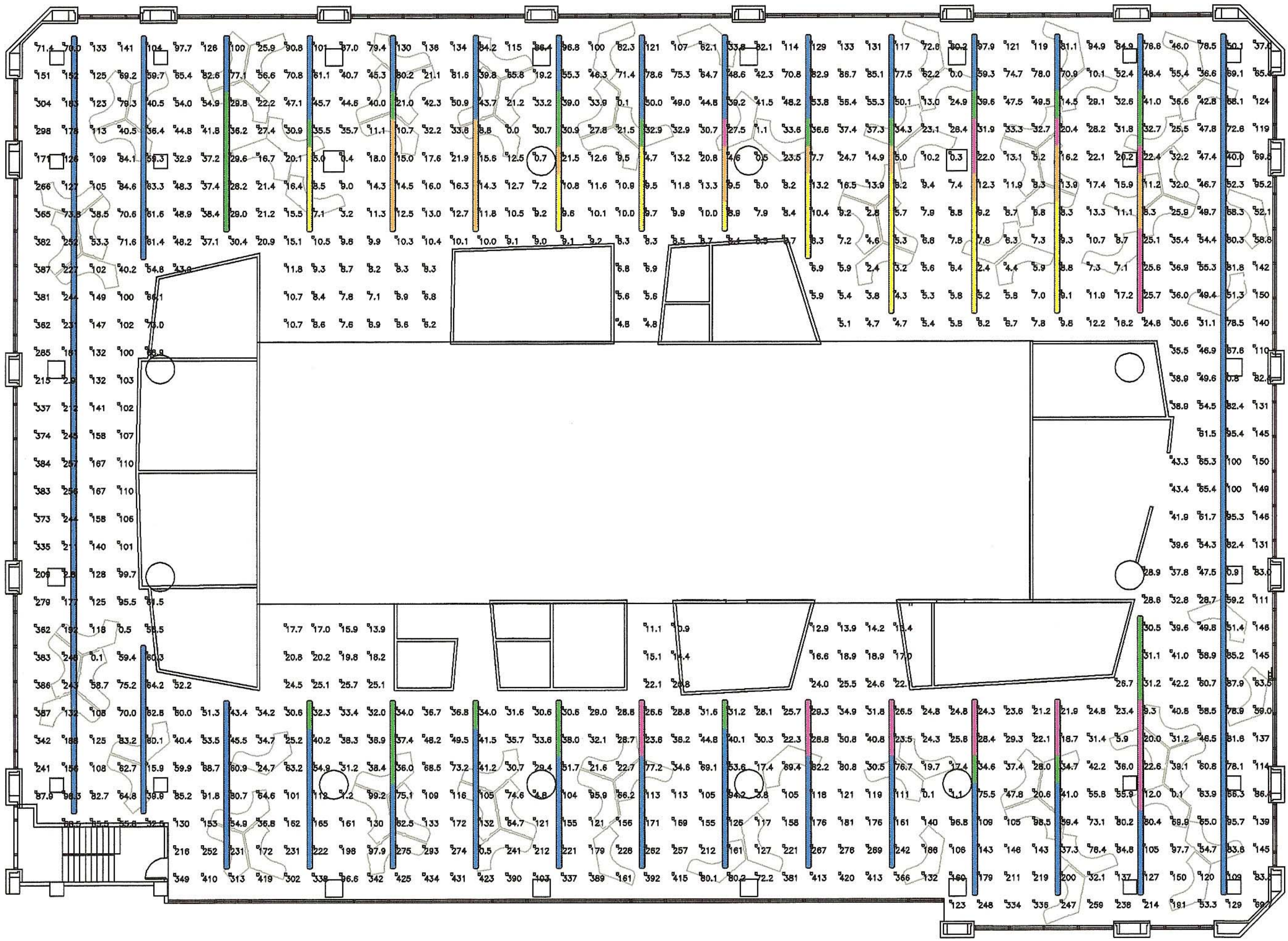
JULY 1, 7:00 AM



SHEET S9 — DAYLIGHTING CASE STUDY

SCALE: NTS

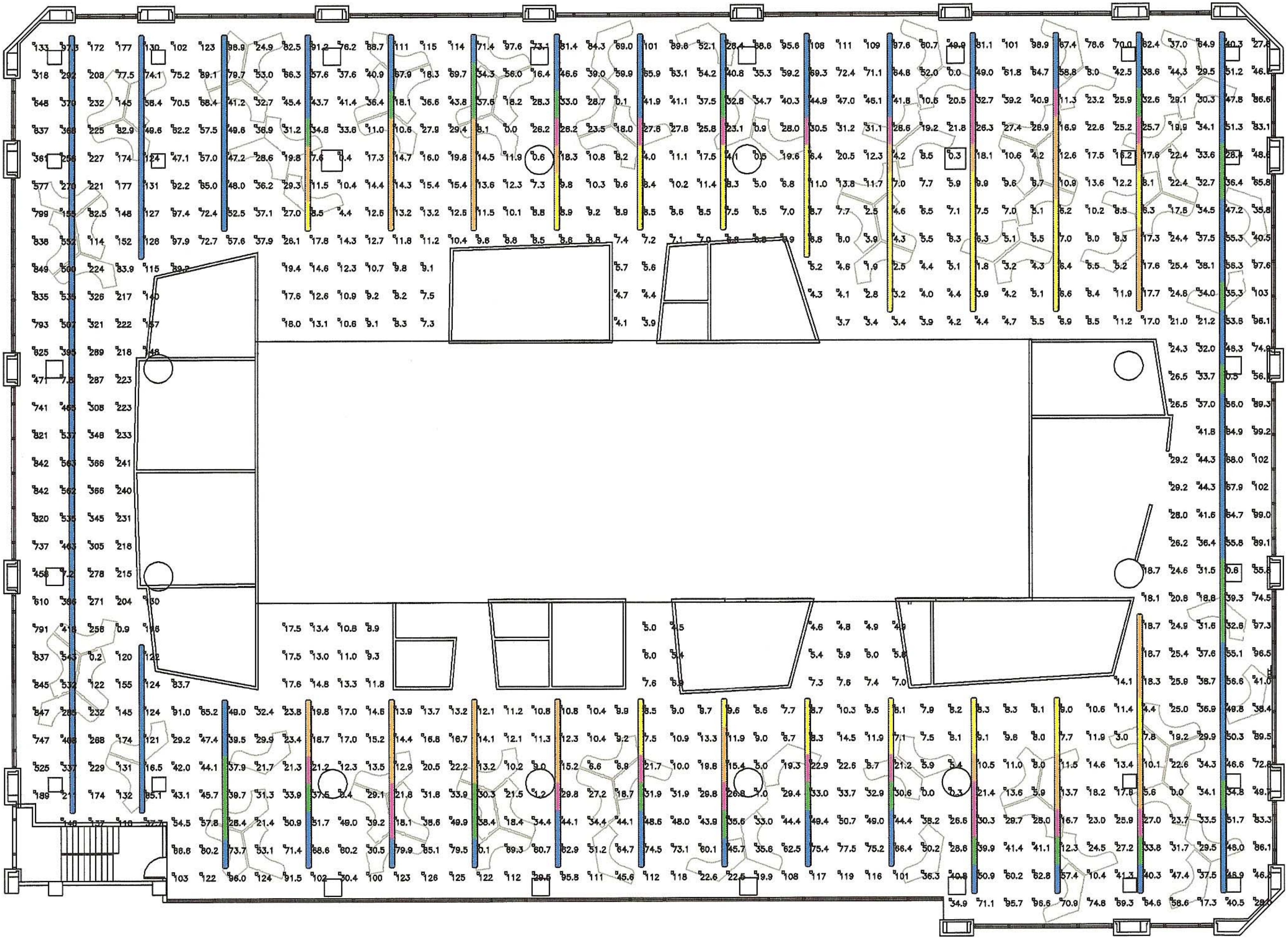
JULY 1, 10:00 AM



SHEET S10 – DAYLIGHTING CASE STUDY

SCALE: NTS

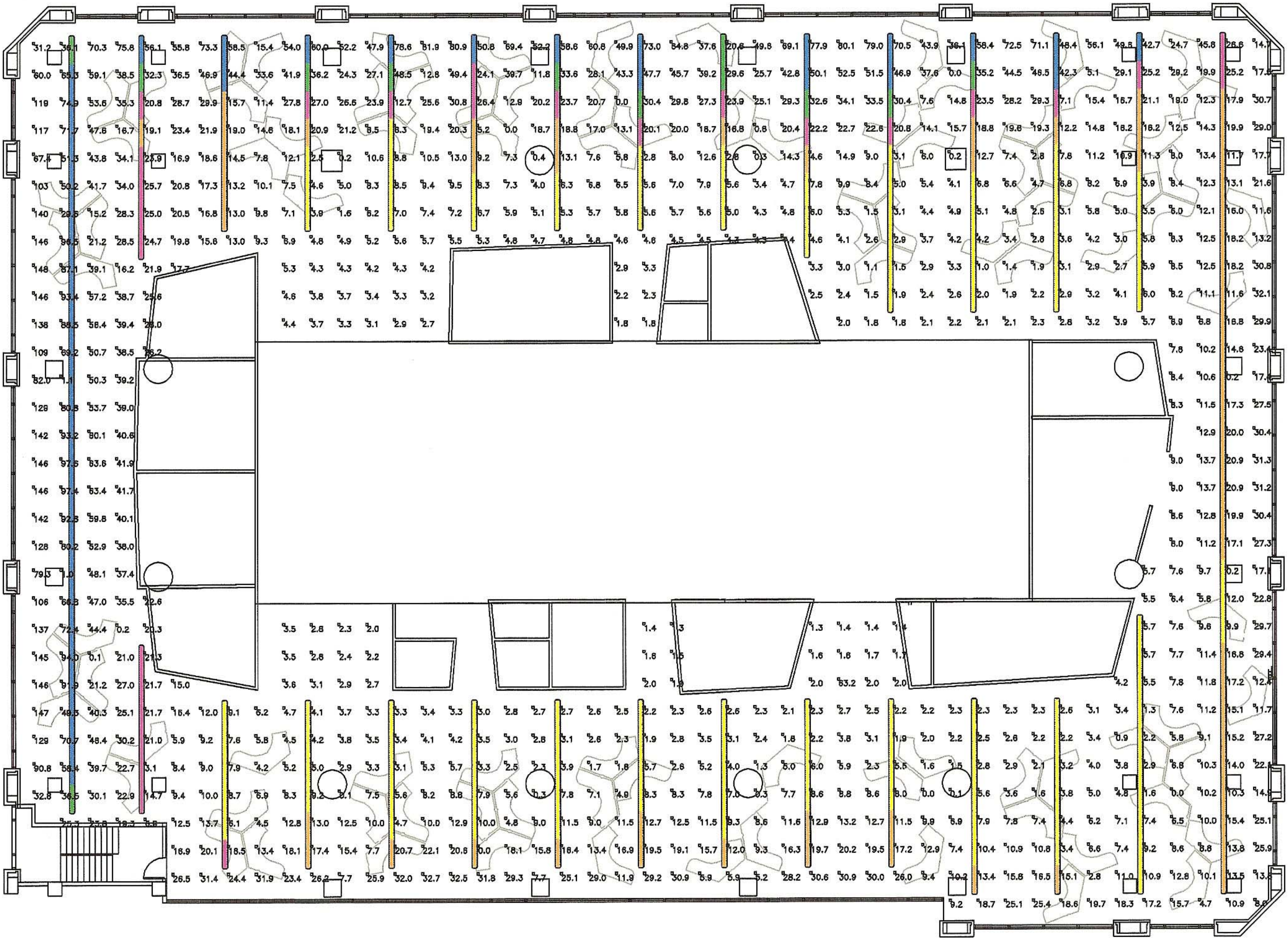
JULY 1, 1:00 PM



SHEET S11 – DAYLIGHTING CASE STUDY

SCALE: NTS

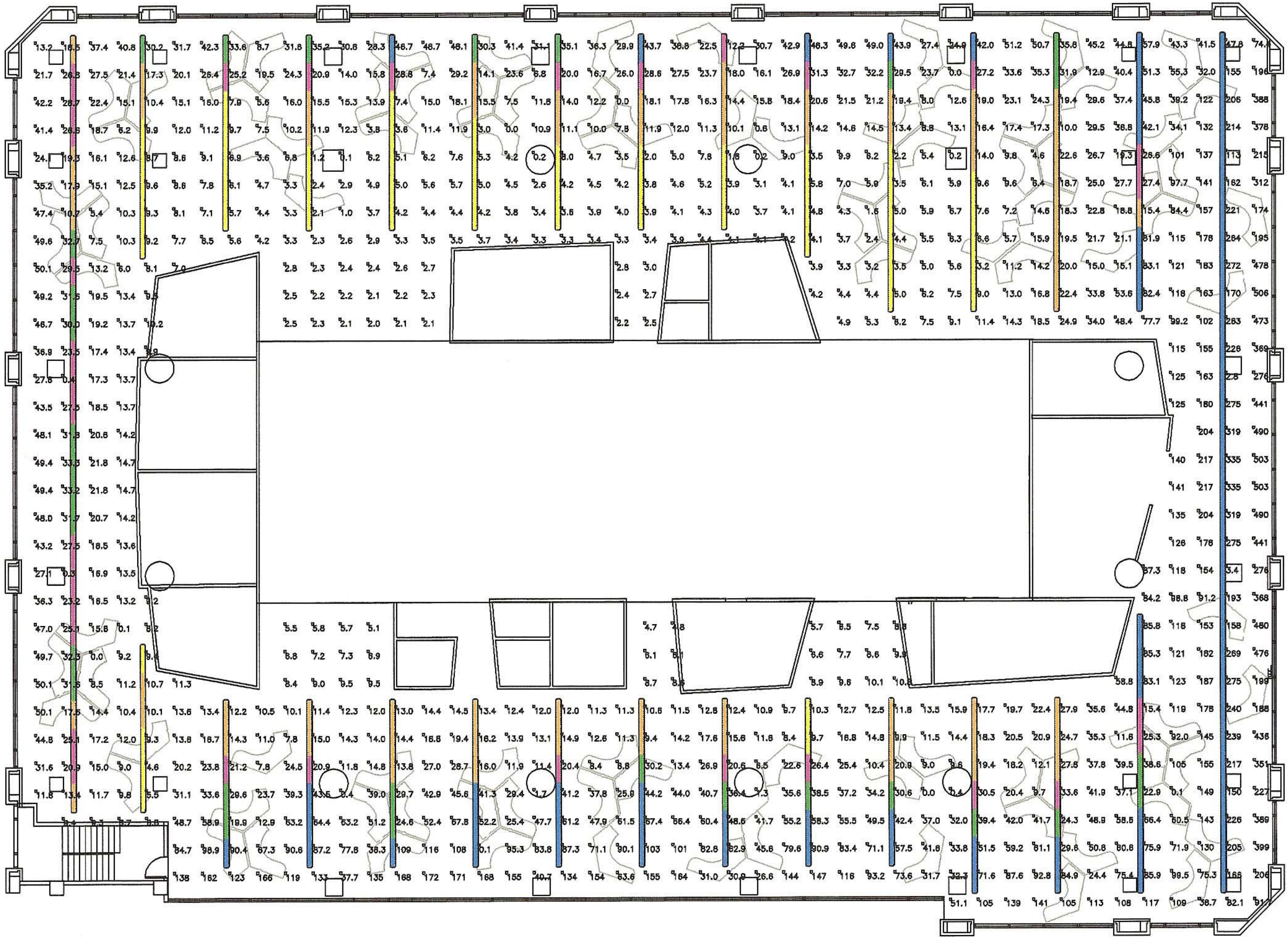
JULY 1, 4:00 PM



SHEET S12 – DAYLIGHTING CASE STUDY

SCALE: NTS

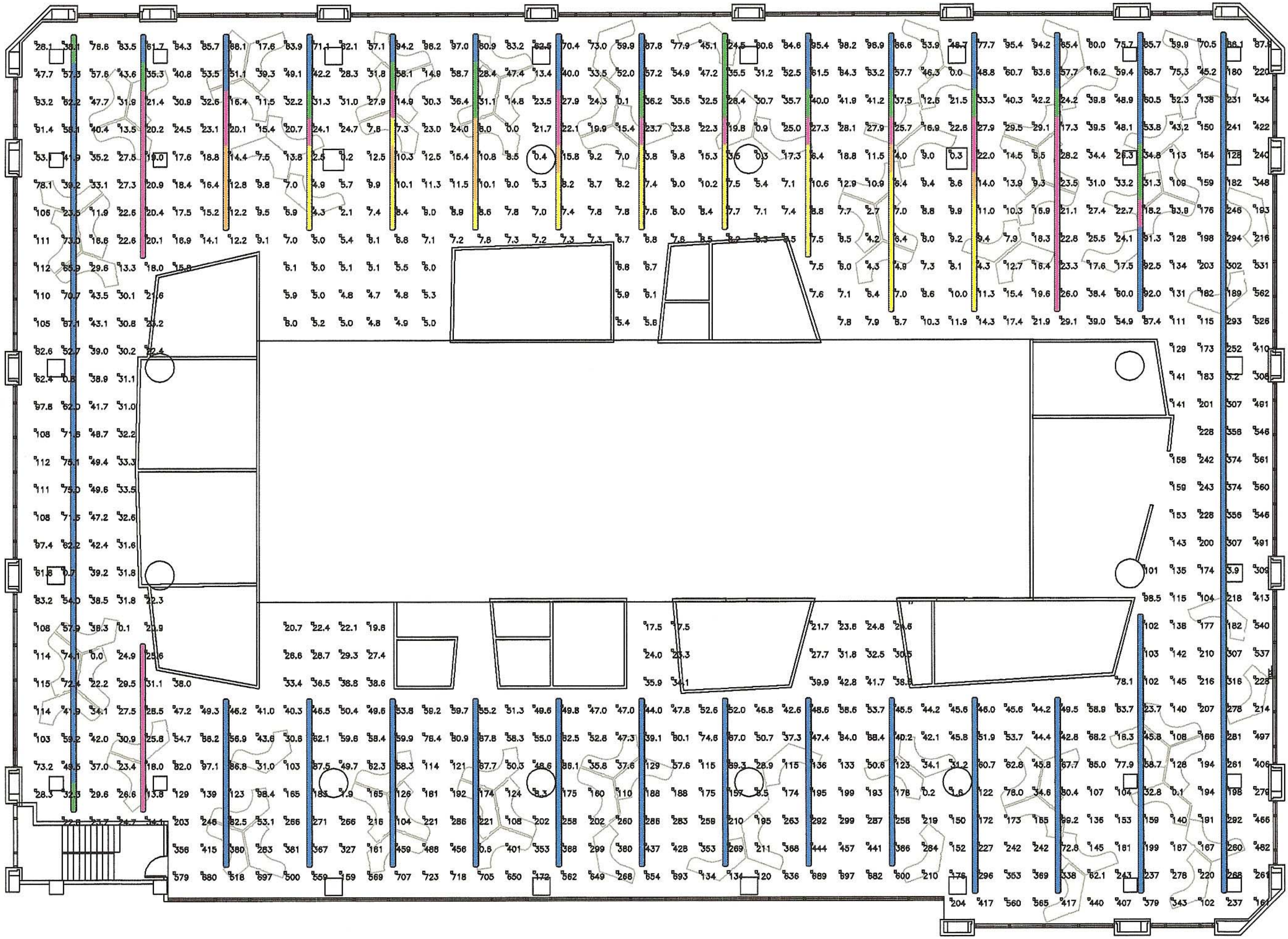
JULY 1, 7:00 PM



SHEET S13 – DAYLIGHTING CASE STUDY

SCALE: NTS

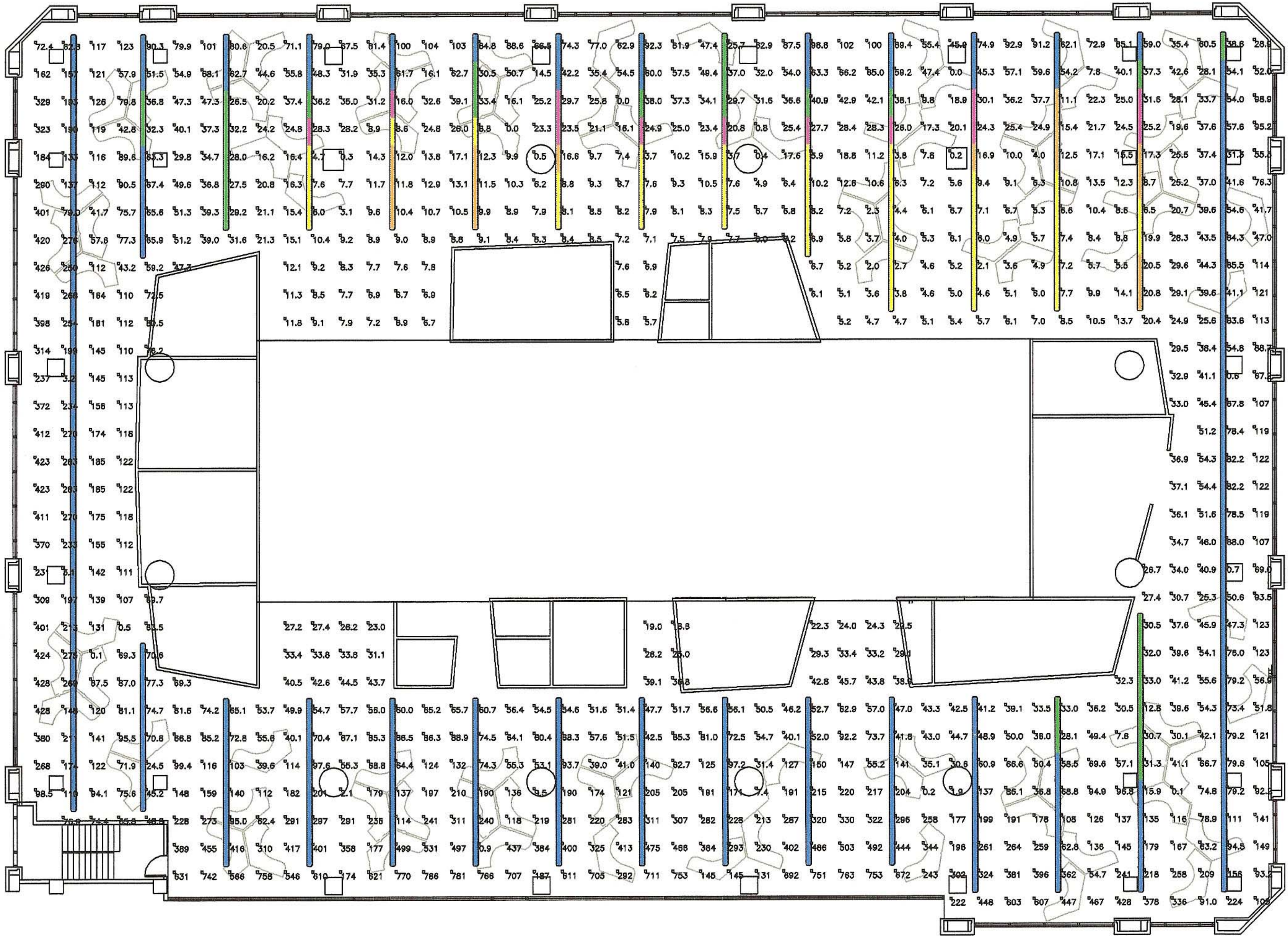
OCTOBER 1, 7:00 AM



SHEET S14 – DAYLIGHTING CASE STUDY

SCALE: NTS

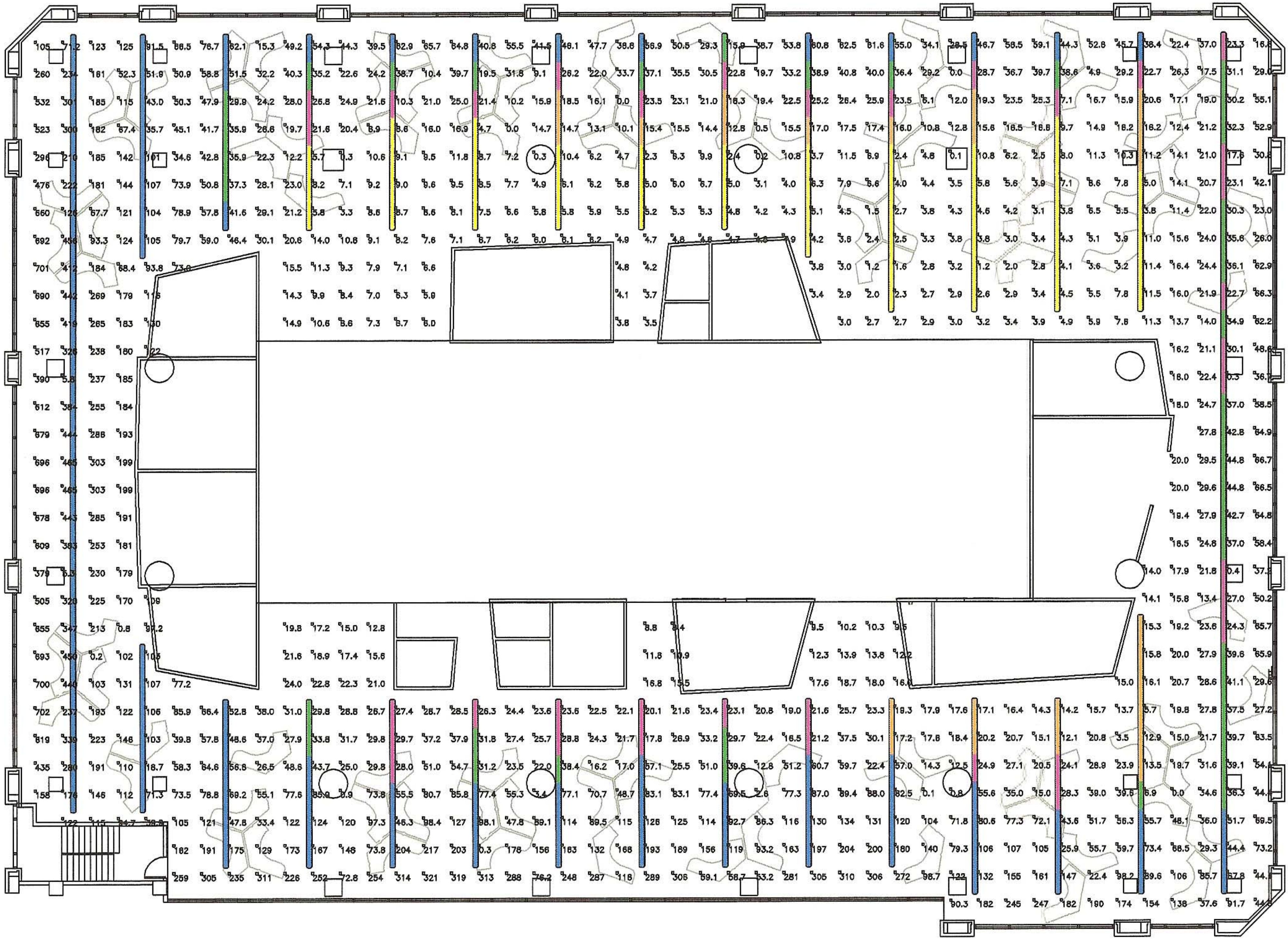
OCTOBER 1, 10:00 AM



SHEET S15 – DAYLIGHTING CASE STUDY

SCALE: NTS

OCTOBER 1, 1:00 PM



SHEET S16 – DAYLIGHTING CASE STUDY

SCALE: NTS

OCTOBER 1, 4:00 PM

Appendix E - Case Study Calculations

DAYLIGHT STUDY CALCULATIONS

SHEET*	DATE	TIME	NUMBER OF FIXTURES DIMMED TO SPECIFIED % LUMEN OUTPUT					WATTS CONSUMED AT % LUMEN OUTPUT**					kWh USED AT SPECIFIED TIME***	AVERAGE ENERGY USE PER DAY****	COST PER DAY*****	AVERAGE ENERGY USE PER DAY******	COST PER DAY *******
			0%	25%	50%	75%	100%	0%	25%	50%	75%	100%					
N/A	JANUARY 1	7:00 AM	0	0	0	0	248	2	29	43	52	64	15.87				
S1	JANUARY 1	10:00 AM	125	34	26	26	37	2	29	43	52	64	6.07				
S2	JANUARY 1	1:00 PM	148	22	21	19	38	2	29	43	52	64	5.26	10.57	$4.12		
S3	JANUARY 1	4:00 PM	68	16	22	72	70	2	29	43	52	64	9.77				
N/A	JANUARY 1	7:00 PM	0	0	0	0	248	2	29	43	52	64	15.87				
S4	APRIL 1	7:00 AM	67	35	50	39	57	2	29	43	52	64	8.98				
S5	APRIL 1	10:00 AM	169	10	33	13	23	2	29	43	52	64	4.20				
S6	APRIL 1	1:00 PM	171	17	13	15	32	2	29	43	52	64	4.22	7.95	$3.10		
S7	APRIL 1	4:00 PM	121	29	26	26	46	2	29	43	52	64	6.50				
N/A	APRIL 1	7:00 PM	0	0	0	0	248	2	29	43	52	64	15.87				
S8	JULY 1	7:00 AM	112	44	27	43	22	2	29	43	52	64	6.31			8.38	3.27
S9	JULY 1	10:00 AM	149	26	34	20	19	2	29	43	52	64	4.77				
S10	JULY 1	1:00 PM	154	29	22	18	25	2	29	43	52	64	4.63	6.80	$2.65		
S11	JULY 1	4:00 PM	116	28	21	41	42	2	29	43	52	64	6.77				
S12	JULY 1	7:00 PM	43	12	26	59	108	2	29	43	52	64	11.53				
S13	OCTOBER 1	7:00 AM	73	29	32	62	52	2	29	43	52	64	8.92				
S14	OCTOBER 1	10:00 AM	161	17	32	10	28	2	29	43	52	64	4.50				
S15	OCTOBER 1	1:00 PM	160	26	12	15	35	2	29	43	52	64	4.61	8.21	$3.20		
S16	OCTOBER 1	4:00 PM	102	39	35	24	48	2	29	43	52	64	7.16				
N/A	OCTOBER 1	7:00 PM	0	0	0	0	248	2	29	43	52	64	15.87				

NOTES:

* Sheet/Date/Time correspond with sheets in Appendix E

** Values come from 'Energy Savings' graph on ballast cutsheet (see Appendix C). Percent power usage at each dimming level was multiplied by (2 lamps) at 32W each divided by the ballast factor (1.00)

*** Average kWh consumed at a particular time of the day was found by multiplying (# of fixtures at % lumen output) by the corresponding (watts consumed at % lumen output). This value was divided by 1000 to change Wh to kWh.

**** Average kWh consumed at any time of the day for each date was found by averaging the kWh at each of the five time of the day for each date.

***** Energy cost per day for each date was calculated by multiplying the average energy use for that day by 12 hours of building occupancy times the energy rate of $0.03246. See calculations on next page for to see how energy rate was calculated.

****** Average kWh consumed per day for any day of the year was calculated by averaging the kWh consumed for each date.

******* The average energy cost per day for any day of the year was calculated by multiplying the average kWh consumed for any day of the year by 12 hours of building occupancy times the energy rate of $0.03246

CASE STUDY CALCULATIONS

CALCULATING COLORADO ENERGY RATE

The following energy rates for Colorado were found on www.xcelenergy.com

Rate for Summer Season (June 1st-September 30): $0.03497

Rate for Winter Season (October 1-May 31): $0.03120

A weighted average based on number of days was used to calculate an average energy rate that could be applied to the whole year = $0.03246

ENERGY COSTS

ESTIMATED COST PER YEAR FOR USING DIMMING:

(COST PER DAY FOR ALL DATES ($3.27))x(365 DAYS)

$1,191.93

BASELINE CALCULATION:

ESTIMATED COST PER YEAR USING 100% LUMEN OUTPUT AT ALL TIMES OF OCCUPANCY:

(248 BALLASTS)x((64 W/BALLAST)/1000)x(12 HOURS)x($0.03246/kWh)x(365 DAYS)

$2,256.60

ENERGY COST SAVINGS FROM DIMMING:

(BASELINE COST) - (COST USING DIMMING)

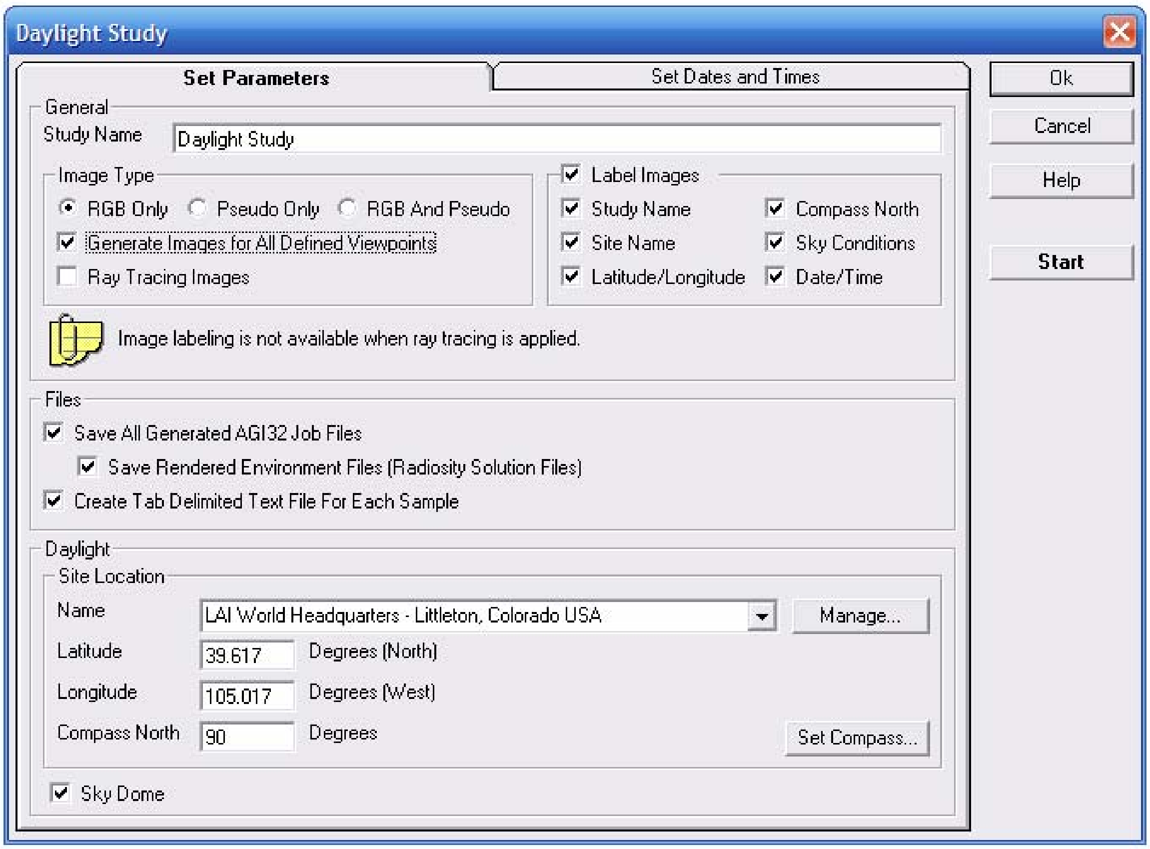
$1,064.67

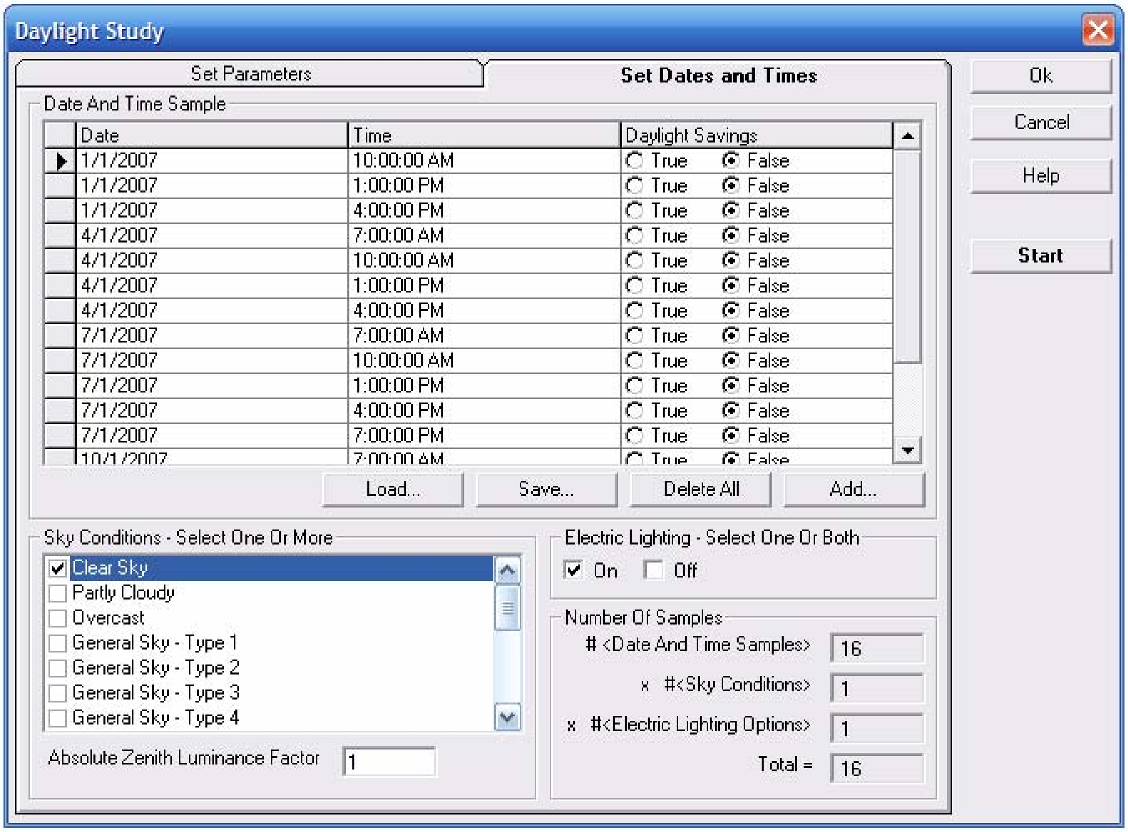
PERCENT SAVINGS:

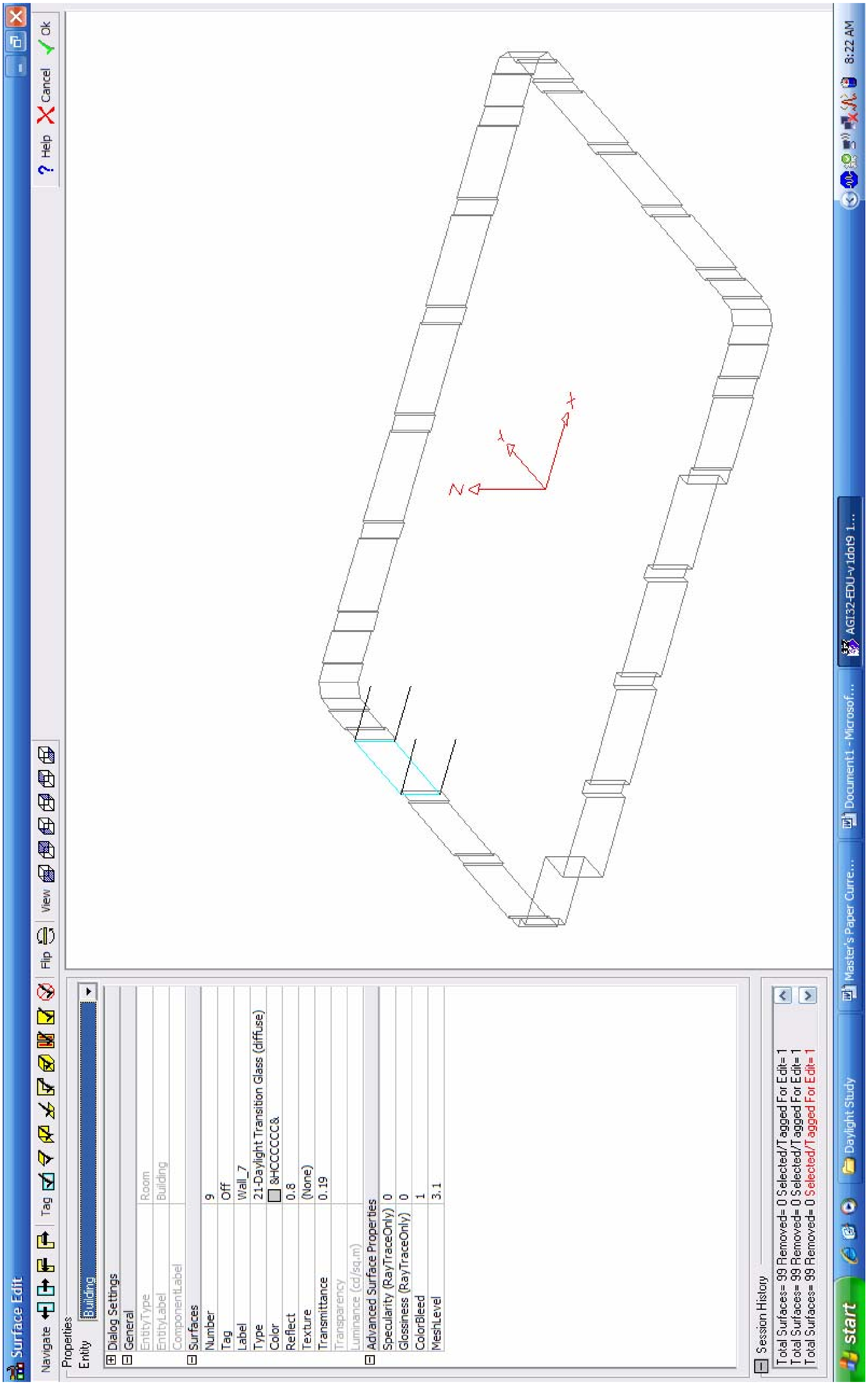
($1,065/$2,257)x100

47.19%

Appendix F - Case Study AGI-32 Screen Shots




Daylight Study
Set Parameters
Set Dates and Times
Ok
Cancel
Help
Start
Date And Time Sample
Date
Time
Daylight Savings
1/1/2007 10:00:00 AM True False
1/1/2007 1:00:00 PM True False
1/1/2007 4:00:00 PM True False
4/1/2007 7:00:00 AM True False
4/1/2007 10:00:00 AM True False
4/1/2007 1:00:00 PM True False
4/1/2007 4:00:00 PM True False
7/1/2007 7:00:00 AM True False
7/1/2007 10:00:00 AM True False
7/1/2007 1:00:00 PM True False
7/1/2007 4:00:00 PM True False
7/1/2007 7:00:00 PM True False
Load...
Save...
Delete All
Add...
Sky Conditions - Select One Or More
Clear Sky
Partly Cloudy
Overcast
General Sky - Type 1
General Sky - Type 2
General Sky - Type 3
General Sky - Type 4
Absolute Zenith Luminance Factor
1
Electric Lighting - Select One Or Both
On
Off
Number Of Samples
<Date And Time Samples>
16
x #<Sky Conditions>
1
x #<Electric Lighting Options>
1
Total =
16


Surface Edit
Navigate
Tag
Flip
View
Help
Cancel
Ok
Properties
Entity
Building
Dialog Settings
General
EntityType
Room
EntityLabel
Building
ComponentLabel
Surfaces
Number
9
Tag
Off
Label
Wall_7
Type
21-Daylight Transition Glass (diffuse)
Color
&HCCCCCC&
Reflect
0.8
Texture
(None)
Transmittance
0.19
Transparency
Luminance (cd/sq.m)
Advanced Surface Properties
Specularity (RayTraceOnly)
0
Glossiness (RayTraceOnly)
0
ColorBleed
1
MeshLevel
3.1
Session History
Total Surfaces= 99 Removed= 0 Selected/Tagged For Edit= 1
Total Surfaces= 99 Removed= 0 Selected/Tagged For Edit= 1
Total Surfaces= 99 Removed= 0 Selected/Tagged For Edit= 1
Z
Y
X
start
Daylight Study
Master's Paper Curre...
Document1 - Microsof...
AGI32-EDU-v1dot9 1...
8:22 AM

Appendix G - Permissions

All images not created by the author are used with permission from the original source.

Figure 4-1

Used with permission from Watt Stopper

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Joy Null

Director of Public Relations

Watt Stopper/Legrand

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Figures 3-1, 7-1, & 7-2

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Stuart Berjansky

Senior Product Manager, Dimming and Controls

Advance

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Figures 4-3 & 4-4

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Figure 4-2

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