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# INTEGRATED ENVIRONMENTAL CONTROL AND MONITORING IN THE INTELLIGENT WORKPLACE

**Final Report**

## 1.0 GOALS AND OBJECTIVES

The Intelligent Workplace with its diverse building systems for environmental. organizational and information technological performance and "plug and play" flexibility is an extremely challenging project in terms of the design and integration of its environmetal systems and associated controls. A systems engineering approach was utilized by the team to achieve the objectives of modularity, energy efficiency, occupancy satisfaction and flexibility. Each system was thoroughly analyzed, the crossover points were identified and the integration of both hardware and software systems were determined.

This project involved the design and engineering of the control and monitoring of environmental quality – visual, thermal, air – in the Intelligent Workplace. The research objectives were to study the performance of the individual systems, to study the integration issues related to each system. to develop a control plan, and to implement and test the integrated systems in a real setting.

In this project, a control strategy with related algorithms for distributed sensors, actuators, and controllers for negotiating central and individual control of HVAC, lighting, and enclosure was developed in order to maximize user comfort, and energy and environmental effectiveness. The subsystems to provide environmental quality in the Intelligent Workplace include an air-based HVAC system with desiccant air handler and Personal Environments®, a water-based HVAC system with radiant cooling panels, the Coolwave® and displacement ventilation, a water flow curtainwall, a PV assisted natural ventilation system, and a lighting system including light redirection louvers, shading devices and daylight-responsive electric lighting. Configurations of sensors, actuators, submeters, and associated hardware, software and networks were designed, including functional requirements for a user interface to illustrate the potential of user-based controls and to educate the users.

This research project was divided into three phases and was initially based on the capabilities of commercial systems and the building construction and occupancy schedules. Phase 1 encompassed working with member companies providing control components in order to establish basic system requirements, to model integration and to identify hardware components. Other commercially available systems were also investigated at this time. During Phase 2, development of construction documents was coordinated with the engineering staffs of member companies. Techniques for evaluating the existing systems were developed. Phase III, the actual implementation of the controls and monitoring systems, was begun after the building was occupied in the Fall of 1997.

## DISCLAIMER

# DISCLAIMER

## 2.0 INTRODUCTION

The goal of the control system design in the Intelligent workplace is the integration of building systems for optimization of occupant satisfaction. organizational flexibility. energy efficiency and environmental effectiveness. The task of designing this control system involves not only the research. development and demonstration of state-of-the-art mechanical and electrical systems, but also their integration.

The ABSIC research team developed functional requirements for the environmental systems considering the needs of both facility manager and the user. There are three levels of control for the environmental systems: scheduled control, sensor control, and user control. The challenges are to achieve the highest possible levels of energy effectiveness simultaneously with the highest levels of user satisfaction.

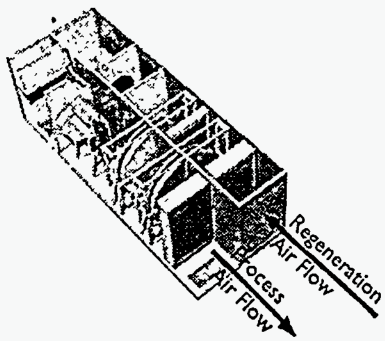
The following sections describe the components of each system, their implementation in the Intelligent Workplace and related control and monitoring issues

## 3.0 MECHANICAL SYSTEMS

The IW is a laboratory for building systems research, therefore it is essential to demonstrate and evaluate a variety of HVAC solutions which are commercially available. In general, the mechanical systems are divided into three zones for research purposes: the south zone which is air based; the north zone which is water based; and the enclosure which combines radiant surfaces and natural ventilation. In this section the technology of each system and its components, their implementation in the IW and control issues are summarized.

## 3.1 Desiccant Air Conditioning System

### Technology Description:




*Desiccant Air Conditioning System*

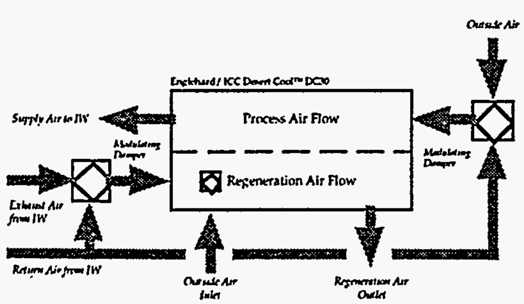
The Englehard/ ICC Desert Cool™ desiccant air conditioning system is an air handling unit that contains a desiccant moisture removal rotor, a heat exchange rotor, process and regeneration fans, process and regeneration air heating coils and an evaporative cooler to provide cool conditioned air without compressors or refrigerants.

The desiccant rotor absorbs moisture from the incoming air in a continuous cycle causing the wheel to become moist. As the moist section of the wheel slowly rotates to the regeneration side, hot (190°F) outgoing (regeneration) air dries out the wheel.

The thermal wheel either pre-heats or pre-cools the supply air depending upon the season. In the pre-heat mode, warm ambient air from the occupied space passes through the thermal wheel on the regeneration side giving up its heat to the wheel and then heating the incoming supply air. In the pre-cool mode, an evaporative cooler cools cool ambient air from the occupied space which then passes through the thermal wheel on the regeneration side giving up its coolness to the wheel and then cooling the incoming supply air.

The regeneration coil is heated by an integral, gas-fired boiler. When paired with a gas-fired cooling plant, the regeneration boiler can sometimes be eliminated to allow maximum efficiency.

### Intelligent Workplace Implementation




MAKE-UP AIR UNIT #1 • AIR FLOW SCHEMATIC
Intelligent Workplace • 19 June 1997

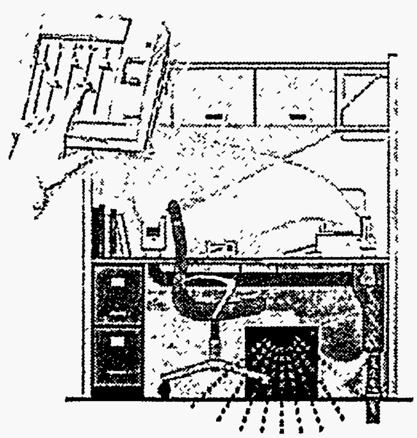
An Englehard/ ICC Desert Cool™ DC30 desiccant air conditioning system with packaged gas-fired boiler is being implemented in the South Zone (short bays) of the Intelligent Workplace (see figure 3.1 in appendix A). The unit has a 3000 cfm supply air capacity. The unit is configured such that the supply air can range from 100% outside air down to the minimum requirement by mixing with return air. The regeneration air can be any combination of outside air, return air or dedicated exhaust air (from the Service Pub™ and/or other heat/ pollution producing devices). A process heating coil is being provided (heated by campus hot water) and a process coiling coil is being provided (cooled by campus chilled water). The supply air temperature will be between 62° – 65°F in the summer and 82° – 85°F in the winter.

### Control Strategy

Johnson Controls Metasys™ will control MUA-1. The operating modes are as follows: process fan on, dehumidification on, three stages of cooling in order of initiation (thermal wheel on, evaporative cooler on, optional cooling coil on), and two stages of heating (in order of initiation - heat recovery with thermal wheel rotating and active heating of process air with hot water being diverted to process heating coil). CBPD researchers will measure indoor air quality performance, air flows and air temperatures under a full range of operational conditions.

## 3.2 Personal Environments™

### Technology Description



The Personal Environments® (PEM) system puts control in the hands of the people who occupy individual workstations. From their desktop control unit, each individual can control heat, air flow, lighting and masking sound. The air is continuously filtered and an integrated occupancy sensor shuts the system down when workstations are vacant, saving energy. The PEM system lets employees concentrate on their work and not on the distractions of an uncomfortable office. Scientific studies show productivity increases as much as 15% when workers are satisfied with their environment.

The PEM is coupled to a pressurized supply air floor plenum with a flex duct allowing simple repositioning or relocation as the workplace is reconfigured.

### Intelligent Workplace Implementation

A supply air Personal Environments® system will be installed in the South Zone of the IW (see figure 3.2 in appendix A). A total of thirty units will be installed as a part of the HVAC system including the MUA–1 and associated ductwork. The IW utilizes a floor plenum construction integrating HVAC ductwork, power, voice and data wiring and fire protection without a redundant concrete slab. For research purposes, both supply air ducts and return air ducts are being installed to allow experimentation with thermal quality and air quality with ducted supply versus ducted return systems. The initial configuration will have ducted supply air and plenum return air and the analog PEM controller. Future plans include a workstation–based graphical user interface.

### Control Strategy

The PEM's are installed on the JCI Metasys® N2 bus communicating with the network control unit (NCU). The physical wiring is configured with AMP consolidation points, so that while the wiring is all homerun through the consolidation point back to the NCU, the communication topology is daisy chain (see figure 3.2 a in appendix A).

The PEM allows individual user control, however, the sensors in each PEM unit will provide temperature, relative humidity and occupancy data back to Metasys®, so that central control of the MUA set points in response to localized conditions is possible. In addition, Metasys® sensors will provide airflow and air quality data.

## 3.3 Water Flow Mullions

### Technology Description

*A Vertical Water Flow Mullion*

The Josef Gartner Company of Gundelfingen, Germany designed and patented the world's only water flow mullions to address the condensation and comfort problems associated with low indoor surface temperatures of metal and glass curtainwalls. The first systems were fabricated from hollow steel tubes welded together to form passage ways for the circulation of hot water (160° – 180°F). Current systems are fabricated in both steel and aluminum.

### Intelligent Workplace Implementation

The curtainwall for the Intelligent Workplace was donated by the Gartner Company and is fabricated from recycled aluminum. The vertical mullions at a 1200mm spacing contain 1/2" diameter black steel pipes bonded into the aluminum extrusion for water distribution . The water circulates at 33 gpm at between 140° - 180°F.

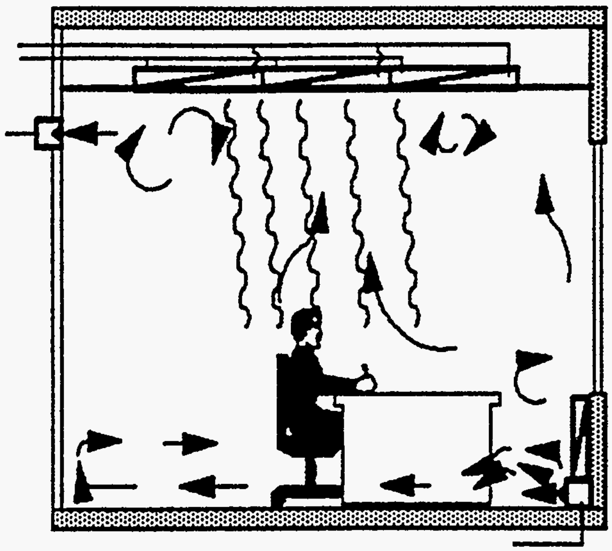
The piping configuration of the IW utilizes one supply water loop and one counterflow return water loop in parallel (see figure 3.3, Appendix A). The four vertical mullions of each bay are piped together with 3/4" diameter supply and return lines in parallel to the main loops and controlled with one Metasys® flow control valve.

### Control Strategy

JCI Metasys® will control the water flow mullion system. A temperature sensor mounted on the glass in each bay controls each flow control valve. Each flow control valve (total of 26) creates an individual zone allowing each zone to respond to differing microclimatic conditions (such as high solar gain on the east on a winter morning but low ambient outdoor temperatures and shade on the west). In addition, Metasys® valves will control water flow and temperature and Metasys® sensors will collect water flow and temperature data.

## 3.4 Displacement Ventilation

### Technology Description



The trend in high performance HVAC systems is to separate the thermal conditioning from the ventilation of a conditioned space. Displacement ventilation is a technique developed in Europe that introduces ventilation air at the perimeter of the space at a temperature within 4°F plus or minus of indoor ambient. The air is introduced at floor level at very low speeds and as the air stream encounters heat sources (people, equipment, etc.) a vertical plume is created raising ventilation air to the occupants' breathing zone. The air is then extracted from the space at the ceiling plane.The vertical flow of air tends to flush the polutants out of the spase more effectively then ceiling–based systems. Thermal conditioning is accomplished through the use of radiant surfaces (see section on left).

### Intelligent Workplace Implementation

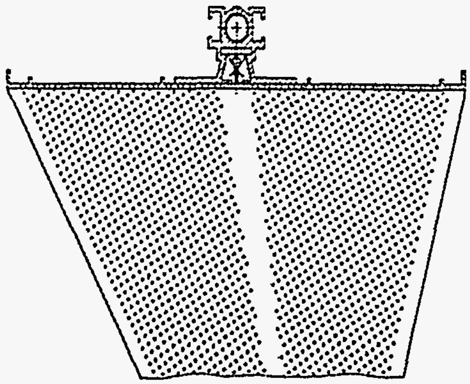
The North Zone of the IW will demonstrate split thermal conditioning/ ventilation systems. LTG is providing the design, engineering and components of the system including the air diffusers and radiant cooling devices (see figure 3.4, Appendix A) for this demonstration. The modular, demountable ductwork will be identical to the ductwork configuration in the south zone. The LTG BLQ diffuser will be integrated with the 1200mm module of the curtainwall on the west, north and east enclosure walls of the North Zone. A Mitsubishi heat recovery air handling unit will provide the conditioned air for the displacement system. Heating and cooling coils within the unit will temper the air. The service pub conditioning will be handled separately.

### Control Strategy

JCI Metasys® will control the components of the displacement ventilation system which include air handler, heating and cooling coils and dampers for each of the displacement diffusers. Sensors will provide data to Metasys® indicating temperature, relative humidity, air quality, airflow and occupancy status.

## 3.5 Radiant Cooling Panels

### Technology Description



Radiant cooling ceilings are metal panels with integral piping and insulation which are installed in ceiling grids or pendant mounted from the structure. Chilled water is circulated through the panels to absorb heat from people and equipment through the principle of radiant heat transfer. A ceiling location is ideal for cooling because the panels have a direct line of sight to the heat sources, but less than satisfactory for heating.

### Intelligent Workplace Implementation

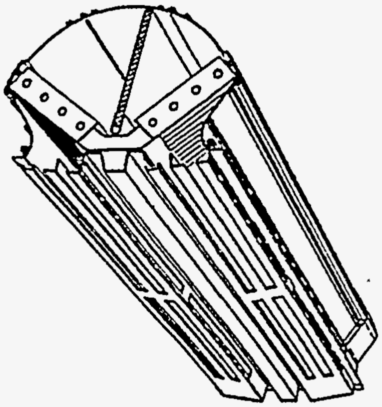
LTG will provide modular, pendant mounted radiant cooling panels for the three perimeter office areas in the North Zone (see figure 3.5, Appendix A). Central chilled water from the campus system will be piped from the 4th floor mechanical room.

### Control Strategy

JCI Metasys® will control the components of the radiant cooling panel system including water flow and temperature. In addition, Metasys® sensors will collect data on dewpoint temperature, air temperature, water flow and temperature, and occupancy status.

## 3.6 Coolwave

### Technology Description



The LTG chilled beam with oscillating fan is a compact. ceiling-mounted unit which cools the air in the room by convection. The fan element is a flat panel mounted between the two cooling coils. The unit draws room air in over one cooling coil as the fan element moves away and pushes air out over the opposite cooling coil into the room. As the flat panel reverses direction, the air flow is reversed. The net effect is to provide excellent mixing of the air, cooling without drafts, and rapid response time. The units are available in different sizes that provide between 35 – 57 W/K (66 – 107 Btu/Hr/°F) with an electrical consumption of just 35 – 42 watts.

### Intelligent Workplace Implementation

The LTG Coolwave will be deployed in the two conferencing (northernmost) bays in the IW (see figure 3.6, Appendix A). The units will be pendant mounted from the roof structure. Central chilled water from the campus system will be piped from the 4th floor mechanical room.

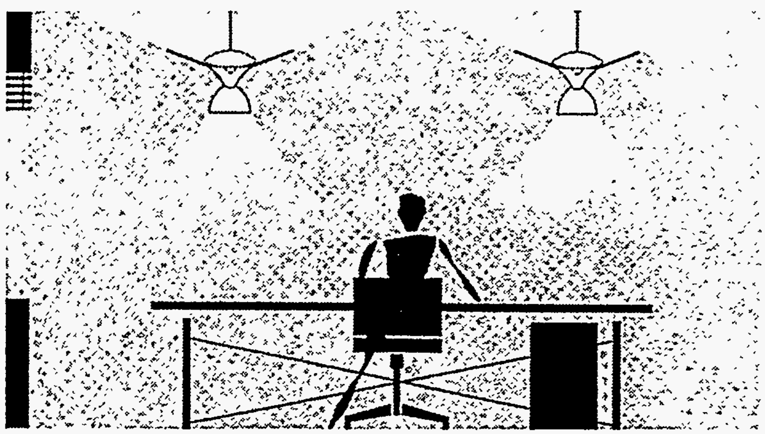
### Control Strategy

JCI Metasys® will control the components of the radiant cooling panel system including water flow and temperature. In addition, Metasys® sensors will collect data on dewpoint, air temperature, water flow, water temperature, and occupancy status.

# 4.0 LIGHTING SYSTEMS

## 4.1 Ambient Lights

### Technology Description



Ambient lighting in the IW will provide 25 fc of illumination on and around the workplane at all times from indirect luminaires. The Zumtobel "La Trave" is a high efficiency direct-indirect luminaire with fluorescent lamps and dimmable electronic ballasts. The efficiency of the luminaire is 74%. Luminaires with efficiencies less than 70% are not suggested for use in commercial buildings by the Illumination Engineering Society of North America (IESNA). The fluorescent lamps are the state-of-the-art T5 lamps. These new lamps have reduced diameters (five eighths of an inch). With their reduced diameters, they have a higher efficiency. They are the most efficient fluorescent lamps in the market today. The ballasts are also high efficiency dimmable electronic ballast introducing minimum noise to the environment.

### Intelligent Workplace Implementation

The La Trave fixture will be mounted to the valley trusses of the IW on relocatable brackets. Their initial locations are displayed in figure 4.1, Appendix A. Power will be provided by a continious track mounted to the underside of the valley truss. This track system allows simple, fast user relocatability. Standard lighting systems in the US work on 120V or 277V. This system is based on a 240V ballast, so the power to the tracks will be increased to 240V with transformers. Together with their indirect component, which is going to accentuate the roof structure, the ambient lights will provide 25 footcandles (or approximately 250 lux) on the workplane.

### Control Strategy

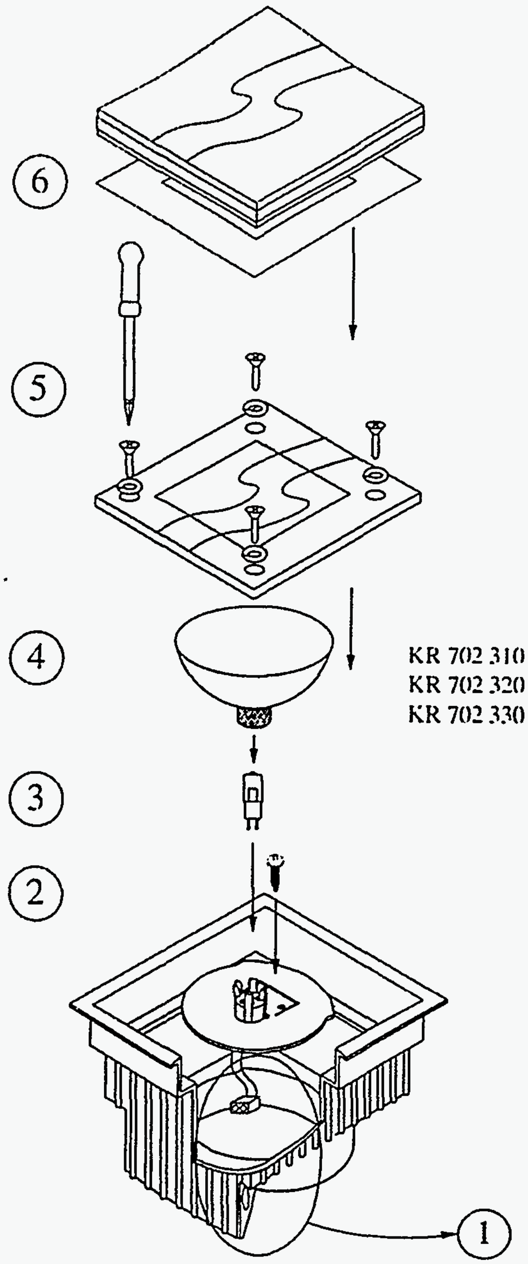
Each fixture will have a dimming unit so that they can be individually controlled. The ambient lighting system will receive information from the illuminance sensors within the space and a single outdoor sensor. These sensors are located as indicated in Figure 4, Appendix A. They will be calibrated according to the illuminances on the workplane. The ambient lighting system will be controlled by Siemens Instabus EIB, a 0-10VDC analog bus line (see section 6). The basic system responses to sensor data is summarized in the table below:

**TABLE 1. System reaction to Sensor Data**

| Illuminance Sensor | Mode of Operation | Ambient Lights |
|---|---|---|
| X < 25 fc | Dimming | On |
| 25 fc < X < 50 fc | Dimming | On |
| X > 50 fc | Switching | Off |

## 4.2 Perimeter Lights

### Technology Description




The lighting system for perimeter lights is called "Flat Up" from Kreon. This fixture is located in the floor between the columns and the facade in each bay. The 145 x 137 x 62 mm fixture is mounted level with the floor. It utilizes a 20W halogen lamp. The typical assembly of this fixture is displayed on the left.

### Intelligent Workplace Implementation

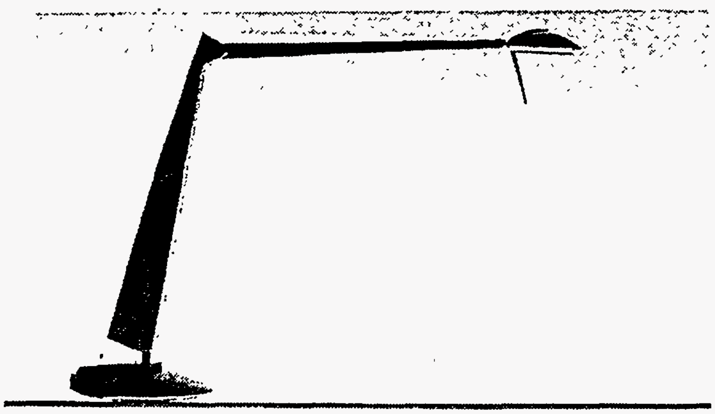
"Flat up" will be installed in between the columns and the facade in each bay. The placing is carefully chosen so that these lights can illuminate the columns. While providing illuminance for the columns to accentuate the structure of the IW, they will also provide lighting to the inside perimeter zone of the IW which receives natural light during the daylight hours. Figure 4.2, Appendix A shows the placement of these fixtures.

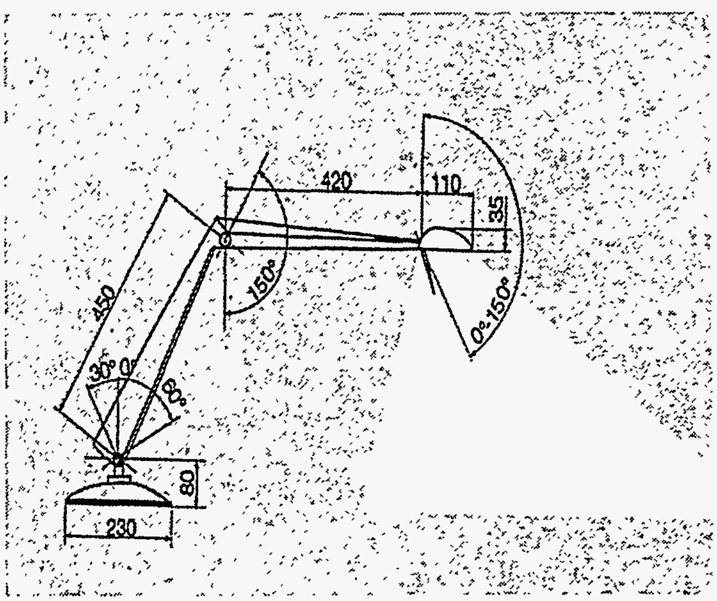
### Control Strategy

The perimeter lights in each bay will be on when there is a person in that bay and when the daylight is no longer available, The system can be scheduled to be activated from dusk until the closing of the IW and then bay by bay according to the occupancy sensors during after hours.The perimeter lighting system will be controlled by Siemens Instabus EIB, a 0-10VDC analog bus line (see section 6).

## 4.3 Task Lights

### Technology Description






The level of illumination on the workplane recommended by IESNA for office lighting is 50 - 70 fc. The ambient lighting system is designed to provide 25 fc on the workplane (2.5 ft. above the floor) at all times, task lights are used to complement the ambient lighting levels when the user deems it necessary. There are two types of task lights both having the same appearance as the task light on the left. in the IW. Both have the same properties in terms of their asymmetric light distribution, adjustable height and angle and removable table top base but one of them uses compact fluorescent lamps and the other halogen lamps. Compact fluorescent lamps are used for their high efficiency and life expectancy and halogen lamps for their color rendering and efficiency in this Intelligent Workplace Implementation

The task lights will be located on workstation surfaces in each workspace. They are relocatable so as to accommodate user needs and current and future organizational layouts.

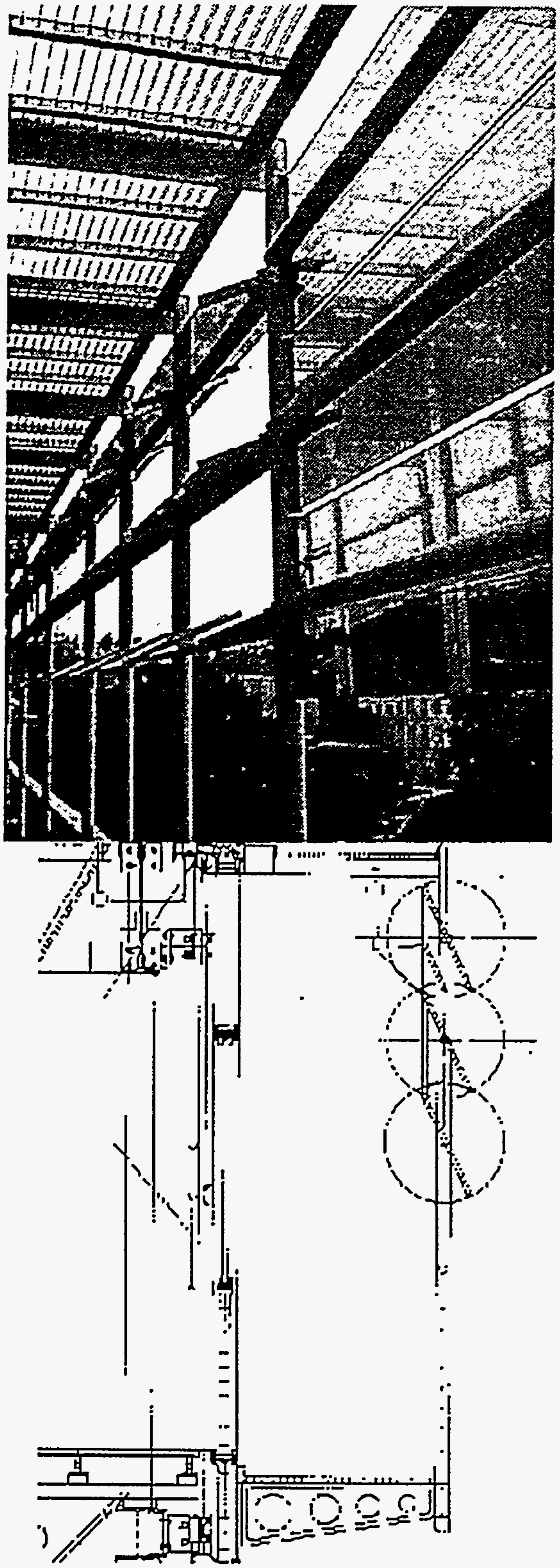
### Control Strategy

In the south zone, the task lights are powered by the task light outlets provided integral with the Personal Environments™ units. The PEMs, equipped with occupancy sensors, turn the task lights on or off based on occupancy status. In the north zone, there will be a strategically placed occupancy sensor in each workspace. The task lights, in this zone, will receive information from these sensors and will be controlled based on the information from these sensors. In addition to the occupancy sensors, the users will have the freedom to turn the lights on or off according to their task requirements. The task lighting system in the north zone will be controlled by Siemens Instabus, a 0-10VDC analog bus line (see section 6).

# 5.0 ENCLOSURE SYSTEMS

## 5.1 Light Redirection Louvers

### Technology Description



Light Redirection Louvres (LRL) are an enclosure technology to enable dynamic control of solar radiation incident on a buildings skin. LRL's allow daylight to be projected deep into the space through the transom while simultaneously minimizing glare near the perimeter at the work surface. The louvres are made of tempered reflective (t=0.14) glass. A motor is used to rotate and position groups of the louvres based on the desired light redirection objectives. The louvers can also be used to effectively shade the building when conditions warrant.

### Intelligent Workplace Implementation

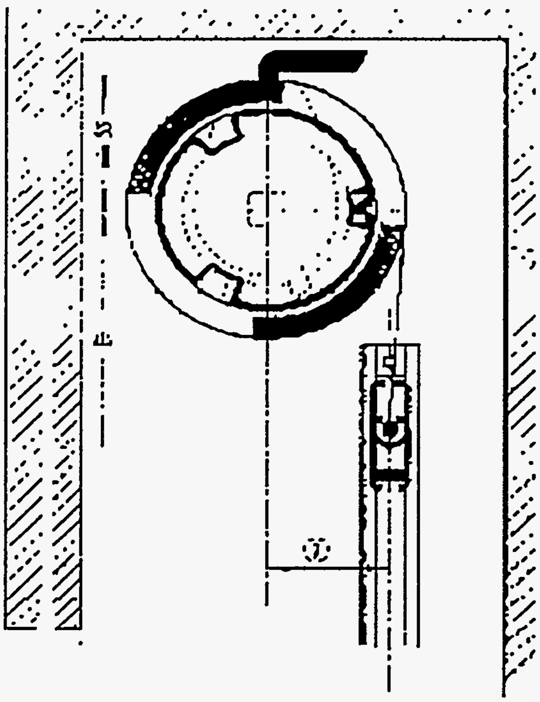
In the Intelligent Workplace, the light redirection louvres are an integrated part of the facade fabricated by the Josef Gartner Company. The LRLs are located on the east, west and south facades (see figure 5.1 in appendix A). They are arranged in modules that are 2.4 m wide, with each module containing three parallel louvres. Each motor controls between 2 and 6 modules. The 2 modules on the south demonstrate integral photovoltaic cells from FLACH-GLAS AG for the generation of electricity .

### Control Strategy:

In the IW, the control of the light redirection louvres is determined by the position of the sun, the extent of cloud cover, indoor thermal conditions, and indoor lighting conditions (illuminance and glare). The primary objective of the control strategy is to provide adequate daylight (ambient illuminance) in the interior, while minimizing glare, and minimizing energy use for lighting, heating and cooling. This multi-objective control strategy will be implemented in two approaches to facilitate a comparative assessment: a deterministic approach using truth tables, and a machine learning approach that utilizes prior building operation patterns to determine the optimal control of the louvres.The LRL's will be controlled by Siemens Instabus EIB, a 0-10VDC analog bus line (see section 6).

## 5.2 Internal Shades

### Technology Description



The shading devices used in the Intelligent Workplace are Krulland Horiso™ rollable fabric shades. When deployed, these shades still allow for outdoor views, while providing glare control, and limited solar control. The shades can be motorized or manually operated.

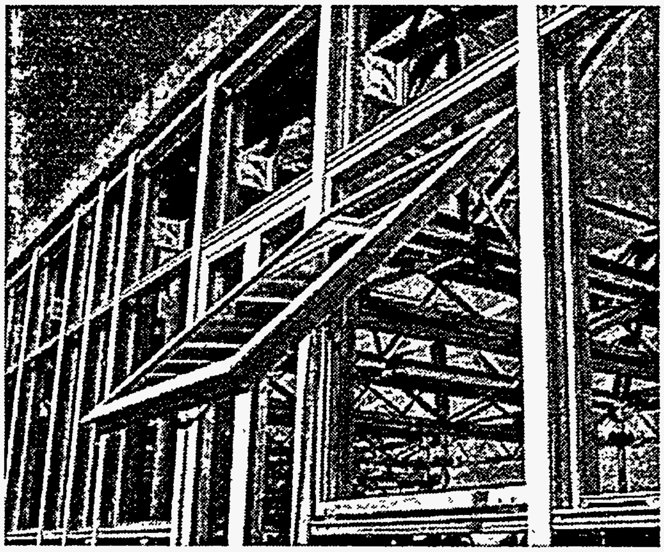
### Intelligent Workplace Implementation

Each facade module in the IW will have a motorized shade. The figure 5.2, Appendix A indicates the mapping of shades to motors, which was designed to provide individual control while minimizing the number of motors required. The section drawing (left) shows the shade roller configuration and guide channels. In the north conference area there will be two shades: a light shade for glare control and a dark "black-out" shade that allows the room to be darkened for presentations. The switches to operate the shade are located on the facade. The shades can be operated by the user or centrally through the Instabus EIB Interface.

### Control Strategy

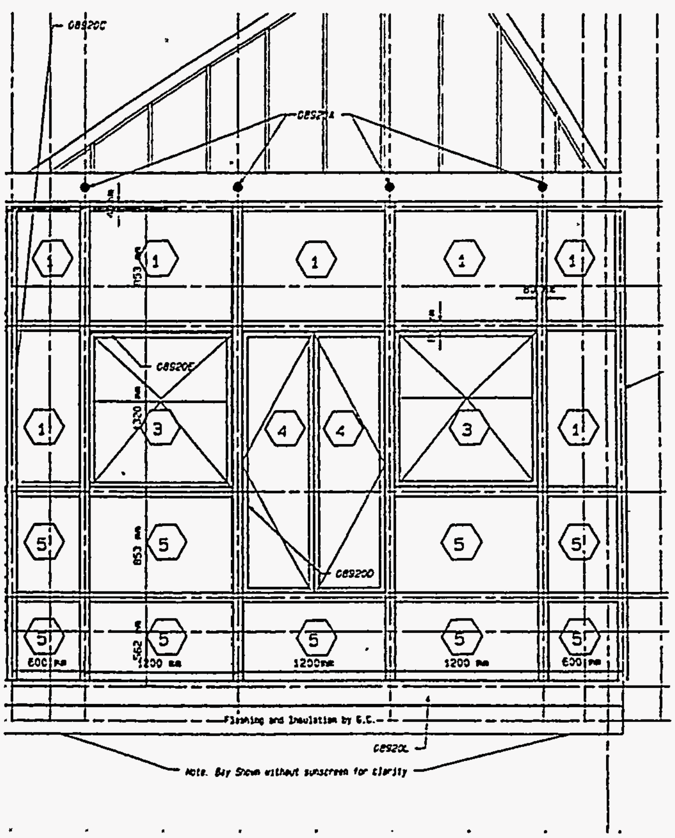
Since the internal shades are primarily for glare control, their deployment is user-driven. However, the shades can also be controlled centrally, to optimize shade operation, or to account for circumstances when users are not in the building. For instance, on winter mornings it may be desirable to have all shades retracted after sunrise to maximize solar gain. If shades have been left deployed from the previous day, the central control can then be used to retract all shades. The occupants can then deploy them based on individual glare control requirements. The interior shade system will be controlled by Siemens Instabus.(see section 6).

## 5.3 Operable Windows



### Technology Description

The operable window technology used in the Intelligent Workplace was developed by the Josef Gartner Company as an integral part of a modular facade. The window is connected to the vertical mullions on each side with drop pivots, such that the operable unit slides down and pivots out when it is opened, as shown in the picture on the left, taken during construction. The resulting opening configuration (upper and lower openings) provides a more effective air flow pattern in the space than standard casement or double-hung windows. This construction also allows the windows to be left partially open during rain. The operable units are thermally broken, as is the whole facade.



### Intelligent Workplace Implementation

In the Intelligent Workplace, there are two operable units per bay of the facade (see figure 5.3, Appendix A), as well as double in–swinging doors that provide access to the catwalk, as shown in the facade drawing on the left (windows are marked 5, and doors 4).

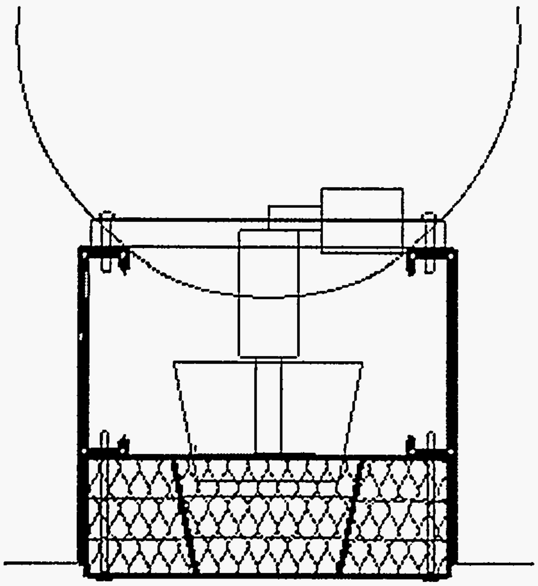
### Control Strategy

The operable windows in the Intelligent workplace are controlled by the users, with appropriate control interfaces to mechanical systems. Each window has a contact switch to indicate if it is open or closed. Whenever a window is opened, the mechanical conditioning in that area is shut off. The assumption is that the open windows adequately provide both ventilation and thermal conditioning needs. Accordingly, when the windows are closed, the mechanical conditioning for the space can be activated.

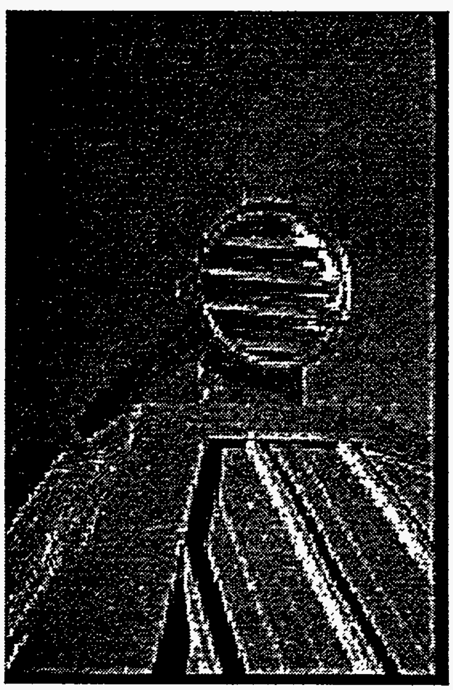
In order to improve the control of operable windows, it is anticipated that the control system will inform the users as to whether it is appropriate or inappropriate to open the windows for natural ventilation. The system will determine this based on the outdoor temperature, humidity, wind and precipitation conditions, and indoor thermal loads.

## 5.4 Overhead Ventilators

### Technology Description



*Motorized Damper and Insulation*



#### Technology

Overhead ventilators are used to create stack effect to assist in the natural ventilation of air. They are always placed near the roof so they can effectively vent out the hot air which has a natural tendency to rise upwards. The efficiency of overhead ventilators can be further increased by equipping them with mechanical fans.

#### IW Implementation

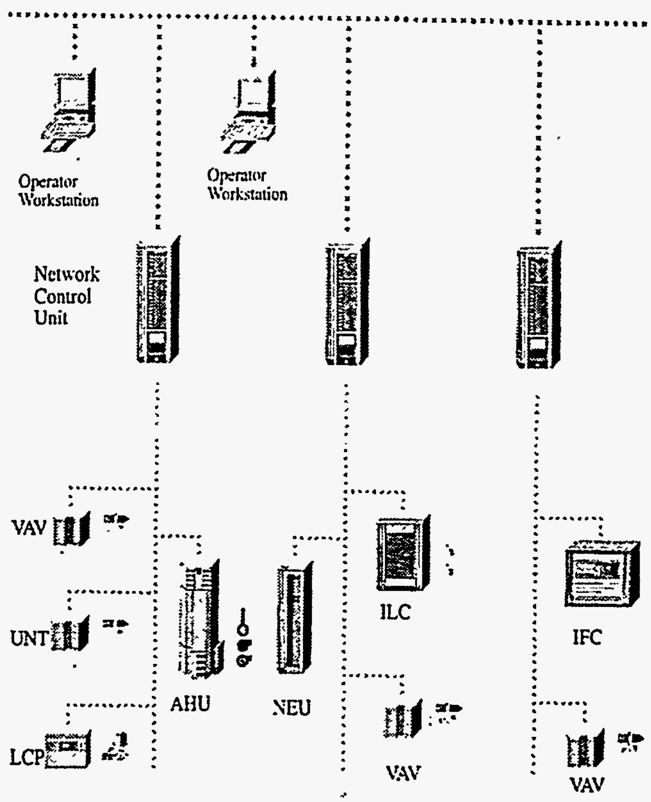
In the Intelligent Workplace, overhead ventilators have been placed on all 9 bays at the eastern and the western end. The radius of each overhead ventilator is 10.5" which should be enough to exhaust all the indoor contaminants in the worst circumstances. Overhead ventilators are an integral part of Intelligent Workplace's strategy to maintain excellent indoor air quality (IAQ) in tandem with the Johnson Control's PEMs and the LTG displacement ventilation system. Under optimal outdoor conditions, overhead ventilators will result in substantial energy savings because of its ability to run the IW in a passive mode.

#### Control Strategy

In the IW, the control of overhead ventilators will be coupled with the overall control of HVAC system. However, the overhead ventilators will be most effective in situations when the outdoor conditions (air temperature and relative humidity) are ideal for turning off the HVAC system. Under such passive conditions, fan assisted overhead ventilators can make use of stack effect and displacement ventilation to maintain comfortable conditions inside the IntelligentWorkplace. The overall control strategy will be governed by the outdoor thermal conditions, thermal comfort of occupants and the energy savings that can be accomplished by the various control options.

# 6.0 INTEGRATED CONTROLS

The integrated control system of the Intelligent Workplace includes the control of the aforementioned systems and their components. In order to achieve integrated control of the environmental systems in the IW, three commercially available systems will be initially installed; Johnson Control's Metasys™, Siemens' Instabus, and Zumtoble's Luxmate. In this section, each of these control systems and their integration will be summarized.

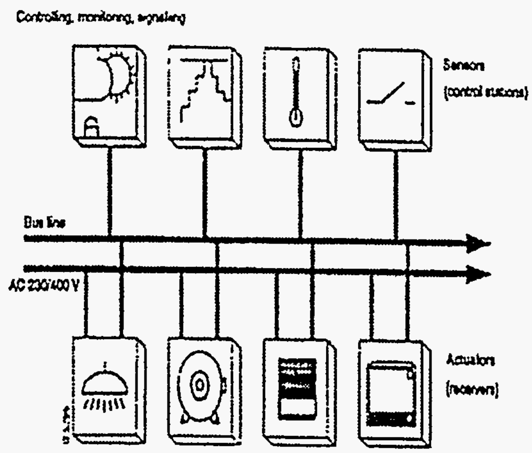



- JC Metasys™: This is a distributed system that allows for the collection and monitoring of data from sensors, management of the information collected and monitored, and the control of each of the components. Each component (i.e. desiccant wheels, PEM's, etc.) is controlled by an application specific controllers (ASC's).These communicate with each other through a subnetwork called Optomux. The information from the ASC's propagate through the Optomux and are gathered in network control units (NCU's). NCU's communicate with each other and with operator workstation through ARCNET which operates at 2.5Mbaud over coaxial, twisted pair or fiberoptic cable. (The iW implementation will utilize Ethernet over CAT 5 cabling.) Metasys' network architecture is indicated in the figure to the right.
  JCI, AMP and the CBPD have used the IW as an opportunity to explore issues related to unifying the cabling of data, voice and control networks. Unification will allow: a single contractor to be responsible for the installation of data, voice and control networks thereby reducing price and increasing quality; would allow a sole source manufacturer to guarantee the cabling infrastructure; and would facilitate comprehensive management of the cabling infrastructure from the building occupant's perspective.

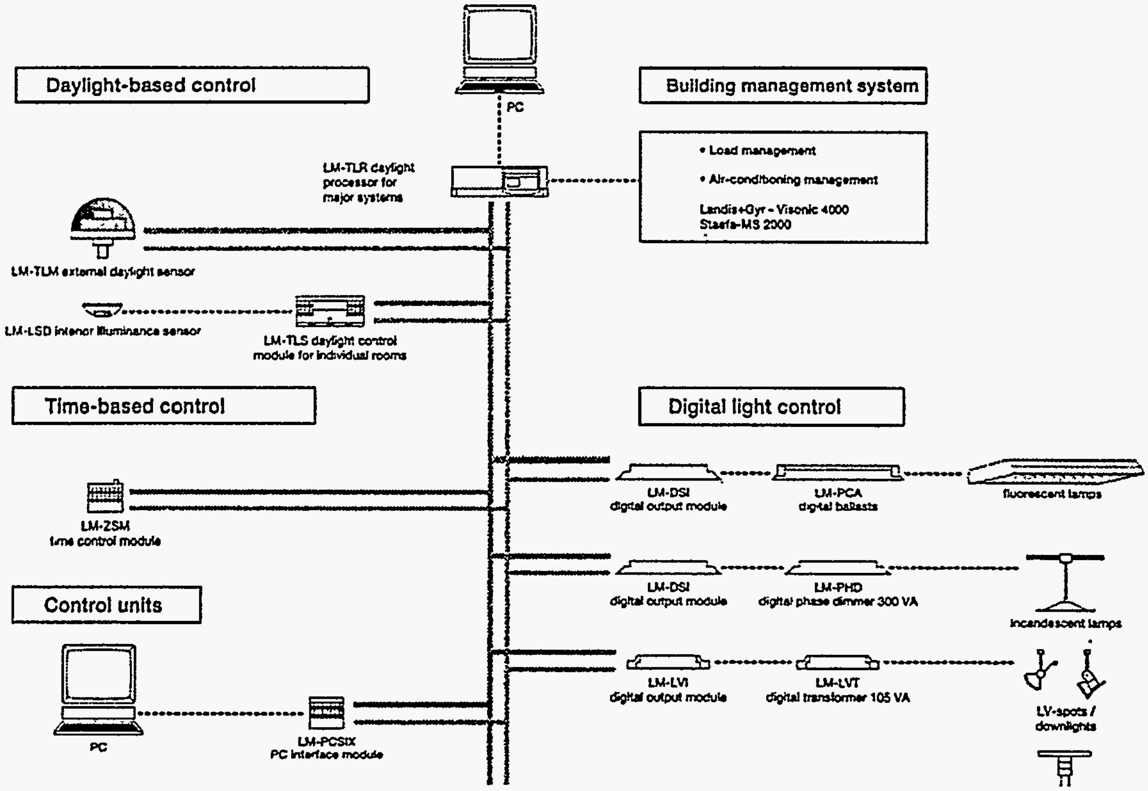
- The cabling infrastructure that was designed for implementation in the IW is indicated in figures 6.1, 6.2 and 6.3, Appendix A. The Main Data Frame (MDF) houses active electronics which connect the IW to the campus infrastructure. Parallel patch panels connect the horizontal distribution system to the active electronics. The horizontal system utilizes consolidation zones to simplify the installation, reduce costs, facilitate flexibility and improve cable management. AMP will fabricate six-user consolidation points for the data/ voice system. In addition to the copper data link, AMP will demonstrate optical cable to the desk. Therefore from the MDF to the consolidation point, there will be 1 twelve strand optical cable and 12 four pair CAT 5 cables for data and 1 twenty five pair CAT 5 cable for voice. Each consolidation point will service a maximum of six users through the AMP Access Floor Workstation Module (AFWM). The five gang AFWM will contain three duplex outlets, a single face plate with four RJ45 connections, and a faceplate for an optical connection. Two RJ45's will be for data, one RJ45 for voice and a spare RJ45 is available for control wiring, such as the N2 bus line for the PEMs. The control wiring follows a similar concept of consolidation point boxes.
  JCI, AMP and the CBPD will research two different methods of control cabling in the IW - the first, for the PEMs, will support homeruns to the Metasys™ NCU with parallel patch panels at the MDF used to

configure the daisy chain and the second, for the other ASCs, will support daisy chaining in the control consolidation box to achive further reductions in cabling quantities.
JCI Metasys™ will actively control MUA #1 and MUA#2, associated dampers, water flow mullions, the Coolwave™ and the radiant cooling ceiling. Metasys™ will collect data from the PEMs, Instabus™ and from the array of diagnostic sensors throughout the facility.

- Siemens Instabus: Instabus is a 0-10 Volt DC analog bus line that allows the devices attached to it to communicate with each other. Each device connected to this busline has a bus coupling unit (BCU) that has a unique address, which provides flexibility for the system. Each device depending on the type can collect information from and/or actuate other devices. All devices can be grouped or ungrouped through the EIB software interface. The Instabus implementation in the IW will be for the control of the lighting system. An N2 bus interface card was developed in Europe and will be utilized in the IW for the integration of Instabus and Metasys. The Metasys™ Operator Workstation (OWS) will run the EIB software in a separate window. The Instabus hardware including BCU, DIN rails and power supply will be located adjacent to the Metasys equipment. From the four DIN rails, four bus lines, each with a 64-component capacity, will extend throughout the IW. Bus lines in the floor plenum will control the perimeter uplights, and bus lines in the ceiling cable trays will control the Zumtobel luminaires, light redirection louvers, shade motors and door/ window sensors. The large device capacity (64 devices x 4 bus lines) is designed to facilitate the controls research. Siemens is exploring the fabrication of consolidation boxes for Instabus which will combine low voltage devices with line voltage connections in a rated assembly to facilitate installation and plug and play operation.




- Zumtobel Luxmate™: Luxmate™ is a digital lighting control system with a 0-15 Volt DC digital bus line and a proprietary communication protocol. The network architecture has three layers: the management layer, the automation layer and the field layer. The management layer contains the sky scanner the system PC and the main touch panel. The automation layer contains the daylight computer and interfaces to the JCI OWS. The field layer contains the luminaires, the shades and the user controllers (hard wired or infra-red). A wire bus line(s) connects digital control devices that can be integrally mounted in each luminaire. The system is an open loop control system that allows an outdoor light sensor to individually control luminaires in response to daylight conditions. This requires an intial calibration for each ballast/ digital device, then during use, the system interpolates between the dark and light points. The individual digital controls allow the creation and storage of "scenes", special lighting effects which restore some of the dynamic qualities associated with daylight to the electrical lighting system.
Zumtobel will retrofit the analog luminaires digital ballasts and devices and intall the Luxmate™ system after the initial period of occupancy for the IW, so that performance and integration comparisons with the Instabus lighting control system can be made.




## 6.1 Control Plan

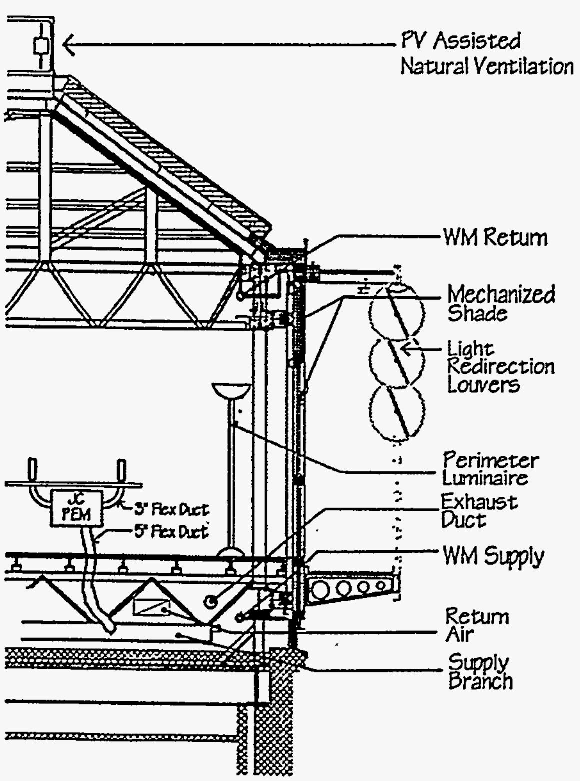
JCI Metasys™ will be the primary building control and data collection/ storage system for the IW. The research objectives for the IW explicitly include exploration of alternative control technologies, as well as their integration issues. As of the date of this report, Siemens Instabus™ and Zumtobel Luxmate™ are two member company technologies that will be installed and tested in the IW. JCI Metasys™ will control the basic HVAC systems and collect/ store data from the diagnostic sensors arrayed throughout the IW. The lighting system will initially be controlled by Instabus™. The ambient lighting system deploys 106 luminaires. These luminaires, provided by Zumtobel, will house analog ballasts and bus coupling units for Instabus and digital ballasts and DSI's for LUXMATE. Figure 6.1, Appendix A shows the typical implementation and integration of these systems. Metasys™ and Instabus will be sharing the same operator work station and communicating through a commercially available N2 interface card. The control/ data collection system will be used to validate the control algorithms and to establish baseline performance metrics.

## 6.2 Control Interfaces

As the systems are individually designed and developed in the absence of universally accepted industry standards, just installing systems from different vendors does not ensure an integrated systems environment. For example, an HVAC system and a lighting system may be optimal and modular but they may be spatially and functionally incompatible.

The interactions of the systems and their effect on each other must be carefully considered in order to provide satisfactory environments for the users as well as cost effectiveness for the operators. The cross over points of the three major systems in the Intelligent Workplace are described below:

- Enclosure and Mechanical System Integration: The enclosure from its glazing type to its external devices, has immense implications on the loads for the mechanical system. It can lessen or heighten the effect of the conditions of the external environment on the internal environment. In the IW a dynamic facade is utilized to actively create a comfortable environment for the occupants . The light redirection louvers can cut off the heat from the sun as well as allowing deep penetration of daylight to the benefit of the occupants inside the building.
- Enclosure and Lighting System Integration: The enclosure has a direct effect on the energy implications of the electrical systems. The daylight that penetrates into the building does not necessarily ensure the required quality and quantity of light at the location where it is needed. The enclosure in the Intelligent Workplace not only has static measures for allowing daylight to penetrate into the space but it also has dynamic measures for actively mitigating the varying daylight conditions and providing the required quality of light for the occupants. Light redirection louvers are designed to reject heat gain in the summer and internal shades address the possible glare problem.
- Mechanical and Lighting System Integration: Lighting loads are one of the most dominant loads in the buildings. The electricity that is provided to run these systems is ultimately converted to heat. Providing the appropriate conditions for lamps and luminaires can greatly affect their efficiency. The full benefits of integrating HVAC system with the lighting systems are: improved performance of air conditioning system, efficient handling of heat produced by the lighting, and efficient lamp performance. The degree of benefits depend upon the quantity of energy involved and the effectiveness of integration.



## 6.3 Diagnostics Equipment

In addition to the sensors and actuators that will be installed for the operation of the control system, a wide variety of instruments to measure visual, thermal, air and acoustical quality will be purchased and deployed with the grant received from National Science Foundation.

There will be 12 illuminance sensors placed on a grid throughout the IW as shown in figure 7.1, Appendix A. A grid of CO2 sensors will be initially located as shown in figure 7.2, Appendix A. The data collected from these sensors will be used to assess the effectiveness of the building control systems.

In addition to these instruments, portable diagnostics equipment (a list of the instruments is included in Appendix A) and a complete wether station will be used to collect environmental data and to assess the effectiveness of the control system.

## 6.4 Intelligent Controls

Control Architecture: The successful integration of control hardware and software is a crucial issue especially in Intelligent Workplace. Considering the diversity of control components, making interfaces among different control components based on the open architecture scheme is a challenge itself in both design and implementation phases. Different communication protocols and control bus structures should be successfully interfaced and integrated. For example, Johnson Control's METASYS and Siemens's EIB have their own protocols and bus architecture. To integrate those control components developed by multiple manufacturers, interfaces among different control systems(or subsystems) must be properly developed. These interfaces could rely on certain software design patterns to enable flexible additions or replacements of new control components while maintaining the original control system architecture. Recently introduced bridge and adapter patterns in software engineering shed light on this problem. Especially, a bridge pattern is useful when a control component is incomplete or unavailable thus multiple implementations under the same interface are needed. As was specified in the OWL project, the sensor interface is implemented as stub code, file system, or sensor driver. The Light Redirection Louvers (LRL) interface also could be implemented by stubbing it out, a simple file defining quantified inputs and outputs , or by being connected to the actual LRL driver. The more important pattern in IW control software is an adapter. Adapter can be used for wrap up existing control system interfaces provided by different vendors. Making those legacy APIs (Application Programming Interface) the integrated parts of a new control system is possible by adapters. For example, if the PEM interface is to be integrated to the entire IW control system, the PEM adapter could be codified to wrap up existing PEM interface. Clients of the IW control system can be connected to this adapter to activate the control services the original PEM interface used to provide. The actual vendor specific APIs could be hidden from the clients while the entire control system is organized under a unified development environment.

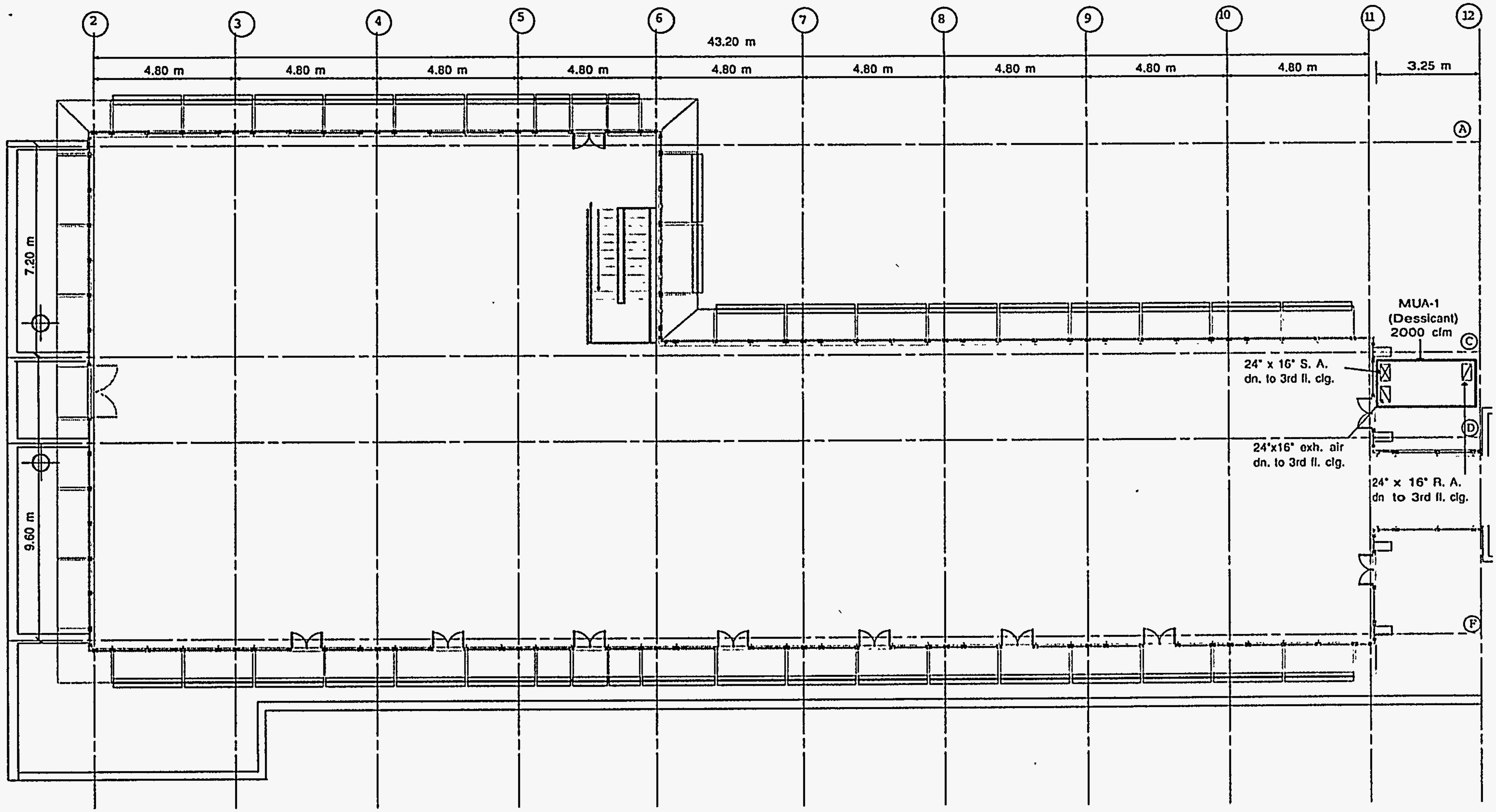
The control interface is one of the important issues demanding a careful design and implementation. Multi-modality and remote control could be the major issues in control interface design and implementation. In the OWL project, multi-modal control interface was suggested to extend the modes of inputs and outputs between the users and the control system. This multi-modality is supposed to handle various types of input and output modes such as text, icons, menus, voice, or tactile stimuli. Most of current control interfaces available have GUI (Graphic User Interface) features. Icons, menus, windows, and other visual components have been typical elements for the interaction between the users and the computers. For building control, only a few people could access the control interface in conventional way of building operation. Emerging innovations in user-based control scheme demand that the extended group of people should be able to access the control interface even at remote locations. For this reason, multi-modality in building control interface is becoming more and more important. This new control interface scheme might be able to handle diversified user preferences as well as the physical handicaps of some user groups. Suppose a person is visually handicapped. this person can control his/her environment using voice activated commands. A person who has both visual and auditory handicaps still can use tactile mode control interface if such a device is provided. In terms of actual realization of such a multi-modal control interface, a couple of distinctive interface design schemes can be considered. A general approach in this case might be making many-to-one mappings between various modes of input (or output) and a specific control command (or a system response). A user can click switch-on icon from the screen or simply say "switch on" to activate switch_on ( ) method on the control server program. The built-in control API should be able to translate those multiple modes of input into a corresponding control command. This process is totally hidden from the users. The other type of interface design is to make a specific mode of input(or output) process independent from each other. Voice mail and e-mail are the examples in this category. What is internally represented and how it works in either mailing mode are totally distinctive throughout the overall processes even though both of them can handle the same asynchronous communications. This type of user interface design is not likely to be the major approach in IW control interface design and implementation multiple input modes translated control command system actuation Remote monitoring and control is another issue in IW control interface design and implementation. IR(Infra-Red) switch is already available for increasing mobility within a limited distance. A truly location independent monitoring and control of building systems could be done by using web technology. In the OWL project this new control interface scenario has been implemented and tested with JAVA based distributed computing technology. Ideally, facility manager or any other authorized user can activate specific building system function(s) from any place with any type of computer platform. Setting security and increasing the speed of error-free data transfer are the major technical challenges for this type of control interface design.

Control intelligence is the core of control software which is responsible for generating control decisions based on the measured or predicted environmental parameters. In scheduled control, the control decisions are predefined according to the seasonal and daily changes of environmental conditions impacting individual or globally optimized behaviors of the systems in a building. Therefore, the knowledge necessary for establishing a system schedule must be gained through a careful consideration on the interactions between predicted environmental changes and the impacts of the pertinent system behaviors. On the other hand, This deterministic approach is not flexible enough especially when dealing with dynamic and uncertain fluctuations of environmental factors. For example, daily weather conditions might vary even beyond weather forecast Scheduled settings of certain systems could be wrong in this case. Interactive control scheme is the solution for most of building system operations for this reason. PID controller or machine learning controller keeps interacting with the dynamic changes in environmental factors as well as the other control parameters to come up with appropriate control decisions. Some control algorithms are developed specifically for predicting and adapting to the dynamic or uncertain conditions. In IW, adaptive controllers using neural network or statistical technique is supposed to play a major role in either localized systems control or in the global control scheme. Control intelligence in the IW will mostly reside in this type of control scheme. For example, dimming and HVAC control could be guided by a well designed and implemented neural network controller to maximize occupants' comfort and to minimize energy consumption at the same time. User-based control scheme is another way of building operation. A PEM unit is supposed to be controlled by an occupant based on his/her preference in immediate physical environment. The major advantage of this control scheme is that it allows maximized satisfaction of individual occupant because most of control decisions are to be made by a specific person. The potential conflict between user controls and the globally optimized control should be resolved in more intelligent way. Those three types of control schemes such as scheduled control, interactive control, and user-based control might be working together to come up with an efficient and effective system control in the IW.

# APPENDIX A

# FIGURES

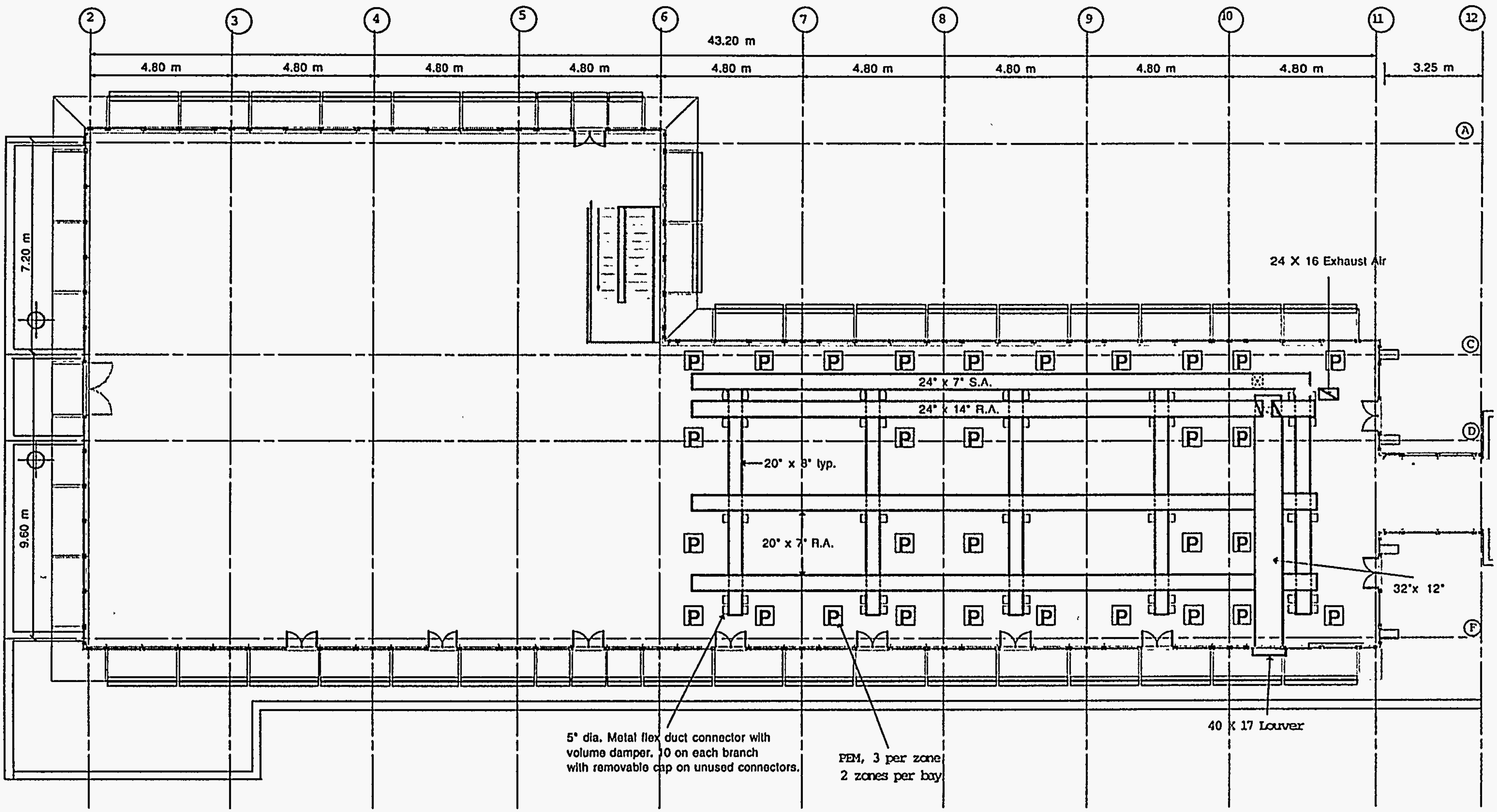
## LIST OF DIAGNOSTICS EQUIPMENT




**INTELLIGENT WORKPLACE CONTROLS**

Scale: 1:200 18 June 1997 N

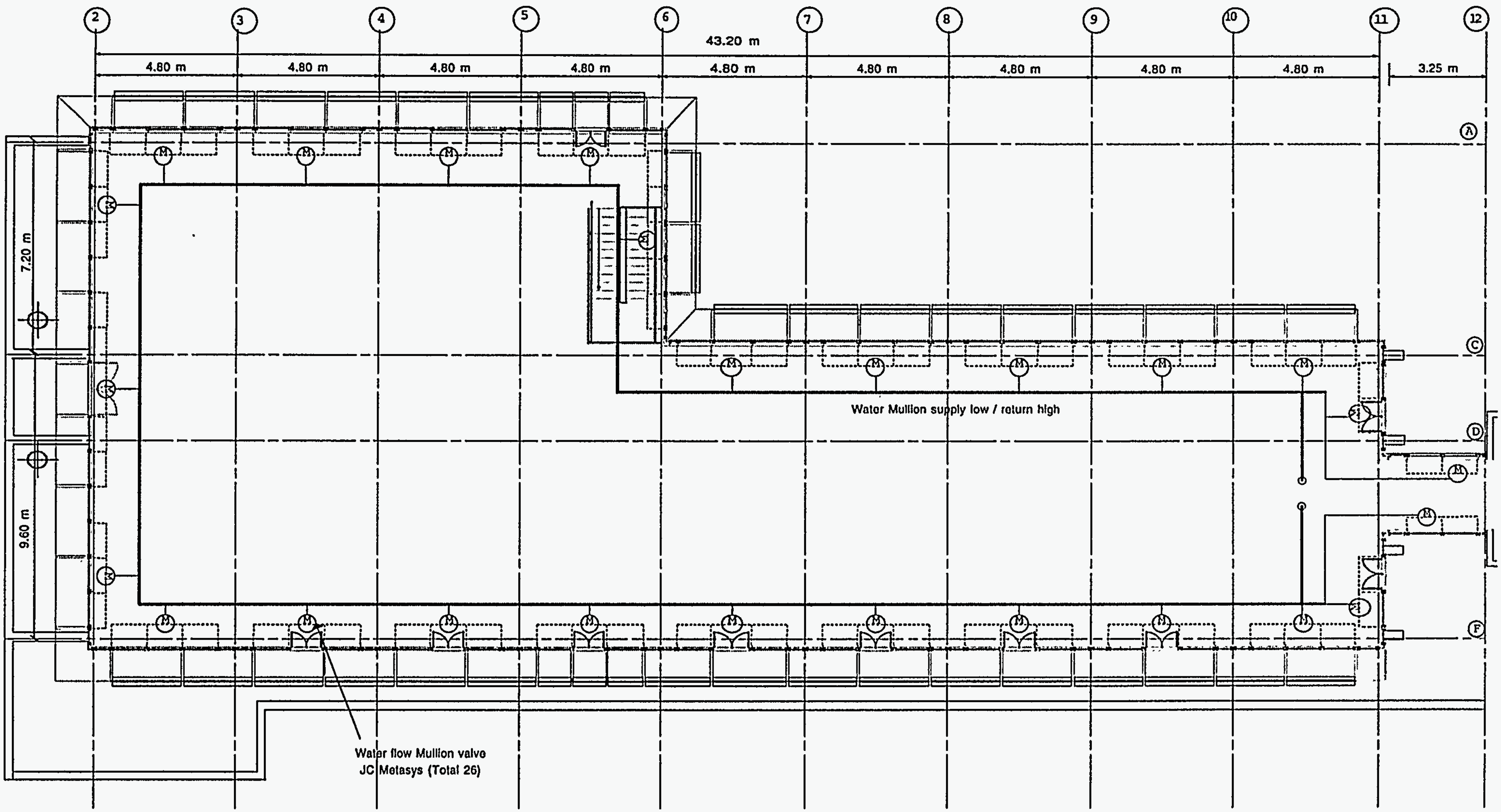
3.1 Desiccant Air Handling Scheme




**INTELLIGENT WORKPLACE CONTROLS**

Scale: 1:200　　18 June 1997　　N

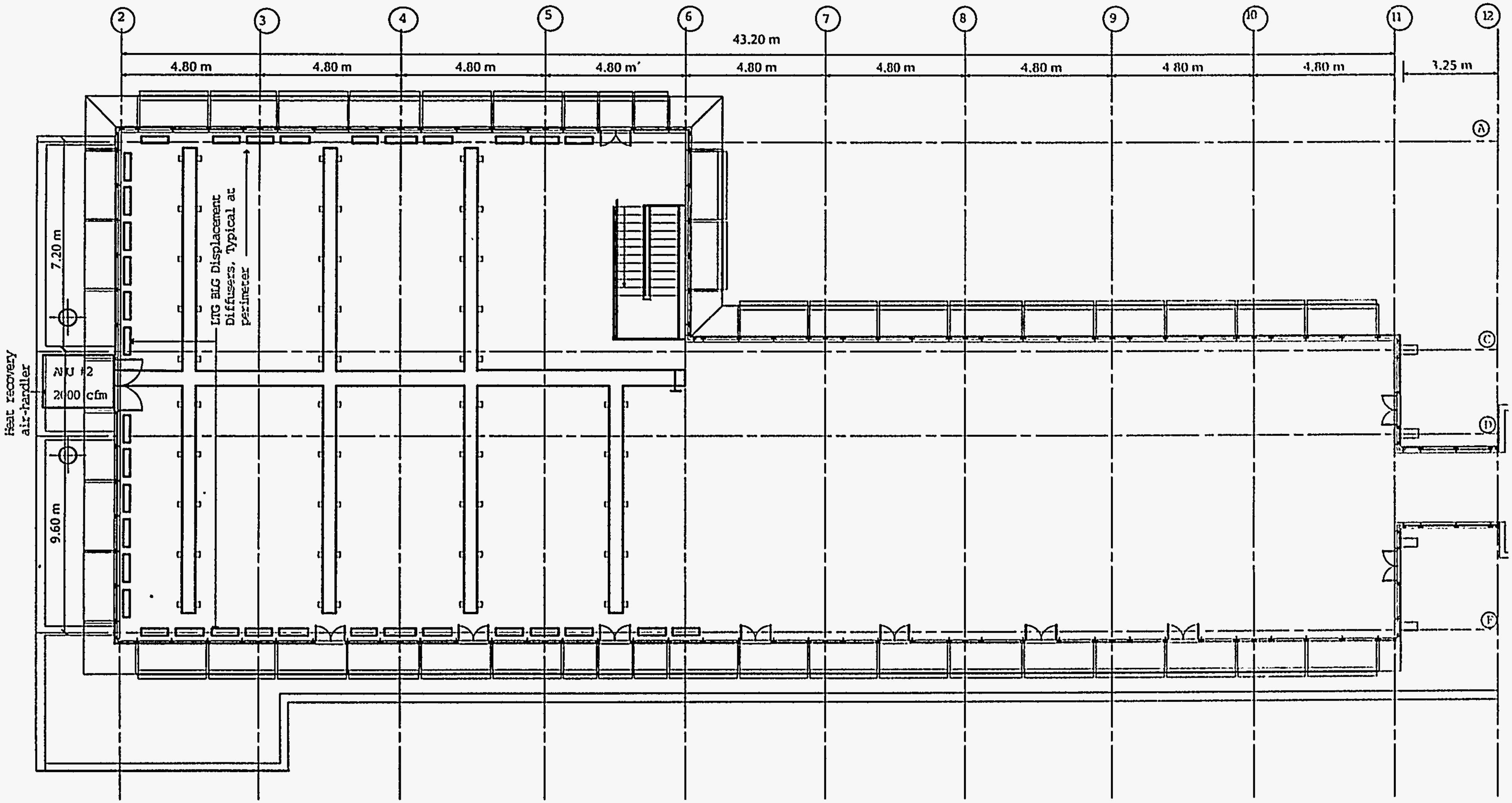
3.2. Personal Environments Placement Scheme




**INTELLIGENT WORKPLACE CONTROLS**

Scale: 1:200 18 June 1997 N

3.3 Water Mullion Scheme




**INTELLIGENT WORKPLACE CONTROLS**

3.4. DISPLACEMENT VENTILATION SCHEM

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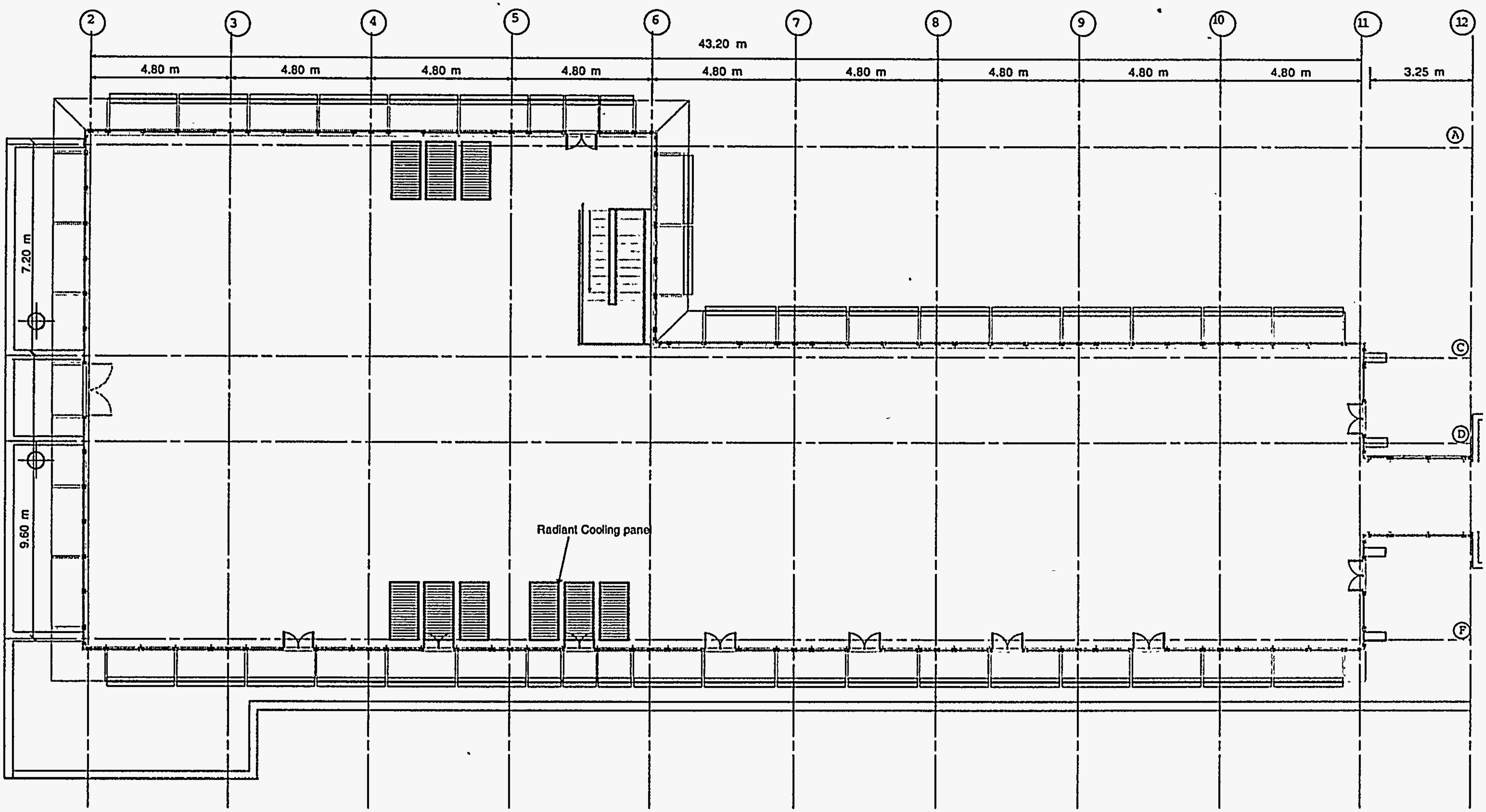
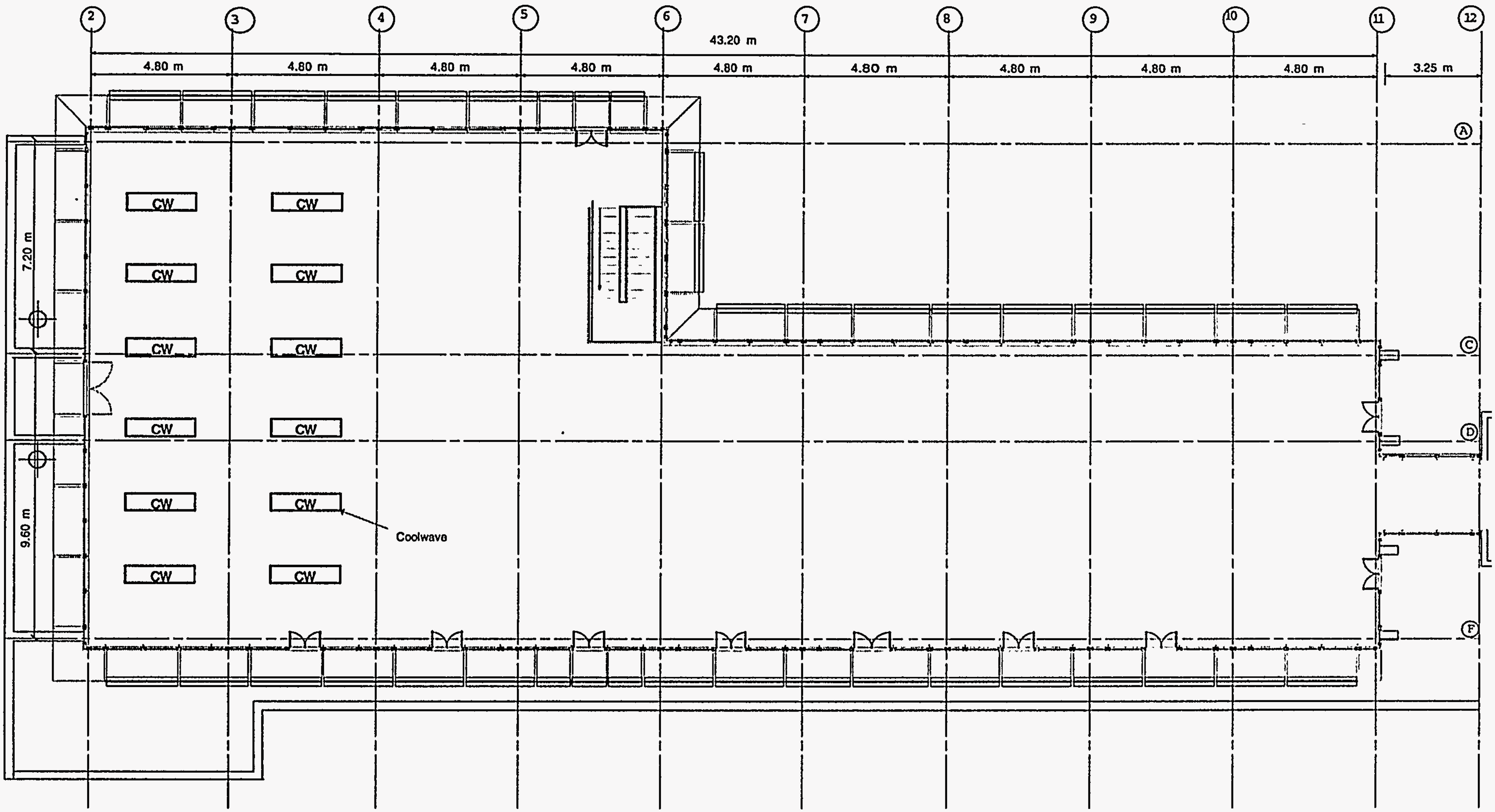



**INTELLIGENT WORKPLACE CONTROLS**

Scale: 1:200 18 June 1997 N

3.5 Radiant Cooling Panels Scheme




**INTELLIGENT WORKPLACE CONTROLS**

3.6 Coolwave Scheme

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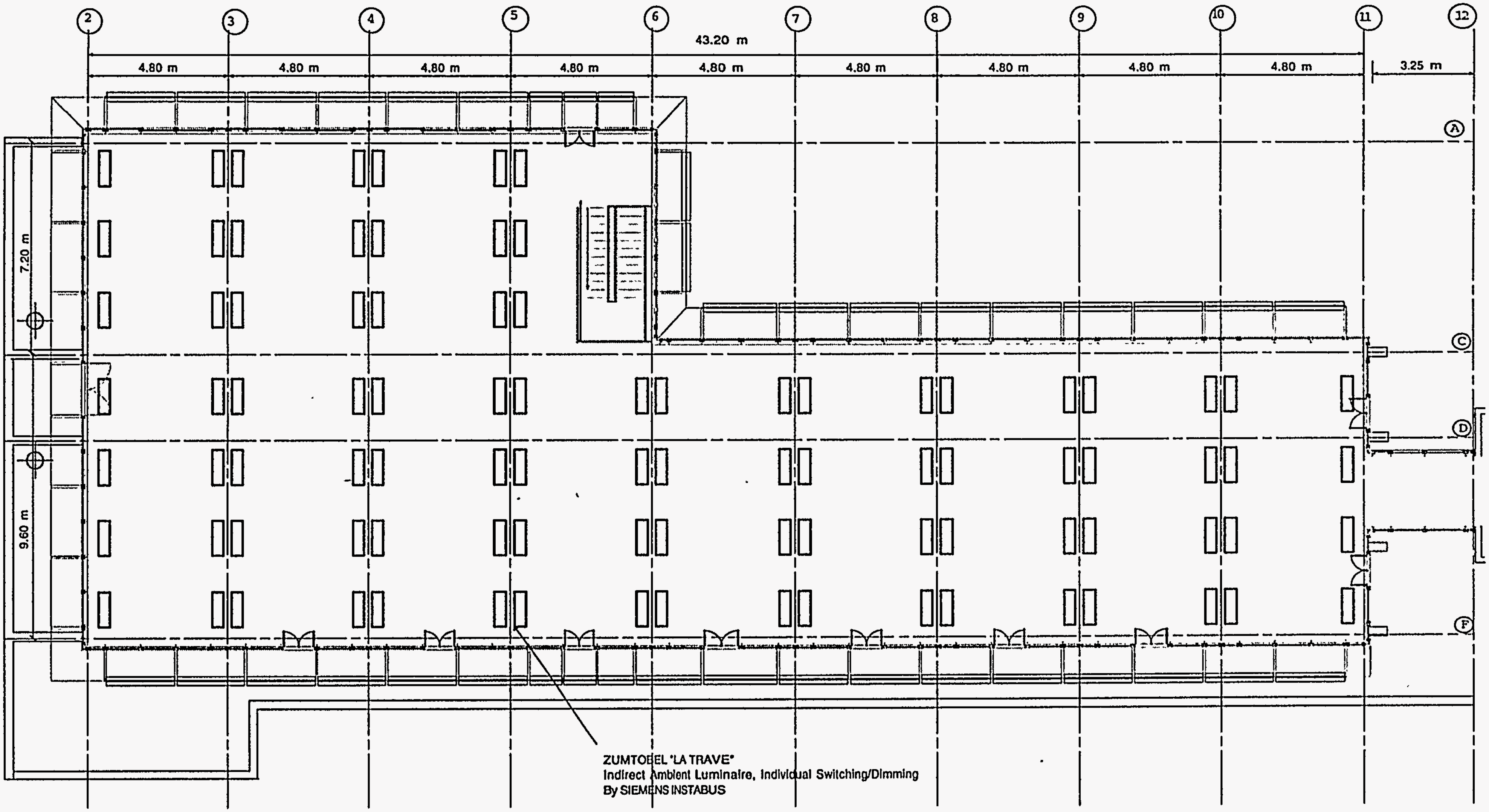
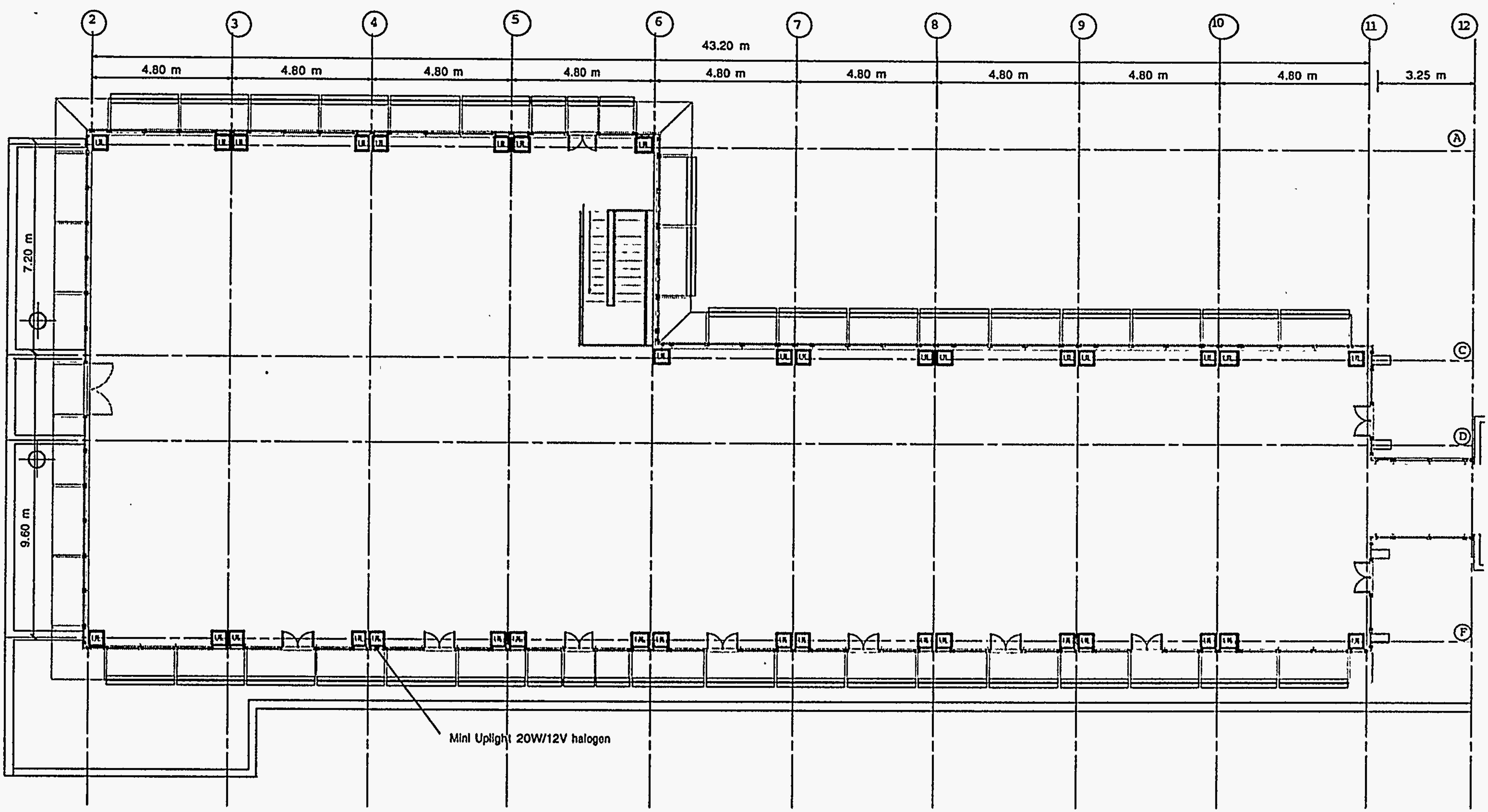



**INTELLIGENT WORKPLACE CONTROLS**

Scale: 1:200 18 June 1997

4.1 Ambient Lighting Scheme




**INTELLIGENT WORKPLACE CONTROLS**

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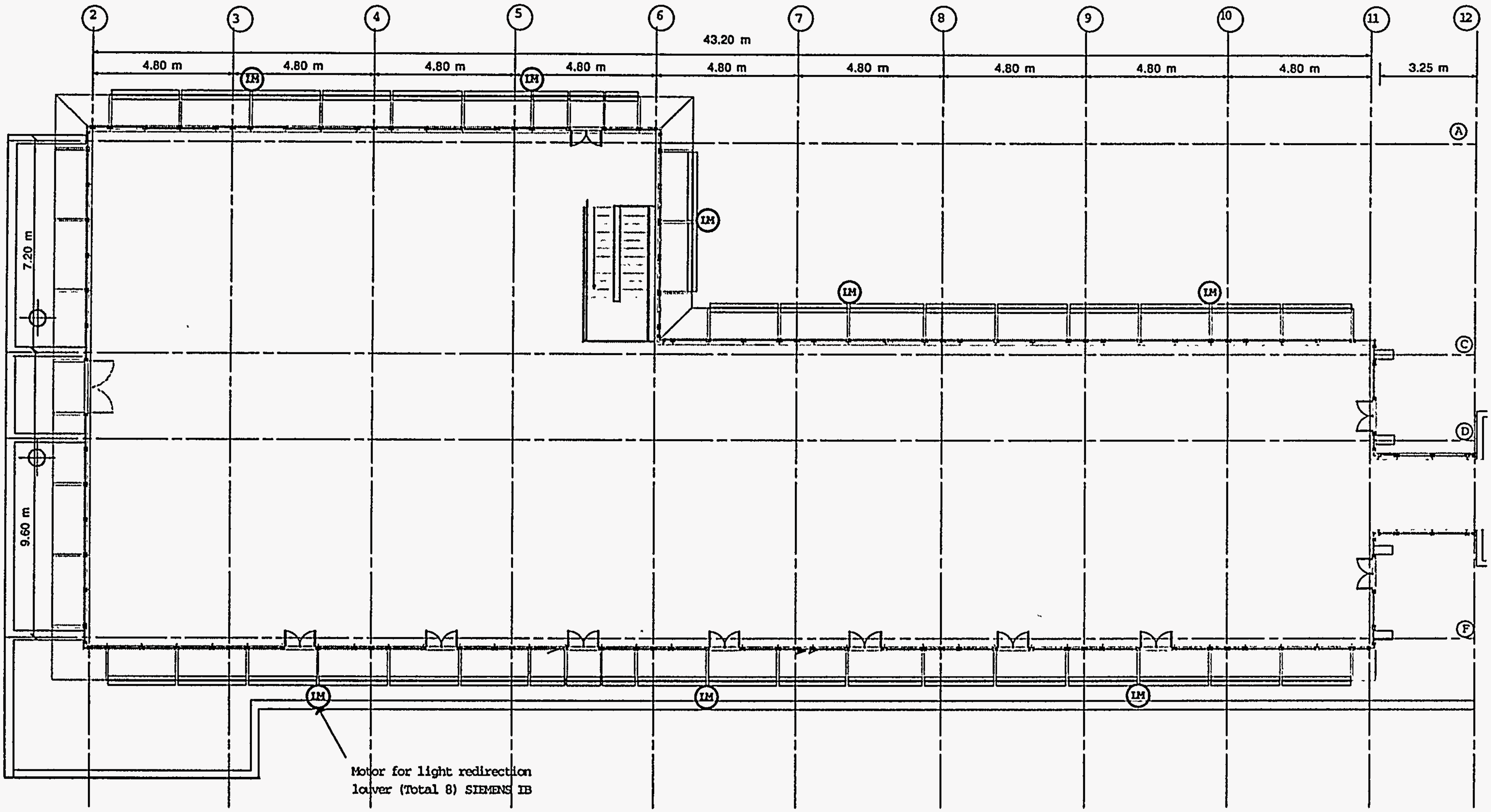
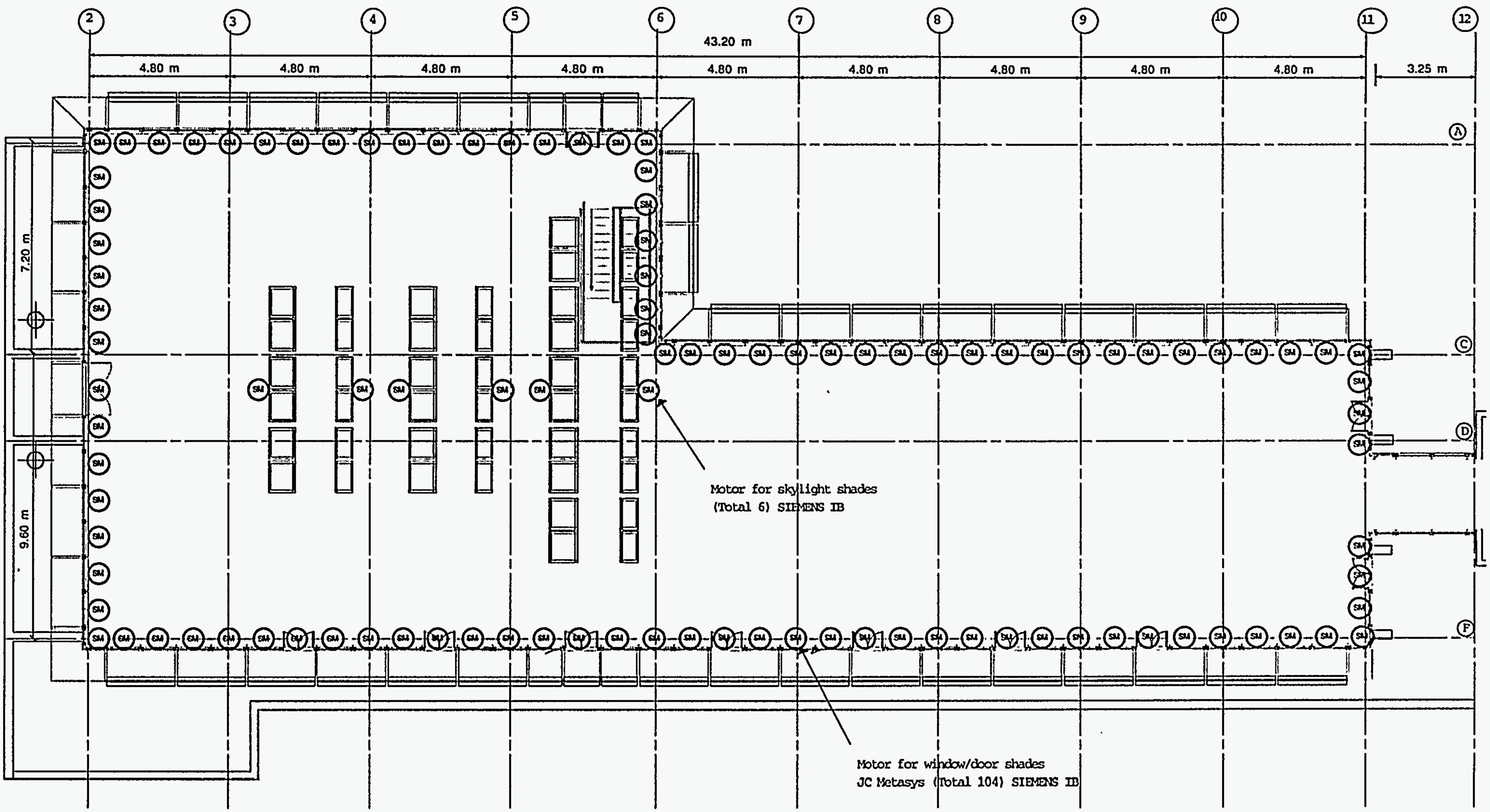
4.2 Perimeter Lighting scheme




**INTELLIGENT WORKPLACE CONTROLS**

Scale: 1:200 18 June 1997 N

5.1 Light Redirection Louvers




**INTELLIGENT WORKPLACE CONTROLS**

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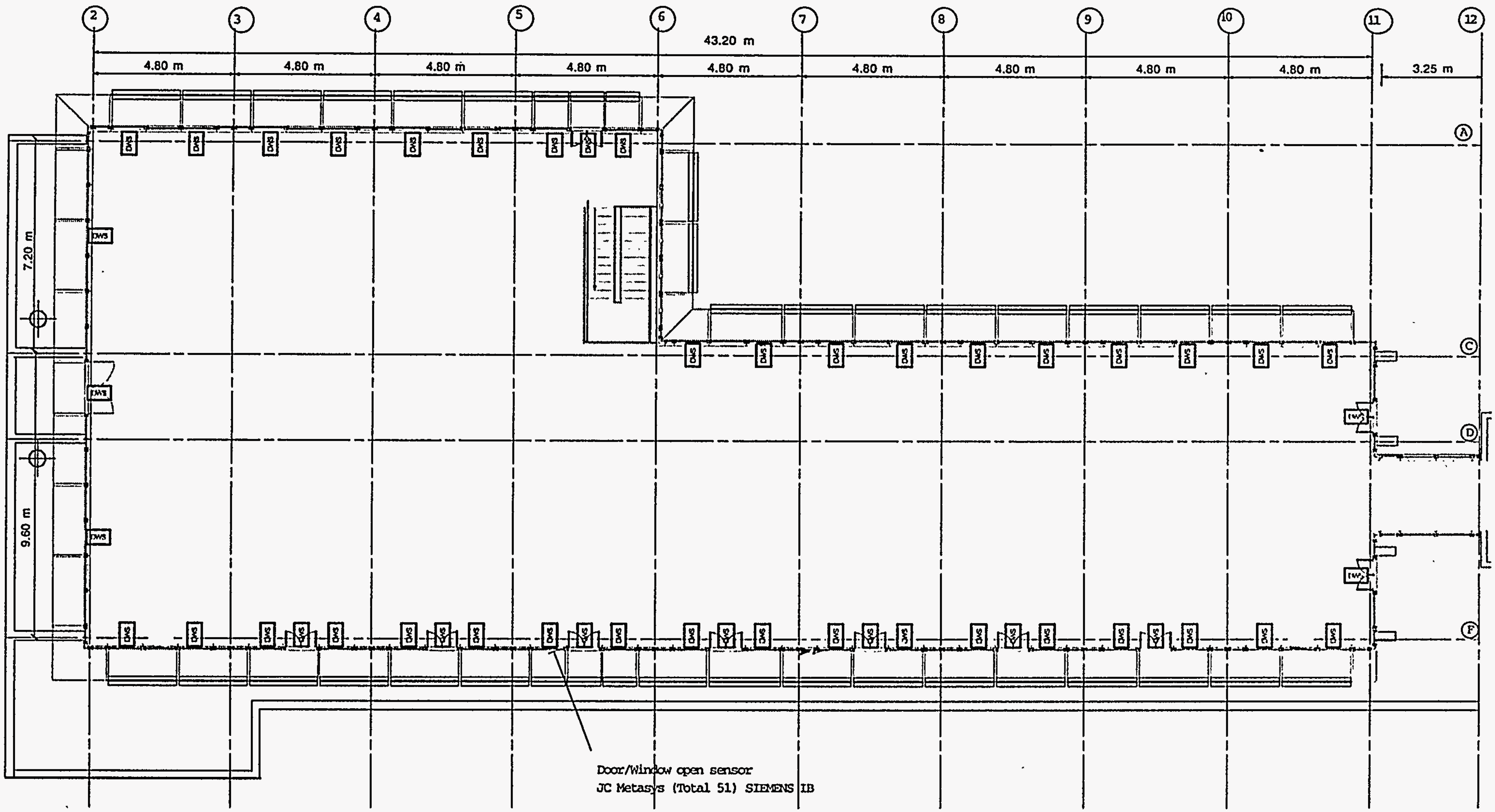
5.2 Motorized Shades Scheme




**INTELLIGENT WORKPLACE CONTROLS**

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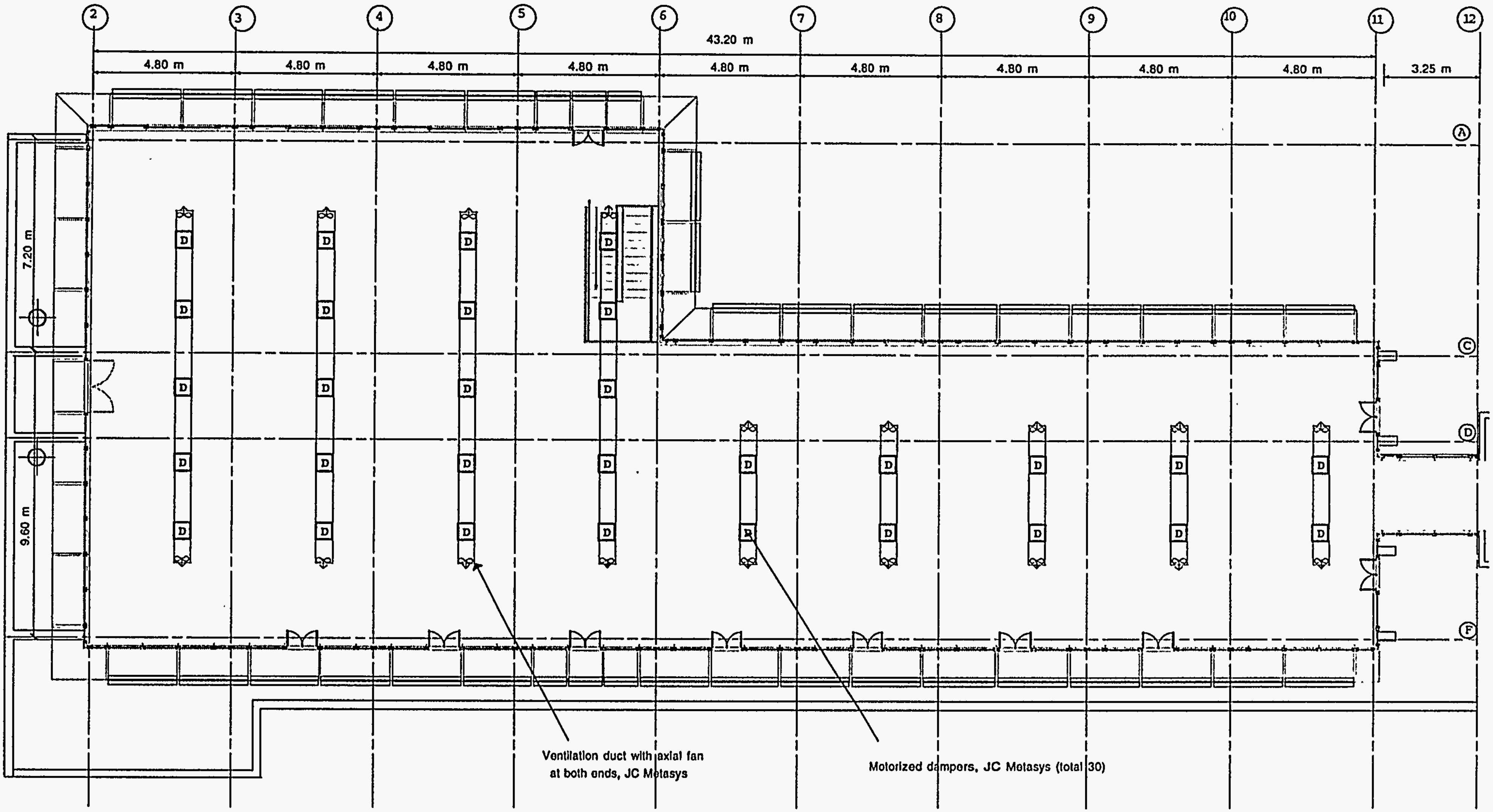
5.3 Operable Door/Window Sensor Scheme




**INTELLIGENT WORKPLACE CONTROLS**

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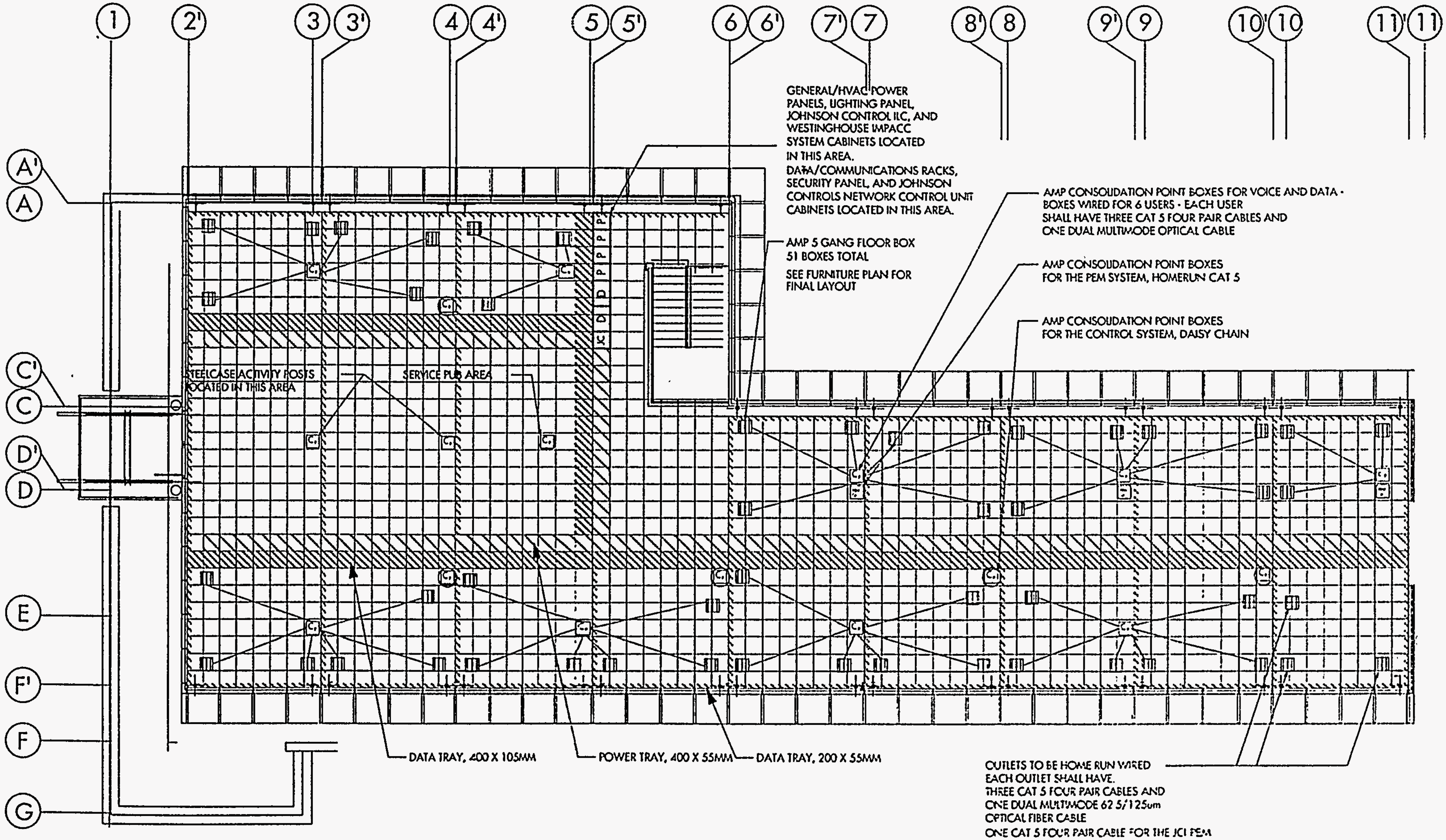
5.4 Ventilation Scheme




DATACOMM/ CONTROL WIRING PLAN

SCALE = 1:200

Figure 6.1

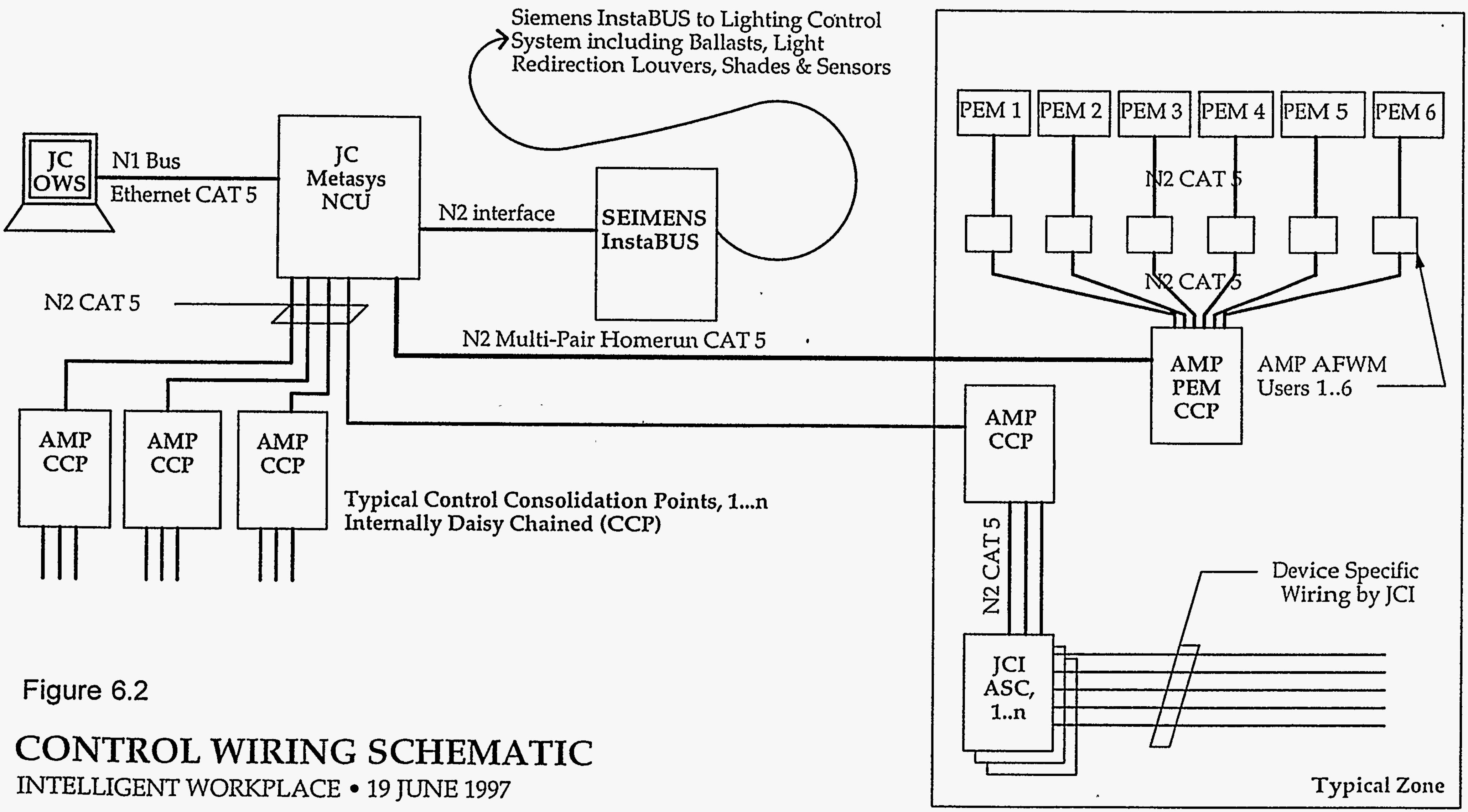
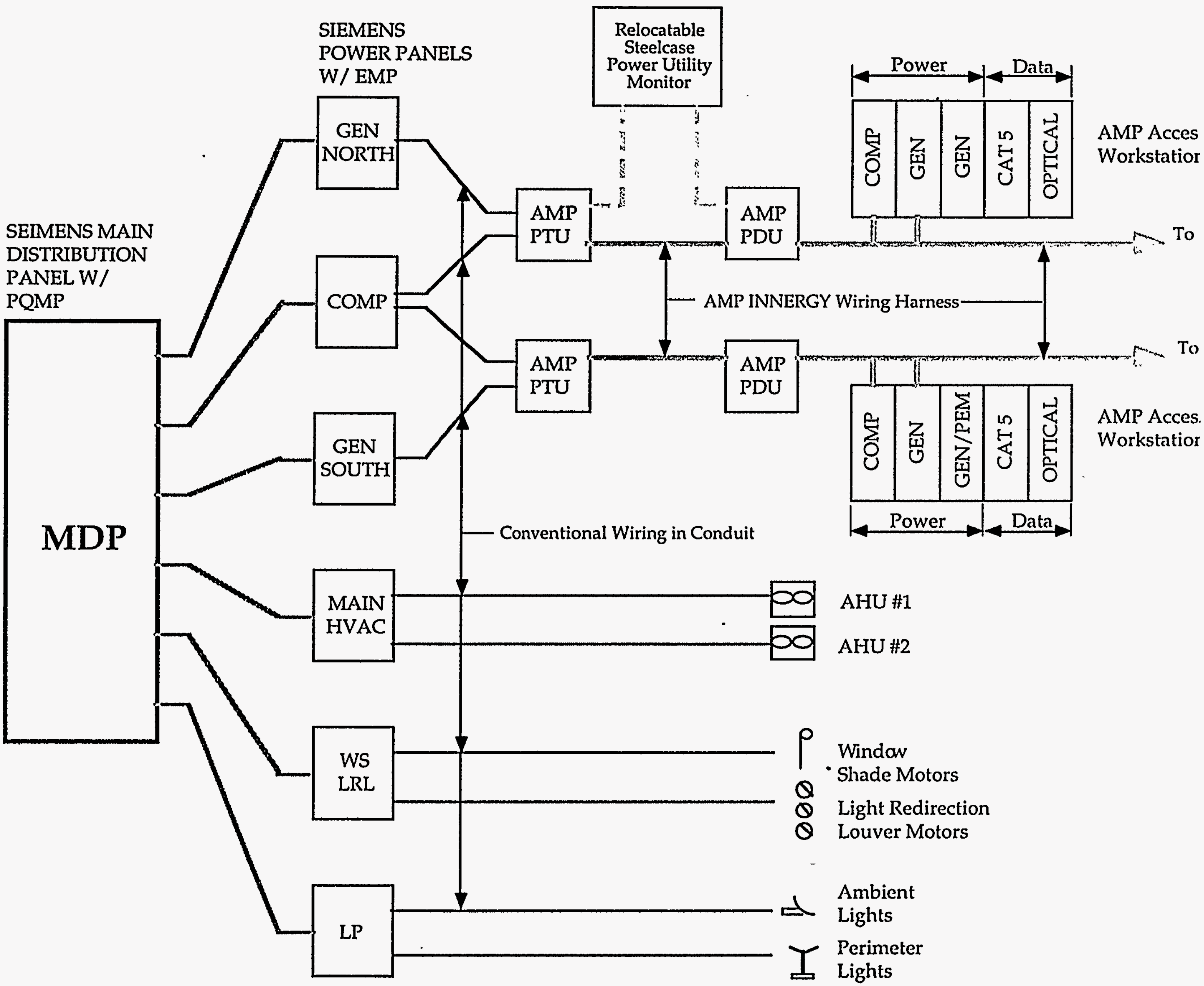



Figure 6.2

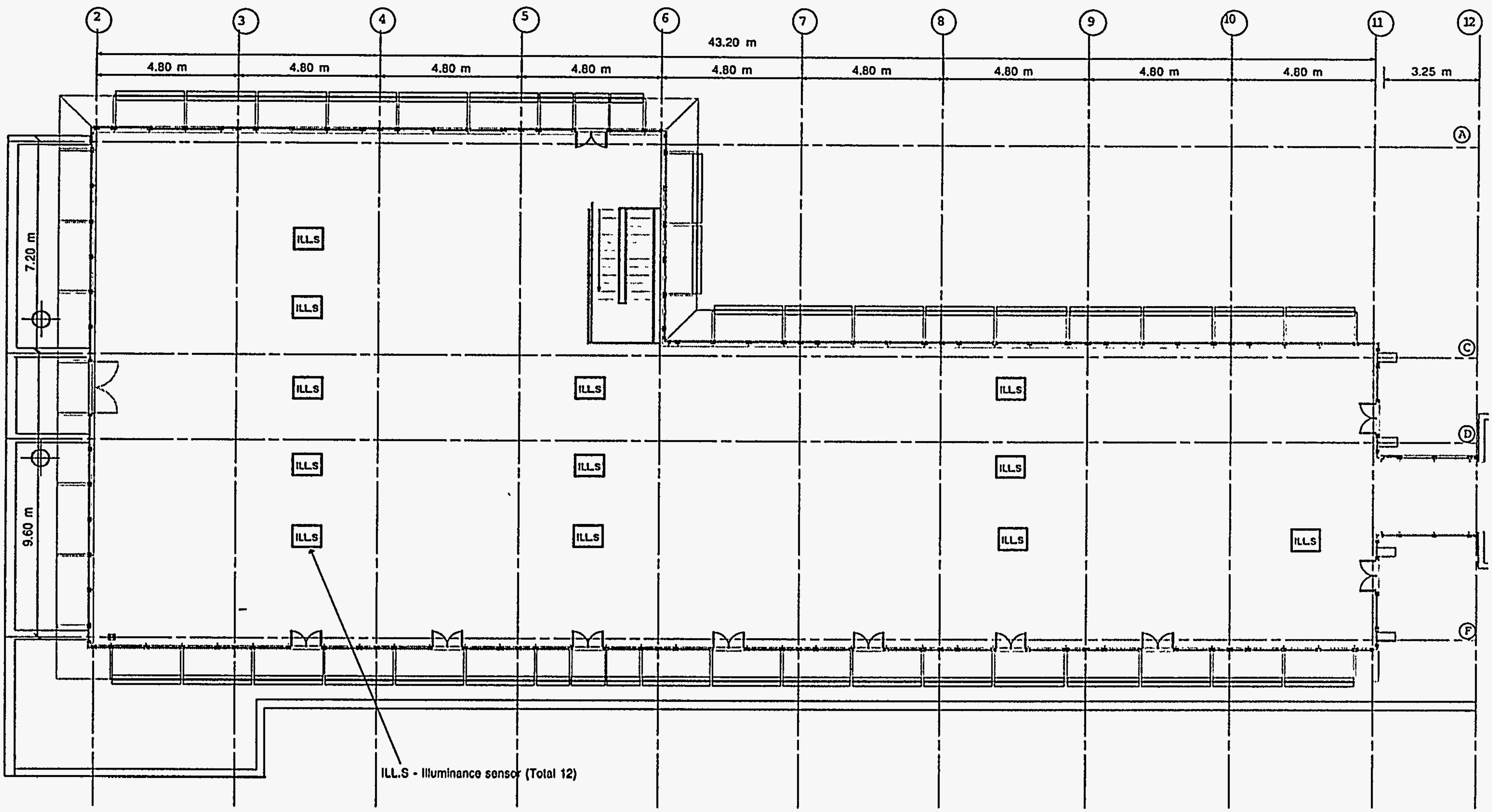
## CONTROL WIRING SCHEMATIC

INTELLIGENT WORKPLACE • 19 JUNE 1997




**POWER WIRING & MONITORING SCHEMATIC**
Intelligent Workplace • 19 June 1997

Figure 6.3




**INTELLIGENT WORKPLACE CONTROLS**

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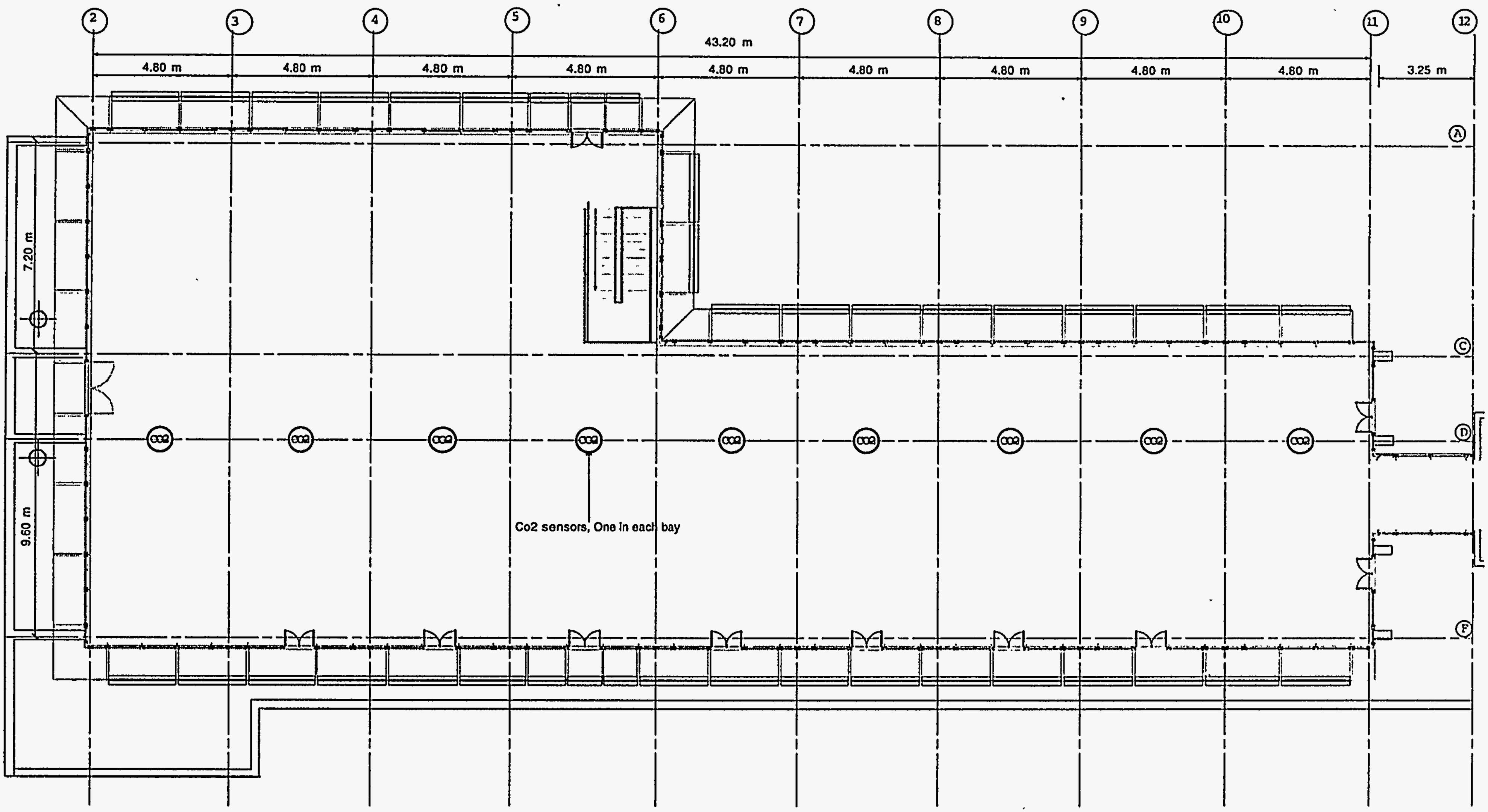
7.1 Light Sensor Scheme




**INTELLIGENT WORKPLACE CONTROLS**

Scale: 1:200 18 June 1997

7.2 CO2 Sensor Scheme

# List of Diagnostics Equipment

| | |
|---|---|
| **A. Thermal Comfort, Thermal Diagnostics, and IAQ** | |
| **Indoor Climate Analyzer Set** | |
| Indoor climate analyzer | 6,900.00 |
| Air temp. transducer | 757.00 |
| Surface temp. transducer | 908.00 |
| Radiant temp. asymmetry trans. | 2,722.00 |
| Air humidity trans. | 2,057.00 |
| Air velocity Trans. | 2,057.00 |
| Operative temp. Trans. | 1,407.00 |
| Trans. carrying case | |
| Delta Arm Tripod | |
| Tripod Mounting adaptor | |
| Software | 995.00 |
| | |
| **Thermal Comfort Meter** | 5,100.00 |
| Thermal Comfort Transducer | |
| Tripod Adaptor | |
| Battery Box | |
| | |
| **Thermal Comfort Data Logger** | |
| Thermal Comfort Data Logger | 3,100.00 |
| Extension type UA 1276 | 1,575.00 |
| Extension type UA 1277 | 1,575.00 |
| | |
| | |
| **Tracer Gas Systems** | |
| Multi gas monitor | 23,335.00 |
| Multi point Sampler | 22,890.00 |
| Software | 9,800.00 |
| Cables | |
| Optical Filters | 5,500.00 |
| | |
| **Blower Door** | 3,375.00 |
| | |
| **Subtotal A** | **94,053.00** |
| | |
| **B. Acoustics** | |
| **Precision Sound level Meter** | |
| Precision Sound level Meter | 6,995.00 |
| 1/3-1/1 Octave Filter | 2,850.00 |
| Room Acoustic module | 1,823.00 |
| Statistic Analysis Module | 872.00 |
| Frequency Analysis Module | 883.00 |
| Interface Module | 901.00 |
| Software | 636.00 |

| | |
|---|---|
| **Modular Precision Sound Analyzer** | |
| Modular Precision Sound Analyzer | 11,200.00 |
| Software | 2,121.00 |
| | |
| **Dual Channel Frequency Analyzer** | |
| Dual Channel Frequency Analyzer | 18,995.00 |
| Sound Intensity Probe | 7,318.00 |
| 1/2" microphone | 1,716.00 |
| Preamplifier | 3,256.00 |
| Accelerometer | 1,912.00 |
| Dual CH. FFT Option | 4,752.00 |
| Building Acoustics Program | 2,721.00 |
| Signal Generator Option | 3,536.00 |
| | |
| **Calibration Instruments** | |
| Sound Intensity Calibrator | 5,220.00 |
| Vibration Calibrator | 2,395.00 |
| | |
| **Others** | |
| Sound Source | 6,276.00 |
| Extension Cable for Microphone 3m | 650.00 |
| Extension Cable for Microphone 30m | 434.00 |
| Extension Cable for Accelerometer 3m | 254.00 |
| | |
| | |
| **Subtotal B** | **87,716.00** |
| | |
| **C. Visual Diagnostics** | |
| **Illuminance Meter** | |
| Minolta T-1 | 745.00 |
| Minolta T-1H | 845.00 |
| Minolta T-1M | 1,070.00 |
| Tektronix J1811 | 675.00 |
| | |
| **Luminance Meter** | |
| Minolta LS-100 | 2,995.00 |
| Minolta LS-110 | 2,995.00 |
| Minolta Data Printer | 745.00 |
| Accessories for Minolta | 339.00 |
| Tektronix J1803 | 550.00 |
| IQ Cam | 22,325.00 |
| | |
| | |
| | |

| | |
|---|---|
| Subtotal C | 33,284.00 |
| | |
| TOTAL | 215,053.00 |

# INTEGRATED ENVIRONMENTAL CONTROL AND MONITORING IN THE INTELLIGENT WORKPLACE

**Interim Report**

## 1.0 Summary

The control system of the IW involves various complex systems unlike other office spaces. Therefore, research is being conducted to resolve some of the issues related to these systems. This report contains information on the systems and the progress on each aspect of their investigation.

## 2.0 Objectives

The objective of this research is to study the various systems integration issues, to design and engineer these issues into control strategies and to implement and test the integrated systems in a real setting.

This project investigates the following objectives:

- To model a control strategy with related algorithms for distributed sensors, actuators, and controllers for negotiating central and individual control of HVAC, lighting, enclosure in order to maximize user comfort, as well as energy and environmental effectiveness.
- To model configuration of sensors, controllers, submeters, and workstation-based hardware and software for: shading, light redirection, electric light; operable windows, assisted natural ventilation, desiccant cooling, refrigerant cooling; radiant facade, water based conditioning, air based conditioning.

## 3.0 Working Groups

There are five working groups in this project. Each of these groups investigate one system or approach. The groups and the work conducted by these groups are presented below.

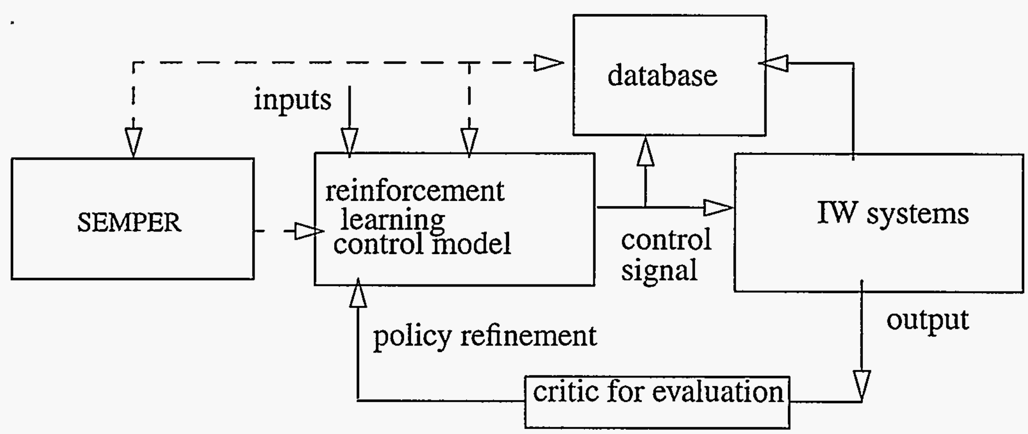
### 3.1 Machine Learning-Based Control Strategy for Intelligent Workplace

Increasing number of researches and system development efforts are going on in machine learning-based building system control domain. For example, reinforcement learning technique uses agent's current sensor values to refine its estimate for the new state. It simply requires a scalar performance measure without indicating the direction for improvement. Therefore, correct response to individual inputs to train the network is not necessary. This kind of control technique can deal with transient building process such as temperature increase by solar radiation by using temporal credit mechanism. Machine learning-based adaptive control of HVAC system and lighting systems (both daylight and artificial light) can provide necessary control intelligence to dynamically respond to the weather conditions, occupancy status, and user preference. Training or retraining of machine learning-based controller can be supported by a simulation program such as SEMPER.

This strategy is expected to reduce training time and to expand control model's adaptation capability in various operational conditions.

Once machine learning-based control model is installed, this type of controller keeps refining it control policies by interacting with actual systems while it controls building systems. Machine learning-based control model is supposed to use special sensor such as occupancy sensor as well as WWW (World Wide Web) weather forecast data. This is to implement responsive control scheme so that it can dynamically respond to the occupancy status and the weather changes. For example, occupancy sensor senses the number of occupants and their locations and the controller responds accordingly. Machine learning control model can work with simulation like SEMPER. In this case, SEMPER can be the knowledge provider for the training of machine learning-based control model. For example, in lighting system control, the seasonal solar insulation pattern can be easily trained by SEMPER so that the machine learning-based controller doesn't have to go through the whole year to capture this type of knowledge. The other domain of potential cooperation between SEMPER and machine learning-based control model is for efficient adaptation of system control to the temporal or longer-term building component changes. Simulation like SEMPER can assist the re-training of machine learning- based control model while it takes over the system control, temporarily.

Machine learning-based control model can be installed on Pentium PC. Software-wisely, the actual integration of machine learning-based control model with other control component in Intelligent Workplace can be done by object communication technique. This control model needs access to the actuators, sensors, database, and SEMPER. Control model outputs and actual system outputs can be logged on database for further analysis.The performance of machine learning-based control model can be evaluated by measuring its learning rate and its responsiveness to the various system conditions and user preference.




Exemplary Machine Learning-Based IW System Control Scheme

## 3.2 Control Points of the IW

### 3.2.1 Air handling scheme (see attached drawing)

The IW is served by two systems: Water Source Heat Pumps (WSHP)and the Personal Environmental Modules (PEM). The air handling unit for the PEM's is a desiccant system with a capacity of 2000 cfm and capability of 80% energy exchange from the return air. The WSHP's are served by a simple desiccant system of 1200 cfm capacity with heat recovery from exhaust air.

### 3.2.2 **Water mullion scheme** (see attached drawing)

In addition to the air handling systems, water mullions are provided along the perimeter. One motor is provided for every four mullions with a total of twenty seven motors. $CO_2$ sensors would be placed in each bay to monitor the indoor air quality. The ventilation channels, one in each bay, have two axial fans each and are used for the purposes of ventilation when the outdoor air is suitable for bringing into the space without requiring any conditioning.

### 3.2.3 **Lighting scheme** (see attached drawing)

The ambient lights are grouped as perimeter and interior lights. The perimeter lights are controlled on on/off basis. The interior lights are dimmable and will be controlled based on the light levels in each bay. In addition each bay would have illuminance sensors at every meter in order to obtain the profile of light levels in each bay.

### 3.2.4 **Envelope control scheme** (see attached drawing)

Each operable window/door is equipped with a sensor to relay the open/closed/partly open position to the central control system. In addition, each door/window is equipped with motorized shades for glare control. The skylight shades are controlled by one motor each for the north and south side of each bay.

## 3.3 Window Shades

The IW will have moveable window shades for glare and solar control. The detailed specification and control of these shades is currently under review. It is anticipated that fabric shades manufactured by Krulland will be used for the window shades.

### 3.3.1 Energy Implications of External vs. Internal Shades

Since solar heat gain is summer is an important issue to be addressed, particularly with the dominant east-west facade orientation in the IW, the use of an external moveable fabric shade was considered. Detailed energy simulations using DOE-2.1E were carried out to determine the energy implications of depolying such external shades. With regard to the configuration and control of these shades the following assumptions were made:

- The external shades are located below the light-redirection louvres, and can extend down to the railing along the catwalk.
- The solar transmittance of the shade is 25%.
- Seasonal shading schedules were derived assuming that shades were deployed whenever there is direct solar radiation on the associated facade during occupancy hours. This approximately corresponds to a scenario in which users deploy the shades whenever there is sun in their workspace.

The simulation results showed that the use of external shades instead of internal shades resulted ina 1.4% decrease in annual energy use. Thus, the choice of internal vs. external shades in the IW is inconsequential from an energetic point of view. It should be noted however that this is not necessarily generalizable to other buildings. In the IW, this is most likely because the overhead grating and the light-redirection louvres already provide significant solar control and the marginal increase in solar heat gain control from external or internal fabric shades is thereby insignificant.

### 3.3.2 Configuration and Control of Shades

With regard to the configuration and control of the shades, the following issues are being addressed, in cooperation with the researchers at Krulland:

- Control of shades: There will be global control of the shades, with local user over-ride. The switches to operate the shade will be located on the mullions of the facade. Alternatively, if the shade motors have a clutch, the users can manually raise or lower the shade.
- Resolution of control: Each facade bay has five shades. Although each shade could potentially have its own motor, it is currently anticipated that there will be three motors per bay (1 for the door module, and one each for the shades on either side of the door.
- Location for door shade: Since the doors open inward, it may be more desirable for the shade to be located on the outside, so that the doors can be opened while the shade is deployed.
- Dual shade fabrics: In the north end of the IW, there is the need to darken the space for presentations, etc. These areas therefore require two types of shades - a lighter shade for glare control, and a darker shade for darkening the space. Solutions to accommodate two shades are currently being developed.

## 3.4 Ventilation Controls

### 3.4.1 Input parameters required for ventilation controls:

- Outside and Inside Air Temperature
- Outside and Inside Relative Humidity
- Outside Air Velocity
- Outside Air Direction
- A representative/composite index ($CO_2$, Radon, TVOC) of outdoor air quality (OAQ)

The steps needed for finding out if the outdoor environment is fit for natural ventilation:

1. We need 1 control point to read these sensory data from weather station.
2. For each of these five values, the ventilation control algorithm will make sure that the values are within the specified range (the table below suggests some ranges which may change depending on our simulation/monitroing results). Alternatively, we could use a thermal comfort index like PMV or SET* to facilitate our decision-making process.

| Variables | Range |
|---|---|
| *Outside air temperature* | 17°C - 26°C |
| *Outside relative humidity* | 30% - 70% |
| *Outside air velocity* | less than 0.5 $m \cdot s^{-1}$ |
| *Outside air direction* | None |
| *OAQ index* | $CO_2$ concentration in ppm |

3. We can admit unlimited amount of outside air in the ideal condition ($T_{setpoint} = T_{outside}$). For other conditions, the feasibility of natural ventilation will depend on such factors as

the lower limit of $T_{outside}$, which would not result in thermal discomfort for people sitting close to the window and also not incur a big energy penalty. The following calculation will determine the amount of outside air which can be allowed to come in for that time step. This number would be extrapolated to find the number of windows and the duration for which they can be opened. The assumption is that air admitted through the windows will gradually mix with the indoor air. If the conditions seem satisfactory, one on more green lights (see the 4th point) would be turned on. The equation is:

$$: C_p \times (T_{setpoint} - T_{outside}) = V_{space} \times C_p \times (T_{inside} - T_{se} \qquad \text{(EQ 1)}$$

4. Once all the parameters are satisfied, a green light will come on informing the occupants about the pleasant conditions outside. Two or three light will be strategically located inside the IW so that at least one of them is in the line of sight of each person working in the IW. If we allow for selective opening of windows in case the air velocity is not within the specified range then we may have to increase the number of "ventilation zones" from 3 to may be 5 or 6.

### 3.4.2 Implications of natural ventilation on the HVAC system

| Before Natural Ventilation | After Natural Ventilation |
|---|---|
| *HVAC system in cooling mode* | **Remains in cooling mode with lower load** |
| | Remains in cooling mode with higher load |
| | **Goes into 100% ventilation mode** |
| | Goes into heating mode |
| *HVAC system in 100% ventilation mode* | Goes into cooling mode |
| | **Remains in 100% ventilation mode** |
| | Goes into heating mode |
| *HVAC system in heating mode* | N/A |

The above table will help in developing the control logic for the coupling mechanism which checks the system operation mode before opting for natural ventilation to safeguard the energy performance of IW.

## 3.5 Object-Oriented Workplace Laboratory Project

The fourth year class of the School of Computer Science chose the Intelligent Workplace as its research domain for the fall semester course, Software Engineering (15.413). Approximately 50 students divided into groups to develop software applications relevant to the needs of the IW. The project is called OWL (Object Oriented Workplace Laboratory) and investigated the following areas:

- System Architecture
- User Interface
- Database
- Visualization

- Facilities Management
- Controls

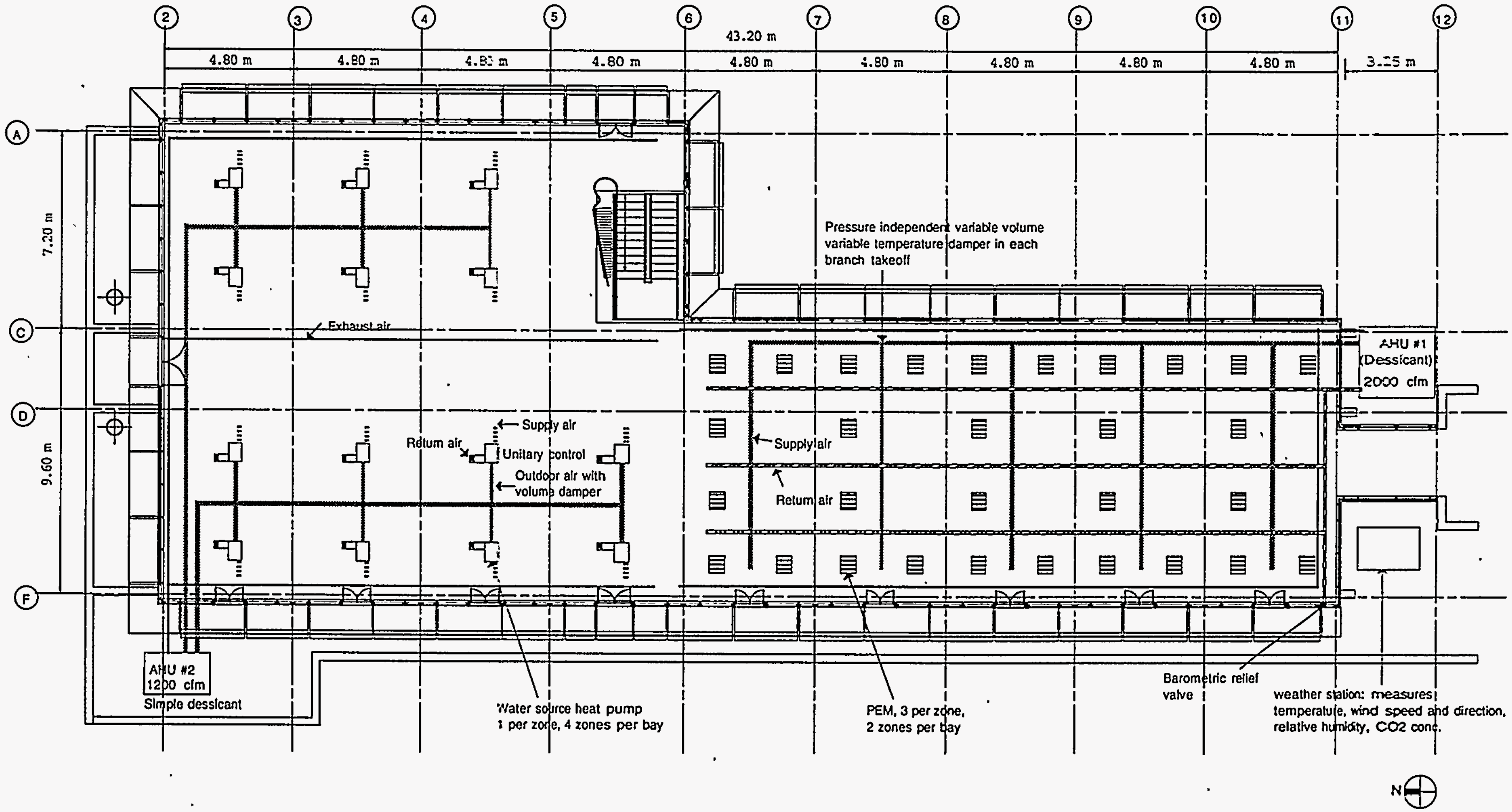
The controls group chose to implement control strategies for the daylighting/ electrical lighting system. The group developed control strategies based on input from CBPD personnel. A demonstration of the control system was set up in the second bay of the south zone. The light redirection louvers were energized and temporary dimmable, high efficiency luminaires were installed. The control software is running on a 133 MHz Pentium and is executing its commands through an Analog-Digital serial board with sixteen ports.

It is anticipated that the control strategies and algoritms will be ported over to Metasys and Instabus, when those systems are installed during Phase IV.

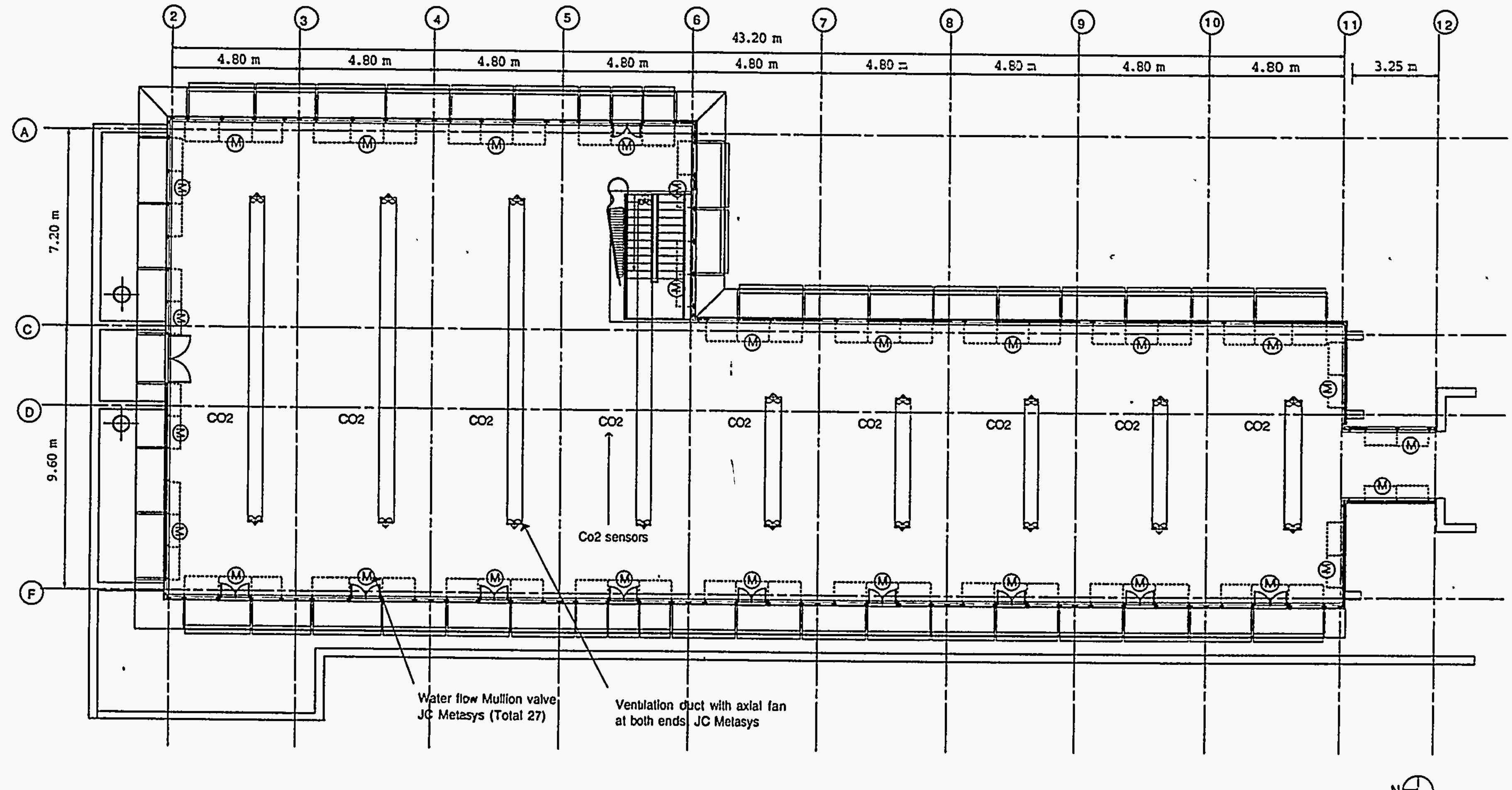
# 4.0 Control Drawings

## 4.1 Control Point Diagrams:

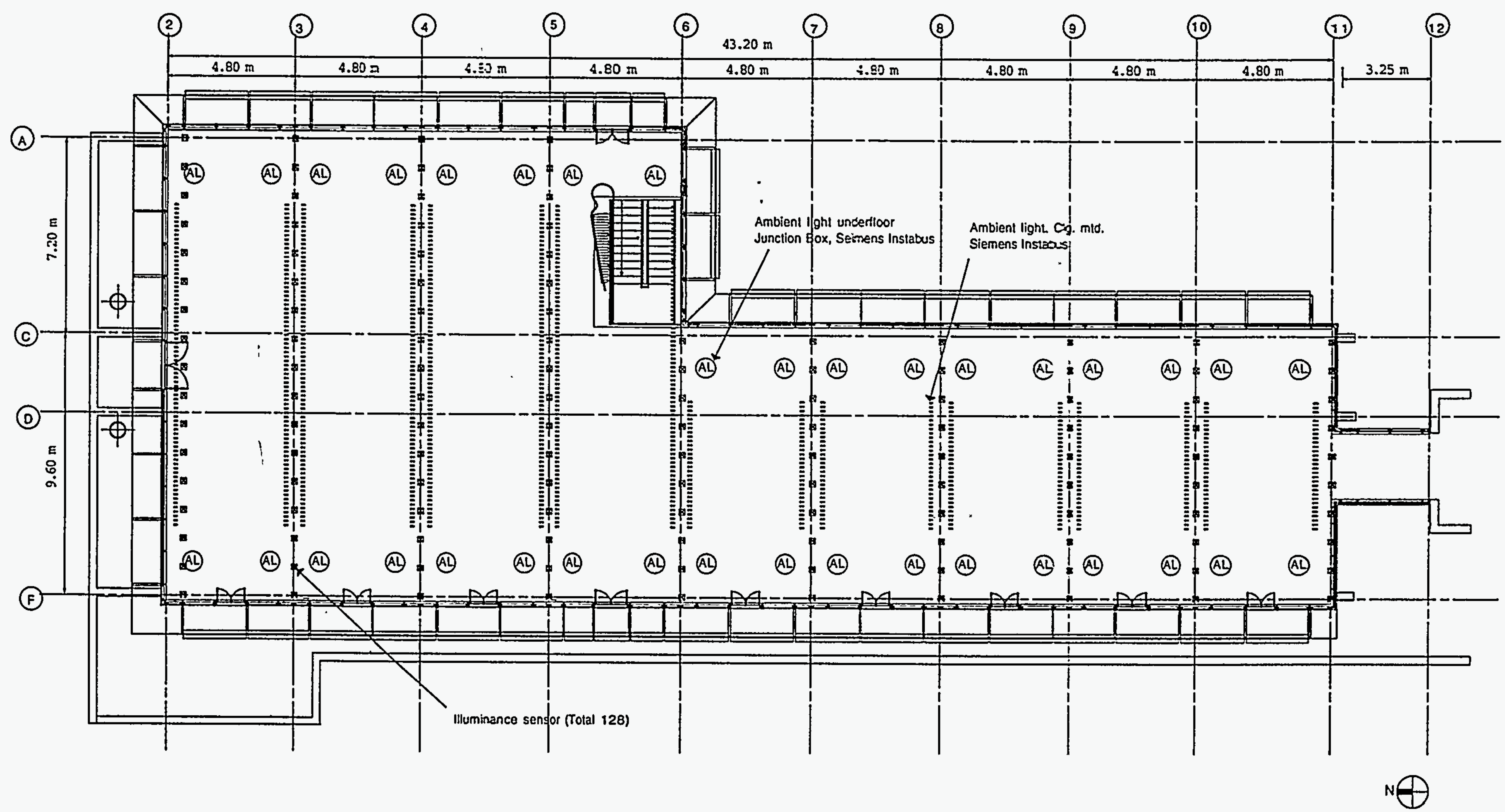
- Air handling Scheme
- Water Mullion Scheme
- Lighting Scheme
- Envelope Control Scheme



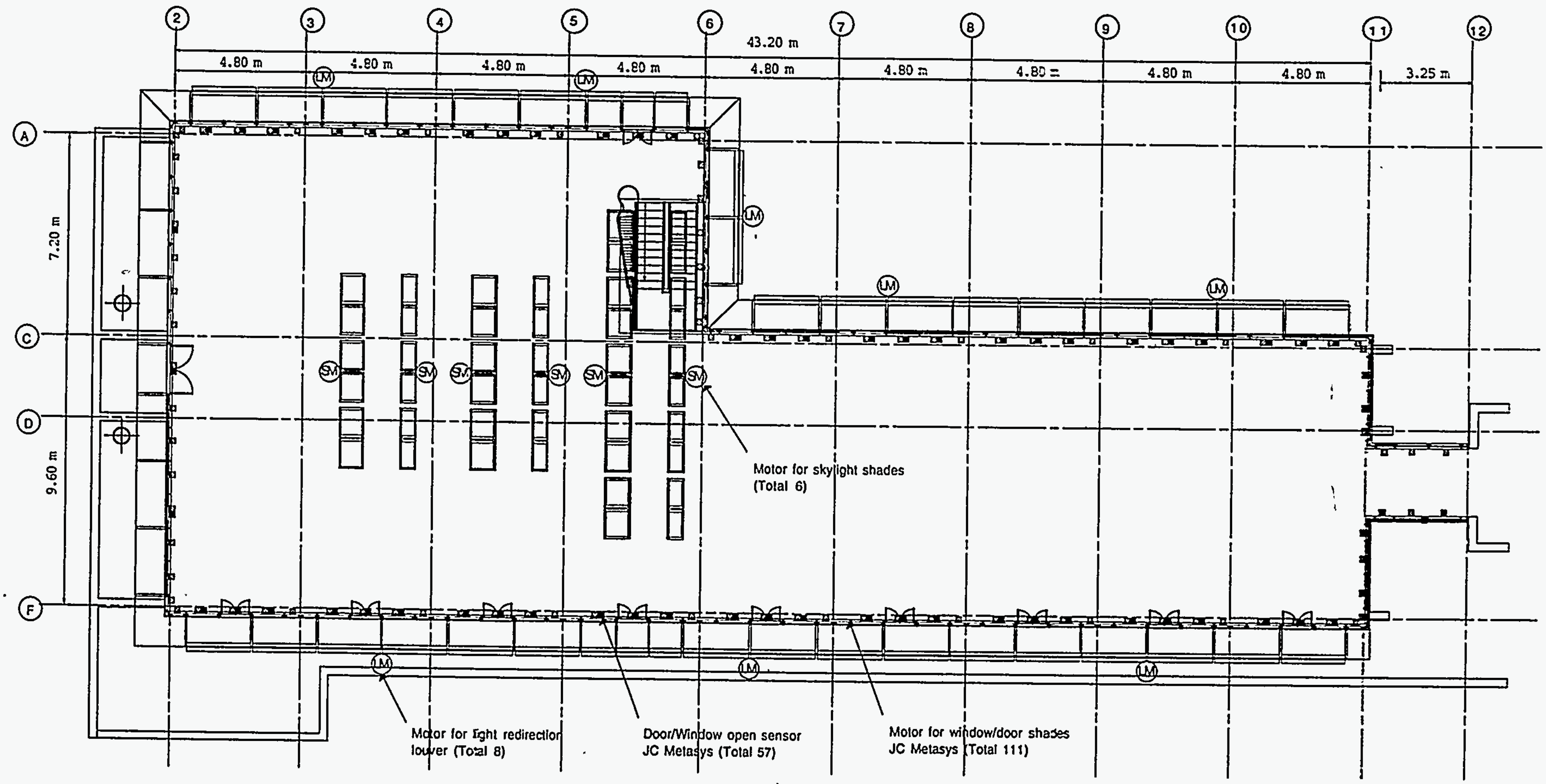

INTELLIGENT WORKPLACE CONTROLS 19 NOV 1996 AIR HANDLING SCHEME




INTELLIGENT WORKPLACE CONTROLS 19 NOV 1996 WATER MULLION SCHEME




INTELLIGENT WORKPLACE CONTROLS 19 NOV 1996 LIGHTING SCHEME




INTELLIGENT WORKPLACE CONTROLS 19 NOV 1996

ENVELOPE CONTROL SCHEME

# Integrated Environmental Control and Monitoring in the Intelligent Workplace

Preliminary Report - Control System Schematics

## 1.0 OVERVIEW

The Intelligent Workplace with its diverse building systems for environmental, organizational and information technological performance and "plug and play" flexibility is an extremely challenging project in terms of the design and integration of its environmetal systems and associated controls. A systems engineering approach was utilized by the team to achieve the objectives of modularity, energy efficiency, occupancy satisfaction and flexibility. Each system was thoroughly analyzed, the crossover points were identified and the integration of both hardware and software systems were determined.

This project involved the design and engineering of the control and monitoring of environmental quality – visual, thermal, air – in the Intelligent Workplace. The research objectives were to study the performance of the individual systems, to study the integration issues related to each system, to develop a control plan, and to implement and test the integrated systems in a real setting.

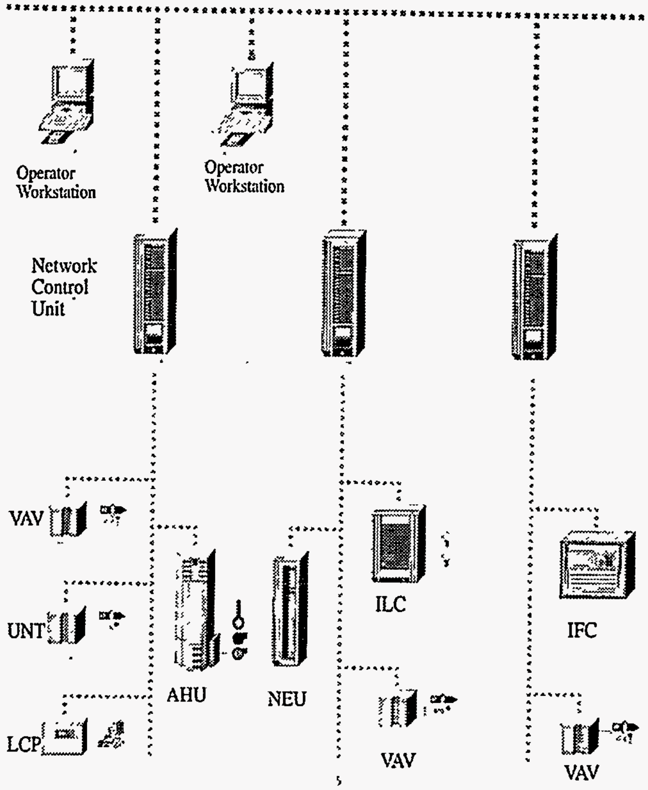
In this project, a control strategy with related algorithms for distributed sensors, actuators, and controllers for negotiating central and individual control of HVAC, lighting, and enclosure was developed in order to maximize user comfort, and energy and environmental effectiveness. The subsystems to provide environmental quality in the Intelligent Workplace include an air-based HVAC system with desiccant air handler and Personal Environments®, a water-based HVAC system with radiant cooling panels, the Coolwave® and displacement ventilation, a water flow curtainwall, a PV assisted natural ventilation system, and a lighting system including light redirection louvers, shading devices and daylight-responsive electric lighting.

This preliminary report outlines the integrated controls for the Intelligent Workplace, particularly the configuration of the Metasys and Instabus systems.

# 2.0 INTEGRATED CONTROLS

In order to achieve integrated control of the environmental systems in the IW, three commercially available systems will be initially installed; Johnson Control's Metasys™, Siemens' Instabus, and Zumtoble's Luxmate. In this section, each of these control systems and their integration will be summarized.

- JC Metasys™: This is a distributed system that allows for the collection and monitoring of data from sensors, management of the information collected and monitored, and the control of each of the components. Each component (i.e. desiccant wheels, PEM's, etc.) is controlled by an application specific controllers (ASC's).These communicate with each other through a subnetwork called Optomux. The information from the ASC's propagate through the Optomux and are gathered in network control units (NCU's). NCU's communicate with each other and with operator workstation through ARCNET which operates at 2.5Mbaud over coaxial, twisted pair or fiberoptic cable. (The iW implementation will utilize Ethernet over CAT 5 cabling.) Metasys' network architecture is indicated in the figure to the right.

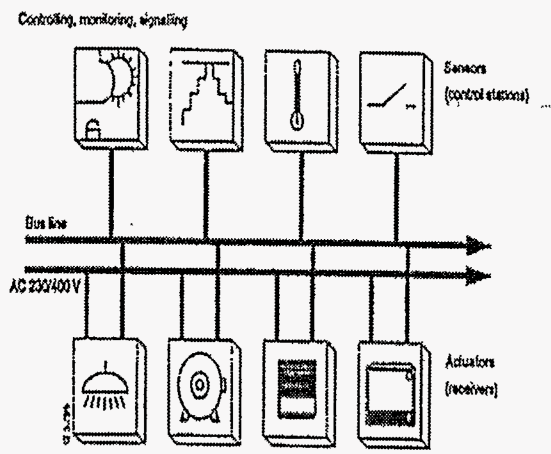
  JCI, AMP and the CBPD have used the IW as an opportunity to explore issues related to unifying the cabling of data, voice and control networks. Unification will allow: a single contractor to be responsible for the installation of data, voice and control networks thereby reducing price and increasing quality; would allow a sole source manufacturer to guarantee the cabling infrastructure; and would facilitate comprehensive management of the cabling infrastructure from the building occupant's perspective.

- The cabling infrastructure that was designed for implementation in the IW is indicated in attached drawings 1 and 2. The Main Data Frame (MDF) houses active electronics which connect the IW to the campus infrastructure. Parallel patch panels connect the horizontal distribution system to the active electronics. The horizontal system utilizes consolidation zones to simplify the installation, reduce costs, facilitate flexibility and improve cable management. AMP will fabricate six-user consolidation points for the data/ voice system. In addition to the copper data link, AMP will demonstrate optical cable to the desk. Therefore from the MDF to the consolidation point, there will be 1 twelve strand optical cable and 12 four pair CAT 5 cables for data and 1 twenty five pair CAT 5 cable for voice. Each consolidation point will service a maximum of six users through the AMP Access Floor Workstation Module (AFWM). The five gang AFWM will contain three duplex outlets, a single face plate with four RJ45 connections, and a faceplate for an optical connection. Two RJ45's will be for data, one RJ45 for voice and a spare RJ45 is available for control wiring, such as the N2 bus line for the PEMs. The control wiring follows a similar concept of consolidation point boxes.

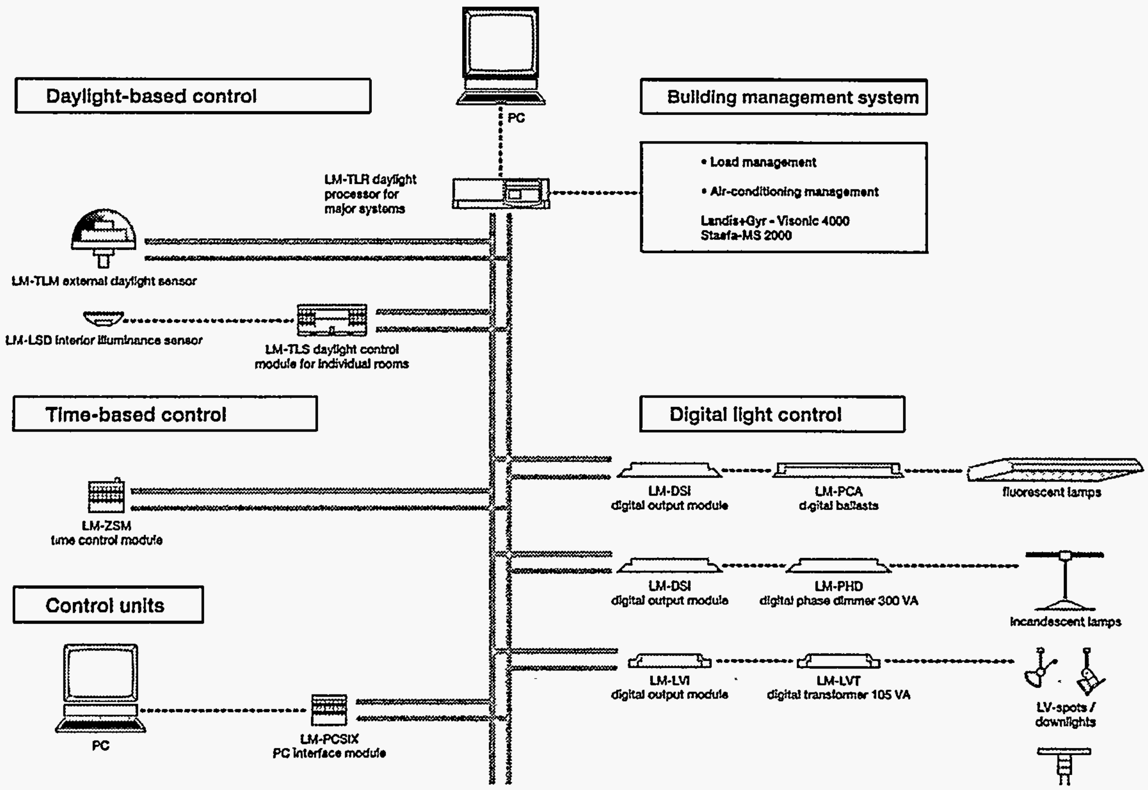
  JCI, AMP and the CBPD will research two different methods of control cabling in the IW - the first, for the PEMs, will support homeruns to the Metasys™ NCU with parallel patch panels at the MDF used to configure the daisy chain and the second, for the other ASCs, will support daisy chaining in the control consolidation box to achive further reductions in cabling quantities.

JCI Metasys™ will actively control MUA #1 and MUA#2, associated dampers, water flow mullions, the Coolwave™ and the radiant cooling ceiling. Metasys™ will collect data from the PEMs, Instabus™ and from the array of diagnostic sensors throughout the facility.

- Siemens Instabus: Instabus is a 0-10 Volt DC analog bus line that allows the devices attached to it to communicate with each other. Each device connected to this busline has a bus coupling unit (BCU) that has a unique address, which provides flexibility for the system. Each device depending on the type can collect information from and/or actuate other devices. All devices can be grouped or ungrouped through the EIB software interface. The Instabus implementation in the IW will be for the control of the lighting system. An N2 bus interface card was developed in Europe and will be utilized in the IW for the integration of Instabus and Metasys. The Metasys™ Operator Workstation (OWS) will run the EIB software in a separate window. The Instabus hardware including BCU, DIN rails and power supply will be located adjacent to the Metasys equipment. From the four DIN rails, four bus lines, each with a 64-component capacity, will extend throughout the IW. Bus lines in the floor plenum will control the perimeter uplights, and bus lines in the ceiling cable trays will control the Zumtobel luminaires, light redirection louvers, shade motors and door/ window sensors. The large device capacity (64 devices x 4 bus lines) is designed to facilitate the controls research. Siemens is exploring the fabrication of consolidation boxes for Instabus which will combine low voltage devices with line voltage connections in a rated assembly to facilitate installation and plug and play operation.




- Zumtobel Luxmate™: Luxmate™ is a digital lighting control system with a 0-15 Volt DC digital bus line and a proprietary communication protocol. The network architecture has three layers: the management layer, the automation layer and the field layer. The management layer contains the sky scanner the system PC and the main touch panel. The automation layer contains the daylight computer and interfaces to the JCI OWS. The field layer contains the luminaires, the shades and the user controllers (hard wired or infra-red). A  wire bus line(s) connects digital control devices that can be integrally mounted in each luminaire. The system is an open loop control system that allows an outdoor light sensor to individually control luminaires in response to daylight conditions. This requires an intial calibration for each ballast/ digital device, then during use, the system interpolates between the dark and light points. The individual digital controls allow the creation and storage of "scenes", special lighting effects which restore some of the dynamic qualities associated with daylight to the electrical lighting system.
Zumtobel will retrofit the analog luminaires digital ballasts and devices and intall the Luxmate™ system after the initial period of occupancy for the IW, so that performance and integration comparisons with the Instabus lighting control system can be made.




## 2.1 Control Plan

JCI Metasys™ will be the primary building control and data collection/ storage system for the IW. The research objectives for the IW explicitly include exploration of alternative control technologies, as well as their integration issues. As of the date of this report, Siemens Instabus™ and Zumtobel Luxmate™ are two member company technologies that will be installed and tested in the IW. JCI Metasys™ will control the basic HVAC systems and collect/ store data from the diagnostic sensors arrayed throughout the IW. The lighting system will initially be controlled by Instabus™. The ambient lighting system deploys 106 luminaires. These luminaires, provided by Zumtobel, will house analog ballasts and bus coupling units for Instabus and digital ballasts and DSI's for LUXMATE. Figure 6.1, Appendix A shows the typical implementation and integration of these systems. Metasys™ and Instabus will be sharing the same operator work station and communicating through a commercially available N2 interface card. The control/ data collection system will be used to validate the control algorithms and to establish baseline performance metrics.

## 2.2 Control Interfaces

As the systems are individually designed and developed in the absence of universally accepted industry standards, just installing systems from different vendors does not ensure an integrated systems environment. For example, an HVAC system and a lighting system may be optimal and modular but they may be spatially and functionally incompatible.

The interactions of the systems and their effect on each other must be carefully considered in order to provide satisfactory environments for the users as well as cost effectiveness for the operators. The cross over points of the three major systems in the Intelligent Workplace are described below:

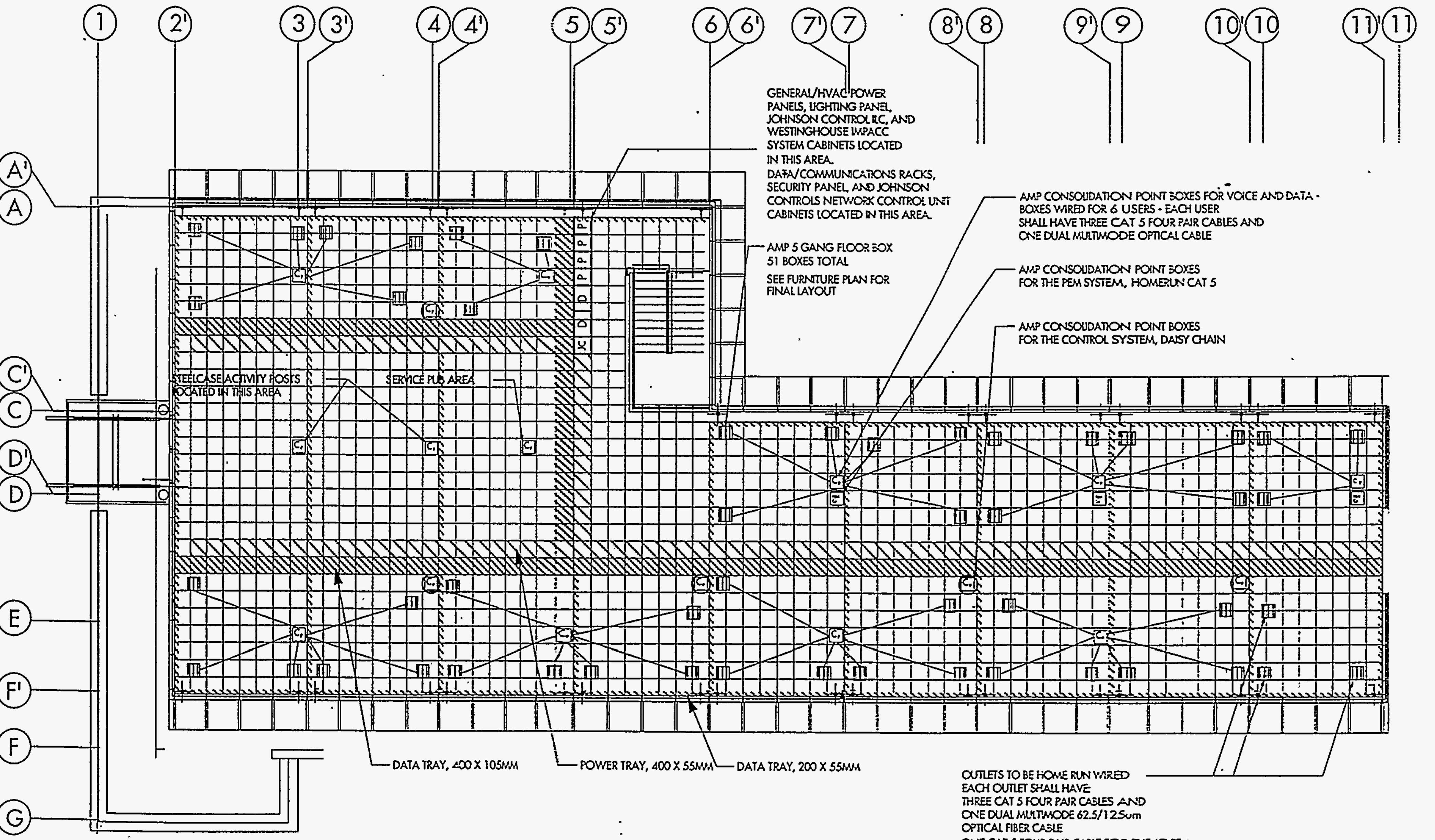
- Enclosure and Mechanical System Integration: The enclosure from its glazing type to its external devices, has immense implications on the loads for the mechanical system. It can lessen or heighten the effect of the conditions of the external environment on the internal environment. In the IW a dynamic facade is utilized to actively create a comfortable environment for the occupants . The light redirection louvers can cut off the heat from the sun as well as allowing deep penetration of daylight to the benefit of the occupants inside the building.
- Enclosure and Lighting System Integration: The enclosure has a direct effect on the energy implications of the electrical systems. The daylight that penetrates into the building does not necessarily ensure the required quality and quantity of light at the location where it is needed. The enclosure in the Intelligent Workplace not only has static measures for allowing daylight to penetrate into the space but it also has dynamic measures for actively mitigating the varying daylight conditions and providing the required quality of light for the occupants. Light redirection louvers are designed to reject heat gain in the summer and internal shades address the possible glare problem.
- Mechanical and Lighting System Integration: Lighting loads are one of the most dominant loads in the buildings. The electricity that is provided to run these systems is ultimately converted to heat. Providing the appropriate conditions for lamps and luminaires can greatly affect their efficiency. The full benefits of integrating HVAC system with the lighting systems are: improved performance of air conditioning system, efficient handling of heat produced by the lighting, and efficient lamp performance. The degree of benefits depend upon the quantity of energy involved and the effectiveness of integration.

## 2.3 Intelligent Controls

Control Architecture: The successful integration of control hardware and software is a crucial issue especially in Intelligent Workplace. Considering the diversity of control components, making interfaces among different control components based on the open architecture scheme is a challenge itself in both design and implementation phases. Different communication protocols and control bus structures should be successfully interfaced and integrated. For example, Johnson Control's METASYS and Siemens's EIB have their own protocols and bus architecture. To integrate those control components developed by multiple manufacturers, interfaces among different control systems(or subsystems) must be properly developed. These interfaces could rely on certain software design patterns to enable flexible additions or replacements of new control components while maintaining the original control system architecture. Recently introduced bridge and adapter patterns in software engineering shed light on this problem. Especially, a bridge pattern is useful when a control component is incomplete or unavailable thus multiple implementations under the same interface are needed. As was specified in the OWL project, the sensor interface is implemented as stub code, file system, or sensor driver. The Light Redirection Louvers (LRL) interface also could be implemented by stubbing it out, a simple file defining quantified inputs and outputs , or by being connected to the actual LRL driver. The more important pattern in IW control software is an adapter. Adapter can be used for wrap up existing control system interfaces provided by different vendors. Making those legacy APIs (Application Programming Interface) the integrated parts of a new control system is possible by adapters. For example, if the PEM interface is to be integrated to the entire IW control system, the PEM adapter could be codified to wrap up existing PEM interface. Clients of the IW control system can be connected to this adapter to activate the control services the original PEM interface used to provide. The actual vendor specific APIs could be hidden from the clients while the entire control system is organized under a unified development environment.

The control interface is one of the important issues demanding a careful design and implementation. Multi-modality and remote control could be the major issues in control interface design and implementation. In the OWL project, multi-modal control interface was suggested to extend the modes of inputs and outputs between the users and the control system. This multi-modality is supposed to handle various types of input and output modes such as text, icons, menus, voice, or tactile stimuli. Most of current control interfaces available have GUI (Graphic User Interface) features. Icons, menus, windows, and other visual components have been typical elements for the interaction between the users and the computers. For building control, only a few people could access the control interface in conventional way of building operation. Emerging innovations in user-based control scheme demand that the extended group of people should be able to access the control interface even at remote locations. For this reason, multi-modality in building control interface is becoming more and more important. This new control interface scheme might be able to handle diversified user preferences as well as the physical handicaps of some user groups. Suppose a person is visually handicapped, this person can control his/her environment using voice activated commands. A person who has both visual and auditory handicaps still can use tactile mode control interface if such a device is provided. In terms of actual realization of such a multi-modal control interface, a couple of distinctive interface design schemes can be considered. A general approach in this case might be making many-to-one mappings between various modes of input (or output) and a specific control command (or a system response). A user can click switch-on icon from the screen or simply say "switch on" to activate switch_on ( ) method on the control server program. The built-in control API should be able to translate those multiple modes of input into a corresponding control command. This process is totally hidden from the users. The other type of interface design is to make a specific mode of input(or output) process independent from each other. Voice mail and e-mail are the examples in this category. What is internally represented and how it works in either mailing mode are totally distinctive throughout the overall processes even though both of them can handle the same asynchronous communications. This type of user interface design is not likely to be the major approach in IW control interface design and implementation multiple input modes translated control command system actuation Remote monitoring and control is another issue in IW control interface design and implementation. IR(Infra-Red) switch is already available for increasing mobility within a limited distance. A truly location independent monitoring and control of building systems could be done by using web technology. In the OWL project this new control interface scenario has been implemented and tested with JAVA based distributed computing technology. Ideally, facility manager or any other authorized user can activate specific building system function(s) from any place with any type of computer platform. Setting security and increasing the speed of error-free data transfer are the major technical challenges for this type of control interface design.

Control intelligence is the core of control software which is responsible for generating control decisions based on the measured or predicted environmental parameters. In scheduled control, the control decisions are predefined according to the seasonal and daily changes of environmental conditions impacting individual or globally optimized behaviors of the systems in a building. Therefore, the knowledge necessary for establishing a system schedule must be gained through a careful consideration on the interactions between predicted environmental changes and the impacts of the pertinent system behaviors. On the other hand, This deterministic approach is not flexible enough especially when dealing with dynamic and uncertain fluctuations of environmental factors. For example, daily weather conditions might vary even beyond weather forecast Scheduled settings of certain systems could be wrong in this case. Interactive control scheme is the solution for most of building system operations for this reason. PID controller or machine learning controller keeps interacting with the dynamic changes in environmental factors as well as the other control parameters to come up with appropriate control decisions. Some control algorithms are developed specifically for predicting and adapting to the dynamic or uncertain conditions. In IW, adaptive controllers using neural network or statistical technique is supposed to play a major role in either localized systems control or in the global control scheme. Control intelligence in the IW will mostly reside in this type of control scheme. For example, dimming and HVAC control could be guided by a well designed and implemented neural network controller to maximize occupants' comfort and to minimize energy consumption at the same time. User-based control scheme is another way of building operation. A PEM unit is supposed to be controlled by an occupant based on his/her preference in immediate physical environment. The major advantage of this control scheme is that it allows maximized satisfaction of individual occupant because most of control decisions are to be made by a specific person. The potential conflict between user controls and the globally optimized control should be resolved in more intelligent way. Those three types of control schemes such as scheduled control, interactive control, and user-based control might be working together to come up with an efficient and effective system control in the IW.




DATACOMM/ CONTROL WIRING PLAN

SCALE = 1:200

Figure 1

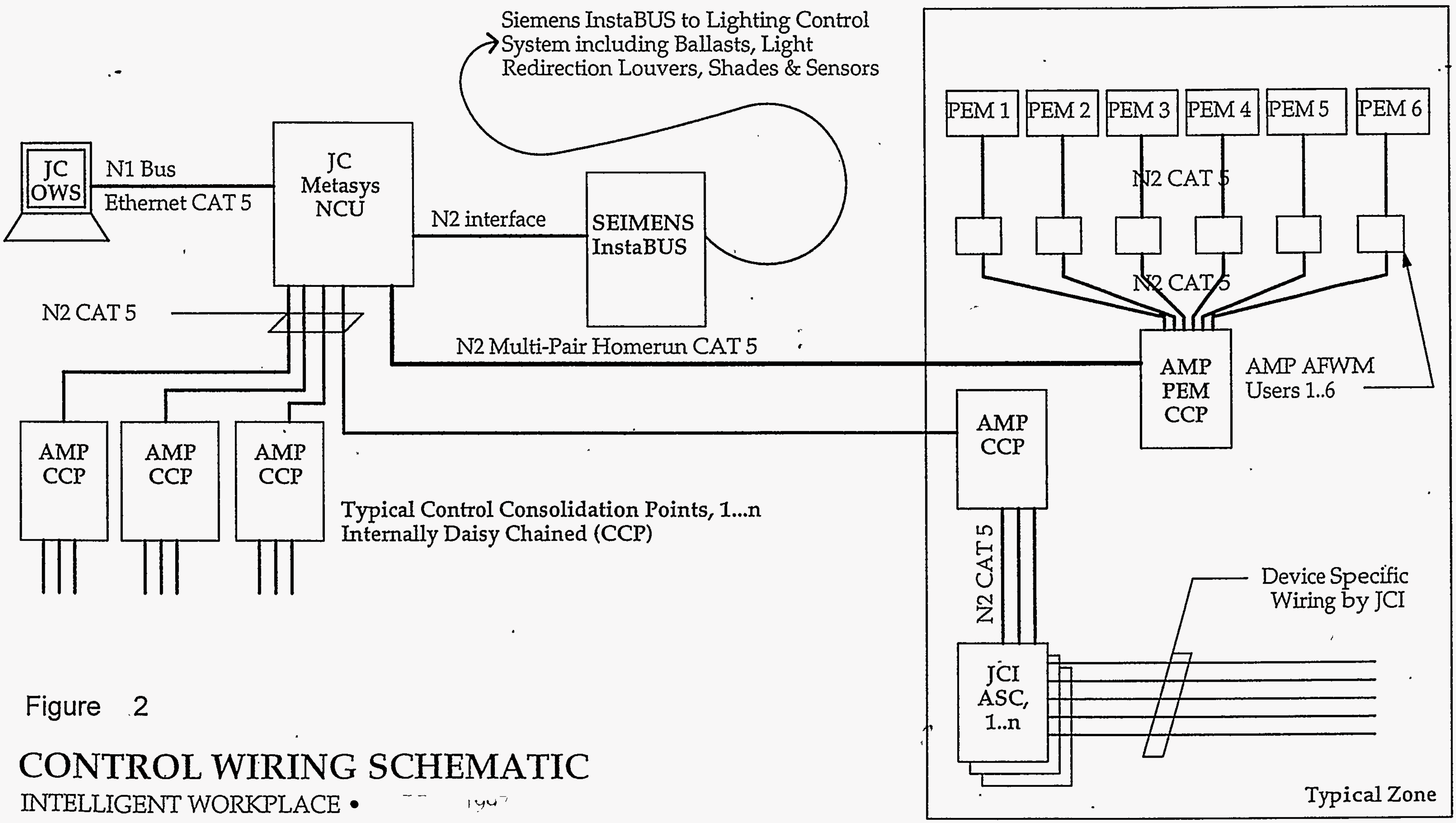



Figure 2

# CONTROL WIRING SCHEMATIC

INTELLIGENT WORKPLACE •