MASSACHUSETTS INSTITUTE OF TECHNOLOGY

JUNE 1, 1999

HVAC SYSTEMS ANALYSIS

Prepared by: Vanderweil Engineers, Inc. M/E/P
Frank O. Gehry & Associates Architects
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Over the past year, Vanderweil Engineers and the Stata Center Design Team have explored various options for the HVAC system in the Stata Center.

Based on the results of this exploration, the Design Team proposed an HVAC system based on the displacement ventilation concept, which distributes conditioned air to occupied spaces through an accessible raised floor.

The proposed system has the following advantages over a conventional Overhead VAV system:

Improved thermal and acoustical comfort

Improved indoor air quality

Spatial characteristics more compatible with the architectural design

More adaptability and flexibility

Better energy efficiency

Better synergy with electrical and data distribution system

Lower first cost

Lower life cycle cost

The June 29 1998 Facilities Program for the Stata Center lists the global Project Goals, as defined by MIT. Among them:

Create comfortable workplace environments with good access to natural light, exterior views and outside air while maintaining appropriate acoustical conditions.

Explore alternatives to traditional office arrangements.

Develop flexible internal floor plan configurations and systems to accommodate short, medium and long-term cycles of the Research spaces.

Incorporate a very flexible data acquisition and delivery system infrastructure that will survive frequent changes in technology.

Explore environmentally responsible systems, new products and technical innovations within the cost parameters established at the end of programming.

Anticipate new technologies such as flat panel displays, speech recognition, wireless networks, electronic whiteboards and video-conferencing.

Select building systems and materials that will be compatible with current Institute maintenance budgets and staffing.

Design for longer life cycles and hence longer pay-back periods.

In response to these goals, the Stata Center Design Team has been investigating building systems that will promote comfort, flexibility and energy efficiency. During the programming and Schematic Design phases, the Design Team looked into the possibility of using climate walls, also known as double-façade systems, which have been built in Europe with great success. Through this investigation, it quickly became apparent that integrating the façade and HVAC systems would emphasize the advantages of climate walls.

However, at the end of Schematic Design, the idea of climate walls or climate windows was abandoned due to budget considerations. The search for potential alternatives to a traditional HVAC system continued. Three new candidates were compared to a traditional overhead VAV system.

These candidates were: a radiant beam system, a radiant ceiling system, and a displacement ventilation system. The results of this study can be found in a separate document, “HVAC Systems Comparison”, prepared by Vanderweil Engineers. The study identified the potential advantages of the Displacement Ventilation system over conventional air or water-based radiant systems, in the context of the Stata Center program and location. Preliminary conclusions drawn by this report led to the inclusion of the Displacement Ventilation system in the Schematic Design (SD) in order to test its compatibility with the architectural scheme and better define its cost.

Since the end of SD, the Design Team has been researching this system further in order to make a formal proposal to the Client Team at the end of the first phase of the Design Development. This is the purpose of this report. It examines the Displacement Ventilation system in terms of comfort, architecture, performance and cost, and compares it to a conventional HVAC system.

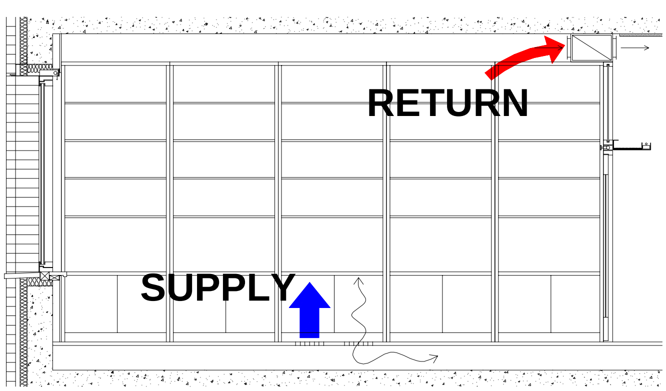
SYSTEM DESCRIPTION

Displacement Ventilation Concept

Displacement Ventilation is an innovative concept for the ventilation and air-conditioning of buildings. It uses the natural buoyancy of warm air to provide improved ventilation. First developed for use in industrial buildings, Displacement Ventilation now enjoys an increasing percentage of market share for many applications throughout the world. It is viewed as proven technology in the Scandinavian countries, where it has been in use since the 1970's. In North America, interest in this type of system is rapidly growing.

Displacement Ventilation differs from conventional HVAC systems in several important ways. Conventional Overhead VAV systems can be thought of as "mixing" systems. Air is supplied at the ceiling at a relatively high velocity and at a temperature about 20°F below the desired room temperature. The supply air mixes with the room air to provide a nearly uniform temperature. Because of the mixing effect, used room air recirculates, resulting in relatively low ventilation effectiveness. In a perfect conventional system, the air being exhausted from the space has the same temperature and contaminant concentration as the room air.

In contrast, Displacement Ventilation systems supply air at or near the floor level at a low velocity and at a temperature only slightly below the desired room temperature. The cooler supply air "displaces" the warmer room air, creating a zone of fresh, cool air at the occupied level. Heat and contaminants produced by activities in the space rise to the ceiling where they are exhausted from the space. The air being exhausted from the space has a higher temperature and higher contaminant concentration than the room air.



Typical office section.

Displacement Ventilation combined with an Accessible Raised Floor

The proposed HVAC system uses the displacement ventilation concept in combination with an accessible raised floor. The underfloor area is utilized as a low-pressure supply plenum. Underfloor ductwork is minimized, and with floor slab insulation, can be eliminated entirely.

Air is distributed at the individual rooms through variable volume supply modules. These modules control the volume of air supplied to the space based on room temperature. They operate at a very low-pressure drop and low discharge velocity. This minimizes generated noise and allows the supply plenum to operate at very low pressure, minimizing air leakage from the floor plenum.

At the air handler, the displacement system is similar to the conventional system. There is, however, one important difference. The displacement system uses a face and bypass configuration at the cooling coil due to the need for humidity contol at the higher supply temperature. When necessary, a portion of the supply air is dehumidified, then mixed with the bypass air to provide the required supply air temperature and humidity. This configuration also provides the opportunity to provide a higher level of filtration for the bypass air, resulting in cleaner supply air to the space.

COMFORT

Compatibility with Operable Windows

The possibility to open windows in offices is a requirement of the June 26 1998 Facilities Program. The future residents of the Stata Center have clearly expressed their desire to have access to exterior air and sounds from their work place.

Operable windows have an impact on the HVAC system, which has to be responsive and able to shut down locally since the main purpose of opening a window is to let exterior conditions influence the interior environment. This response has to be organized in zones in order to allow the level of individual freedom sought by the users. Ideally, each enclosed office should constitute a zone. This is relatively simple to achieve from a technical point of view with most HVAC systems, though it may add significant cost. In the case of the Overhead VAV system, each isolated zone would require a VAV box, which is a fairly expensive solution. In the Displacement Ventilation system, the floor grilles are fitted with a motorized damper for temperature control; this provides the automatic shutoff function at a lower cost. All systems will require ”smart windows” equipped with contacts linked to the shutoff function.

It is more difficult to provide individual freedom, with regards to operable windows inside larger open office areas or laboratories. The Displacement Ventilation system has the advantage of offering smaller control zones (see next section). With this system, it is more likely that windows can be made operable in such spaces without compromising individual preferences.

Though the Displaced Ventilation system will shut down locally when a window is opened in a particular zone, the surface of the floor will remain cool for a certain amount of time. Hence, there is a risk of condensation at the floor surface during the warm and humid months of August and July. This is also the case for an overhead system, even more so since the delivery temperature is lower; condensation may form on the supply grilles and the insulated ductwork. In all cases, this is not considered to be a major problem at this time. It will be studied further with the help of a full-scale prototype. The installation of special indicators on the window frames to inform users of a risk of condensation may be considered.

Finally when windows are opened, wind pressure effects may interfere with the operation of HVAC systems in general. The displacement system is more susceptible to this due to its lower operating pressure. This can be mitigated if “smart window” technology is utilized.

Air Temperature Stratification

Thermal Comfort

Both the displacement system and conventional systems will be able to provide good thermal comfort for the residents of the Stata Center. However, the displacement system offers several features that we believe will increase the likelihood of an individual resident being satisfied with his or her personal environment.

The displacement system offers a minor benefit in that the cool temperature of the raised floor will allow it to act as a thermal heat sink for radiant energy in the room. Based on our exploration of radiant systems, we believe that this radiant cooling effect is likely to improve comfort, as perceived by the residents.

A more significant difference between the proposed system and a conventional system is the relative ease in which the displacement system can be configured to create small zones of thermal control.

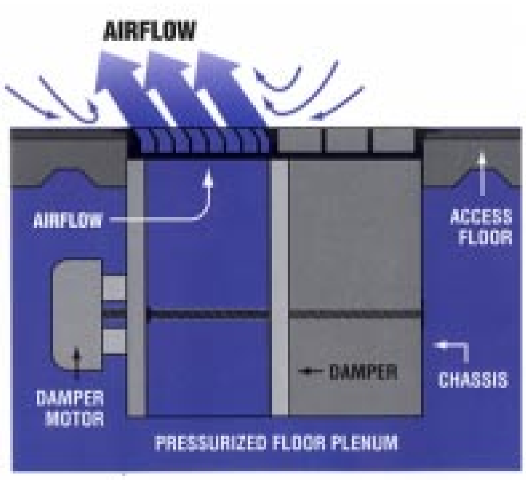
In a conventional system each thermal zone requires a dedicated VAV box. Separate zones for each office can be created, but installation becomes expensive, and the ceiling space may be extremely crowded with equipment. In open areas, the relatively high discharge velocities required by the conventional system limit the minimum size of zones. Typically, open areas are not subdivided into multiple zones of control.

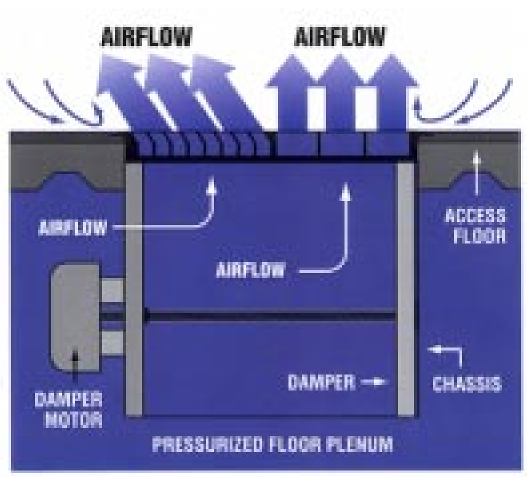
In the proposed displacement system each supply grille is variable volume. Individual grilles can stand alone as a single zone, or can be ganged with other grilles to form larger zones. The effect is equivalent an overhead system with dedicated VAV boxes for each supply grille. In open areas, the low discharge velocity, and the upward movement of air created by the displacement effect help to create individual thermal zones in the area surrounding each grille. This allows each resident individualized control of their personal environment, even in open areas.

The benefits of these individualized zones extend far into the future of Stata. Over time, open areas of the building will get reconfigured. With an overhead system, the original placement of grilles, and arrangement of zoning may be ideal for the original space configuration. But, when the area is rearranged, it is unlikely that the overhead system will be reconfigured for the new space plan. The displacement system offers a major benefit in this regard. The system can be easily modified to provide a new, ideal arrangement for the new space plan. The HVAC system becomes a piece of furniture, to be moved as easily as a desk or computer. With a conventional system, in 2015 the residents of Stata are unhappy because the HVAC is no longer configured for their current usage. With the proposed displacement system, the residents of Stata are still happy in 2015, because the HVAC system has been arranged exactly as they want it to be.

Air Movement

One concern frequently raised about underfloor supply systems regards the presence of "drafts" especially on legs at the floor level. Because the proposed underfloor displacement system utilizes low velocity, high induction grilles at the floor, we believe the possibility of draft conditions is greatly reduced. The proposed system is much different than the old-style computer room floor which many people are familiar with. The level of user control available further reduces the likelihood of complaint caused by the system. Space occupants can quickly and easily modify the airflow patterns from the individual supply outlets by adjusting the grilles. Also, since the relocation of outlets is simple, the residents can modify their placement themselves, on a trial and error basis.





"M.I.T." Floor Grill. (York)

Indoor air quality

The displacement system will result in better indoor air quality in the Stata Center. There are three reasons for this:

1. Displacement Ventilation systems have a higher ventilation effectiveness than overhead systems.

Ventilation effectiveness is a measure of how efficiently fresh air is introduced to a space. It is defined by the following equation:

$$VE = \frac{Ce-Cs}{Cr-Cs}$$

Where:

VE = Ventilation effectiveness

Ce = Contaminant concentration of air exhausted

Cs = Contaminant concentration of air supply

Cr = Contaminant concentration in breathing zone

In a perfect overhead "mixing" system Ce = Cr; therefore the theoretical maximum is 1.0. Often some supply air short-circuits so Ce<Cr. For a typical conventional overhead system, VE = 0.8.

In the displacement system Ce>Cr; this results in a VE=1.2 typically.

In a displacement system the condition of the air in the breathing zone is closer to the condition of the supply air than in the conventional system.

2. Greater utilization of airside economizer – in the displacement system the number of hours during which air is recirculated through the building is reduced. When in airside economizer mode, all contaminants created in the building are exhausted to the outdoors

3. Improved filtration – in a conventional system, recirculated return air is minimally filtered prior to reintroduction to the occupied space. In the displacement system, because of the face and bypass configuration of the air handler, recirculated air passes through high efficiency filtration prior to reintroduction. As a result, supply air has a low concentration of particulates, and other contaminants.

Acoustics

In terms of meeting the Acoustical Program requirements, while both the Displacement Ventilation and the Overhead VAV options can be made to perform for this project with little acoustical challenge for HVAC design, the Displacement Ventilation, in the opinion of the Design Team retains greater, overall acoustical design advantages.

Office occupants in search of HVAC background noise as close to silence as possible will more likely find it in the under-floor supply air system since the supplied air will require considerably lower velocities at the register than the overhead design. While such a quiet ambience presents its own problems in terms of making other intruding noise more apparent (see below), when there are no such intrusions, near silence might be achieved. While such a low ambient noise is not a programmed requirement, the users recognize it as possibly a much-appreciated benefit when it would be available. The appreciation is possible, however, only in the absence of other intruding noises, which, in the very low ambient, might become more annoying than in a higher ambient.

Overall acoustical design implementations are simpler (and possibly less expensive) for the Displacement Ventilation option than for the overhead, ducted option. Of course, special attention has to be given to the design and construction of the floor system. A weight of 10 psf is required for the raised floor in order to control noise bleed between offices with a cavity below the demising wall and air grilles about eleven feet apart. The products that are being considered meet this requirement. A careful placement of the supply modules, avoiding a direct “line of sight” between them, will also mitigate noise transmission. Certain offices may require a very short length of lined, aluminum flex duct attached to the side of the in-floor terminal. This need will be further defined through the testing of a full-scale office prototype.

The one significant acoustical disadvantage of the Displacement Ventilation system involves the fairly clear requirement that an electronic sound masking system of some complexity will need to be designed for both the offices and most of the surrounding areas within about 30ft of the offices. The need is less clear in the case of the Overhead VAV option, although if desired, the complexity of its design is almost equally problematic. Overall the displacement system, combined with sound masking, will offer a wider selection of acoustical environments within the acceptable range.

Floor Sensation

Most of the future users of the Stata Center have experienced the sensation of walking on a raised floor in a computer machine room, where they are commonly found. The floors feel elastic and hollow, which is fine for such specialized spaces but would not be acceptable in corridors, offices and other types of laboratories. Based on this experience, the Client has expressed strong concerns regarding the general use of a cavity floor over the research areas. The existing raised floors in the NE-43 building are built with relatively lightweight steel panels. The Design Team has been looking at heavier products, better suited to a general application.

Two types of floor panels are currently considered. The first one is a lightweight concrete panel with a thickness of 1.5 to 2 inches. A product of this type has been used in the EMR building designed by Frank Gehry and Associates. Client representatives have had the opportunity to walk on this floor, and by their own admission, were not able to tell that it was raised. A similar American product was used for a preliminary mock-up at the site office of the Stata Center Project Team. The comments heard by the Design Team have so far been positive.

The other type of floor panel is a cement-filled steel pan. A large installation of this particular product was “field-tested” by the Design Team and members of the Client Team. The general impression of the walking sensation was not positive. Though the floor felt fairly firm, its hollowness was noticeable. This floor panel type has not been completely discarded yet because it may offer other advantages.

It is our opinion that a concrete panel system will be able to satisfy the Client’s requirement in terms of floor sensation. This opinion can be verified through the “field-test” of an existing installation. The Design Team will organize a visit to a building in the vicinity of MIT shortly after the presentation of this report.

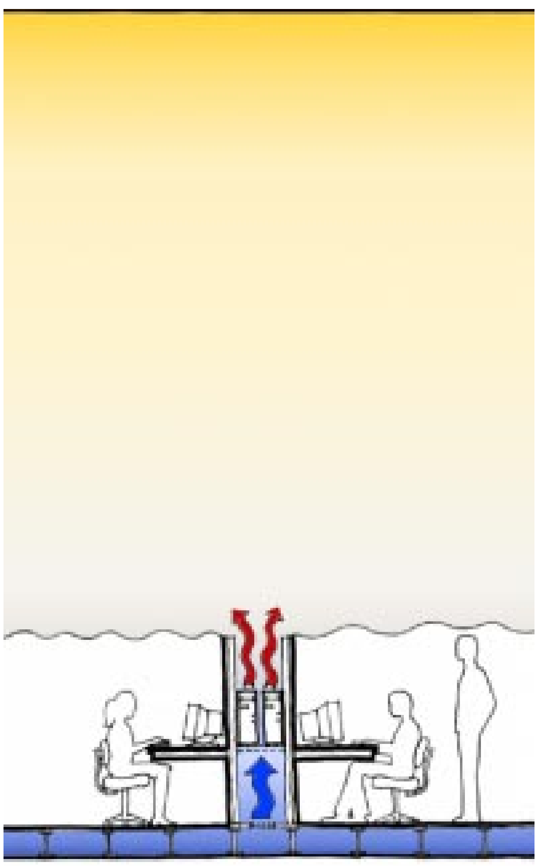
Central Processing Unit Integration

The negative impact of individual Central Processing Units on the work environment has been identified during the programming stage. These units generate a lot of heat, which in a facility like the Stata Center will constitute a large part of the load. In addition, their fans generate a high noise level. It became a goal of this project to better integrate this essential equipment in order to mitigate its impact on the acoustical environment and the building's energy efficiency.

The Design Team and MIT researchers have looked at the possibility of removing the heat generated by CPUs at the source, with a water-based system using a coil installed at the box. The heat would be captured by water instead of being transferred to the room air, significantly lowering its cooling load. At this time, the Design Team has not endorsed this concept for economic and functional reasons.

However, the Displacement Ventilation system may offer a different solution to the same problems. Since the conditioned air is being supplied at the floor where the CPUs usually sit, the displacement effect could be used to transfer the heat to the unoccupied zone (above 6 to 7 feet). The CPUs would have to be stored inside an insulated enclosure, open at the top like a chimney. The enclosure of the CPUs would have several effects on the performance of the HVAC system. First, because the heat from the CPUs is exhausted away from the occupied zone through the enclosure, the cooling load in the occupied zone is reduced. This effect will improve comfort for the residents. It will also reduce the air quantity required for cooling the occupied space, which should reduce overall fan energy consumption. Second, the temperature of return air to the building air conditioning system will be increased. There is minimal net change to the building cooling load, but the higher return air temperature will increase the hours of opportunity for airside economizer operation, reducing overall building energy consumption. In these conditions, heat produced in the enclosures is simply exhausted from the building, with minimal effect on building occupants. So the enclosures should improve comfort, and save energy.

The insulated enclosure would also create an acoustical separation if conventional fan-equipped CPUs were used. But since the floor plenum will provide more than adequate ventilation, the custom enclosure could replace the standard CPU box and its fan, insuring optimum acoustical performance and a more compact installation. The sketch shown here does not go this far and illustrates the potential installation of a cluster of standard CPUs inside a custom-designed enclosure. This may represent a significant advantage of a floor delivery system, particularly for such a computer intensive building.



CPU Ventilation Concept

ARCHITECTURE

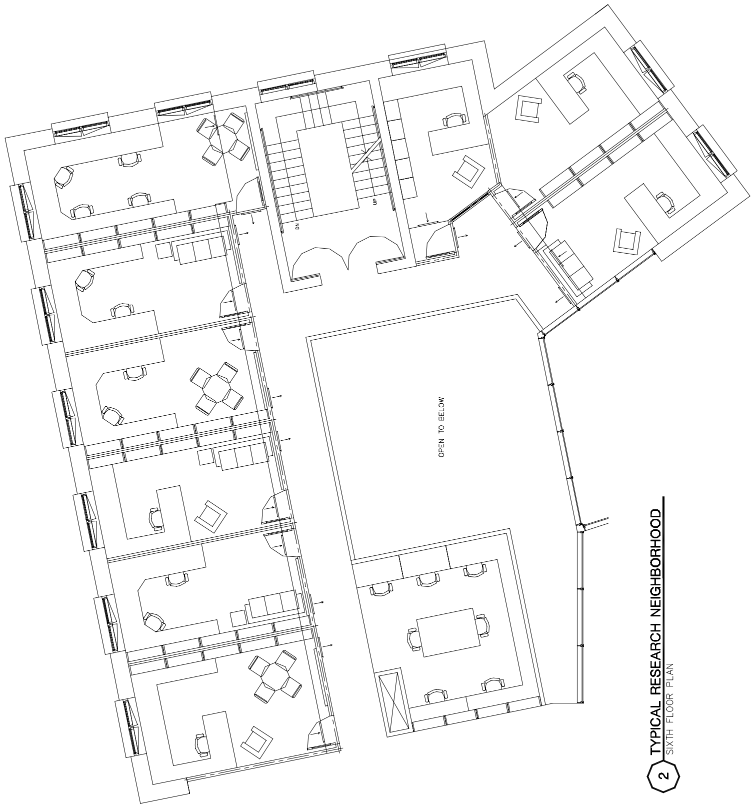
Spatial Characteristics

In the displacement system, horizontal distribution ductwork is minimized. This results in more efficient use of the building volume. The vertical distribution occupies roughly the same volume as the overhead system. The space required for the air handling units is slightly larger with the displacement system because of their configuration. However, this inefficiency is not significant since more than half the overall capacity is generated from units located on the roof.

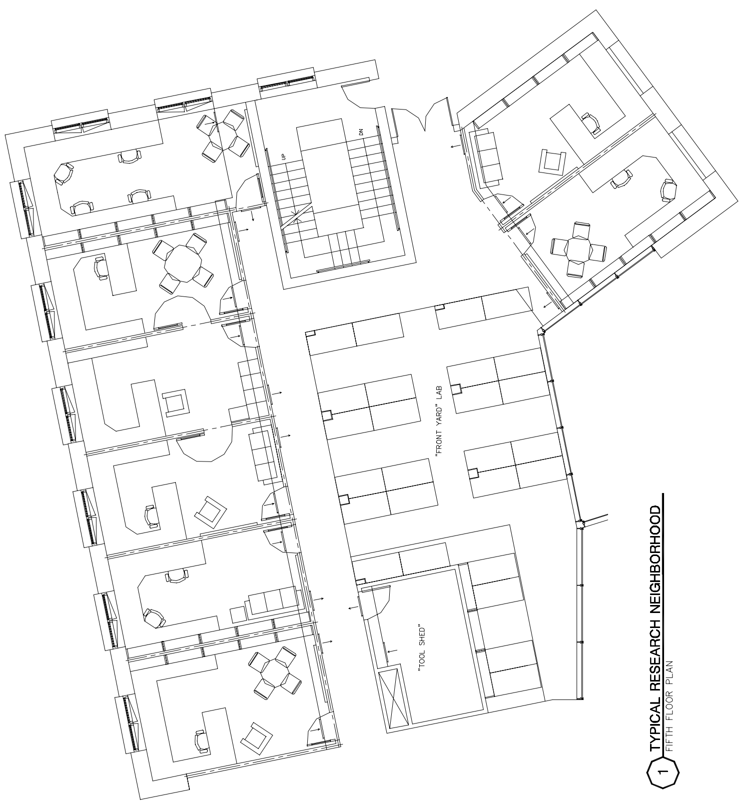
A major architectural advantage of the Displaced Ventilation system is that it requires only minimal ductwork at the ceiling. The system proposed by the Design Team has a duct for air return only at the ceiling of the main corridors used for common circulation. The air is drawn from the research neighborhoods and the larger meeting spaces from a single point. All supply ductwork is concealed in the floor. This eliminates the need for dropped ceilings everywhere except above the circulation mentioned earlier. By comparison, an Overhead VAV system would require dropped ceilings or soffits in all corridors as well as in all rooms exceeding a depth of about 15 feet, which is most of the program.

The absence of false ceilings will contribute to a much “cleaner” interior architecture. The rooms will feel taller and more “solid”.

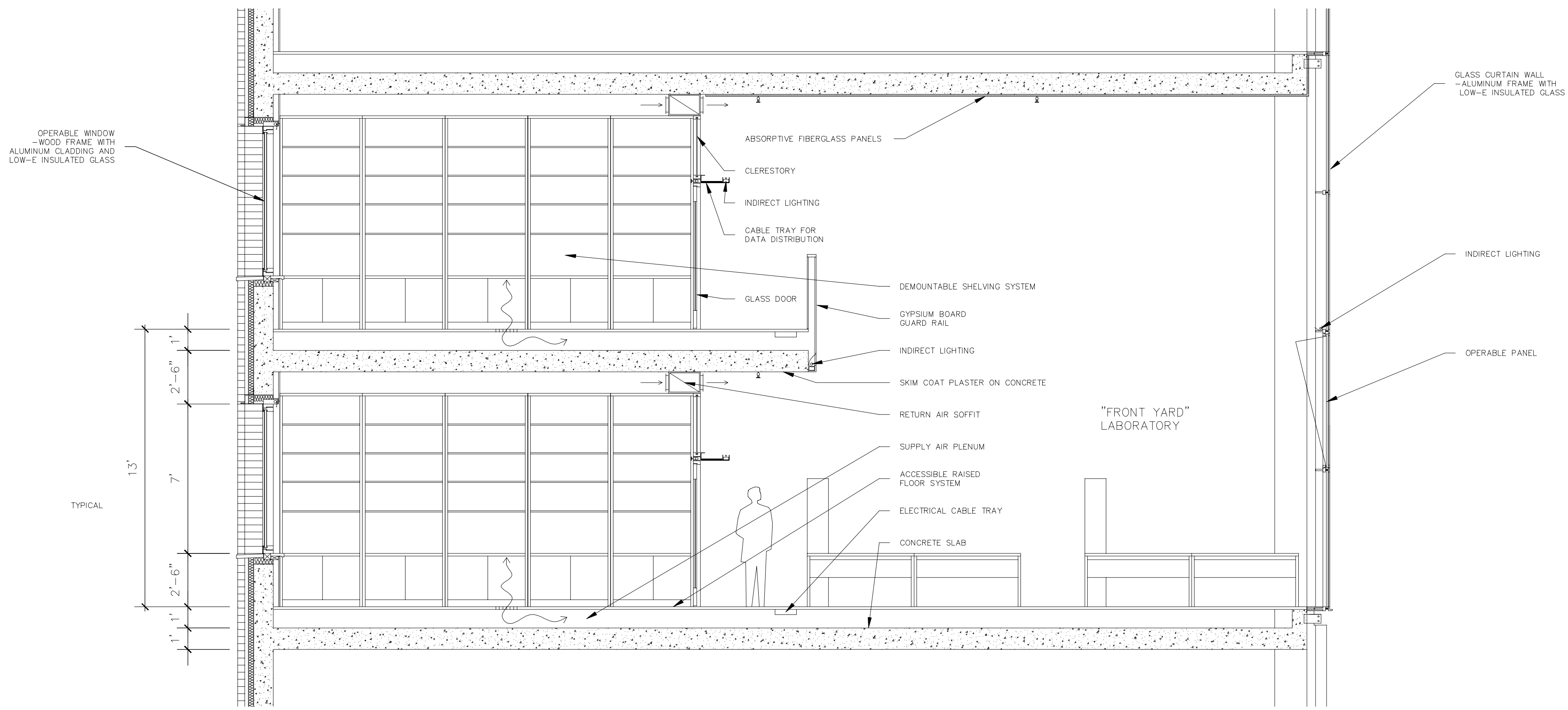
Typical Office.



2 TYPICAL RESEARCH NEIGHBORHOOD
SIXTH FLOOR PLAN



1 TYPICAL RESEARCH NEIGHBORHOOD
FIFTH FLOOR PLAN



3 TYPICAL NEIGHBORHOOD SECTION

1/4"=1'-0"


Carpet


Sealed Concrete


Painted Steel

Finishes

The impression of height and solidity will be enhanced by the fact that most ceilings will be finished with a simple skim coat of plaster applied underneath the concrete slab, without the unavoidable access panels that an overhead ductwork system requires. The acoustical treatment needed at the ceiling of the double-height laboratories is the same for both HVAC solutions.

This also applies to the floor finish in most spaces, which will be carpet. The access floor requires that the carpet is tiled but there are products available that make the joints disappear. In rooms where carpet is not necessary or even required, the exposed floor panels would become a perfectly acceptable finish that compares favorably to the overhead system equivalent, a sealed concrete topping slab. The concrete floor panels introduced can be frameless, without exposed fasteners and tightly butt jointed. Since they are prefabricated, their finish will be more consistent than that of a poured in place topping slab. The steel floor panels, which are currently unsatisfactory in terms of walking sensation, would also offer an interesting finished appearance. They can be painted or sealed.

EMR Building, Bad Oeyenhausen, Germany. Frank O. Gehry & Associates

Spatial Flexibility

The partitions are built on top of the floor in a Displacement Ventilation system in order to maintain a continuous plenum underneath. This is possible because the raised floor constitutes an acoustical barrier. Since there are no ceiling conditions to deal with above, the partitions can be easily added or relocated. In order to achieve the same degree of partition flexibility, an overhead system would require a continuous dropped ceiling of a significant mass, for acoustical separation, which is not found in typical drywall or tiled installations. This would also result in a loss of room height since the ceiling plenum would most likely be deeper (typically 24 inches) than its floor equivalent (12 inches in our case).

But the most significant advantage of the Displacement Ventilation in terms of flexibility of layout and operation, is the fact that conditioned air is available at almost any given point of the floor plate. Only the panels located under fixed partitions and heavy pieces of furniture and equipment will not be readily available. This availability is also within reach of the user; floor grilles can be moved without the help of specialized personnel and modifications to the air delivery system do not require modifications to the fixed interior construction. HVAC points can be relocated to accommodate the movement of workstations and can be added to accommodate an increase in capacity in terms of people or equipment.

The accessible raised floor in itself offers more flexibility than a low-profile cavity floor, which would complement an overhead HVAC, in terms of access to the electrical distribution system. This will be addressed later. However, the raised construction also limits the use of the floor surface for certain activities; for example, the Leg Laboratory will have to be directly on the concrete slab.

PERFORMANCE

Energy Efficiency

One measure of performance of an HVAC system is its energy consumption. As part the Design Team's exploration of the various systems, Vanderweil Engineers has performed computer simulations of the different alternatives. The results of these simulations indicate that the Displacement Ventilation system is likely to consume less energy than the Overhead VAV system.

The primary reason for this is found in the proposed system's higher supply air temperature. Because the displacement system has a supply air temperature approximately 10°F warmer than the conventional system, the displacement system has more opportunity to take advantage of the air-side economizer cycle, naturally cooling the building using outdoor air instead of mechanically cooled air. This reduces the hours when chilled water from the MIT Central Plant is used.

Because the supply air temperature is 10°F closer to the peak outdoor temperature, the peak ventilation load is reduced in the displacement system. This results in a lower peak-cooling load than the conventional system.

These two factors; 1) increased use of economizers, and 2) reduced peak cooling load allow the displacement system to consume less energy than the conventional system.

Energy usage simulation of the Stata Center, using the DOE-2 energy simulation computer program, show energy consumption as follows:

System Energy Consumption	
Conventional VAV	39,300 btu/sf/yr
Displacement System	30,500 btu/sf/y
	22% reduction

If we apply the current MIT utility billing rates to the utilities consumed:

System Energy Cost	
Conventional VAV	$0.69/sf/yr
Displacement System	$0.55/sf/yr

Load Flexibility

Because Displacement Ventilation is a variable volume system it will adapt to changing loads as easily as the conventional overhead system. The displacement system has an additional advantage in that it can be easily modified if space usage is changed. If the existing configuration is inadequate to condition the space due to increased loads, more floor outlets can be added quickly and easily.

Heat Recovery

Because the return air temperature from the displacement system is warmer than from the conventional system, there are increased opportunities to recover this excess heat for other usage. This may be particularly interesting in the case of the Stata Center where exterior snowmelt systems will be required at the Upper Terrace and Raised Garden.

Thermal Mass

The displacement system can be operated in a manner that allows thermal storage using the building's mass. In the cool evening hours, outside air can be used to cool the building, and especially the floor slabs, down to a minimum temperature. The cooled floor slabs will act as a heat sink throughout the warmer daylight hours, reducing building demands for mechanical cooling. The conventional system cannot be operated in this manner.

Synergy with Electrical and Data Distribution System

Independently of the HVAC system, the Design Team is proposing to distribute power through the floor and data in overhead cable trays. Power distribution will be more functional and flexible with an accessible raised floor, compared to a low-profile cavity floor or a "walkercell" system, which would complement an overhead HVAC system. It will be possible to install power outlets at any point of the floor plate, as was the case with the air supply grilles. The floor plenum will also be able to accommodate data distribution. This capacity will be available to supplement the overhead cable tray network and perhaps even replace it inside the double-height laboratories and open office areas.

Fire-safety Requirements

The building in general will have a fully compliant high-rise, analogue, addressable, supervised, alarm system in accordance with MIT standards. Smoke detectors are not required by code to be installed under the raised floor, as proposed in the SD submissions. Where server rooms or other computer systems requiring large cable systems are built-out and where the plenum space is utilized for the management of data cabling, detectors will be added per the standards for computer room detection.

Structural Capacity

The structural capacity that has been programmed for the research spaces is 125 psf in the Warehouse and 80 psf in the Towers. All raised floor systems currently under consideration can take a load of 125 psf or more.

Maintenance

The issue of cleanliness is frequently raised regarding raised floor systems. The classic concern is the spilled cup of coffee. While it is true that some dirt and dust will end up below the floor, this effect will be mitigated by the pressurized nature of the plenum. All air distribution systems eventually require cleaning. The underfloor system has a greater likelihood of being cleaned since the active elements of the HVAC system are located under the raised floor where they are more easily accessible than overhead. The much smaller quantity of supply air ducts also makes ductwork maintenance less significant.

Compatibility with Wet Laboratories

Though it would no longer be accessible, the raised floor surface can be made waterproof for certain laboratory uses. The required drainage piping would fit inside the floor cavity. The air supply can be transferred from the plenum to the base of the perimeter walls, which would be thicker than normal partitions to accept ventilation ducts.

COST

First Cost

Beacon Skanska has prepared an HVAC cost analysis as a follow-up to the Schematic Design cost estimate. This analysis compares the cost of the Displacement Ventilation system to the cost of an Overhead VAV system with two floor system options, a low-profile raised floor and a localized “walkercell” system. The analysis is based on Schematic Design plans and quantities and encompasses not only the HVAC system but also the electrical, sprinkler and interior components. It shows net savings of at least $86,000 and as much as $470,000 depending on the floor system

In addition to these savings to the construction budget, there is a direct savings to MIT in required capacity at the central plant. We estimate the peak building cooling load to be 105 tons less if the Displacement Ventilation system is used, compared to the conventional system. This is 105 tons, which MIT avoids installing in their central plant. At an estimated cost of $2,000 per ton for central plant capacity, this is an avoided cost of $220,000.

Life Cycle Cost

In addition to the reduced first cost, the displacement system offers energy cost savings, as we have discussed above.

A life cycle cost analysis based on a 20 year life and 5% interest rate shows:

Life Cycle Cost – Displacement vs. Overhead

Minimum Construction Cost Savings
$86,650

Estimated Avoided Plant Capacity
$220,000

Estimated Energy Cost Savings/Yr.

$42,833

Estimated Total Savings over 20 years $830,444

Net Present Value of Estimated Savings $533,793

The displacement system appears to save at least a half million dollars, over a 20-year life.

Another factor influencing life cycle cost, which we have not estimated, is the cost of reconfiguring the system. In a typical building, the interiors are reconfigured fairly regularly. A typical "churn" rate (based on surveys of building owners) for a commercial office building can be as high as 40% per year. The Stata Center research spaces may not reconfigure as often as a standard commercial building but they will probably have a shorter configuration life than most MIT facilities. The underfloor system will be significantly less costly to reconfigure than the overhead system. Depending on the rate of building reconfiguration, these savings could be several times larger than the savings due to energy costs or initial construction costs.

Raised Floor/HVAC Cost Analysis vs. Displaced Ventilation System

Category	Displacement Ventilation System Per 100% Schematic Estimate Description	Value	Overhead VAV System Option A Channel Floor Description	Value	Overhead VAV System Option B "Walkercell" System Description	Value
06 INTERIOR CONSTRUCTION						
06 INTERIOR CONSTRUCTION	Accessible 12" raised floor (Based on 249,520 sf @8.00)	Included	"Channel Floor" (Based on 249,520 sf @ $1.25 channel floor material, $1.50 channel floor installation & $2.75 for topping)	-623,800	"Walkercell" system in the laboratories, warehouse and associated area with topping slab. All other areas scheduled to receive raised floor in 100% schematic estimate shall remain without raised flooring. (Based on 70,475 @ 10.00 for walkerduct & 4.00 for 4" topping)	-1,009,510
Ceiling	Skim coat plaster on concrete Gypsum board dropping ceiling Gypsum board soffit Absorptive fiberglass panel	Included	Skim coat plaster on concrete Gypsum board dropping ceiling Gypsum board soffit Absorptive fiberglass panel (Differences are not in the systems but in the quantities. Most ductwork is concealed)	$453,410	Skim coat plaster on concrete Gypsum board dropped ceiling Gypsum board soffit Absorptive fiberglass panel (Differences are not in the systems but in the quantities. Most ductwork is concealed.)	$453,410
08 HVAC						
Overview	Space is conditioned by air supplied through raised floor. Individual zones are controlled by variable volume supply modules located in the floor. Air quantily is approximately identical to VAV system.	Included	Space is conditioned by air supplied from supply grilles located at ceiling. Individual zones are controlled by VAV boxes mounted above the hung ceiling. Air quantity is approximately identical to Displacement system.	See Below	Space is conditioned by air supplied from supply grilles located at ceiling. Individual zones are controlled by VAV boxes mounted above the hung ceiling. Air quantity is approximately identical to Displacement system.	See Below
Plant	Identical in each system	Included	Identical in each system	No Change	Identical in each system	No Change
Air Handling Units	6-60,000 CFM AHU's with face and bypass on the cooling coil.	Included	6-60,000 CFM AHU's. Identical to Displacement system except that face and bypass is not required.	Minimal Change	6-60,000 CFM AHU's. Identical to Displacement system except that face and bypass is not required.	Minimal Change
Vertical Ductwork	Identical in each system	Included	Identical in each system	No Change	Identical in each system	No Change
Horizontal Distribution Ductwork-Supply	Raised floor is used as a pressurized plenum for supply air distribution. Ductwork is minimized, limited to insulated ductwork to within approximately 50 ft. of each supply outlet.	Included	Typical VAV system. Medium pressure duct loop runs throughout ceiling space, connecting to each VAV box.	$817,500	Typical VAV system. Medium pressure duct loop runs throughout ceiling space, connecting to each VAV box.	$817,500
Horizontal Distribution Ductwork-Return	Return mains located in common corridor ceiling space. Areas without hung ceilings shall have open return.	Included	In hung ceiling areas, return air plenum will be utilized. Elsewhere, return shall be ducted.	Included	In hung ceiling areas, return air plenum will be utilized. Elsewhere, return shall be ducted.	Included

Raised Floor/HVAC Cost Analysis vs. Displaced Ventilation System

Category	Displacement Ventilation System		Overhead VAV System Option A		Overhead VAV System Option B	
	Per 100% Schematic Estimate		Channel Floor		"Walkercell" System	
	Description	Value	Description	Value	Description	Value
Zoning	Each room shall be an individual zone of control.	Included	Ideally, each room shall be an individual zone of control. As a value engineering item, grouping of areas with identical exposures onto a single zone may be considered.	No Change	Ideally, each room shall be an individual zone of control. As a value engineering item, grouping of areas with identical exposures onto a single zone may be considered.	No Change
Zone supply systems	Floor VAV supply modules, York model MIT or similar.	Included	Single-duct VAV boxes, with or without hot water reheat, with sound attenuator, will be used to provide control of individual zones. Low pressure distribution ductwork shall connect VAV boxes to room distribution devices.	-540,000	Single-duct VAV boxes, with or without hot water reheat, with sound attenuator, will be used to provide control of individual zones. Low pressure distribution ductwork shall connect VAV boxes to room distribution devices.	-540,000
Perimeter heating system	In perimeter zones, floor supply modules shall be connected to a fan-powered hot water heating unit. Hot water supply and return piping shall loop the floor connected to each heating unit.	Included	In perimeter zones, VAV boxes shall include hot water coils, for heating. In some curtain wall areas, additional heating in the form of tin-tube radiation will also be required. Hot water supply and return piping shall loop the floor connected to each unit.	See Zone Supply Systems	In perimeter zones, VAV boxes shall include hot water coils, for heating. In some curtain wall areas, additional heating in the form of tin-tube radiation will also be required. Hot water supply and return piping shall loop the floor connected to each unit.	See Zone Supply Systems
Inlets and outlets	Floor supply modules shall be used for supply distribution. Return grilles at corridor soffit shall be sidewall type.	Included	Ceiling supply devices shall be square ceiling diffusers in open areas, and linear diffusers at windows and curtain walls. Return grilles in plenum areas shall be square perforated or louvered type.	$292,500	Ceiling supply devices shall be square ceiling diffusers in open areas, and linear diffusers at windows and curtain walls. Return grilles in plenum areas shall be square perforated or louvered type.	$292,500
10 SPRINKLERS						
Sidewall sprinklers	The sprinkler system shall be installed to conceal piping loop in the soffit around perimeter offices with sidewall sprinkler heads utilized. Refer to schematic plans and system description for more information.	Included	Change all sidewall sprinkler heads to concealed pendant heads in areas receiving ceiling that were previously plastered slab. This creates more branch piping.	$72,750	Change all sidewall sprinkler heads to concealed pendant heads in areas receiving ceiling that were previously plastered slab. This creates more branch piping.	$72,750

Raised Floor/HVAC Cost Analysis vs. Displaced Ventilation System

Category	Displacement Ventilation System		Overhead VAV System Option A		Overhead VAV System Option B	
	Per 100% Schematic Estimate		Channel Floor		"Walkercell" System	
	Description	Value	Description	Value	Description	Value
ELECTRICAL	The electrical system for the raised floor displacement scheme consists of a modular under floor wiring system similar to Tate Flex with floor box outlets. In the Towers, for the perimeter offices utilizing fixed dry wall partitions, standard wall outlets may be used in lieu of the floor box outlets. Note, wall outlets to be connected to the modular under-floor distribution with plug-in fitting. Refer to schematic plans and system description for further information.	Included	The Electrical system for the low profile raised floor scheme would have conventional wiring vs. the modular under floor wiring in the displacement scheme. In the towers, for the perimeter offices utilizing fixed drywall partitions, standard wall outlets will be used.	No Change	To accommodate MIT's request for flexibility and the higher power consumption rates expected for the open labs and warehouse areas, we recommend the Walkercell system rather than the Walkerduct system. The Walkercell system has a larger capacity for cable and power receptacles in the floor activation boxes. The following grid/spacing criteria should meet there requirements:	No Change
					1. Walkercell WRC1 series with prepunched preset openings 24" on center and PK series preset extensions with activation boxes 48" on center (capable of 2 duplex receptacles and 2 low tension outlets). Each walkercell WRC1 assembly should be separated six (6) feet on center (which allows an activation box grid of 4' by 6' with capacity to modify to a 2' by 6' grid). 2. A Walker trench headers should be provided perpendicular to the walkercell assemblies at a 50 foot spacing. Smaller areas (less than 2500 sf) may be equipped with one trench header centered through the space. 3. Underfloor wiring would be conventional vs. the modular.	
Premium Cost vs. Displaced Ventitation System		**Included**		**$472,360**		**$86,650**

Notes:
1. Floor options do not include finish flooring costs.
2. Concrete topings may affect structural design. These costs have not been considered at this time.
3. Slab depressions to accommodate 12" raised flooring have not been included.
4. Low profile raised floor is based upon present interface system used in construction mock-up at Mit Stata field offices.

CONCLUSION

The Design Team strongly recommends a Displacement Ventilation approach, combined with an accessible raised floor, for a majority of the Stata Center program spaces. In our opinion this approach is well suited to the architectural design and project goals. Relative to a traditional Overhead VAV system, the Displacement Ventilation system will:

Provide more comfortable interior conditions

Facilitate the design of a more pleasant interior architecture

Be more energy efficient and environmentally responsible

Offer a lower installation cost and significantly lower life-cycle cost

A final decision between a floor system and a ceiling system is required at this stage of the process to allow the architectural and technical design to reach the next level of detail. If the recommendations contained in this report are approved, the Design Team will continue to develop the Displacement Ventilation strategy, and investigate additional measures to increase the effectiveness of this system. A mock-up program will be set up to test and optimize the technical and architectural properties described in this document. One enhancement under consideration is to introduce a radiant cooling component in the Displaced Ventilation system to increase its energy and spatial efficiency. This modified approach would only affect the dimensions of the HVAC system in a positive way and would not provoke significant architectural and technical design changes at a Design Development level. This would be the object of further research in the coming weeks and would be addressed in an upcoming report.