AEI Team #04-2013

February 22, 2013

Mechanical Design

Team 04-2013

Our one true aim is to enhance the quality of the communities we work with through innovative ideas and an integrated design approach.

Ingenuity | Quality | Enjoyment | Integrity

Contents

Executive Summary

The mechanical team has addressed the design and construction issues that were essential to the development of a new elementary school to be located in Reading, PA. After reviewing the project requirements, **two separate construction phases** were proposed, with the first being for the elementary school and the second for the clinic and natatorium space. **Three separate mechanical systems** will be used, one for the school, clinic and natatorium.

Upon our analysis it was determined that a **ground source heat pump system** would provide the necessary thermal comfort to condition the spaces and allow the building to consume less energy. Design calculations supported the use of a split system for the ventilation and terminal units. By separating these systems, five dedicated outdoor air units will take the majority of the sensible and latent loads allowing for smaller terminal units ranging in size from ¾ to 3 tons.

The second construction phase was proposed as an add/alternate for the clinic and natatorium space. The proposal provides the owner the choice to proceed with construction for this element. The mechanical system for the clinic space was considered separately. Adhering to the team's assumptions for conditions of the existing school, the mechanical team designed a retrofit for the mechanical system to keep the clinical project low cost while reaping as many other benefits as possible. The proposed **variable refrigerant volume (VRV) system** with heat recovery was designed for low maintenance and a long life. It offered redundancy, energy efficiency, and sustainability, all critical characteristics for the space. The mechanical system for the natatorium included **an all-encompassing air handler unit** allowing for a space unique operating schedule and adequate control of the humidity and temperature in the pool area.

Introduction: The mechanical specific project goal was to create a system that stimulates involvement in the classroom and provides an inviting work environment. The primary BIM goal regarding the building's mechanical system was to **reduce the energy consumption** of the building **through the coordination** of all disciplines. Project requirements heavily influenced and guided all controversial and tradeoff decisions during the design process.

Project Performance Goals

- ***Accessible***
- ***Adaptable***
- ***Energy Efficient***
- ***Sustainable***
- ***Secure***
- ***LEED Certified***

INFLUENCE

Mechanical System Responsibilities

- ***Heating & Cooling Loading***
- ***Mechanical System Design***
- ***Plumbing Design***
- ***Energy Saving Analysis***
- ***Building Automation System***
- ***Value Engineering***

What We are Doing To Integrate: Building Information Modeling between all four disciplines, construction management, structural, lighting/electrical, and mechanical, led to the design of a fully integrated elementary school. Three primary aspects affecting the integration of the mechanical design process included the site, enclosure and mechanical system. The site conditions were analyzed to determine the best location and orientation for the school based on HVAC design, day lighting, constructability, security, and pedestrian flow. Providing flexibility for a geothermal field was a mechanical design consideration during the site planning stage. Rooftop unit locations were coordinated with the structural designers to ensure that the structure in place could support the load without requiring extra members and to avoid long duct runs. Plenum and shaft space was coordinated between lighting/electrical, mechanical, and structural to find the best usage of space. The enclosure was heavily coordinated between all options as structure had to support the load, construction had to find a cost effective constructible solution, and mechanical and lighting/electrical had to analyze day lighting vs. heat transfer aspects. With all of the adopted integration design solutions, the team was able to save the energy, money, and space.

Summary of Mechanical Design Process: The mechanical team considered the site, enclosure, interior spaces, and various systems prior to selecting the final system and sizing the associated equipment. All four disciplines analyzed the site conditions and determined the best location and orientation for the school, clinic and natatorium. With the site layout finalized, a baseline load using the minimum requirements set by ASHRAE 90.1 was calculated using Trane Trace 700. To achieve the project performance goals, methods of reducing the total energy consumption and the design load were addressed.

Construction Phase 1: The elementary school enclosure was evaluated between all options while keeping energy efficiency and constructability in mind. To select enclosure materials reducing the energy consumption of the building, the ASHRAE 30% and 50% energy savings guides for K-12 schools were used. The enclosure **design reduced the energy consumption by 15%.** With the exterior design completed, the mechanical system could be addressed. The building layout and interior spaces were analyzed and ventilation zones were determined. Based on design goals, several mechanical systems were run in Trace and compared to the baseline calculation. Following an analysis of the results, a **ground source heat pump system** with designated outdoor air system to condition the school was chosen. The ground source heat pump system **reduced the energy consumption by 17%.** Research was then conducted to properly size the equipment. From the various decisions, the elementary school **had a 32% energy savings**. The plumbing design of the elementary school was designed to **reduce the water usage of the building by 45.7%** and will save the school $9,160 per year.

Construction Phase 2: Assumptions for the clinic and natatorium were made before comparing mechanical systems and making a final system selection. Appendix O of the integration paper provides a list of all assumptions. All enclosure elements were assumed to meet the ASHRAE 90.1 baseline conditions for the purpose of calculating our heating and cooling loads to compare various systems. Both modular chillers and variable refrigerant volume systems were compared to the baseline calculation for the clinic space. A **variable refrigerant volume system** with heat recovery was selected for retrofit, space, and maintenance purposes. The variable refrigerant volume system **reduced the energy consumption of the clinic space by 13%.** Pool specific air handlers were researched to find one most compatible for the space. An air handler with a reheat, exhaust, purge and event mode was chosen based on the several uses for the pool. By using the heat recovery system to help heat the pool water, **1,399 MMBTH and approximately $3,850 per year were saved**.

Site

The proposed location for the elementary school was an urban setting located in Reading, Pennsylvania. The existing buildings and new construction occupied a one block area on the corner of North Thirteenth Street and Amity Street. Figure 1a and 1b below illustrate the revision of the site plans.

(a) *(b)*

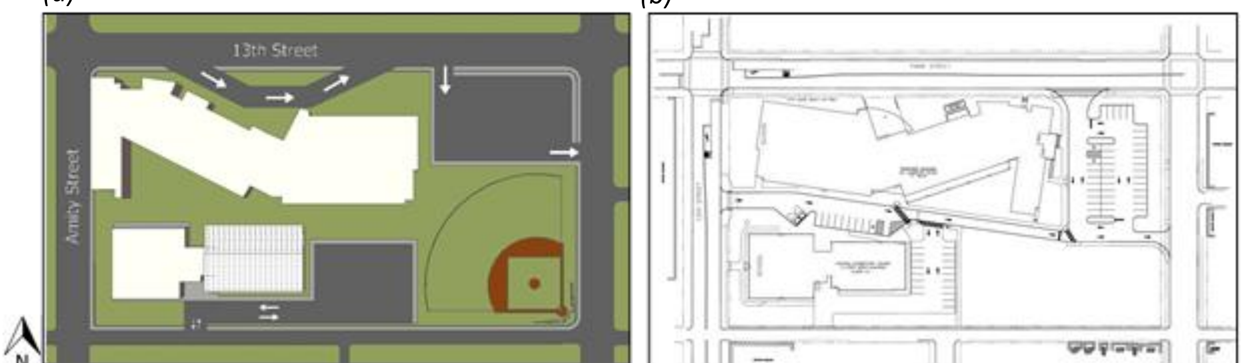


Figure 1. Site Plans for (a) proposed layout (b) original provided by AEI.

To minimize the building operating costs, the orientation of the building was considered. The original building plan provided by AEI was mirrored along the Y-axis and then rotated to allow for more usable outdoor space in a moderately dense urban environment. When making changes to our site, energy efficiency was considered. South-facing windows optimized the amount of sunlight entering the classrooms while maintaining adequate thermal control. Overhangs and other sun control devices were selected to prevent unwanted glare and solar overheating while maximizing thermal gain during winter months. The gym was located on the northern side to limit solar heat gain in a space primarily in cooling mode year round. The glazing on north also optimized day lighting and view. For details about the lighting optimization see the lighting/electrical report.

Construction Phase 1

With the site adjusted, enclosure determined, and mechanical system selected for the elementary school, Trace analyzed the energy savings of the proposed changes versus the baseline scenario. There was a 32% reduction of total building energy consumption. Figure 2 below diagrams the energy use intensity.

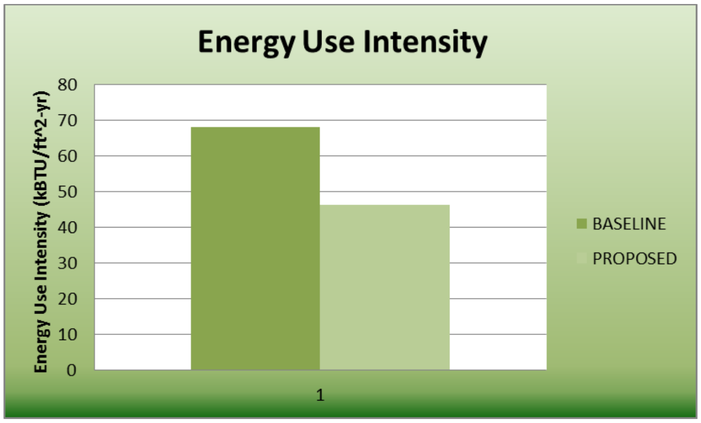


Figure 2. Energy Use Intensity with Proposed Materials and System Selection

Enclosure

The mechanical specific goal of the enclosure was to reduce the energy consumption of the building. Because of this goal, it was extremely important to encompass all disciplines as well as address each aspect of the enclosure. The primary components of the enclosure were the facade, comprised of both the walls and fenestrations, and the roof (including the green roof).

Enclosure Design Process: In designing the enclosure, the requirements as set forth by ASHRAE 90.1 were considered. The standard provides code for maximum U-values for all elements of the enclosure. Wall, window, roof and floor thermal properties are a major contributor to the load in a space. To determine our target U-value for all enclosure elements we followed the ASHRAE 50% energy savings design guide for K-12 schools. Lastly, to verify that our enclosure would achieve energy savings, an energy simulation was run in Trane Trace 700.

Wall Design Criteria

ASHRAE 90.1 Required U-value = 0.069
ASHRAE 50% energy savings recommended U-value = 0.037

Wall Selection Process: In order to select a constructable, cost-effective wall capable of meeting our target U-value various manufacturers were contacted. A CarbonCast High Performance Insulated Wall Panel was finally selected for the enclosure. This wall can be constructed to meet an R-value as high as 30 and has the capability to incorporate any facade veneer of choice and will cost $27/SF. Figure 3 provides a detailed section of the wall panels.

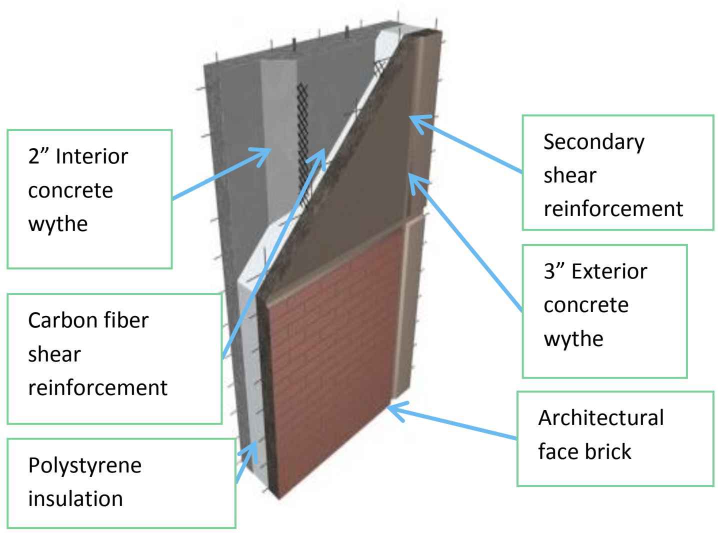


Figure 3: Typical Precast Panel Section (High Concrete Group LLC 2010)

Wall Material Selection Results

Concrete R-Value = 0.18 ^{O}F-ft^{2}-h/Btu-in (MEEB Table E.1 P. 1562)
Expanded Polystyrene Insulation R-Value = 5 0.18 ^{O}F-ft^{2}-h/Btu-in (MEEB P. 1552)
Brick/Limestone R-Value = 0.18 0.18 ^{O}F-ft^{2}-h/Btu-in (MEEB P. 1558)
Total R-Value = 0.18*6 + 5*5 = 26.08 (U-value = 1/R-Value = 0.383 BTU/h-ft^{2}-^{O}F)

Window Design Criteria

ASHRAE 90.1 Requirements: U-Value = 0.55, SHGC = 0.4,

ASHRAE 50% Energy savings recommendation: U-value = 0.45, SHGC = 0.5, VT = 0.63

Window Selection Process Trace analyzed various window types, sizes and shapes for possible energy savings. The energy savings were compared to a daylight analysis. For further daylight analysis, please view the lighting/electrical report. After compiling results, an energy efficient window of economical size was purchased at a reasonable cost of $6.85/SF.

Window Material Selection Results

Our Window: A double high performance tint with argon window was selected and had the following properties: U-Value = 0.54, SHGC = 0.4, VT = 0.6. An overall window to wall ratio as stated by ASHRAE is to be under 40%. The proposed window to wall ratio for this elementary school is designed at 29.5%. Figure 4a and 4b diagram the window energy use comparison during the heating and cooling seasons respectively.

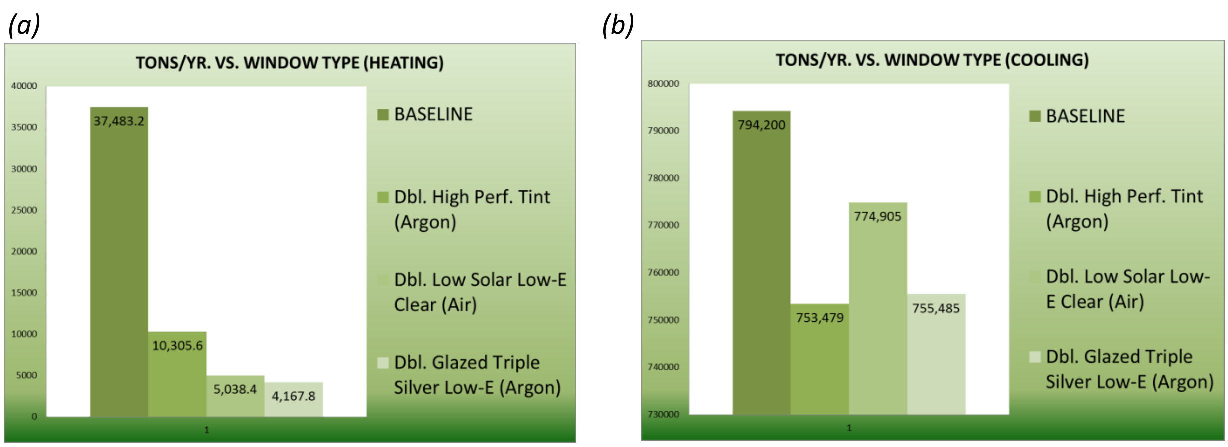


Figure 4. Window Energy Use Intensity for (a) heating, (b) cooling

Roof Design Criteria

ASHRAE 90.1 U-value = 0.048 with insulation entirely above deck, c.i.

ASHRAE 50% energy savings recommended U-value = 0.0333 with c.i

Solar reflectance = 0.55 for three year aged

SRI = 64 for three year aged

Roof Selection Process: To achieve the target U-value various roof assemblies were analyzed. It was determined that a target value of 0.0333 BTU/hr-ft2 ^{o}F and constructability of the roof at $45.15/sf was achievable. It was also important to consider using continuous insulation. Continuous insulation is important in order to keep framing members from by-passing the insulation and causing a thermal bridge in our roof. For a detailed section of the roofing materials see Figures 5a-5c below.

Roof Material Selection Results

Our Roof: U-value = 0.0333 with continuous insulation (c.i.), solar reflectance = 0.55, solar reflectance index = 64

Green Roof Analysis: Using energy prices of $0.165 electricity per kWh and $1.20 utility (piped) gas per therm, the energy savings of various green roof choices were analyzed. The analysis was based on a roof area of 5313 SF of which the green roof covers 80%. The remaining 20% had pavers for the school children to access and have class. A summary of the calculations are in Table 1.

Table 1. Sample Green Roof Savings Data

Depth (in)	Irrigated?	Energy Savings compared to Dark Roof	Energy Savings Compared to White Roof	Runoff (in) 1
2 in	No	$408.63	$244.25	16.5
2 in	Yes	$419.48	$255.10	25
4 in	No	$433.09	$268.71	14.6
4 in	Yes	$444.28	$279.20	22.6
6 in	No	$445.14	$280.76	11
6 in	Yes	$455.40	$291.02	18.6

[1]For reference, a conventional roof had 39.6 in of runoff annually.

(a) *(b)* *(c)*

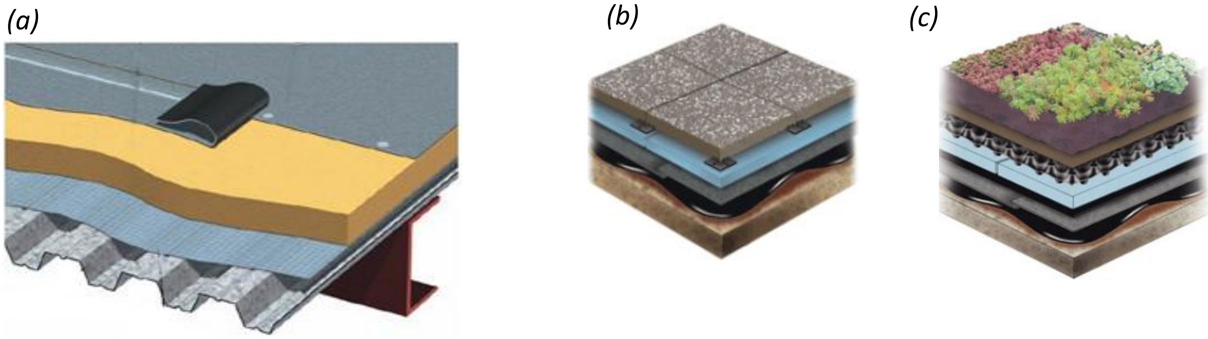


Figure 5. Roof sections of (a) general roof (Tegral, 2012), (b) green roof pavers assembly (American Hydrotech Inc., 2013)*, and (c) extensive green roof assembly* (American Hydrotech Inc., 2013)

Roof Drain Calculations: When designing the roof, the size of roof drains and gutters for our storm water system was determined. In order to calculate the proper size of our drains and pipes, guidelines set forth in the International Plumbing Code 2012 were followed. From the code the design rainfall rate (inches/hr) was determined and Tables 1106.2,3 and 6 from the code were used to size the drains and pipe mains. For a detailed process of the calculation see Appendix B. A sample of the calculation can be seen in Table 2.

Table 2. Sample Roof Drain Calculation

Roof Drain Calculations									
AREA	SF	2 Drains	3 Drains	4 Drains	5 Drains	6 Drains	# of Drains	Size	Gutter Size
Gym	9715	4858	3238	2429	1943	1619	4	3" Rd.	3"

Entire Enclosure Energy Savings Results: The proposed enclosure design reduced the energy consumption of the building by 15%.

Mechanical and Plumbing Systems

Design process: In order to provide an environment suitable for learning and achieving among the entire school and community, the interior spaces were a major design factor. The existing architectural plans were analyzed and a proper research of the spaces was completed. The plans were slightly modified to incorporate mechanical shaft space as well as additional heat pump closets. The primary spaces to design for included: welcome atrium, classrooms, administration, multipurpose facility, and the kitchen. The key factors in determining space conditions and design criteria for each space are in Table 3. Based on these spaces, ventilations zones could be determined.

Table 3. Space Specific Design Considerations

Space	Considerations
Atrium	3 story full glass façade; extra sensible loads; susceptible to fluctuation in temperature due to outdoor conditions
Classrooms	Primary focus; accounts for 80% of school; comfort is the main concern for students' and teachers' benefit; age difference of occupants; both sensible and latent load
Administration	Longer daily usage; year round operation; adult occupied
Multipurpose Facility	Large sensible and latent loads; large capacity; various uses (large occupancy but sedentary during performances, smaller occupancy but active sport events or physical education classes); added controllability based on space usage/occupancy
Pool	Requires special treatment from chemicals; humidity control; two primary spaces: pool, spectator
Clinic	100% ventilation (exhaust all air due to possible contamination); 24/7 availability
Corridor	Glass curtain wall in certain areas; transition space; house duct and fire protection mains
Kitchen	Special exhaust and makeup air; for energy savings keep the makeup air rate below 60% (the remaining 40% air needed will be transfer air or HVAC supply); variable or 2-speed exhaust fan control for operations with high diversity of appliances and/or schedule of use; pressurization; meets code requirements; large loads due to equipment in space (both sensible and latent)

Ventilation System Design Process

Ventilation Zones: The zone distribution was determined by usage type and time and space requirements. Figure 6a-6d offer a detailed zoning plan. Based on the spaces and their requirements, the school was divided into five ventilation zones with a dedicated outdoor air handler.

Zone 1: Multipurpose Facility
To accommodate for both school and community use, the multipurpose facility was put on its own zone. It was assumed that the facility will be used year round and on the weekends. Due to events and afterschool programs, it will have the ability to be conditioned longer hours as well.
Zone 2: Kitchen and surrounding areas
The kitchen was put on its own zone to allow for the specialized systems in the kitchen.
Zone 3: Administration
Due to the year round usage of the administration space, it was added to a zone.
Zone 4: East Wing Classrooms **&** ***Zone 5***: West Wing Classrooms
The classrooms wings were split up into two zones in order to eliminate long duct runs (less pressure drop) and to accommodate for smaller shaft spaces located on opposite ends of the building. For specific locations of rooftop units, see mechanical drawing M104 Roof Mechanical Plan.

To account for added shaft space and prevent longer runs, an additional shaft space was created. The architectural plans were slightly altered. Figure 7a and 7b below illustrate the specific changes to the floor plan.

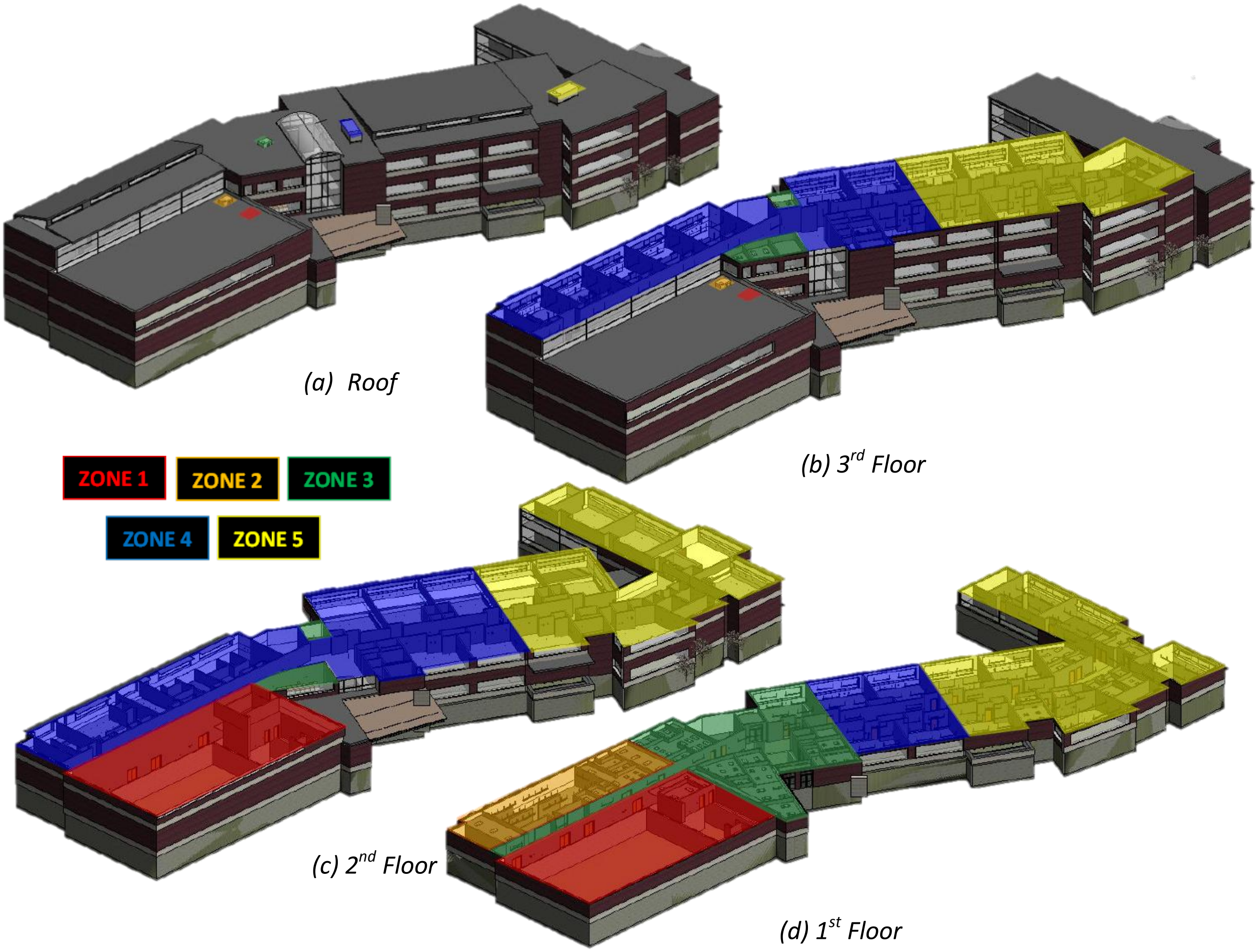


Figure 6. Zone Plan for (a) roof, (b) 3rd floor, (c) 2nd floor, and (d) 1st floor.

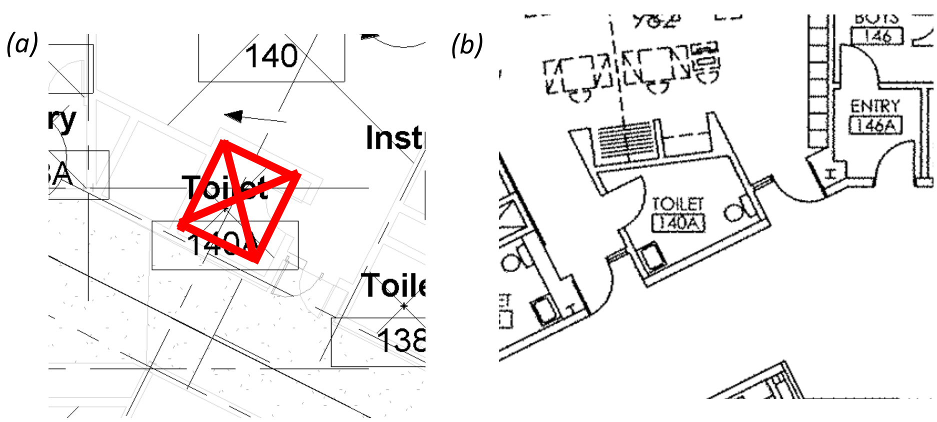


Figure 7. Architectural Plans showing (a) proposed additional shaft space and (b) original room layout

Ventilation and Exhaust calculation method: Using ASHRAE 62.1, the amount of ventilation and exhaust air required could be calculated. Providing the correct amount of ventilation and exhaust air creates a comfortable learning environment. A sample calculation for the ventilation and exhaust air can be seen in Table 4 and 5 below, respectively. Since it was determined that a ground source heat pump system would be used in the building, the ventilation rate was calculated for a 100% outdoor system with only 30 percent of the minimum needing to be supplied to the space, so the equation is as follows :

$$V_{oz} = (R_p * P_z + R_a * A_z)*0.7$$

Table 4. Sample Ventilation Calculation for a Typical Classroom (critical space)

Room Number	Name	Room Type	Rp(CFM/per)	Pz	Ra (CFM/SF)	Az (SF)	Vbz	Ez	Voz
143	Classroom	Classrooms (ages 5–8)	10	30	0.6	798	778.8	1	545

Table 5. Sample Exhaust Air Calculation for a Typical Bathroom and Critical Space

Room Name	Number	Exh. Rate cfm/unit	Number of Units	Exh. Rate cfm/SF	SF	TOTAL CFM	Total CFM
Boys Restroom	146	70	3			210	0
Cust.	147			1	61	0	61

The amount of exhaust air for bathrooms and other critical spaces were calculated by the formulas presented below respectively.

CFM = Exh. Rate(cfm/unit)*# of Units [for bathrooms]

CFM = Exh. Rate(cfm/sf)*SF of space [for critical spaces]

The total amount of air exhausted for the elementary school was **7,135 CFM**. The total amount of ventilation air can be seen per zone in Table 6 below.

Table 6. Zone Ventilation Total

Zone	Ventilation CFM
1	6,718
2	944
3	1,937
4	12,927
5	13,470
TOTAL	**35,996**

Ventilation Supply Design: When sizing the dedicated outdoor air units there were multiple considerations. Outdoor air could be delivered at a neutral temperature (~70^{O}F) or at a "cold" temperature (~50^{O}F). Both supply air conditions should dehumidify the outdoor air to help offset the latent load in the space. When deciding the ventilation supply air conditions, the advantages and disadvantages of each condition were considered.

The main advantage of supplying air at a neutral temperature was to allow the outdoor unit to provide all the dehumidifation for the building. This simplifies the local comfort control of the terminal heat pump units, making the heat pumps only account for the remaining sensible load. The disadvantage to supplying air at a neutral temperature was that it wastes sensible cooling. When the ourdoor air handler dehumidifies the outdoor air to the desired constion, it must then be reheated to the neutral temperature. This requires the terminal heat pumps to account for larger sensible loads. The advantage of supplying air at a cold temperature was to allow the ventilation air to offset a much larger potrotion of the space's sensible load.

After analyzing the advantages and disadvantages of each supply condition it was determined that the ventilation air would be supplied at a "cold" temperature. Because the terminal units were able to be sized down, this reduced the size of the terminal units by 48% and occupied less floor space in the heat pump closets. It was then determined to decouple the terminal heat pumps from the supplied ventilation air. By decoupling the system, the supply air of our terminal units would be less than if the outdoor ducts were connected to our local units. The local units have the ability turn off when the outdoor air supplied to the space is cool enough to meet the entire load for the space. Figure 8 shows a view of the building coordination. Figure 9 illustrates the decoupled mechanical system layout. The decoupled system can be seen throughout the school on a room by room basis in mechanical drawings M102-M103. Three dimensional coordination images of the corridor, a classroom, and the gymnasium can be seen in mechanical drawings M501-M502.

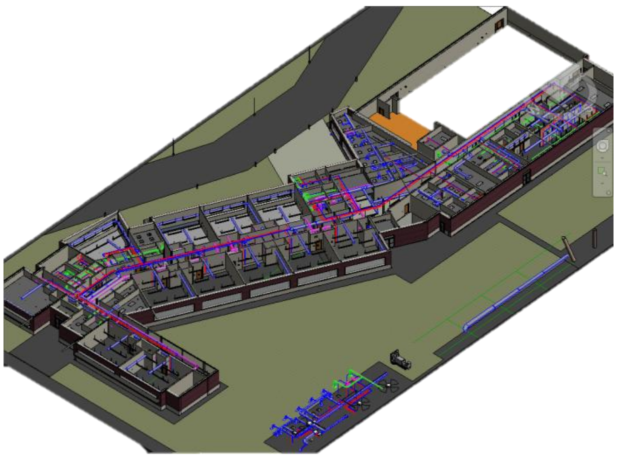


Figure 8. Building Coordination Model

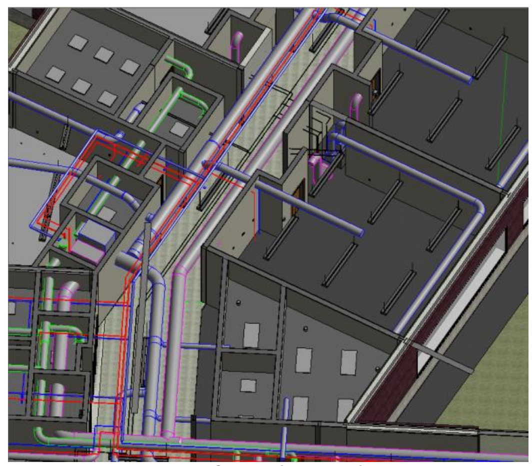


Figure 9. View of Mechanical System Layout

Due to the different usage and hours of occupancy, several control techniques were utilized. Space occupancy sensors, thermostats, and CO_2 sensors will be employed. Although it comes with a high initial cost, a Building Automation System was utilized due to the transient occupancy of a school. The system, if installed initially, will prove useful for the building's energy use reduction. Additionally, installing a BAS during construction will be cheaper than installing during a later renovation.

The DOAS was tied in with each space and will cool the air (maximum cooling of 55°F) as needed by the critical space latent load for that zone. This allowed the system to use free cooling when available. Because the ventilation air was already decentralized, the spaces each had individual controls for the heat pumps to account for the remaining sensible load. The sensors were connected to the heat pumps and varied the flow from the ground loop to control the amount of heating and cooling to the air. Dampers were used in the return air side of the heat pump.

Duct Sizing Method: Airflow to each space varied from approximately 25 CFM to 6,200 CFM. Ducts were sized using a "Ductulator" for a constant drop of 0.08 inches W.G. per 100'. In most cases, this allows for a velocity less than 800 FPM. The lower velocity and low pressure ducts were important as there are exposed ceilings in a school where acoustics were important. Kitchen exhaust ducts were sized to a constant velocity of 1,900FPM as NFPA requires a velocity between 1,500 FPM and 2,200 FPM. Ducts were sized to be at least 6" round or 8"x6" rectangular to be most economical. Due to the velocity and size of the ducts, each could utilize a fire damper. Rectangular ducts aimed to have the lowest aspect ratio (Duct Width:Duct Depth)possible, but never exceeding 4:1. As the aspect ratio increased, the cost of the added metal, both initial and to structurally support, versus the same air volume increased. Also, all takeoffs were a minimum of 2 inches smaller than the connecting main. An air distribution riser diagram can be found in drawing M401.

System Calculations

Loads on DOAS and Heat Pump Units: With the sensible loads previously calculated using Trace, the latent loads had to be calculated to finish sizing the units. To calculate the latent in each of the spaces the following equation was used:

$$\Delta W = (\text{\# of people})(250\ \text{Btu/h})/(0.69 * \text{CFM})\ [\text{gr of H20/lb dry air}]$$

Once the total latent load for each space was determined, the amount addressed by the AHU and heat pumps had to be determined. With the DOAS supplying at a minimum temperature of 55F, the maximum ΔW accounted for was 10 gr of H2O/lb of dry air. The remaining latent load in each space was addressed by the heat pump and was calculated by:

$$\Delta W_{heat\ pump} = (\Delta W_{total} - \Delta W_{AHU})\ [\text{gr of H20/ lb dry air}]$$

The sensible and latent loads for both the AHU and heat pumps were calculated using the equations:

$$Q_{latent\ AHU} = 0.69 * (\text{CFM}) * (\Delta W)/1000\ [\text{MBH}]$$
$$Q_{sensible\ AHU} = 1.1 * (\text{CFM}) * (\Delta T)/1000\ [\text{MBH}]$$
$$Q_{latent\ heat\ pump} = 0.69 * (\text{CFM}) * (\Delta W_{heat\ pump})/1000\ [\text{MBH}]$$

The humidity ratio difference for the AHU latent load was 95-55 gr H20/lb dry air. The temperature difference for the AHU sensible was 88.2-55F. The humidity ratio difference for the heat pump latent load was the remaining ΔW as calculated (above) per space. For a sample calculation of the latent and sensible loads see Table 7 and for detailed psychrometric analysis see Figure 10 below.

Table 7. Sample Calculation for Latent and Sensible Loads

Room Type	Rp(CFM/per)	Pz	Ra (CFM/SF)	Az (SF)	Vbz	Ez	Voz	ΔW	ΔW by Heat Pump	q_{latent} by AHU	$q_{sensible}$ by AHU	q_{latent} by Heat Pump
Classrooms (ages 5–8)	10	34	0.6	685	751	1	526	23	13	14.509	19.199	4.873

The AHU specific calculations and details are in the DOAS Schedule in Appendix C.

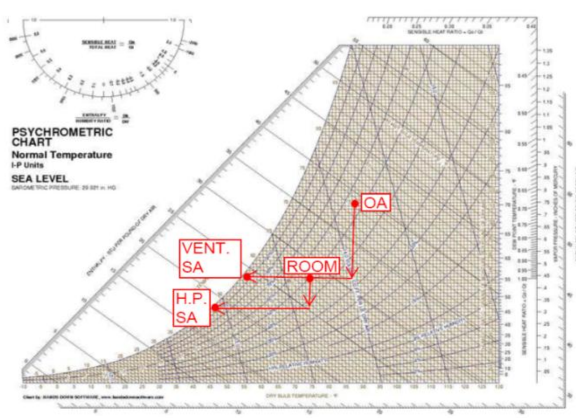


Figure 10. Pyschrometric Chart Detailing System State Points

Heat Pump Sizing and Selection: Using the calculated sensible and latent loads on the AHU and the remaining sensible loads on the heat pumps, the equipment could be sized and selected. The total load on the heat pump was calculated by taking the difference from sensible of the space minus the sensible taken by the AHU and adding the latent previously calculated. Using manufacturer specifications, a general size was determined based on the controlling MBH (either heating or cooling depending on the space). The heat pumps selected range in size from ¾ ton to 3 tons. For a sample heat pump sizing calculation see Table 8 below.

Table 8. Sample Heat Pump Sizing Calculation

Zone 5 - WSHP Load Calculations										
ZONE	ROOMS	SENSIBLE LOAD (MBH)	HEATING LOAD (MBH)	VENTILATION CFM	qlatent by AHU	qsensible by AHU	qlatent by Heat Pump	qsensible by Heat Pump	HEAT PUMP COOLING LOAD (MBH)	HEAT PUMP COOLING LOAD (TONS)
1	CLASSROOM 136	14.0	4.918	526	14.509	19.199	4.873	-5.198564	-0.326	-0.027
	CORRIDOR 149	3.0	0.3	249	6.874	9.096	-1.719	-6.095671	-7.814	-0.651

A summary of the heat pump sizes used throughout the building was shown in Table 9.

Table 9. Summary of Heat Pump Sizes

Heat Pump Schedule					
	Size				
Zone	7	9	12	15	24
1	-	-	-	-	-
2	3	-	-	-	-
3	8	1	0	1	1
4	11	4	4	-	-
5	12	4	9	1	-

Bore Hole Sizing Process: The method described in Ch. 34 of the ASHRAE Handbook of Applications was used to determine the required length for the ground heat exchanger. The ground loop had to be calculated for the worst case of cooling and heating. A block cooling load of 151 tons and the block heating load of 44 tons was used. These values were calculated using Trane Trace 700. In order to avoid an overly large ground loop, an entering heat pump temperature of 75^{O}F was used for cooling and entering heat pump temperature of 45^{O}F was used for heating. With the length calculated, we then determined the drilling depth for the 1 ¼" high density polyethylene piping to be 300 ft. Per the boring log, drilling depths greater than 315 ft risked hitting bed rock. For a detailed calculation see Appendix D and for the boring log see Appendix E. Refer to drawing M101 for the bore field mechanical plan.

Bore Hole Size Results: COOLING LENGTH: 26,384 ft with 54 bore holes drilled to 300ft.
HEATING LENGTH: 9475 ft with 16 bore holes drilled to 300ft.

Bore Hole Cost Analysis and Cooling Tower Comparison: In order to determine the economic feasibility of the ground loop heat exchanger, a comparison of a hybrid ground source heat pump system was done. The hybrid system added a cooling tower to eliminate some load of the ground loop. Note that all calculations and cost numbers were taken from RS means.

Bore Hole Cost Analysis and Cooling Tower Comparison Results: After discussing the results with the rest of the project team, it was decided that due to extra pumping and initial costs for the cooling tower, we would still be designing the ground loop at full design conditions. Table 10 shows the results had a hybrid system been employed. Appendix F offers a more detailed cost analysis break down.

Table 10. Cost Estimate Comparison for a Hybrid System

	LOAD COVERAGE BY COOLING TOWER			
	0%	10%	20%	30%
# Boreholes	44	39	34	29
Borehole Depth [ft]	300	300	300	300
Borhole Length [ft]	26384	22943	19672	16400
Grout Fill [ft^3]	4890	4252	3646	3040
Daily Output (ft/day)	600	600	600	600
Days of Installation	44	38	33	27
Grout Cost	$91,007	$79,138	$67,855	$56,569
Drilling Cost	$181,522	$157,848	$135,343	$112,832
Piping Cost (includes installation)	$29,484	$25,639	$21,983	$18,327
Cooling Tower Cost	$0	$1,968	$2,769	$3,974
Initial Cost	**$302,013**	**$264,592**	**$227,951**	**$191,702**

*Note: The cooling tower cost researched appears to be lower than the expected industry standard.

Pump Sizing: For redundancy (in case of failure), two pumps were needed for the ground source loop for redundancy in case one pump was to fail. To size the pumps, the total flow (gpm) of the system was determined. Since the well field was sized at a flow rate of 3 gpm/ton, the flow rate was found by taking the load in tons times 3 gpm/ton. The pressure loss was determined by using a piping system sizer. Using a calculation spreadsheet the equivalent length of all piping components was found and the total pressure losses were determined by summing the individual section losses multiplied by the pressure loss from the piping system sizer. This gave the pressure loss in ftH2O and based on the flow rate a pump could be selected from a manufacturer. A variable frequency drive pump was selected in order to save energy. It was selected for a calculated flow rate of 453 gpm and 66.2 ft H2O. For a detailed calculation see Appendix G.

Plumbing Design Considerations: For the interior plumbing system, the building was designed with a cold water, hot water, and hot water recirculation line to allow each plumbing fixture to always have hot water readily available. For a detailed calculation of the domestic hot water demand loads, see Table 11. Plumbing fixtures that reduce the water use consumption of the building were chosen to save the owner $9,160 per year and promote a more sustainable building. For a detailed calculation of the water use reduction and savings see Appendix H. Refer to drawings M301-302 for plumbing plans.

Table 11. Domestic Hot Water Demand Calculations

DOMESTIC HOT WATER DEMAND LOADS				
Fixture	#	Connection Size	Gallons/hour (4 ft/s)	Total (4 ft/s)
Lavatory Sink	85	1/2"	2	170
Service Sink	6	1 1/4"	15	90
Kitchen Sink	6	1 1/4"	15	90
Dishwasher	2	1 1/2"	150	300
			Total:	650
			X Demand Factor (0.25)	**162.5**

Pipe Sizing Method: The International Plumbing Code 2012 lists flow rates for commercial plumbing fixtures. Table 604.3 stated that water closets required 4 gpm, showers required 3 gpm, sinks required 3 gpm. An assumption was made that commercial dishwashers required 6 gpm of water. Please note that urinals would not be considered since the building used waterless urinals. The pipes could be sized by adding up the flow in gpm for each branch/main and comparing the flow to a piping system sizer. The cold water main was sized for 4" on the first floor, 3" on the second floor and 2 ½" on the thirds. The hot water main was sized for 3" on the first floor, 2 ½" on the second floor and 1 ½" on the third floor. The hot water recirculation main was sized for ¾" for all three floors.

Construction Phase 2

Phase 2 was proposed as an Add/Alternate to the elementary school project. The existing building renovation included a clinic and a new wing will be rebuilt to house the competition pool. The space has special design requirements due to its use as a clinic and natatorium space. Proper contaminant control was the main design criteria for the clinic and humidity is the main design criteria for the natatorium. The estimated HVAC cost for the clinic and natatorium cost was $245000 and $160000, respectively. The majority of the natatorium cost was the air handler totaling $125000. The plumbing cost was estimated to be $186,000. For more information, please view the construction appendix.

Clinic: The clinic space was equipped with a variable refrigerant volume system with heat recovery. The original proposal was a geothermal, variable refrigerant volume system. However, after determining that the building cooling load was a mere 10 tons, it was decided that a geothermal system would not be economical to install. By designing the heat recovery system, the new system can tie into the existing water loop using the pre-existing boiler and cooling tower to maintain the desired loop temperature. The system included one indoor condensing unit which was connected to the refrigerant circuit to serve each of the indoor fan coil units. A 100% outside air processing unit was installed to meet the ventilation requirements of the spaces. The pre-existing air handler was still used to cool the remainder of the building. Refer to drawing M102a and M301a for the clinic mechanical and plumbing plans.

Ventilation: In order to determine the required amount of ventilation air and the load taken by the outdoor processing unit, the same procedure was used as we described above for the school. The sensible and latent load for the outdoor air processing unit was calculated and the supply air conditions were determined.

Duct and Pipe Sizing Methods: Ductwork and piping was sized to the same standards as mentioned previously in construction phase 1.

Equipment Sizing: The same method that was used for calculating the heat pump sizes for the school described above was used to determine the fan coil unit sizes. The outdoor air processing unit accounted for the majority of the sensible and latent loads and the indoor fan coil units account for the remaining loads required by the interior spaces. Appendix J summarizes the VRV equipment and a details a typical HVAC piping layout.

Natatorium: Some important design characteristics for the natatorium include: pool water chemistry, indoor air quality, occupant comfort, energy cost, and asset protection. Based on these characteristics, a pool specific packaged air handling unit was chosen to provide ventilation, dehumidification, and heat recovery. Refer to drawing M102a and M301a for the natatorium mechanical and plumbing plans.

Both ventilation and dehumidification were used to manage small amounts of pollutants from normal pool activity. By providing adequate dehumidification, corrosion on steel beams should be prevented. The space surface temperature was calculated using (for a detailed calculation see Appendix K) the following equation:

$$\boldsymbol{T_s = T_i - \left(k * \left(\frac{1}{R}\right) * (T_i - T_o)\right)}$$

T_s = Surface Temperature

T_i = Indoor Air Temperature

k = Constant of 0.68 for Vertical Surfaces

R= R Value of Structural Panel

T_o = Outdoor Temperature

and then compared to the dew point to ensure no visible condensation would occur on surfaces. Maintaining proper pool water chemistry was crucial as it affects the indoor air quality (IAQ). To maintain proper IAQ, the amount of ventilation air was calculated. The space was split into the pool itself as well the spectator area for optimum comfort. A sample calculation of the amount of outdoor air required as well as the exhaust air can be found in Tables 12a and 12b. The exhaust rate was calculated using 110%OA to maintain .05 to 0.15" WC negative pressure.

Comfort was also a main concern. Temperature and moisture level of the space was designed to account for the variety of ages and activities taking place in the pool. For a detailed calculation on moisture load of the pool and evaporation rate, refer to Appendix J. The dehumidifier was sized to remove the moisture at a rate equal to the evaporation rate of the pool. Duct design was critical in providing a comfortable space for the occupants. It was important to not direct airflow over the pool surface as it causes discomfort to any swimmers leaving the water.

Table 12a. Outdoor Air Calculation

Outdoor Air (CFM)		
	Pool	Spectator
Water Area (ft2)	4,920	
Wet Deck Area	625	
Spectator Area		1,906
Number of Spectators/1000SF		150
Number of Spectators		286
CFM/sf (pool)	0.48	
CFM/sf (spectator)	0.06	0.06
CFM/person	-	7.5
OA CFM	**2,399**	**2,259**

Table 12b. Exhaust Air Calculation

Exhaust Air (CFM)		
	Pool	Spectator
OA CFM	2,399	2,259
Exhaust CFM	**2,639**	**2,484**

Duct design was important in preventing any structural problems. A wall wash of 80 % of supply air is to be directed at walls and 20% of supply air is to be directed at the ceiling. This is done to prevent stratification or stagnation near the ceiling.

Heat recovery was utilized for heating the both the pool water and space as it was expected to be in heating mode for 70-90% of the year. The pool itself provides a heat sink for recovered energy. Because the conditions constantly change, it was important to be able to adjust to the variations. To further provide energy use reductions, the outdoor air supply rates can be reduced during non-peak hours or when outside conditions permit to lower the operating cost.

Leadership in Energy and Environmental Design (LEED)

To meet the goal of making the building LEED Certified we are planning to qualify 4 credits Water Efficiency, 13 credits for Energy and Atmosphere and 9 credits for Indoor Air Quality. For a detailed summary of the LEED documentation please see Appendix L. This gave a grand total of 26 points for the mechanical and plumbing considerations. Please refer to the integration paper (Appendix P) for a detailed breakdown of the total LEED points for the entire project. A sample calculation for LEED points towards water use reduction is shown below in Table 13 and we expect to receive 4 points.

Table 13. Water Use Reduction

Water Efficiency - Credit 3 Water Use Reduction		
Fixture Type	Baseline Usage	Design Usage
Water Closets	4,234	2911
Urinals	1,323	0
Lavatory Faucets	1,984	992
TOTAL	7,541	3,903
Reduction	**46%**	

Conclusions

The design for the Reading Elementary School was driven by team goals, project goals, and discipline goals. The team chose goals to help with collaboration, integration, and decision making. Upon receiving the project details, as a BIM team, we determined our project specific goal was to create an **innovative, high-performance environment in a way that stimulates involvement in both education and the community**. Following the project goals, each discipline defined specific goals. The mechanical goals were to achieve energy savings while maintaining a stimulating and comfortable learning environment. With goals in mind, research followed. The project was divided into two construction phases: the school and the clinic/natatorium space.

Construction Phase 1: Water source and ground source geothermal systems, standard boiler/chiller combinations, and chilled beams were researched and compared. After comparing each system, a **ground source geothermal loop** with dedicated outdoor air system was chosen. Ventilation zones were designed based on size, usage, and schedule allowing for maximum energy savings and convenience. Following the ventilation and load calculations for each space, the equipment was sized. The DOAS is able to account for a majority of the latent and sensible loads while the heat pumps account for the remainders. Because of this, heat pump **size can be reduced by 48%.** With the energy savings, convenience, and security aspects in mind, a decoupled ground source heat pump with dedicated outdoor air unit system was selected for the school achieving an overall **energy reduction of 32%.**

Construction Phase 2: The BIM team went through and specified uses, assumptions, and established goals for designing the space. Since the space is a renovation of the existing building, it was important to make logical assumptions of what the space had and needed. The same process of research, analysis, and design was followed. Separate systems for both the pool and clinic were used to account for each condition and usage time. A **Variable Refrigerant Volume (VRV) system** was proposed as the best solution for the retrofit of the existing school to allow for a long life and low initial cost achieving an **energy reduction of 13%.** Following the initial natatorium design, the mechanical team was able to begin work. Initial calculations included evaporation rate of the pool, latent load, and surface temperature (dew points). Equipment satisfying these loads was then researched. An **all-encompassing AHU** was chosen for the pool resulting in an energy **savings of 1398 MMBTH**, or approximately **$1650/yr** when compared to the design solution using a standard pool heater.

BIM Conclusion: Using BIM and fully coordinating efforts between all disciplines from the first stage of the design process produced a fully integrated building. Upon receiving the project, the entire project team began brainstorming project goals and requirements to retain unity. The goals were based on functionality, affordability and longevity, and appeal. Early in the design process, the team analyzed and designed a fully functional site to directly benefit lighting, construction management, and mechanical options. By mirroring the building and rotating it flush with the road, construction traffic flow, pedestrian and traffic flow, daylighting and thermal gain were optimized. Enclosure materials were affordable, long lasting, easy to transport, easy to support, offered valuable thermal barriers and allowed daylight to benefit all options. Shortly after finalizing the site layout, the mechanical team analyzed the floor plans and devised a potential zoning plan. This allowed integration among the mechanical and structural teams for the placement of the rooftop units. Structural engineers did not need additional reinforcement and mechanical runs were kept relatively short. The mechanical system integrated with other options in places such as plenums and shafts. The added energy savings, as well as cost savings, during design, construction, and operation are directly translated to the owner and the environment. **By integrating and coordinating throughout the entire design process, backtracking and redesigning was virtually eliminated.** Because of the integration, the building was fully functional, has a long lifetime, and offered appeal to the students and community.

Contents

Appendix A – References

American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc (2006). *Smart Dedicated Outdoor Air Systems*. ASHRAE Journal, Vol. 48, July 2006.

American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc (2007). *Ventilation for Acceptable Indoor Air Quality*. ASHRAE Standard 62.1, 2007.

American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc (2007). *Energy Standard for Buildings Except Low-Rise Residential Buildings*. ASHRAE Standard 90.1, 2007.

American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc (2011). *Advanced Energy Design Guide for K-12 School Buildings, Achieving 50% Energy Savings Toward a Net Zero Energy Building*. ASHRAE, 2011.

American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc (2011). *Advanced Energy Design Guide for K-12 School Buildings, Achieving 30% Energy Savings Toward a Net Zero Energy Building*. ASHRAE, 2011.

Desert Aire (2009). *Swimming Pool Load Calculations.* Fall 2012. Web.< www.desert-aire.com>.

International Plumbing Code (2012). *International Plumbing Code*. International Code Council, 2011.

Stein, Benjamin, et al (2006). *Mechanical and Electrical Equipment for Buildings*. Hoboken, NJ: John Wiley and Sons, Inc. P. 1562

Tegral Flat Roof Decking. 2012. Photograph. *Tegral*. Web.

VRV III System Air Conditioners – Installation Manual. Daikin-McQuay.

Appendix B – Roof Drain Calculations

Roof Drain Calculations									
AREA	SF	2 Drains	3 Drains	4 Drains	5 Drains	6 Drains	# of Drains	Size	Gutter Size
Gym	9715	4858	3238	2429	1943	1619	4	3" Rd.	3"
Gym Stair	352	176	117	88	70	59	1	2" Rd.	3"
South Gym classroom	2553	1277	851	638	511	426	2	2" x 3"	8"
Gym Corridor	2090	1045	697	523	418	348	2	2" x 3"	8"
Main Entrance Area	5700	2850	1900	1425	1140	950	2	3" Rd.	3"
Middle Classrooms	5195	2598	1732	1299	1039	866	3	2" x 3"	8"
Middle Classrooms	1257	629	419	314	251	210	2	2" x 3"	8"
Second Main Flat Roof	4027	2014	1342	1007	805	671	2	3" Rd.	3"
Green Roof	5313	2657	1771	1328	1063	886	2	3" Rd.	3"

In order to size the roof drains properly, the average rainfall rate had to be determined. Using Figure 1106.1 in the International Plumbing Code, the 1-hour rainfall rate was determined to be 3 inches for Pennsylvania. Then using Table 1106.2/3 posted in the International Plumbing Code the amount of area each drain size can properly cover was determined. Using the amount of area covered by each drain, we calculated the amount of drains we will need to cover the entire roof area.

Below are a few notes taken from the International Plumbing Code that we needed to consider in order to properly design the drainage system:

- As Horizontal Roof Area Increases for where pipes connect, the size of horizontal pipe must go up accordingly
- Not less than two roof drains shall be installed in roof areas 10,000 SF or less
- Not less than four roof drains shall be installed in roof areas over 10,000 SF
- Subsoil drains should be open-jointed, horizontally split or perforated pipe and not less than 4" in diameter

Appendix C – DOAS Schedule

Table 1. DOAS Unit Selection

DOAS Unit Selection							
ZONE	OA Summer	Supply Temp	Cooling Total (MBH)	OA Winter	Heating (MBH)	Supply Air (CFM)	Static Pressure (in. wg.)
DOAS-1	89.2DB, 72.5 WB	55 DB, 55 WB	431	7.0 DB	57	6718	4
DOAS-2	89.2DB, 72.5 WB	55 DB, 55 WB	61	7.0 DB	6	944	4
DOAS-3	89.2DB, 72.5 WB	55 DB, 55 WB	124	7.0 DB	20	1937	4
DOAS-4	89.2DB, 72.5 WB	55 DB, 55 WB	829	7.0 DB	200	12927	4
DOAS-5	89.2DB, 72.5 WB	55 DB, 55 WB	866	7.0 DB	247	13499	4

In order to properly size the air handling unit, the latent load and sensible load in each space was calculated. To calculate the latent on the air handling unit we first needed to determine the humidity ratio that the air handling unit needs to account for using the following equation:

$$\Delta W = (\text{\# of people})(250\ \text{Btu/h})/(0.69*\text{CFM})\ [\text{gr of H20/lb dry air}].$$

After determining that ΔW = 95 – 55 and ΔT = 88.2 - 55, the latent load and the sensible loads for each space were calculated by the following equations:

$$Q_{latent\ AHU} = 0.69*(\text{CFM})*(\Delta W)/1000\ [\text{MBH}]$$
$$Q_{sensible\ AHU} = 1.1*(\text{CFM})*(\Delta T)/1000\ [\text{MBH}]$$

The latent and sensible load for each space were added together to determine the overall cooling load (MBH) on the dedicated outdoor air unit and the heating load (MBH) was calculated using Trane Trace 700. The calculation method for zone 1 is detailed below in Table 2. Please note that the same process was done for zones 2-5.

Table 2. Zone 1 – Dedicated Outdoor Air Unit Load Calculation

Room Number	Name	Room Type	Rp(CFM/per)	Pz	Ra (CFM/SF)	Az (SF)	Vbz	Ez	Voz	ΔW	ΔW by Heat Pump	q_{latent} by AHU	$q_{sensible}$ by AHU
104	Multi-Purpose	Gym, stadium (play area)	0	711	1.5	5903	8854.5	1	6198	33	23	171.069	226.356
105	Stage	Music/theater/dance	10	30	0.3	995	598.5	1	419	26	16	11.563	15.300
106	Storage	Occupiable storage rooms for liquids or gels	5	1	0.6	115	74	1	52	7	-3	1.430	1.892
107	Ramp	Corridors	0	0	0.3	233	69.9	1	49	0	-10	1.350	1.787

AHU TOTAL:	430.747

Appendix D – Bore Hole Sizing Calculations

GROUND LOOP HEAT EXCHANGER LENGTH		
Short Circuit Heat Loss Factor	F_sc	1.04
Ground Thermal Resistance (Annual Pulse)	R_ga	0.26
Net Annual Heat Transfer to Ground	q_a	134895.40 53
Trace Load (Cooling)	q_peak _c	1812829
Trace Load (Heating)	q_peak _h	527508
Power Consumed at design cooling load (Watts)	W	113097
Thermal Resistance of Bore	R_b	0.09
Part-Load Factor	PLF	1
Thermal Resistance of Ground (Monthly Pulse)	R_gm	0.24
Thermal Resistance of ground (Daily Pulse)	R_gd	0.15
Undisturbed Ground Temperature	T_g	55
Temp (HP Inlet)	T_wi	70
Temp (HP Outlet)	T_wo	78.72
Temp penalty	T_p	3.4
Thermal Diffusivity	α	0.9
Bore Diamter (ft)	d_b	0.5
Bore Fill Conductivity	k_g	0.1

Cooling EFLH	550
Heating EFLH	350

Bore Depth (ft)	# of Bores
100	161
150	107
200	80
300	54
350	46
400	40
450	36
500	32

LENGTH_cooling (ft)	**32186.00104**
LENGTH_heating (ft)	**4570.800291**

T_1	3650
T_2	3680
T_3	3680.25
F_of	52560
F_o1	436
F_o2	3.6
G_f	0.91
G_1	0.55
G_2	0.21

The tables above document the calculation for the size of the ground loop for the ground source heat pump system. The calculation method described in the ASHRAE Handbook of Applications was used to determine all of the necessary inputs in the following equation to determine the proper length:

$$L_c = \frac{q_a R_{ga} + (q_{lc} - 3.41 W_c)(R_b + \mathrm{PLF}_m R_{gm} + R_{gd} F_{sc})}{t_g - \frac{t_{wi} + t_{wo}}{2} - t_p}$$

Appendix E – Boring Log

Boring ID: B-2

(2 of 2)

Drilling Equipment	: CME-75
Casing Diameter	: 4.25"
Casing Type	: HSA/NQ
Date Started	: 3/25/08
Date Completed	: 3/25/08
Weather	: Sunny, 51 F
0 hr Depth to GW	: caved to 30.5', set tremie
24 hr Depth to GW	: Dry
48 hr Depth to GW	: Dry
7-Day Depth to GW	: Dry

Depth (ft.)	Surface Elev.(ft.) 366	Sample No.	Blows per 0.5 ft.	Recovery (ft)	RQD (%)	Description (Burmister)	USCS Symbol	Graphic	Pocket Penetrometer Reading (tsf)	Remarks
25	341									
26	340	S-10	2 2 3 5	2.0		23.0' - 29.5' Red-Brown Tan SILT and CLAY, little Fine Sand, trace Fine Gravel, moist			2.0	
27	339									
28	338									
29	337	S-11	3 2 3 3	1.9					2.25	
30	336									
31	335					29.5' - 33.0' Light Brown to Medium Brown Fine SAND, trace Clay and Silt, moist				
32	334									
33	333	S-12	4 9 50/.3	1.0		33.0' - 33.3' Weathered Limestone, Gray				Limestone Fragments in bottom of S-12 spoon
34	332					END OF BORING 33.3'				
35	331									
36	330									
37	329									
38	328									
39	327									
40	326									
41	325									
42	324									
43	323									
44	322									
45	321									
46	320									
47	319									
48	318									
49	317									
50										

Boring Log as provided by AEI Competition.

Appendix F – Cost Analysis for Hybrid System

	LOAD COVERAGE BY COOLING TOWER			
	0%	10%	20%	30%
# Boreholes	40	35	30	25
Borehole Depth [ft]	300	300	300	300
Borhole Length [ft]	24230	21205	18181	15157
Grout Fill [ft^3]	4491	3930	3370	2809
Daily Output (ft/day)	600	600	600	600
Days of Installation	40	35	30	25
Grout Cost	$83,577	$73,143	$62,712	$52,281
Drilling Cost	$166,702	$145,890	$125,085	$104,280
Piping Cost (includes installation)	$27,077	$23,697	$20,317	$16,938
Cooling Tower Cost	$0	$1,968	$2,769	$3,974
Initial Cost	**$277,356**	**$244,698**	**$210,883**	**$177,473**

**Cost/foot length includes 1-1/4" High Density Polyethylene Piping (HDPE), welding every 40' of pipe (as specified by RS Means), and grout pricing.

The calculation used the 9475 feet of heating as previously calculated. It also assumed a labor cost of $4125.50/ day of drilling. The cooling tower prices were found at http://www.coolingtowerservices.biz.

RS MEANS FOR DRILLING								
Unit	Crew	Daily Output	Labor Hours	Bare Material	Bare Labor	Bare Equipment	Bare Total	Total O&P
LF	B23	600	0.067		2.37	4.51	6.88	8.6
RS MEANS FOR GROUT FILL								
Unit	Crew	Daily Output	Labor Hours	Bare Material	Bare Labor	Bare Equipment	Bare Total	Total O&P
CF	B61	250	0.16	11.3	6	1.31	18.61	22.99
RS MEANS FOR HDPE PIPE (BASED ON 40' PIPE)								
Unit	Crew	Daily Output	Labor Hours	Bare Material	Bare Labor	Bare Equipment	Bare Total	Total O&P
LF				0.91				1
EA	4 Skwk	175	0.183		8.3		8.3	12.85

Cooling Tower Costs	
15 ton (10%)	$1,968
30 ton (20%)	$2,769
45 ton (30%)	$3,974

**ADD 1 weld joint every 40 feet

Appendix G – Pump Sizing Calculations

In order to determine the proper head requirement for our ground loop pumps we first had to lay out the piping in revit and size the pipes using a pipe sizing tool. The pipe sizing tool allowed us to determine the pressure loss (ft/100ft) and the velocity of the fluid (ft/s) going through the pipe based on the flow (gal/min). We then used the equivalent length method described in the ASHRAE handbook to determine the total head for the pumps. The ASHRAE handbook lists a variety of different components and their respective equivalent lengths. The equivalent length for each component was inputted into the spreadsheet below, so that we could determine the section pressure loss. The section pressure loss (ftH2O) was determined by the following equation, (pressure loss*equivalent length)/100. Each section pressure loss was then added together to determine that the total pressure loss in the system is 55.1 ftH2O. Please note that a 20% factor of safety used to determine the final pressure loss number in order to account for potential error in the calculation. The total pressure was determined to be 66 ftH2O.

Section	Pipe Size (inches)	Flow (gal/min)	Pressure Loss (ft/100ft)	Velocity (ft/s)	System Components	No. Components	Equivalent Length Method		
							Equivalent Length of Component (ft)	Equivalent Length (ft)	Section Pressure Losses (ftH20)
1 --> 2	1 1/4	8	1.3	1.8	Straight Pipe	1	300.0	300.0	3.9
					Tee	2	1.8	3.6	0.0
					90 Degree Elbow	1	1.7	1.7	0.0
								Total	3.9
2 --> 3	4	453	10.8	11.4	Straight Pipe	1	240.0	240.0	3.1
					Check Valve (Swing)	1	6.0	6.0	0.1
					Balancing Valve	1	1.6	1.6	0.0
					Tee	24	1.8	43.2	0.6
					90 Degree Elbow	5	1.7	8.5	0.1
								Total	3.9

The calculation was continued for the remaining sections.

Note 1. This section includes the entire length of 1" pipe and all associated fittings.

TOTAL:	55.1 ftH2O
Safety Factor (20%)	11.0 ftH2O
TOTAL:	**66.2 ftH2O**

Appendix H – Water Use Reduction Calculations

Water Closets						
FTE	Female Ratio	Uses/Day	FTE	Male Ratio	Uses/Day	**Total Uses**
1323	0.5	3	1323	0.5	1	**2646**

LEED Baseline (gpf)	Baseline usage (gal)	Baseline Cost	Our Design (gpf)	Our Design Usage (gal)	Our Cost	**Savings**
1.6	4233.6	$22.95	1.1	2910.6	$15.78	**$7.17**

Urinals						
FTE	Female Ratio	Uses/Day	FTE	Male Ratio	Uses/Day	**Total Uses**
1323	0.5	0	1323	0.5	2	**1323**

LEED Baseline (gpf)	Baseline usage(gal)	Baseline Cost	Our Design (gpf)	Our Design Usage (gal)	Our Cost	**Savings**
1	1323	$7.17	0	0	$0.00	**$7.17**

Lavatory Faucet						
FTE	Duration	Uses/Day	FTE	Male Ratio	Uses/Day	**Total Uses (min)**
1323	30	3				**1984.5**

LEED Baseline (gpm)	Baseline usage (gal)	Baseline Cost	Our Design (gpm)	Our Design Usage (gal)	Our Cost	**Savings**
1.5	2976.75	$16.13	0.5	992.25	$5.38	$10.76

The water use reduction calculation was based on the method described in LEED 2009 for schools. We first needed to determine the full-time equivalent occupancy of the school which was found to be 1323 people. Then using the recommendations put forth by LEED, the baseline gallons per flush, uses per day, male ratio and female ratio were found for each fixture type. Using these inputs we baseline water usage for the building (gallons) and the total cost to use the water. The cost to use the water was found using the following equation, (Water Usage*$5.42). $5.42 is the average cost of water for the city of Reading, PA. After deciding to choose low-flow fixtures, we calculated the water use reduction and savings of operation for the building. We reduced the consumption of water by 45.7% and will save the school $9,160 per year. Please note that the savings described above are savings per day.

Appendix J – Clinic Equipment Schedule and VRV System Layout

Table 1 below details the fan coil unit schedule for the clinic space.

Table 1. Fan Coil Schedule

Fan Coil Schedule				
QTY	Model	Sensible Capacity	Total Capacity	CFM
9	FXMQ07PVJU	6483.000	7500	317
1	FXMQ12PVJU	9895	12000	335
2	FXZQ30PVJU	23884	30000	883
5	FXZQ07M7VJU	5900	7500	320

Table 2 below details the indoor condensing unit schedule for the clinic space.

Table 2. Indoor Condensing Unit Schedule

VRV-WIII - Indoor Condensing Unit with Heat Recovery Schedule									
QTY	Cooling Capacity (Btu/h)	Full Load EER	Heating Capacity	Full Load COP	Power	Liquid Pipe Size	Suction Gas Pipe Size	Discharge Gas Pipe Size	Maximum #of Indoor Units
1	144,000	15.1	162,000	5.3	208/120	1/2"	1 1/8"	7/8"	20

The figure below details the typical piping from the indoor condensing unit to each branch selector unit and each refrigerant network joint. The suction gas, HP/LP, and Liquid pipes are supplied to the branch selector units from the indoor condensing unit. The branch selector unit then supplies a liquid and gas pipe line to each refrigerant network joint which connects the liquid and gas lines to each fan coil unit.

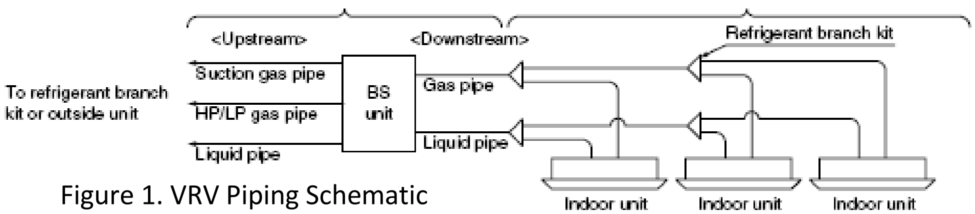
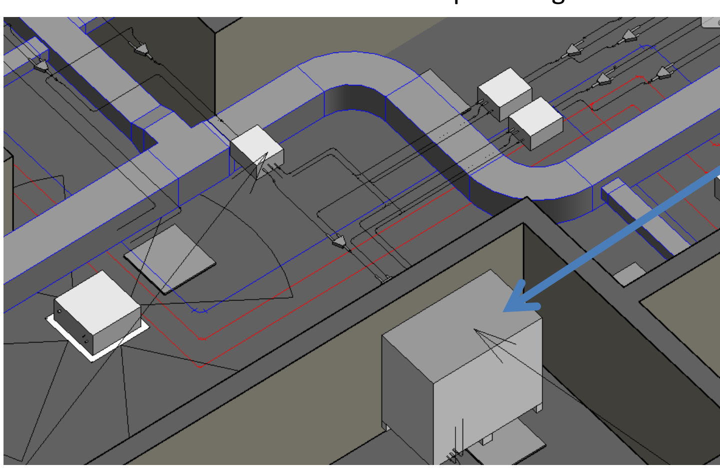


Figure 1. VRV Piping Schematic

(Daikin-McQuay Installation Manual)

The figure below is a 3D view of the HVAC piping for the VRV system in the clinic space and detailing the coordination between duct work and plumbing.



12 Ton Indoor Condensing Unit with Heat Recovery

Figure 2. 3D view of Clinic HVAC Piping

Appendix K – Natatorium Cost Savings Calculation

Pool Savings Calculation					
Givens:					
Tp	Pool Water Temperature	80	F		
Ta	Air Temperature	82	F		
ERF60	ERF (Active Hours-60% RH)	0.036	lb/h/sf		
ERF50	ERF (Non-Active Hours-50% RH)	0.048	lb/h/sf		
H60	Number of Active Hours	11	h		
H50	Number of Non-Active Hours	13	h		
AF	Activity Factor	1			
ERFavg	Average Evaporation Rate Factor	0.0295	lb/h/sf		
Ap	Pool Water Surface Area	4920	sf		
ER	Pool Evaporation Rate	145.14	lb/h		
Ecp	Energy Consumption to Heat Pool Water	1398569040	Btu/yr	549535.9686	HP
$$$	Convert Pool Energy Usage into Annual Heating Cost				
	Heat Pool Using Gas: (@$1.192/CCF)	**$ 22,227.92**	$/yr		
	Savings from using this equipment	$ 1,648.61	$/yr	$ 20,579.32	$/yr
	Heat Pool Using Electric: (@$0.172/kWh)	**$ 70,481.65**	$/yr		
	Savings from using this equipment	$ 3,846.75	$/yr	$ 66,634.90	$/yr

With the pool air handler criteria calculated, the feasibility of the economizer and water heater was addressed. Following the simple calculation above, the annual energy and cost savings were calculated. Due to the pool air handler equipped including an economizer as well as pool water heater, the owner is able to save both energy and money. Dectron's Indoor Pool Design Guide was used as a basis for this analysis.

Appendix K – Pool Load Calculations

Surface temperatures within the space were found using the predetermined indoor temperature and outdoor temperature, from BIN data. Because the vertical spaces were controlling, K=0.68 was used. ASHRAE's maximum U-value of a metal framed glass curtain wall structural panel was used. See table 1 for the calculation.

Table 1. Surface Temperature of Space

Surface Temperature of Space			
	Ts=Ti-(K*U)*(Ti-To)		
		Heating	Cooling
Indoor Temp	Ti	82	82
Outdoor Temp	To	7	89.2
Constant .68 for Vert Surface	K	0.68	0.68
U value of Struct Panel	U	0.45	0.45
Space Surface Temp	**Ts**	**59.05**	**84.2032**

Surface temperatures within the space were found using the predetermined indoor temperature and outdoor temperature, from BIN data. Because the vertical spaces were controlling, K=0.68 was used. ASHRAE's maximum U-value of a metal framed glass curtain wall structural panel was used. See table 1 for the calculation.

The moisture load calculation is based on occupancy so it differs for active and inactive time periods. The number of spectators was based on ASHRAE 62.1. See table 2 for the calculation.

The evaporation calculation was based on both active and inactive time periods as well. The equation: Lb/h=.1*A*(pw-pa)*AF , calculated the evaporation rate in pounds per hour of the pool surface. The surface water temperature and room air dew point from table 1 were used to find the saturated vapor and pressure respectively. The activity factor pertains to the level of activity within the pool, with a higher activity factor for more splashing and dynamic activity. Because the pool still evaporates overnight, an inactive value of 0.5 was used. 0.5 was also used for competition events.

Table 2. Moisture Load Calculation

Moisture Load			
		Day (active)	Night (inactive)
Moisture Load/person	BTU/h per person	190	190
Number of People (spectator)	people	285.9	0
Conversion (BTU/h to Lb/h)		1061	1061
Moisture Load	Lb/h	51.1979265	0

Table 3. Evaporation Rate Calculation

Evaporation Rate of Pool			
	Lb/h=.1*A*(ΔP)*AF		
		Day (active)	Night (inactive)
Area of Pool Surface	A	4920	4920
Sat. Vapor Pressure @ Surface Water Temp	pw	0.5069	0.5069
Sat Pressure @ Room Air Dew Point	pa	0.299554	0.299554
Activity Factor	AF	1	0.5
Evaporation of Water	wp	102.014232	51.007116

The space required 153 Lb/h of moisture to be removed from the air during the active periods and 51 Lb/h of moisture to be removed from the air during inactive periods. The air handler selected is able to remove 165 Lb/h of moisture, which is well within the range needed.

Ventilation, or outdoor air, and exhaust air regulated adequate indoor air quality. The natatorium was divided into two separate areas, the pool itself and the spectator area, to provide the right mixture of air to each space.   ASHRAE 62.1 requirements for CFM/sf for both the pool and spectator areas were used in this calculation. See Table 5 for the ventilation calculation.

Exhausting the correct amount of air was key indoor air quality. It is imperative to maintain a safe concentration of chemicals in the mixed air of the space for both occupancy and structural safety. The exhaust rate was calculated using 110%OA to maintain .05 to 0.15" WC negative pressure. See Table 6 below for the exhaust calculation. Negative pressurization helps to contain the pool air and prevent it from leaking into the corridor linking to the remainder of the building. Because of the various uses of the pool, an air handler equipped with "purge" mode was selected. Purge mode maintains adequate indoor air quality during pool "shocking," or heavy chlorination.

Table 5. Ventilation Calculation

Outdoor Air		
	Pool	Spectator
Water Area (ft2)	4920	
Wet Deck Area	625	
Spectator Area		1906
Number of Spectators/1000SF		150
Number of Spectators		285.9
CFM/sf (pool)	0.48	
CFM/sf (spectator)	0.06	0.06
CFM/person	-	7.5
OA CFM	**2399.1**	**2258.61**

Table 6. Exhaust Calculation

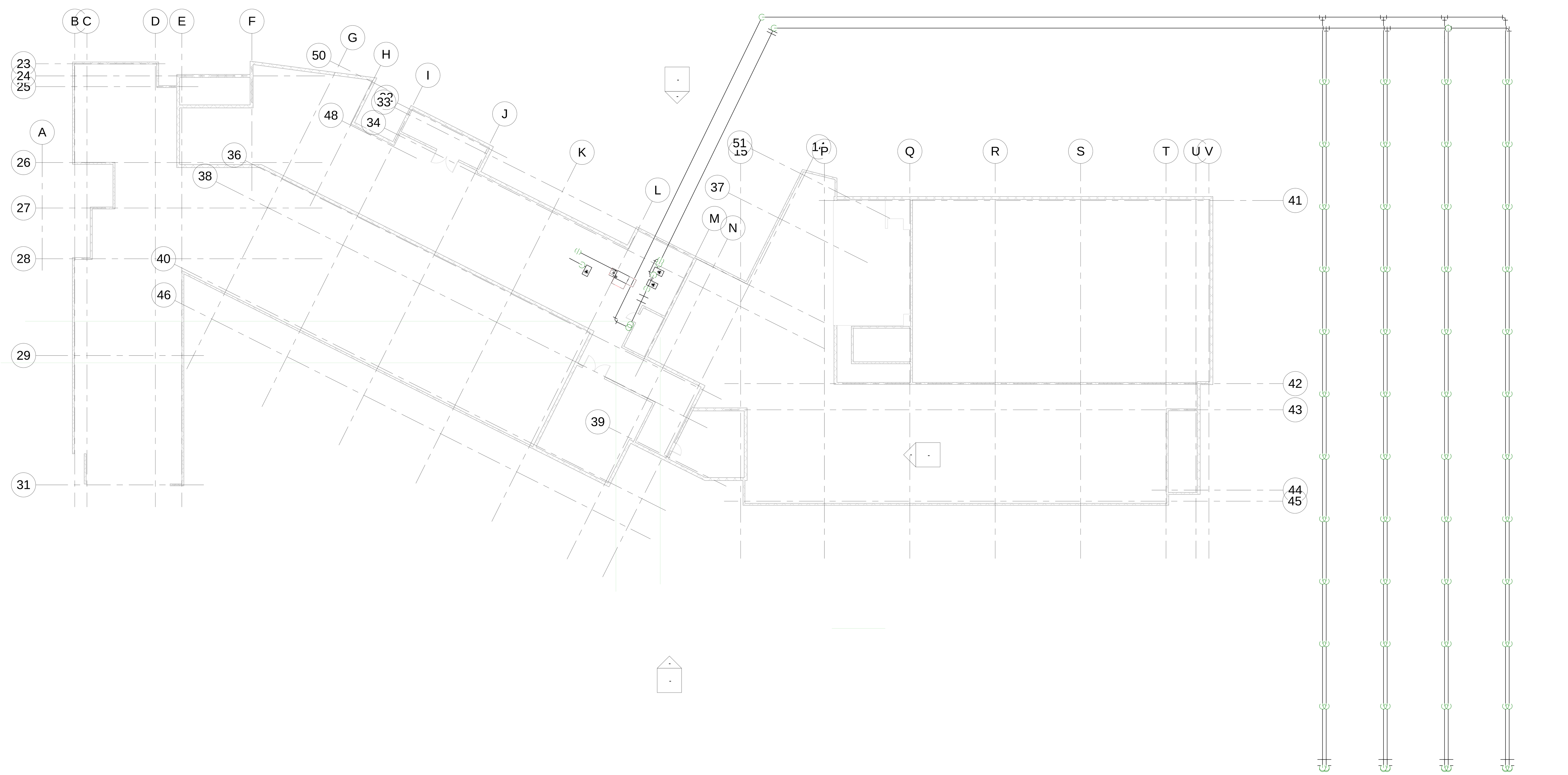
Exhaust Air		
	Pool	Spectator
CFM OA	2399.1	2258.61
Exhaust CFM	**2639.01**	**2484.471**

Appendix L – LEED Point List

Water Efficiency	
Prerequisite	**Y/N**
Water Use Reduction - 20% Reduction	Y
Credit	**Points**
Water Use Reduction	4
Energy and Atmosphere	
Prerequisite	**Y/N**
Fundamental Commissioning	Y
Minimum Energy Performance	Y
Fundamental Refrigerant Management	Y
Credit	**Points**
Optimize Energy Performance	12
Enhanced Refrigerant Management	1
Indoor Environmental Quality	
Prerequisite	**Y/N**
Minimum Indoor Air Quality Performance	Y
Environmental Tobacco Smoke Control	Y
Minimum Acoustical Performance	Y
Credit	**Points**
Outdoor Air Delivery Monitoring	1
Increased Ventilation	1
Construction IAQ Management Plan	2
Low-Emitting Materials	1
Indoor Chemical and Pollutant Source Control	1
Controllability of Systems - Thermal Comfort	1
Thermal Comfort - Design	1
Thermal Comfort - Verification	1
Total	**26**

The following chart documenting the exhaust rate for every room in the school will count for 1 LEED credit towards Indoor Chemical and Pollutant Source Control.

Indoor Chemical and Pollutant Source Control	
Room with Pollutant	Exhaust Rate
Cust.	61
Cust.	53
Cust.	20
Storage	95
Art Classroom	502
Cust.	53
Cust.	61
Cust.	22
Instructor Storage	270
Cust.	53



1 Mechanical Basement
1/16" = 1'-0"

Drawing Notes:

A. 54 Bore Holes drilled at 6" Diameter to 300' and routed with two 1 1/4" High Density Polyethylene piping and back filled with high thermal conductivity grout.

B. Bore Holes are spaced 20' Apart.

C. Supply and Return Mains are sized at 4" for 453 gpm.

D. The well field was designed at 3gpm/ton.

E. 2 Variable Speed Drive Pumps sized at 62 ftH2O and 453 gpm are used to circulate the water through the ground loop.

Consultant
Address
Address
Address
Phone

Consultant
Address
Address
Address
Phone

Consultant
Address
Address
Address
Phone

Consultant
Address
Address
Address
Phone

Consultant
Address
Address
Address
Phone

No.	Description	Date

AEI Team #04-2013

Reading Area Elementary School

Basement and Bore Field Mechanical

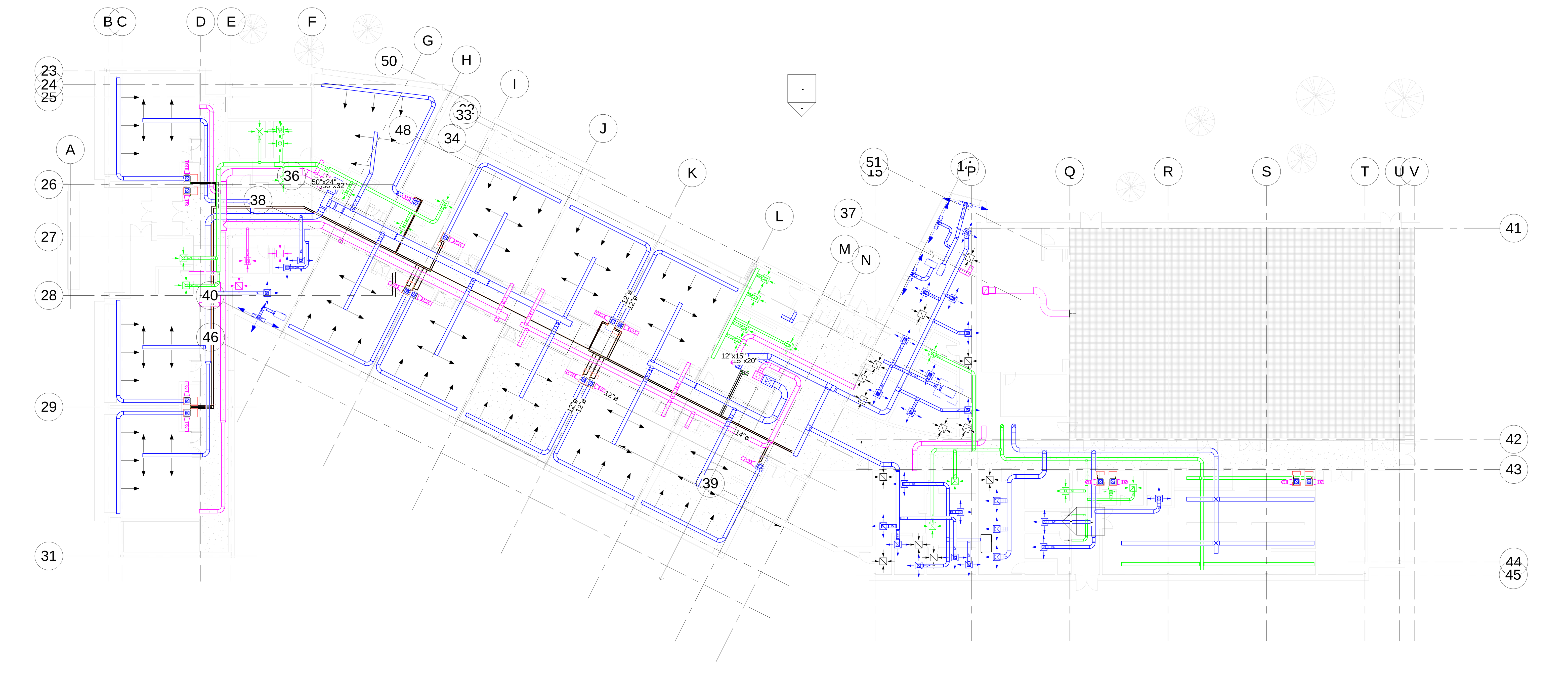
Project Number	04-2013
Date	22 Feb. 2013
Drawn By	04-2013
Checked By	Checker

M101

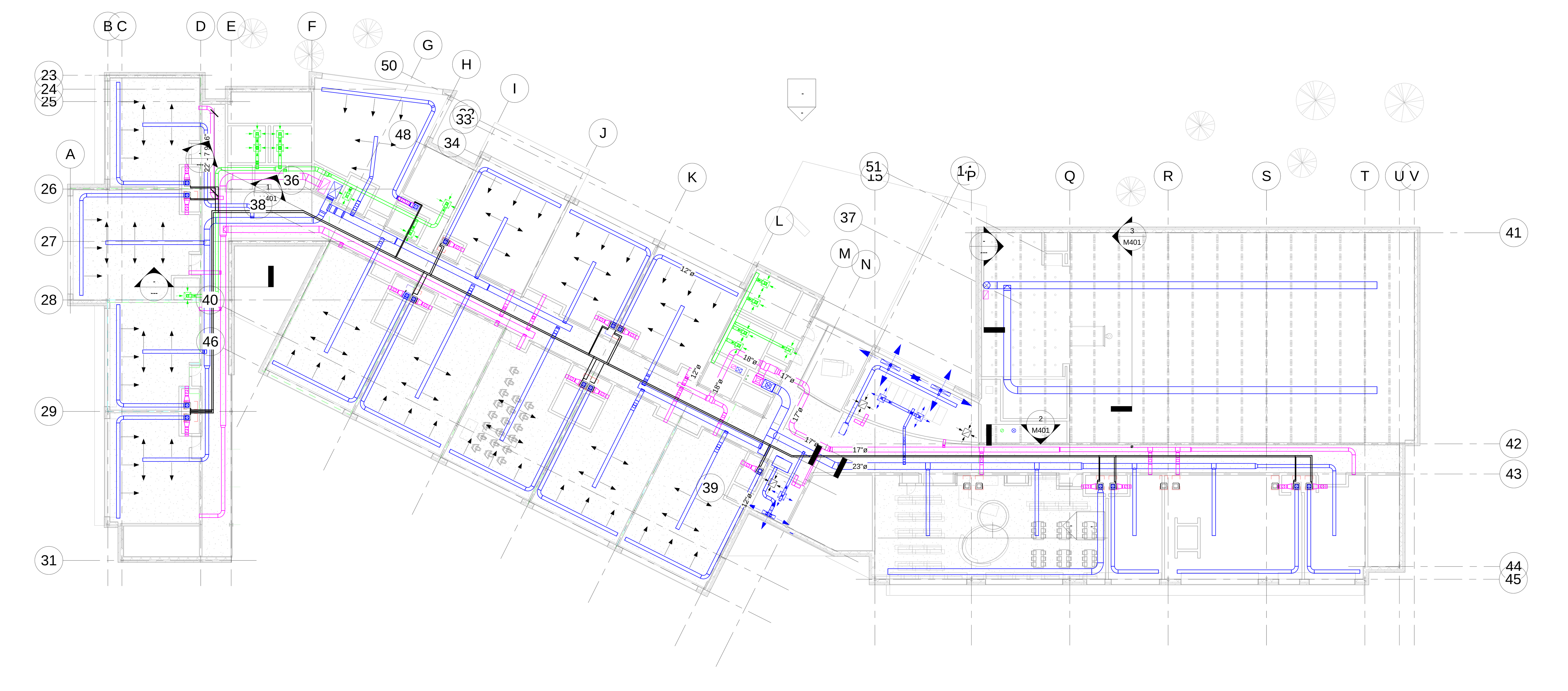
Scale	1/16" = 1'-0"

2/22/2013 3:18:46 AM

Drawing Notes:
A. Heat Pump water supply and return sized at 1 1/2"
B. Each Heat Pump shall have isolation valves installed to allow for future maintenance.
C. Main and branch duct sized for 0.08 inH20/100ft.
D. Kitchen exhaust sized for 1900 FPM.
E. High-induction diffusers used for classrooms.
F. Arrows represent the diffuser flow.



2 School HVAC First
1/16" = 1'-0"



1 School HVAC Second
1/16" = 1'-0"

Autodesk® Revit®

www.autodesk.com/revit

Consultant
Address
Address
Address
Phone

Consultant
Address
Address
Address
Phone

Consultant
Address
Address
Address
Phone

Consultant
Address
Address
Address
Phone

Consultant
Address
Address
Address
Phone

No.	Description	Date

AEI Team #04-2013

Reading Area Elementary School

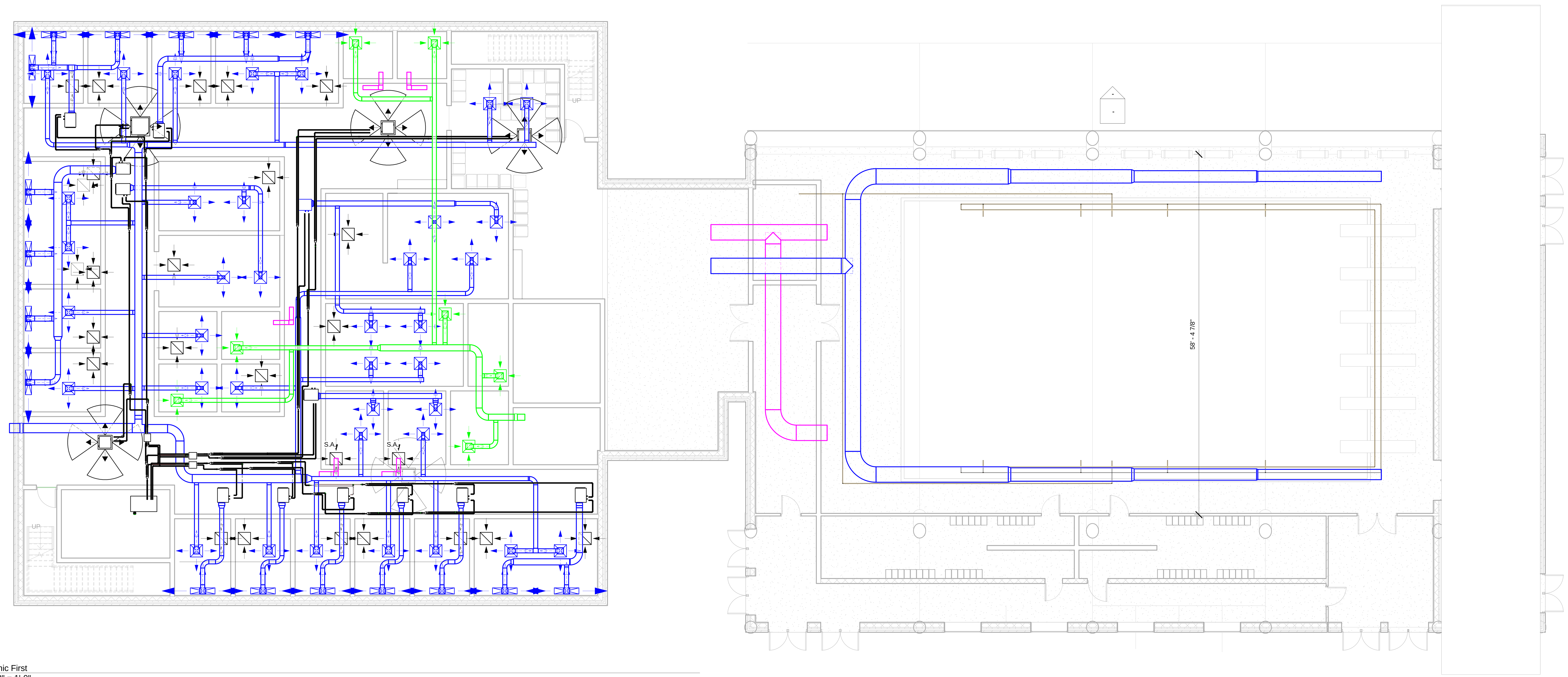
First and Second Floor Mechanical Plan

Project Number	04-2013
Date	22 Feb. 2013
Drawn By	Author
Checked By	Checker

M102

Scale	1/16" = 1'-0"

2/22/2013 6:27:58 AM



1 Clinic First
1/8" = 1'-0"

Drawing Notes:

A. (3) Total Branch Selector Units equipped with suction gas pipe, HP/LP gas pipe, and liquid pipe on the inlet side.

B. (11) Refrigerant Network Joints containing a hot gas pipe connection

C.(11) Refrigerant Network Joints containing a liquid pipe connection

D.(16) Fan Coil Units

F. (1) Indoor condensing unit tied into existing HVAC system

G. Each FCU shall have isolation valves installed to allow for future maintenance.

Drawing Notes:

A. (2) 30"Ø Supply Ducts

B. (2) 30"Ø Return Ducts

C. AHU heats pool water, provides heating and cooling for the space, and dehumidifies the air to the approriate level.

D. AHU connects gas pipe to existing boiler for space heating.

Autodesk® Revit®

www.autodesk.com/revit

Consultant
Address
Address
Address
Phone

Consultant
Address
Address
Address
Phone

Consultant
Address
Address
Address
Phone

Consultant
Address
Address
Address
Phone

Consultant
Address
Address
Address
Phone

No.	Description	Date

AEI Team #04-2013

Reading Area Elementary School

First Floor Mechanical Plan- Phase 2

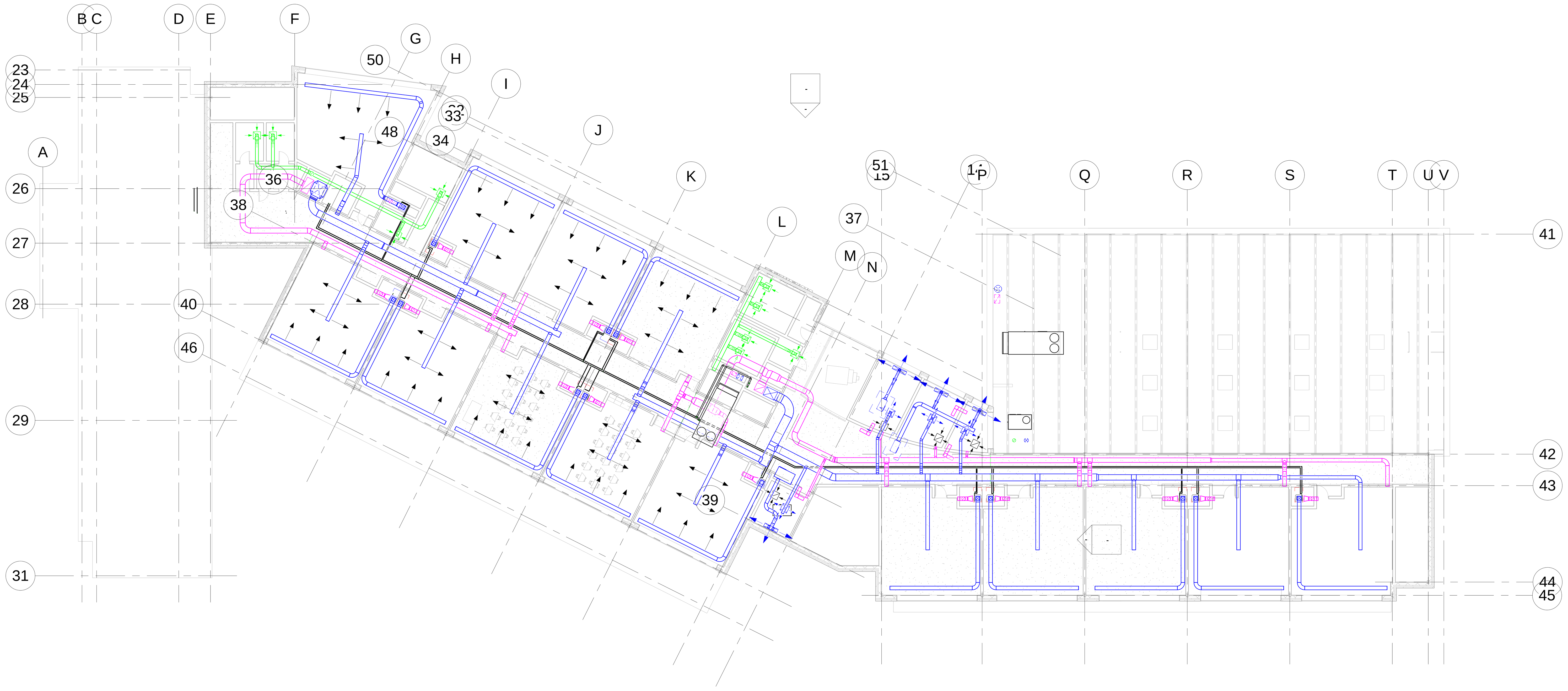
Project Number	04-2013
Date	22 Feb. 2013
Drawn By	Author
Checked By	Checker

M102a

Scale 1/8" = 1'-0"

2/22/2013 5:43:51 AM

Drawing Notes:
A. Heat Pump water supply and return sized at 1 1/2"
B. Each Heat Pump shall have isolation valves installed to allow for future maintenance.
C. Main and branch duct sized for 0.08 inH20/100ft.
D. High-induction diffusers used for classrooms.
E. Arrows represent the diffuser flow.



1 School HVAC Third
1/16" = 1'-0"

General Desing Notes:
A. The drawings provided by AEI showed alloted space outside of each classroom. These were conviently used to house the heat pumps. Each closet offers enough clearance space for each heat pump to ensure safe working environments.
B. A decoupled system provided the ventilation air from the DOAS and additional heating/cooling from the heat pumps.

Autodesk Revit

www.autodesk.com/revit

Consultant
Address
Address
Address
Phone

Consultant
Address
Address
Address
Phone

Consultant
Address
Address
Address
Phone

Consultant
Address
Address
Address
Phone

Consultant
Address
Address
Address
Phone

No.	Description	Date

AEI Team #04-2013

Reading Area Elementary School

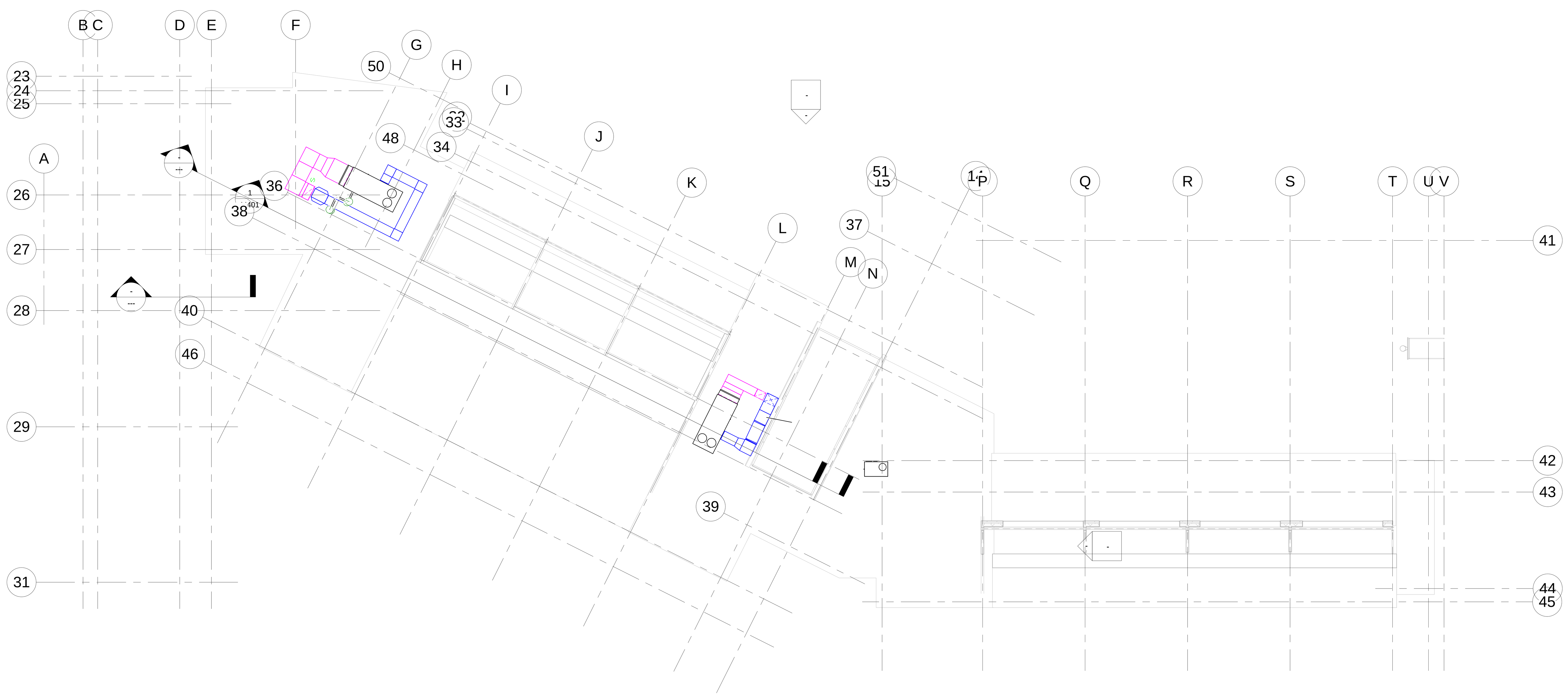
Third Floor Mechanical Plan

Project Number	04-2013
Date	22 Feb. 2013
Drawn By	Author
Checked By	Checker

M103

Scale	1/16" = 1'-0"

2/22/2013 6:34:22 AM



1 School HVAC
1/16" = 1'-0"

Autodesk® Revit®

www.autodesk.com/revit

Consultant
Address
Address
Address
Phone

Consultant
Address
Address
Address
Phone

Consultant
Address
Address
Address
Phone

Consultant
Address
Address
Address
Phone

Consultant
Address
Address
Address
Phone

No.	Description	Date

AEI Team #04-2013

Reading Area Elementary School

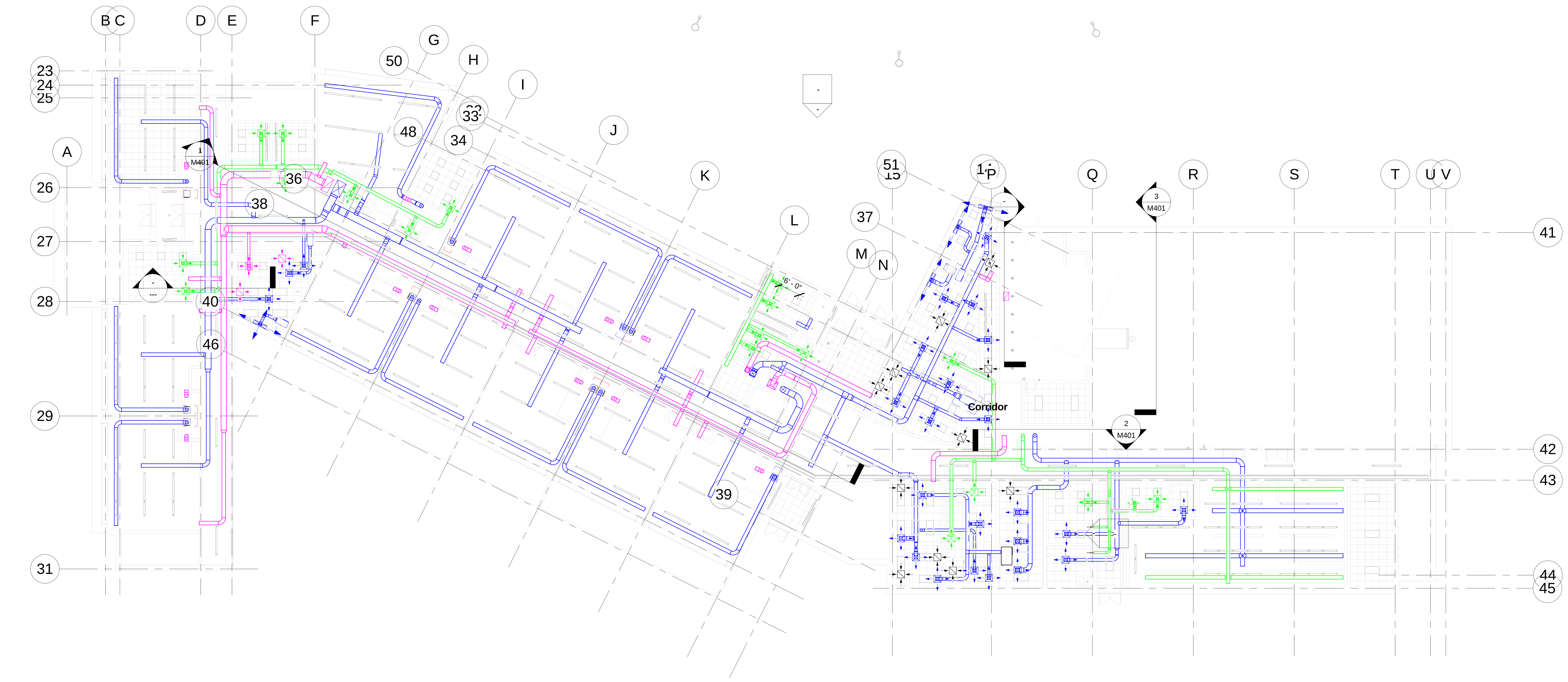
Roof Mechanical Plan

Project Number	04-2013
Date	22 Feb. 2013
Drawn By	Author
Checked By	Checker

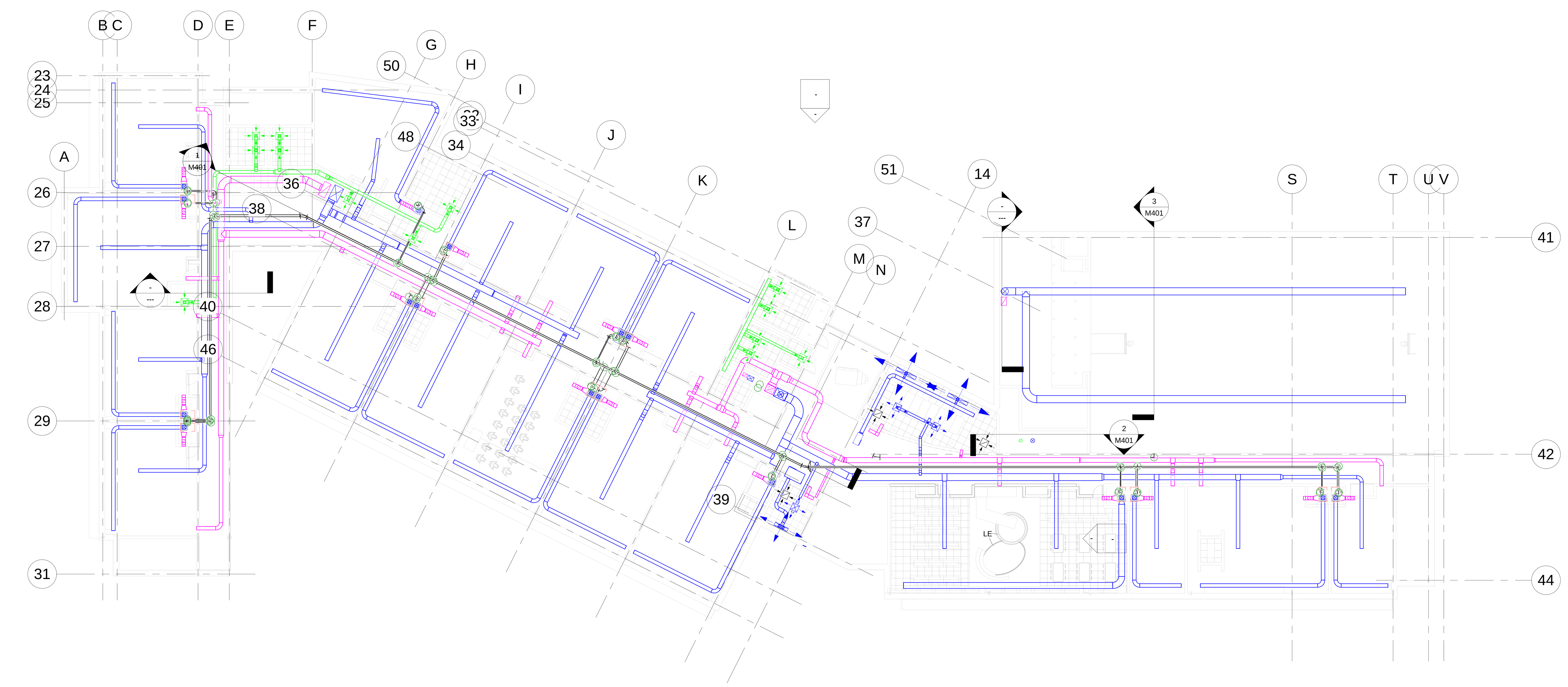
M104

Scale	1/16" = 1'-0"

2/22/2013 6:34:30 AM



1 - Ceiling Mech
1/16" = 1'-0"



2 - Ceiling Mech
1/16" = 1'-0"

Drawing Notes: See Sheet M102 for additional drawing notes

Autodesk® Revit®

www.autodesk.com/revit

Consultant
Address
Address
Address
Phone

Consultant
Address
Address
Address
Phone

Consultant
Address
Address
Address
Phone

Consultant
Address
Address
Address
Phone

Consultant
Address
Address
Address
Phone

No.	Description	Date

AEI Team #04-2013

Reading Area Elementary School

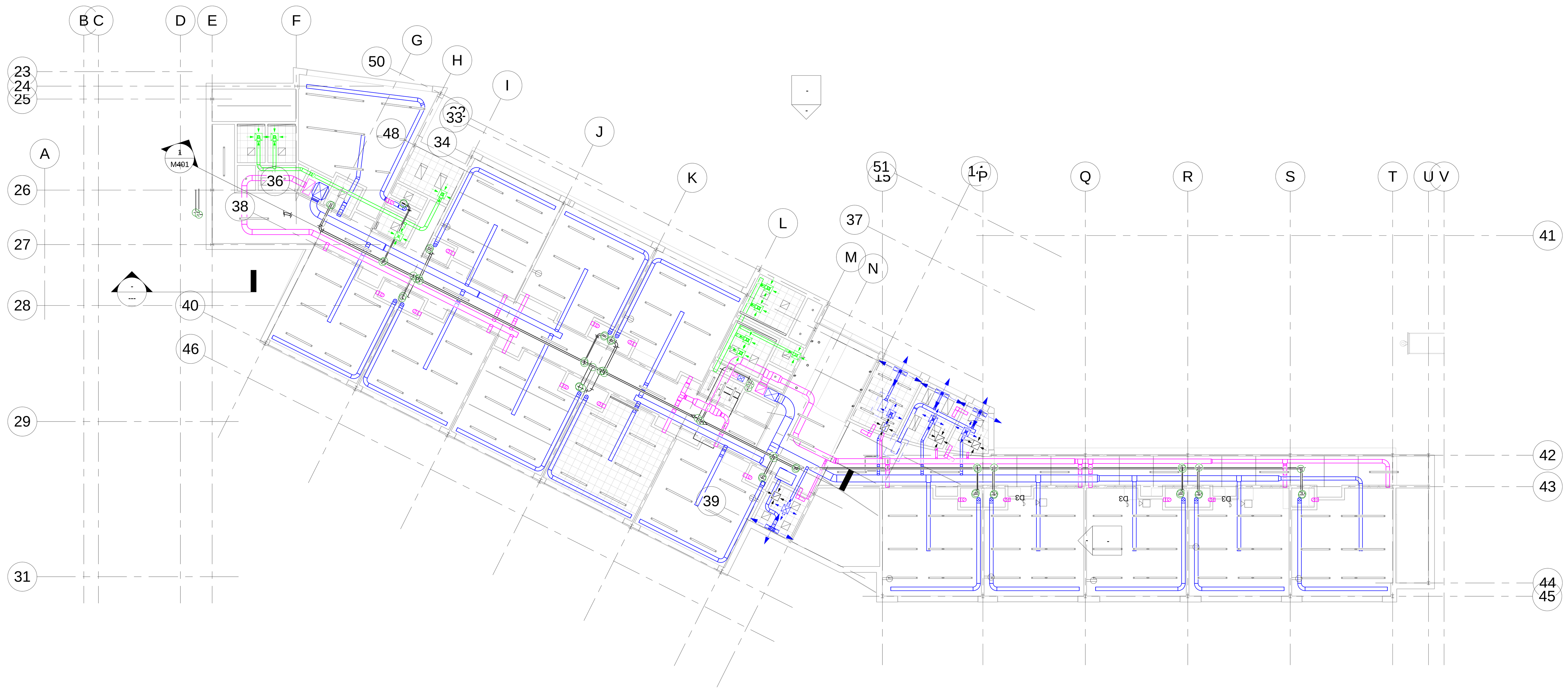
First & Second Floor Reflected Ceiling Plan

Project Number	04-2013
Date	22 Feb. 2013
Drawn By	04-2013
Checked By	Checker

M201

Scale	1/16" = 1'-0"

2/22/2013 4:46:18 AM



1 3 - Ceiling Mech
1/16" = 1'-0"

Drawing Notes:
See Sheet M103 for additional drawing notes.

Autodesk Revit

www.autodesk.com/revit

Consultant
Address
Address
Address
Phone

Consultant
Address
Address
Address
Phone

Consultant
Address
Address
Address
Phone

Consultant
Address
Address
Address
Phone

Consultant
Address
Address
Address
Phone

No.	Description	Date

AEI Team #04-2013

Reading Area Elementary School

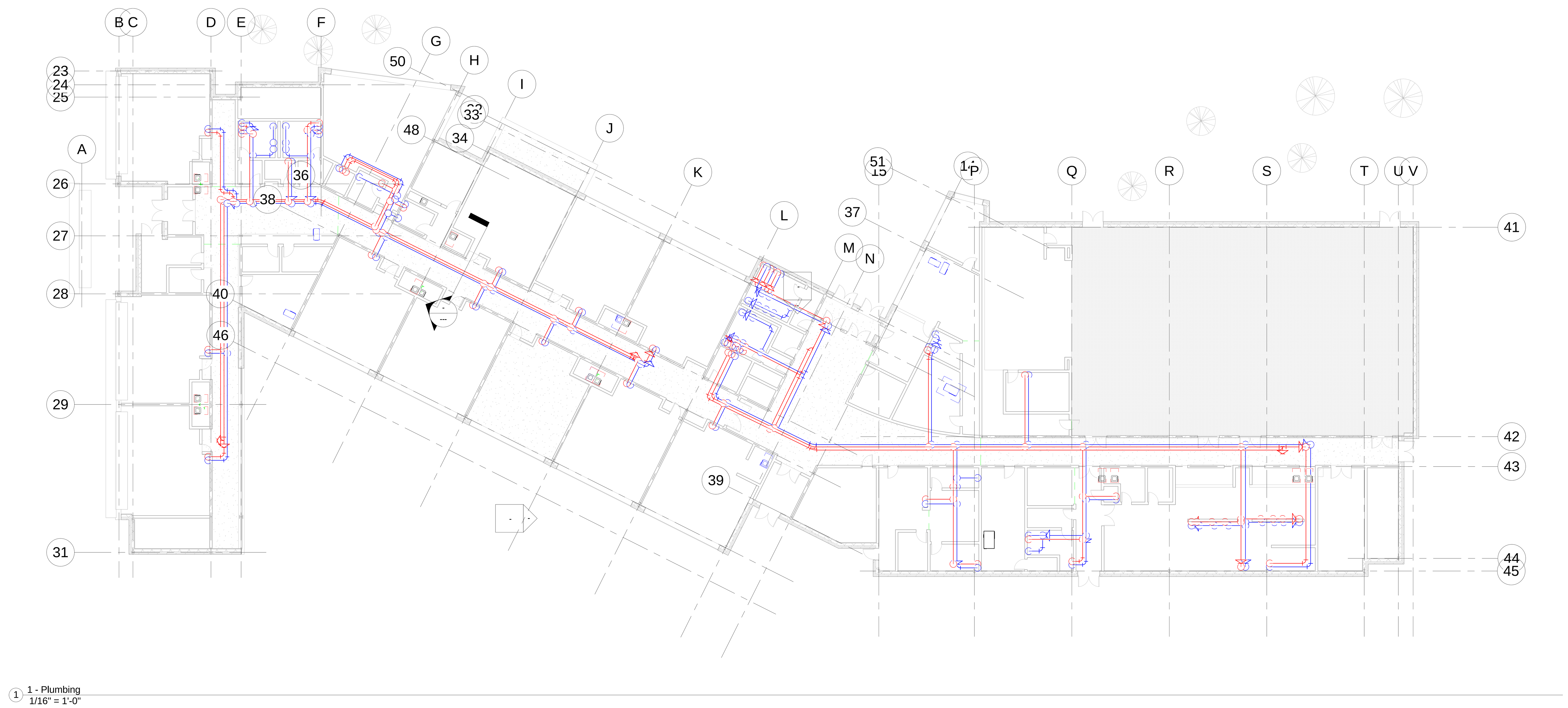
Third Floor Reflected Ceiling Plan

Project Number	04-2013
Date	22 Feb. 2013
Drawn By	Author
Checked By	Checker

M202

Scale 1/16" = 1'-0"

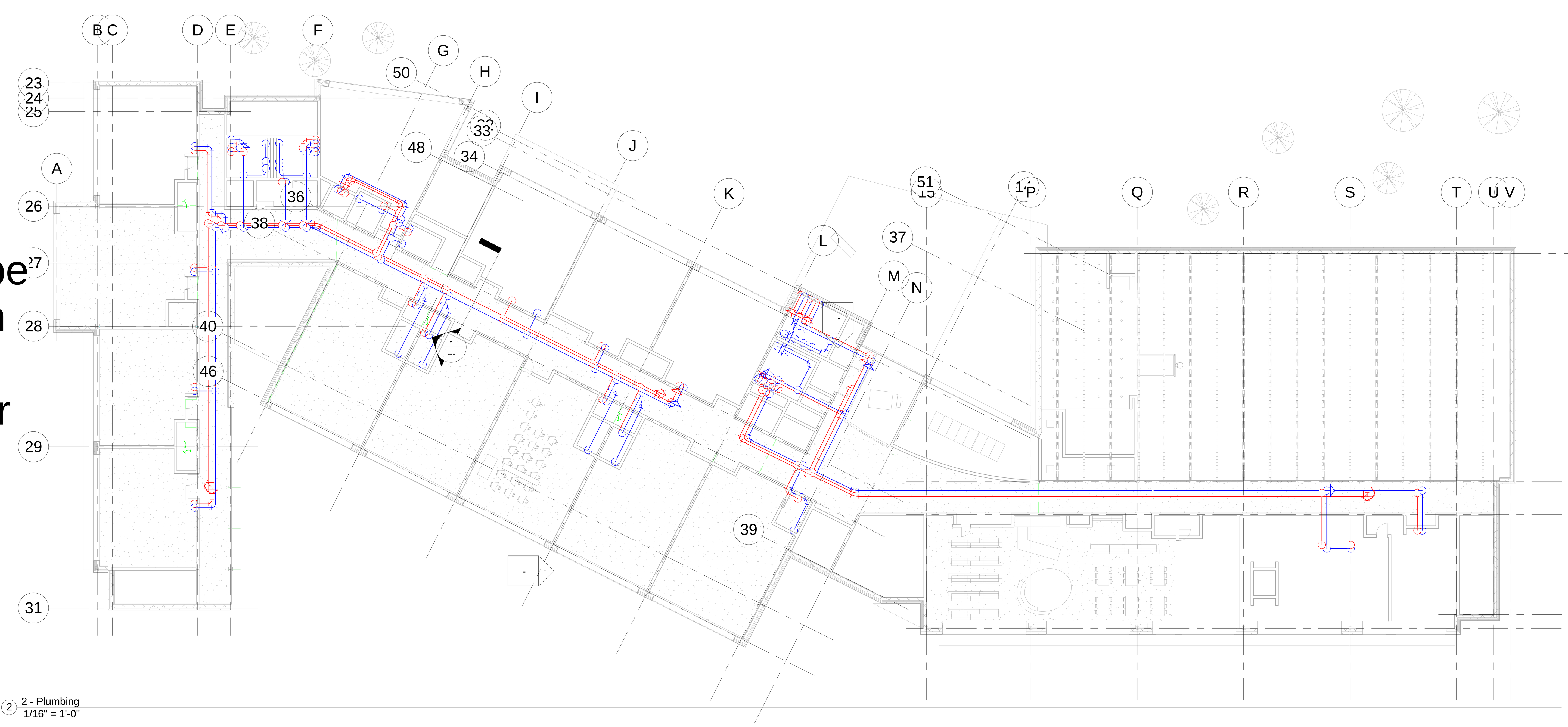
2/22/2013 4:46:36 AM



1 - Plumbing
1/16" = 1'-0"

Drawing Notes:

A. 4" CW Main on 1st floor
B. 3" HW Main on 1st floor
C. 3/4" HWR Main on both floors
D. Balancing valves shall be installed at the end of each hot water recirculation line.
E. 3" CW Main on 2nd floor
F. 2 1/2" HW Main on 2nd floor
G. Each fixture shall have isolation valves installed to allow for future maintenance.



2 - Plumbing
1/16" = 1'-0"

Consultant
Address
Address
Address
Phone

Consultant
Address
Address
Address
Phone

Consultant
Address
Address
Address
Phone

Consultant
Address
Address
Address
Phone

Consultant
Address
Address
Address
Phone

No.	Description	Date

AEI Team #04-2013

Reading Area Elementary School

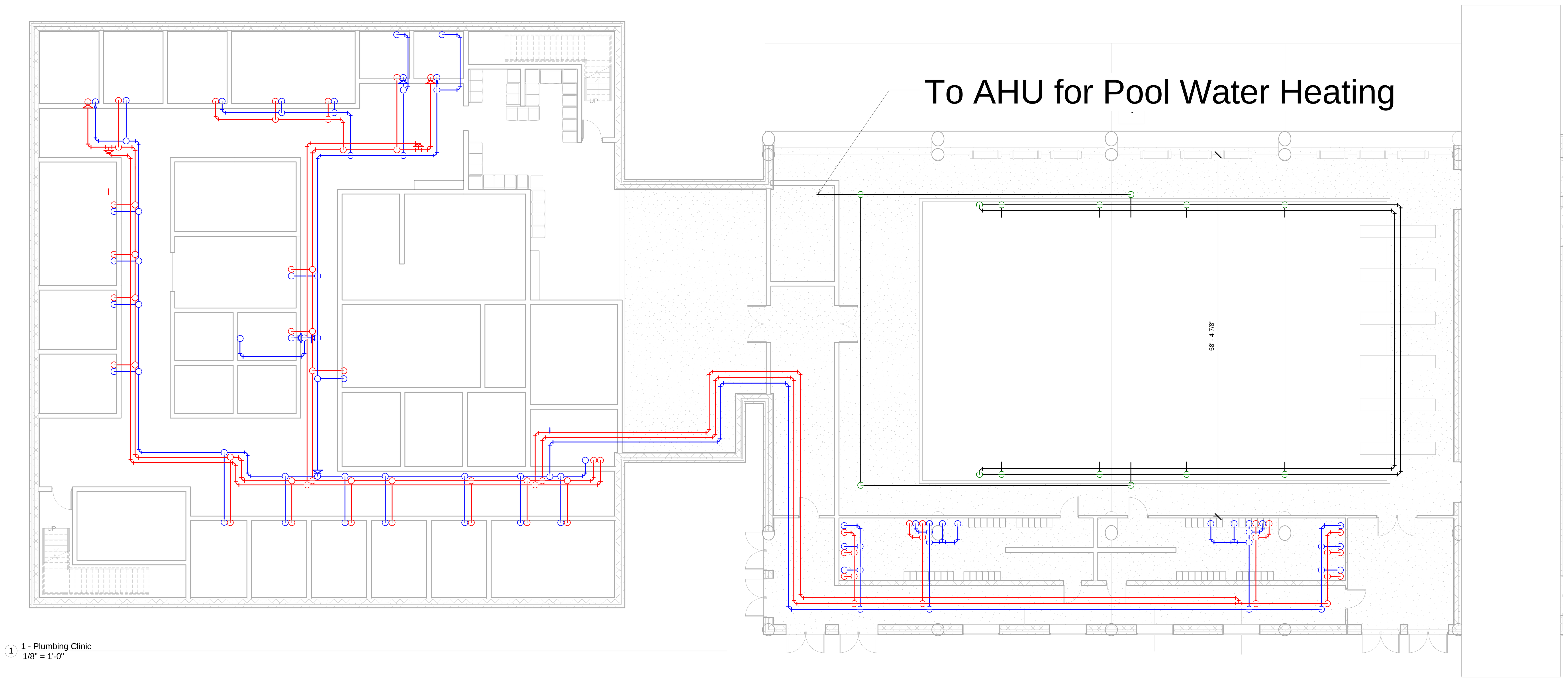
First and Second Floor Plumbing Plan - Phase 1

Project Number	04-2013
Date	22 Feb. 2013
Drawn By	Author
Checked By	Checker

M301

Scale 1/16" = 1'-0"

2/22/2013 6:34:50 AM



1 - Plumbing Clinic
1/8" = 1'-0"

Drawing Notes:
A. Cold Water Main sized at 3"
B. Hot Water Main sized at 2"
C. Hot Water Recirc. sized at 1/2"
D. Balancing valves shall be installed at the end of each hot water recirculation line.
E. Each fixture shall have isolation valves installed to allow for future maintenance.

Autodesk® Revit®

www.autodesk.com/revit

Consultant
Address
Address
Address
Phone

Consultant
Address
Address
Address
Phone

Consultant
Address
Address
Address
Phone

Consultant
Address
Address
Address
Phone

Consultant
Address
Address
Address
Phone

No.	Description	Date

AEI Team #04-2013

Reading Area Elementary School

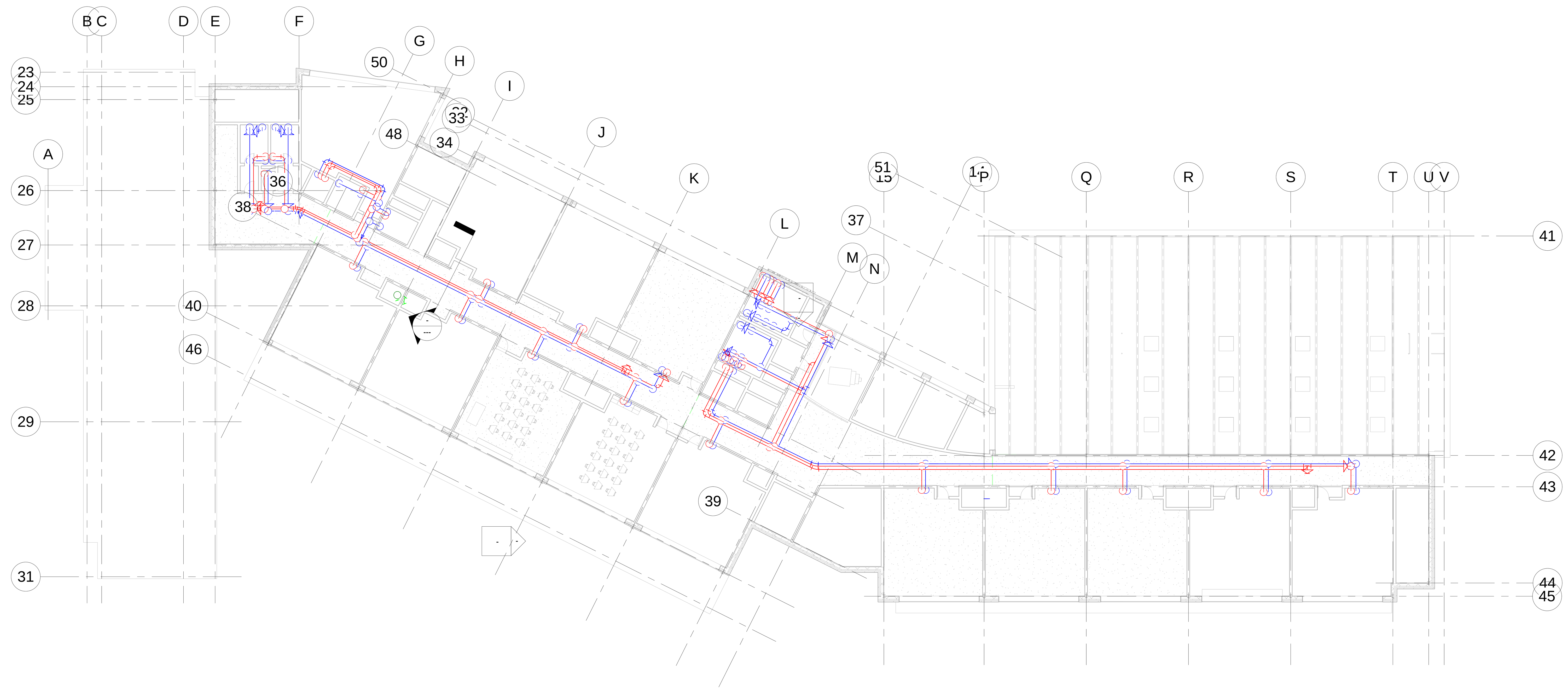
First Floor Plumbing Plan - Phase 2

Project Number	04-2013
Date	22 Feb. 2013
Drawn By	Author
Checked By	Checker

M301a

Scale 1/8" = 1'-0"

2/22/2013 6:35:02 AM



1 3- Plumbing
1/16" = 1'-0"

Drawing Notes:
A. 2" CW Main
B. 1 1/2" HW Main
C. 3/4" HWR Main
D. Balancing valves shall be installed at the end of each hot water recirculation line
E. Each fixture shall have isolation valves to allow for future maintenance.

Consultant
Address
Address
Address
Phone

Consultant
Address
Address
Address
Phone

Consultant
Address
Address
Address
Phone

Consultant
Address
Address
Address
Phone

Consultant
Address
Address
Address
Phone

No.	Description	Date

AEI Team #04-2013

Reading Area Elementary School

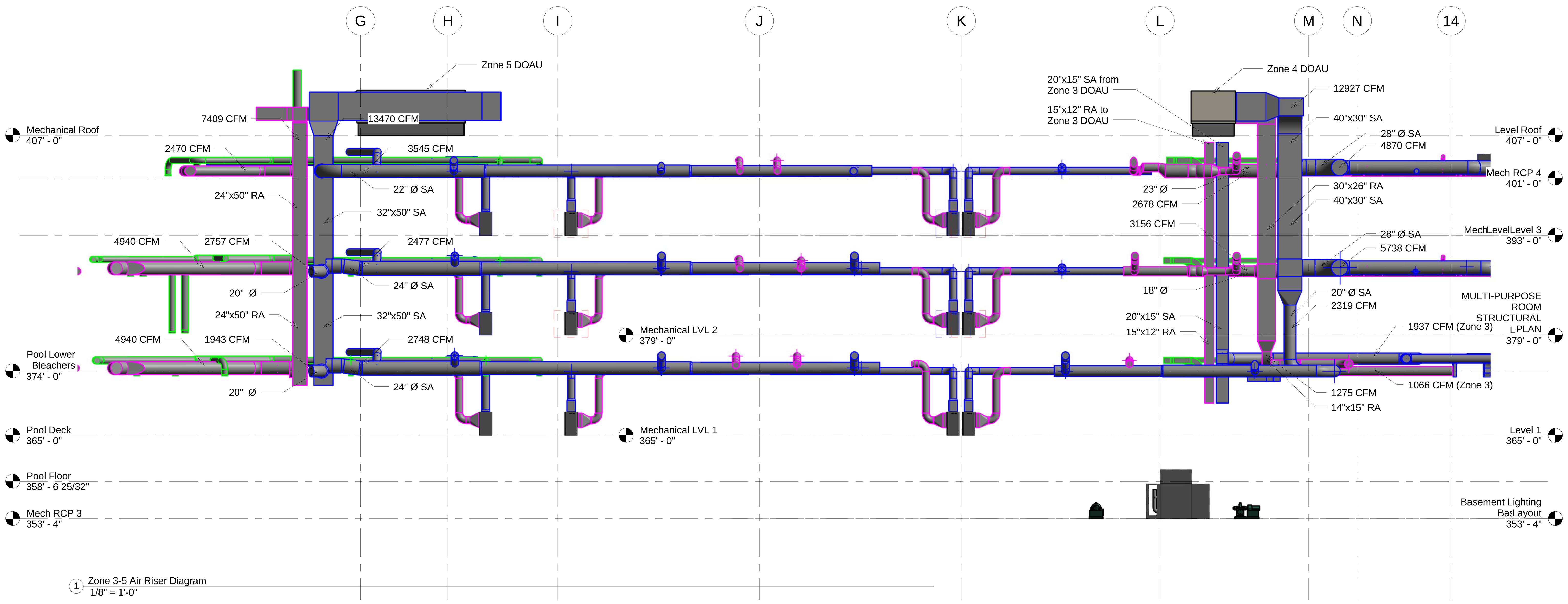
Third Floor Plumbing Plan

Project Number	04-2013
Date	22 Feb. 2013
Drawn By	Author
Checked By	Checker

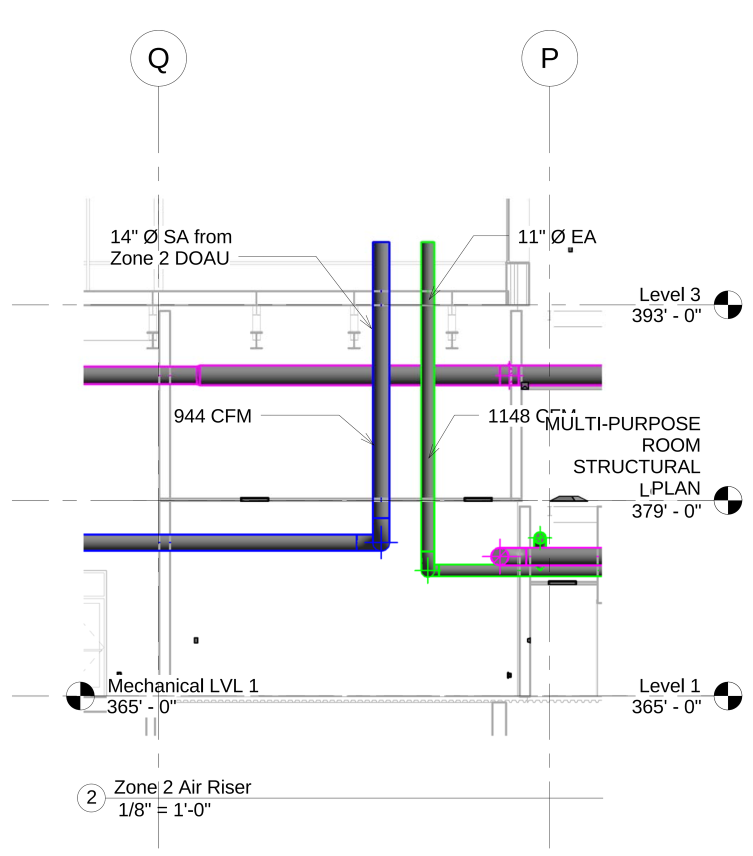
M302

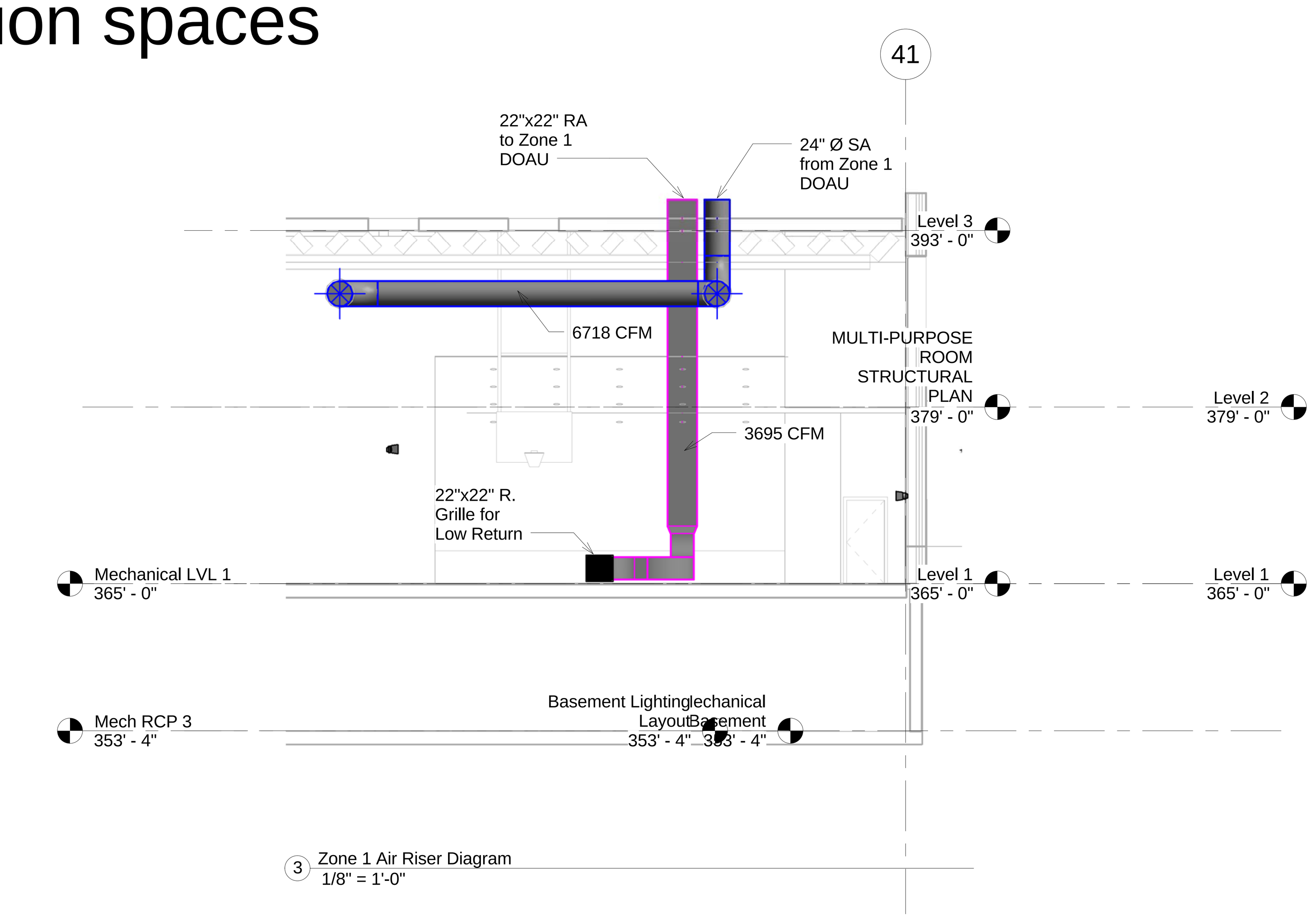
Scale	1/16" = 1'-0"

2/22/2013 6:35:19 AM



Drawing Notes:
A. DOAU 4 and DOAU 5 serve the main spaces within the school
B. DOAU 3 serves the administration spaces





Drawing Notes:
A. 22" Ø SA, 944 CFM
B. All air from kitchen is directly exhausted and will negatively pressurize the space to contain contaminants and odor.

Drawing Notes:
A. A low return is utilized for better mixing of the air in the multipurpose space.
B.24" Ø SA, 6718 CFM
C.22"x22" RA, 3695 CFM
D.Fabric Duct is utilized for better mxing

Autodesk Revit

www.autodesk.com/revit

Consultant
Address
Address
Address
Phone

Consultant
Address
Address
Address
Phone

Consultant
Address
Address
Address
Phone

Consultant
Address
Address
Address
Phone

Consultant
Address
Address
Address
Phone

No.	Description	Date

AEI Team #04-2013

Reading Area Elementary School

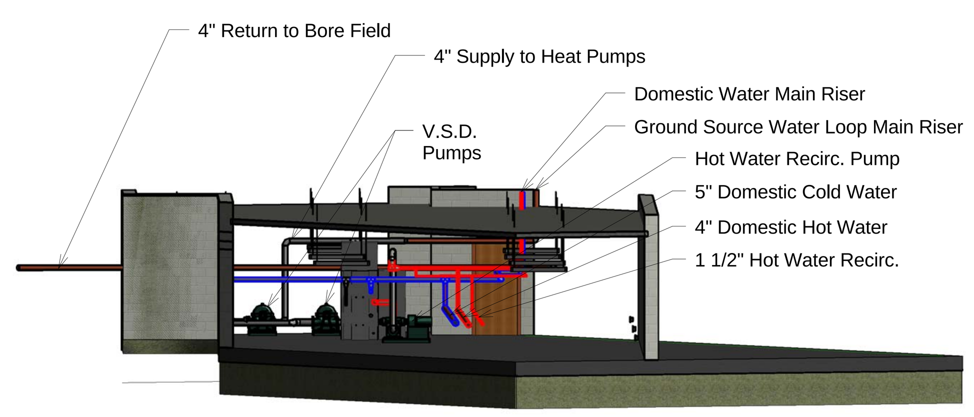
Air Distribution Riser Diagram

Project Number	04-2013
Date	22 Feb. 2013
Drawn By	Author
Checked By	Checker

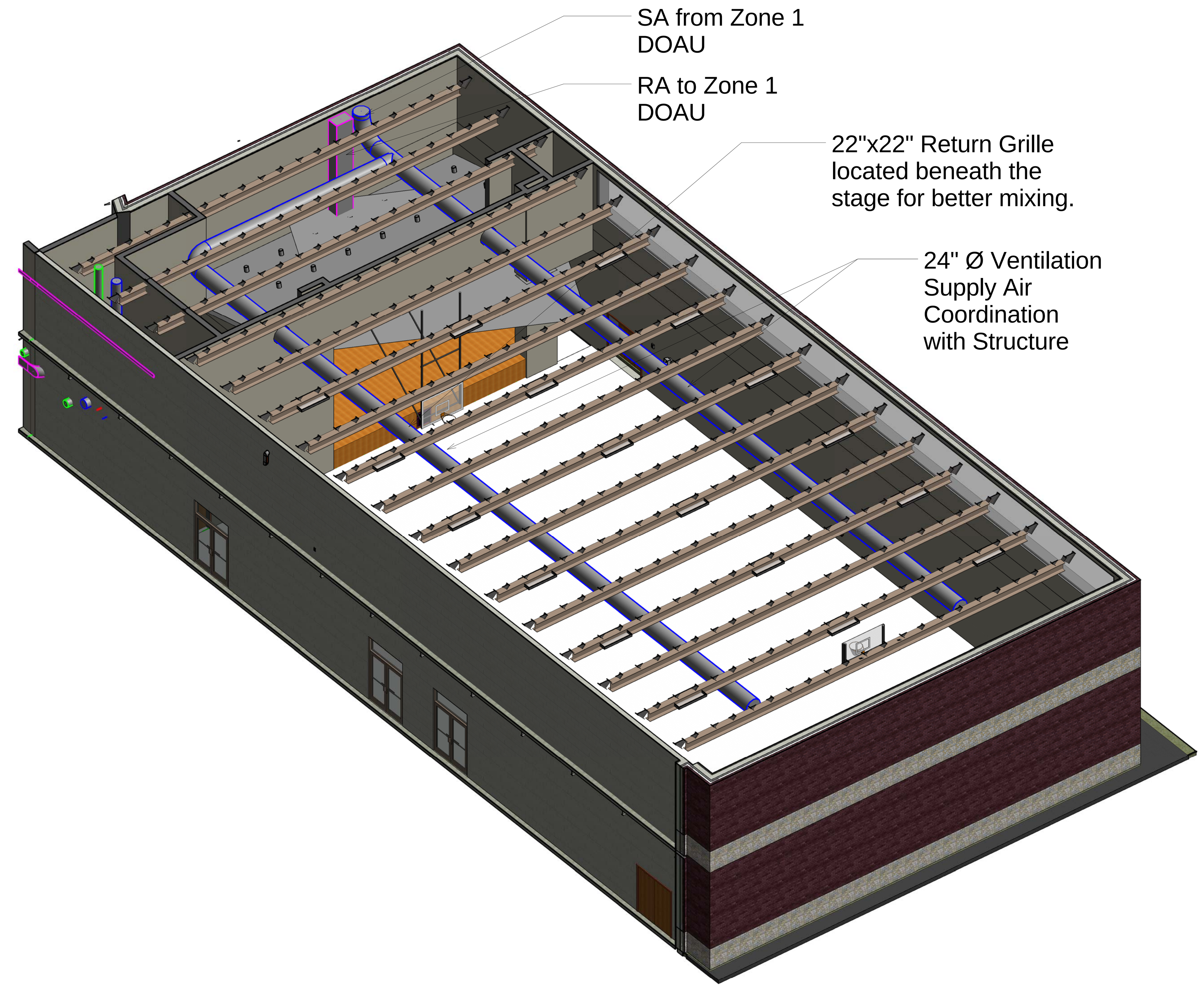
M401

Scale 1/8" = 1'-0"

2/22/2013 5:43:08 AM



3 Mechanical Room View



2 Gym Coordination

Drawing Notes:
A. Fabric duct is used to allow for better air distribution and for durability against gym events in the multipurpose room.

1 Atrium Coordination

Drawing Notes:
A. All Ductwork, HVAC piping, and plumbing piping are exposed to utilize the school as a teaching tool.
B. Heavy integration of the atrium space was required as it is the main pedestrian access to the building.

Autodesk® Revit®

www.autodesk.com/revit

Consultant
Address
Address
Address
Phone

Consultant
Address
Address
Address
Phone

Consultant
Address
Address
Address
Phone

Consultant
Address
Address
Address
Phone

Consultant
Address
Address
Address
Phone

No.	Description	Date

AEI Team #04-2013

Reading Area Elementary School

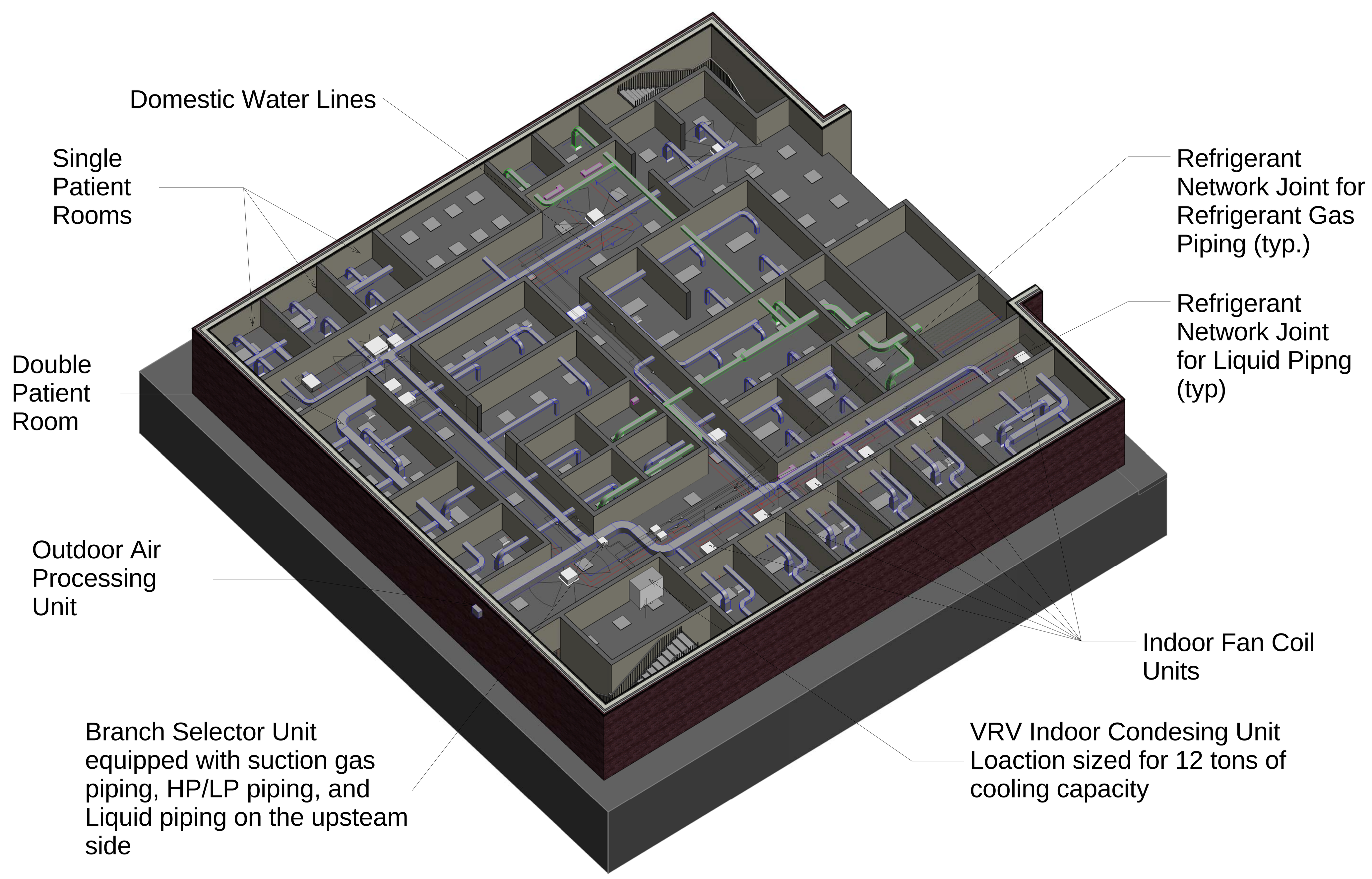
3D Coordination

Project Number	04-2013
Date	22 Feb. 2013
Drawn By	Author
Checked By	Checker

M501

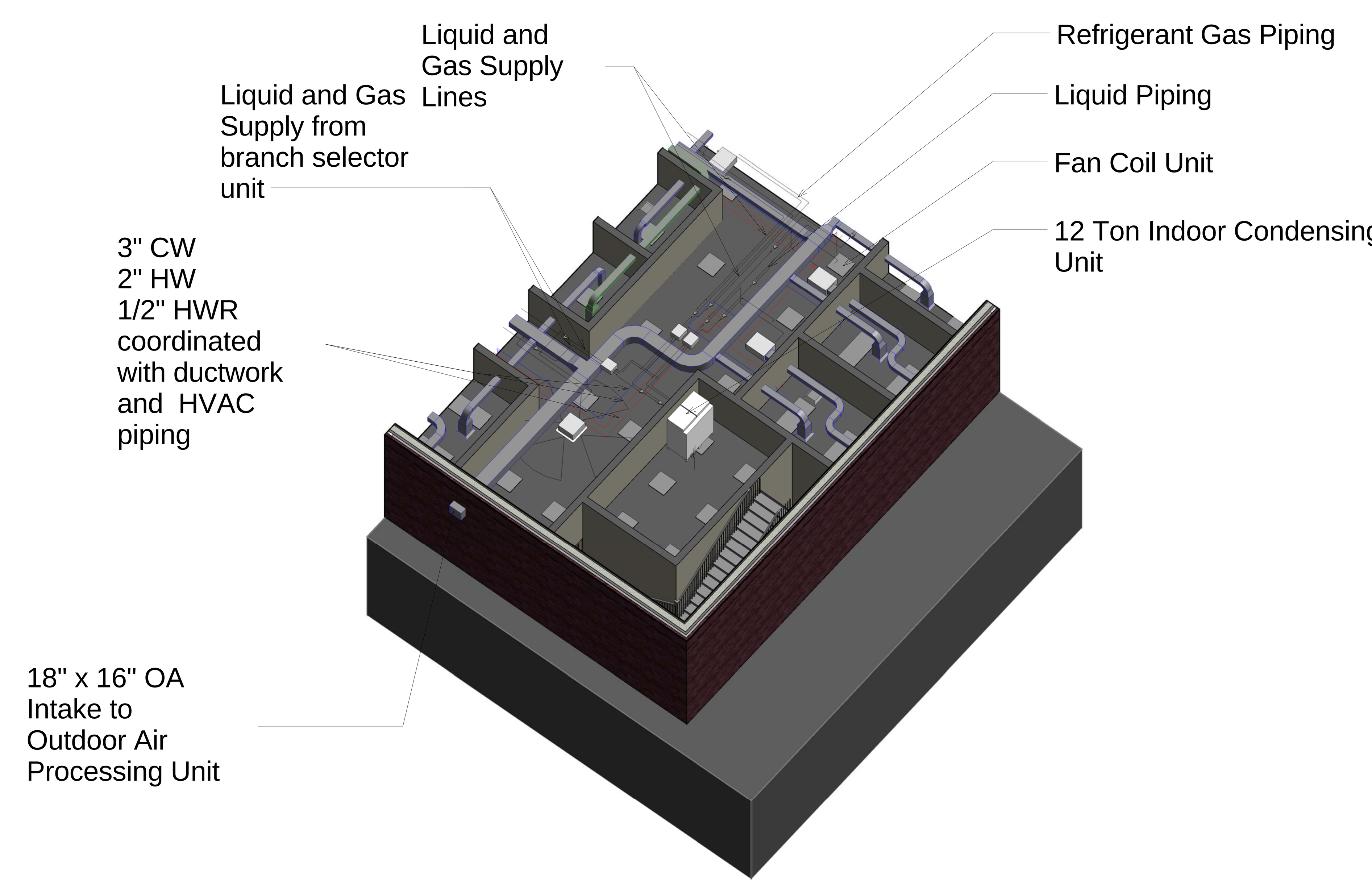
Scale

2/22/2013 5:13:27 AM



2 Clinic Coordination

Drawing Notes:
A. (1) 12 Ton Indoor Condensing Unit with Heat Recovery Tied Into Existing Boiler and Chiller Loop
B. (1) Outdoor Air Processing Unit, 944 CFM
C. (16) Fan Coil Units
D. (3) Branch Selector Units
E. (22) Refrigerant Network Joints



1 VRV Coordination

Autodesk® Revit®

www.autodesk.com/revit

No.	Description	Date

AEI Team #04-2013

Reading Elementary School

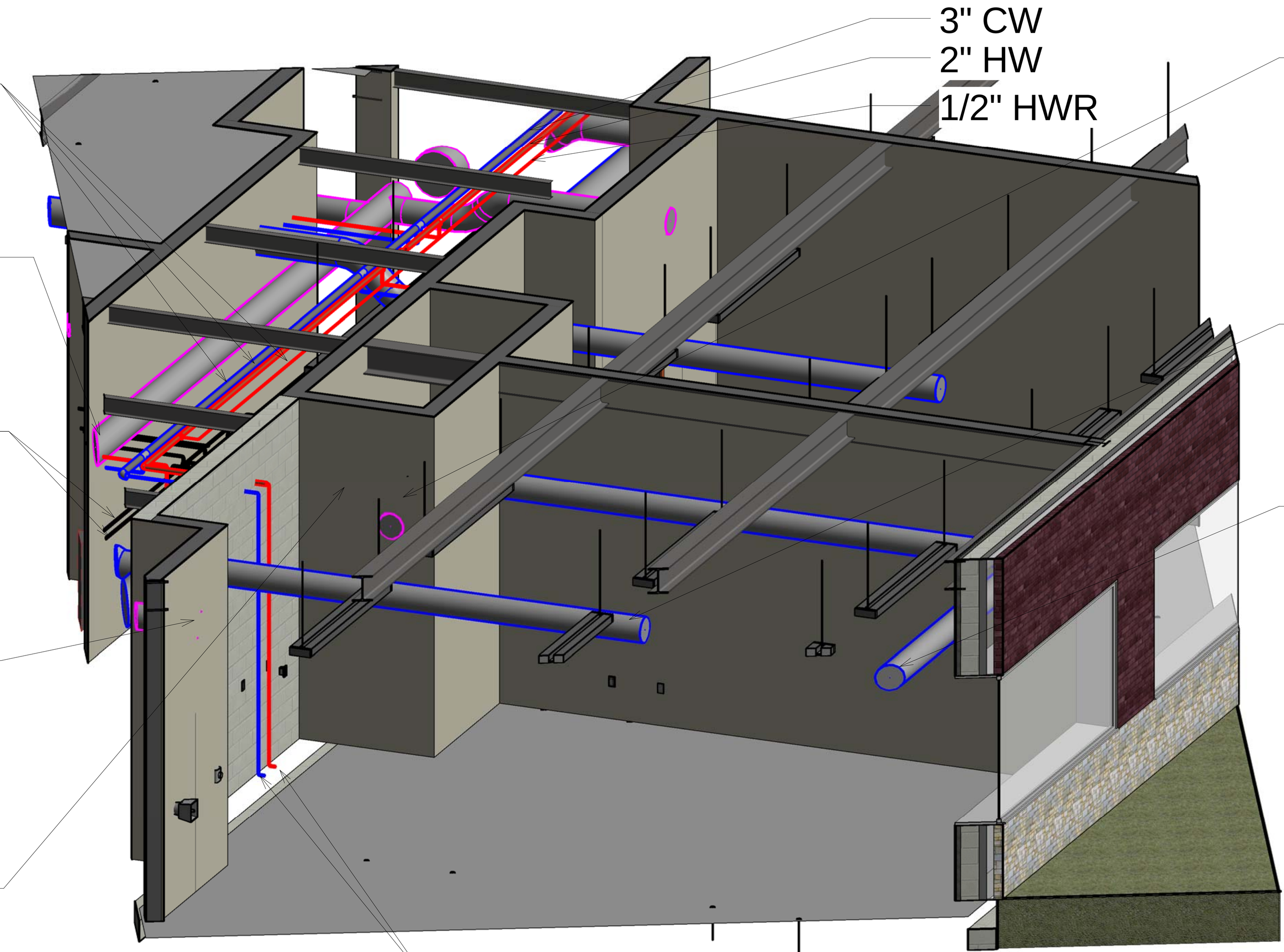
3D Coordination - Phase 2

Project Number	04-2013
Date	22 February 2013
Drawn By	04-2013
Checked By	Checker

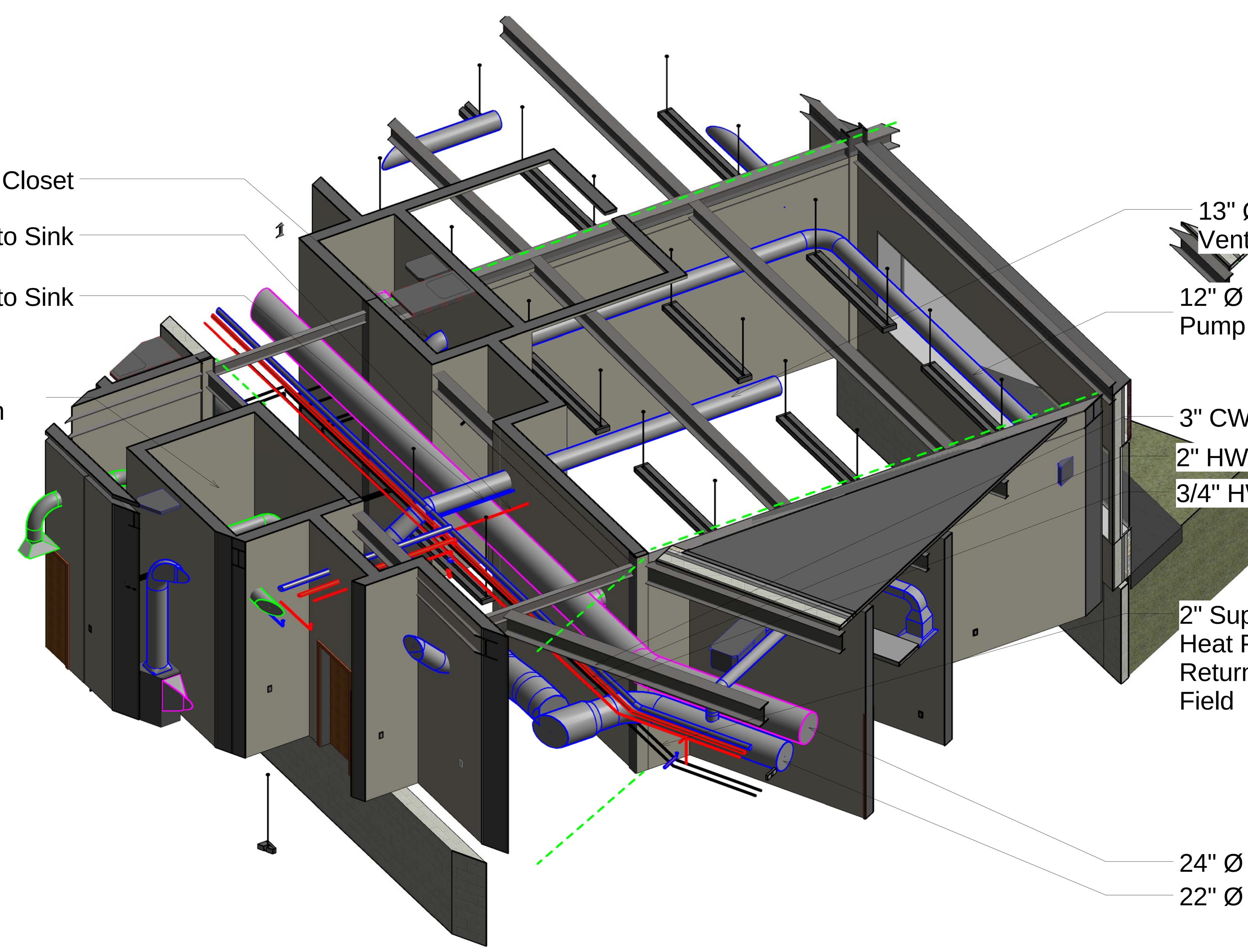
M501a

Scale

2/22/2013 5:46:34 AM



1 Classroom and Corridor Coordination



2 Classroom Coordination

Autodesk Revit

www.autodesk.com/revit

Consultant
Address
Address
Address
Phone

Consultant
Address
Address
Address
Phone

Consultant
Address
Address
Address
Phone

Consultant
Address
Address
Address
Phone

Consultant
Address
Address
Address
Phone

No.	Description	Date

AEI Team #04-2013

Reading Area Elementary School

3D Coordination

Project Number	04-2013
Date	22 Feb. 2013
Drawn By	Author
Checked By	Checker

M502

Scale

2/22/2013 5:16:25 AM