High Performance Relocatable Classrooms

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ABSTRACT

The school market segment represents a significant national building opportunity for relocatable classrooms over the next few years. This opportunity is driven by a number of factors, including mandatory class size reduction policies, increases in population, construction time limitations, and economic issues. One of every eight square feet of commercial building space in the United States and Canada is devoted to education.

Oftentimes, site-built schools are not an option to meet all of the classroom requirements for school districts. Relocatables offer a significantly less expensive alternative and can be ordered and delivered to a building site much quicker than building a classroom via the traditional design and construct process. In California alone, 28,000 new relocatable classrooms were supplied during 1996 and 1997.

Concerns about the quality of these relocatable classrooms have been magnified by a number of recent media reports. In response to these concerns, a high-performance relocatable classroom design was initiated by Southern California Edison and its partners. The design criteria addressed critical factors that affect high performance relocatables and student productivity. Some of the factors addressed include visual and acoustic comfort, security, durability, efficiency, and air quality.

Two prototypical classrooms were fabricated in adherence to the design criteria. Based on computer simulation models, both prototypes demonstrate significant energy savings over the minimum standard of a classroom conforming to the California energy codes. They also demonstrate an integrated design approach that enhances the performance of the standard relocatable classroom.

This paper explores the design process and describes the two resulting prototypical relocatable classroom designs. Findings of the computer energy modeling, daylight analyses and material selection are provided and illustrations of the two prototype classroom schemes are presented.

Introduction

The Modular Building Institute (MBI), a nationwide trade association for modular buildings, estimates that more than 220,000 relocatable classrooms are currently in use by public schools throughout the United States (Roman 2003). The State of California reports that the number of relocatable classrooms is expected to increase by five percent yearly (Jenkins, Phillips & Waldman 2003). This increase persists in spite of the California Assembly's 1998 revocation of its requirement that State-funded campus plans designate 30 percent of classrooms to be relocatable (Jenkins, Phillips & Waldman 2003).

Nearly 6.2 million children, teachers, and administrators (one-fifth of California's population) spend most of their day inside a California school facility (CHPS 2002). A survey of California school districts reports that just under one-third of California's 268,000 K-12 public school classrooms, in the 2000-2001 school year, were relocatables (Jenkins, Phillips & Waldman 2003).

High performance relocatables create classrooms that offer an improved learning environment while saving energy, conserving resources, and reducing operating costs. High performance relocatables achieve these goals by implementing a whole-building, integrated design. Each building component is studied and selected for the most appropriate, sustainable material or system according to both technological performance (utilizing today's most advanced equipment) and building performance (as an integrated system of synchronized parts).

A recent study completed by the California Environmental Protection Agency (EPA) for the Air Resources Board found that indoor environmental quality (IEQ) factors, such as poorly performing heating, ventilating, and air-conditioning (HVAC) systems, poor acoustics, chemical out gassing, water entry and mold growth, inadequate daylighting, and electric lighting, were prevalent among the population of relocatable classrooms studied (Jenkins, Phillips & Waldman 2003).

Southern California Edison began an initiative in the mid-1990's to promote the development of high performance relocatable classrooms. As a result, two schemes were prepared that addressed factors such as energy efficiency, indoor environmental quality, and visual and acoustic comfort. Each of the schemes derived from an integrated design process incorporating detailed computer modeling throughout the design process. Physical model testing was used for fenestration optimization and commissioning validated the predicted performance of the prototype relocatables.

Initiative Description

Southern California Edison (SCE), as part of its commitment to develop innovative energy efficiency solutions, initiated two high performance relocatable classroom designs. SCE's partners in this effort included California Energy Commission, California's Division of the State Architect, national laboratories, school design practitioners, school districts, relocatable manufacturers, and human factors specialists. The project was designed to apply sustainable practices to relocatable classrooms.

Designing these strategies included addressing visual comfort by optimizing fenestration for daylight distribution and integrating daylight distribution with electric lighting systems, fine tuning acoustics through the use of appropriate materials and accommodations for HVAC systems, improving construction durability, reducing energy consumption with high-efficiency equipment, and reducing impacts on the indoor air quality with improved ventilation and better interior finishes.

Design Charrette

Each of the two prototypical classroom projects commenced with a design charrette. The charrettes encompassed a full day of technical presentations and design sessions. Participants included relocatable classroom manufacturers, school district administrators and design personnel, architects, mechanical and electrical engineers, lighting designers, energy efficiency pundits, and building energy modelers.

Each project team discussed a broad range of issues, explored ideas for classroom improvements, and developed sketches for a prototype relocatable classroom integrating innovations. One key issue identified during these charrettes involved the perception of portable classrooms as temporary structures. Participants felt that the installation and operating costs of relocatable classrooms were driven by the purchasing expectations of school districts and modular classroom manufacturers. Since the relocatables are oftentimes perceived to be temporary structures, the building systems' quality and maintenance may suffer as a result. School district participants agreed that, in reality, portable classrooms are rarely moved after their initial installation.

Specific design objectives were identified during each charrette. These included:

- Site planning and landscaping
  - Group classrooms to create useful outdoor spaces
  - Consider solar orientation
  - Landscape classrooms for improved appearance and shading
- Building design
  - Consider various floor plan aspect ratios
  - Consider ceiling treatments
  - Consider siting for accessibility
  - Consider site preparation for long-term, moisture and runoff control
- Integrate daylighting with efficient electric lighting
  - Provide a daylit classroom
  - Use direct/indirect, efficient fluorescent luminaires
  - Integrate electric lighting controls to respond to daylight
- HVAC system design
  - Consider designs other than the traditional, wall-mounted HVAC unit
  - Consider alternative cooling and heating technologies
  - Explore alternatives to improve Indoor Environmental Quality (IEQ)
- Sustainable building materials
  - Consider installing high albedo roofing and other envelope features
  - Use recycled content and renewable material resources
  - Avoid materials with high volatile organic compounds (VOC) content

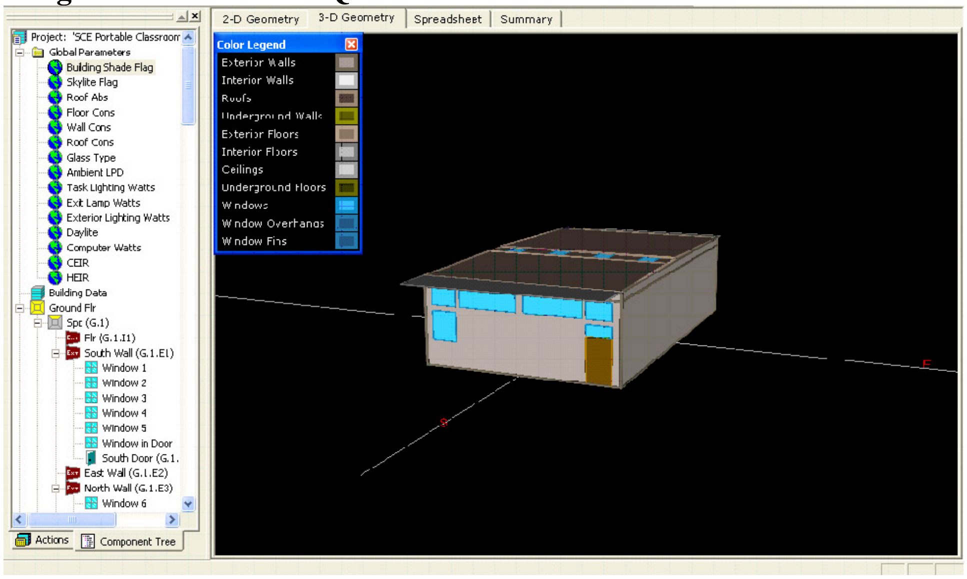
Computer Modeling

One of the project objectives was to exceed the California Building Energy Efficiency Standards (Title 24) by at least 30 percent. In order to create an energy baseline and to document measure savings, detailed 8,760-hour computer energy models with eQuest were created using eQuest software for each prototype classroom. See Figure 1 for a graphic of the Scheme 2 computer model.

Each proposed energy measure was examined through a parametric simulation and review method in order to determine the measure savings hierarchy. Packages of measures were modeled for the specific project climates, facilitating the selection of an optimum group of building efficiency measures.

The instrumentation and monitoring of the performance of various elements of each classroom allow the building models to be revisited and normalized for site conditions. In this way, the models can predict relocatable classroom performance at other sites and climates.

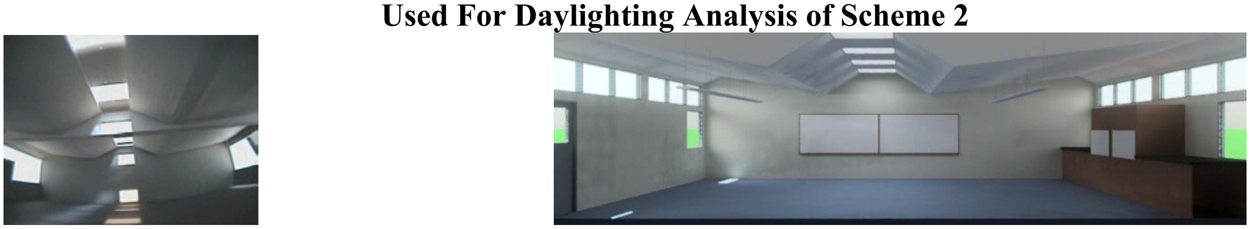
Figure 1. 3d View of eQuest Model Used in Simulation of Scheme 2



Daylight Analysis

Physical and computer models were created for each portable classroom in order to optimize the fenestration locations and to avoid direct beam sunlight at inopportune times. Figure 2 illustrates an interior view of the scheme 2 design using a heliodon and an interior view of the same classroom simulated with a Radiance computer model. The daylight studies considered evenness of daylight distribution, building orientation, and glare considerations.

Figure 2. Physical Model and Computer Simulation Used For Daylighting Analysis of Scheme 2



Electric lighting controls were integrated into the designs to maximize efficiency opportunities while optimizing visual performance. Additionally, direct lighting of teaching wall surfaces was implemented in response to studies showing improved student performance due to brighter learning walls (Rea 1993).

Mechanical Systems

Most contemporary relocatable classroom heating, ventilating, and air-conditioning (HVAC) systems are wall-mounted, packaged units. These units offer the advantages of low price and straight-forward, short duration installation requirements. Also, wall-mounted units installed on the building exterior may be serviced with minimal disruption to the classroom.

The disadvantages of wall-mount units include the noise levels they generate, the relatively low peak efficiency of the systems, and the close proximity of their fresh air ventilation and exhaust airstreams. Two different HVAC systems were designed and installed for the two prototype relocatables.

The Scheme One HVAC system is a split-system heat pump with both the condensing and fan-coil units housed in closets within the classroom. The air entering the condensing unit is drawn from the crawl space and discharged through a louver on the side of the building. Outdoor air is drawn into the mixed air plenum through an inlet at the top of the classroom and exhaust air exits at the end opposite the return air grille. Since the crawl space is cooler than ambient air during space cooling periods, this design improved the operating efficiency by lowering the condenser inlet air temperature. The design also located air inlets and outlets to avoid recirculation.

In the Scheme Two classroom, a displacement ventilation system delivers tempered air to low, sidewall supply diffusers that introduce the air at a low velocity. The supply air conditions the occupied portion of the space and is returned to the HVAC air handler through a cabinet-top grille. A small, heat pump chiller delivers chilled or hot water to a heat exchanger in the air handler in order to deliver a consistent supply air temperature. The system is designed to be capable of operating at 100% outdoor air. As with the Scheme One system, all HVAC components are located in mechanical closets within the classroom footprint. The Scheme Two HVAC system is accessible through an outside door.

Commissioning

The first prototype classroom was commissioned from the design phase through building occupancy. The commissioning process included documentation of the design objectives and the actual construction assemblies.

The building's lighting, HVAC, and acoustic performance were tested through short-term monitoring to validate those systems' operating conditions. Lighting level tests were conducted with desktop lighting level sensors to provide data on the performance of the daylighting design. Tests of the dimming controls for the electric lighting revealed problems with sensor location and adjustment. Since the dimming controls were installed according to the manufacturer's specifications, these problems were reported to the manufacturer for evaluation and correction.

Acoustic and HVAC performance tests of the classroom revealed problems with higher than expected sound levels and poor reverberation performance. The high sound reverberation resulted from the use of hard ceiling surfaces and the geometry of the classroom. The problem can be corrected by adding sound absorbing materials to various interior surfaces. The HVAC system generated more noise than anticipated due to problems in the construction of various system components. For example, supply air duct liner was eliminated by the mechanical contractor who thought that the liner was an unnecessary thermal insulation requirement.

The second prototype classroom has been documented since the initial design charrette and will also undergo a series of functional performance tests once it is sited and ready for occupancy.

Solutions

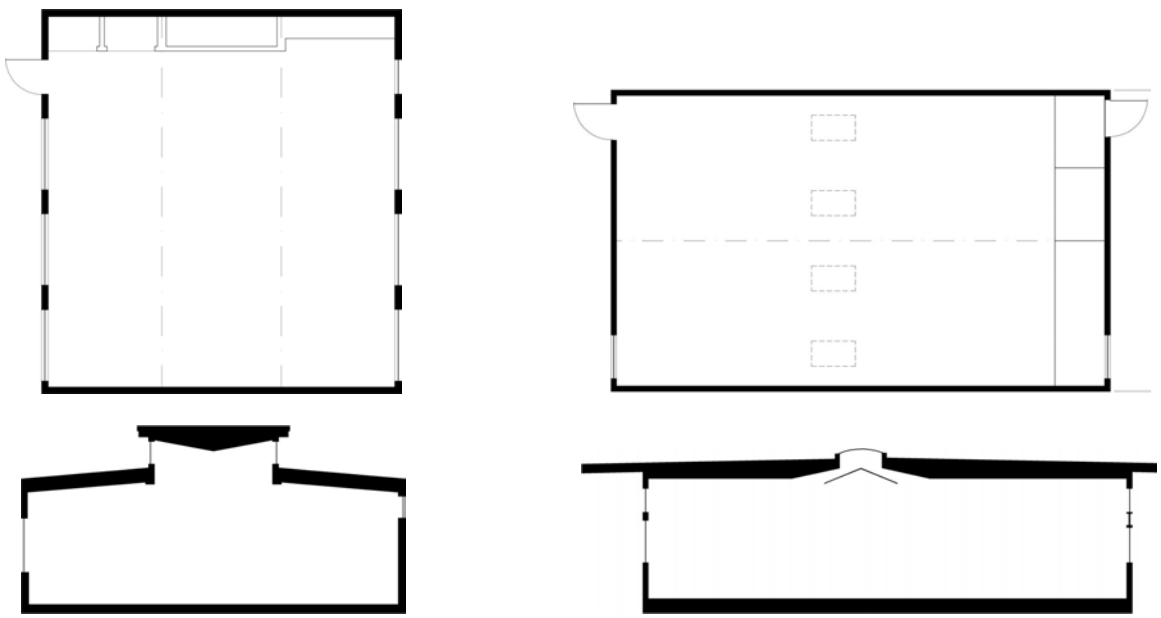
The two prototype classrooms were approached using two distinct schemes, which employed different design strategies for the floor plan, fenestration, and space conditioning solutions. Detailed specifications for the two prototypes are provided in the Appendix.

Floor Plan

Scheme One implemented a three-bay, square floor plan (30’ x 32’). Scheme Two implemented a rectangular two-bay solution (24’ x 40’). Both schemes made available the requisite 960 square feet. Plans and sections of each prototype scheme are illustrated in Figure 3.

The school districts preferred the three-bay model (30’ x 32’) over the two-bay model; however, the two-bay model was less expensive to fabricate.

Figure 3. Floor Plan and Section of Scheme One, Left, and Scheme Two, Right

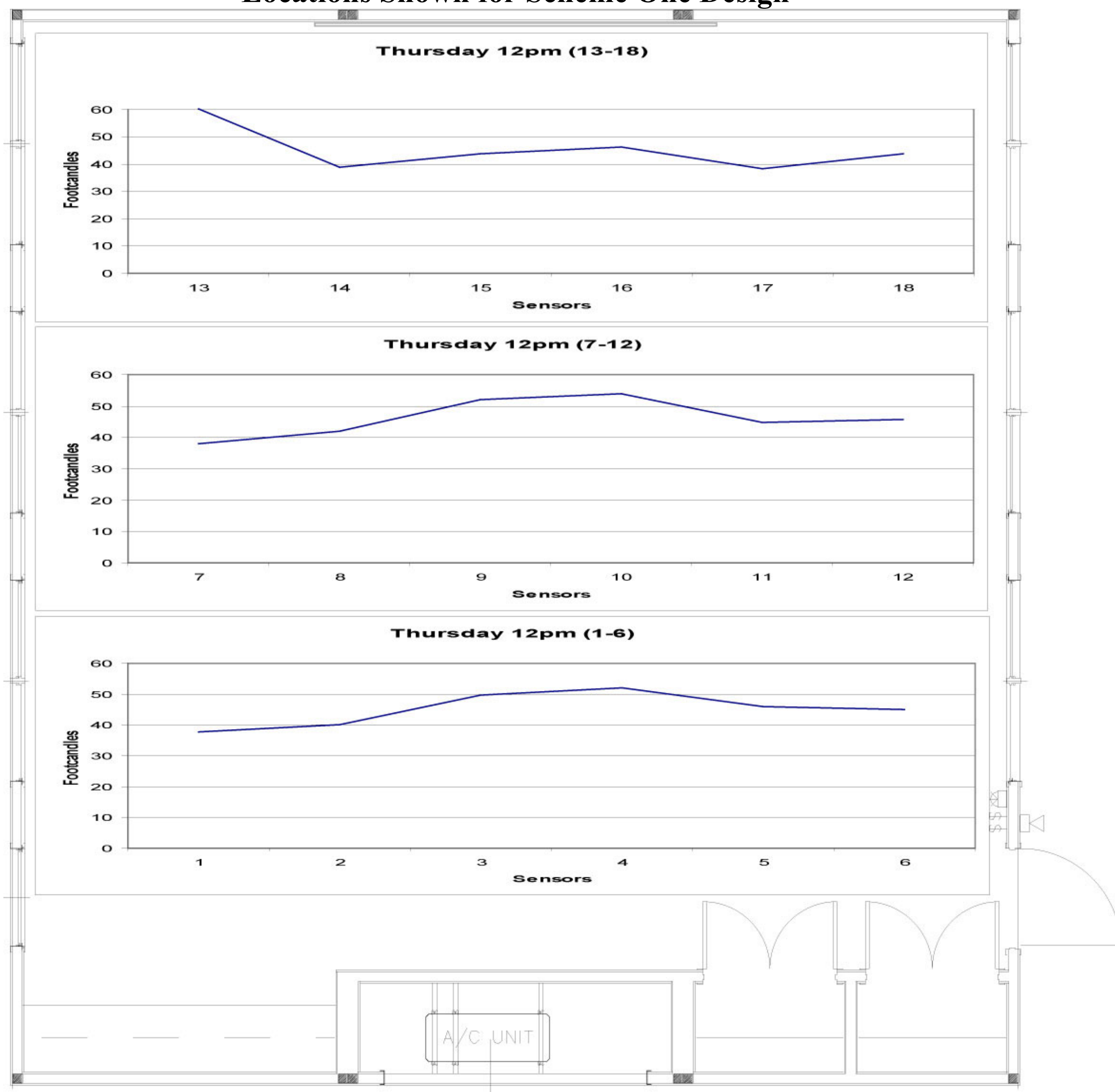


Fenestration

The target for surface illumination in the classrooms was 35 footcandles. Scheme One implemented a roof monitor with operable windows, which allowed for significant saturation of daylight through both clear and overcast conditions. Figure 4 presents a sampling of instrumented results for the Scheme One solution, showing footcandles as a function of distance from the apertures. Methods used to collect this data consisted of creating an array of 18 photometric sensors inside the classroom and one photometric sensor located on the roof of the classroom to document the results of available outside solar illumination to received interior surface illumination. The sensors were mounted on top of classroom desks in 3 rows, space 10 feet apart and 6 columns spaced 5 feet apart. Measurements were documented by computer every 15 minutes as average reading simultaneously taken every few seconds. Data was taken 24 hours a day over a few months. Results graphically illustrated in Figure 2 shows the locations of each sensor in plan and the recorded surface illumination level on a sunny day in April at 12:00 pm.

Scheme Two implemented a lower floor-to-ceiling height and skylights with fenestration controls to control skylight brightness and increase ceiling brightness in the space. Additionally, there were windows on the sidewalls for sidelight application.

Figure 4. Graphic Illustration Intended to Reflect Light Intensity Level at the Locations Shown for Scheme One Design



Space Conditioning

Scheme One implemented a split-system heat pump with ducted ventilation air and exhaust air discharged from the opposite end of the classroom. The split system was designed to be entirely factory installed. Split-systems are available at efficiencies significantly higher than those of wall-mounted units. Additionally, the noise generated from the system could be dampened and attenuated through the proper design of equipment closets.

Scheme Two implemented a displacement ventilation HVAC system. These systems typically use only 60 percent of the supply air of a conventional system and deliver air much closer to the temperature of the space setpoint. The displacement ventilation system improves comfort and indoor air quality by not mixing air in the conditioned space. The building energy performance simulation results for Scheme Two are tabulated in Table 1, which shows that the energy consumption is estimated at 50 percent less than that of a minimally compliant Title 24 building. Additionally, the Scheme 2 design provides a peak demand reduction of approximately 7 percent.

Table 1. Simulated Building Performance Energy Summary, Scheme 2

	Alternative Description	Title 24	Cost $	Peak kW	Total kWh	Ambient kWh	Exit kWh	Exterior kWh	Equip kWh	Cooling kWh	Heating kWh	Fans kWh	DHW kWh
Title 24 Base Case	Minimally 2001 Compliant	100%	1,437	6.3	7,115	3,032	35	203	484	2,694	407	260	-
Scheme 2 Design	Energy Efficient Design w/ Chiller	50%	828	5.9	3,576	438	35	129	484	1,623	607	260	-

Acoustic Design

Each prototype was designed to provide excellent acoustic performance by minimizing background noise. The objective was to attain an A-scale reading of 45 dB for the unoccupied classroom with electric lights on and the HVAC compressor and fans operating. Generally, the HVAC components create the most offensive background noise in a relocatable classroom and little can be done to attenuate that noise. One reason for this condition is the use of large return air grilles that connect directly to the interior- or exterior-mounted packaged HVAC units. This direct connection allows unit-generated noise and vibration-generated noise to enter the classroom without means for attenuation.

The HVAC system designs in each prototype provide equipment isolation to minimize vibration-generated noise. In addition, each system component is housed in a closet that is acoustically insulated from the classroom.

The use of hard ceilings in the prototype designs creates a challenge for good acoustic performance since they support sound reverberation. The addition of acoustic ceiling and wall finish materials mitigates this problem.

Conclusions

The demonstration schemes described herein have been presented to school officials and designers who have experienced the spaces and identified high performance opportunities for their own projects. Scheme One was included in the best practices manual developed by the Collaborative for High Performance Schools (CHPS) and brochures have been distributed to thousands of school administrators, faculty, and designers.

The relocatable classroom continues to be a mainstay of California K-12 campus planning and an important component of school districts' budget planning. It is a more flexible, economical, and timely solution than the permanent traditional classroom. The demand for relocatable classrooms continues to rise as mandates are issued to improve teacher-student ratios, yearly enrollment fluctuates, and temporary needs arise due to modernizations.

This initiative was successful in engaging stakeholders interested in high performance relocatable design and has fostered thoughtful consideration for the use of integrated design processes and sustainable building construction practices in the relocatable classroom market. This effort has contributed to higher expectations for relocatable classrooms and provides valuable information for school districts, manufacturers, and community members who want to build relocatables that are be more durable, energy-efficient, environmentally sustainable, and targeted toward maximizing the comfort and effectiveness of the learning environment for students and teachers.

Appendix: Prototype Specifications

Table 2. Architecture/Planning

Base Design	Prototype 1	Prototype 2
Rectangular plan (24'x40'), no skylights, no daylighting, no operable windows	Modular in three sections to create square plan (30'x32'), monitor, daylighting, operable windows	Rectangular plan (24"x40"), skylights, daylighting.
No built-in storage, with exterior mounted unitary heat pump	Built-in storage zone with interior HVAC recess	Built-in storage zone with interior HVAC recess

Table 3. Structure and Framing

Base Design	Prototype 1	Prototype 2
Steel moment frame with 2x6 metal studs @ 16" on center, 2x7 steel floor joists @ 32" o.c., 2x8 steel roof joists @ 48" o.c.	Steel moment frame with 2x4 studs @ 16" o.c., 2x6 steel roof members.	Steel moment frame with 2x6 metal studs @ 16" o.c., 2x7 steel floor joists @ 32" o.c., 2x8 steel roof joists @ 48" o.c. with seismic straps.
Temporary wood pad foundation	Permanent continuous concrete foundation with venting.	Temporary wood pad foundation with venting and insulation

Table 4. Building Envelope

Base Design	Prototype 1	Prototype 2
Plywood walls with ½” tackable wallboard, 5/8” gyp., R-11 Batt insulation, ½” plywood sheathing/finish board (wall absorptance=0.7)	5/8” gyp., R-13 Batt insulation, ½” exterior grade plywood, 5/8” fiberboard (R-0.73), 1/8” one-coat stucco system	½” tackable wallboard, 5/8” gyp., R-13 Batt insulation, ½” plywood sheathing/finish board (wall absorptance=0.7)
Metal frame window U-value=0.81, SHGC North=0.61 (SC=0.70), SHGC non-North = 0.61 (SC=0.70)	Aluminum frame windows with double glazing and thermal break, low-e coating (on #2 surface) on all windows, operable windows U-0.60, SHGC=0.35, VT=0.70	Aluminum frame windows with dual-glazed insulating units, low-e (on #2 surface) U=0.49, SHGC=0.36, VT=0.63, with light shelf
Hot mop roofing with white coating (Abs=0.45)	White Membrane roofing	Cool Roof EPDM Roofing (Abs = 0.45)
R-11 roof insulation and ¾” plywood sheathing	R-30 roof insulation with 5/8” oriented strand board decking	R-30 Rigid Roof Insulation over ¾” plywood sheathing
R-11 underfloor insulation	R-11 underfloor insulation with film under insulation	R-19 underfloor insulation
1-1/8” exterior grade plywood Subfloor with rolled carpeting	1-1/8” exterior grade plywood subfloor	1-1/8” exterior grade plywood subfloor with linoleum flooring
Steel craft door with upper glass window, polystyrene core R=3.8		Steelcraft door, L series, type G with polystyrene core R=3.8
	1’-0” overhang on monitor glazing, no overhang on low south windows	2’-0” overhang on south windows, 5’-0” overhang on North windows
		Hardy lap siding
		Triple glazed acrylic skylight SC=0.58, U-value=0.30, VT=0.45 with well factor VT=0.34, with reflector

Table 5. Interior Finishes

Base Design	Prototype 1	Prototype 2
5/8” Vinyl covered gyp. walls, acoustic tile ceilings	5/8” gyp. on walls and ceilings with low	5/8” gyp. painted with low-VOC paints and burlap wrapped homosote panels on walls, acoustic ceiling tile on ceilings with high recycled content
Tackable vinyl-covered wallboard interior finish	Cabinet substrate fabricated with low	MDF Substrate for cabinetry
Particle board cabinets with plastic laminate on exposed surfaces	Carpet tiles made from recycled material and affixed with low	
1” metal blinds on all windows	Horizontal mini	2” metal blinds on clerestory windows and micro fiber shades on lower vision windows

Table 6. HVAC Systems

Base Design	Prototype 1	Prototype 2
Exterior mounted unitary heat pump EER=9.31 (67/80/95) in cooling mode. COP=2.81 (47F). Airflow of 1520 cfm, assume static of 0.3" wc (10.5 SEER)	Interior split system heat pump (4 ton) with underfloor condenser air supply, dedicated fresh air supply, SEER 11.5, HSPF 8.2	Displacement ventilation system with split fan coil 1000 CFM @ 0.35" wc., air cooled, heat pump chiller EER=12
Exhausting barometric relief damper EA included in packaged unit	Barometric relief damper	Exhausting barometric relief damper EA thru barometric damper located at wall
Outdoor air inlet included in packaged unit, economizers are available	CO_2 sensor and demand controlled ventilation with maximum outdoor air capability of 600 cfm	OA ducted to RA plenum from exterior louver wall with 100% OA operation capability
Wall mounted, programmable thermostat	Occupancy controls	HVAC control with thermostat, programmable, fan on during all operating modes, heating setback and preheat sequences included. Occupancy controls enable ventilation shut-off

Table 7. Lighting

Base Design	Prototype 1	Prototype 2
Ceiling mounted T-12 fluorescent fixtures, 1.6W/sf	Switching for direct/indirect lighting with dimming ballasts and dimming controls	Suspended fluorescent direct/indirect pendants, two rows (four luminaires each), Finelite Series 10, 3-T8 lamps per luminaire, 22' on center spacing for rows, with dimming ballasts down to 5 percent. Three whiteboard lights, Peerless chalkboard light, 1-T8 lamp per luminaire, electronic ballast (90W per 4'-0" pendant, 720W + 90W = watts; 810W/876sf=0.925 w/sf)
	Two rows direct/indirect (60W per 4'-0" pendant, 360W per row = 720W total)	Occupancy sensors
	Occupancy lighting control	Daylighting control with photosensors
	Whiteboard light and control	

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