Hawaii High Performance School Guidelines

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Prepared for:

Department of Business, Economic Development & Tourism
State of Hawaii

DBEDT
THE DEPARTMENT OF BUSINESS, ECONOMIC DEVELOPMENT & TOURISM
STATE OF HAWAII

Prepared by:

Architectural Energy Corporation

ARCHITECTURAL ENERGY
CORPORATION
Integrated Engineered Solutions

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Contents

1 Introduction

The focus of these guidelines is on the highest priority topics related to new school construction and major renovations in Hawaii. The topics are considered to be the highest priority because they address opportunities that are either unique to Hawaii or not well covered by existing guidelines.

Where appropriate, references are included to other documents, such as the *Hawaii Commercial Building Guideline for Energy Efficiency* and the *CHPS Best Practices Manual* for detailed design guidance.

The guidelines were established in collaboration between DOE, DAGS, DBEDT, and Architectural Energy Corporation.

1.1 Guideline Audience

The intended audience for these guidelines is the following:

- DOE project managers who are planning and budgeting projects.
- Project managers who are overseeing design and construction.
- Facilities managers and personnel who maintain schools and have a say in the selection of system types.
- Architects, mechanical engineers, electrical engineers and lighting designers working on DOE school projects.

1.2 Guideline Goals

- Provide guidance to decision makers for **budgeting** and prioritizing projects.
- Provide guidance to designers on identifying and evaluating design alternatives and developing plans and specifications.
- Cover both new construction and renovation (especially air conditioning retrofits).
- Encourage decision making based on life-cycle cost.
- Encourage integrated design decisions.

2 Project Planning and Budgeting (Roadmap)

2.1 Summary

This section presents a “roadmap” to the process of managing a high performance school project. This roadmap consists of a list of recommended considerations at the following phases of the project development process.

- Project scope development
- Preliminary budget estimate
- Consultant selection
- Design
- Bidding
- Construction
- Furniture and equipment

While the recommendations are listed under the “Details for the Project Manager” section 2.3, they are valid considerations to be taken into account throughout the life of the project—from initial planning into design and construction—by all of the project team.

2.2 Background

Budgets that are set early in the planning process can restrict high performance design opportunities. The intent of this guideline is to encourage consideration of operating costs, as well as other benefits such as improved indoor environmental quality, in the up-front budgeting process.

These opportunities include reduction or elimination of HVAC equipment due to measures that reduce cooling loads. Examples of cooling load reduction measures include lighting power reduction, roof insulation, cool roof membrane, or window shading. Therefore these potential projects should also be considered when setting a budget, especially for renovation projects.

2.2.1 Sustainable Building Costs

A recent study performed for the State of California came to the following conclusion about first costs.[1]

> “Largely derived from several dozen conversations with architects, developers and others, the data indicates that the average construction cost premium for green buildings is almost 2%, or about $4/ft^2 in California, substantially less than is generally perceived.”

Studies performed for the City of Los Angeles by Architectural Energy Corporation (then Eley Associates) estimated the cost for LEED compliance to be an additional 3% — 4% for construction, with an additional design cost equal to about 1% of the construction cost. These studies looked at fire stations, police stations and animal care and control facilities.

CHPS estimates that the cost for complying with the CHPS criteria is roughly $2/ft^2.

School Type	Hard Costs	Soft Cost	Total Initial Costs	Average Energy Use	20% Energy Savings	Simple Payback	Life Cycle Cost
K-6	$0.65/ ft²	$1.10/ft²	$1.75/ft²	$1.31/ft²	-$0.26/ft²	6.7 years	-$1.34/ft²
7-8	$0.65/ ft²	$1.25/ft²	$1.90/ft²	$1.61/ft²	-$0.32/ft²	5.9 years	-$1.86/ft²
9-12	$0.65/ ft²	$1.40/ft²	$2.05/ft²	$1.75/ft²	-$0.35/ft²	5.9 years	-$2.07/ft²

2.3 Details for the Project Manager

This section lists considerations for the project manager at each step of the process. Table 1 highlights the appropriate activities at each project phase, and the following sections provide more details about each step. These recommendations are focused on achieving high performance school goals, including the following:

- Energy efficiency
- Indoor air quality
- Acoustic performance
- Visual comfort
- Thermal comfort
- Resource efficiency

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[1] Katz, et al. *The Costs and Financial Benefits of Green Buildings: A Report to California’s Sustainable Building Task Force*, October 2003

Table 1 — Highlights of High Performance School Roadmap Activities

Project Phase	Activities for the Project Manager
Project Scope Development	Identify performance goals and potential design strategies for inclusion in project scope for both new construction and renovation projects. Determine appropriate level of project commissioning.
Preliminary Budget Estimate	Include construction costs, design fees, commissioning fees and other allowances for high performance design measures.
Consultant Selection	Include high performance design experience in evaluation. Develop consultant scope that includes appropriate evaluation and documentation tasks. Select commissioning agent if appropriate of the project.
Design Phase	Oversee design team and commissioning consultant in developing and tracking performance indicators, evaluating integrated design opportunities, performing lifecycle cost analysis, performing design reviews, and including appropriate contractor requirements in the construction documents.
Bidding Phase	Pre-qualify bidders, requiring experience with appropriate high performance measures.
Construction Phase	Track construction-phase commissioning activities
Furniture and Equipment	Consider indoor air quality impact of furnishings. Consider selection of furnishing materials with low environmental impact. Specify Energy Star equipment.

2.3.1 Project Scope Development

Many of the decisions related to producing a high performance school can be addressed later, during the design phase of the project, but there are some issues that should be addressed when the project scope is being developed. It is especially important to consider integrated design opportunities at this initial stage.

For new construction projects, there are two recommendations regarding development of the project scope. The first recommendation is that a preliminary approach be described for dealing with each of the high performance characteristics listed in Table 2. By considering these issues at this early scoping phase, the project manager may identify budget issues and will also help highlight high performance goals for the rest of the project team. The second recommendation (which is related to the first one) is that the scope answers the specific questions listed in

Table 3, which will lead to the development of a more accurate project budget.

Table 2 — Basic High Performance Characteristics to be Described in Project Scope

Thermal Comfort Strategy	Natural ventilation combined with solar load control measures, and perhaps ceiling fans, wherever possible. Different strategies may be appropriate for different buildings on the same campus or for different spaces within the same building, depending on the space usage. See Air Conditioning and Natural Ventilation sections of these guidelines.
Indoor Air Quality Strategy	Anticipated ventilation method: either natural ventilation, mechanical ventilation or mixed mode ventilation. Selection of site to avoid external sources of air pollution. Specification of finishes and furnishings to limit emissions of toxic substances.
Daylighting strategy	The goals for daylighting (e.g. all classrooms shall be completely daylighted) should be established because there may be an impact on building form and orientation that may affect budget.
Acoustic strategy	It should be determined as early as possible whether special measures will be necessary to reduce noise from external sources at the site. These measures can have a significant budget impact
Solar control strategy	If necessary for the budgeting phase, special solar control measures should be identified. These measures may include building orientation or building form, which can have a significant budget impact.
Commissioning strategy	The level of commissioning appropriate for the project should be identified at this stage. See the Commissioning guideline
Energy efficiency strategy.	Consider including energy performance goals in the project, such as a target of 20 percent better than minimum energy code requirements
Resource efficiency strategy	Include goals for the use of materials with high durability, low environmental impact, waste reduction, and recycled content. Also address special goals regarding site selection and construction waste management.

Table 3 — Specific Budget-Related Questions to be Answered During Project Scope Development

Scope Questions	Discussion
Air conditioning or not	Depends on location and space usage among many other factors. See the section titled “Air Conditioning Applicability”.
Air conditioning system type (if applicable)	This choice may not be necessary at the project scoping phase but can have a significant impact on the budget. Therefore, if a high performance system is desired, some allowance may be necessary at this point. See the sections titled “Air Conditioning System Type Selection” and “Air Conditioning System Design Details”.
Building form (e.g. number of stories, classrooms with windows on both sides)	A building form conducive to natural ventilation and daylighting opportunities typically requires windows on two opposite walls. Therefore, exterior wall area may be greater than the least costly building form options. See the guideline sections titled “Daylighting” and “Natural Ventilation”.
Unusual acoustic mitigation measures	If the selected site is close to busy roads or other noise sources, then the budget should account for the cost of noise mitigation measures necessary to meet acoustic standards. Such measures might include sound walls, laminated glass windows, and special wall constructions.
Level of commissioning	See the section titled “Commissioning” for guidelines on the appropriate level of commissioning and budget estimates.
Special material goals	Determine whether the project will have goals related to use of sustainable materials, which can have a budget impact.
Control system	Determine the requirements for a building automation system, which is critical if there will be air conditioning.
Certification	Include costs for documentation certification with LEED or CHPS requirements if appropriate.

For most renovation projects there are also high performance school goals to be considered when developing the project scope. For renovations it is especially important to consider the opportunities for integrated design. Sometimes a combination of projects can yield significant benefits compared to the same projects implemented separately. Some opportunities may be lost if these potential synergies are not considered when the project scope is being developed. In addition, it is important to consider these opportunities when developing the scope so that a design consultant with appropriate skills can be selected. The following is a list of renovation-type projects along with a brief explanation of the impact on high performance goals and the potential for integrated design benefits.

- AC installation. Addition of air conditioning has a huge impact on energy consumption, and the scope should address the energy efficiency goals for the system to be installed. In addition, consider performing a lighting retrofit (which may be cost effective on its own) before installing air conditioning because the cooling load reduction may allow selection of a smaller AC unit. Also consider other load reduction measures such as roof insulation, cool roof membrane, window shading, window replacement, reflective exterior wall color, and automatic daylighting controls on electric lights.

- AC replacement. When an existing air conditioning system is to be replaced, then it is important to address the energy efficiency of the replacement as well as the indoor air quality performance. Older AC systems may not meet modern ventilation requirements. An AC replacement project is also an opportunity to implement cooling load reduction measures and perhaps install a smaller AC unit.

- Painting. Consider the selection of paint type and the timing of painting due to the impact on indoor air quality. Also consider the reflectance of the selected paint color and its impact on the lighting and daylighting performance.

- Paving. The selection of paving type affects storm water runoff; consider permeable paving options. The reflectance of the paving material can affect the local thermal environment; choosing a light colored paving may help improve comfort in a naturally ventilated school. Recycled material options should also be considered.

- Landscaping and irrigation. Selection of plants and irrigation methods obviously has an impact on water consumption. Consider also the impact on the need for pesticides as well as the impact on the local thermal environment. Addition of trees or ground cover can lower local temperatures and may help improve comfort in naturally ventilated schools. Conversely, elimination of landscaping can have a negative impact.

- Window replacement. Selection of replacement windows should consider energy efficiency, natural ventilation opportunities, security, daylight, visual comfort, and acoustics. Windows have a significant impact on several of the high performance school goals.

- Roof. At time of reroofing, uninsulated roofs should be insulated because there is a significant impact on thermal comfort in naturally ventilated schools and a big impact on energy efficiency in air conditioned spaces. A cool roof surface should be considered.

- Lighting retrofit. If a lighting system needs to be replaced, then consider the opportunities for improving the design with, for example, a pendant-mounted system, rather than a straight lamp and ballast replacement. It may be possible to make the improvement in lighting quality while also reducing energy consumption.

- Plumbing fixture replacement. Consider water-saving alternatives.

- Floor coverings. Consider the air quality implications. For example, carpet is harder to keep clean than hard coverings.

- Window coverings. Consider the impact on daylighting performance and visual comfort.

- Wall coverings. Wall coverings can have an impact on the daylighting performance (reflective colors improve light distribution). Impermeable wall coverings such as vinyl can trap moisture and lead to mold problems, affecting indoor air quality.
- Casework and furniture. In the scope for addition or replacement of casework, consider indoor air quality (off-gassing), durability, and resource efficiency (e.g. wheatboard).
- Exterior lighting. Consider the potential of a “dark campus” approach to security lighting, where motion sensors are used to turn on lights rather than leaving lights on all night.

2.3.2 Preliminary Budget Estimate

The preliminary budget estimate should include consideration of the following:

- Construction budget to cover integrated design opportunities identified in the project scope.
- Design fees to cover life-cycle cost analysis and energy performance analysis
- Commissioning fees. See the commissioning guideline section.
- Allowance for integrated design opportunities that may be identified later during the design phase (to be used only for related projects that provide life-cycle cost benefits).

2.3.3 Consultant Selection

The appropriate scope of work for design consultants will obviously vary from one project to the next, but in general it should include the following items:

- Review of integrated design options
- Life cycle cost analysis for system alternatives
- Participation in design phase commissioning activities

The selection criteria for design consultants should include the following as appropriate for the project:

- Experience with sustainable school design (e.g. LEED, CHPS)
- Experience with energy efficient design and building energy analysis
- Natural ventilation design experience

- Life cycle cost analysis experience
- Acoustic design experience
- Lighting design and daylighting design experience

If an independent commissioning agent is required for the project, then the selection should also be made at this time. See the commissioning section of the guidelines for more details regarding scope and qualifications.

2.3.4 Design Phase

This section lists a number of recommended activities for the project design phase. The overall intent of these activities is that high performance measures are identified early and then properly implemented in the construction documents.

One of the concepts presented here is that a set of performance indicators be identified at the beginning and that these indicators be used by the project manager to evaluate the design as it progresses. It is difficult to define a comprehensive set of indicators, but those recommended here are intended to focus attention on some of the important high performance school goals. For most of these indicators there is not a single pass/fail level of performance that is appropriate for all cases because constraints vary from one project to the next. But they provide a tool that the project manager and quality assurance (QA) staff can implement to help ensure that issues are addressed.

Table 4 — Recommended Design-Phase Activities

Activity	Description	Responsibility
Define performance indicators	Develop a list of indicators and performance targets that can be used to track performance as the design progresses. The list might include the following: • Peak cooling load (Btu/ft^2) • Cooling system capacity (Btu/ft^2) • Cooling efficiency at full load (kW/ton) • Cooling efficiency at partial load (kW/ton) • Cooling airflow (cfm/ft^2) • Fan system efficiency at full load (W/cfm) • Fan system efficiency at part load (W/Btuh of cooling delivered) • Lighting power (W/ft^2) • Electric lighting illumination (footcandles) • Other lighting performance indices • Electrical design load (W/ft^2) • Outdoor air ventilation rate (cfm/ft^2) • Air filtration efficiency (% or MERV) • Daylighted area (% or ft^2) • Desired daylighting illumination levels (fc) • Peak solar load (Btu/ft^2) • Acoustic performance (NC, dBa, reverberation time) • Predicted energy consumption (kWh/yr, therms/yr) • Building material recycled content (%) • Construction waste recycling (%) • Water consumption (gallons/yr)	Design team, with input from DOE & others
Design intent document	This document is compiled by the commissioning agent or design team and describes the owner's requirements related to building performance. The list of targeted performance indicators should be included. The design intent document serves as a guide throughout the design and construction process to help ensure that performance goals are achieved. Examples are available in many of the resources listed in the Commissioning guideline.	Design team, with input from DOE & others, review by commissioning provider
Integrated design options review	A discussion of the following specific issues: load reduction, air quality strategy, solar control strategy, lighting and daylighting strategy, thermal comfort strategy, energy efficiency, visual comfort strategy.	Design team, with input from DOE & others
Energy performance analysis	Energy simulation analysis if appropriate may be part of the AC system selection and life-cycle cost analysis.	Design team, with input from DOE & others
AC system selection process (if applicable)	Evaluate system alternatives. See the Air Conditioning System Type Selection section for details.	Design team, with input from DOE & others
Life cycle cost analysis	Project decisions should be made on the basis of lowest life-cycle cost (LCC), with the goal of maximizing the project's value to the State. See the LCC guideline for recommended calculation method.	Design team, with input from DOE & others
Basis of design document	Description of the chosen design alternative. Documentation of assumptions used in developing the design and explanations of the reasons for major design decisions.	Design team; review by commissioning provider

Activity	**Description**	**Responsibility**
Schematic Design Phase third-party design review	For energy efficiency and sustainability and compliance with high performance school guidelines. Record progress toward meeting the performance goals listed in the design intent document.	By commissioning consultant
Design Development Phase third-party design review	For energy efficiency and sustainability and compliance with high performance school guidelines. Record progress toward meeting the performance goals listed in the design intent document.	By commissioning consultant
Construction Documents Phase third-party design review	For energy efficiency and sustainability and compliance with high performance school guidelines. Record progress toward meeting the performance goals listed in the design intent document.	By commissioning consultant
Miscellaneous Construction Document Items	Ensure that the construction documents include the following (as appropriate): Requirements regarding phasing of construction. Limitations on construction operation hours to minimize disruptions at existing school sites Construction waste management requirements	Design team; input from DOE/DAGS

2.3.5 Bidding Phase

If possible, require that the contractor meet minimum qualifications for experience with construction of energy efficient systems, construction waste management, construction phase air quality management, and collaboration with commissioning provider. A selection method that should be considered is to pre-qualify bidders based on these criteria, and then choose the best bid from among the pre-qualified contractors.

2.3.6 Construction Phase

See the Commissioning section for recommended construction phase activities. The purpose of those commissioning activities is to ensure that the design is implemented as intended and that proper training and operating instructions are provided by the contractor.

2.3.7 Furniture and Equipment

When furniture and equipment are specified, consider the impact on the high performance goals. Some of the issues to consider include the following:

- Choose furniture that facilitates flexibility, ease of room re-arrangement, durability, student comfort, and ergonomics.
- Materials for furnishings should be selected to minimize emissions of harmful substances.
- Furnishings should have recycled content or low environmental impact.

- Color of furnishings may affect the performance of the lighting and daylighting designs.

- Equipment selection can affect the achievement of acoustic performance standards. Computers, projectors, and other equipment can be significant sources of noise.

- Electronic equipment or other heat generating equipment will affect the ability of the AC system to maintain comfort.

- Energy efficient equipment, including computers, printers, and copiers can be identified by an Energy Star rating.

2.4 Resources/Standards

Katz, et al. *The Costs and Financial Benefits of Green Buildings: A Report to California's Sustainable Building Task Force*, October 2003

Matthiessen & Morris*, Costing Green: A Comprehensive Cost Database and Budgeting Methodology*, Davis Langdon Adamson, http://www.davislangdon-usa.com/publications.html.

Steven Winter Associates, *GSA Cost Study,* October 2004. http://www.wbdg.org/

> The U.S. General Services Administration (GSA) commissioned this ground breaking study, completed in October 2004, to estimate the costs to develop "green" federal facilities using the U.S. Green Building Council's *Leadership in Energy and Environmental Design* (LEED) Building Rating System, Version 2.1. The report provides a detailed and structured review of both the hard cost and soft cost implications of achieving Certified, Silver, and Gold LEED ratings for two GSA building types, using GSA's established design standards as the point of comparison.
>
> The two building types examined in the study are:
>
> 1. A new mid-rise federal Courthouse (five stories, 262,000 GSF, including 15,000 GSF of underground parking; base construction cost is approximately $220/GSF).
>
> 2. A mid-rise federal Office Building modernization (nine stories, 306,600 GSF, including 40,700 GSF of underground parking; base construction cost is approximately $130/GSF).
>
> These building types reflect a significant percentage of GSA's planned capital projects over the next five to ten years.

[For both building types, low- and high-cost estimates were developed at the Certified, Silver, and Gold rating levels in order to bracket the LEED costs. The estimated percent change in hard costs for the new courthouse were: Certified: Low (-0.4%), High (+1.0%). Silver: Low (-0.03%), High (+4.4%). Gold: Low (+1.4%), High (+8.1%).].

3 Life-Cycle Cost Analysis

3.1 Summary

Project decisions should be made on the basis of lowest life-cycle cost (LCC), with the goal of maximizing the project's value to the State. The intent of this LCC recommendation is to minimize ongoing operating and maintenance cost as well as to account for integrated design opportunities. In LCC methodology, alternative projects are evaluated against a base case. If a single alternative is being considered, then the base case can be "do nothing."

This section actually describes two decision-making tools: a LCC calculation method and a method to evaluate alternatives based qualitative factors. The ultimate decision should be based on a combination of these two results.

The incremental cost and savings estimations for project alternatives shall include the following items as appropriate. If there is no difference in cost between alternatives for some of these items, then those costs need not be included in the LCC calculation.

- Project administration cost
- Design cost
- Construction costs (including credits for reduced air conditioning, electrical, and other systems costs)
- Energy cost
- Water cost
- Sewage cost
- Maintenance cost
- Replacement cost
- Residual value

The following items shall also be considered in the comparison of alternatives even though it may not be possible to give them a specific economic value.

- Occupant access to daylight and views
- Occupant thermal comfort
- Indoor air quality
- Access to operable openings for natural ventilation
- Use of standardized parts and materials (for easier maintenance)
- Compatibility with State maintenance staff capabilities

The following economic criteria shall be used for life-cycle cost evaluations. If different economic criteria are used, then they must be used for all alternatives to achieve a “level playing field.”

- A real discount rate of 3 percent
- Project lifetime of 30 years

Where the project budget is not large enough to pay for the alternative with the lowest LCC, then the appropriate agency official should: 1) seek additional funds; 2) investigate cost reduction options in other parts of the project; or 3) choose the alternative with the lowest LCC that fits within the project budget.

3.2 Background

This guideline provides LCC analysis instructions to design teams to encourage use of consistent methods and assumptions for all projects. This section provides a brief overview of some concepts used in LCC analysis: discount rate, present value, project lifetime, and energy cost escalation rate.

3.2.1 Discount Rate

Expenses or costs that occur in the future have a smaller value in current dollars. The rate at which future expenses or costs are discounted is the discount rate. It is the percent reduction in future benefits or costs for each year in the future.

The discount rate can be "real" or "nominal." The real discount rate is the rate at which future benefits or costs are discounted without consideration for inflation. If future expenses and costs are quantified in current dollars, a real discount rate is used. It is generally easier to quantify future benefits and costs in current dollars, so a real discount rate is commonly used in economic analysis. The nominal discount rate is the real discount rate plus the inflation rate.

The discount rate is the rate of return that an investor typically makes or expects to make from other investment opportunities with a similar risk. It also indicates whether an investor has a short-term or long-term perspective. Investors with a short-term perspective generally have a higher discount rate, while investors with a long-term perspective have a lower discount rate. Risk must also be considered in selecting a discount rate.

For State investment in schools, a low discount rate is appropriate due to the low risk associated with energy efficiency investments.

3.2.2 Present Value

The discount rate can be used to calculate the “present value” of a future expense. The present value of expenses is lower for expenses that occur further in the future. For a single expense that occurs “n” years in the future, the present worth factor (PWF) is calculated using the following equation, where “i” is the discount rate:

$$\mathrm{PWF} = \frac{1}{(1 + \mathrm{i})^{\mathrm{n}}}$$

The equation above is appropriate for one-time expenses in the future, such as replacement costs. Table 7 below lists values of the PWF for different lifetimes based on a 3 percent discount rate.

For a series of future expenses, such as annual energy costs or annual maintenance costs, the uniform present worth factor (UPWF) is a shortcut to calculating the present value. Most engineering-economics textbooks have tables that list UPWF for different discount rates and project lifetimes. The UPWF for a 3 percent discount rate and 30 year lifetime is 19.6, which means that a $1.00 annual expense that occurs for 30 years has a present value of $19.60.

Spreadsheet programs include functions to calculate UPWF. In Excel, the “PV” function can be used to calculate the present value of a recurring expense.

3.2.3 Project Lifetime/ Study Period

The LCC results depend significantly on the assumption used for project lifetime, which is the number of years into the future for which operating, maintenance, and replacement costs will be considered. Choice of a longer lifetime favors investments in designs with lower operating and maintenance costs. Use of a shorter study period favors designs with lower first cost.

For State building projects, a long lifetime is appropriate for analysis because most projects are expected to be in service for many years. The recommended project lifetime for LCC analysis is 30 years.

3.2.4 Energy Cost Escalation Rate

The energy cost escalation rate is the difference between the rate of change in energy price and the general inflation rate. The energy cost escalation rate is zero if energy prices increase at the same rate as general goods and services. If, for example, energy prices are expected to rise at 3% per year, and inflation is 2% per year, then the energy cost escalation rate is 1%.

For simplicity, and due to the difficult of predicting future energy costs, it is recommended that a zero energy cost escalation rate be used for LCC analysis on State projects. This assumption helps avoid overestimating energy savings, and it is generally consistent with historical energy prices.

3.3 Details for the Project Manager

Life-cycle cost analysis should be performed during the schematic design phase to compare design alternatives. Additional LCC analysis may be appropriate during later design phases as well. Examples of appropriate LCC analysis subjects include the following:

- Selection of air conditioning and ventilation system type
- Comparison of natural ventilation and air conditioning strategies
- Comparison of roof insulation alternatives
- Comparison of water-cooled and air-cooled cooling equipment
- Comparison of pool heating systems

Developing construction cost and energy cost estimates for design alternatives takes time, and there should be a budget allocation for LCC analysis. Costs will vary depending on the scope and size of the project. A very rough rule of thumb for LCC analysis energy modeling is a cost of about 0.5 percent of the construction budget.

It may not always be appropriate to select the alternative with the lowest LCC if there are differences in non-monetary impacts between design alternatives. Therefore, some judgment may be necessary to assess the value of differences in areas such as health and comfort benefits. The next section includes a method for ranking alternatives based on non-monetary criteria.

3.4 Details for Design Consultant

This section contains general guidance for performing LCC calculations for State projects and also describes LCC information to be provided to the State's project manager. Alternative calculation methods may be approved by the State's project manager if appropriate.

There are two parts to the recommended evaluation method. The first part is the LCC calculation, which is an economic evaluation of alternatives. Those LCC results should be summarized as shown in Table 5. The second part is a qualitative evaluation that is based on factors that are difficult to express in economic terms. The results of the qualitative evaluation should be presented as shown in Table 8. These two tables are shown here as being formatted to compare three alternatives: A, B, and C. More columns may be added, of course, if more alternatives are being evaluated.

Table 5 — Life-Cycle Cost Summary Format for Multiple Alternatives.

	Present Value Cost		
	Alt. A	Alt. B	Alt. C
Project Administration Cost			
Design Cost			
Construction Cost			
Energy Cost			
Water Cost			
Sewage/Disposal Cost			
Maintenance Labor Cost			
Maintenance Material Cost			
Replacement Cost #1			
Replacement Cost #2			
Replacement Cost #3			
Residual Value			
Total LCC			

The present value costs summarized in the previous table shall be calculated as shown in Table 6. The cost items in this calculation are described in the following sections.

Table 6 — Life-Cycle Cost Calculation for a Single Design Alternative

	Cost			Present Value Multiplier*		Present Value
Project Administration Cost		($)	X	1.0	=	
Design Cost		($)	X	1.0	=	
Construction Cost		($)	X	1.0	=	
Energy Cost		($/yr)	X	19.6	=	
Water Cost		($/yr)	X	19.6	=	
Sewage/Disposal Cost		($/yr)	X	19.6	=	
Maintenance Labor Cost		($/yr)	X	19.6	=	
Maintenance Material Cost		($/yr)	X	19.6	=	
Replacement Cost #1		($)	X		=	

Replacement Cost #2		($)	X		=	
Replacement Cost #3		($)	X		=	
Residual Value		($)	X	-0.41	=	
Life-Cycle Cost					Total	

*Based on a 3% discount rate and 30 year project lifetime.

3.4.1 Project Administration Cost

Together with the State's project manager, determine whether there are any administrative costs that will vary between alternatives. If the costs are the same for all alternatives, then zero may be entered.

3.4.2 Design Cost

Enter the incremental cost required for the design team to implement the alternative. If the design cost is the same for all alternatives, then zero may be entered.

3.4.3 Construction Cost

Enter the incremental construction cost estimate for the alternative, including contractor markups. Be sure to account for any savings due to elimination or reduction in size of equipment due to efficiency measures. Consider both mechanical system and electrical distribution system impacts.

3.4.4 Energy Cost

Enter the estimated annual energy cost ($/yr) based on energy simulation or approved engineering calculation method. Use actual current utility rates. If only incremental energy cost is estimated, then enter zero for the cost of the base case and enter a negative cost (savings) for the alternative(s).

3.4.5 Water Cost

Enter annual water cost based on approved engineering calculation method. Use actual current water rates. If there is no difference in water consumption between the alternatives, then zero may be entered.

3.4.6 Sewage/Disposal Cost

Enter annual sewage cost based on approved engineering calculation method. Use actual current sewage rates. If there is no difference in sewage output among the alternatives, then zero may be entered.

3.4.7 Maintenance Labor Cost

Enter the annual maintenance labor cost based on $_ per hour for mechanical system maintenance, or actual cost of a service contract if applicable. Incremental maintenance costs may be used by entering zero for the baseline case and entering the extra cost (positive) or cost savings (negative) for each alternative. If there is no difference in maintenance cost between alternatives, then zero may be entered for all cases.

3.4.8 Maintenance Material Cost

Enter the annual cost for components such as filters and lamps that are replaced as part of regular maintenance. Incremental material costs may be used by entering zero for the baseline case and entering the extra cost (positive) or cost savings (negative) for each alternative. If there is no difference in maintenance material cost between alternatives, then zero may be entered for all cases.

3.4.9 Replacement Cost

For equipment that lasts less than the project lifetime (i.e. 30 years), the replacement cost should be included in the LCC calculation. Table 6 includes rows for up to three different replacement costs, but as many as necessary can be added. The cost should be entered in current dollars. The present value multiplier can be found in Table 7, as a function of the year of replacement. If, for example, a piece of equipment is expected to last 15 years, then the present value multiplier is 0.64. In other words, the present value of the cost of replacing $100 worth of equipment in 15 years is $64 in current dollars.

Table 7 — Present Value Multipliers for Replacement Cost (for use in Table 6).

Year of Replacement	Replacement Cost Multiplier
5	0.86
10	0.74
15	0.64
20	0.55
25	0.48

Based on 3 percent discount rate

3.4.10 Residual Value

If there is a significant difference in value or useful life for different alternatives at the end of the project lifetime, then residual value should be entered. Such a difference might occur if, for example, one alternative has equipment that lasts 15 years and the other has equipment that lasts 25 years. In both alternatives there will need to be one replacement during the 30 year analysis timeframe, but the first alternative will have no equipment life remaining at the end of 30 years, while the second will have another 20 years of useful life. Therefore, it is appropriate to assign a "residual value" to the equipment in the second alternative. Some judgment is needed to assign an appropriate value. At the high end the residual value is the original cost of the equipment prorated based on remaining life. At the low end is the price that the used equipment could be sold for at that time (which is often zero).

3.4.11 Qualitative Factors

Not all factors in a LCC calculation can be quantified in terms of cost. Some of these other factors are listed in Table 8, where qualitative performance can be ranked. Additional criteria may be appropriate for specific projects. For each criterion, a weighting factor should be determined that represents the level of importance (1= not important, 10 = very important). Then each alternative should be given a score indicating how well it satisfies each criterion. Finally, the total score for each alternative is calculated by summing the product of weighting times score for all the criteria. The results of this qualitative analysis should be presented together with the LCC calculation summary shown in Table 5 so that both the quantitative and qualitative information can be used to make design decisions.

Table 8 — Ranking of Alternatives Based on Non-Monetary Criteria

		Score (1 = poor, 10 = excellent)		
Criterion	**Weighting (1 to 10)**	**Alt. A**	**Alt. B**	**Alt. C**
Occupant Access to Views				
Illumination Provided by Daylight				
Occupant Thermal Comfort				
Occupant Access to Operable Openings				
Indoor air quality				
Compatibility with State maintenance staff capabilities				
Use of standardized parts and materials (for easier maintenance)				
Other:				
Other:				
Sum of (Weighting * Score)	--			

3.5 Resources/Standards

Building Life-Cycle Cost (BLCC), developed by the National Institute of Standards and Technology (NIST). http://www.eere.energy.gov/femp/information/download_blcc.cfm.

eVALUator is an easy-to-use Windows™-based program that calculates the lifecycle benefits of investments that improve building design. It analyzes the financial benefits from buildings that reduce energy cost, raise employee productivity, and enhance tenant satisfaction. www.energydesignresources.com.

EPA's "Energy Star Cash Flow Opportunity Calculator" (CFOC). The CFOC is another "tool" DOE/DAGS can use in their quest for highly energy efficient facilities. Plug loads are a concern, so, using this tool, DOE/DAGS can determine how much equipment and services can be installed by using the energy efficiency savings realized from the project to pay for the financing of the needed equipment.

http://www.energystar.gov/ia/business/CFO_01July04.xls

3.6 LCC Glossary

The following definitions come from the Life-cycle Costing Manual for the Federal Energy Management Program (see references below) and are provided here for convenience. Please see that document for additional definitions.

Discount rate. The rate of interest, reflecting the investor's time value of money (or opportunity cost), that is used in discount formulas or to select discount factors which in turn are used to convert ("discount") cash flows to a common time. Real discount rates reflect time value of money apart from changes in the purchasing power of the dollar and are used to discount constant dollar cash flows; nominal discount rates include changes in the purchasing power of the dollar and are used to discount current dollar cash flows.

Life-cycle cost. The total discounted dollar costs of owning, operating, maintaining, and disposing of a building or building system over the appropriate study period.

Present value. The time-equivalent value of past, present, or future cash flows as of the beginning of the base year.

Residual value. The estimated value, net of any disposal costs, of any building or building system removed or replaced during the study period, or remaining at the end of the study period, or recovered through resale or reuse at the end of the study period (also called resale value, salvage value, or retention value)

Uniform present value (worth) factor. The discount factor used to convert uniform annual values to a time-equivalent present value.

Study period. The length of time covered by the economic evaluation. This includes both the planning/construction period and the service period.

3.7 Example LCC Calculation

A simple scenario is presented here as an example of using the LCC calculations described above.

3.7.1 Air Conditioning Retrofit Example

In this example, air conditioning is to be added to an existing school. An LCC calculation is to be performed to determine whether it is also cost effective to install roof insulation (existing uninsulated concrete roof) and to replace the existing lighting system (2 watts per square foot) at the same time.

- Alternative A ($30,000): 5-ton packaged rooftop unit installed on existing classroom. Installed cost is $30,000 per classroom.

- Alternative B ($35,000): Two inches of foam board installed on top of roof deck, topped by new roof membrane. 4-ton packaged rooftop unit installed (smaller unit due to lower cooling load with insulation). Cost of insulation and new roof is $7000, and cost of installing 4-ton system is $28,000. Additional design cost for roof is $500.

- Alternative C ($40,000): Replace existing lighting system with pendant-mounted high-efficiency system, reducing installed lighting power from 2.0 to 1.0 watts per square foot. Also include roof insulation from Alternative B and install 3.5-ton AC system. Installed cost for new lighting system is $6,000, for AC system is $27,000, and for roof insulation is $7,000. Additional design cost for lighting is $1000 and for roof is $500.

The energy cost for alternative A is $1,550/yr, for B is $1,230/yr, and for C is $930/yr per classroom. To get an accurate LCC result it is important to consider the condition of the existing roof, because if we replace the membrane in Alternatives B and C, then we will not have to replace the roof again as soon as if we choose Alternative A. For this analysis, we assume that the existing roof membrane is 10 years old and has an expected 20-year life. The cost of replacing the roof membrane will be about $5,000. Therefore, in Alternative A we need to spend $5,000 in year 10, and then at the end of the 30-year study period there will be no residual value (it will need to be replaced again). In Alternatives A and B, there will be a $5,000 cost to replace the roof in year 20, and then the roof will still have one-half of its life remaining at year 30.

The following tables show that Alternative B has the lowest life-cycle cost ($61,329) even though the initial cost of the project is $5,000 higher than alternative A. The result for Alternative C is only slightly higher ($61,448) and might be the best choice because it would also improve the visual environment, providing some non-monetary benefit compared to the other two options.

	Cost					Present Value
Project Administration Cost		($)	X	1.0	=	$0
Design Cost	0	($)	X	1.0	=	$0
Construction Cost	30000	($)	X	1.0	=	$30,000
Energy Cost	1550	($/yr)	X	19.6	=	$30,381
Water Cost	0	($/yr)	X	19.6	=	$0
Sewage/Disposal Cost	0	($/yr)	X	19.6	=	$0
Maintenance Labor Cost	0	($/yr)	X	19.6	=	$0
Maintenance Material Cost	0	($/yr)	X	19.6	=	$0
Replacement Cost #1	5000	($)	X	0.74	=	$3,700
Replacement Cost #2	0	($)	X		=	$0
Replacement Cost #3	0	($)	X		=	$0
Residual Value	0	($)	X	-0.41	=	$0
				Life-Cycle Cost		$64,081

Figure 1 — Alternative A (AC only)

	Cost					Present Value
Project Administration Cost		($)	X	1.0	=	$0
Design Cost	500	($)	X	1.0	=	$500
Construction Cost	35000	($)	X	1.0	=	$35,000
Energy Cost	1230	($/yr)	X	19.6	=	$24,109
Water Cost	0	($/yr)	X	19.6	=	$0
Sewage/Disposal Cost	0	($/yr)	X	19.6	=	$0
Maintenance Labor Cost	0	($/yr)	X	19.6	=	$0
Maintenance Material Cost	0	($/yr)	X	19.6	=	$0
Replacement Cost #1	5000	($)	X	0.55	=	$2,750
Replacement Cost #2	0	($)	X		=	$0
Replacement Cost #3	0	($)	X		=	$0
Residual Value	2500	($)	X	-0.41	=	-$1,030
				Life-Cycle Cost		$61,329

Figure 2 — Alternative B (AC + Roof Insulation)

	Cost					Present Value
Project Administration Cost		($)	X	1.0	=	$0
Design Cost	1500	($)	X	1.0	=	$1,500
Construction Cost	40000	($)	X	1.0	=	$40,000
Energy Cost	930	($/yr)	X	19.6	=	$18,228
Water Cost	0	($/yr)	X	19.6	=	$0
Sewage/Disposal Cost	0	($/yr)	X	19.6	=	$0
Maintenance Labor Cost	0	($/yr)	X	19.6	=	$0
Maintenance Material Cost	0	($/yr)	X	19.6	=	$0
Replacement Cost #1	5000	($)	X	0.55	=	$2,750
Replacement Cost #2	0	($)	X		=	$0
Replacement Cost #3	0	($)	X		=	$0
Residual Value	2500	($)	X	-0.41	=	-$1,030
				Life-Cycle Cost		$61,448

Figure 3 — Alternative C (AC + Roof Insulation + Lighting Replacement)

	Present Value		
	Alt. A	Alt. B	Alt. C
Project Administration Cost	$0	$0	$0
Design Cost	$0	$500	$1,500
Construction Cost	$30,000	$35,000	$40,000
Energy Cost	$30,381	$24,109	$18,228
Water Cost	$0	$0	$0
Sewage/Disposal Cost	$0	$0	$0
Maintenance Labor Cost	$0	$0	$0
Maintenance Material Cost	$0	$0	$0
Replacement Cost #1	$3,700	$2,750	$2,750
Replacement Cost #2	$0	$0	$0
Replacement Cost #3	$0	$0	$0
Residual Value	$0	-$1,030	-$1,030
Total	$64,081	$61,329	$61,448

Figure 4 — Summary of LCC Results

4 Commissioning

4.1 Summary

The intent of the commissioning process is to ensure that systems are designed to meet the owner's needs, work as intended, and perform at optimal energy efficiency. This process starts at the initial planning phase of a construction project and continues through the post-occupancy period. The appropriate choice of commissioning activities depends on the type and size of the project. Ideally, a complete commissioning process is part of every project. However, from a practical point of view, the full process may not be cost effective for small projects.

The intent of this guideline is to help the project manager to define the appropriate level of commissioning activities, to assign responsibility for those activities, and to manage the commissioning process.

To simplify the project manager's task of specifying the appropriate level of commissioning, two levels of commissioning effort are defined in this guideline: "basic" commissioning and "additional" commissioning. This two-tiered approach is consistent with the commissioning requirements of LEED[2] and CHPS[3]. These two levels of commissioning are described below in the section titled Details for the Project Manager.

4.2 Background

High performance schools can only be achieved with some level of commissioning. No matter how carefully a school is designed, if the building materials, equipment, and systems weren't installed properly or aren't operating as intended, the health, productivity, and other benefits of high performance design will not be achieved.

Studies show that many building systems will not operate as expected unless they are commissioned. One study of sixty newly-constructed, nonresidential buildings revealed that more than half had controls problems, 40% had malfunctioning HVAC equipment, and one-third had sensors that did not operate properly. In many of the buildings, equipment called for in the plans and specifications was actually missing. One-fourth of the buildings had energy management control systems (EMCS), with economizers or variable-speed drives that did not run properly.

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[2] Leadership in Energy and Environmental Design (LEED), a rating system developed by the US Green Building Council. www.usgbc.org.

[3] Collaborative for High Performance Schools (CHPS), has developed a rating system specifically for schools. www.chps.net.

Commissioning is a systematic process of ensuring that all building systems perform interactively according to the contract documents, the design intent, and the district's operational needs. Commissioning is occasionally confused with testing, adjusting, and balancing (TAB). Testing, adjusting, and balancing measures building air and water flows, but commissioning encompasses a much broader scope of work. Building commissioning typically involves four distinct "phases" in which specific tasks are performed by the various team members throughout the process. The four phases are pre-design, design, construction, and warranty.

The commissioning process integrates the traditionally separate functions of equipment startup; control system calibration; testing, adjusting and balancing; equipment documentation; and facility staff training, as well as adds the activities of documented functional testing and verification.

Commissioning can take place for one building system or for the entire facility; however, the more comprehensive the commissioning, the greater the impact on school performance.

Whichever level of commissioning chosen, a commissioning provider/agent should be engaged during the schematic design phase or earlier.

It is therefore important that commissioning responsibilities—particularly who will bear the cost of correcting conditions that do not meet specifications—are clearly spelled out in the beginning of the design process.

Typical costs for commissioning are described in the Details for Project Manager section that follows. Benefits of commissioning include the following:

- Improved efficiency
- Reduced change orders
- Improved maintainability
- Improved occupant comfort and productivity

A recent study of commissioning costs and benefits includes the following findings:[4]

- Commissioning cost for new construction ranges from $0.49 to $1.66 per square foot (2003 dollars) with a median of $1.00 per square foot (equal to 0.6 percent of total construction cost). Consultant fee equals about 80 percent of this total commissioning cost.

- When cost savings such as equipment downsizing is included, then the median net cost for commissioning decreases from 0.6 percent to 0.2 percent, with many projects showing a net cost decrease because the first cost savings are greater than the commissioning cost.

Another report provides the commissioning cost estimates listed in Table 9. For projects of 30,000 ft^2 or less, the higher end of the range is appropriate. For larger projects the lower end of the range is typical. The complexity of systems to be commissioned also has an impact on costs; therefore some judgment is necessary in setting a budget.

Table 9 — Commissioning Cost Allowance for Project Budget

Commissioned System	Commissioning Cost
HVAC and controls	2.0% — 3.0% of total mechanical cost
Electrical system	1.0% — 2.0% of total electrical cost
HVAC, controls and electrical	0.5% — 1.5% of total construction cost

Source: Establishing Commissioning Costs, 2002, www.peci.org,

4.3 Details for the Project Manager

This section includes information to help the project manager oversee the commissioning process at each step of the project, from initial project scope development through construction.

4.3.1 Project Scope Development Phase

To facilitate budgeting, the project scope should include the following information listed in Table 10. See the following discussion for more details.

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[4] Mills, Evan, et.al., *The Cost Effectiveness of Commercial-Building Commissioning*, Lawrence Berkeley National Laboratory, December 15, 2004. http://eetd.lbl.gov/emills/PUBS/Cx-Costs-Benefits.html. The new construction results cover a survey of 74 buildings located in 15 states.

Table 10 — Commissioning Scope Checklist for Project Scope Development Phase

Level of commissioning
_____ Basic commissioning
_____ Additional commissioning
Party responsible for commissioning
_____ State official: _______________
_____ Independent commissioning agent
Systems to be commissioned
_____ Air conditioning
_____ Energy management and control system (EMCS)
_____ Lighting occupancy sensors
_____ Lighting daylighting control
_____ Lighting time of day control
_____ Natural ventilation
_____ Water heating
_____ Swimming pool
_____ Kitchen equipment
_____ Security
_____ Clocks
_____ Fire alarm

At this early stage, a detailed commissioning scope may not be appropriate, but the level of commissioning effort can be defined in a number of ways to aid the budgeting process. In this guideline, two levels of commissioning are described: “basic” and “additional.” In general, more complex systems require more commissioning, and larger projects can afford higher levels of commissioning.

“Basic” commissioning requirements should apply under the following conditions:

- Any new construction project covering 5,000 ft^2 or more of floor area.
- Any renovation project that meet all of the following criteria: 1) project cost of $1,000,000 or more; 2) floor area covered of 5,000 ft^2 or more; and 3) project scope includes HVAC replacement, building control system installation or upgrade, or lighting system controls.
- Any project for which LEED or CHPS compliance is sought. In those cases, these basic level commissioning requirements are roughly equal to the “prerequisite” commissioning requirements in those two rating systems.

Under basic commissioning, a third party or State official (at the project manager’s discretion) should perform the tasks listed in Table 11, as applicable for the scope of the project.

Table 11 — "Basic" Commissioning Task List

- Verify that lighting controls have been installed per design and have been tested to work as intended. Includes daylight controls, occupancy controls, multi-level switching, and automatic time-of-day control.
- Verify that ventilation and air conditioning system equipment is installed per design and that outdoor air flow, supply air flow, fluid flows, and controls are tested to meet design criteria.
- Verify that energy management and control system (EMCS) has been tested to perform the sequence of operations and to provide trend logs per design. Verify that sensor calibrations have been performed.
- Verify that a complete guide for operating and maintenance staff is provided.
- Verify that a short operating brief for school administrators and teachers is provided.
- Verify that training has been provided to operating staff.

"Additional" commissioning requirements should apply to projects that meet the following criteria:

- New construction projects covering 30,000 ft^2 or more of floor area.
- Renovation projects that meet all of the following criteria: 1) project cost of $5,000,000 or more; 2) floor area covered of 50,000 ft^2 or more; and 3) project scope includes HVAC replacement, building control system installation or upgrade, or lighting system controls.

The additional commissioning requirements include the following items listed in Table 12.

Table 12 — "Additional" Commissioning Task List

- Engage a commissioning agent.
- Develop and utilize a commissioning plan.
- Develop design intent and basis of design documentation.
- Include commissioning requirements in the construction documents.
- Conduct a focused review of the design prior to the construction documents phase.
- Conduct a focused review of the construction documents when close to completion.
- Conduct a selective review of contractor submittals of commissioned equipment.
- Verify installation, functional performance, training, and documentation.
- Develop a system and energy management manual.
- Have a contract in place for a near-warranty end, or post-occupancy, review.
- Complete a commissioning report

The choice of whether to use an independent commissioning consultant or "in-house" staff to carry out commissioning tasks will depend on the size and complexity of the project. For small projects it may not make sense to hire an independent consultant. The "basic" level of commissioning can generally be carried out by in-house staff (if they are available). The "additional" level of commissioning should be implemented by an independent commissioning consultant.

At a minimum, the list of systems to be commissioned should include the following because they have the biggest potential impact on the energy efficiency of the school:

- Mechanical ventilation and air conditioning
- Building automation systems (also known as energy management systems)
- Automatic lighting control systems

There are other systems that might be appropriate to include on the commissioning list, such as:

- Swimming pools
- Kitchens
- Natural ventilation
- Security
- Fire alarm
- Clocks

4.3.2 Preliminary Budget Estimate for Commissioning

Recommended budget allowances for commissioning are provided in Table 13 and Table 14. These costs are listed in terms of dollars per square foot of floor area. The first table covers the most critical systems, which should be always be included in the commissioning scope (as long as they are expected to be included in the design). The second table includes allowances for additional systems that either have little energy impact or that are less commonly part of project scope.

Table 13 — Preliminary Budget Guidelines for Commissioning for Critical Systems ($ per square foot)

		Level of Commissioning	
Systems to be Commissioned		**Basic**	**Additional**
Air conditioning		$0.10	$0.35
Energy management and control system (EMCS)		$0.10	$0.30
Lighting occupancy sensors		$0.03	$0.05
Lighting daylighting control		$0.10	$0.25
Lighting time of day control		$0.02	$0.05
	Total cost	$0.35	$1.00

Table 14 — Preliminary Budget Guidelines for Commissioning for Other Systems ($ per square foot)

	Level of Commissioning	
Systems to be Commissioned	**Basic**	**Additional**
Natural ventilation	$0.01	$0.05
Water heating	$0.01	$0.05
Swimming pool	$0.01	$0.10
Kitchen equipment	$0.01	$0.10
Security	$0.01	$0.10
Clocks	$0.01	$0.05
Fire alarm	$0.01	$0.10
Total	$0.07	$0.55

4.3.3 Consultant Selection for Commissioning

As mentioned in the Policy section earlier, the appropriate person to be in charge of commissioning depends on the size of the project. If only “Basic Commissioning” is required, then either a third party or State official may be in charge. If “Additional Commissioning” is required, then a third-party commissioning agent must be hired. The recommended qualifications listed below are borrowed from the CHPS Best Practices Manual, Volume 5 Commissioning.

Minimum Qualifications

- Experience in design, specification, installation, or operating of commercial building mechanical and control systems.
- Experience commissioning projects of similar size and equipment in the last 3 years. This includes writing functional performance test plans.
- History of responsiveness and proper references.

- Meet district's liability requirements.
- Experience working with project teams, project management, conducting scoping meetings, and good communication skills.

Optional Qualifications

- Direct responsibility for project management of at least two commercial construction or installation projects with mechanical costs greater than or equal to current project costs.
- Experience installing designs and/or troubleshooting direct digital controls and energy management systems, if applicable.
- Demonstrated familiarity with metering and monitoring.
- Knowledge and familiarity with air/water testing and balancing.
- Experience planning and delivering O&M training.
- Building contracting background.
- Overall understanding by the commissioning team of all building systems including building envelope, structural, and fire/life safety components.

4.3.4 Design and Construction Phase Commissioning

The project manager should make sure that commissioning activities take place as planned. During the design phase the specific activities and deliverables may vary between projects. However as a general guide, Table 15 provides a checklist to help the project manager to track commissioning tasks.

Table 15 — Commissioning Deliverable Checklist

Deliverables	Basic Commissioning	Additional Commissioning
Commissioning plan		☐
Design intent documentation		☐
Basis of design documentation		☐
Commission requirements in the construction documents (specifications)		☐
Design review report (prior to the start of construction documents phase)		☐
Design review report (prior to the completion of construction documents phase)		☐
Contractor submittals review report for commissioned equipment.		☐
Pre-functional test report (verifying installation)	☐	☐
Functional performance test report	☐	☐
System and energy management manual		☐
Commissioning report.		☐
Contract in place for a near-warranty end, or post-occupancy, review.		☐
Verification that a complete guide for operating and maintenance staff is provided.	☐	☐
Verification that a short operating brief for school administrators and teachers is provided.	☐	☐
Verification that training has been provided to operating staff.	☐	☐
Post-occupancy commissioning report		☐

4.4 Details for Designer

A great deal of information is available to assist the designer in developing commissioning specifications. See the resources listed in the following section for details. Commissioning specifications shall be developed for each project and shall include at a minimum the following information:

- Commissioning roles and responsibilities of the contractor, design team, district, and commissioning agent.
- Project closeout requirements that link contractor payment to successful completion of commissioning.
- Section 01810 Commissioning (or equivalent section containing general commissioning requirements).
- Section 15999 Mechanical System Commissioning (or equivalent section).
- Section 16999 Electrical System Commissioning (or equivalent section).

4.5 Resources

ASHRAE Guideline 1-1996 The HVAC Commissioning Process, www.ashrae.org.

Building Commissioning Association, www.bcxa.org.

California Commissioning Collaborative, www.cacx.org.

Collaborative for High Performance Schools (CHPS), *Best Practices Manual, Volume 2, Design*, 2002, www.chps.net. (*Best Practices Manual, Volume 5, Commissioning 2005* to be published mid-2005)

Energy Design Resources, *Commissioning Guidelines*, www.energydesignresources.com.

Energy Design Resources, *Cx Assistant*. An online tool that helps in the development of commissioning documentation. www.energydesignresources.com.

Adopting the Commissioning Process for Successful Procurement of Schools. January 16, 2003. Prepared by Farnsworth Group for the California Department of General Services.

Mills, Evan, et.al., *The Cost Effectiveness of Commercial-Building Commissioning*, Lawrence Berkeley National Laboratory, December 15, 2004. http://eetd.lbl.gov/emills/PUBS/Cx-Costs-Benefits.html.

Portland Energy Conservation Incorporated, www.peci.org.

5 Air Conditioning Applicability

5.1 Summary

The point of this section is to provide guidance in determining whether air conditioning is appropriate. This decision applies to new construction as well as existing school buildings. The general options in order of preference are:

- Natural ventilation
- Mixed mode ventilation (allows use of natural ventilation for part of the year)
- Air conditioning only

Air conditioning should be considered only for classrooms and administration areas, and only under the following circumstances (which should be documented as part of the design process):

- The Board of Education Policy 6700 defines conditions where air conditioning can be provided based on temperature. This policy states the following:

  > Air conditioning may be installed if the Effective Temperature, as determined by the "New Effective Temperature Scale," as defined in the American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc. (ASHRAE) Handbook, exceeds 80°F for 18 school days in classrooms and 25 weekdays in administration/staff facilities during any 12 month period.

- Outdoor air contaminants at the site make the use of unfiltered ventilation air a health hazard to occupants.
- Odors due to external sources cannot be mitigated.
- External noise level is greater than L10= 65 dBA at the windows or other potential natural ventilation openings, and the external noise sources cannot be mitigated with reasonable measures such as installing sound barriers along roadways or relocating equipment or other noise sources.
- It can be shown that reasonable design provisions for natural ventilation and heat gain reduction (such as roof insulation, cool roof membrane, radiant barriers, window shading, lighting power reduction, daylighting controls) cannot maintain comfortable indoor air temperatures from exceeding 80°F for 18 days for classrooms and 25 weekdays in the administration/staff facilities during any 12 month period.

- Load reduction measures have been carried out prior to installation of an air conditioning system, including reduction of lighting power to no greater than the energy code power allowance, insulation of roof to R-19 or equivalent performance (see the *Hawaii Commercial Building Guidelines* section on Cool Roof Systems that illustrates roof construction alternatives), minimizing of solar heat gain through windows via overhangs, external sunshades, window film, or glazing replacement with a glazing having SHGC of 0.40 or lower.

- Air leakage paths are eliminated, including jalousie windows that cannot provide an airtight seal.

- It can be established that adding air conditioning will not create moisture or humidity conditions conducive to mold growth within the space or in the building structure.

Where air conditioning is unavoidable, the building should be designed for “mixed mode” ventilation, meaning that air conditioning can be turned off and natural ventilation can be employed to provide comfort and air quality when milder outdoor conditions occur. In terms of outdoor temperatures, the entire State experiences conditions conducive to natural ventilation for at least part of the year. Exceptions to the mixed mode recommendation include cases where it can be shown that permanent external noise or outdoor air quality problems make natural ventilation undesirable.

5.2 Background

Air conditioning carries a significant up-front price tag and large lifetime costs for energy, maintenance, and equipment replacement. Initial cost for air conditioning in new construction is at least $\$15/ft^2$ and for retrofits is more than $\$25/ft^2$. The annual energy costs for air conditioning in a school are $\$0.50/ft^2$ or more. The present value of these air conditioning energy costs considered over a 30-year classroom lifetime is about $\$10/ft^2$ (assuming a 3% real discount rate). The present value of equipment replacement 15 years in the future is $\$10/ft^2$ to $\$16/ft^2$ (also assuming a 3% real discount rate). Therefore, a decision to install air conditioning incurs a life-cycle cost on the order of $\$35/ft^2$ to $\$50/ft^2$ in today’s dollars, which adds up to $35,000 to $50,000 per classroom. Due to the significant costs, it is important to establish criteria for when air conditioning is necessary and desirable.

In many cases, the need for air conditioning can be avoided by designing to minimize heat gain (both solar and internal) and by providing air movement via natural ventilation or ceiling fans. There are also many other measures that can help make natural ventilation feasible, such as shading of the site, orienting openings to minimize noise, and siting buildings to avoid sources of outdoor air contamination or odors.

The San Diego Unified School District established a temperature standard which states that classroom temperatures should not exceed 78°F for more than 10 percent of school hours. Air conditioning is allowed only in cases where these standards are exceeded.

ASHRAE Standard 55-2004 includes new information about thermal comfort for occupants of buildings with access to natural ventilation. The result of the new comfort model is illustrated in the following figures, taken from the Natural Ventilation chapter of the *Hawaii Commercial Building Guidelines for Energy Efficiency*. These show that natural ventilation should be able to provide comfort for much of the school year in Honolulu and all of the school year in Hilo.

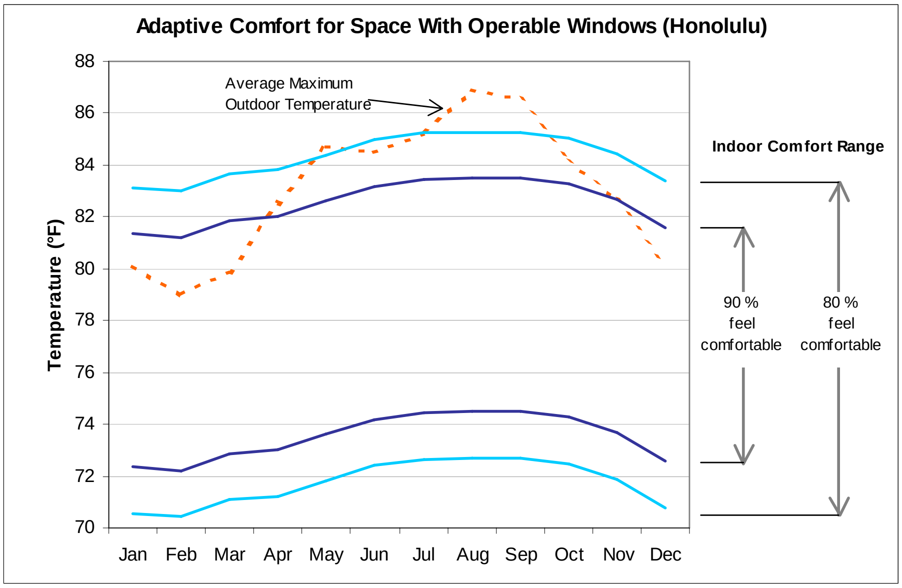

Figure 5 — Indoor comfort range in naturally ventilated buildings in Honolulu

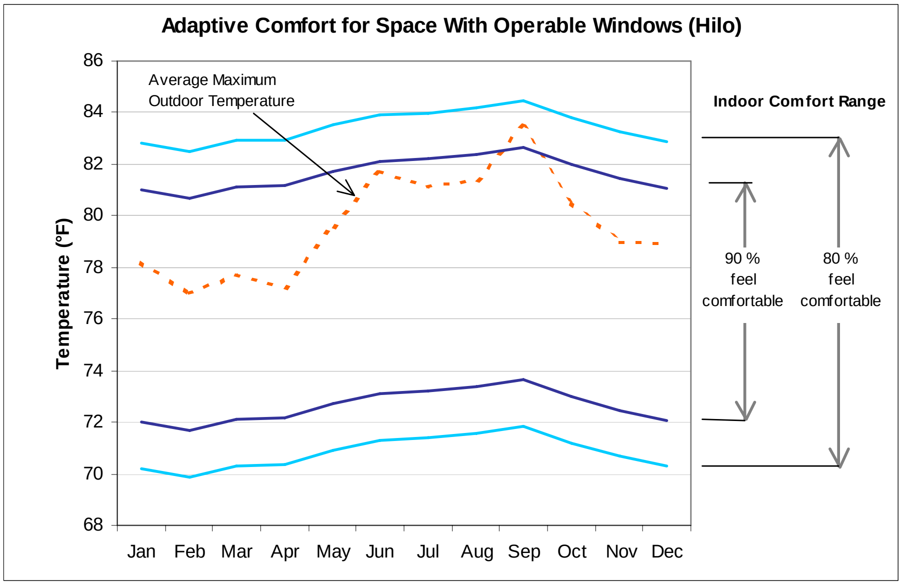

Figure 6 — Indoor comfort range in naturally ventilated buildings in Hilo

The following two tables show average hourly outdoor temperatures for Honolulu and Hilo and indicate the hours that fall outside the new ASHRAE comfort range. They show that there are times of the day between May and October when Honolulu is outside the 90% comfort conditions, and times in August and September when the 80% comfort conditions are exceeded. The table for Hilo shows that outdoor temperatures meet comfort conditions all year.

Table 16 — Average outdoor hourly temperatures (°F) for Honolulu. Dotted line marks the hours when outdoor temperature exceeds indoor comfort limits in naturally ventilated buildings for 10% of occupants. Source of temperature data: Typical Meteorological Year Data, U.S. National Climatic Data Center.

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
HOUR													
1	69.3	68.2	70.2	71.1	72.7	75.4	75.4	77.2	76.4	75.6	72.9	69.7	**72.9**
2	68.8	67.9	69.6	70.8	72.3	75.1	74.9	77.1	76.0	75.1	72.4	69.4	**72.5**
3	68.4	67.6	69.1	70.1	71.8	74.7	74.5	76.7	75.6	74.9	72.1	69.4	**72.1**
4	68.1	67.6	68.8	69.9	71.4	74.3	74.3	76.3	75.3	74.4	71.9	69.2	**71.8**
5	67.8	67.3	68.2	69.9	70.8	74.0	73.9	76.1	74.9	74.2	71.7	69.2	**71.5**
6	67.6	66.6	69.3	69.6	70.5	74.0	75.3	75.8	76.1	75.3	71.8	69.4	**71.8**
7	67.3	66.5	70.4	70.5	73.4	75.1	76.8	76.6	77.4	76.3	71.7	69.6	**72.7**
8	69.1	67.5	71.5	73.9	77.0	77.5	78.2	78.5	78.6	77.5	74.1	69.8	**74.5**
9	73.3	71.2	73.6	76.1	79.3	79.3	80.0	80.4	80.6	79.2	77.2	72.7	**76.9**
10	76.3	73.7	75.9	78.5	81.3	80.9	81.7	82.5	82.8	80.9	79.6	75.4	**79.2**
11	77.7	75.9	78.0	79.9	82.5	82.4	83.5	83.8	84.8	82.6	80.7	78.3	**80.9**
12	78.5	77.1	78.5	81.0	83.3	82.9	83.9	85.4	85.2	82.8	81.4	78.7	**81.6**
13	78.7	77.5	79.3	81.4	84.0	83.5	84.2	85.7	85.9	83.5	81.6	79.2	**82.1**
14	79.0	77.9	79.9	81.0	83.4	83.5	84.6	86.2	86.3	83.7	81.7	79.6	**82.2**
15	78.1	77.5	79.2	80.9	82.8	83.4	83.7	85.6	85.4	82.9	81.1	78.8	**81.6**
16	77.3	76.3	78.6	80.5	81.5	82.7	83.0	84.4	84.3	81.9	79.7	78.0	**80.7**
17	75.6	75.4	77.9	78.5	79.8	81.6	82.1	83.4	83.4	81.1	78.2	77.2	**79.5**
18	73.5	73.9	76.5	76.2	78.0	80.0	80.4	81.2	81.8	79.9	76.0	75.8	**77.8**
19	72.2	72.2	75.1	73.6	75.9	78.4	78.9	79.5	80.1	78.6	75.2	74.5	**76.2**
20	71.5	71.5	73.6	72.7	74.9	77.2	77.3	78.7	78.5	77.5	74.3	73.1	**75.1**
21	71.2	70.5	72.9	72.6	74.5	76.9	77.0	78.3	78.3	77.2	74.2	72.2	**74.7**
22	70.5	69.5	72.2	72.3	74.1	76.7	76.5	78.1	77.6	76.8	73.6	71.4	**74.1**
23	69.9	69.0	71.6	71.8	73.9	76.4	76.3	77.8	77.4	76.5	73.4	70.5	**73.7**
24	69.7	68.7	71.0	71.4	73.6	75.8	75.8	77.7	77.0	76.0	73.1	70.2	**73.4**
Avg. Outdoor Temperature (Dry bulb)	72.1	71.7	73.8	74.3	76.1	78	78.8	78.9	78.9	78.2	76.3	72.9	75.8
AVG. DAILY MAX. TEMP.	80.1	79	79.9	82.5	84.7	84.5	85.2	86.9	86.5	84.2	82.6	80.1	83
AVG. DAILY MIN. TEMP.	66.1	65.4	67.7	68.8	70.2	73.5	73.7	75.5	74.8	73.8	70.8	67.5	70.7

⬚ 10% feel uncomfortable

▭ Typical occupied hours (7 am - 6 pm)

🟦 20% feel uncomfortable

Table 17 — Average outdoor hourly temperatures (°F) for Hilo. There are no cases where the hourly average temperature exceeds comfort limits. Source of temperature data: Typical Meteorological Year Data, U.S. National Climatic Data Center.

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
HOUR													
1	67.4	66.4	67.7	68.3	69.2	69.8	71.2	71.3	72.1	71.0	69.2	67.4	**69.3**
2	67.0	65.8	67.3	67.7	68.7	69.4	70.6	70.6	71.4	70.8	68.6	66.9	**68.7**
3	66.6	65.5	67.0	67.2	68.4	69.1	70.4	70.3	71.1	70.2	68.4	66.7	**68.4**
4	66.1	65.2	66.7	66.8	68.0	68.8	70.3	70.1	70.8	69.5	68.1	66.2	**68.1**
5	65.8	65.0	66.3	66.3	67.6	68.5	69.9	69.8	70.5	69.2	67.9	65.9	**67.7**
6	66.4	65.7	67.1	67.8	69.7	70.5	69.9	71.5	72.2	68.9	68.8	66.6	**68.8**
7	66.9	66.3	67.8	69.4	71.8	72.7	70.9	73.4	73.9	69.7	69.6	67.3	**70.0**
8	67.5	67.1	68.7	70.9	73.8	74.8	74.1	75.1	75.7	73.5	70.6	68.0	**71.7**
9	70.7	69.7	71.3	72.6	75.3	76.5	76.2	76.6	78.0	77.0	72.9	71.3	**74.0**
10	73.9	72.4	73.7	74.3	76.9	77.9	78.0	78.5	80.3	78.1	75.1	74.5	**76.2**
11	77.1	75.0	76.3	76.0	78.4	79.7	79.3	80.1	82.6	78.6	77.5	77.7	**78.2**
12	77.1	75.6	76.6	76.0	78.4	80.3	79.9	80.4	82.4	79.0	77.8	77.9	**78.5**
13	77.1	76.1	77.1	76.5	78.5	80.9	80.0	80.7	82.4	79.1	78.2	78.2	**78.8**
14	77.1	76.6	77.5	76.5	78.5	81.5	80.2	80.9	82.2	79.3	78.6	78.5	**79.0**
15	76.1	75.6	76.8	75.8	77.9	80.5	79.9	80.2	81.3	79.0	77.5	77.1	**78.2**
16	75.2	74.7	76.0	75.0	77.4	79.4	79.1	79.7	80.3	77.9	76.3	75.9	**77.3**
17	74.2	73.7	75.3	74.4	76.8	78.4	78.1	79.0	79.4	76.6	75.2	74.5	**76.3**
18	73.1	72.2	73.9	73.2	75.4	76.7	76.8	77.5	78.0	75.6	74.1	73.1	**75.0**
19	71.8	70.8	72.3	72.1	73.7	74.8	75.1	76.1	76.6	74.5	73.1	71.8	**73.6**
20	70.7	69.2	70.9	71.0	72.3	73.1	74.0	74.6	75.2	73.6	72.0	70.3	**72.3**
21	69.9	68.7	70.1	70.5	71.6	72.3	73.6	74.1	74.7	73.1	71.3	69.6	**71.6**
22	69.2	68.0	69.5	69.9	70.8	71.4	72.9	73.4	73.9	72.4	70.7	68.8	**70.9**
23	68.4	67.5	68.7	69.4	70.2	70.6	72.4	72.8	73.3	71.8	70.1	68.1	**70.3**
24	67.9	66.9	68.3	68.8	69.6	70.3	71.8	72.1	72.6	71.5	69.5	67.6	**69.8**
Avg. Outdoor Temperature (Dry bulb)	71.0	70.0	71.4	71.5	73.3	74.5	74.8	75.4	76.3	74.2	72.5	71.3	73.0
AVG. DAILY MAX. TEMP.	78.2	77.0	77.7	77.2	79.6	81.7	81.1	81.4	83.4	80.5	79.0	78.9	79.7
AVG. DAILY MIN. TEMP.	65.0	64.2	65.9	66.0	67.3	68.1	69.4	69.5	70.2	68.3	67.4	65.3	67.2

All hours fall within 90% comfort range

☐ Typical occupied hours (7 am - 6 pm)

One challenge when setting an air conditioning policy based on outdoor air temperature is finding an appropriate source of weather data. The wide range of micro climates in Hawaii makes the task especially difficult. Data from two sources are summarized on the following pages. The first is the Western Regional Climatic Center, which posts data on the Internet for 27 locations around the state. Data for five locations are summarized in Figure 7, which shows daily maximum temperatures and the number of days per year they occur.

The second source illustrated below is hourly Typical Meteorological Year (TMY2) data from the National Climatic Data Center. Figure 8 shows the number of hours per year that each temperature occurs. This information is available for only the four locations shown in Figure 8.

There is some inconsistency between these two sources. For example, Figure 7 shows that daily maximum temperature in Honolulu exceeds 88°F for 60 to 70 days per year, but Figure 8 shows temperatures in Honolulu never reaching 88°F, and show only 10 hours per year at 87°F. However, the two data sources also show some patterns, including the fact that temperatures in Hilo and Lihue appear to be 85°F or less for all hours.

On-site temperature monitoring can be used, but great care is necessary to get accurate readings. And year-to-year variations can be significant.

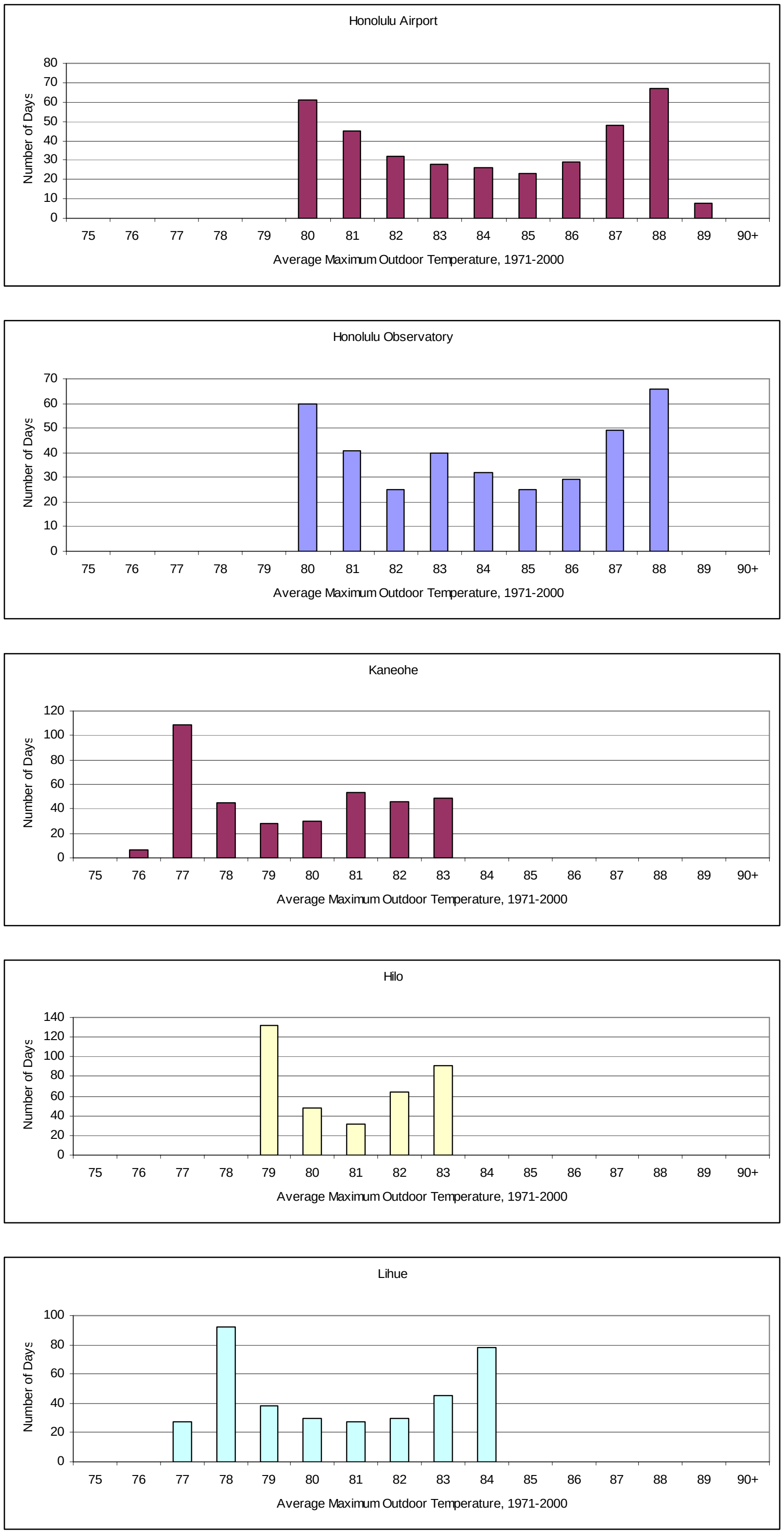

Figure 7 — Maximum Daily Temperature Data for Five Hawaii Locations. Average Maximums for 1971-2001. Source: Western Regional Climatic Center, http://www.wrcc.dri.edu/summary/climsmhi.html

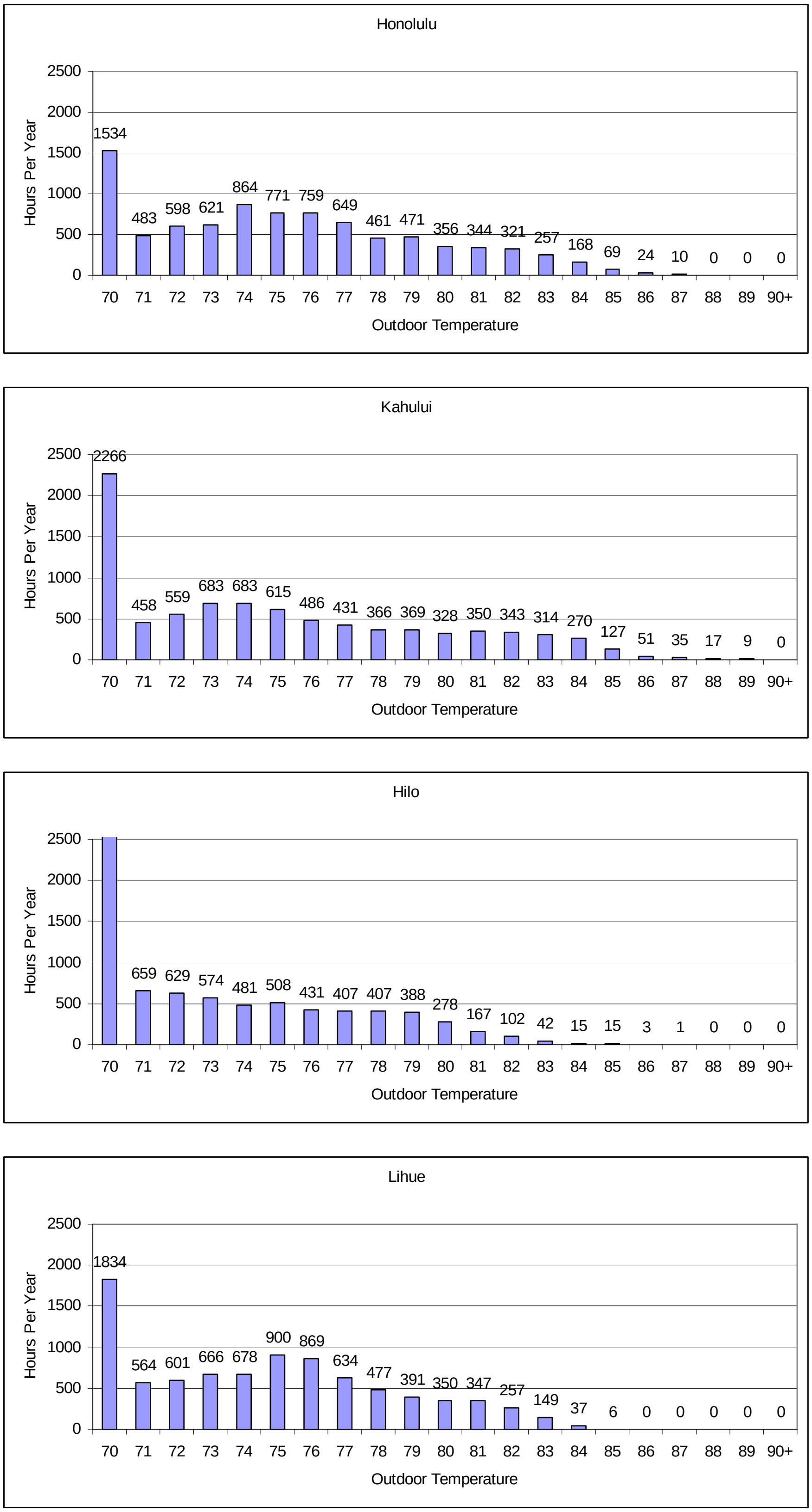

Figure 8 — Outdoor Hourly Temperature Distribution for Four Hawaii Locations. Source: Typical Meteorological Year (TMY2) data from National Climatic Data Center

5.3 Details for the Project Manager

The decision whether or not to use air conditioning needs to occur during the project scope development process, so that an appropriate budget can be developed. In cases where there is uncertainty regarding issues such as local air quality or noise, then an investigation may be necessary. Where air conditioning is unavoidable, consider whether it can be used for only portions of a campus or individual building where comfort and air quality problems cannot be mitigated through passive measures.

Prior to installing air conditioning in an existing building, ensure that the load reduction measures listed in the policy above (e.g. lighting retrofit, roof insulation) have been carried out or already exist. In some cases, those measures will eliminate the need for air conditioning. In all cases, they will allow smaller air conditioning equipment to be installed and will reduce operating costs.

5.4 Details for Design Consultants

An integrated package of measures is usually necessary in order to avoid the need for air conditioning. See the *Hawaii Commercial Building Guidelines for Energy Efficiency* for information about natural ventilation, efficient lighting, cool roof systems, and window shading.

See also the policies regarding Air Conditioning System Type Selection, Air Conditioning System Sizing, and Air Conditioning Design Details.

5.5 Resources

Hawaii Commercial Building Guidelines for Energy Efficiency. 2003. Prepared by Architectural Energy Corporation for DBEDT. http://www.archenergy.com/library/general/hawaiigl/.

National Climatic Data Center, http://www.ncdc.noaa.gov/.

Western Regional Climatic Center, http://www.wrcc.dri.edu/.

6 Air Conditioning System Type Selection

6.1 Summary

When air conditioning is determined to be necessary, a minimum of two alternative system types should be compared based on the criteria in Table 18 or a similarly rigorous method in which the reasoning behind the selection is documented. In making a system selection some judgment is necessary, including consideration of both the score calculated based on the method in Table 18 as well as the life-cycle cost estimate for each alternative.

Table 18 — Air Conditioning and Ventilation System Evaluation Matrix

System Description
Describe the system characteristics here.

central / room-by-room
chilled water / packaged
variable air volume (single-duct or dual-duct) / constant volume
dual-path / single-path
water-cooled / air-cooled
overhead air distribution / displacement ventilation / underfloor air distribution
ducted return / plenum return
special controls
other special characteristics

Criteria	**Criteria Weight (Totals to 100)**	**Comments**	**Score (1 to 10) 1 = poor 10 = excellent**
Mechanical System First Costs	12		
Impact on Other Trades: General Contractor	6		
Impact on Other Trades: Electrical Contractor	4		
Floor Space Requirements	6		
Ceiling Space Requirements	3		
Energy Efficiency: Normal Operation	8		
Energy Efficiency: Off-hour Operation	2		
Flexibility for After-School-Hours Operation	5		
Acoustical Impact	8		
Dehumidification Performance Over Full Operating Range	6		
Indoor Air Quality	8		
Comfort	8		
Ease of Maintenance During School Hours	4		
Compatibility with Maintenance Staff Resources	6		
Use of Standardized Parts	4		
Maintenance Cost and Reliability	4		
Longevity	4		
Flexibility for Future Occupancy Changes	2		
	100	**Total Score** (Rooftop/Floor-by-Floor) **(Sum of Weight × Score, maximum is 1000)**	

The following system elements should be given consideration for each project:

- Variable air volume (crucial to energy savings and comfort)
- Dual-path air handler arrangement (capability to cool outside ventilation air separately from return air for better dehumidification)
- Displacement ventilation
- Demand-control ventilation
- Water-cooled or evaporatively cooled condenser (as opposed to air cooled)

6.2 Background

There are always performance and cost tradeoffs when comparing different AC system options. Therefore, the best choice may not be immediately obvious, and the best choice may vary from one project to the next depending on project constraints. Therefore, rather than specify one or two required systems, this recommendation sets a minimum level of analysis to be performed when selecting a system.

6.3 Details for Project Manager

First, ensure that a determination has been made that AC is necessary (see the separate guideline regarding air conditioning applicability), and that all cost-effective heat-load mitigation measures (i.e., roof and wall insulation, high-performance windows, etc.) have been implemented or included in the project plans before selecting an AC system type.

Work with the design team during programming or schematic design phases to evaluate AC system options using the method described in this section or an equally rigorous method.

Use the selection criteria as a tool to help make an optimal selection, it is not absolutely required that the system with the best score be the one that is selected. However, there must be documentation of the justification for the selection that is made.

Once a system type is selected, then focus on ensuring efficiency and air quality issues are considered in developing the AC system design details. See the section titled Air Conditioning System Design Details.

6.4 Details for Designer

The version of the system selection matrix in Table 19 includes brief descriptions of the meaning of each of the criteria. When this table is filled out by the designer, those comments should be replaced with a brief discussion of the relative merits or drawbacks for each system option. One table should be filled out for each system type being evaluated. The criteria weights listed in the table should be considered examples, and the appropriate weights for each project should be discussed between the designer and the project manager.

Table 19 — System Evaluation Matrix with Notes for Designer

System Description
Describe the system characteristics here.

central / room-by-room

chilled water / packaged

variable air volume (single-duct or dual-duct) / constant volume

dual-path / single-path

water-cooled / air-cooled

overhead air distribution / displacement ventilation / under-floor air distribution

ducted return / plenum return

special controls

other special characteristics

Criteria	**Criteria Weight (Totals to 100)**	**Comments** ***(Note: The comments below are provided as guidance to the designer. When this table is filled out by the designer, these comments should be replaced with a brief discussion of the relative merits or drawbacks for each system option)***	**Score (1 to 10)** **1 = poor** **10 = excellent**
Mechanical System First Costs	12	First cost ranked relative to other system options.	
Impact on Other Trades: General Contractor	6	Impact on construction requirements such as mechanical rooms, duct enclosures, shafts, equipment screens.	
Impact on Other Trades: Electrical Contractor	4	Impact on electrical system cost and complexity.	
Floor Space Requirements	6	Impact on usable floor area.	
Ceiling Space Requirements	3	Amount of space required for ducts, fan coils or other system components.	
Energy Efficiency: Normal Operation	8	Energy performance during normal school hours relative to the other system options.	
Energy Efficiency: Off-hour Operation	2	Energy performance after normal school hours if only portions of the school are occupied.	
Flexibility for After-School-Hours Operation	5	The ability to air condition only portions of the school for after-hour activities.	
Acoustical Impact	8	Relative impact on noise in the classrooms and other spaces.	
Dehumidification Performance Over Full Operating Range	6	Ability to extract moisture from the supply air to maintain comfort and air quality even when space sensible cooling loads are low.	
Indoor Air Quality	8	Ability to provide adequate level of clean outdoor air to the occupied zone.	
Comfort	8	Ability to maintain stable comfort and humidity	
Ease of Maintenance During School Hours	4	Ability to be accessed for routine or emergency maintenance tasks without disrupting classes.	
Compatibility with Maintenance Staff Resources	6	Level of training required to perform maintenance tasks, and frequency of maintenance required.	
Use of Standardized Parts	4	Commonly replaced components are standard items that can be stocked by Central Services or easily sourced in Hawaii.	
Maintenance Cost and Reliability	4	Cost and reliability relative to the other system options.	
Longevity	4	Relative lifetime of different system options. This can be an issue when comparing water-cooled and air-cooled equipment and when comparing indoor vs. outdoor equipment placement.	
Flexibility for Future Occupancy Changes	2	Ease of rezoning, adding capacity, or adapting to change in occupancy.	
	100	**Total Score** (Rooftop/Floor-by-Floor) **(Sum of Weight × Score, maximum is 1000)**	

7 Air Conditioning System Design Details

This section addresses specific AC design details that have an impact on efficiency, performance, and reliability. Hawaii's unique conditions mean that optimal choices are sometimes different than in other parts of the U.S.

7.1 Summary

Air conditioning system designers should give consideration to the following system design preferences when selecting a system type and when developing design details.

7.1.1 Air Distribution

Variable air volume (VAV) systems are preferred. A VAV system generally provides fan savings as well as good dehumidification performance. Dehumidification improves because the supply air temperature can be maintained at 55°F or below while the air volume is modulated to control space temperature. The typical application of a VAV system is a central air handler that serves multiple zones. However, VAV control should also be considered for single-zone systems that are traditionally constant volume. Significant fan energy savings and improved dehumidification performance are possible if space temperature in single zone systems is controlled by varying air flow rather than supply air temperature.

If a constant air volume strategy is selected instead of VAV, then a “dual-path” air handler arrangement or other special measure to improve dehumidification performance is highly recommended (see next section). Otherwise, when cooling loads in the space are low and the supply air temperature rises to avoid overcooling, less moisture will be removed from the supply air.

A dual-fan, dual-duct system may be a good choice for buildings with high, yet variable, outside air ventilation requirements such as classroom buildings. Traditionally, a dual-duct system has a “warm” duct and a “cold” duct, and each zone has a mixing box that combines these airflows to maintain space temperature control. However, in the Hawaii classroom context, this system can consist of a “ventilation” duct and a “cooling” duct. The “ventilation” duct delivers cooled outside air and is sized for the ventilation load (e.g. 15 cfm/person) the “cooling” duct delivers cooled return air. Each duct has its own air handler with separate fan and cooling coil. At the zone level, a dual-duct VAV box provides demand control ventilation and space temperature control. The VAV damper on the vent-duct inlet is controlled (between max and min setpoints) based on a CO_2 sensor located in the space. Therefore, when a space is unoccupied, the outdoor air flow to that zone will drop to a minimum setpoint. The “cooling” duct damper is controlled based on a space temperature signal. Therefore, as cooling loads in the space increase, the airflow from the cooling duct will increase. The supply air temperature of the “ventilation” duct will always be maintained fairly low (e.g. 53°F) to extract moisture from the outdoor air. The temperature of the “cooling” duct can be reset depending on cooling demand from the zones.

Displacement ventilation should be considered for classrooms. Delivering supply air at low velocity near the floor level allows space cooling loads to be handled with roughly 65°F supply air temperature. Air quality improves compared to standard overhead mixing air distribution. Note that a “dual path” arrangement is probably necessary to provide adequate dehumidification at the higher supply air temperature.

Central air handlers are generally preferred over single-zone air handlers, though either can be a good choice in specific cases. The benefits to central air handlers include easier maintenance of filters and cooling coils, better potential acoustic performance because fans can be remote from classrooms, and better potential for efficiency with larger fans and motors.

7.1.2 Air Handler

A dual path arrangement is preferred, especially for constant volume air handlers, to improve dehumidification performance at low-load conditions. There are several ways to implement a dual-path system; the common feature of all dual-path systems is that the outside air that is introduced for ventilation is cooled separately from the return air. The typical method is to provide a separate cooling coil on the outside air. In Hawaii, with its year-round dehumidification requirements, this outside air cooling coil may not even need a modulating control valve. The outside air can be provided with constant cooling, and the space temperature can be controlled with the main cooling coil that is located in the return air or mixed air path. See the *Hawaii Commercial Building Guidelines for Energy Efficiency* chapter on Dehumidification for more information.

Another variation on the dual-path arrangement include using a separate air handler for outside air, sometimes called a dedicated outside air system (DOAS) that delivers air to other central air handlers (e.g. floor-by-floor) or to fan coils.

Select cooling coils and filters for a face air velocity of 400 ft per minute or lower to minimize air pressure loss.

Consider UV-lamps on the cooling coils and condensate drain pans, especially in areas with dusty outdoor conditions, to inhibit mold growth.

Consider demand control ventilation in all spaces with variable occupancy, especially larger spaces such as gyms and multipurpose rooms if they are air conditioned.

Design for supply air temperature of 50°F to 55°F, and avoid supply air temperature reset controls because increasing the SAT typically reduces the dehumidification performance.

To help maintain good indoor air quality, specify filters with ratings equal to or greater than MERV 12 or 85% dust spot efficiency.

7.1.3 Chilled Water Cooling Systems

Chilled water systems are generally preferred over packaged cooling systems due to better potential energy efficiency. And when compared to individual packaged (i.e. DX) classroom units, the chilled water fan-coil system also offers better acoustic performance.

Chilled water pumping arrangement should be primary-only, variable-flow as a first choice and primary-secondary with variable-flow secondary loop as second choice.

Cooling coils should be selected to provide a chilled water temperature rise (delta T) of at least 16°F across the coil in order to minimize pumping energy and improve chiller efficiency.

Chilled water supply temperature should be 40°F to 44°F.

Chilled water supply temperature should not be reset upwards at low loads because cooling coil dehumidification performance will suffer. Instead, make sure that the cooling coil is selected so that it can operate over the full range of anticipated load conditions with constant entering chilled water temperature. Pay special attention to low-load conditions.

Water-cooled chillers (i.e. systems with cooling towers) are generally preferred due to greater energy efficiency and typically longer life than air-cooled chillers.

Select cooling towers for an approach temperature of 6°F or less in order to provide cooler condenser water and improve chiller efficiency.

If air-cooled chillers are specified, then careful attention to the specification of the condenser (outdoor) coil is required to ensure long life in Hawaii's climate. When there is an option, then thicker and more widely spaced fins are preferred.

7.1.4 Consider thermal energy storage to reduce peak electric load. Packaged Cooling Systems

Select equipment to maximize latent cooling (dehumidification) capacity.

Consider systems with refrigerant subcooling coils downstream of the evaporator (cooling) coil to increase latent capacity.

Do not oversize packaged air conditioners because excessive on/off cycling dramatically reduces dehumidification performance at partial load.

Consider systems with multiple refrigerant circuits and split coils where at low load only a portion of the supply air is cooled to low temperature and dehumidified.

Pay careful attention to the specification of the condenser (outdoor) coil to ensure long life in Hawaii's climate. When there is an option, then thicker and more widely spaced fins are preferred to help avoid degradation.

7.1.5 Controls

Direct digital control (DDC) is recommended for all new air conditioning systems to allow remote monitoring of operating schedules and system performance.

Control system shall at a minimum provide remote time-of-day on/off control, remote adjustment of space temperature setpoints, system monitoring (trending) and remote data access, and alarming for system faults or out-of-range values.

Control system trend logs shall be set up to monitor system performance, and the control system shall have adequate data storage capacity for at least 3 months of 15 minute interval readings of the following at a minimum (as applicable depending on system type): space temperature, supply air temperature, outdoor air temperature, fan speed, chilled water supply and return temperatures, condenser water supply and return temperatures, chiller electric demand, and pump speed.

VAV systems shall have static pressure reset control whenever DDC control is extended to the zone level.

VAV systems shall *not* use supply air temperature reset control unless it can be shown that dehumidification performance will be adequate when the temperature is increased.

Chilled water systems shall not use chilled water temperature reset control unless is can be shown that dehumidification performance will be satisfactory over the full range of potential loads.

7.1.6 Load Calculations and System Sizing

Sizing of air conditioning systems can have a significant impact on energy efficiency and dehumidification performance. Oversized systems cost more and often perform worse than properly sized equipment.

A minimum of two, and perhaps more, load calculations should be performed for different conditions. In addition to a traditional peak design load calculation, which is based on conditions that occur for a relatively few hours per year and are often based on conservative assumptions, also perform a load calculations for typical (or most frequent) conditions. The typical conditions should include realistic lighting and plug loads and include impact of window shades. The purpose of the typical conditions calculation is to provide a point to evaluate system comfort performance and efficiency and ensure that the system works optimally under the loads it will see most of the time.

7.1.7 General Issues

For areas such as laboratories that require 100 percent outside air, consider heat recovery.

Specify adequate weather protection for equipment.

Provide occupants with some level of temperature control.

Consider using a ground-coupled heat rejection system instead of typical water-cooled or air-cooled alternatives. A ground-coupled system typically consists of a loop of pipe buried in a horizontal trench or vertical well that acts as a heat exchanger between condenser fluid and the ground. The feasibility of a ground-coupled system depends on soil conditions and availability of space for the ground heat exchanger.

8 Natural Ventilation

There are number of building envelope design features that affect natural ventilation performance. In addition there are a number of issues that are unique to Hawaii. This guideline summarizes recommendations for natural ventilation design strategies.

8.1 Summary of Natural Ventilation Design Recommendations[5]

- Natural ventilation has to be an integral part of the schematic design phase.
- Provide 5% — 8% of the floor area as free ventilation area. Equal inlet and outlet areas maximize airflow whereas outlets that are 2% — 5% larger than inlets produce higher air velocities.
- The inlet location affects airflow patterns far more significantly than outlet location. Locate inlets at the occupied level. Stagger location of the outlet openings both vertically and horizontally by a few feet (relative to the inlet locations) to achieve longer air paths through the space.
- Thermal mass helps the effectiveness of natural ventilation. Concrete walls and floors can act as heat reservoirs, absorbing heat through the day and dissipating it at night. At night, natural ventilation can be used to increase the amount of dissipated heat. Most mass wall strategies, such as double layers of drywall, can also help improve acoustic separation between spaces.
- Inlets and outlets should be designed with security in mind so that they can be left open overnight in order to cool the building mass before occupants arrive in the morning.
- Integration with Daylighting and View Windows. The openings for cross ventilation must work together with the daylighting design. One typical solution for Hawaii is to use low windows as inlets on the north or northeast side to capture the prevailing trade winds. These windows are also relatively easy to shade from the sun with small overhangs. The outlet openings can then be located on the south or southwest side higher in the wall where they are easier to shade from the sun.
- High Ceilings. Increased ceiling height can extend the period when natural ventilation is effective and also allows the use of ceiling fans. At the same time, a high ceiling can

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[5] Much of the information in this section is distilled from a draft version of the Advanced Buildings Guidelines, being developed by the New Buildings Institute.

improve daylight penetration as well as allow the use of suspended lighting fixtures. A minimum height of 9 ft is recommended for ceiling fans such that the fan blades are at least 8 ft from the floor and 1 ft from the ceiling.

- For natural ventilation to function properly, solar gains and internal heat gains should be minimized. Use shading devices like overhangs, awnings, and fins to control solar gains.
- Provide windows that can be opened or shut in increments. This allows the occupants to vary the inlet and outlet areas according to seasonal variations.
- Ensure that vents and windows are accessible and easy to use. Avoid blocking windows with exterior objects such as shrubs and fences, but do not eliminate shading.
- Use features like overhangs, awning windows, eaves, and porches to protect the openings from rain. Awning windows work very well for cross ventilation because they provide more airflow than double hung windows (for the same glazed area) and also provide protection from rain. Casement windows provide maximum airflow in both perpendicular and oblique wind conditions, but also offer less rain protection than awning windows.
- The incoming air may be cooled through good site planning, landscaping, and planting strategies. If a water body is planned for the site, place it on the windward side to pre-cool the incoming air through evaporative cooling. Planting tall deciduous trees on the windward side will lower the temperature of the inflow and shade the openings.
- Locations of adjacent buildings may cause complex wind patterns. Wind tunnel testing may help determine flow patterns around buildings in urban areas.
- Consider using ceiling fans to improve comfort when winds are calm.
    - Use “Quiet Type” energy-efficient ceiling fan and motor assemblies.
    - A larger fan provides a greater range of airflow settings and ventilates a larger area at lower velocities, with less noise, and only slightly more power than similar smaller units. Use two 48 in. fans in classrooms (based on 30 ft x 32 ft classrooms). These will move air most effectively in a 4 ft to 6 ft radius, and somewhat less effectively for another 3 ft to 4 ft radius. At the level of seated occupants, this will achieve air speeds ranging from 50 fpm to 200 fpm. Beyond 30 fpm, every additional 15 fpm results in a perceived 1°F drop in temperature. The more blade surface, the more air it will catch.

  - Ceiling fans work best when the blades are 8 ft to 9 ft above the floor and 10 in. to 12 in. below the ceiling. Placing fans so the blades are closer than 8 in. to the ceiling can decrease the efficiency by 40%. Fans also require at least 18 in. of clearance between the blade tips and walls. Two types of mountings are available for ceiling fans—rod and hugger. In rod fans, the motor housing is suspended from the mounting bracket by a rod. With hugger fans, the motor housing is mounted directly to the ceiling box. Hugger fans are not as efficient as rod fans in the down motion, especially at higher speeds. The blades will starve themselves for air when they are too close to the ceiling.

  - Select a fan with at least a two-speed control for better regulation of air movement.

  - Fans should be on only when the space is occupied; otherwise the movement of the motor is also introducing some heat in the room without any cooling benefits. Remember that ceiling fans cool people, not spaces. Consider using an occupancy sensor in conjunction with an occupancy sensor for the lighting system.

- Exterior noise can defeat even the best natural ventilation design if occupants must close the openings to eliminate distractions. Therefore, a successful natural ventilation design also needs to consider the placement of openings relative to exterior noise sources.

- As noted in the earlier section “Air Conditioning Applicability,” designing for good natural ventilation is desirable even in buildings with air conditioning because it allows “mixed-mode” operation. However, the design details may be different for spaces that also include air conditioning. The most important issue is that natural ventilation openings (typically windows) be air tight when closed.

8.2 Resources

For guidelines on cross ventilation, stack ventilation, and ceiling fans see:

> *Hawaii Commercial Building Guidelines for Energy Efficiency.* 2003. Prepared by Architectural Energy Corporation for DBEDT. http://www.archenergy.com/library/general/hawaiigl/.*Field Guide for Energy Performance, Comfort, and Value in Hawaii Homes, Edition 1/0b,* Available from DBEDT. Chapter 11, “Airflow Around Buildings,” and Chapter 12, “Airflow in Buildings,” provide good provide recommendations for natural ventilation design.

9 Daylighting

Daylighting is an important feature of a high performance school. Research has shown daylighting can dramatically reduce energy costs and substantially improve student test scores. This section summarizes daylighting design principles and includes a list of resources for detailed information. Please see also High Performance Hawaii Classroom section of this guideline for some specific daylighting design examples.

9.1 Summary of Daylighting Principles

Daylighting strategies described in the *Hawaii Commercial Building Guidelines for Energy Efficiency* include the following:

- Provide uniform illumination using GOOD DAYLIGHT DESIGN
- Provide access to exterior views through VIEW WINDOWS
- Use CLERESTORIES for deeper daylight penetration
- Add LIGHTSHELVES TO CLERESTORIES to improve daylight distribution
- Balance daylight from window walls with WALL-WASH TOP-LIGHTING
- Provide even daylight with CENTRAL TOPLIGHTING
- Use PATTERNED TOPLIGHTING to provide even illumination across a large area
- Use LINEAR TOPLIGHTING to direct movement or provide visual orientation in a linear space
- Employ TUBULAR SKYLIGHTS for toplighting areas with deep roof cavities and for low-cost retrofits

The following principles, which are also discussed in *the Hawaii Commercial Building Guidelines for Energy Efficiency*, are fundamental elements of good daylighting design:

- Prevent direct beams of sunlight from penetrating the space
- Provide uniform illumination
- Avoid glare

- Provide methods of controlling daylight
- Integrate daylight with electric lighting
- Lay out the interior spaces so that they benefit from daylighting opportunities
- Optimize the aperture size
- Consider safety and security issues when designing daylighting apertures

9.2 Resources

Advanced Lighting Guidelines. White Salmon, OR: New Buildings Institute, 2001. Web site: www.newbuildings.org.

Ander, Gregg. *Daylighting Performance and Design*. NY: John Wiley & Sons, Inc., 1997.

Collaborative for High Performance Schools (CHPS), *Best Practices Manual, Volume 2, Design*, 2002, www.chps.net. (*Best Practices Manual, Volume 5, Commissioning 2005* to be published mid-2005)

Daylighting Initiative Case Studies and Project Reports. San Francisco: Pacific Gas & Electric Company, 1999. Web site: www.pge.com/pec/daylight.

Hawaii Commercial Building Guidelines for Energy Efficiency. 2003. Prepared by Architectural Energy Corporation for DBEDT. http://www.archenergy.com/library/general/hawaiigl/.

IESNA Lighting Handbook, 9th edition. NY: Illuminating Engineering Society of North America (IESNA), 2000. Web site: www.iesna.org.

SkyCalc. A Microsoft Excel-based spreadsheet used to determine the optimum skylighting strategy for a building. Available from www.energydesignresources.com.

Skylighting Guidelines. California: Energy Design Resources. Web site: www.energydesignresources.com.

10 Classroom Acoustics

There are three fundamental strategies to ensure a superior acoustical environment:

- Reduce sound reverberation time inside the classroom.
- Limit transmission of noise from outside the classroom.
- Minimize background noise from the building's HVAC system and other equipment.

Acoustics design standards for Hawaii are included in the *Education Specifications and Standards for Facilities*.

For more information about designing for superior acoustic in schools, see the following reference:

> Collaborative for High Performance Schools (CHPS), *Best Practices Manual, Volume 2, Design*, 2005. www.chps.net. (to be published mid-2005)

11 Additional Topics

The information in this section is covered in less detail than the proceeding guidelines, with references to existing guidelines for more information.

11.1 Construction and Demolition (C&D) Waste Management.

Resources:

- A Contractor's Waste Management Guide, Best Practices and Tools for Job Site Recycling and Waste Reduction in Hawaii. Prepared by O'Brien & Company for DBEDT. www.hawaii.gov/dbedt/ert/chc.
- Listing of Construction and Demolition Waste Management Facilities, Clean Hawaii Center, DBEDT. www.hawaii.gov/dbedt/ert/chc.
- Collaborative for High Performance Schools (CHPS) Best Practices Manual, Volume 2. www.chps.net

11.2 Stormwater Management

- Collaborative for High Performance Schools (CHPS) Best Practices Manual, Volume 2. www.chps.net
- International Erosion Control Association. Provides technical assistance and an annual Erosion Control Products and Services Directory. (800) 455 4322 or http://www.ieca.org/.
- Stream Corridor Restoration: Principles, Processes and Practices developed by 14 Federal Agencies. Available at http://www.usda.gov/streamrestoration/.
- Stormwater and Urban Runoff Seminars — Guide for Builders and Developers, NAHB, Edited by Susan Asmus, Washington DC, (800) 368 5242 x538 or http://www.nahb.com/.
- Stormwater Management for Construction Activities: Developing Pollution Prevention Plans and Best Management Practices: Summary Guidance. EPA#833 R 92 001, October 1992, U.S. Environmental Protection Agency Office of Wastewater Management, 401 M St. SW, Mail Code EN 336, Washington DC, 20460. (800) 245 6510, (202) 260 7786 or http://www.epa.gov/owm/sw/construction/.

- Storm Water Phase II Final Rule: Small Storm Water Program Overview. http:/www.epa.gov/npdes/pubs/fact1-0.pdf

11.3 Electric Lighting and Control Guidelines

The values below correspond to the recommendations in the IESNA Lighting Handbook, 9th Edition. While a lighting designer might identify more specific tasks and specific illumination to support those tasks, the listed values suit general requirements.

It is recommended that ASHRAE 90.1-1999/2001 be used as a basis for lighting designs. Although counties in Hawaii have not yet adopted this standard, it provides many energy saving and maintenance benefits over previous standards.

Table 20 — Recommended Average Maintained Values in Footcandles (fc).

Space	Illuminance (fc) For lux, multiply values by 10	Comments
Classrooms	40-50	See note.
Drafting, lab, shop	50	See note.
Corridors, stairways, washroom	10	Security needs may indicate 15 fc or more.
Library	30	See note; add task lighting for special tasks
Food preparation areas	50	See IESNA Lighting Handbook, 9th Edition, for more details.
Dining/cafeteria	10-30	10fc works for simple dining, but security may suggest more. Also, some tasks like self-serve may need task lighting for more illumination. Multipurpose spaces may need 30fc; fluorescent lighting with multi-level switching may work best.
Gymnasium	30-50-80	Elementary schools only need 30fc, but high school competition needs 50fc. 80fc is recommended for important high school interschool events. Fluorescent lighting with multi-level switches may work best.
Locker room	10	Security needs may indicate 20fc or more; some tasks need task lighting.

Note: All areas with computers (computer lab, drafting, art, etc.) need 30 fc or less. Use multi-level switches for fluorescent lighting, since some users prefer 15 fc or less, and task lighting as necessary for reading and other tasks that need more light.

There are several very good references available with lighting design recommendations.

- Advanced Lighting Guidelines. www.newbuildings.org

- Collaborative for High Performance Schools (CHPS) Best Practices Manual, Volume 2. www.chps.net
- *Hawaii Commercial Building Guidelines for Energy Efficiency.* 2003. Prepared by Architectural Energy Corporation for DBEDT. http://www.archenergy.com/library/general/hawaiigl/.

11.4 Enclosure and Insulation Guidelines

Energy efficient windows, window shading, and cool roof systems are covered in great detail in the following reference.

- *Hawaii Commercial Building Guidelines for Energy Efficiency.* 2003. Prepared by Architectural Energy Corporation for DBEDT. http://www.archenergy.com/library/general/hawaiigl/.

12 High Performance Hawaii Classroom

12.1 Summary

A high performance classroom benefits most from good daylight design. Good daylight design incorporates adequate illumination, uniform distribution and reduced glare. While shading is important to reduce peak loads and energy consumption, it has a bigger influence in ensuring that full daylight benefits are captured, because a lack of shades increases glare and direct solar penetration that compromise visual comfort. Location and distribution of windows and glazing choice with high light transmission and relatively low solar transmission also affects daylight design. In addition, efficient electric lighting design integrated with dimming daylight controls and occupancy sensors, can save a significant amount of energy and shave some peak load. The other big cost saver is ensuring that the fenestration design is integrated to facilitate natural ventilation. Even without natural ventilation, if all the recommended energy efficiency measures are implemented, one can expect savings of $ 1.00/ft^2 as shown in Figure 9.

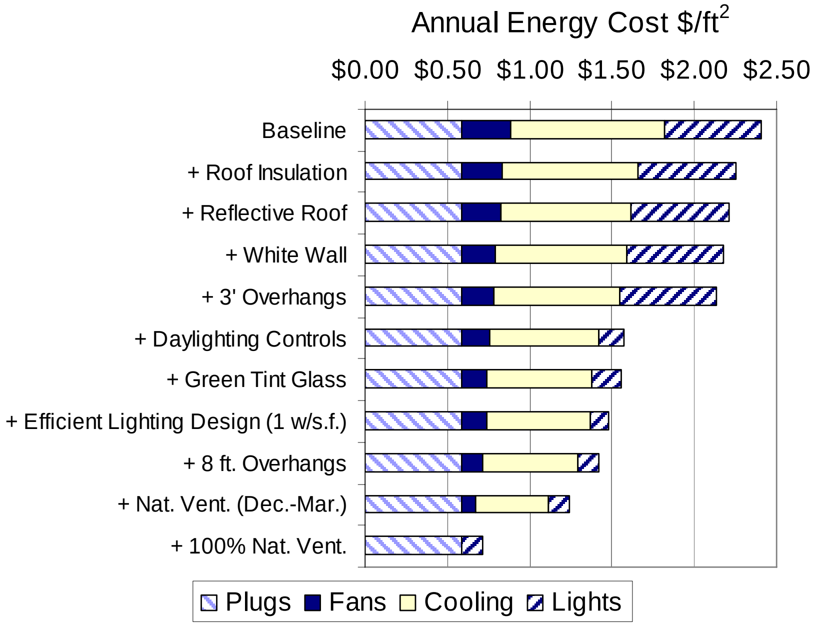


Figure 9 — Impact of Energy Efficiency Measures on Utility Cost

12.2 Introduction

Compared to large commercial buildings, classrooms are subject to proportionally greater envelope and occupant internal loads. Figure 10 shows that the energy consumption is almost evenly distributed between lights and plugs, and HVAC energy. Space loads are almost evenly distributed between internal loads due to occupants, lights and plugs, and external loads from envelope as shown in Figure 11. Hence, energy efficient guidelines related to envelope are as important to lighting and HVAC measures. However, in case of portable classrooms, heat gains through the external sources is slightly higher than in case of the classroom mainly because all walls are considered exposed in the case of portable classrooms.

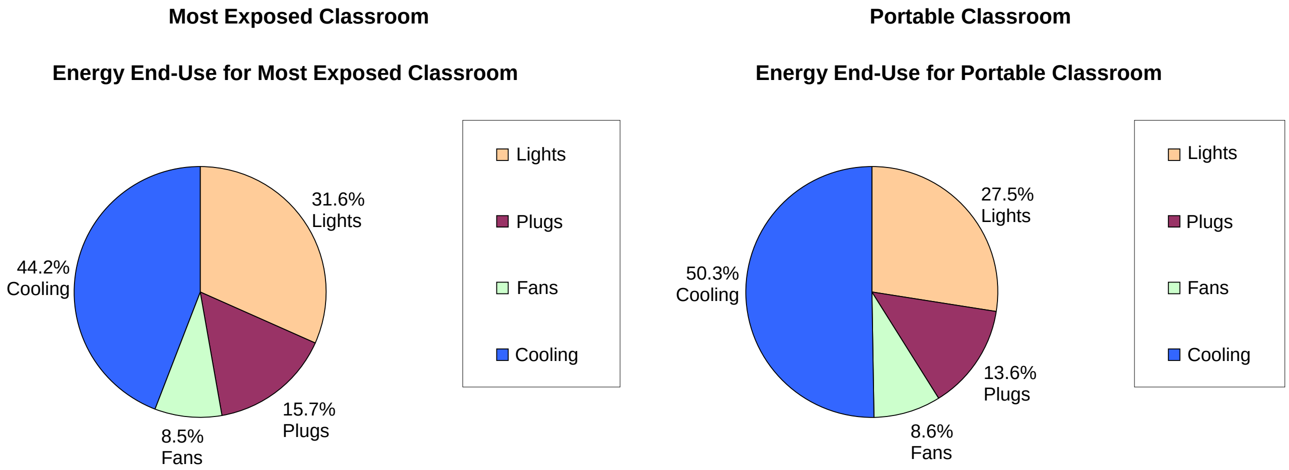


Figure 10 — Energy Distribution by End-Use

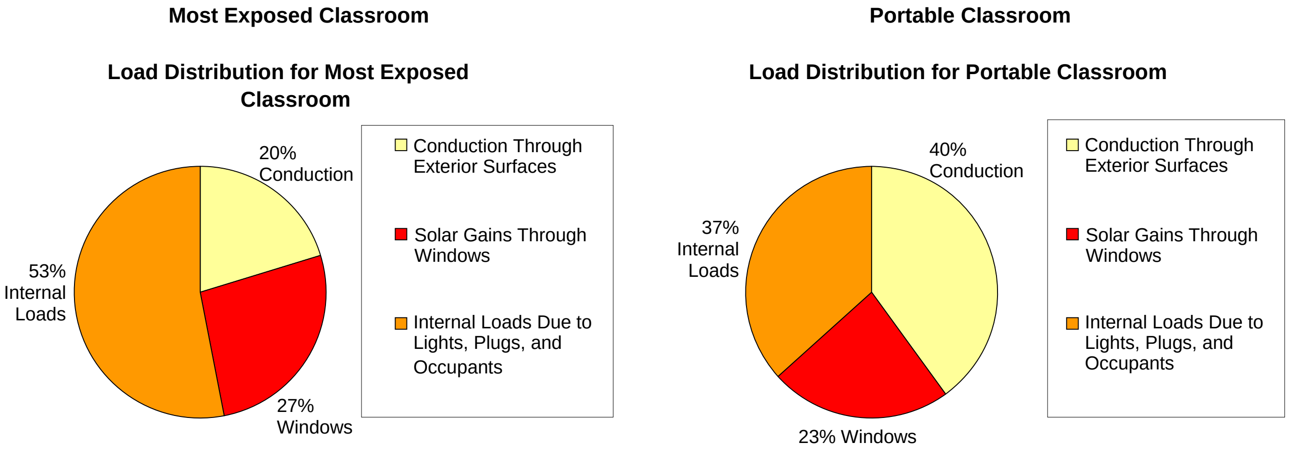


Figure 11 — Distribution of Loads Through External and Internal Sources in a Typical Classroom

The primary purpose of this study was to provide a package of best practices for a few frequently occurring classroom designs, which included:

- Least exposed classroom: A first floor classroom with only one wall exposed.

- Most exposed classroom: A top floor classroom with at least 2 exposed walls and exposed roof.
- Portable classroom: A portable classroom with a raised floor.

However, based on the energy simulation results, the relative impact of various energy efficiency measures that were examined were similar for all three cases. Hence, the results that support the guidelines have not been distinguished into three separate categories.

The two alternative packages that have been identified are:

- Best Practice: This represents the ideal combination of measures based on energy savings, low life-cycle cost, environmental and health benefits.
- Alternative Package: This includes trade-offs that may be substituted when it is not possible to implement the best practice classroom.

In general, the most critical strategy for classrooms in Hawaii is to reduce solar gains and provide adequate daylighting. Most of the external heat gain is through the roof and window. While windows can be shaded to prevent solar heat gains, roofs should to be light-colored in order to keep solar gains off by reflecting most of it. These are fairly simple, low-maintenance and very effective strategies.

Once the external gains have been controlled, the total air-conditioning load can be further reduced by using an efficient lighting design, occupancy sensors and daylight controls to reduce lighting energy as well as heat added to the space from lights when they are on.

Hawaii is blessed with very moderate climatic conditions, and reducing external and internal gains can extend the hours when comfortable indoor temperatures can be attained by natural ventilation.

Table 21 — Summary of "Best Practice" and "Alternative" Classroom Characteristics

	Best Practice	**Alternative**
Orientation	The ideal orientation for windows is facing north or south, as these orientations are least exposed to direct solar exposure. Any direct solar penetration on the south side can be controlled quite easily with relatively short overhangs (ideally as deep as the window is high). This orientation also facilitates taking advantage of prevalent trade winds from a northerly direction for natural ventilation.	If the ideal orientation is not possible, try to orient windows towards southeast and northwest. If this is not possible, due to site/design constraints, use evergreen vegetation with dense foliage and large spread to shade windows on the east and west side. This will not only reduce solar gains but also provide a "relief" through the view windows.
Roof	A light-colored roof with a radiant barrier is the best solution. Use a sloped roof design to facilitate drainage and add ceiling, and use the attic space to allow use of radiant barrier insulation.	Adding an equivalent of about R-13 will make up for not having a radiant barrier, but can be more expensive. Alternately, adding equivalent of an inch of rigid insulation will substitute for not having a light-colored roof.
Ceiling	Use light-colored ceiling located at least 10' height. The light color enhances daylight distribution. The high ceiling height facilitates better daylight distribution by allowing at least 2' of space to accommodate daylight windows above view windows, and allows for pendant mounted lighting.	Even if 10' high ceilings cannot be achieved, light color is still imperative to good daylight distribution. Retain at least 1'-6" to accommodate daylight windows even if this means compromising the height of the view windows.
Wall	Wall color has less impact on heat gains compared to roof. Shading is the most effective way of reducing heat gains. In case of mass walls, adding insulation is not as beneficial as making the walls light colored. Concrete walls have additional ventilation and acoustic benefits compared to light framed walls.	If walls are not shaded, light colored walls are more beneficial than adding insulation. However, insulation may be an appropriate strategy for framed walls if it cannot be ensured that the reflective wall color will be maintained for the life of the building.
Fenestration	The most important strategy is to shade windows. Windows on the south or north side can be shaded very easily. Shading also helps in controlling glare which can interfere with good daylight distribution. Laminated glazing with high performance tint is a cost-effective choice for daylighting benefits as well as security and protection against extremely windy conditions Ideally, separate the glazing into view windows and daylight windows. Minimize glazing area for view windows and use tinted glass to avoid glare. Locate view windows flush to side walls for surface illumination; operable blinds for privacy optional. Locate daylight windows flush to ceiling and side walls to illuminate interior surfaces evenly. Use high light transmission glass; approximately 40 ft^2 on either side of classroom. Locate the walkway cover just below the clerestory, and paint it white or a very light-color to bounce daylight further into the space. Where this is not possible, such as in the lower floor on the walkway side, increase the depth of the clerestories to 2'-6". Locating windows on opposite walls balances daylight on both vertical and horizontal planes. The teaching wall should be located on an internal wall to take advantage of this balanced distribution.	Use high performance glass (such as high performance tint low-e) if windows are not shaded, to reduce solar gains without compromising available daylight. Glare can be controlled only via shading devices – such as interior blinds, or light shelves. Tinted glazing can also reduce glare but not as much as with good shading design. If adequate ceiling height is not available to locate adequate area of daylight and view windows, compromise the height of view windows in favor of larger daylight windows. Use skylights equivalent to 3% of roof area to balance daylight distribution in the space, if it's not possible to put daylight windows on two sides.

	Best Practice	Alternative
Lighting	Use rows of suspended pendant fixtures with second generation T-8 lamps and high efficiency electronic ballasts, so that lighting rows are parallel to daylight source. Install daylight sensors and dual technology occupancy sensors.	Use recessed troffers in place of suspended fixtures.
Natural Ventilation	Use approximately 40 ft^2 ventilation area per each opposing wall at occupant level. Locate inlets close to the floor on north side for prevailing winds and simpler shading. They should seal tightly for warm season. Casement, awning, or hopper-type windows are appropriate. Lower portion of inlet can be left open for night cooling; fixed exterior louvers for the inlet prevents rain intrusion and provides security. The inlet location affects airflow patterns far more significantly than outlet location. Use operable clerestories as outlets.	If vents cannot be located close to the floor, use bottom half of view windows on north side as inlet and top half of view windows on opposite wall as outlet. If openings cannot be located on opposite walls, locate inlets on one wall and outlets in the adjacent wall as far away from the inlet as possible.

12.2.1 Orientation

Description

Orientation is one of the first things that needs to be addressed early in the design phase. While the decision related to orientation is influenced by many factors, such as program and site constraints, it is critical to optimize it in early stages of design, as it significantly impacts envelope loads and daylighting opportunities. Especially, in classrooms where envelope loads constitute over 50% of the total air-conditioning loads, ideal orientation is the first step towards reducing air-conditioning loads, due to solar gains and opening up opportunities for daylight and related lighting energy savings.

Results

The impact of orientation is two-fold. While the energy use may not vary significantly based on orientation, the decision has a significant impact on peak loads. The following graphs illustrate the impact of orientation on utility cost as well as peak loads. Optimizing the orientation can reduce AC size and hence, reduce HVAC equipment cost. However, if the roof is uninsulated and not protected from solar gains, orientation has very little impact on over all cooling loads because majority of the cooling load is dominated by the roof.

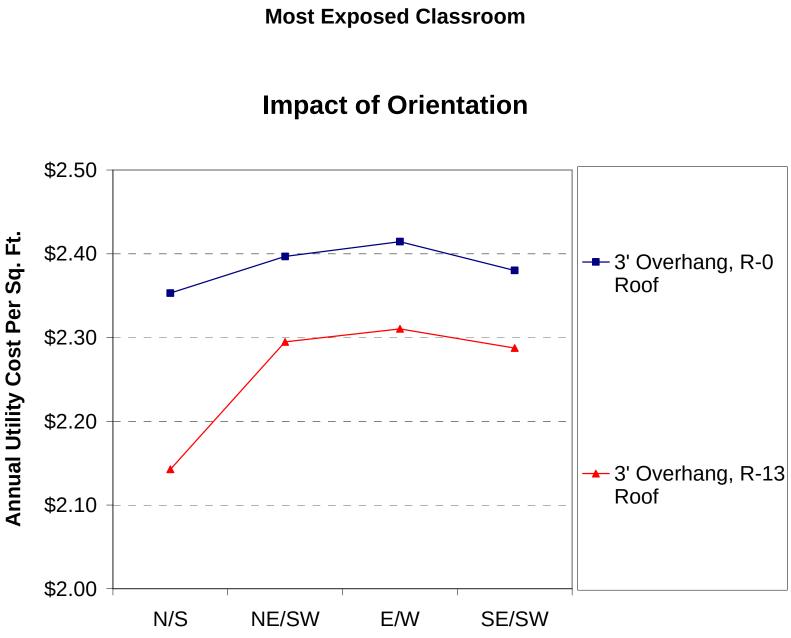


Figure 12 — Impact of Orientation on Utility Cost

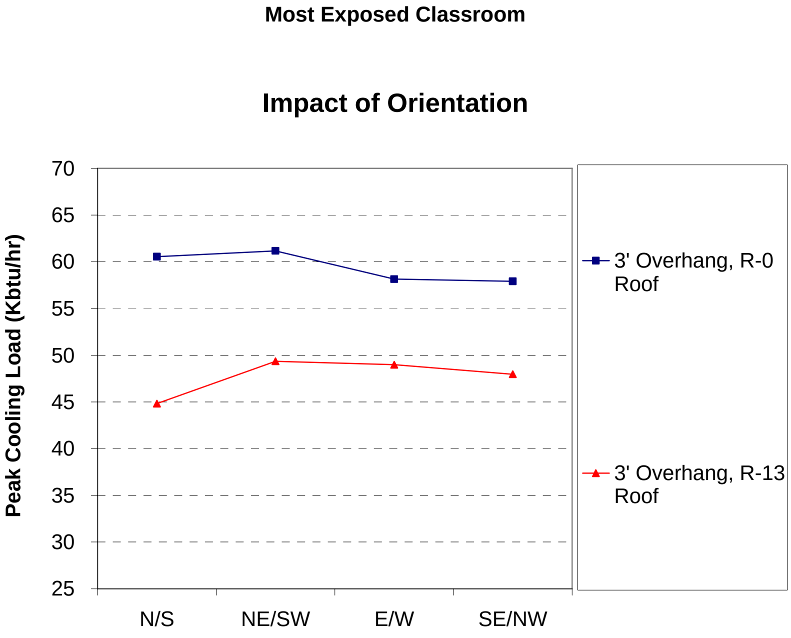
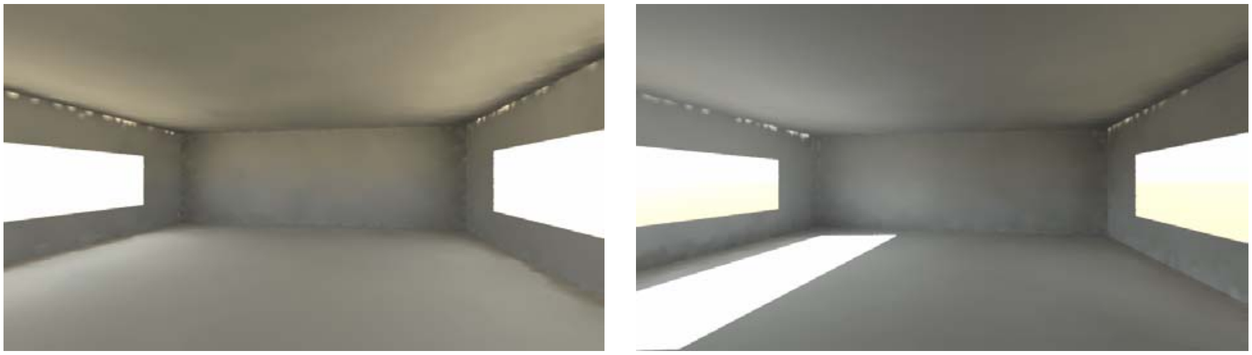


Figure 13 — Impact of Orientation on Peak Load

The other more significant impact of orientation is when daylight design is integrated with the classroom. In order to take advantage of available natural light and save lighting energy, a uniform, glare-free distribution has to be ensured within the space. The following graphics show how a west-facing room is subject to glare during late afternoon hours even with an overhang.



South Facing Classroom **West Facing Classroom**

Figure 14 — Impact of Orientation on Daylight

Economic Impact

Orientation for fenestration is a design choice and a result of site and programmatic constraints, and there is no incremental cost associated with this recommendation. However, there are some utility cost benefits, and slightly lower initial cost associated with smaller equipment cost when orientation is optimized. However, this is true only is roof is insulated, which is addressed in the next portion of this study.

Recommendation

In classrooms (including portables) the ideal orientation is to have windows facing north and/or south. The next best choice in case of site constraints would be to have the windows facing southeast, northeast or northwest. Avoid windows facing west and south west directions.

Maintenance and Operation

None.

12.2.2 Roof Design

Description

The roof is subject to high solar loads, and unlike walls, they are typically unshaded. The best way to reduce heat gains through the roof is through careful material choices. Various materials can impact heat transfer through roofs – color, insulation and radiant barrier.

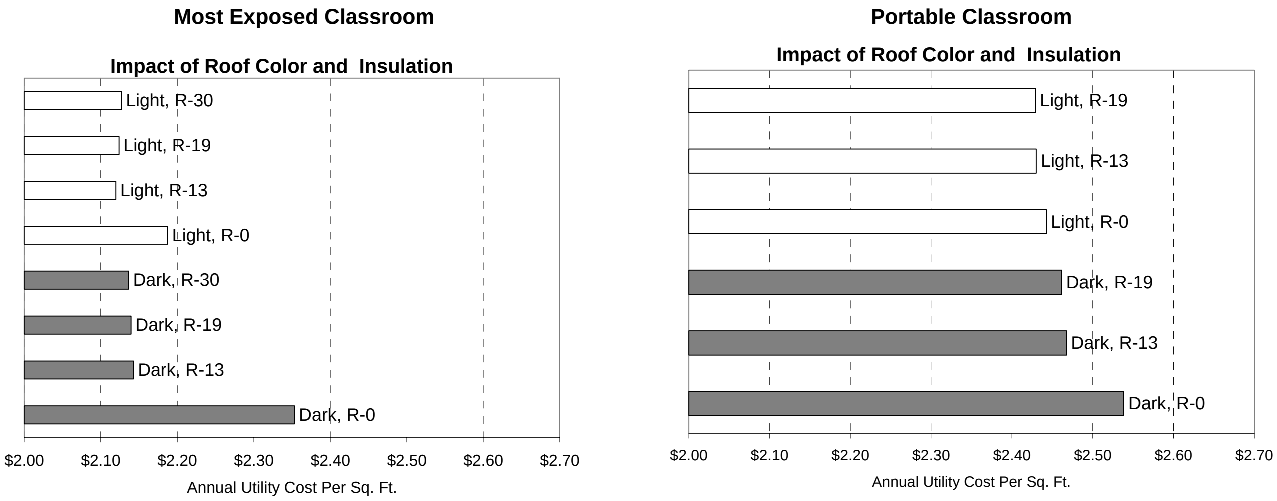
A “cool roof” is light-colored, non-metallic material that acts as the finishing layer on the roof. It could be a single-ply membrane or a liquid coating, but should be ENERGY STAR qualified, and have an initial reflectance greater than 0.65 and an emittance greater than 0.8.

A radiant barrier is a material with a shiny metallic finish, and having a low emittance, such as aluminum foil. It should be installed in ceilings of attic spaces to be effective. The most inexpensive method is to use plywood or composition board with a film that is pre-applied to the board. Alternately, a more expensive and more effective method is to drape foil over the rafters before the sheathing is installed. Radiant barriers work by reducing heat gains from the warm ceiling to the cooler attic floor.

The Hawaii Energy Code takes into account all these factors and incorporates them in calculating the Roof Heat Gain Factor, which is required to be lower than 0.05.

Results

Figure 15 shows that in cooling dominated climates such as in Hawaii, more insulation doesn't necessarily translate into proportionately higher benefits. While roof color has a much bigger impact when there is no insulation, Figure 15 also shows that it is relatively more energy efficient to have some insulation (R-13) in combination with a light-colored roof. In addition, adding insulation also significantly reduces peak loads as shown in Figure 16, though more so in case of the site built classroom than portable classroom as there is a greater contribution of loads in the portable classroom due to uninsulated walls in the portable baseline as opposed to thermal mass walls in the site built-baseline. Previous studies done for commercial structures in Hawaii, show that installing a radiant barrier has a similar impact on heat transfer through the roof as an equivalent of R-13 insulation.



Most Exposed Classroom

Impact of Roof Color and Insulation

Portable Classroom

Impact of Roof Color and Insulation

Figure 15 — Impact of Roof Color and Insulation on Utility Cost

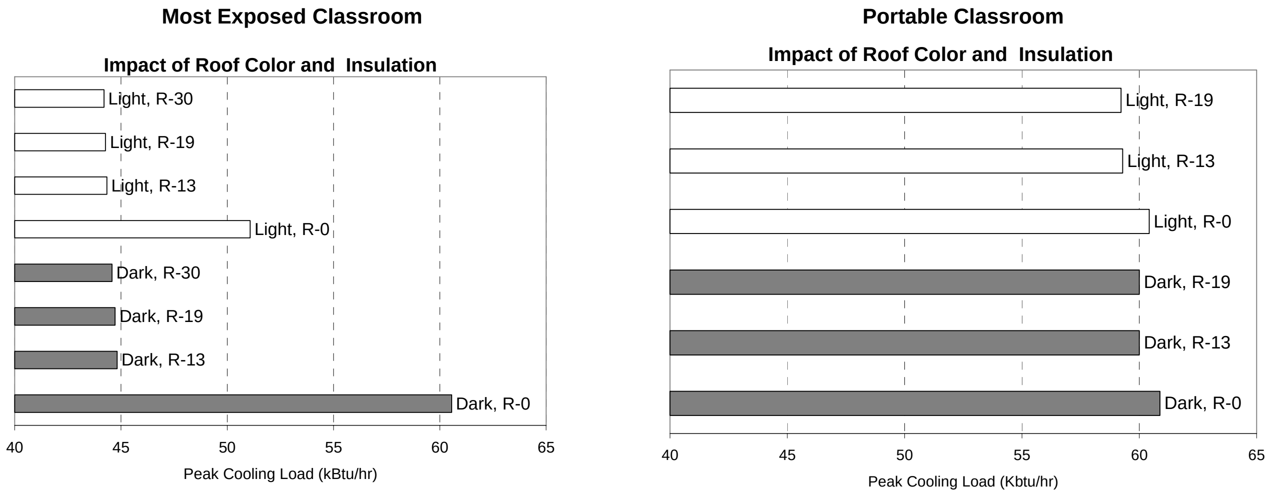


Figure 16 — Impact of Roof Color and Insulation on Peak Loads

Economic Impact

Rigid insulation installed over structural decks is more expensive than installing batt insulation in framed cavities, due to construction details and added insulation cost. The average cost of insulation is varies from \$ 0.25/ ft^2 to \$ 2.00/ ft^2 depending on level of insulation. Typically, R-13 batt insulation costs about \$ 0.60/ ft^2, whereas equivalent rigid insulation costs almost twice as much. The cost of installing a radiant barrier is only 0.15/ft^2 to \$ 0.25/ft^2, with similar thermal benefits.

While the incremental cost for installing a cool roof is only \$ 0.10/ft^2 to \$ 0.20/ft^2 when it is a color choice, such as in case of a single-ply membrane roof design or painted metal roof, it can be as high as \$ 2.00/ /ft^2 if a built-up roof is part of the base design. The additional cost for installing equivalent insulation (R-5) varies between \$ 0.50/ft^2 to \$ 1.00/ft^2. However, a potentially longer roof life associated with a cool roof due to less thermal stresses is another economic benefit to be considered.

Recommendation

Figure 15 and Figure 16 indicate that combining R-13 insulation with a light-colored roof have the lowest energy cost, and peak demand. Thus, the optimum choice would be to use a light-colored roof, with a radiant barrier[6]. Substitute a radiant barrier with equivalent of R-13 insulation, if attic space is not available. If a light colored roof is not preferred due to aesthetic reasons, or initial incremental cost, use the equivalent of one inch of foam board (R-5) to substitute for the cool roof.

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[6] As mentioned earlier, a radiant barrier is equivalent to about R-13 insulation in its thermal impact.

Maintenance and Operation

Insulation materials themselves require no maintenance, but should be protected from moisture at all times. Moisture reduces thermal performance of the material as well as encourages mildew growth that can cause IAQ problems.

Cool roofs need to be cleaned each year to remove dirt accumulated over time that reduces the reflective properties and performance of the roof overtime. Manufacturer's instructions should be followed as cleaning by high-pressure spray may not be suitable for all cool-roof membranes and could damage the membrane. Liquid-applied coatings may need to be refinished every 5 years or so.

Radiant barriers don't require any maintenance unless they are damaged due to intrusive work in the attic. In case of damage, the damaged section will need to be replaced.

12.2.3 Exterior Wall Design

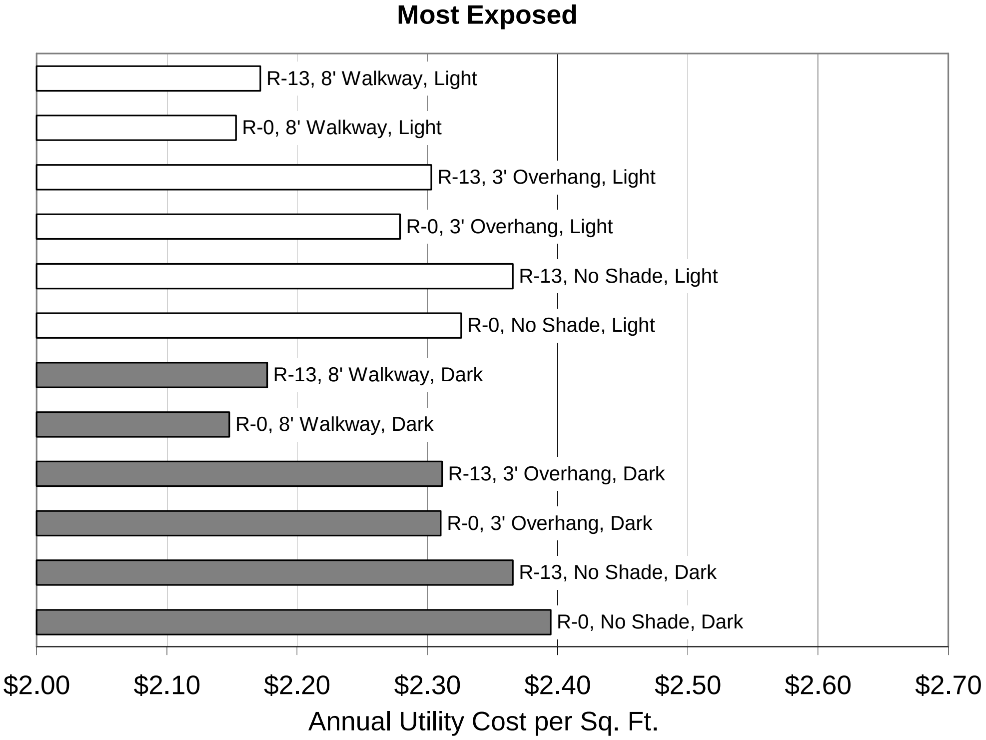
Description

The construction of exterior walls not only affects energy consumption and peak loads, but also affects thermal and aural comfort. Solar loads coming in through the walls are affected by color, orientation, shading and insulation. As discussed earlier, orientation is the first step to reducing heat gains through walls and windows.

Results

Shading has a much bigger impact on reducing energy consumption than adding insulation. Similarly, color has a bigger impact on energy savings than insulation, but the benefit due to color reduces as the walls get more shaded. The biggest savings occur when an 8' walkway is added on the exterior to shade the walls. However, in cases where the wall has significant thermal mass, insulation added on the interior wall is actually detrimental to the performance. This is because the interior insulation compromises the thermal mass effect in the CMU walls from the interior heat gains, so daytime loads from all other sources "build up" faster when the walls are insulated. In addition, without any fan, night time operation or economizers, the heat loss from this heat build-up at night is impeded by the insulation.

Most Exposed Classroom



Portable Classroom

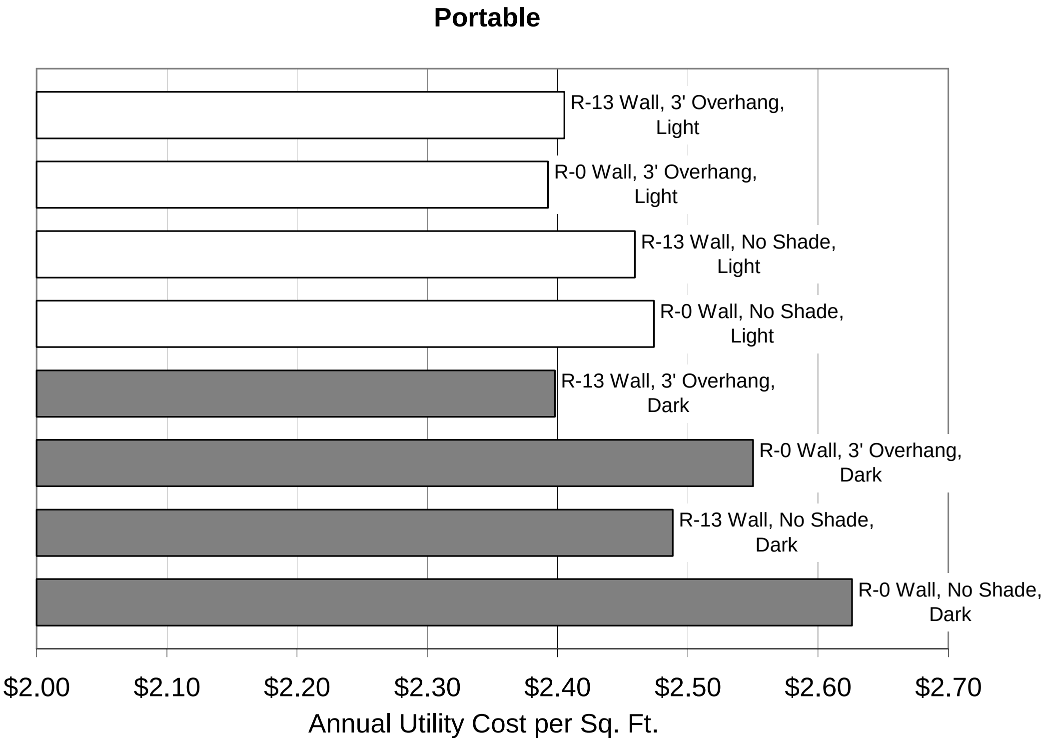
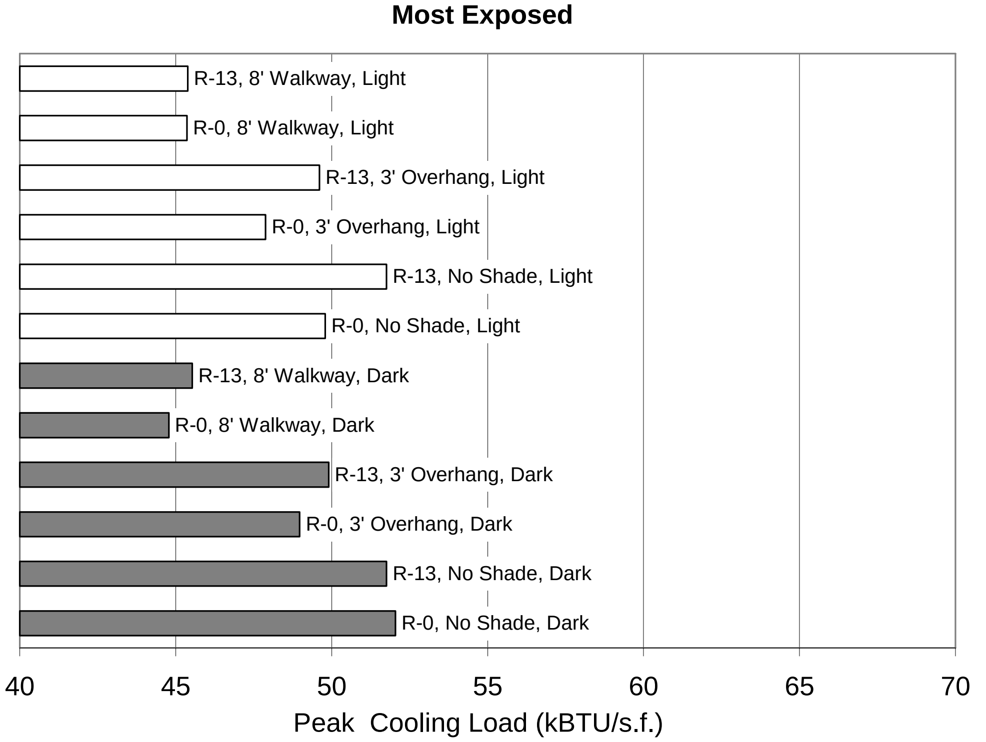


Figure 17 — Impact of Wall Color and Insulation on Utility Cost

Most Exposed Classroom



Portable Classroom

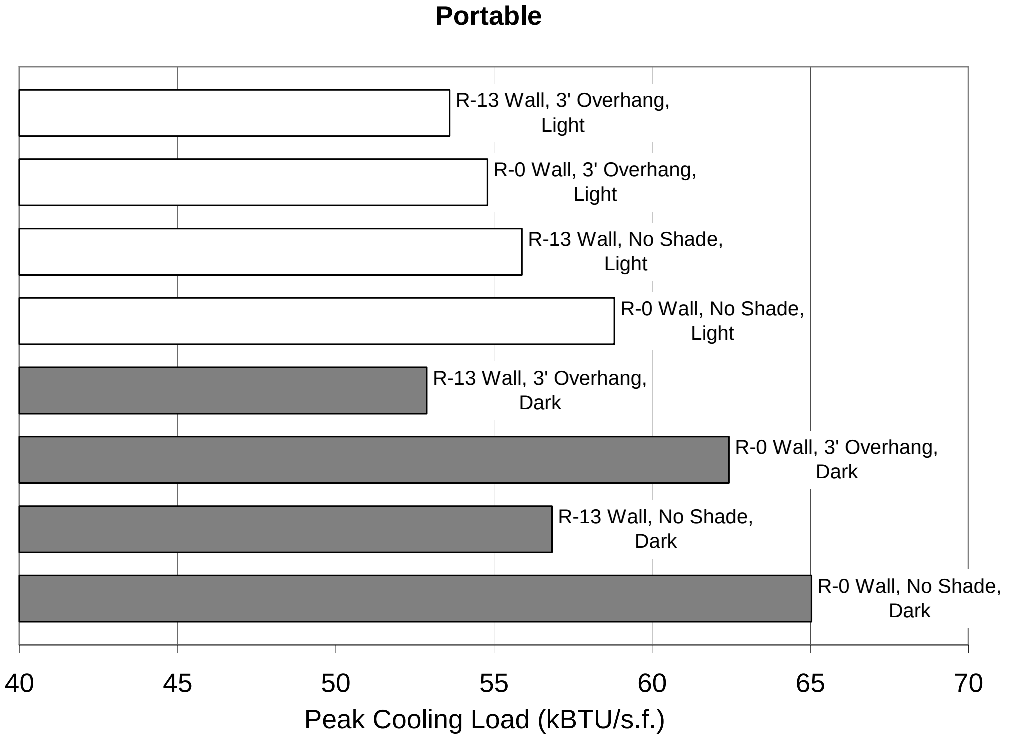


Figure 18 — Impact of Wall Color and Insulation on Peak Loads

Economic Analysis

Adding an external walkway does not necessarily incur any incremental cost as this is a design decision pertaining to locating of circulation. Similarly, a light-colored wall does not cost any more than a dark colored wall, as it is a only a paint color choice (it may have higher maintenance cost). However, adding wall insulation can cost anywhere between \$ 0.60 /ft^2 for batt insulation.

Recommendation

The best option is to design the classroom building in such as way such that the circulation is on the exterior of the classroom protected by a shade (assumed 8' in depth). In that case, the color choice or insulation has very little bearing on cooling loads. The next best alternative (if a walkway is not possible) is to have a 3' foot projection at the roof level, and have a white-colored wall [7]without any insulation. Light-color may be traded for insulation, but insulation will not necessarily perform better and will cost more in terms of initial investment.

Operation and Maintenance

Light wall color will require periodic repainting and may be more likely to attract graffiti. Overhang design helps in protecting the wall from rains and possible degradation of color due to dirt and mildew growth.

12.2.4 Fenestration Design

Description

Windows are typically the largest contributor to solar loads through the envelope. Solar loads coming in through the windows are affected by orientation, shading and glazing type. The first strategy in fenestration design is to shade windows. The second strategy is to choose the right glazing type to reduce solar gains.

Results

As in case of walls, the best strategy is to shade the windows. Once the windows are well shaded, the glazing choice has less of an impact on energy consumption. Similarly, if the windows are adequately shaded, the glazing type has relatively lower impact on peak loads. However, with or without overhangs, spectrally-selective laminated glazing is the optimal

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[7] Light-colored walls will have slightly lower benefit than a white wall.

solution to reducing solar gains further. Laminated glass also offers penetration resistance for better security and hurricane safety.

See Chapter 5, Energy-Efficient Windows, in *Hawaii Commercial Building Guidelines for Energy Efficiency*, for detailed design guidelines.

Economic Impact

See Chapter 5, Energy-Efficient Windows, in *Hawaii Commercial Building Guidelines for Energy Efficiency*, for detailed economic impact.

Recommendation

Integrating the walkway design with single laminated glazing is the best choice. A deep shade such as the 8' walkway would also benefit daylight design.

Operation and Maintenance

Choice of glazing does not affect maintenance cost. Overhangs don't require any significant maintenance.

12.2.5 Daylight Design

Description

Good daylight design is integral to the success of a high performance classroom. It achieves the maximum energy savings, cuts down on peak load significantly, and increases productivity and health benefits by providing a visually comforting environment.

Good daylight should provide adequate illumination, be evenly distributed and avoid glare. All these factors are influenced by glazed area, glazing choice and location of fenestration.

Results

The following results show that the optimal window area for good daylight design is about 30% of the wall area in which the window is located. Ideally, optimize skylight area to 3%-5% of the floor area to be daylit.

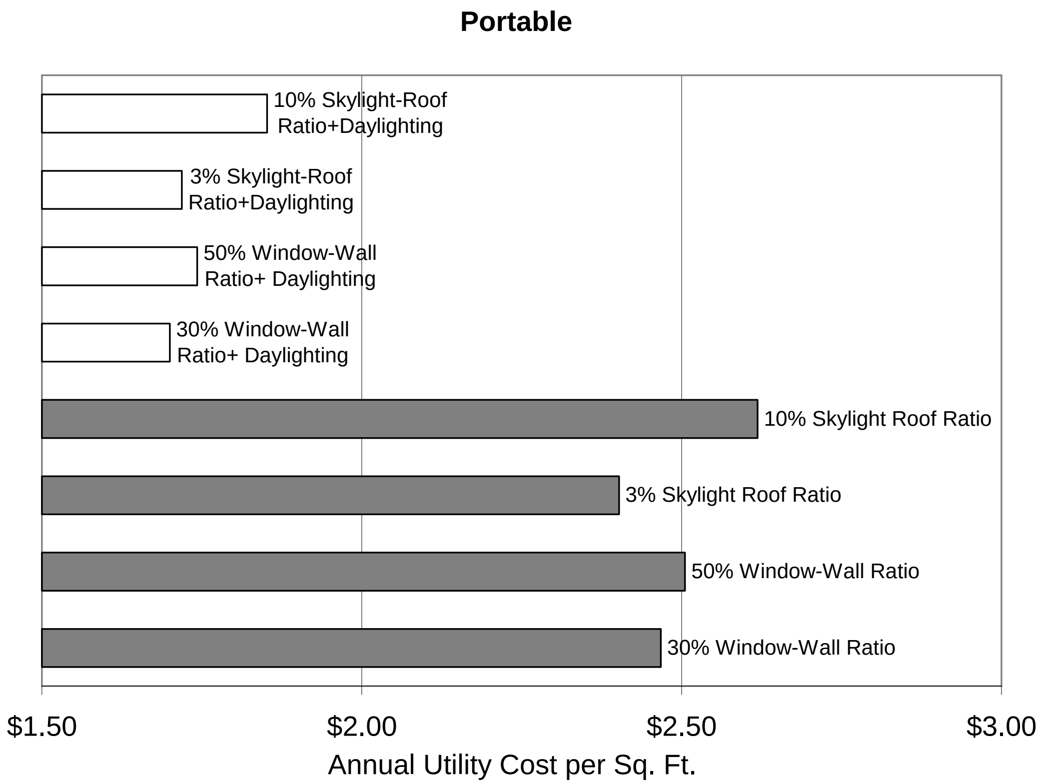

Figure 19 — Impact of Daylighting on Utility Cost

Recommendation

Based on these results and additional analysis done for other classrooms, daylight has a big impact on energy savings. Ideally locate windows on opposite sides of the wall to achieve uniform distribution. Distinguish between daylight windows and view windows. Locate daylight windows close to the ceiling and walls, to enhance daylight penetration. If windows can't be located on two opposite walls, balance daylight distribution by locating skylights on the side of the room without any daylight windows. The optimum skylight area should be somewhere between 3%-5% of the floor area to be daylit by skylights.

The following figures show that even though the glazed area is not greater in the better daylit classroom, location and distribution of windows are critical in contributing to higher and more uniform illumination.

See section on daylight design guidelines for summary of design recommendations.

In addition, see Collaborative for High Performance School, Best Practices Manual, 2002 for additional details. (www.chps.net), as well as Chapter 3 on daylighting in Hawaii Commercial Building Guidelines for Energy Efficiency.

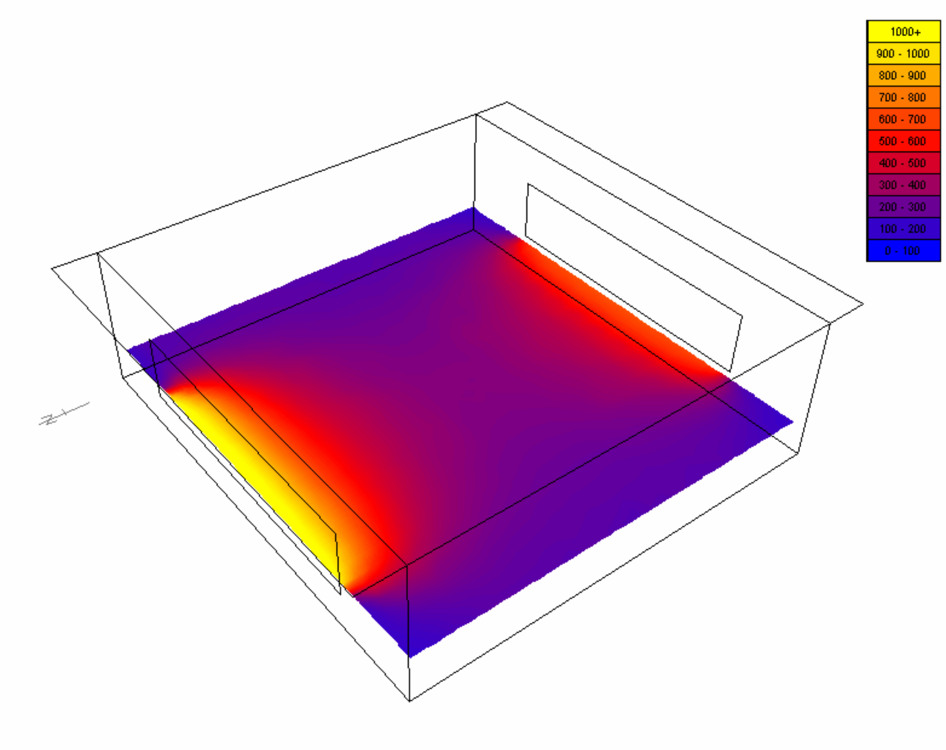

Figure 20 — Daylight Distribution from Centrally Located View Windows

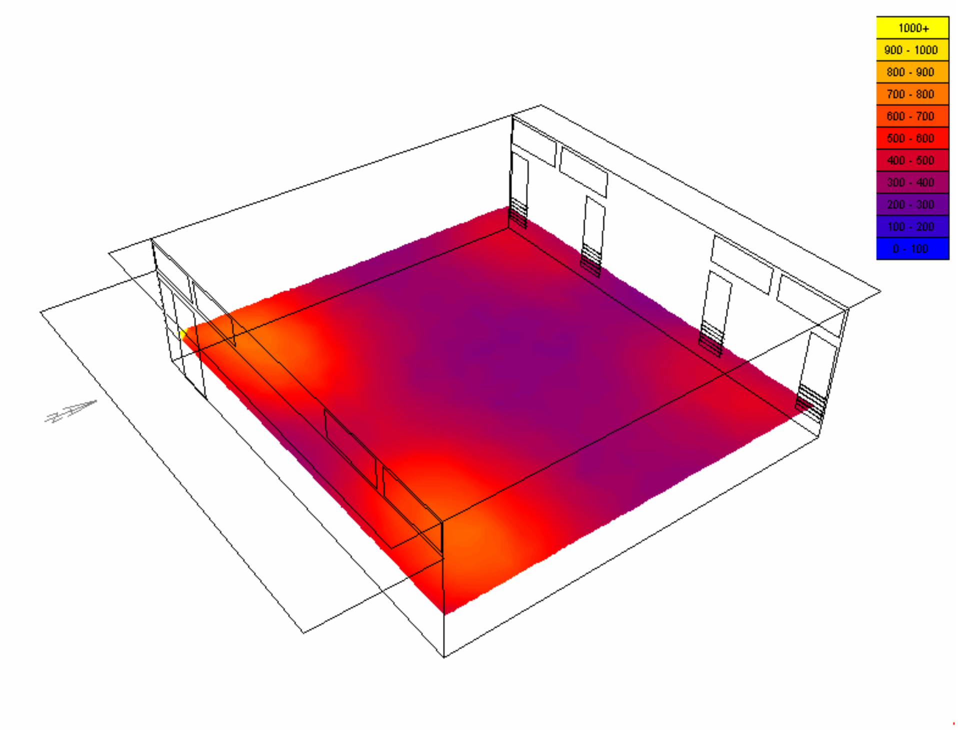

Figure 21 — Enhanced Daylight Distribution from Evenly Distributed Clerestories and View Windows

Operation and Maintenance

Light shelves need to be cleaned periodically to maintain optimal performance.

12.2.6 Electric Lighting Design

Description

Electric lighting is one of the major energy consumers in schools. Efficient design along with daylight controls can save about 75% or more in lighting energy when properly implemented. Adequate and uniform illumination is necessary for visual comfort and ability to carry out the visual tasks, prevalent in a classroom environment. In addition, low electric lighting use reduces heat contributed to the space and saves air conditioning energy, as well as increases the potential for natural ventilation.

Results

Reducing lighting power from 1.6 watts/ft^2 down to 1.0 watts/ft^2, not only saves lighting energy but also reduces cooling energy marginally (2%) and peak load by 5%. However, greater savings can be expected if successful daylight design is not in place. Thus, this measure is even more critical if good daylight design cannot be implemented.

Recommendation

To achieve uniform lighting distribution, the best option is to have suspended lighting systems with 75% - 85% luminaire efficiency using some amount of light reflected upward towards the ceiling. Indirect fixtures minimize bright spots but require a white ceiling (or some very light colored) ceilings and upper walls, and at least 9’-6” high ceilings, with minimum of 18” suspension height. Direct-indirect fixtures distribute light almost evenly between upward and downward directions. In spaces with low ceiling heights, use surface or recessed fluorescent troffers having at least 78% luminaire efficiency.

Use T-8 lamps with electronic ballasts to achieve a lighting power density of 0.9 W/ft^2 – 1.1 W/ft^2, and maintain 40-50 footcandles at desk height.

Integrate lighting design with daylight sensors and dimming or stepped ballasts. Use dual technology occupancy sensors to turn off lights when the space is unoccupied.

See *Collaborative for High Performance School, Best Practices Manual, 2002* for additional details. (www.chps.net), as well as Chapter 4, Electric Lighting and Controls, in *Hawaii Commercial Building Guidelines for Energy Efficiency*.

Economic Impact

In general, efficient lamps with good lighting design is one of the most-cost effective measures as not only does it save lighting energy, it also reduces peak loads by reducing the amount of heat emitted to the space when lights are on.

Operation and Maintenance Issues

There are no special maintenance issues. Lamps need to be replaced at approximately 12,000 to 16,000 hours of operation, as with all fluorescent systems. Luminaires need to be cleaned annually, to maintain light output, which can diminish over time due to dust accumulation. Lensed luminaires may be occasionally abused, but lens replacement is relatively inexpensive.

12.2.7 Natural Ventilation

Description

Natural ventilation or ventilation due to ceiling fans is a good solution for Hawaii, as during the winter months temperatures stay largely within comfort zones. If passive means are adopted to reduce loads along with ceiling fans, the classroom can potentially be operated without air-conditioning throughout the year without compromising thermal comfort. Thermal mass and adequate shading are key to extending the season when natural ventilation can meet comfort requirements.

Results

Natural ventilation saves about \$0.50/ ft^2, assuming that the classroom can be ventilated for at least 4 months in the winter with the recommended shading and daylight design.

Recommendation

See section on natural ventilation guidelines for summary of design recommendations.

In addition, see *Collaborative for High Performance School, Best Practices Manual, 2002* for additional details. (www.chps.net), as well as Chapter 2 on natural ventilation in *Hawaii Commercial Building Guidelines for Energy Efficiency.*

Economic Impact

Natural ventilation has no incremental cost as it is only a matter of locating an optimum amount of operable window area in favorable locations.

Operation and Maintenance Issues

There are no special maintenance issues.

12.3 Assumptions

Scenario #1: Least Exposed Classroom

This is a first floor classroom with only one wall exposed to outdoor conditions. The dimensions are 32 ft by 30 ft with a ten foot ceiling height. The construction is concrete masonry, with slab on grade floor, concrete ceiling, and metal-framed partition walls separating adjacent classrooms. Window area is 96 ft^2, with single-pane clear glass and a 3 ft overhang. Lighting is recessed or surface-mounted linear fluorescent fixtures with installed power of 1.6 W/ft^2. The room is air conditioned and maintained at 75°F during school hours.

Scenario #2: Most Exposed Classroom

This scenario is an upper floor classroom with two opposite walls exposed to exterior conditions. The dimensions and constructions are the same as in scenario #1, with the addition of an uninsulated concrete roof and an additional 80 ft^2 of window area on the second exterior wall.

Scenario #3: Portable Classroom

The portable classroom has all 4 walls and roof exposed, and consists of a wood-framed structure with no insulation. Window area and design is assumed the same as the most exposed case.