ADAPTATION TOWARD A SUSTAINABLE BUILT ENVIRONMENT:
A Technical Potential and Quantification of Benefit for Existing Building Deep Energy Retrofits in a Subtropic Climate

Frank Alsup
May 10th, 2013

Doctorate Project : 100% Document
Submitted towards the fulfillment of the requirements for the Doctor of Architecture Degree.

School of Architecture
University of Hawaii at Manoa

Spring 2013

Committee
Stephen Meder, ArchD - Chair
Jim Maskrey, MEP, MBA
Robyn A. Vettraino, LEED AP
Manfred J. Zapka, PhD,PE,LEED AP,CEM,CBE

Abstract

The issues surrounding energy consumption in our existing building stock is proving to be a key component in the move toward a truly sustainable built environment. Best practice energy levels today are much lower than they have been in the past meaning that the buildings we are currently occupying are using much more than they need to be. It is clear that the majority of these structures will remain in operation through 2030 and even 2050. In order to limit overall energy consumption for the foreseeable future, our societies will need to focus on existing building retrofits based on finding the minimum consumptions possible.

Methods for attaining deep energy retrofits can be applied to a wide variety of climates and building typologies. Measures utilized to realize results will vary by climate, building function, building use, and other site specific variables. This project focuses on developing a methodology and set of criteria for determining approaches to deep energy retrofits for office space in the Hawaiian climate. The method generated focuses on a passive first approach in order to pursue the deepest savings - otherwise known as a technical potential energy solution.

The method is then applied to a specific property in Honolulu to display its potential energy consumption and economic benefits. Best practice levels were researched and applied to the property in question. By reducing active and passive loading, the space is able to reach temperature level suitable for natural ventilation with a ceiling fan assist. Application of the strategies to this property were able to show the potential to save 83% over its existing condition and a consumption level of 7.53 kBtu/sf/yr. Future steps would need to consider a moisture mitigation strategy which are not included in this package.

Benefits stemming from the design are many and are calculated to a life cycle present value to show an order of magnitude value associated with the package. Direct owner value is calculated to a present value of $47/SF and qualitative tenant benefits equate to $368/SF showing that direct owner benefit is not enough accomplish the scope proposed, but when combined with tenant benefit it becomes an option that may be viable and deserves further investigation. Benefits quantified include energy savings, indoor environmental improvements, value adding amenities, and increased square footage included in the design package.

T. o. C.

T.o.F

Preface

Adaptation to a Sustainable Design

It is becoming increasingly important that we reduce consumption of natural resources and reform approaches to energy conservation. Society has debated the breadth of Earth's natural resources. There have been varying degrees of opinion as to how many people the planet can support and for how long, but it has become clear that the expanse of human societies does not stop. It grows through time. We cannot continue to consume more than we naturally produce and we must move away from technologies which work with energy supplies having adverse effects on our environments.

In recent history, we as a population have mostly come to accept that our future will undoubtedly require some reformatting from the way we have come to do things. It is becoming increasingly apparent that we are in danger or already have permanently altered the state of our environment. The architecture profession, realizing that 40% of all energy used goes into constructing and maintaining our buildings[1], has been at the forefront of this evolution thus far. Organizations like the USGBC have made momentous strides in organizing green concepts, teaching people in the profession, and pushing for industries to act on them. What should be seen as the first phase of this evolution looks to be a resounding success. The status quo has changed. People have received a significant amount of education through main stream media and are aware that we should look for more environmentally conscious ways to live our lives. All of these examples of the sustainable movement are notable and represent a major shift in thinking.

But this is only the first step. We are not sustainable. We are just aware that we need to be. Notable projects have proven that it is possible to do significantly better than we did in the past, but almost all design is far from being truly sustainable. We have seen the first wave. It is now time to take the next step. As we progress, we build on what has come before us. That is what we must continue to do.

Future practice will need to push to utilize a straight forward approach and framework to minimize the inherent inefficiencies and wastefulness which are brought on by the

[1] "High Performance Green Buildings." Environmental and Energy Study Institute, accessed November 28th, 2010, http://www.eesi.org/buildings.

methodology of which we design. It will also need to strive to display the value that this process poses and push to maximize the perceived benefit to what we produce.

Definition of Sustainability

In prepping to meet project goals, it is important to define the parameters of sustainability. Along with the popularity this movement has inspired, it has also acquired a widely varied idea of what constitutes a successful system. This is because the concept - sustainable design - is a multifaceted issue that draws upon many areas of expertise. By giving the concept a set of parameters to pursue, it begins to solidify its meaning and provides an avenue for realizing the end goal. A successful endgoal would include:

-A place's ability to produce as much energy as it uses

-Shrinking place's carbon footprint to zero

-Zero extracted throughput (non-regenerative resources) extracted for use in the making of place

-No harm to the biosphere (the part of the world in which life can exist)

-Creates a healthy environment for inhabitants

and finally,

-An ability for the place to address and create an environment to solve social issues of the time and region

Areas of Implication

Energy, Material Makeup, Indoor Environmental Quality, Water Consumption, and Economics will all be affected in an evolution toward a sustainable design. Through careful consideration of these areas, we will be able to move past the challenges of today and towards a sustainable future. This project, in essence, will focus on the most urgent implication today – energy. As this important pursuit moves to fruition, other areas will be incorporated where synergies exist.

Water Consumption

Nationally, clean water supply has become a focus due to issues surrounding drought and subsequent lack of supply as well as for reasons regarding the energy needed to purify water to a usable level. In Hawaii, the issue of supply source is less of an issue due to the relative amount of precipitation we receive in comparison with some arid mainland regions. But the energy required to create potable water is still an important issue due to the inherent shortages of a clean and renewable energy supply.

When looked at on a regional or municipal level, there are 2 ways to approach cleaning a water supply's energy footprint. This is done by either reducing the carbon load per gallon, or through water conservation efforts.[2] The latter is the area where individual designers can have the most impact. According to the National Science and Technology

---

[2] Adrian Smith + Gordon Gill Architecture, *Toward Carbon Zero: The Chicago Central Area Decarbonization Plan* (Mulgrave: Images Publishing Group Pty Ltd, 2011), 159.

Council, 12% of all water use is in buildings. Developing strategies to save water are relatively easy, and should be incorporated in every construction effort.

Through conservation strategies, notable projects have been able to significantly reduce the amount of water used both in new construction projects and in retrofit settings simply through replacing plumbing fixtures with contemporary counterparts which use significantly less gallons per minute. More extreme measures can and should be considered where possible.

Indoor Environmental Quality

One particularly important aspect to consider in the adaptation toward sustainable design is the indoor space and how it relates to the health and well being of its occupants. What began as an effort to ensure a space's occupants would be entitled to an environment that did not cause harm to their health, has evolved into a an argument that is poised to increase an occupant's enjoyment of the place. When developed a bit more it becomes justification for increased productivity which has economic benefits.[3]

Indoor air quality is a particularly important part of the overall environmental quality. Indoor air can be much more polluted than exterior air - LEED reports that indoor air can be 2 to 5 times more polluted. Extreme cases have been noted at more than 100 times more polluted than outdoor air.[4] Strategies for indoor air improvement have been shown to significantly improve occupant's reaction to the indoors creating an enticing argument for improving the quality of air in any commercial setting.

The productivity argument has gained popularity in the last decade as a plausible way to create value for green design. Increased productivity and reduced sick days taken quickly translates into savings for any business and ultimately property value in many cases.

> "The potential annual savings and productivity gains from improved indoor environmental quality in the United States are estimated $6 billion to $14 billion from reduced respiratory disease, $1 billion to $4 billion from reduced allergies and asthma, $10 billion to $30 billion from reduced sick building syndrome symptoms, and $20 billion to $160 billion from direct improvements in worker performance that are unrelated to health."[5]

Taken more broadly though, the indoor (and even exterior) environmental quality of a space is the essence of what good architecture has always argued for - the delightful experience of space.

---

[3] Greg Kats, "The Costs and Financial Benefits of Green Buildings: A Report to California's Sustainable Building Task Force," (California's Sustainable Building Task Force, 2003), 46.
[4] U. S. Green Building Council, *Green Building Design and Construction* (Washington DC: U. S. Green Building Council, 2009).401.
[5] Ibid

Material Makeup

"Construction Materials - including buildings, roads, and infrastructure supplies – make up 60 percent of the total flow of materials (excluding food and fuel) through the US Economy."[6]

"Building Construction and demolition waste accounts for 60 percent of nonindustrial waste and more than 30 percent of the mercury in landfills in the United States."[7]

The architectural profession is heavily responsible for maintaining a high level of materials stewardship. It is our profession that specs new materials and make the plans for how to maintain them once aged in place.

An important component of sustainability from one of the movement's founders, William McDonough, is a new conception of material flows. Instead of seeing materials as a waste management problem, which interventions here and there slow their trip from cradle to grave, materials are seen as nutrients that can be maintained in two safe metabolisms: biological and technical.[8] Design must strive for ways to make this possible. Materials designed as "biological nutrients" can biodegrade safely and restore the soil after use. Materials designed as "technical nutrients" can provide high-quality, high-tech ingredients for generation after generation of synthetic products—again a harvest of value.[9]

One business man who has helped to pave the way for others in the materials industry is Ray C. Anderson. Mr. Anderson was the CEO of Interface Global. He represented a rare breed of business leader in that he has pledged to do the most he can to minimize his companies' effect on the environment. In fact, he pledged to make his company 100% sustainable by 2020. How does he define sustainable? His goal "means zero extracted throughput per dollar of sales and no harm to the biosphere."[10]

To obtain his goals, his concepts began very simply: eliminate waste, educate every employee about the environment and what's at stake, give each person the knowledge and tools to contribute; take savings from waste elimination and invest in new energy and material saving technology & product innovations.[11]

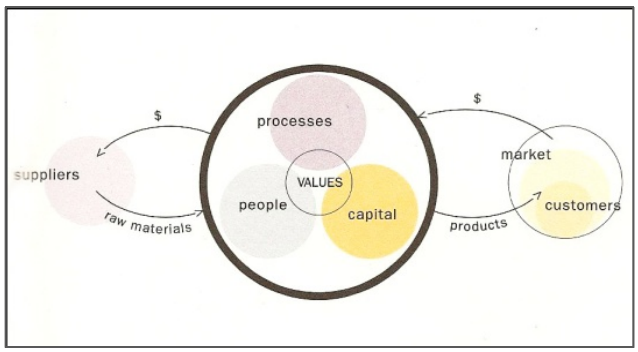


Figure 1 - Anderson's Typical Supply Chain of 20th Century Linear Model

6 Hillary Brown, FAIA. "Toward Zero Carbon Buildings." In *The Post Carbon Reader: Managing the 21st Century's Sustainable Crises*, edited by Richard Heinberg and Daniel Lerch (Healdsberg: Watershed Media) 324.
7 Ibid
8 Hawken, Paul. *The Ecology of Commerce: A Declaration of Sustainability*. Revised Edition ed. (New York: Harper Buisness, 2010), 105-117.
9 Ibid
10 Anderson, Ray C. *Toward a Sustainable Enterprise: The Interface Model: Mid-Course Correction*. (Atlanta: : The Peregrinzilla Press, 1998), 130.

11 Hawken, Paul. *The Ecology of Commerce: A Declaration of Sustainability*. Revised Edition ed. (New York: Harper Buisness, 2010), 71-72.

Anderson made his company accountable for its actions by publishing reports which display the area in which they need to improve and the goals they have in order to do this. Anderson has made it his most personal quest to "Obtain zero".

He begins with the typical 20th century linear model in which product goes from earth to consumer to landfill, and slowly explains the steps he has and will take to eventually move to a cyclical cycle in which all of the elements of his manufacturing move in a circular fashion from supplier to manufacturer to customer and back to supplier. This cycle avoids Lithosphere and Recaptures Biosphere elements to end in a net zero output. In the 21st century model, where one gives it also receives and thus comes to an equilibrium.[12] This of course is a generic description, it begins to depict how he plans on accomplishing his goals. By looking at such holistic analysis, one could start to imagine the components of an architectural design process too.

Anderson's ideas are directly in line with those of the Cradle to Cradle (developed by William McDonough and his team) mentality of utilizing technical nutrients that flow from manufacturer to consumer and when the consumer is done with them, they return back to the manufacturer for reuse.[13]

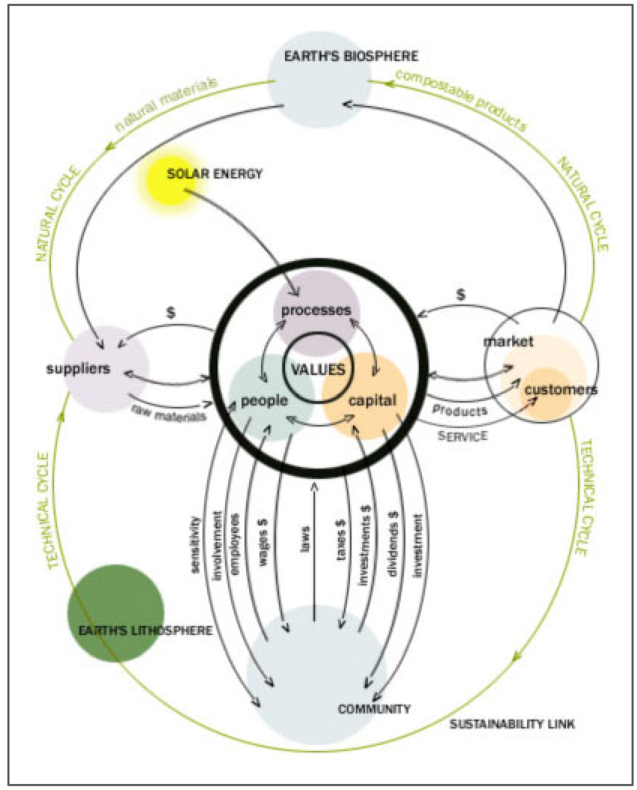


Figure 2 - Anderson's Prototypical Company of the 21st Century

This train of thought has led to vast improvements in material flows in the last few decades. Understanding the concepts of embedded energy and recycling (upcycling & downcycling) are proving to ease consequences of our need to build. Furthermore, through an understanding of operational energy consumption, improved materials are able to be developed which take all of the throughput considerations into account, as well as reduce the need require active conditioning of the spaces once they are put into place.

Energy Consumption

Sustainable building efforts today are becoming increasingly focused on energy savings. Unyielding efforts of newfound institutions like Architecture 2030 and the 2030 Challenge are quickly shifting the debate to one that is heavily based on the energy performance of buildings. This is due to the mounting evidence that the energy we are using is the prime culprit for global climate change. The 2030 Challenge's success is beginning to show through the increased stringency of codes on both local and national level. The IECC has recently adopted further stringent thresholds which will put new building stock on pace

[12] Anderson, Ray C. *Toward a Sustainable Enterprise: The Interface Model: Mid-Course Correction*. (Atlanta: : The Peregrinzilla Press, 1998), 104-127.

[13] William McDonough & Michael Braungart. *Cradle to Cradle : Remaking the Way We Make Things* Vol. 1st ed. (New York: North Point Press, 2002) 109-115.

with the challenge.[14] Locally, Hawaii's HCEI is advertising a 70% reduction in building's carbon emissions from energy by 2030. 30% of which will be through building efficiencies.[15]

Today our most pressing goal needs to be the replacement of the pollution based energy system. All of the other areas of implication end up contributing to energy. Our energy use – weather through transportation of materials, embedded energy, or building power supply, is the major contributor to climate change. Our biggest impact in the movement toward sustainability can be realized through a concerted focus on energy, its use, and its production. Once accomplished, other issues should be pursued.

The most important piece of the energy puzzle lies in its continued use throughout the life of the building. Energy use will need to focus on utilizing high levels of emergy otherwise known as developing and maintaining highly efficient design. Providing a highly efficient solution benefits all parties involved. Owners get the financial benefit of reduced energy costs and often higher property value. Tenants of the space see more productivity from occupants. Municipalities see a reduction in the demand on infrastructure which saves money in construction costs. And perhaps the most important benefit of this is its ability to cut energy demand allowing society the chance to transfer to a zero carbon energy source.

With the success of green rating systems and private goal oriented startups has come the eventual buy-in of Federal, State, and Local jurisdictions. For instance, federally built buildings are now required to be LEED Silver. Progressive states like California are mandating higher and higher levels of energy efficiencies as well as implementing renewable energy policies to offset dirty generation of power. Municipal leaders like Chicago and New York are putting forth inspiring plans – some aiming to completely decarbonize by 2030. These plans will ultimately <u>mandate</u> the architectural profession take on these goals and carry them to fruition.

In the context of Honolulu, the benefit of an energy retrofit for efficiency is compounded. Honolulu has historically shown the highest energy prices in the nation. This is mostly due to its relative isolation from the rest of the world and the fact that non-renewable energy sources must be shipped to the island to be manufactured into a usable energy source. The reliance on non-renewables will continue to ensure that this trend stays true. Any move toward a renewable energy supply offers a solution which will begin to narrow the gap in cost difference. In either case, renewable or non, a focus on methods of energy efficiency in the Hawaiian context will continue to offer high levels of environmental as well as financial benefit for the life of the property.

The Hawai'i Clean Energy Initiative was put into place to relieve the pressure of an economy that is completely dependent on importing foreign sources of energy. Hawaii looks toward the ultimate goal of energy independence, but has put forth the goals of "70% clean energy by 2030 with 30% from efficiency measures, and 40% coming from locally generated renewable sources."[16] Efficiency reductions of 30% will be obtained by reducing electricity demand by 4300 gigawatt hours by 2030. In order to reduce the use of electricity by end

---

[14] Architecture2030, "2030 Goes Code," Architecture2030, http://architecture2030.org/hot_topics/2030-goes-code.
[15] Hawaii Clean Energy Initiative, "Hawaii Clean Energy Initiative," http://www.hawaiicleanenergyinitiative.org/.
[16] Ibid.

users HCEI will align the efficiency regulatory policy and framework with clean energy goals, support the retrofitting of residential and commercial existing buildings, strengthen new construction policies and building codes, and identify non-building related energy efficiency measures.[17]

Net Zero and Zero Carbon

It has long been established that in order to supply buildings with a clean and renewable energy supply, we will need to begin to focus on efficiency as well as new production methods. This is due to the shear space that a renewable supply will take up in relation to area of non-renewable based power plants. Estimates have pointed out that to get to a level which could be considered to a Zero Carbon offset potential without enlarging the building's footprint, we will typically need to pursue efficiencies with a 70% reduction in consumption.[18] This staggering statistic has shown that we must continue to rethink methods and strategies of design to focus on energy efficiency in every way possible in order to evolve towards a zero carbon goal.

Currently we are witnessing an unprecedented push towards a Net Zero Energy or Zero Carbon product in the built environment. This is the next logical step beyond awareness and education of sustainability. Now that we have an understanding of what sustainability is, we can begin to transform our processes to realize these goals. A net zero energy approach to our built environment will in effect, will help to mitigate our most troublesome environmental challenge stemming from our built environment - the release of massive amounts of carbon into our atmosphere.

Net Zero and Zero Carbon Design is usually associated with new construction though. This leaves the bulk of our built environment unaddressed and still contributing to pollution at the same rates as in the past. Our existing building infrastructure is and will be the backbone of the energy issue for easily the next 50 years.[19] It is this reason that we must shift our focus towards a dual path when designing our cities.[20]

1) Improving our current building stock to minimize/reverse its overall effects on the degradation of our environment and climate
2) Developing architectural approaches to building zero energy new construction

Economics

Beyond the Limits of Growth

Today, it appears that we are encountering a repositioning of ideals - one that moves away from the assumption that we can base our success on expansion. This shift in paradigm and subsequent reality is that we will be forced to reconsider the way we exist. For very long, we have proceeded under the mentality that sustained growth is possible. This continued growth has led the bulk of society to appear to be sustained in growth. But just because the

---

[17] Reasearch and Economic Analysis Divison, "Renewable Energy in Hawaii," ed. Economic Development and Tourism Department of Business (Honolulu: State of Hawaii, 2011).
[18] Hillary Brown, FAIA. "Toward Zero Carbon Buildings." In *The Post Carbon Reader: Managing the 21st Century's Sustainable Crises*, edited by Richard Heinberg and Daniel Lerch (Healdsberg: Watershed Media) 328.
[19] Ibid.
[20] Ibid, 327-329.

growth has continued over generations does not mean that one day it won't come to a point that it has outgrown its possibilities. Many have argued that at some point we will hit a point at which expansion is no longer possible. The end of the carbon age is the assumption that society has finally hit a barrier currently causing the "sustained growth" to shrink.[21] Proponents of this example, use economics to argue the drive for an exponential economic growth has begat a problem that causes other systems to degrade exponentially.[22] To support the sustained growth means that jobs are created. The subsequent general feeling of well being causes population growth and the world population doubles, then triples, and doesn't stop. As products/commodities are developed at an accelerated pace, a non-renewable energy resources are exhausted and their cost begins to rise. The systems that our society have set up are not independent. What happens to one has profound effect on many others, invariably shifting the balance of the whole and everything grows - even where it should not.

These thinkers look to a time when an overall plateau is seen as the desired goal. Richard Heinberg in an essay titled "Beyond the Limits of Growth" argues that we have reached the limit that we cannot grow anymore, and thus will need to determine a new way forward. Hopefully a way in which we create a system of "resilience". This resilience is seen to be achieved by revamping the processes of how we accomplish ideas and create, market, and sale product.

In order to go beyond the status quo of today's green architecture movement, we will need to fundamentally change the nature of business to move toward a social and environmentally conscious architecture. "To create an enduring society, we will need a system of commerce and production where each and every act is inherently sustainable and restorative"[23] This idea, provided by Paul Hawken, pushes him to define the objectives which he sees as imperative for business moving forward. Many of these will affect architecture, the process of design, and the construction industry at some of the most fundamental levels.

1. "Reduce carbon emissions of energy 80% by 2030 and total number of resource usage 80% by 2050... We already have the technology to do this in every economic sector including energy."
2. "Provide secure, stable, and meaningful employment for people everywhere. The concept that moving toward environmental restoration is economically hazardous is upside down. It is the present take-make waste system that has over 1 billion people who want a job unemployed. Creating a restored, safe, and secure world is the greatest job creation program there is."
3. "Be self organizing rather than regulated or morally mandated."
4. "Honor market principles. No plan to reverse environmental degradation can be enacted if it requires a wholesale change in the dynamics of the market."
5. "Be more rewarding than our present way of life."

[21] Lerch, Daniel. "Beyond Limits of Growth." In *The Post Carbon Reader: Managing the 21st Century's Sustainable Crises*, edited by Richard Heinberg and Daniel Lerch (Healdsberg: Watershed Media, 2010) 3-4.

[22] Ibid, 7-8.

[23] Hawken, Paul. *The Ecology of Commerce: A Declaration of Sustainability*. Revised Edition ed. (New York: Harper Buisness, 2010), XII.

6. "Restore habitats, ecosystems, and societies to their optimum... We passed the point where present planetary resources can be relied on to support the population for the next 50 years. A viable transformation must turn back the resource clock and devote itself to restoring damaged and deteriorating living and social systems."
7. "Rely on current income... Human communities need to need to act like natural ones, living with a natural ebb and flow of energy from the sun and plants. This means redesigning all the industrial, residential, and transportation processes so that whatever we use springs easily from the earth (and sun) and gracefully cycles back to it."
8. "Be fun and engaging, strive for an aesthetic outcome."[24]

Externalized Costs

"Markets are superb at setting prices but incapable of recognizing costs"[25] We will not have a chance at being truly sustainable until the least expensive items are also the most environmentally benign. Until this happens, there are inherent flaws in business. Being economic and being sustainable remain in conflict and at odds.[26] Externalizing costs is one way that markets of the past have pushed to make economic profit. In the midst, they have created an environment that seeks to rape environments of their natural capitol. Finding the opportunities to advertise areas where this already happens that companies can make quick and decisive progress in advancing sustainable practices and popular knowledge of them. Any business which looks to make a difference in the sustainable evolution will need to have a firm grasp on how the economy will shift in order to give more value to environmental capitol which has historically been over looked in previous business models and design methodologies.

Areas of Implication: Concluded

Energy, Material Makeup, Indoor Environmental Quality, Water Consumption, and Economics will all be affected in an evolution toward a sustainable design. Through careful consideration of these areas, we will be able to move past the challenges of today and towards a sustainable future. This project will focus on the most urgent implication today - energy. But as we move to solve each one of these individual issues, we will undoubtedly need to consider each of the others in order to come to a holistic solution. What follows is an attempt to calculate and display both the research behind and the actual design of a highest and best energy use of existing conditions - taking into account other areas of implication like economics, indoor air quality, and material resources where possible in the timeframe allotted.

Currently, there exists a stark difference between the promise of sustainable theory and real world expectations of design. This project will look to bring the two closer. Part of this is providing proof and insight that explains the value associated with efficient design. Shifting deliverables in order to depict this value in a very clear and manageable way will serve to both explain the value of design as well as make designers more accountable for what is being proposed. Today we have the ability to provide a product which not only puts into place

---

[24] Ibid, XII - XV
[25] Ibid, 85
[26] Ibid, 84

important environmental and aesthetic concepts, but also offers specific data showing the performance of the product. This data has the potential to lead us to subsequent environmental and economic savings from realizing the design. However, this method of design has not become the status quo in contemporary practice.

1

Project Statement

There are 2 paths which will need to be pursued in relation to Zero Carbon methodologies – one for new construction and one for existing building retrofits. With over 45 million structures in the US, it is clear that the majority will still be in operation by midcentury.[27] This depicts an overwhelming need for deep energy retrofits if we are going to meet the efficiency goals set forth like the 2030 challenge and the locally proposed HCEI. For this reason, this study will focus on the existing building retrofit methodologies. The good news is that methods of retrofit for deep energy efficiency are available and have been proven to have a large impact on energy consumption. Unfortunately, examples within the constraints of Hawaii are very few. This project will look to provide an example to add to the dialogue surrounding energy efficiency retrofits in Hawaii and the financial benefits they provide.

Methodology

This research provides a Technical Potential retrofit of an existing office space in Leeward Oahu. A technical potential solution seeks to show what is physically possible to accomplish with today's technology and construction skills. It is seen as a major milestone on the road to determining the highest levels of efficiency. The approach explores alternatives which may appear to be too expensive at first glance, but prove to make great sense once more developed.

Vehicles for efficient design will be explored to quantify results and data. DesignBuildier, using EnergyPlus and Radiance as engines, offers a holistic approach to performing energy analysis. Development of standardized methodology for development of the energy model is seen as one such barrier.[28] A calibrated existing conditions model is developed as a baseline and followed by 2 levels of improvements resulting in a technical potential solution.

This project will offer a solution which will look to optimize windows, walls, roofs, lighting, and equipment loads. Optimizing these systems significantly affects loading requirements to the HVAC which can significantly downgrade the need for such services. After the existing conditions undergo optimization, focus areas will be revisited to look for

---

[27] Hillary Brown, FAIA. "Toward Zero Carbon Buildings." In *The Post Carbon Reader: Managing the 21st Century's Sustainable Crises*, edited by Richard Heinberg and Daniel Lerch (Healdsberg: Watershed Media) 328.

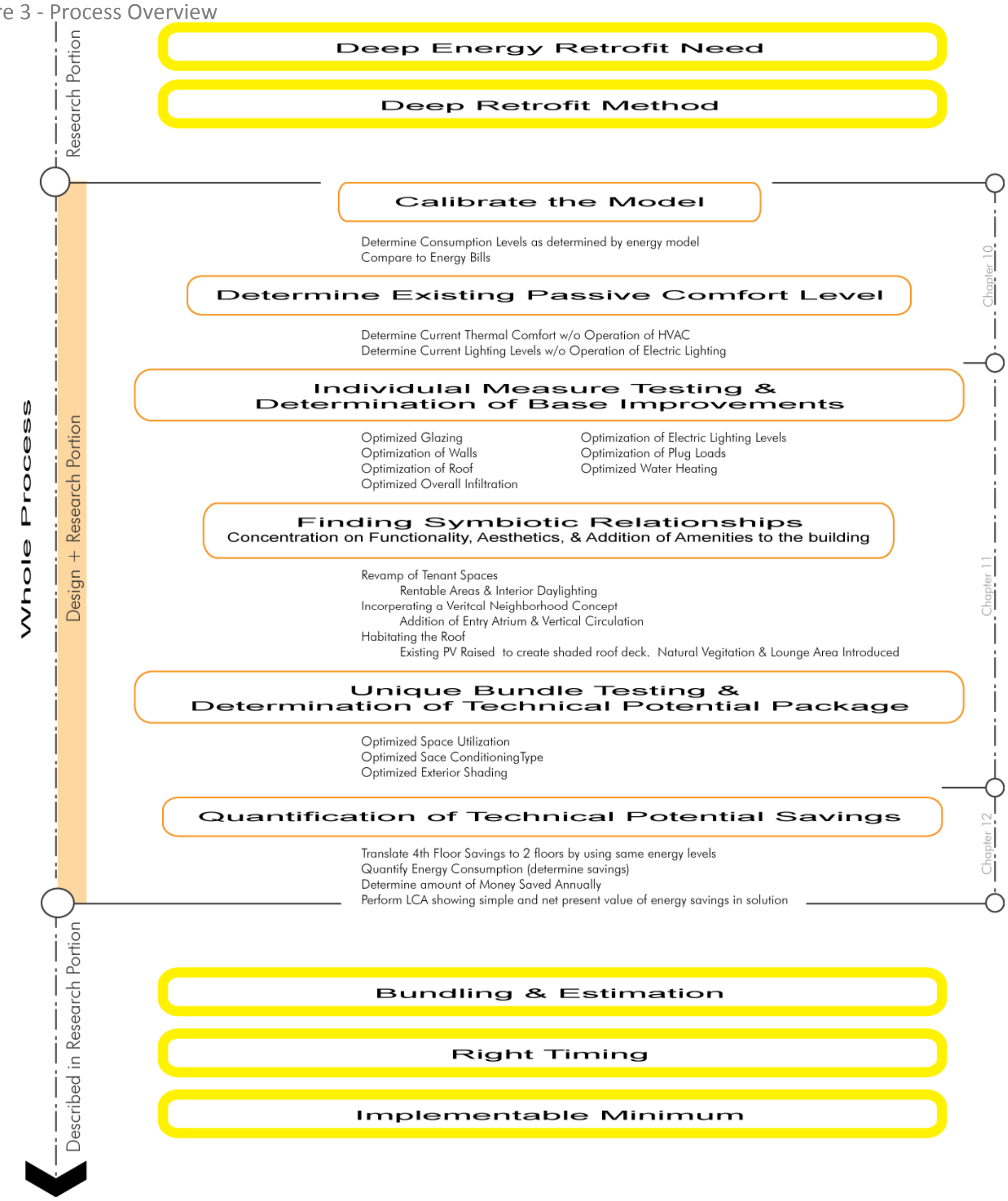
[28] Rocky Mountain Institute, "Rmi Report Highlights Opportunities for More Effective Building Energy Modeling," Rocky Mountain Institute, http://blog.rmi.org/RMIReportHighlightsOpportunitiesBuildingEnergyModeling.

efficiencies through spatial reconfiguration, exterior shading strategy, and method of attaining thermal comfort. Throughout the effort, opportunities to improve aesthetics, functionality, and value adding amenities will be sought and incorporated where possible.

Final Project delivery includes presentation documentation of the final set of EEM's considered to be a Technical Potential for the property in question. Financial benefit is outlined to begin to show its potential for realization. Future steps are outlined to show how further development of the design can push to a financially viable and implementable solution.

By implementing a results based design methodology to the rehabilitation of our local Leeward Oahu structures, we will come closer to one of the most important milestones in the sustainable movement: the sustainability of what we already have. Through this method of design, practitioners will be able to minimize/negate the project's carbon footprint, minimize energy consumption, as well as maintain a viable return on investment to move toward a true sustainable design.

Figure 3 - Process Overview



Pursuit of a Passive Design

Often, energy retrofits are associated with rehabilitation or replacement of engineered components like HVAC or electric lighting rather than considering deeper strategies which look to increase the passive performance before offsetting loads with new equipment. Frequently, considering wall, roof, floor, and glazing interventions in conjunction with active mechanical or electrical systems will produce the highest efficiency. Furthermore, incorporation of passive cooling and lighting approaches can significantly reduce or remove loading required by mechanical or electric means. In a Hawaiian context, combining passive and active strategies based on a passive first approach can often provide the most efficient options and pay for themselves in the retrofit's life. This can be determined through an integrated design approach which is able to reach larger goals through the addition of multiple efficiency strategies. These strategies can produce better results than the sum of their parts.

A retrofit for energy efficiency has its own unique concerns when located in a Leeward Oahu context. Studies have shown that interiors have the potential to reach high levels of comfort for most of the year without being cooled by mechanical needs. Buildings in this climate have the opportunity to explore natural ventilation without the help of mechanical cooling for much of the year.

Examples of progressive passive designs are few. Understanding of natural cooling methods are seldom undertaken in a commercial situation, even though passive cooling has been shown to be preferred by the majority of the population. Through a technical potential solution, this research is able to show natural ventilation is able to provide acceptable levels of comfort with the adaptive model for thermal comfort and a ceiling fan assist. Futhermore, the resulting package is able to achieve an 83% energy reduction to a level of 7.5 kBtu/sf/yr.

Economic Viability

It is clear that the efficiencies needed to ensure meaningful impact will not be pursued simply through mass understanding of the climate consequences associated with inaction. Retrofits will need to find ways to become financially relevant in order to be viable approaches in today's society. Through a prioritization of methods and strategies based on financial reward as well as a renewed climate stewardship, universal progress can be made.

Frequently, considering wall, roof, floor, and glazing interventions in conjunction with active mechanical or electrical systems will produce the highest efficiency and can be adjusted to provide the lowest life cycle cost. This is done through a Net Present Value Analysis which is able to show a comparison of Benefit and Cost. In this process, both items are brought back to a present value taking potential discount rate and inflation into account. When the benefits outweigh the costs, the investment is considered beneficial. This type of approach is considered to be a standard for determining viable projects.

This research looks at the process and advocates a preliminary, designer led benefits analysis before a full cost analysis is undertaken. For the proposed technical potential solution, a present benefit of $47/SF for the owner and $368/SF benefit for the tenant are found at a discount rate of 10% and inflation of 1.5%. Together this creates a package that has potential to be economically viable.

2

Defining a Purpose: An Architect's Biggest Lever

In 2009 Auden Schendler wrote of the need for businesses of all types to search out the angle which will give them the largest leverage to create change in the green movement. He pointed out examples like Wal-Mart, Ford, and his own company, the Aspen Skiing Company. In describing each company's greening efforts, he mentions successes and failures. These examples began to show how each company should use its expertise and societal context to figure out how to make the most positive impact in moving toward a sustainable future.[29]

In considering this, an Architect must think of the built environment. More specifically, in taking the lead from emerging pacesetters in the industry like Architecture 2030, they must consider the energy used and the physical state of the structures that house them. We have the unmistaken responsibility to make our buildings as energy efficient as possible. Past approaches made the mistake of not putting a high enough value on the resources they would use, leaving today's profession with the responsibility to improve on what others have put in place.

When considering retrofits, we must make them usable, yes; make them healthy; make them operate in a less wasteful manner with reference to materials; work with the mechanical engineers to make sure systems are the most efficient they can be; be a sounding board for successes is clear, yes; but in the end, the most fundamental and perhaps largest impact an Architect deliver to the sustainable movement lies in the overall passive performance of a design. You build it so that it performs as efficiently as possible before the active systems are introduced. You master the design of the envelope, ventilation rates, daylighting, and proportion of space in relation to function. Today, an Architect's most important impact will be realized through their approach to energy in all of its forms. This must be the first focus of an Architect looking to create sustainable design. Incorporation of passive concepts and their subsequent strategies will lead to a body of work making the most difference in energy consumption.

---

[29] Schendler, Auden. *Getting Green Done: Hard Truths from the Front Lines of the Sustainability Revolution* (New York: Public Affairs, 2009), 87-103.

Limiting an architect's role in the movement toward sustainability to passive design strategies would be a bit naïve, if you were saying that was their only contribution. It is not. With the responsibility of being the architect, also comes the overall project management. They must be able to steer design and construction towards the ultimate goal. They must be able to coordinate any active systems put in place to offset remaining energy needs after all passive efficiencies are exhausted. They must be able to include a litany of strategies to address tenant health concerns, which as it turns out, align very well with passive design in many cases. They must create an environment of contemporary usability and delight within the space. They must have an approach to lifecycle concerns of the existing building as well as the intervention. Striking the correct balance in the pursuit of technical potential will be key.

Existing Buildings and Retrofit Potential

Using a projection of the nation's growth in building area and historical data taken from the DOE's CBECs survey, a running projection of 30 year old buildings (or retrofit ripe) square footage is able to be discerned using a 2.2% annual demolition rate. The 30 year threshold is selected due to its relationship to HVAC end of life. 20-30 years is considered a good rule of thumb, 30 being a more conservative estimate.

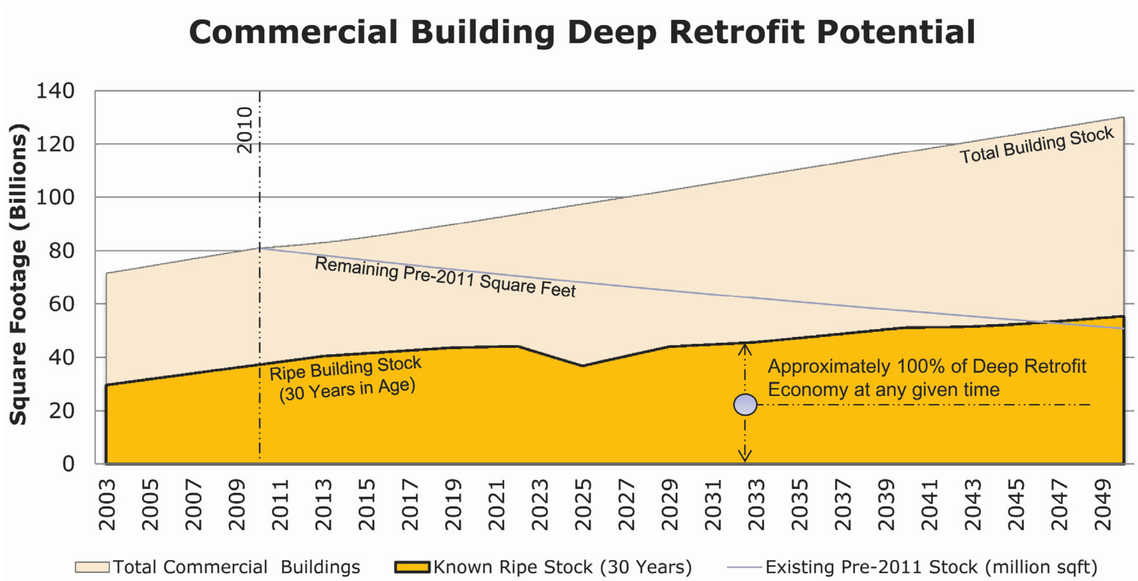


Figure 4 – Diagram Showing National Potential for Commercial Building Deep Energy Retrofits[30]

From this excercise, we are able to see that a very large share of our buildings are ripe for retrofit at any given time (loosely approximated at 40%). How much of that actually goes through a deep energy retrofit process, will significantly impact our energy consumption future.

This efficiency approach will also save money with ever escalating costs of energy supply. The Rocky Mountain Institute's Retrofit Depot reports that "One in three U.S. commercial buildings are old, failing and offer a window of opportunity for a deep energy

[30] Frank Alsup, "Measuring Deep Retrofit Impact," (Boulder, Colorado: Rocky Mountain Institute, 2012).

retrofit."[31] They also show that energy retrofits can be profitable citing the rehabilitation of the Empire State Building which was able to achieve a 40% energy savings with an astounding 3 year payback.[32]

Consumption Realizations

Any green building should have energy efficiency concerns at the forefront of their design strategies. "Show me the utility bills," Joseph Lstiburek, a respected energy engineer says. "Compare the building to a building of similar size and similar occupancy in a similar climate. And if you don't show any savings—shut up. You can't be "green" if you don't save any energy."[33]

While preparing this research document, I had my own energy efficiency realization while in discussions with a client. I had the opportunity to work on his residence addition. Part of the scope included offsetting his energy use with a PV array. The array went in and was able to offset his use, but during the process, the client told us that he was in the midst of installing an array on his commercial office building. This was not an integrated design process, meaning he did not consider other building systems before offsetting the power. But racking out all of the roof's usable space was only able to account for approximately 20% of his monthly electrical use. This visualization was alarming to me considering the relative footprint of the structure in relation to square footage. While it is multiple stories, it has relatively large floor plates compared to many multistory structures. The roof area appeared quite large and I would have hoped that he would be able to achieve more onsite production as a percentage of the overall usage. As it would turn out, this commercial office building would eventually become the focus property of the design portion of this research to see what a difference could be made resulting from a deep energy retrofit.

While this client's story is perplexing, it becomes very clear that one cannot just add PV to a structure to have it mitigate its energy expectations. There must be a focused effort to achieve much higher efficiencies in the building's systems beforehand. With the above reference, 20% of the total power needed was being referenced. Later analysis of the building's energy use and PV generation approximated it at 24%. In a best retrofit scenario – primed and ready on the levels of a Sears Tower proportions (80% reduction in power supply to the site),[34] the owner could experience roughly 55% additional reduction through efficiency measures. With efficiencies such as these, 24% suddenly turns into 55% of total power needed. This shows that it is not the PV alone that is required to make an impact; it needs to be coupled with a highly efficient demand in order to begin to be effective.

---

[31] Rocky Mountain Institute, "Why Deep Retrofits?," Rocky Mountain Institute, http://www.retrofitdepot.org/WhyDeepRetrofit.
[32] Ibid
[33] Joseph W. Lstiburek, "Prioritizing Green: It's the Energy Stupid," *Insight*, no. 007 (2008).
[34] Architecture, *Toward Carbon Zero: The Chicago Central Area Decarbonization Plan*, 9.

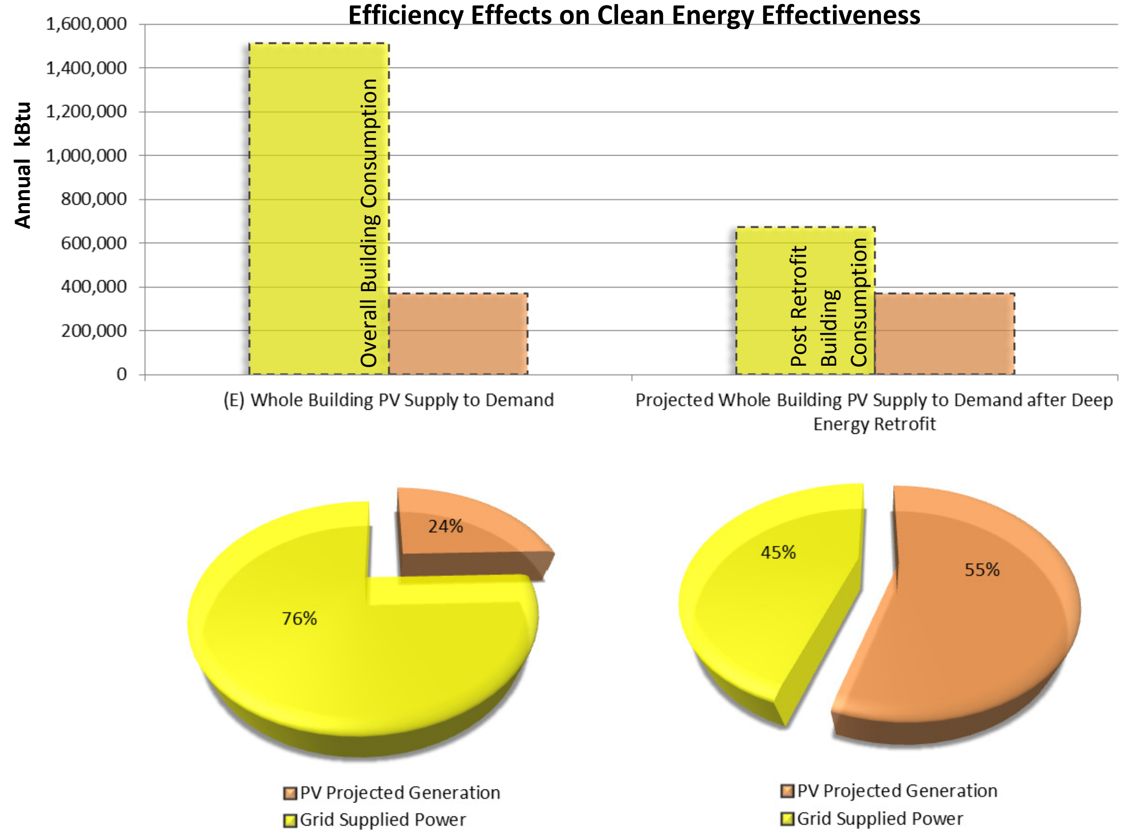


Figure 5 – Efficiency Effects on Clean Energy Effectiveness

Currently, Hawaii's local energy efficiency initiative – HCEI or Hawaii Clean Energy Initiative – is advertising goals of a 70% reduction in dirty energy. 30% is slated to come from efficiency measures and 40% from local renewable generated sources.[35] In order to meet these goals individual buildings will need to take part in reducing their loads.

Efficiencies of this nature are possible and can be economically viable. By reviewing a building's power usage through an energy survey, a general understanding of the aggregated energy consumption is understood. From there, strategies to mitigate this usage can be developed and integrated. Do to Hawaii's unique climate and mild temperature swings, patterns of individual building's power aggregation are unique to these islands. Understanding the typical existing patterns as well as patterns of retrofitted buildings, allows designers to offer Energy Efficiency Measures (EEM's) for consideration.

[35] Initiative, "Hawaii Clean Energy Initiative".

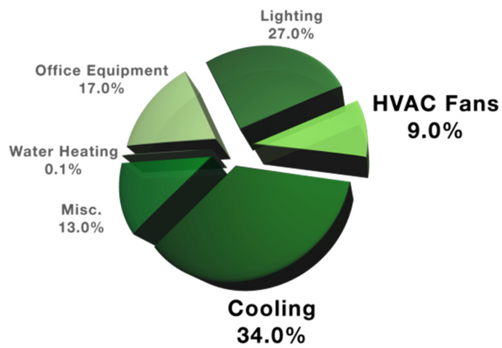


Figure 6 Typical Aggregate Energy Use of Office in HI

The figure at the left shows the aggregate power usage of a typical office building in Hawaii.[36] Each individual's aggregated use is unique and should not be assumed, but through review of how the power is specifically used, certain segments areas can be significantly reduced. This will alter the spread of aggregated energy and minimize overall energy use.

This project will look at ways to limit each system's impact on the on the building's overall consumption. More standard ESCO or engineer led energy retrofits today often provide a similar approach, but can be somewhat short sighted in they don't pursue deeper passive savings that can be realized in conjunction with the active measures. Approaches with a passive first mentality have a need for an Architect's involvement; and since Architecture has yet to become a prominent voice in this retrofit discussion, these more narrow scopes have become the standard of practice in the industry today. In this way, an Architect led energy retrofit team has the potential to become the most effective in providing the deepest energy savings, while bringing in the design insight necessary to solve additional issues in the process.

[36] Eley Associates, "Hawaii Commercial Building Guidelines for Energy Efficiency," (Honolulu: Energy, Resources & Technology Division, Dept. of Business, Economic Development and Tourism, State of Hawaii, 2004). 1-15.

3

Project Methodology

"The point is, post-carbon – like sustainability, like resilience, like transition – is best thought of as a process, not a goal. In many ways, what makes a community or a product "sustainable" ultimately has a less to do with a list of "green" characteristics it might boast and more to do with the processes from which it emerges. If getting to "post-carbon" is a process, the good news is that we can all participate in and contribute to that experience." _Daniel Lerch [37]

Integrated Design

One of the most important mantras coming out of the efficient design movement is the concept of Integrated Design. Architects are seeing that by opening the preliminary design process up to collaboration with specific consultants early on, designs are pushed to perform at a much higher level of designed efficiency. Questions like what kind of daylight levels are needed(?) and how does that translate to a percentage of wall:glazing(?) are answered early allowing architectural designers to be equipped with the necessary data needed to make informed decisions on how to lay out the program on the site in a manner that meets project goals instead of guessing. This approach is particularly important in an existing building retrofit situation. Knowing where and how to save becomes the primary question.

Removing Barriers

As with any design process, an unlimited number of potential barriers lie in queu waiting to potentially stall progress. Building Retrofits for energy have their own set of typical barriers. Identifying, and mitigating those barriers (like providing correct timing) in a methodical way offer the greatest potential that challenges will not permanently halt a given project. An integrated design team is one of the best ways to remove barriers from a process by providing multiple points of view on any given topic.

One of the most typical barriers for an energy retrofit is the lack of confidence in financial return. Typically owners and design teams can realize much higher confidence in producing optimal outcomes when certain aspects of the team and project program are met.

[37] Lerch, Daniel. Introduction. In *The Post Carbon Reader: Managing the 21st Century's Sustainable Crises*, edited by Richard Heinberg and Daniel Lerch (Healdsberg: Watershed Media, 2010) xxiii.

The process differentiators that enable deeper savings exist throughout the entire retrofit process. Examples of such process differentiators include[38]:

A continuously collaborative team;
The advantage of a highly informed and motivated client;
The existence of a fully budgeted 'baseline' capital improvement plan (to enable piggybacking on planned equipment and infrastructure upgrades);
The more extensive and integrated investigation of potential energy efficiency measures;
The development of the theoretical minimum energy use or stretched technical potential;
The evaluation of opportunities in tenant spaces;
The establishment of a sophisticated yet digestible business case to compel the owner to push for deeper energy savings.

One major concern within the energy retrofit industry, is the concept of diminishing returns. In some cases, as more and more energy saving measures are introduced into the building, the design team will hit a point where it less and less of a return in savings to the client. What teams have begun to notice is that diminishing returns are a very real concern until certain thresholds are passed. What has been found is that once a certain point has been reached, the design team is allowed to revisit and simplify other systems, creating a net savings where there previously was deficit.

Amory Lovins in "High Performance by Integrative Design" states in the Empire State Building Retrofit, the addition of efficiencies from multiple strategies allow for cost barriers to ultimately be overcome. This retrofit was able to get to a point where major savings are allowed through reduced costs in large ticket items like mechanical equipment. Taken from this perspective, integrative design coupled with whole building analysis provides avenue to attain real ROI from design.

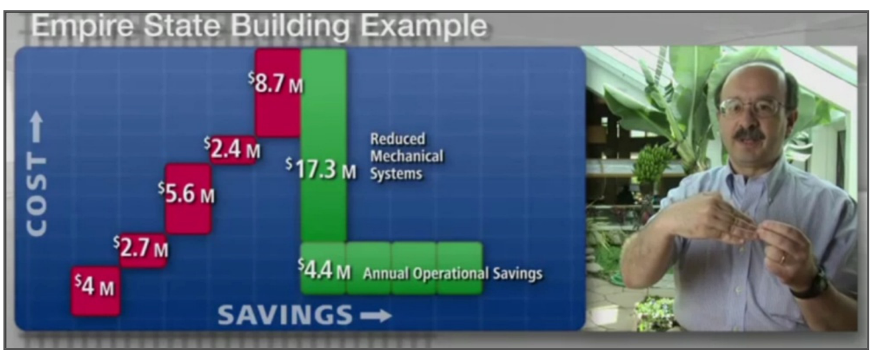


Figure 7 – Amory Lovins explaining integrated design techniques and the financial benefit[39]

---

[38] John Zhai Nicole LeClaire & Michael Bendewald, "Deep Energy Retrofit of Commercial Buildings: A Key Pathway toward Low-Carbon Cities," *Future Science* (2011).
[39] Rocky Mountain Institute, *High Performance by Integrative Design*, (Boulder: Rocky Mountain Institute, 2010).

Energy Retrofit Process

This project will look to provide a Technical Potential retrofit of an existing office space in Leeward Oahu. A technical potential solution seeks to show what is physically possible to accomplish with today's technology and construction skills. This type of solution is seen as a major milestone on the road to determining a solution which attains the highest levels of efficiency while still remaining economically feasible. It allows the team to explore alternatives which may appear to be too expensive at first glance, but prove viable once more developed. The following displays the overall process pursued in developing the technical potential solution.

Step 1: Identify Triggers. In cases where triggers are present, they can help to inspire energy reduction efforts and other architectural services. These should be understood at the outset of a project.

Step 2: Preliminary Audit. Comparison between current and historical utility bills and regional averages otherwise known as a "Benchmarking Audit".

Step 3: Walk Through with Initial Insights: At this point, the facilities are toured to determine the overall state of the building and its systems. Initial thoughts as to what strategies the project should focus on are developed.

Step 4: Existing Conditions: Once the final site is toured, an initial pass on the energy model is made. Getting the energy model calibrated as close to actual energy consumption is key. The Energy Modeling exercise allows analysis all of the building's systems together rather than independently as in traditional energy retrofits. A semi-calibrated model is planned for this particular project.

> For this effort, sub-metering will not be possible, hence the semi-calibrated designation. However, the focus property does have 4 meters supplying power to the building. This will allow for some level of designated aggregate energy use.

Once Existing Conditions have been modeled, a return to the site to field verify any questionable items may be necessary. An interview of the building operator or any other invested staff could be conducted to air any solutions the owners and operators have been considering.

Step 5: Generate a list of Energy Efficiency Measures tailored to the facilities at hand. Many efficiency measures will start out somewhat generic and be tailored as they are considered on a more detailed basis. As measures are developed and considered in unison with others, bundles of measures are developed to maximize efficiency.

Step 6: Test Independently and In Bundles. Each measure will be tested independently for energy consumption reduction. Multiple types of product replacement / scenarios will be tested for each measure where possible. Since more than just energy consumption needs to be considered, a decision making protocol is put in place to streamline decision making.

Step7: Synergies Identified. Where possible, additional value and aesthetic enhancements are sought to "piggy back" on the energy improvements. Often times, for little additional cost, multiple benefits can be added to the scope which increases the impact of the final result.

> In this effort, a gut rehab of the 3rd and 4th floor interior will be undertaken to increase usability and indoor environmental quality; a roof adaptation to an occupiable roof deck will be undertaken; and a vertical circulation concept will be explored for additional values.

Step 8: Technical Potential. Using energy model, develop bundle of measures that will bring the property to the lowest possible energy use allowable with today's technology.

10 Ways to Time a Deep Energy Retrofit: Triggers

Coordination with consultants is one aspect of Integrated Design; coordination with clients is another. Close coordination with clients is an absolute requirement when undertaking the energy retrofit of an existing building with return on investment as a priority. Correct timing and coordination of budget is an absolute necessity. The Rocky Mountain Institute stresses the importance of providing retrofits within a given window of opportunity. RMI offers 10 ways to time a deep energy retrofit which "can significantly improve both the economics and convenience of the energy improvements"[40]:

1) **Redevelopment or market repositioning:** Will require (perhaps over several years) significant capital expense to which the cost of a deep retrofit would be incremental and likely small in comparison.
2) **Roof, window or siding replacement:** Planned roof, window and siding replacements provide opportunities for significant improvements in daylighting and efficiency at small incremental cost, providing the leverage for a deep retrofit that reduces loads and therefore the cost of replacing major equipment such as HVAC and lighting.
3) **End (or near end) of life HVAC, lighting or other major equipment replacement:** Major equipment replacements provide opportunity to also address the envelope and other building systems as part of a deep retrofit. After reducing thermal and electrical loads, the marginal cost of replacing the major equipment with much smaller equipment (or no equipment at all) can be negative, as in the case of the Empire State Building.

[40] "Timing a Deep Energy Retrofit," Rocky Mountain Institute, http://www.retrofitdepot.org/TimingDeepEnergyRetrofit_More.

4) **Upgrades to meet code:** Life safety upgrades may require substantial disruption and cost, enough that the incremental investment and effort to radically improve the building efficiency becomes not only feasible but also profitable.
5) **New owner or refinancing:** New ownership or refinancing can put in place attractively financed building upgrades as part of the transaction, upgrades that may not have been possible at other times.
6) **Major occupancy change:** A company or tenant moving a significant number of people or product into a building or major turnover in square footage presents a prime opportunity for a deep retrofit, for two reasons. First, a deep retrofit can generate layouts that improve energy and space efficiency, and can create more leasable space through downsizing mechanical equipment. Second, ownership can leverage tenant investment in the fit-out.
7) **Building greening:** An owner or tenant-driven desire to achieve green building or energy certification may require significant work on the building and its systems, which may then make a deep retrofit economical.
8) **Large utility incentives:** Many utilities will subsidize the cost for a deep retrofit, covering initial evaluations through construction. In some regions, the incentives might be large enough to make the deep retrofit economical.
9) **Fixing an "energy hog":** There are buildings, often unnoticed, with such high energy-use or high energy-prices (perhaps after a major rate increase) that deep retrofits have good economics without leveraging any of the factors above.
10) **Portfolio planning:** As part of an ongoing energy management plan for a portfolio of buildings, an owner may desire a set of efficiency measures to be replicated across the portfolio. These measures can be developed from the deep retrofit of a typical building.

Property Survey & Audit

A thorough property survey will be necessary to create an accurate simulation model of the project. Understanding the existing building context is the first step to developing efficiency measures to test and value. Having aggregated energy usage, exterior microclimate analysis, as well as interior environmental conditions will ensure that energy simulation model can be calibrated to a high level of confidence before proceeding with intervention simulations.

Historical and existing functions as well as intent for passive performance can offer significant insight into the building's potential performance. Often times the original function of the building can be altered such that original passive design techniques are either rendered ineffective or deliberately altered in previous retrofits. Understanding the original performance strategies of the building can often lead to large efficiencies. Along the same lines, understanding why a building was retrofitted in the past can also provide insight as to what was unsuccessful about the original design.

Identification of potential onsite renewable power supplies should be defined. As property is surveyed, a preliminary renewable energy capacity is helpful to understand the limits that a net zero energy retrofit would require. Passive design for efficiency should always be the first design intent, but this will quickly help the designer to understand the scale of efficiencies needed if a net zero project is being pursued. In denser properties, this will also help to understand when a net zero outcome will not be an option.

Tenant Survey

Understanding the subculture of the tenant is also an primary consideration. Often times tenant's operation of the space can make or break planned energy efficiencies based on their level of commitment. Understanding this aspect will lead to plausible controllability measures focused either on occupant control or automation.

Social makeup of the users also dictates communication styles, functional operation of day to day activities, and overall program for the building. Maximizing an office's effectiveness as a business often comes down to understanding the tenant dynamic which includes an understanding of firm culture as well as mission. Understanding those approaches are key to developing a successful office space because it will help to maximize communication and social comfort for all of the occupants.

4

An Alternate Benchmark Approach

One of the first major hurdles to understand energy usage is knowledge of what types of energy intensities major building types are currently using. Although there is a broad understanding of this on a national level, local climate often plays a significant role in determining energy consumption. A comprehensive database of energy use by building type and climatic region is a significant need. Previously, the CBECS database has been the best option to fulfill this important role. Its data set has been widely accepted as the country's major resource for building energy consumption. Unfortunately, what has historically been updated on a 4 year cycle, is now almost a decade old.[41] Since its last update, much progress has been made, and the baselines depicted in CBECS are widely considered outdated. Current projections have the next version of CBECS being released in 2014.[42]

Other methods which consider the use of baselines have also surfaced. IECC and ASHRAE 90.1are such baselines. Expressed as a maximum allowable by code, they are both widely accepted, allowing multiple paths to compliance. Unfortunately, neither of these seem to be expressed as a static EUI. Rather, they are discussed through meeting or beating a set of prescriptive criteria for any given geometry of spaces. To further distort acceptable levels, they are updated every 3 years, getting stricter and stricter as time goes on. Although necessary, this method of compliance is quickly leading to dysfunction and misunderstanding within the industry.

IECC's approach, while somewhat effective in covering overall energy consumption, it is not telling the whole story of what is possible. Examples of projects showing NetZero efficiencies have proven that much more is possible and could be expected. Unfortunately, an understanding of the level of efficiency needed for a NetZero project is rarely understood, even within the design profession. Thus a revised approach will need to be disseminated to the industry in order to create an environment ready for more substantial efficiency levels.

[41] U.S. Energy Information Administration, "2003 Commercial Buildings Energy Consumption Survey: Sample Design " U.S. Department of Energy, http://www.eia.gov/emeu/cbecs/2003sample.html.
[42] "Cbecs Status," http://www.eia.gov/consumption/commercial/.

An Alternate Benchmark Approach

When considering energy efficient design of any kind it is necessary to understand expectations for the project. Typically, a baseline is considered to be an expectation or average rather than goal. Benchmarks are similar to a baseline in that they set appoint of reference. The reference could be a good, bad, or average example depending on context. Goals are developed based on the specifics of the site and the existing building's conditions. What is typically missing from this scenario is an understanding of best practice design within a particular climate and program. Without this understanding, it is difficult to set accurate energy goals for individual projects.

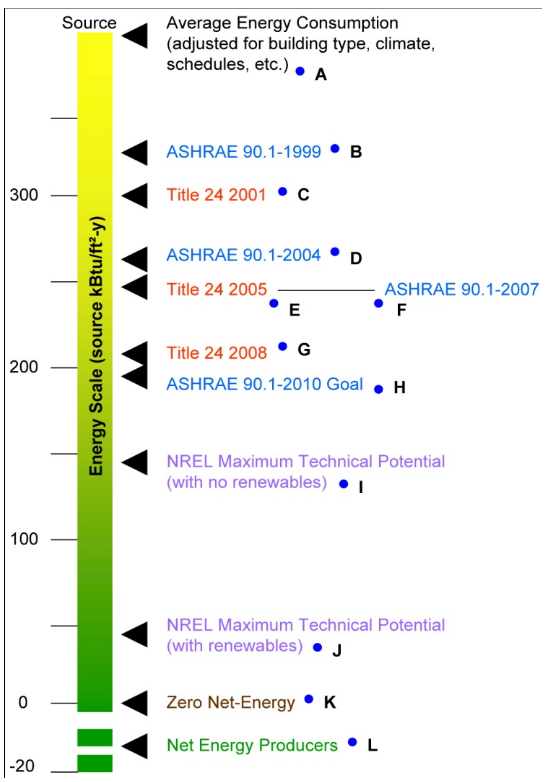


Figure 8 - Energy Benchmark Metric with Reference to Important Energy Milestones

What each region is in need of is a better idea not only of a static baseline, but what is truly possible to accomplish with today's technology. This can be established through a reference to an energy use metric within the baseline itself. By focusing on a system where the theoretical minimum energy use or technical potential becomes a part of the scale, further understanding of the energy use can be achieved. In order to do this, some reference to an Energy Use Intensity (EUI) (Btu/SF-yr) must be developed. Once established, a reference back to a static metric can become the norm. With this shift, a higher level of transparency will be achieved within the industry.

Similar alternative methods of benchmarking have already been developed. One such example (at the left)[43] uses the Energy Star percentile rating of 0-100, with 100 being the average energy consumption controlled for building type, and location; and 0 being a NetZero energy situation.

By utilizing a scale referencing so many different milestones, a true understanding of where the building lies with reference to each can be understood. With a systematic approach so inclusive, LEED, Energy Star, and ASHRAE standards/codes could be reconfigured so they all referenced a similar scale. Since this scale also has an EUI reference, the system also becomes much more understandable when comparing program types and climates.

[43] Architectural Energy Corporation Building Programs Unit, "Rethinking Percent Savings:The Problem with Percent Savings and the New Scale for a Zero Net-Energy Future, Cs 08.17," (Architectural Energy Corperation & Southern California Edison, 2009).

Technical Potential Approach

This project will argue that one of the most important notes within that scale is the reference a Technical Potential level of energy efficiency. This value represents the maximum efficiency possible using current technologies. The reference on this scale would show the lowest consumption per square foot recorded to date. This reference allows design professionals as well as owners to understand how close they are coming to a known maximum efficiency. As technology advances, the technical potential marker can move lower and lower on the scale.

The technical potential exercise was developed to reframe the question of energy efficiency. Practices like NREL and Rocky Mountain Institute have utilized the pursuit of a technical potential as a way to rework the process of attaining the highest efficiencies financially possible. Its process takes into account a thorough knowledge of building sciences and regional strategies to maximize the efficiency of a given space type. This first step in the process does not take into account cost constraints, merely what is technically possible given current known technologies.

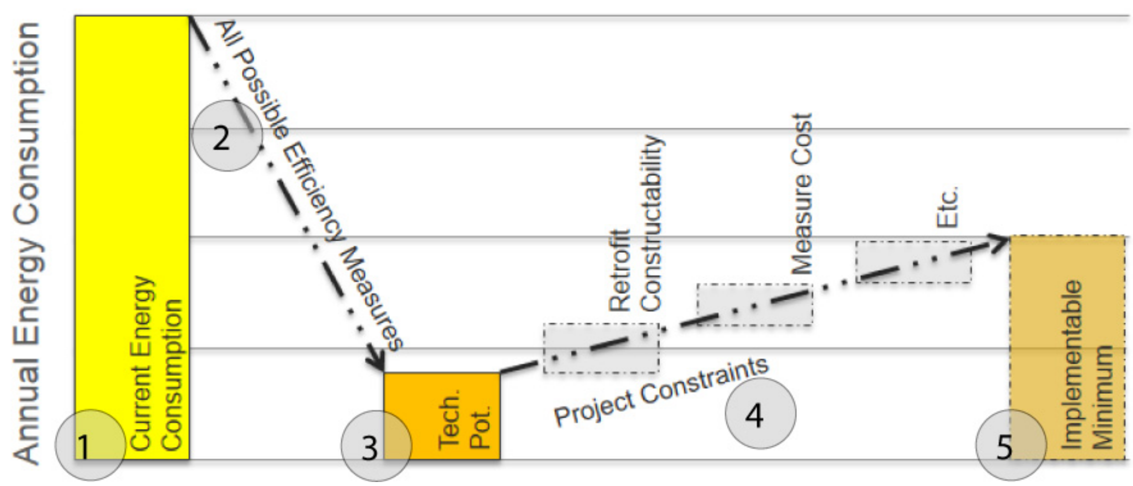


Figure 9 - Typical Building Energy Use Technical Potential Explanation

1. Determine the current energy use (or average) and end-use break down
2. Brainstorm efficiency targets and measures (including envelope performance, daylighting, system design, and system elimination)
3. Estimate the technical potential – the building's lowest technically feasible energy use
4. Analyze efficiency measures, taking into account non-negotiable constraints (i.e. time, financial, etc.)
5. Arrive at the implementable minimum

A retrofit project utilizing a technical potential as depicted in the figure above,[44] begins with a current energy use. As many measures as possible are considered to lower the energy use until a final estimate of the technical potential energy efficiency is reached. In a typical project, retrofit or new construction, cost and other real world constraints are added to the minimum as required to come to the implementable minimum.

Region is important in the technical potential estimate. This is particularly true of the Hawaiian Climate. Hawaii offers a very specific set of environmental criteria that are both highly docile in areas like change of temperature, and highly challenging in areas of humidity. For these reasons, Hawaii needs to have its own approach to energy efficient design if it's to reduce its dependence on energy sources.

[44] Rocky Mountain Institute, "Retrofit Initiative: Technical Potential," ed. Rocky Mountain Institute (Boulder2012).

5

Quantifying Investment and Benefit

Return on Investment is a key consideration of any owner when looking to make improvements to an existing property. It is even more so, when owners are considering a renovation for energy savings. Investment is made up of both cost and benefit. The delta of the two variables determine viability. While initial cost is often understood to a discernable degree, the industry is finding that true benefit is typically not ever fully understood. While both aspects of investment are very important to the process, understanding the financial benefit of a Deep Energy Retrofit, has become a barrier that the industry must overcome.

Through review of the building's aggregate use, Energy Efficiency Measures (EEM's) can be proposed and analyzed for cost effectiveness. Combining EEM's to replace systems at the end of their useful life can produce cost effective plans that reduce the property's energy footprint by 60% or more.[45] The key is to find measures that maximize efficiency while providing a symbiotic scopes of work. In this scope, the difference between success and failure comes down to how the designers are able to integrate the EEM's into effective bundles.

For any existing building retrofit, an understanding of standard methods owners use to fund such projects is essential. From these methods, rules for acceptable endeavors become more apparent and design – attainable.

Funding

Typically owners like improvements that have a repayment of 3-5 years. This is due to the types of financing available for such improvements. Since many of the significant improvements are not achievable within this timeline, other types of "financing vehicles" are becoming more and more plentiful. These include[46]

i. Federal

---

[45] Pike Research, "Retrofit Industry Needs Assessment Study," in *Retrofit Depot*, ed. Rocky Mountain Institute (Boulder: Pike Research, 2010). 4.

[46] Hillary Brown FAIA, "Toward Zero Carbon Buildings," in *The Post Carbon Reader: Managing the 21st Century's Sustainable Crises*, ed. Richard Heinberg and Daniel Lerch (Healdsberg: Watershed Media, 2010).329.

ii. State
iii. Local tax credit programs
iv. Utility rebates
v. Low interest loans
vi. On-bill financing from energy provider
vii. Direct installation programs operated by 3rd party organizations

These mechanisms should be sought wherever possible because they can often be the difference in the viability of the project.

Jurisdiction and Local Utility Incentives

When considering return on investment budgeting exercises, it is also necessary to understand federal, state, and local jurisdiction and utilities intentions for the property. In some cases, they can offer financial benefit for providing energy efficiencies or other amenities which are deemed in the city's best interest. These can be in the form of tax incentives or rebates and can significantly impact a project's breadth of scope or even viability.

HECO currently offers incentives for reductions in annual kWh reductions or reductions peak loading requirements. These include rebates for peak demand reduction ($125 / kW) and kWh energy savings ($.05 / kWh for a year – 5 years if untested).[47]

Another program, Hawaii Energy offers rebates and incentives based on individual measures. Rebates and incentives vary and need to be coordinated with the program, but benefits range from sponsorship of energy modeling studies to incorporation of efficient lighting.

Design Specific Budgeting

Many approaches have been put into place for determining the overall cost of a building retrofit. Originally, retrofits were only looked at as a maintenance cost (expense) and undertaken on a needed basis. In the past, these costs were generally considered a loss and the benefit portion was rarely understood. However, today rates are much higher and the value associated with reduced energy bills are starting to become a real concern within a building's operating overhead. Today the push to define the savings of a given renovation has evolved past the simple payback (initial cost / annual savings) to include adjustments for interest and profit that would have been made on the money if the retrofit had not been undertaken. Projections of energy cost increases over time sweeten the incentive. This approach leads estimators to 2 types of estimation – Life Cycle Costing and Life Cycle Analysis.

Building Retrofit for net savings is generally considered to be a Capital Investment. Capital Investments typically have 4 characteristics that are used to define them. [48] (1) Usually they are relatively large in relation to the organization's means and (2) their expense is usually returned over the life of the investment which is several-many years in length. (3)

---

[47] Eley Associates, "Hawaii Commercial Building Guidelines for Energy Efficiency." 2-6.
[48] Turner Capehart, and Kennedy., *Guide to Energy Management*, Sixth Edition ed. (Lilburn, GA: The Fairmont Press, Inc., 2008).132.

Capital Investments are irreversible. After the investment has been undertaken, changing paths ultimately results in a loss of funds. (4) This type of investment usually has many important tax benefits associated with it depending on financing that can help to increase viability.

Budgeting for Capital Investment costs are typically put into one of 3 categories: acquisition, utilization, and disposal.[49] Acquisition includes the purchase price, installation costs, training costs, as well as design and construction fees. Utilization costs are those which are energy, operations, and maintenance costs incurred throughout the life of the improvement. The costs can be positive or negative and directly (labor, materials) or indirectly (business costs effects within space) associated with the retrofit. Examples of indirect cost include: Salaries, Janitorial Costs, and Cleaning Supplies. Disposal quantifies the end of life concerns. These costs are incurred or recovered when the end of the retrofit's lifecycle has been met and when prep (salvage and demo) for the next effort is undertaken.

Acquisition and Disposal estimates are relatively easy to understand and quantify with an amount of experience in the process. The bulk of the effort in calculating a good Capital Investment versus a bad one is in determining utilization costs and comparing them to estimates of costs if bare minimum improvements were undertaken.

Employee Cost of Operation

The people that inhabit buildings will ultimately be the largest cost of the building/business operation. A typical business will follow an expense pattern of 1 energy : 10 rent : 100 salary. Therefore any project attempting to provide a return on investment for the owner/operator will need to concentrate on aspects of design that improve productivity within the work environment. However, value based on productivity increases looks to be difficult to accurately quantify. Experimental data often has many variables to consider and must quantified carefully. For these reasons, savings based on increased productivity are often presented as a separate line item when quantifying savings.

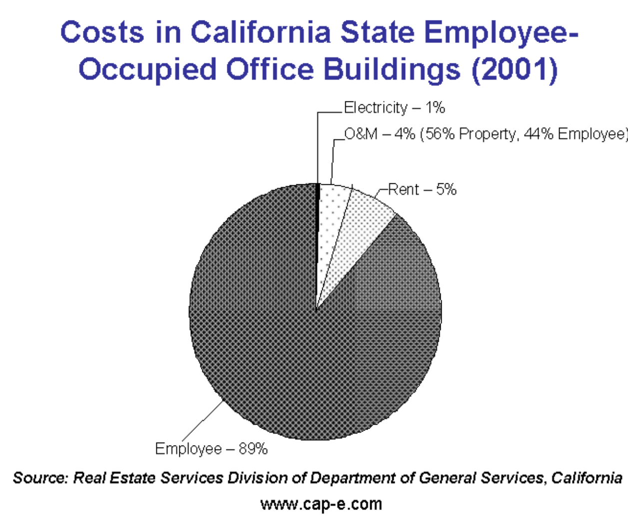


Figure 10 – Costs in California State Employee – Occupied Office Buildings (2001)

49 Ibid.

Category	20-year Net Present Value
Energy Savings	$5.80
Emissions Savings	$1.20
Water Savings	$0.50
Operations and Maintenance Savings	$8.50
Productivity and Health Value	$36.90 to $55.30
Subtotal	$52.90 to $71.30
Average Extra Cost of Building Green	(-3.00 to -$5.00)
Total 20-year Net Benefit	$50 to $65

Source: Capital E Analysis

Value Beyond Energy Cost Savings

Retrofitting for energy efficiencies and lower power usage often provide avenue to incorporate other benefits in the process. Issues associated with tenant health, contemporary usability, retrofit life cycle, water conservation, and approach to material selection also become important considerations. Identifying areas where these improvements can be provided should also be considered both for tenant and owner financial benefit.

The following list of benefits have been assembled based on extensive research into real world benefits seen in retrofit scenarios. These values can be used as justification for improvement in areas where strong corollaries exist.

Figure 11 - Value Beyond Cost Savings References

Benefit	Strategy Showing Benefit	Benefit Quantification
(+) Property Value	Energy Star Certification	(+) 5.8-26% (1,3,10,11,12)
	LEED Certification	(+) 9.9-25% (3,11)
	Thermal Efficiency	$18 increased valuation per $1 savings in energy costs (1)
(+) Occupancy Rates	Energy Star Certification	(+) 1.3-11% (2,10,12,13)
	LEED Certification	(+) 8-18% (2,13)
(+) Lease Rates	Energy Star Certification	(+) 3-15.2% (1,3,4,10,11,12,13)
	LEED Certification	(+) 5-17.3% (3,4,13)
(+) Tasks Performed, Speed, and Accuracy [Productivity]	High Performance Lighting	(+) 0.4-26.1% (8)
	Natural Ventilation	(+) 9.75-18% (5)
	Increased Ventilation	For the ranges of 14-30 cfm/person : 0.8% increase per 10cfm/person increase. For 30+ cfm/person: 0.3% increase per 10cfm/person increase (9)
	Increased Ventilation	0.1-14.4% (8)
	Individual Control of Task Air	(+) 0.5-11% (8)
	Increased IAQ	1% Increase Per 10% decrease in occupants dissatisfied with IEQ (9)
	Increased Pollutant Source Control	(+)4-16% (9)
	Temperature	0.37-0.43% performance drop per 1°F change in from optimal temperature (9)
	Temperature	(+) 5.5% for temperature control (8)
	Air Filtration	(+) 0.9-2.2% (8)
	Moisture / Humidity Control	(+) 0.2-0.4% (8)
(-) Absenteeism	Daylighting	(-) 15% (5)

	Natural Ventilation	(-) 71% (5)
	Increased Ventilation	(-) 35% in short term absence with doubling of ventilation rate (25 to 50 cfm per person) (9)
(-) Adverse Health Symptoms	Daylighting	(-) 13-34% (8)
	Mixed-Mode Ventilation	(-) 5.1-70% (5,8)
	Increased Ventilation	(-) 6.8-87.3% (8)
	Individual Control of Task Air	(-) 20-47% (8)
	Increased Pollutant Source Control	(-) 13.5-85% (8)
	Moisture / Humidity Control	(-) 15-72.5% (8)
(+) Retail Sales	Daylighting	(+) 0-40% (6)
(+) Test Scores	Daylighting	(+) 3-23% faster progression (7,5)
	Mixed-Mode Ventilation	(+) 7.5% (5)
	Increased Ventilation	(+) 5-10% when 30 cfm per student (9)

Corresponding Citations in the Table Above

1) Eichholtz, P., Kok, N., & Quigley, J. 2009. Doing Well by Doing Good? An Analysis of the Financial Performance of Green Office Buildings in the USA. Berkeley, CA. Retrieved March 16th, 2012, from http://www.rics.org/site/scripts/download_info.aspx?downloadID=19&fileID=5763.

2)Fuerst, F., & McAllister, P. What is the Effect of Eco-Labeling on the Office Occupancy Rates in the USA? Henley University of Reading, UK, FibreSeries, January, 2010. Retrieved January 30, 2012, from http://www.rics.org/site/scripts/download_info.aspx?fileID=5749&categoryID=523.

3) Fuerst, F., & McAllister, P. 2010. Green Noise or Green Value? Measuring the Effects of Environmental Certification on Office Values. American Real Estate and Urban Economics Association. Retrieved April 13, 2012, from http://sallan.org/pdf-docs/Fuerst_HPB_Value.pdf

4) Fuerst, F., & McAllister, P. 2009. New Evidence on the Green Building Rent and Price Premium. Henley University of Reading, UK. Retrieved January 30, 2012, from http://www.immobilierdurable.eu/images/2128_uploads/Fuerst_New_paper.pdf.

5) Gurtekin PhD, B., Hartkopf PhD, V., & Loftness FAIA, V. BUILDING INVESTMENT DECISION SUPPORT (BIDS). Carnegie Mellon University Center for Building Performance and Diagnostics.

6) Heschong Mahone Group, Inc. 2003. Daylight and Retail Sales. Technical Report for the California Energy Commission. Retrieved March 21, 2012, from http://www.h-m-g.com/downloads/Daylighting/order_daylighting.htm.

7) Heschong Mahone Group, Inc. 1999. Daylighting in Schools : An Investigation into the Relationship Between Daylighting and Human Performance. Technical Report for the California Energy Commission. Retrieved March 21, 2012, from http://www.h-m-g.com/downloads/Daylighting/order_daylighting.htm.

8) Kats, G. 2010. Greening Our Built World: Costs, Benefits, and Strategies. Island Press, Inc.: Washington DC.

9) Lawrence Berkely National Laboratory. Indoor Air Quality Scientific Resource Bank: Impacts of Indoor Environments on Human Performance and Productivity. Berkeley, CA. Retrieved March 30th, 2012, from http://www.iaqscience.lbl.gov/performance-summary.html.

10) Miller, N. & Pogue, D. 2009. Do Green Buildings Make Dollars and Sense? San Diego, CA. Retrieved March 16th, 2012, from http://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=4&ved=0CEQQFjAD&url=http%3A%2F%2Fwww.imt.org%2Ffiles%2FFileUpload%2Ffiles%2FBenchmark%2FDoGreenBuildingsMakeDollarsSense2.pdf&ei=ncFjT4_RGITlsQLyz6WcCw&usg=AFQjCNExXnO3AdOAg2FkXjKJaw3JOD3Z2A.

11) Miller, N.; Spivey, J.; & Florance, A. 2008. Does Green Pay Off? San Diego. Retrieved April 2nd, 2012 from http://www.costar.com/josre/pdfs/CoStar-JOSRE-Green-Study.pdf.

12) Pivo, G.; Fisher, J. 2009. Income, Value and Returns in Socially Responsible Office Properties. Retrieved April 13, 2012, from http://www.u.arizona.edu/~gpivo/Pivo_Fisher_Investment%20Returns%20from%20RPI%203_3_09.pdf

13) Wiley, J., Benefield J., & Johnson, K. Green Design and the Market for Commercial Space. The Journal of Real Estate Finance and Economics, Vol 41, Number 2, Pgs. 228-243. Retrieved January 30, 2012, from https://springerlink3.metapress.com/content/61tx7k61u5565183/resource-secured/?target=fulltext.pdf&sid=h5fr4fkdpkdsvpzotz3b04u2&sh=www.springerlink.com.

LCC & LCA

A life cycle costing (LCC) approach evaluates and integrates the benefits and costs associated with sustainable buildings. "Life cycle costing, often confused with the more rigorous life cycle assessment (LCA) analysis, looks at costs and benefits over the life of a particular product, technology or system. LCA, in contrast, involves accounting for all upstream and downstream costs of a particular activity, and integrating them through a consistent application of financial discounting. The result – if data is available -- is a current "cradle to grave" inventory, impact assessment and interpretation."[50] This is problematic to a property owner today because it does not portray a true perceived cost. It would portray all of the hidden costs that typically go unnoticed.

[50] Kats, "The Costs and Financial Benefits of Green Buildings: A Report to California's Sustainable Building Task Force," 8.

Examples of hidden costs are everywhere in the economy today. Smoking has been one popular example. Billions of unpaid dollars in expense have been identified and attributed to lost wages and higher health care costs. This translated to an additional $3.43 for each pack that was never paid for by those who manufactured them or by those who smoked them. It was pushed off to society to pay the bill in one way or another. This is the case for almost all production/consumption systems. The costs aren't shared evenly or fairly.[51] Firms looking to practice in a sustainable manner will need to find innovative ways to even costs until the overall system has a chance to catch up and start minimizing externalized costs.

The LCC approach admittedly is not the ultimate strategy for assigning value to a particular strategy, but it is a very thorough way to account for costs incurred by an owner when endeavoring on a construction project. It is important to note that both lifecycle costing and analysis are still evolving toward an agreeable baseline. Generally decisions on whether or not to undertake a retrofit based on budget concerns are based on a cost plus approach, but the LCC is a relatively reliable method to determine additional savings that are incurred under a budget minded approach.

The beauty of the LCC process is that a properly documented design, with the assistance of a construction cost estimator and a net present value exercise, can ultimately depict the amount of investment and returns that can be expected. This type of process allows for a type of design exploration not usually available. It is a method to determine the maximum ROI available to the owner. While this project will focus on energy savings and possibly a few outlying design values beyond energy cost savings, this process can be used to determine the financial value of all types of improvements - as long as each value tested has a definable savings.

Present Value and Net Present Value

Present Value: "PV is the present value of a future stream of financial benefits."[52]

Net Present Value: "NPV reflects a stream of current and future benefits and costs, and results in a value in today's dollars that represents the present value of an investment's future financial benefits minus any initial investment. If positive, the investment should be made (unless an even better investment exists), otherwise it should not."[53]

"Typically, financial benefits for individual elements are calculated on a present value basis and then combined in the conclusion with net costs to arrive at a net present value estimate."[54]

Net present value can be calculated using Microsoft's standard Excel formula[55]:

---

[51] Ibid, 90
[52] Ibid, 9.
[53] Ibid.
[54] Kats, "The Costs and Financial Benefits of Green Buildings: A Report to California's Sustainable Building Task Force."9.
[55] Ibid

$$NPV = \sum_{i=1}^{n} \frac{values_i}{(1+rate)^i}$$

The formula requires the following:

- **Rate**: Interest Rate per time period (5% real)
- **Nper (n)**: The number of time periods (20 years)
- **Pmt (values):** The constant sized payment made each time period (annual financial benefit)

The above author cited, Greg Kats, used a 20 year default for calculating the savings return. This is the typical default taken for building lifecycle savings, but is conservative given that many improved components will ultimately last much longer. This can be adjusted if proof of typical lifespans can be proven for the bulk of improvements. A 5% interest rate is also utilized. Since this report is now a bit dated, an alternate (lower) interest rate can be presumed.

Just as interest is now lower than in the above equation, energy prices continue to rise meaning that any factors or multipliers in relation to energy must also be adjusted based on timing. Using up to date estimation of these factors are imperative because they have a very large effect on the resultant Utilization costs and subsequent estimate of savings.

The interest rate or correlating discount rate, is important to understand because retrofits are typically justified in future energy or productivity savings – the key word being "future". Money today is generally considered to be worth less than money tomorrow. This is due to the potential earning power that money can have and the typical inflation that is seen on an annual basis. The addition of the 2 is commonly known as the discount rate.[56]

Some common methods for converting money between now and the future are listed below given the following factors[57]:

i =	Annual interest rate
n =	Number of annual interest periods (can be years)
P =	Present Value
A =	Single Payment in a series of n equal annual payments
F =	A future value (or future worth)

Some important points to note

1) The end of one year is the beginning of the next.
2) P is at the beginning of a year at a time as regarded as being the present
3) F is at the end of the nth year from a time as regarded as being the present
4) An A occurs at the end of the year of the period under consideration
   When P and A are involved, the first A of the series occurs one year after P
   When F and A are involved, the last A of the series occurs simultaneously with F

[56] Capehart, *Guide to Energy Management*.135.
[57] Ibid, 138-39.

Single Sum,	Future Worth	(F/P,i,n)	$F = A\left[\frac{(1+i)^n - 1}{i}\right]$
	Present Worth	(P/F,i,n)	$A = F\left[\frac{i}{(1+i)^n - 1}\right]$
Uniform Series,	Find P Given A	(F/A,i,n)	$F = A\left[\frac{(1+i)^n - 1}{i}\right]$
	Find A Given F	(A/F,i,n)	$A = F\left[\frac{i}{(1+i)^n - 1}\right]$
	Find A Given P	(A/P,i,n)	$A = P\left[\frac{i(1+i)^n}{(1+i)^n - 1}\right]$
	Find P Given A	(P/A,i,n)	$P = A\left[\frac{(1+i)^n - 1}{i(1+i)^n}\right]$

As stated above each of the above estimated factors are extremely important for determining an estimate with a high potential accuracy. In order to come to reliable results an estimator should rely on a well-defined methodology. The Guide to Energy Management offers their cost analysis methodology for using discounted cash flows:

1. Define the Alternatives: State the problem and list all of the feasible solutions or alternatives which have been selected for economic analysis
2. Estimate Relevant Costs: Each alternative from step 1 is defined in terms of cash flows. Vital information includes the amount, timing, and direction (benefit or cost) of each cash flow
3. Analyze the Alternatives: Identify the most cost effective alternative(s). Being able to show a positive number when added up dictates weather a EEM is cost effective.
4. Perform Sensitivity Tests: Since analysis is generally based on estimated costs, costs can vary, depending on uncertainty. Sensitivity tests allow the designer to see if uncertainties have a pronounced effect on the outcome.

Relevant costs are generally described as:

1. Estimate of Cash Flows
2. Estimate of Interest Rate or Discount Rate
3. Estimate of the Project Life

A Discounted Cash Flow analysis as described above is a prime example of an LCC or Life Cycle Costing method. The act of being able to accurately determine the value of a future sum of money allows the estimator to move past a simple payback period method and thus provide a much more accurate way of determining if a EEM is worth undertaking.

LCC Tools

Many tools have come available to streamline efforts of Life Cycle Costing efforts. Many spreadsheet programs like excel have some of the typical formulas programmed into them. Others take it a step further to begin to make the process of determining cost a bit more user friendly. It is important to note that the use of any LCC tool should be done so with great care and estimators must review formulas to ensure that calculations clear and correct. BLCC, Building Life Cycle Cost, was written for governmental agencies to conform to government standards.[58] The Rocky Mountain Institute has released a new tool called LCCAide which is free on their website and leads an estimator through the data entry and even supports sensitivity tests once a value has been determined.

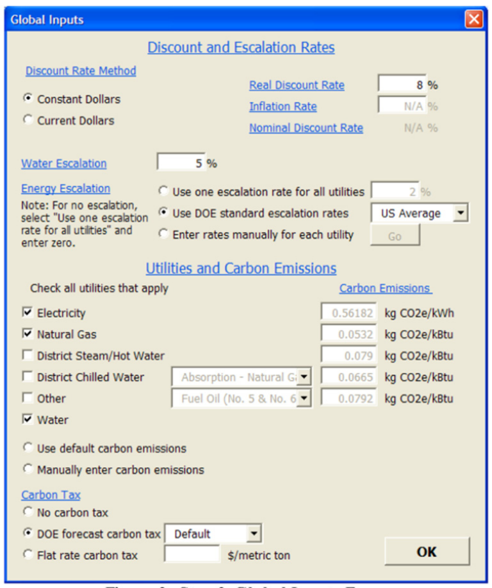


Figure 2. Step 2: Global Inputs Form

When analyzed, the program can provide cost analysis reports over time.

Figure 14 – Cash Flow Analysis

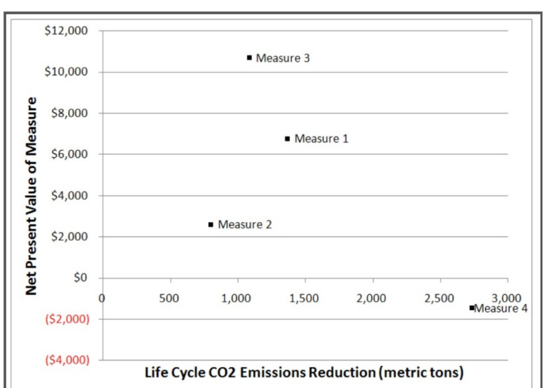


Figure 13. NPV vs. Carbon Reduction Example

LCCAide (Pictured at left and below) utilizes excel spreadsheets to create a commonly recognizable user interface. Data formulas are standardized with factors similar to what is depicted above in the present valuing calculations. LCCAide is set up to simplify the life cycle costing efforts involved with and existing building retrofit for energy savings.

Figure 12 – Adding ASHRAE Baselines

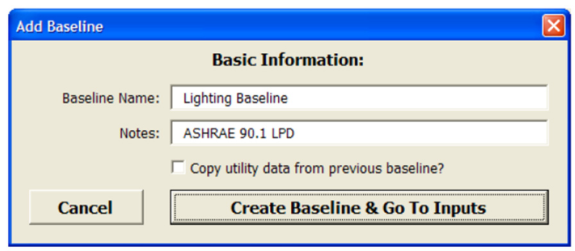


Figure 13 – LCCAide Data Input Example

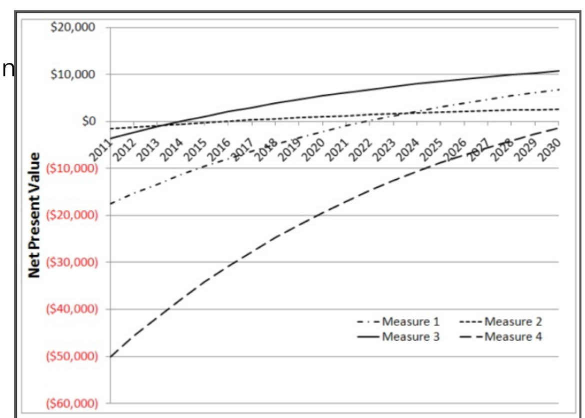


Figure 11. Cash Flow vs. Time Example

Figure 15 – Life Cycle Cost / CO2 Reduction Comparison

[58] Capehart, *Guide to Energy Management*.162.

Measure 1			
Notes	Note 1		
Baseline Description:	Baseline 1		
	Present Value	Annual Value	Qualitative Benefits
Baseline Initial Capital Costs	$50,000	$5,093	
Baseline Salvage Costs	$0	$0	
Measure Initial Capital Costs	($70,000)	($7,130)	
Measure Salvage Costs	$0	$0	
Net Measure Energy Costs	$26,775	$2,727	
Net Measure Water Costs	$0	$0	
Net Measure OM&R Costs	$0	$0	
Net Measure Rebates & Incentives	$0	$0	
Net Measure Other Costs	$0	$0	
Total	$6,775	$690	

Figure 7.16 – Breakdown of EEM Costs

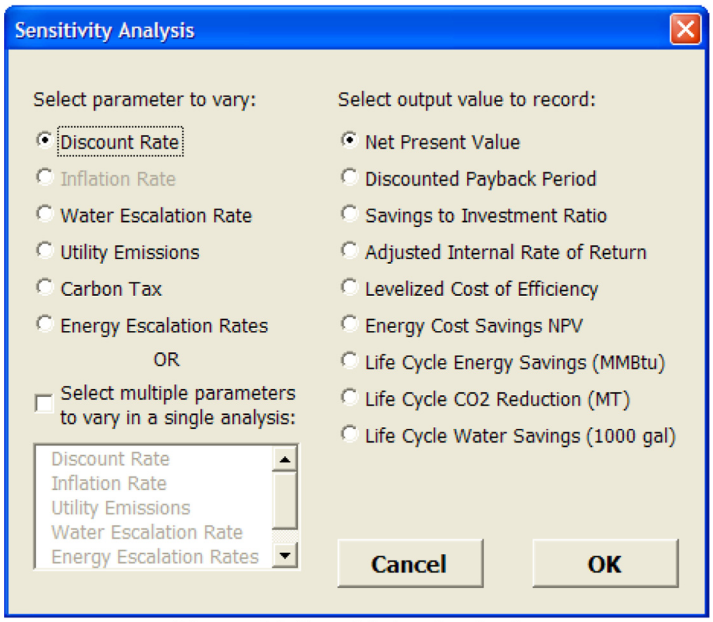


Figure 17 – Sensitivity Analysis Dialogue

Figure 16. Sensitivity Analysis

ROI and Investment Conclusion

Cost to Benefit Analysis is an ever present piece of any construction project. In a retrofit for energy efficiency, this analysis is typically one of the prime drivers in determining whether the project is undertaken, even though it has the potential to offer many other types of benefit.

Through management of the LCCAide file, Life Cycle Costing becomes a helpful and manageable task. With the help and insight it offers, deeper efficiencies and savings will be realized. Coupling with energy simulation, this tool will help owner and designer understand the implications of the decisions they make before the product is constructed. Furthermore, this process allows for an additional layer of iteration allowing the designer to readdress any measures which may test too costly.

6

Passive Design Strategies for Commercial Hawaiian Retrofits

As described earlier, an architect's biggest lever in the sustainability movement is the passive design of their projects. When buildings are truly passively efficient, they negate the need for energy use. Focus on this very straight forward fact should push all architects to strive to improve passive design methods. Currently, there are the strategies and technology to far surpass typical efficiency levels in today's constructed buildings. What is needed is a very thorough understanding of these strategies and their vast implications. This should be undertaken for the benefit of the building's energy footprint, the health/ well-being/ and general enjoyment of the occupants, and the financial bottom line of the building owners and tenants.

Natural Ventilation

Natural Ventilation, especially in Hawaii, shows the much potential for improvement in today's construction setting. The general "uncomfort" level within Honolulu's buildings is astounding considering the overall universal comfort level when sitting outdoors in the shade at any time during the year. The research to follow outlines potential times of comfort without air conditioning as well as guidelines to incorporate natural ventilation into design strategies.

The concept of thermal comfort must begin with an understanding of the human body. The body generally produces more heat than it needs, especially in a Hawaiian Climate. Four environmental factors typically determine how the body can eject heat: Air temperature, Humidity, Air Velocity, and Radiant Temperature. The combination of these 4 factors determine thermal comfort. Air Velocity can be introduced to offset the presence of warm temperature as long as relative humidity is less than 80%.[59]

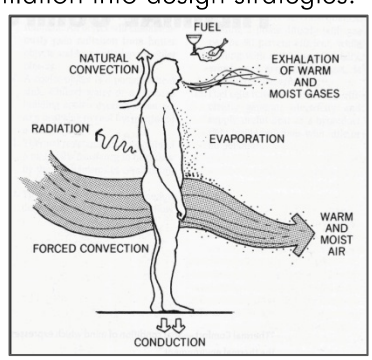


Figure 18 Methods of dissipating heat

[59] Norbert Lechner, *Heating, Cooling, Lighting Design Methods for Architects*, 2nd Edition ed. (New York: John Wiley & Sons, Inc., 2001). 56.

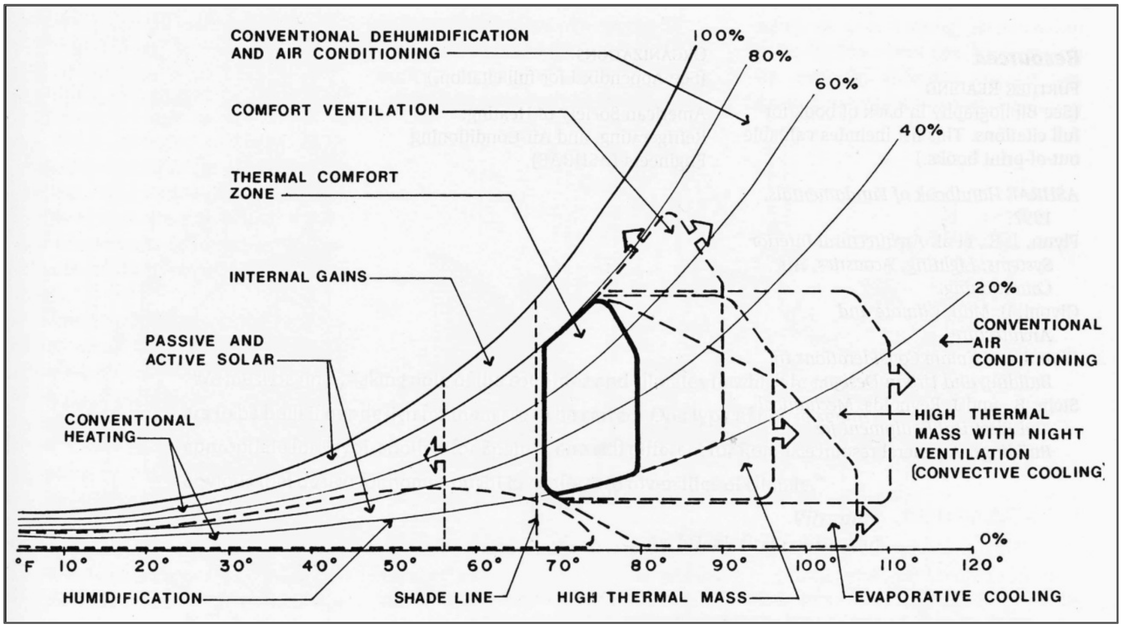


Figure 19 Psychrometric Chart Showing Summary of Design Strategies as a Function of Climate60

These relative adjustments are outlined graphically in a psychrometric chart. Introducing air velocity shifts the zone to allow for comfort.

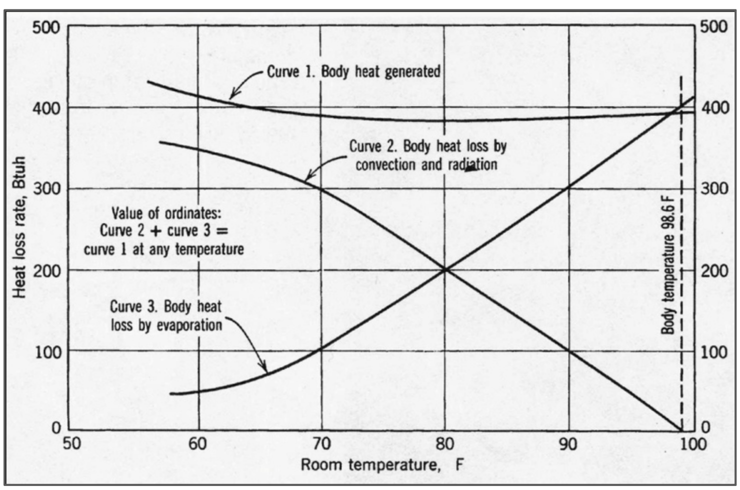


Figure 20 Potential for body heat dissipation from evaporation increases as temperature rises.

Since its main cooling mechanism is through the surface of the skin, evaporative cooling becomes more and more important as temperature increases. In the same manner, body heat loss by convection and radiation become less important.[61] Natural ventilation serves as a passive mechanism to speed up evaporative cooling and put the body into thermal comfort in warm temperatures. Given that Hawaii's temperature is warm for the majority of the year and temperature swings from day to night are relatively small, natural ventilation is a clear opportunity for indoor environments.

ASHRAE 55 is typically thought of as the standard for designation of thermal comfort. The standard is composed of accepted methods for determining thermal comfort. It is based

[60] Ibid. 63.
[61] Ibid. 52-53.

off of what has been termed a static model in which values for comfort are considered universal across indoor environments types, climates, and cultures. This method is considered to have a very narrow window of comfort, especially when applied to the Hawaiian context.

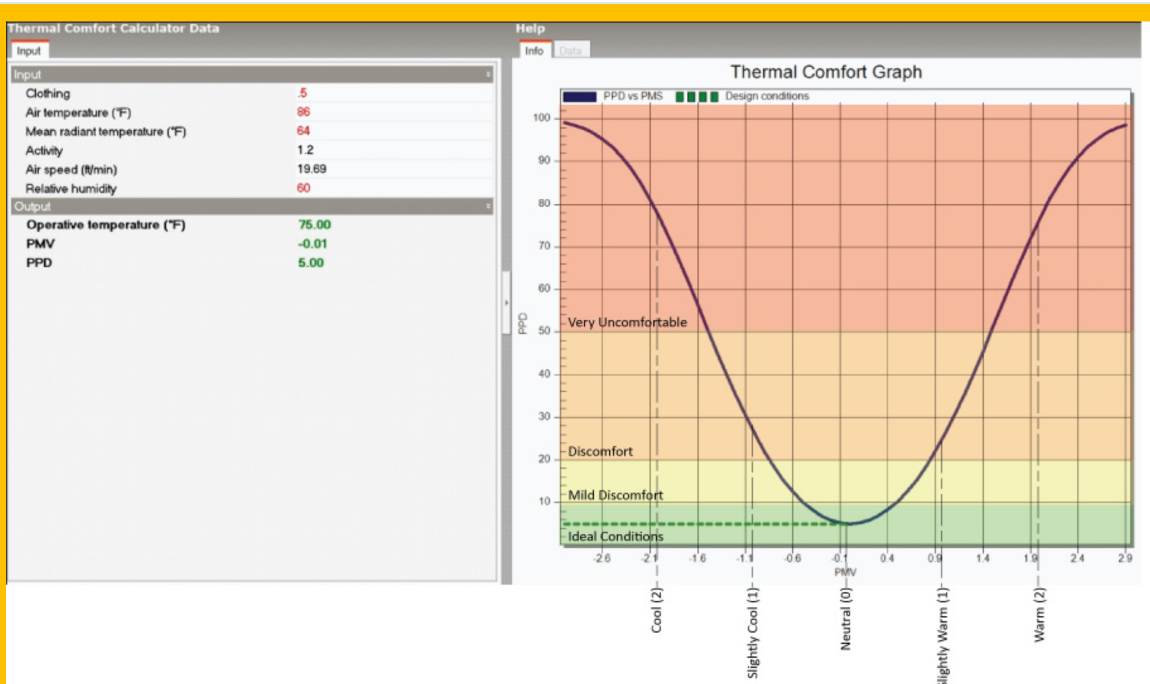


Figure 21 - Graphic PMV Comfort Tool from DesignBuilder. It is enhanced to show levels of comfort when comparing PMV and PPD.

Within the static or PMV-PPD method, comfort is established as having 90% of occupant satisfaction. ASHRAE 55 further depicts this methods comfort window in its figure 5.2.1.1 which is depicted below.[62]

[62] ASHRAE, "Ashrae Standard 55: Thermal Environmental Comfort for Human Occupancy," (Atlanta: ANSI, 2010).

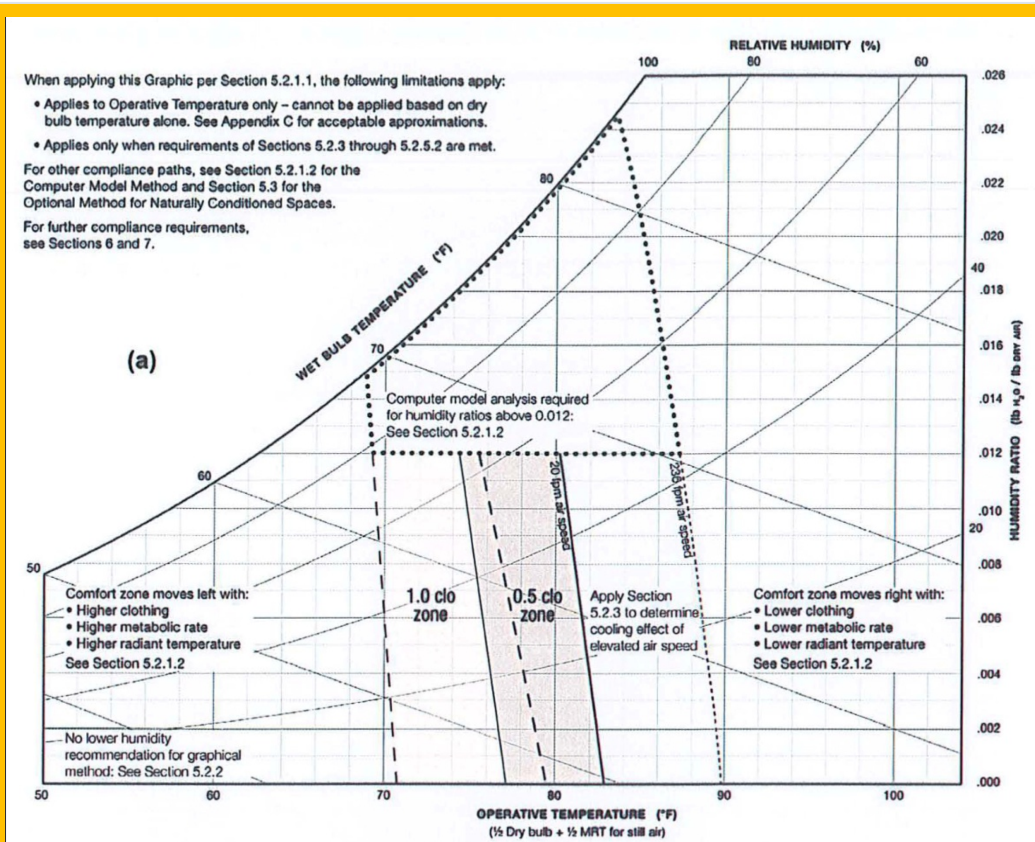


Figure 22 - Graphic Comfort Zone Method: Acceptable Range of Operable Temperature and Humidity

Research provided by Gail Brager and Richard J. de Dear offer a slightly different approach. Their findings offer the idea that the ASHRAE 55 standards are relatively good when considering an environment which is meant to be mechanically controlled. These standards however require energy intensive solutions and often preclude thermally variable solutions. They offer the approach that adaptive models based on behavioral, psychological adjustments should be considered in order to provide the most comfort and open the door to less energy intensive strategies.[63]

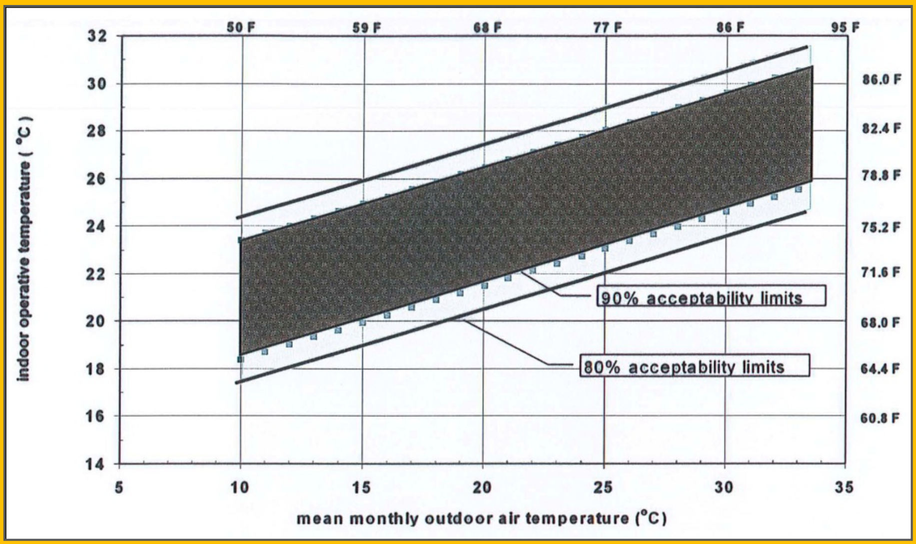
Based on this research, naturally ventilated indoor environments have been shown to provide comfort in a broader range of temperatures. It has also shown that people may even prefer them to mechanically controlled spaces. "For Hawaii, Brager's model means that people in naturally ventilated buildings can be comfortable at higher indoor temperatures as the outdoor air temperature increases" [64]

---

[63] Richard de Dear & G.S. Brager, "Developing an Adaptive Model of Thermal Comfort and Preference," *ASHRAE Transactions* Volume 104 (1)(1998), http://escholarship.org/uc/item/4qq2p9c6.

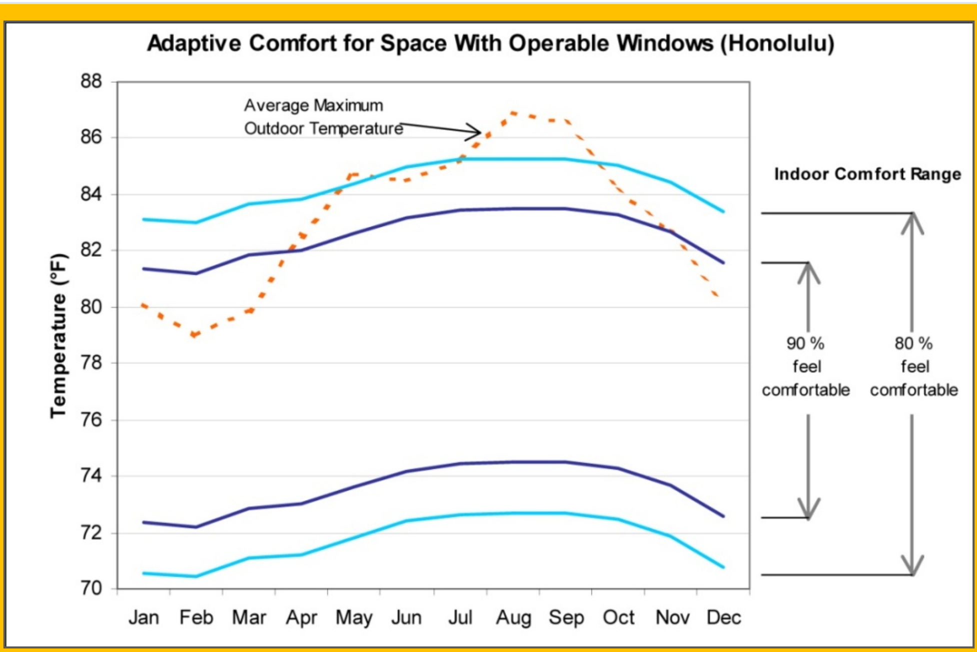
[64] Gail Schiller Brager and Richard de Dear, "A Field-Based Thermal Comfort Standard for Naturally Ventilated Buildings," *Collaborative for High Performance Schools (CHPS) Best Practices Manual, Appendix C* (Eley Associates, 2001). Available at www.chps.net. Also, Gail Schiller Brager and Richard de Dear, "A Standard for Natural Ventilation," *ASHRAE Journal,* vol. 42, no. 10 (October 2000), p. 21-28.

Figure 23
"Thermal comfort model from ASHRAE 55-2010 originally proposed by Gail Brager.."[65]



The graphic directly below[66] leads to the hourly synopsis[67] when overlaid on the typical annual swing of temperature. Brager's Research shows that in a typical naturally ventilated situation, occupants can be comfortable from November-April.

Figure 24 Indoor comfort range in naturally ventilated buildings in Honolulu



[65] ASHRAE, "Ashrae Standard 55: Thermal Environmental Comfort for Human Occupancy."
[66] Associates, "Hawaii Commercial Building Guidelines for Energy Efficiency." 2-3.
[67] Ibid. 2-4.

Figure 25 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.

HOUR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
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

Further analysis shows that uncomfortable hours are typically limited to a portion of the day. Incorporation of measures like ceiling fans provide additional air and/or careful use of building mass and landscaping to reduce heat loads and bring the indoor environment back into the adapted comfort zone.

Air velocity (feet per minute)	Probable impact on occupants
Up to 50 fpm	Unnoticed
50 to 100	Pleasant
100 to 200	Generally pleasant but causing a constant awareness of air movement
200 to 300	From slightly to annoyingly drafty
Above 300	Requires corrective measures if comfort and productivity are to be maintained

Figure 26 Ventilation Rates and Impact on Perception

Typical ventilation and air movement guidelines can be seen to the left.[68] While an increase in air velocity generally can help to increase comfort in warm temperatures, exorbitant amounts of breeze can be considered an annoyance. When air velocity is overlaid on the psychometric chart, more accurate perception of comfort can be derived.

Comparing Methods of Natural Ventilation

It is important to understand the benefits and challenges between natural cooling methods and mechanical. In review, three overlying approaches to ventilation come into play: Natural Ventilation, Mixed Mode, and Mechanically Ventilated.

[68] Ibid. 2-6.

In Hawaii natural ventilation is a viable approach and in many cases has been shown to often times be preferred to mechanical, but there are some major considerations to account for. Humidity is a major limitation for cooling capability.[69] Relative Humidity of less than 80% is needed for ventilation to be an effective form of cooling. High humidity can also be an air quality concern if allowed to infiltrate the indoor environment unchecked. In a Hawaiian climate, often times methods to interrupt the mold cycle must be introduced to avoid creating an unhealthy indoor environment. Natural ventilation has a more limited load capacity than mechanical cooling. Internal and Envelope loads must be designed carefully to mitigate loading.[70] Climatic limitations can be stretched by introducing locally enhanced air velocity like ceiling fans[71] Benefits to a successful passive system are large, including the ability to negate energy required by HVAC equipment often consuming over 43% of the typical office space in Hawaii.[72]

A mixed mode approach begins with intelligent façade design to manage thermal loads. Building systems are designed to maximize naturally ventilated hours. No "standard" for mixed mode has been developed. Each Building is unique. Some descriptive types and approaches have surfaced though. They include:

1. Zoned –
    a. Conditioned and naturally ventilated spaces are separated allowing for more control of conditioned areas
    b. Mechanical ventilation can occur in the hard to ventilate spaces
2. Concurrent mode – exist in the same time and space
3. Change-over mode – switch on and off at different times based on settings
    a. Cross over system will require interlock controls for window assemblies

Mixed mode systems are less climatically dependent than completely naturally ventilated buildings. They are feasible in a large variety of program types and should utilize significantly less energy than purely mechanically conditioned spaces if designed correctly. Clear description of how to operate the systems need to be in place. Tenant control becomes very important due to inherent problems if operated incorrectly. Designers should also be careful to ensure that openings can be tightly sealed. Signaling systems have been developed to alert occupants when windows are open. Deterrents to mixed mode systems include the fact that both natural and mechanical cooling systems must be designed and installed.[73]

Mechanical HVAC systems provide high amount of load flexibility. They can offer climatic independence allowing the interior environment the ability to be its own conditions including temperature, humidity, and air velocity. Detriments to HVAC systems include a higher level of comfort expectation. This is due to the psychological expectation that mechanical systems must perform better than passive.

---

[69] P. Alspach G. Brager, and D. H. Nall, "Natural Vs. Mechanical Ventilation and Cooling," *RSES Journal*, no. February (2011). 19.
[70] Ibid. 20.
[71] Ibid. 20.
[72] Eley Associates, "Hawaii Commercial Building Guidelines for Energy Efficiency." 1-15.
[73] G. Brager, "Natural Vs. Mechanical Ventilation and Cooling." 21-22.

> "Research also has shown that naturally ventilated buildings have reduced problems associated with IAQ. One of the most extensive studies was a cross-sectional analysis of 12 field studies from six countries in Europe and the United States, totaling 467 buildings with approximately 24,000 subjects. Relative to naturally ventilated buildings, the air-conditioned buildings (with or without humidification) showed 30%–200% higher incidences of sick-building-syndrome symptoms."[74]

Mechanical HVAC systems are typically extremely energy intensive and produce only minor temperature shifts in indoor environments in Hawaii.

Methods of Natural Ventilation

Cross ventilation is typically the most cost effective method of natural ventilation as long as the building form and plan layout are open enough to allow breeze continuous flow across the occupied area to the opposite or adjacent exterior walls of the building. It can be used to remove heat from space if the air outside is at a lower temperature than inside. Unfortunately cross ventilation typically does not adequately address thermal comfort in Leeward Hawaii year around because it does not have the capacity to cool air. Cross ventilation works by simulating a cooling effect and is brought on by air movement across the skin. Air coming into the building does not actually drop in temperature or humidity, so it cannot suffice for all seasons.

Designing for cross ventilation is a function of inlet and outlet areas, wind speed, and wind direction relative to the openings. As wind flows around the building, it causes high pressure zones on the windward side and low pressure zones on the leeward. Effective cross ventilation occurs with inlets at the on the positive pressure side and outlets on the negative. Ventilation rates are maximized when openings sizes are maximized and wind is perpendicular to the opening assembly.[75]

Typically form and interior plan layout has a big impact on the effectiveness of cross ventilation. Long facades perpendicular to the wind with a narrow depth are ideal. Single loaded or open plans help to increase efficiency allowing for an unimpeded steady stream of air across the space.[76] Room widths should be limited to 15-20' if openings cannot be provided on 2 separate walls.[77] In Hawaii, the Hawaii Model Energy Code Sec. 8.3 (e) requires that commercial spaces must either be sealed for air leakage or provide comfort ventilation requirements. Comfort ventilation is required as 12% of floor area or being wired for the use of ceiling fans.[78]

Design interventions on an existing structure can often help to inspire cross ventilation where it had not existed. Inlets and outlets must be properly located on each façade to create inlets at positive pressure locations and outlets at negative. Location and opening direction

---

74 Ibid. 19.

75 G.Z. Brown & Mark DeKay, *Sun, Wind, & Light Architectural Design Strategies*, 2nd Edition ed. (New York: John Wiley & Sons, Inc., 2001). 182.

76 Eley Associates, "Hawaii Commercial Building Guidelines for Energy Efficiency." 2-8.

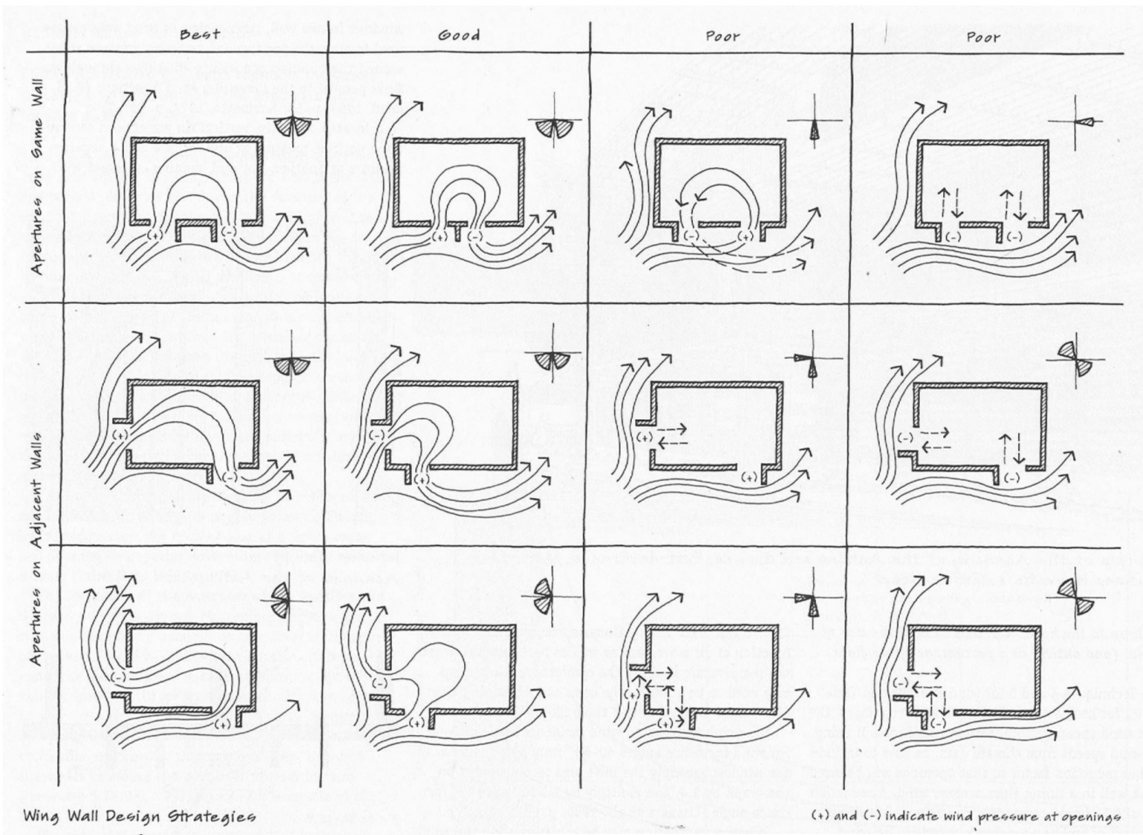
77 Ibid. 2-11.

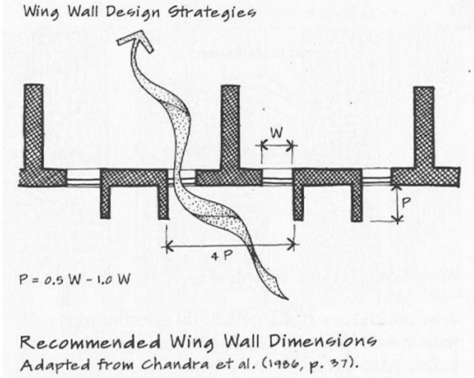
78 Ibid. 2-8.

generally dictate the effectiveness of a cross ventilation system. Typically inlets and outlets are designed at the same amount of area, but 25% larger outlets can inspire maximum air velocity if required.[79] If outlet area is smaller than inlet, outlet area will dictate the amount of airflow for the given locations. Ventilation should be provided at occupant level for evaporative cooling.

Fins, wing walls, and parapets can be introduced to help direct air flow into and out of building. Careful introduction and placement of these interventions can create highly localized pressure zones which can serve to direct currents into and out of a structure.

Figure 27 Wing Wall Design Strategies[80]





When considering these types of strategies, it is necessary to consider the spacing of interventions in order to create effective pressure pockets.

Figure 28 Wing Wall Spacing [81]

When considering methods of cross ventilation in a Hawaii climate it is also necessary to

[79] Ibid. 2-12.
[80] DeKay, *Sun, Wind, & Light Architectural Design Strategies*, 184.
[81] *Sun, Wind, & Light Architectural Design Strategies*. 183.

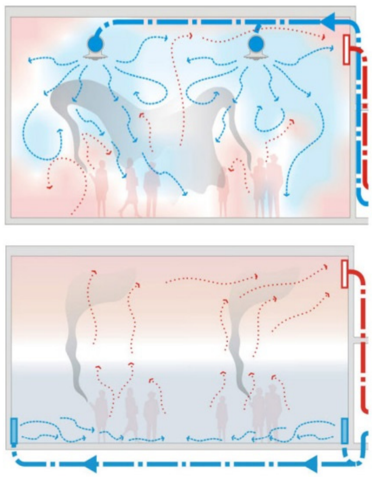
ensure that the building's daylighting system is minimizing the solar heat gains incurred. This is a necessary step in creating a successful indoor comfort level. Steps should also be considered to cool incoming air before it reaches the interior of the structure. Methods of cooling can involve providing a body of water upwind or a shaded intake area.[82] An exterior shaded thermal mass could also help to cool breezes as they enter the space.

Construction costs for a cross ventilation system can typically be low to moderate in comparison with a typical sealed building dehumidified through cooling with reheat. Operable windows have been quoted as being 5-10% more expensive than fixed. These strategies can offset or downsize the need for a mechanical system. Payback on a cross ventilation system has been quoted at 1-4 years.[83]

Stack Ventilation is another approach that can be utilized in lieu of cross ventilation if the building or design does not lend itself toward successful cross vent strategies. A less common approach, stack ventilation or buoyancy driven ventilation systems, begin to offer solutions which can alter temperatures by evacuating heat more quickly than otherwise. Stack ventilation also can be used in conditions that do not provide adequate wind driven ventilation. In this strategy, warm air rises and exits through openings at the top of the room. This air is replaced by cooler air entering in the lower portion of the room. The rate which air moves through the room depends on the vertical distance between inlets and outlets, their size, and the difference between the outside air temperature and the average inside air temperature over the height of the room.[84] Stack ventilation can occur through open atrium spaces or through dedicated chimneys to lead air to the exterior. The hotter the air, the faster it rises. Successful stack ventilation can introduce heat loading to solar chimney or high atrium space through convection or solar gain to inspire quicker ventilation rates. It too will only introduce air at the same temperature as the exterior.

---

[82] Eley Associates, "Hawaii Commercial Building Guidelines for Energy Efficiency." 2-13.
[83] Ibid.2-9.
[84] Brown & DeKay, *Sun, Wind, & Light Architectural Design Strategies*. 185.



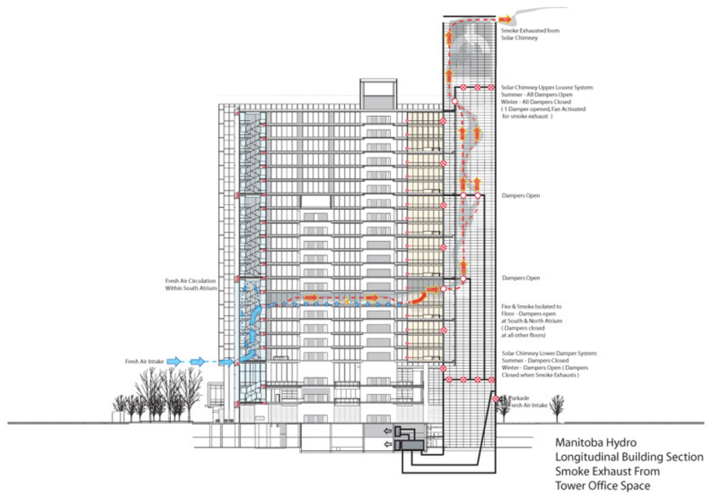


Figure 29 - Stack Effect Concept for Interior Space (Right)[85]

Figure 30 - Stack Effect Concept for Whole Building Passive Ventilation (Left)[86]

Stack ventilation requires a 5' minimum difference between inlet and outlet for a workable temperature gradient. This means that some effect can be seen in within room circulation by providing slightly higher ceilings. Much higher differences in elevation are often used to speed ventilation rates to a successful rate. The airflow induced is directly proportionate to the difference in elevations between inlet and outlet. Existing stairwells can offer a path for ventilated air as long as they are not fire rated. This method of ventilation will often begin to dictate some of the massing and aesthetics of the building.[87]

When using stack ventilation, inlets and outlets should be of equal area. Air flow rates will be dictated by the smaller area between the two. Horizontally oriented intakes and outlets generally allow the elevation differences to be maximized, so they should be utilized. Careful consideration should be taken to make sure that ventilation streams cross inhabited spaces to promote evaporative cooling. Careful control of solar heat gains is especially necessary with this approach since the temperature gradient is used to inspire air movement. A cool air intake is also a good design strategy. This can be induced by drawing air in through a shaded lanai or by pulling it over a body of water.[88]

Benefits for properly designed and operating cross and stack ventilation systems are vast. In reference to energy, significant reductions in cooling loads are possible. HECO currently offers utility rebates for peak demand reduction ($125 / kW) and kWh energy savings ($.05 / kWh for a year – 5 years if untested)[89]. Contaminants can be quickly expelled from the indoor air causing an increase in indoor air quality. Higher thermal comfort levels across higher percentages of people can often be achieved due to noted psychological effects of passive systems. Increased controllability is often a side effect of natural ventilation

[85] KPMB, "Displacement Ventilation," Integrate Design Consortium, http://manitobahydroplace.com/Integrated-Elements/Displacement-Ventilation/.
[86] "Solar Chimney," Integrated Design Consortium, http://manitobahydroplace.com/Integrated-Elements/Solar-Chimney/.
[87] Eley Associates, "Hawaii Commercial Building Guidelines for Energy Efficiency." 2-17.
[88] Eley ibid.
[89] Eley ibid. 2-6.

strategies. Intangible benefits are evident such as visual and tactile connections to the outdoors. These factors have been linked to increased productivity and general enjoyment of the space by tenants.

Daylighting

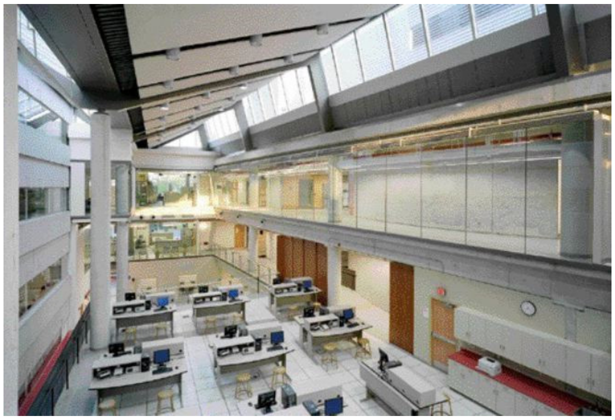


Figure 31 - Toplit Clerestory Example[90]

Figure 32 - Sidelit Atrium Space Example[91]

In the times up to the mid 20th century, daylighting was considered essential to quality architecture. In the second half of the 20th century, daylit spaces became an afterthought to electric lighting and were often not even acknowledged in lighting calculations.[92] Today we are witnessing a resurgence back to daylighting design for a multitude of factors including more efficient energy footprints, better color rendition indoors, access to views as a byproduct, and increased productivity within the space.

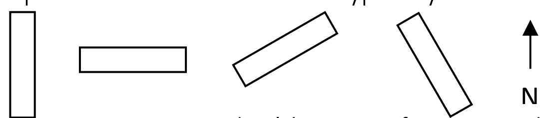
Providing daylighting for occupied indoor spaces has proven to outperform electrical lighting energy wise.[93] It provides savings through reduced loading from electrical lighting, but daylighting has also been shown to cause less thermal heat gain when shaded properly in the Hawaiian context. This fact has shown that increased daylighting can actually lead to reduced HVAC loads, smaller mechanical equipment, and smaller duct sizes. Daylighting and natural ventilation often complement each other as window apertures are often the tool used to stimulate both. This coupled with the benefits associated with view windows and connection to the outdoors where possible, will ensure that occupants are benefitting from the best possible quality of space. Utilizing daylighting strategies for interior space should be utilized in all projects as long as designed properly. Following the strategies below will help to ensure they are.

The Hawaii Model Energy Code limits the maximum Relative Solar Heat Gain for various window-wall ratios. RSHG factor is a function of the shading coefficient of glazing and exterior shade screens and/or louvers, interior shading devices, fins, overhangs. Individual windows can exceed RSHG limits, but the area-weighted average must be less than the maximum limit. The code considers multiple orientations which must be calculated separately based on different coefficients. North is calculated on its own and an average of the South, East, and West makes up the other factor. Most buildings require either shading or

[90] "Day-Lighting: Top-Lighting," in *Veridis* (Wentworth Institute of Technology).
[91] Royal Bank of Scotland Americas Headquarters by Roger Ferris + Partners, United States to, http://www.topboxdesign.com/royal-bank-of-scotland-americas-headquarters-by-roger-ferris-partners-united-states/royal-bank-of-scotland-americas-headquarters-interior-daylight-dimming-systems-office-space-lighting/.
[92] Lechner, *Heating, Cooling, Lighting Design Methods for Architects*. 364-365.
[93] Eley Associates, "Hawaii Commercial Building Guidelines for Energy Efficiency." 3-6.

tinted glass. The Skylight Shading Coefficient limits skylight's maximum area. (Horizontal glazing area) X (% roof area covered by skylights) must be less than or equal to .025.[94]

Controlling daylighting begins with the overall form and orientation of the building. For daylighting, large South and North facades are desired to for easiest control. This can be contradictory to Natural Ventilation strategies which request that the building's largest facades be perpendicular to predominant winds which typically come from the Northeast.



This is often a nonpoint in an existing building retrofit setting where the overall orientation has been selected for you. Strategies often come down to how the architect can adapt the existing form to obtain the best performance and indoor environment.

In Hawaii, design interventions need to begin with the best methods to minimize direct beam solar gain. Shading apertures including horizontal shades on N/S facades as well as Vertical Shades on E/W should be considered if not already in place. Direct sunlight if unimpeded can create unwanted heat and glare. It should be diffused or reflected light minimizes these concerns.

Interventions will need to provide a handful of design criteria in reference to daylight where not already accomplished with the original design. Uniform indoor illumination, elimination of glare, integration with electric lighting, organization of program to benefit from daylighting, and a level of controllability will be needed for successful daylighting.

Weather design for daylight or electric, correct lighting levels need to be maintained. Vertical and horizontal uniform illumination should be strived for in most situations, although the threshold for the vertical component will change for certain uses. An efficient design will need to focus on maximizing correctly shaded daylight for the most hours of the day possible. For office, uniform illumination of 20-30 foot candles is required for typical spaces. Task lighting can be utilized in areas of focused activity to raise levels to 50-75 foot candles.[95] Contrast Ratios between the task and its surroundings should not exceed 3:1 and brightest field should not be more than 5:1.[96]

Strategies for efficient daylight illumination include:[97]

1. Use of uniform top lighting where possible through skylights
    a. Wall Wash Toplighting
        i. May be possible to illuminate for task lighting near wall washed elements. To avoid glare, do not position work planes directly beneath toplit areas.
        ii. Consider balancing light of space by washing opposite walls to provide uniformity across space

[94] Eley ibid. 3-5.
[95] Eley ibid. 3-10.
[96] Eley ibid. 4-7.
[97] Eley ibid. 3-10.

iii. Skylights perform better in overcast or east/west wall washing situations

2. Where toplighting is not possible, use a combination of view windows with high side lighting
3. Paint walls white or very light colors to maximize the daylight. Use saturated colors as accents in small amounts to promote daylight.
4. Provide exterior elements such as walkways or horizontal light shelves to bounce light into space
    a. "Lightshelves and louvers can be located on the exterior of a building, the interior or both. Exterior lightshelves bounce the high-angle summer sun into the space, and also shade the lower window, which helps to stop solar heat gain before it enters the building. Interior lightshelves reflect the low angle winter sun into the space, block direct sun penetration, and reduce glare from the upper glazing."
    b. "Used on one wall, this approach creates a decreasing gradient of useable daylight of roughly 2.5 times the clerestory head height into the space."
    c. "Lightshelves and louvers may be opaque or translucent. If opaque lightshelves are not combined with a lower view window, there may be a dark space on the wall directly under them. To address this, leave a gap between the lightshelf and the wall or use electric lighting to brighten this wall. Translucent shelves provide a soft light under them but must be designed carefully so that occupants with a view of their underside aren't bothered by glare."
5. Reflective or refractive surfaces can redirect light toward ceiling to illuminate surface
6. Experiment with side surfaces of fins to promote bouncing of light into space.

Quality of lighting must be considered while designing to correct illumination levels. The difference between a soft, uniform light across a space and a light source from a single unshielded point can provide the same amount of illuminance, but can have vastly different comfort levels for occupants. Glare through direct line of sight to the light source / sun or strong reflection is most often the cause of light quality issues. Efforts to anticipate and reduce/eliminate glare must be considered in each space. Strategies to avoid glare include:[98]

1. Use louvers / blinds / drapes to control bright daylight and bright surfaces
    a. Exterior work best to avoid heat gain on interior
    b. Where fixed, shade systems need to be designed to avoid direct beam penetration into space
2. Avoid singular punched holes in walls or ceiling which create large contrast on wall
3. Orient shiny surfaces such as computer screens and marker boards to avoid glare
    c. Computer screens parallel or 45 degrees to windows
    d. Polarizing filters or meshes can be applied to window to reduce glare

Unless the space is under lit by daylight, controllability becomes another important consideration. This can give occupants the ability to dim / brighten their space based on

[98] Eley ibid. 3-11 - 3-12.

personal preference. Controllability can be somewhat easily accomplished by shades or blinds and are available in manual or automatic operations.

For maximized efficiency, sensored lighting has been shown to provide the best results. Smart lighting such as automatic daylighting controls, which use photosensors to respond to light levels, cost more than manual controls but ensures savings. Careful placement of fixtures in the space must also be considered to avoid electric fixtures from blocking daylight. [99]

Planning for integration of Daylight / Electric Lighting begins at the programming level of design. Methods of integration include zoning of programmed spaces to maximize daytime activity's exposure to daylight. Layout of the space has as much to do with efficient lighting as controllability / automatic sensored zoning of electric fixtures to reduce loads during the day. Some considerations for layout of space:[100]

1. Rule of thumb – daylight penetration is roughly 2 ½ X the head height

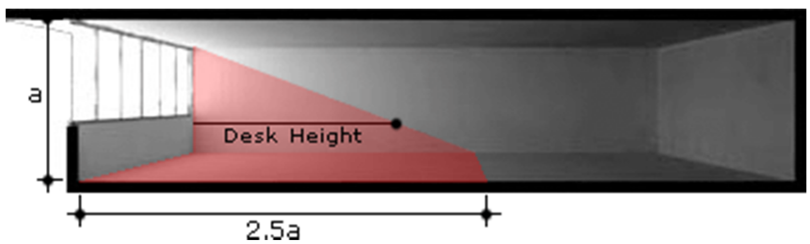


Figure 33 - Useful Daylight is Roughly 2 1/2 times the height of the window head[101]

2. Locate areas with predominantly visual tasks to limit glare
3. During space planning determine spaces that will benefit most from daylight and locate accordingly
    e. Locate large spaces which will require daylighting on the top floor. This will allow them to be top lit
    f. Spaces that are less wide can be located on the periphery of floors below to take advantage of sidelighting
4. Introduce Light Shafts / Courts such that e/w orientations receive diffused light

While daylighting is much more efficient than electric lighting, it is still a thermal energy drain on the space and window assemblies are generally more expensive than opaque construction. For these reasons apertures should be sized accordingly to make efficient use of lighting. Layout methods of pattern and frequency should be optimized to provide correct lighting levels for the desired program. Type of glazing is also a factor in determining correct lighting levels.[102]

Daylighting's effects on occupants are numerous. Daylighting provides better light than electric when glare is controlled. Most daylighting has the added benefit of creating a connection to the outside world, enhancing the bond with both the natural world and society. The effects of views on the psyche are vast and will be undetermined by this study but have

[99] Eley ibid. 3-14 - 3-15.
[100] Eley ibid. 3-15.
[101] "Daylighting: Design Strategies," (Natural Frequency, 2013).
[102] Eley "Hawaii Commercial Building Guidelines for Energy Efficiency." 3-16.

been referenced in a multitude of studies as creating spectacle, enhanced value of space, as well as increased productivity of occupants.

When considering view windows, designers need to be careful of large expanses of unprotected glass as they have a tendency to produce glare. North Facing windows often provide the least glare concerns. Time sensitive spaces can be oriented on East/West sides of spaces with view windows to reduce heat gain, but east/west windows should be limited in more universal uses of space. Due to view windows location on the façade in relation to occupants, they are not most effective daylight delivery system. Illuminance quickly drops off in section. View window strategies need to be combined with daylighting to produce efficient lighting. This is the only way to minimize energy consumption. When exterior shading is not available, use better quality glazing to increase efficiency.

Modeling of daylighting techniques has come relatively far in producing reliable results. What began with physical models and photographs in the sunlight has evolved into computer modeling which can show both accurate layouts of footcandles by square foot and even depict glare based on the light source location and intensity. Programmed lighting models using Energy Plus and Radiance will be utilized to portray lighting simulations for this effort.

Windows

Excellent window design is essential for good daylighting and thermal comfort within an interior space in Hawaii. The strategies below outline the types of glazing that should be utilized in daylighting and view scenarios, as well as ways to mitigate direct beam heat gain through external and internal shades.

When designing for daylighting or views the Solar Heat Gain Coefficient (SHGC) is one of the most important considerations. Solar Heat Gain Coefficient is:

> "The ratio of solar heat gain entering a space through the fenestration area to the incident solar radiation. Solar heat gain includes directly transmitted solar heat and absorbed solar radiation, which then enters the space through reradiation, conduction or convection.
>
> A window that allows no solar gain would have an SHGC of zero, while perfectly transmissive glazing would have an SHGC of 1.0 (these extremes are both theoretical and are not possible in the real world)."[103]

Controlling the SHGC with reference to the Visible Light Transmittance (VLT) becomes the paramount consideration with glazing. In general, a low SHGC and a high VLT are desired in Hawaii. SHGC should be the prime consideration because it will determine the energy performance. However a high VLT will determine how much light is let into the space which is also an important consideration.

Some glazing with tint can have a high SHGC but low VLT which is not desirable for daylighting. In order to best control the ratio, certain tints or spectrally selective Low-emissivity

[103] Eley ibid. 5-2.

glass should be selected. Below are some specific terms to glazing with reference to approaches which need to be considered in a Hawaiian climate.

> "Heat-absorbing tints. These tints are available in a range of colors. Some tints, typically blue or green, offer better visible light transmittance while providing equal or better solar control than gray or bronze tints. Consider using these blue or green tints in daylighting designs. All heat-absorbing tints get hot in direct sunlight, which is an important concern in buildings where occupants work close to windows."[104]
>
> "Heat-reflecting coatings (including low-e). Several types of coatings are available. Some appear mirrorlike, while others are designed to reflect as much heat as possible while also appearing as clear as possible. The latter type of coating is called "spectrally selective" and is a better choice for simultaneously providing daylight and solar control. Some — but not all — of these heat-reflecting coatings will have low-emissivity (low-e) properties. Low-e coatings reduce the radiant heat transfer between two surfaces, for example from one pane to the other in a double-pane glazing. Low-e coatings improve a window's insulation value (lower U-factor), but in Hawaii, SHGC is a much more important concern. Therefore, when specifying a heat-reflecting window, it's not adequate to specify a low-e window; it's critical to specify the desired SHGC and VLT.
>
> Be aware that not all low-e windows have a low SHGC. There are several types of low-e coatings: some reduce solar gain while others allow solar gain. Low-e coatings that allow solar gain are not desirable in Hawaii.
>
> Often these heat-reflecting coatings are applied to one of the surfaces facing the air gap in a double-pane window. This is necessary to protect the coating from scratches that might occur if it were exposed. While it wouldn't normally be cost effective to add a second pane of glass in Hawaii, double-pane windows are necessary if you want the performance benefits of higher performance coatings."[105]
>
> "Laminates. Either heat-absorbing or heat-reflecting plastic film can be sandwiched between two sheets of glass to create a single pane. To provide further solar control, heat-absorbing glass can be used. Laminated glazing provides stronger resistance to lateral forces and is recommended in hurricane prone areas."[106]
>
> "Retrofit films. Plastic films similar to those used to create laminated glass can be applied to the surface of the glass. This should be considered only as a retrofit measure because the exposed film is not as durable as glass."[107]

---

[104] Ibid. 5-4.
[105] Ibid
[106] Eley Associates, "Hawaii Commercial Building Guidelines for Energy Efficiency."5-4.
[107] Ibid

Visible light transmittance (VLT)
"is the ratio of visible light transmitted through the glazing to the total amount of light that strikes the glass. Single-pane clear glass has a VLT of about 0.9, while highly reflective glass can have a VLT as low as 0.05."[108]

U-factor
"measures the heat flow through a window assembly due to the temperature difference between the inside and outside (U-factor = 1/R-value). The lower the U-factor, the lower the rate of heat loss and of heating energy consumption. However, U-factor is more critical in areas that have very hot summers or cold winters. In Hawaii, where the weather is not extremely hot or extremely cold, low SHGC is more important than low U-factor."[109]
Efficacy
"is the ratio of VLT to SHGC. The higher the efficacy, the better the fenestration product is at allowing daylight in and reducing solar gain. Glazing materials with a high efficacy are known as "spectrally selective" because they selectively transmit radiation in the visible portion of the spectrum while blocking solar radiation in the ultraviolet and infrared spectra. Spectrally selective products typically have a VLT to SHGC ratio greater than 1.3."[110]

Projection factor (PF)
"is the ratio of an overhang's horizontal projection to the vertical distance from the windowsill to the bottom of the overhang. The overhang projection is measured as the perpendicular distance from the window surface to the overhang's outside edge."[111]

In the design of windows, it is typical to consider strategies of direct beam mitigation before considering the glass. If daylighting goals can be met by orienting and locating windows in a manner that makes external shading easily attainable, then it is possible that more value can be added to the project by shading externally and proceeding with a lower grade glazing system. In this manner, approach to glazing selection and finding the optimum design solution based on performance, quality, and cost largely becomes an integrated design technique.

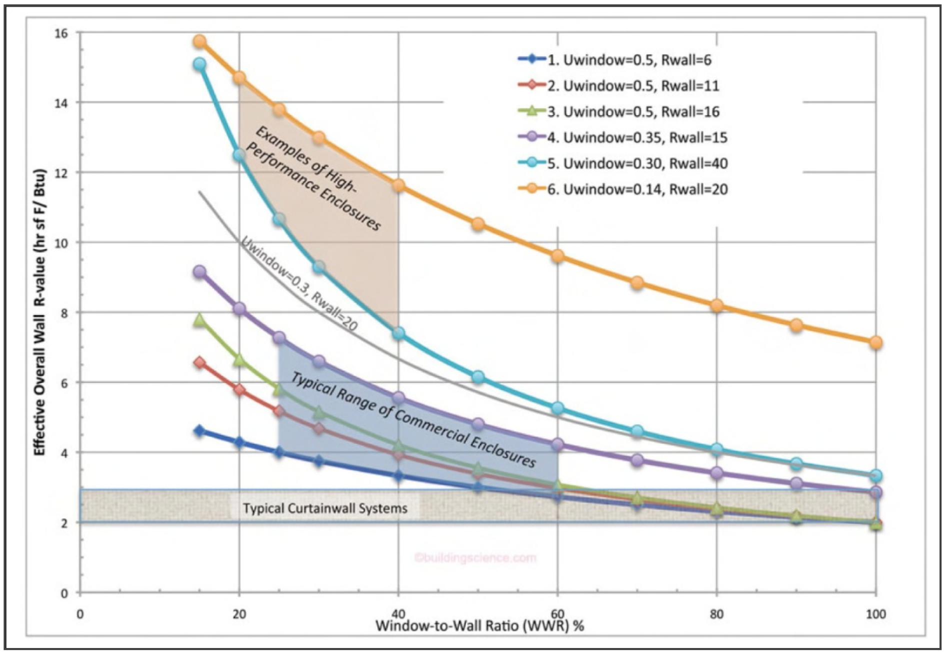
The information above insinuates that the glazed opening is retrofitted in place allowing the quantity of glazing to remain the same. As was depicted above in the daylighting section, efficient design also considers adjusting the sizing of apertures to allow the ideal amount of light to enter the space. The percentage of glazing on a façade also known as the window-wall ratio also becomes an important consideration. Although in Hawaii, it is not as important as other climates when long as shaded correctly.

The next page contains a study by John Straube that was later republished by Joseph Lstiburek showing glazing types and the performance of the overall wall as the percentage of

[108] Ibid
[109] Ibid, 5-3.
[110] Ibid, 5-3.
[111] Ibid, 5-3.

glazing increases. It clearly depicts the drop in the wall's overall R-value for many types of glazing. It also depicts the relative glazed R-value in relation to each other. This relationship is an important concept to consider. Understanding the optimum window-wall ratio for a given section and VLT could allow for significant savings in a retrofit situation.

Figure 34 Enclosure R-value versus Glazing Ratio.



Bottom line is use less glass and use good glass and frames.

Chart is courtesy of John Straube (6). Bad glass ruins good walls.... The impact of thermal bridging through commercial wall assemblies, and heat flow through window systems can be calculated with relatively good accuracy by calculating an area-weighted average of the R-values of the windows and opaque wall sections. The equation takes the form:

$U_{overall} = (WWR * U_{window} + (1-WWR) * U_{wall})$, where $U = 1/R$."[112]

The results of a number of scenarios are plotted in the chart at right. Typical curtainwall systems have an R-value of only 2 or 3, with "high performance" systems (not shown) using highly insulated spandrel panels and best-in-class double glazing may achieve R-4. Only a few systems, such as the Kawneer 7550 series, can achieve R-values of 6 or more.

Curve 1 above is for standard U=0.50 thermally-broken aluminum punched windows with air-filled double-glazed insulated glazing units in a R-12 batt-filled steel-stud brick veneer wall system (R-6). The overall effective R-value of this wall is around 3-to-4 over the normal range of window-to-wall (WWR) ratios of 25 to 50%.

Curve 2 shows that Increasing the R-value of the wall to R-11 by adding an inch of foam on the exterior, results in an increase of only R-0.5 to R-1.5 for the overall R-value for the same range of WWR.

Curve 3 shows how significant an impact window performance can make if a good wall is provided. An externally
insulated R-16 wall, when mated with poor windows produces a vertical enclosure with an R-value of only R-3 to R-6
for the normal range of window area.

Curve 4 assumes a good quality window frame with top quality glazing (low-e, argon-filled): the result for the overall
vertical enclosure is still only R-4 to R-7.

[112] Ph.D. Joseph W. Lstiburek, P.Eng., Fellow ASHRAE, "Prioritizing Green: It's the Energy Stupid," *www.buildingscience.com* 2008.

These first four curves cover the performance of a wide range of commercial enclosures with a wide range of cladding types. The conclusion is that modern commercial vertical enclosures actually have an R-value that is rarely over 7, and more likely in the range of 3-to-5!

Curves 5 and **6** provide an idea of the significant improvements that are possible. Using best-in-class thermally
broken aluminum frames and high-performance glazing (U=0.30), **Curve 5** shows that even with an R-40 wall, the
overall R-value will be in the 7-to-12 range for WWR of less than 40% (the highest ratio recommended for highperformance buildings). Even though this is a low-level, it is still about significantly more than the alternative. The grey curve below

Curve 5 shows the slight benefit gained by increasing wall R-value from 20-to-40, particularly at high glazing ratios.
Curve 6 employs low-e, argon-filled triple-glazed units in an insulated fiberglass frame, to deliver a U-value of only
0.14. Even with a wall insulated to "just" R20, such a combination can deliver an overall R-value of 12-14, two to three times more than typical commercial vertical enclosures.

In all cases, it can be seen that high glazing ratios generate enclosure walls that are expensive to purchase with very high heat loss and heat gain. This high ratio should be avoided in both individual spaces, such as meeting rooms, as for the whole building on average.

Windows and energy consumption have a very dynamic relationship. Technology has allowed for both diverse technologies and widely varying performances. Furthermore, selection of window type is heavily dictated by climate. Windows have 2 important energy considerations, let usable light in, and hold onto conditioned space already inside.

Windows and Energy

1. Largest impact on conditioned space is in the perimeter zones
2. Can eliminate the need for lighting during the day
3. Wall to window ratio typically has a large impact on energy consumption. Understanding the basic relationship between this ratio and energy is key rule of thumb for determining the amount of daylight to design for.
4. "By using windows with solar control, it may be possible to reduce the size of the air conditioning equipment; this equipment savings, in turn, can help offset some of the additional cost of the windows."[113]
5. "In general, glazing types with the lowest SHGC will have the least impact on peaking cooling load. But with small window areas, a higher VLT will be important because it allows electric lighting to be turned off, eliminating the lighting load."[114]
6. "Exterior shading devices such as horizontal overhangs and vertical side fins can significantly reduce overall energy consumption and peak cooling load. For reducing solar heat gain, overhangs are most effective on the south side of a building. On the north side, a small overhang combined with sidefins provides very effective shading. Overhangs have the greatest impact when used with single-pane, clear glass, and a relatively small impact when used with windows that have high-performance tint and low-e coating."[115]

[113]Eley Associates, "Hawaii Commercial Building Guidelines for Energy Efficiency." 5-14.
[114] Ibid
[115] Ibid, 5-19 – 20.

Figure 35 Windows Frame Material Concerns [116]

Frame and Sash	Strategies	Environmental Considerations
Wood	Select windows produced with wood certified by Forest Stewardship Council.	Certified wood prevents degradation to forest and wildlife habitat. Wood can be high maintenance. Good energy performance.
Finishing coat	Specify factory-applied finish.	More durable than field-applied. Controlled finishing environment reduces pollution.
Wood and Plastic Composite	Durable options combine wood fiber, post-consumer waste plastic, recycled PVC scrap, virgin PVC, or recycled wood scrap.	Uses waste, stretching the wood supply. Very durable. Low maintenance. But PVC manufacturing may create pollution. Good energy performance.
Vinyl/PVC	Vinyl frames include foamed PVC insulating core.	Low maintenance. Needs no paint. PVC manufacturing may create pollution. High coefficient of thermal expansion can lead to premature failure of seal. Excellent energy performance.
Fiberglass	Pultruded fiberglass frame members have a hollow profile usually insulated with fiberglass or polyurethane foam.	Durable. Difficult to recycle. Emissions may contribute to indoor air quality problems and manufacture may create pollution. Moderately good energy performance.
Metal	Specify durable, factory-applied finishes: anodized, polyvinlidene fluoride, or siliconized polyester.	Durable. Reduces potential pollution on site. Energy-intensive production. Not the best energy performance.
Source: *GreenSpec: The Environmental Building News Product Directory and Guideline Specifications.* For specific product recommendations, see *GreenSpec* (www.buildinggreen.com) or OIKOS's *REDI Guide* (www.oikos.com).		

Window frame materials are typically hard to specify a clear superior product. From an energy standpoint, vinyl and fiberglass provide the best performance. However, their production methods and recyclability leave much room for improvement. Frame materials are also very important to the performance of the overall glazed assembly. It is typically considered best practice to select the most energy efficient and durable solution.

[116] Associates, "Hawaii Commercial Building Guidelines for Energy Efficiency." 5-19.

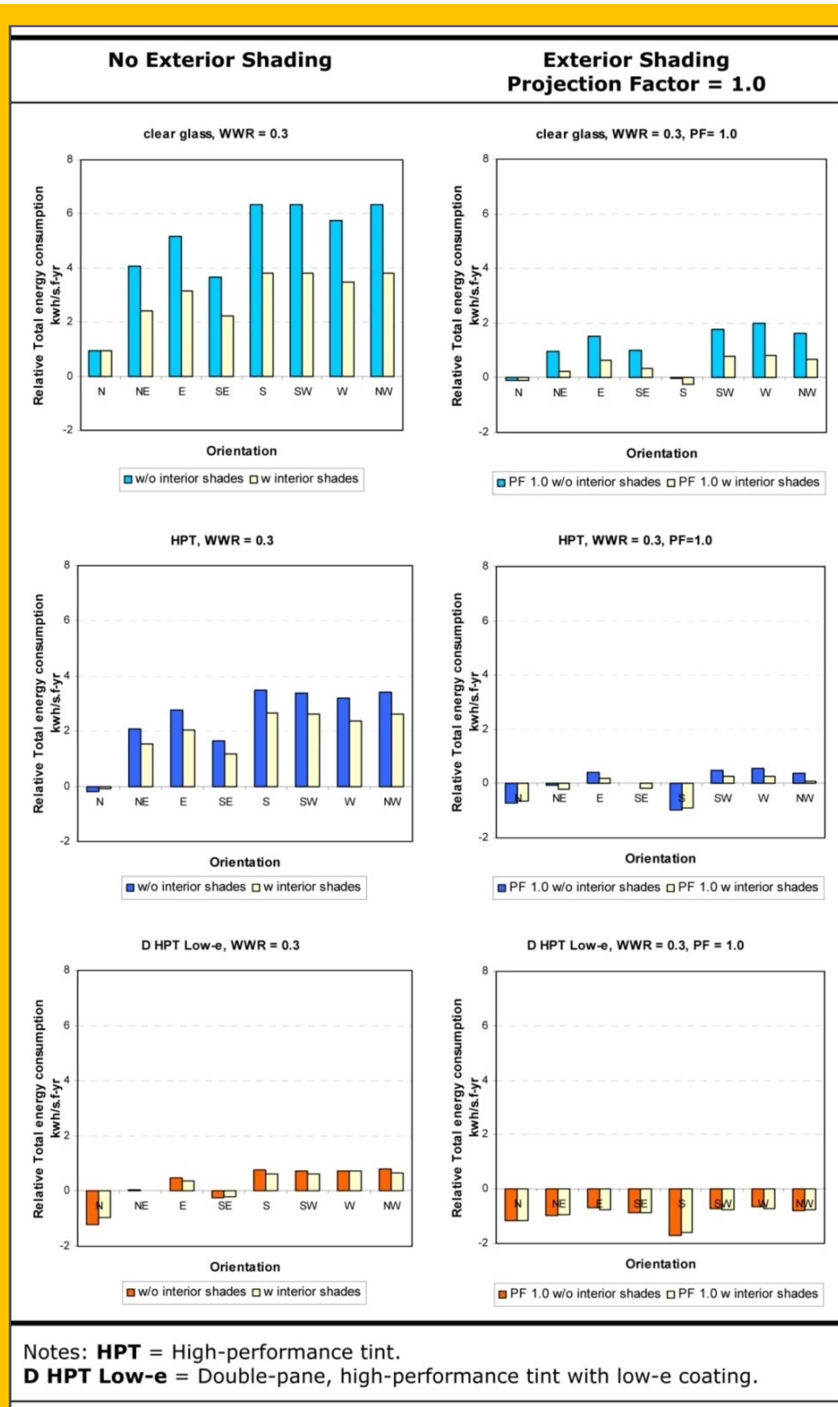
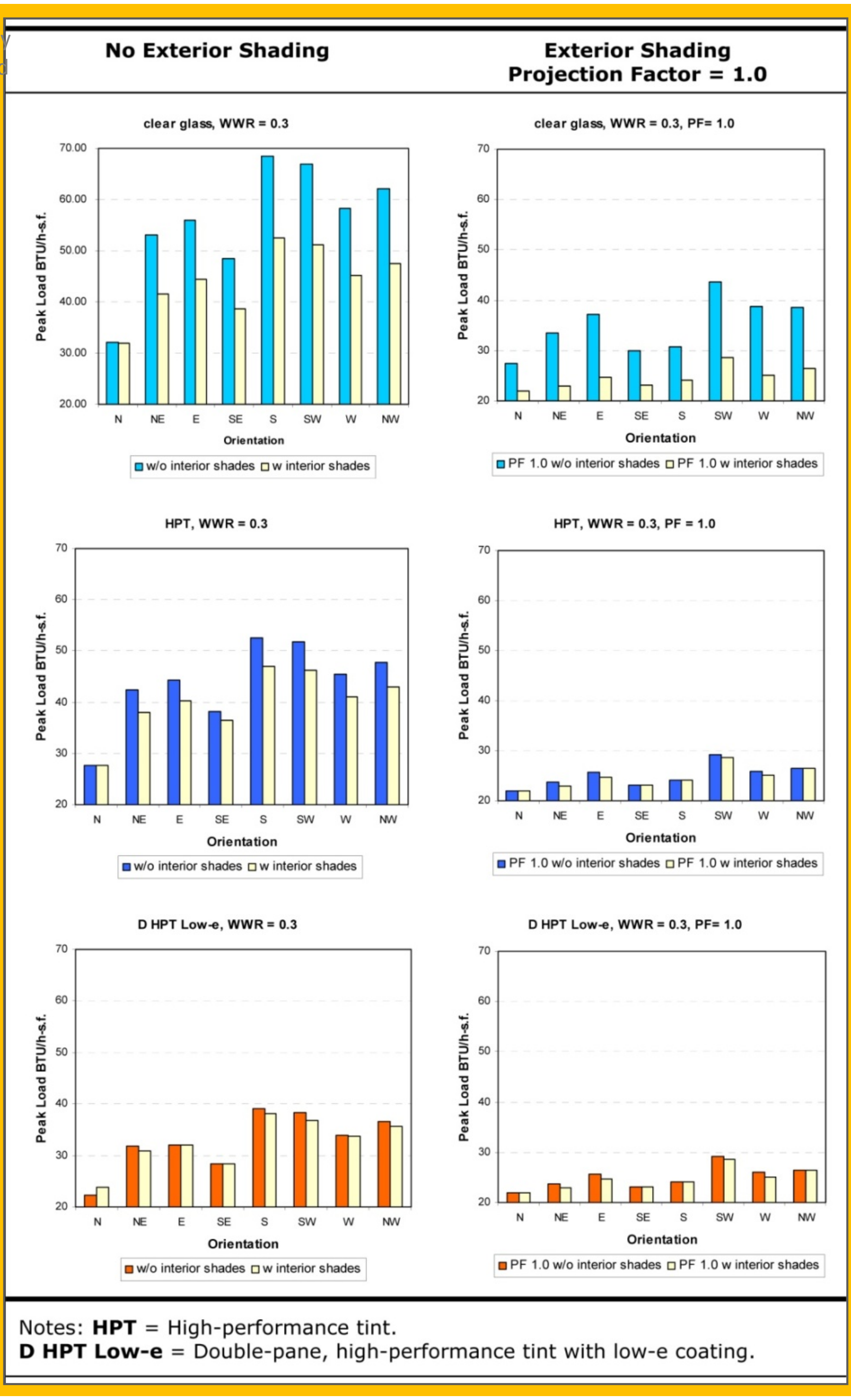


Figure 36 Total energy consumption effect of exterior and interior shading between multiple types of glazing

This table[117] shows a comparison of 3 window types with and without exterior shading. The clear glass chart shows the dramatic effects that shading can have with even single pane clear glass. Below it also shows that the highest quality glass – Dual Pane High Performance Tint with Low-E Coating can provide similar results without exterior shading. When both are combined even more savings is seen.

[117] Eley ibid. 5-23.

Figure 37 Effect of peak energy cooling loads with exterior and interior shading between multiple types of glazing



118

This similar table shows peak energy loads. In which a similar spread of energy use based on glazing, exterior shading, and interior shades is depicted.

[118] Eley ibid. 5-24.

Exterior Overhangs and Vertical Fins

Exterior overhang and vertical fins are a very effective way to mitigate direct heat gain. If properly designed, exterior shading minimizes glare and reduces cooling loads.[119] As seen in the previous pages, type of glass, exterior, and interior shading are all possible factors to improve performance of daylighting and view windows. Exterior shading on clear glazing seems to slightly out-perform even the best glazing which allows the opportunity to save on glazing costs. Exterior shading is superior to interior shading most of the time because it stops the thermal gain before entering the space.

Depending on the project (orientation, location of windows, façade type, shading already in place, etc.) new exterior shading may not be the most effective method for energy efficiency based on ROI but should be tested. Even if not the largest efficiency on its own, it should be considered for some of the symbiotic benefits when considered with better glazing. Correct exterior shading brings more comfort to the perimeter zones of the interior space. In extreme cases, this can literally increase the usable square footage.[120] Highly efficient glazing does not mitigate glare like exterior shading.

In Hawaii, exterior shades are almost always desirable. East and West exposures are particularly difficult to shade with exterior shading alone. However, with the use of high performance glazing, interior shades are usually not needed.[121]

If committed to low-end glazing (single pane clear glass), exterior shading is best way to improve efficiency in Hawaii. A study provided by Honolulu's DBEDT shows that in a window to wall ratio of 25%, lifecycle costs range from $12/ SF of glazing with no shading and $2/SF with shaded windows for approximately 85% of business hours (As compared with the cost of a windowless wall). Conversely, high end glass (Double pane with high performance tint and low-e coating) has been shown to provide a range of $5-$1 within the same conditions.[122]

Cool Roof

Cool Roofs have been shown to significantly reduce thermal loading of structures in relatively simple ways. The most effective types of cool roofs contain multiple components and each should be well understood in order to realize the highest roof efficiencies. Cool roofs are generally described as a roof with high reflectivity and high emissivity. High solar reflectance means that more solar radiation is reflected and not absorbed into the roof. This keeps the surface temperature cooler. Cool roofs are typically light in color. High emissivity helps the assembly to dispel heat quickly by allowing it to radiate to the sky when surroundings are cooler.[123]

Cool roofs are composed of more than just the surface of the roof. Several factors effect a roof's performance. The following list of components which can add to the

[119] Ibid, 5-29.
[120] Eley Associates, "Hawaii Commercial Building Guidelines for Energy Efficiency." 5-30.
[121] Ibid.
[122] Eley Associates, "Hawaii Commercial Building Guidelines for Energy Efficiency." 5-50 – 5-81.
[123] Eley ibid. 6-1.

effectiveness of a roof's performance. Combinations of these components can be beneficial without the use of all of them at once.[124]

1. Membrane characteristics
2. Insulation type and thickness
3. Use of a radiant barrier
4. Presence of air gaps and ventilation

Some recommendations applying to existing building retrofits[125]:

1. Replacing the old roofing membrane with a light-colored single ply membrane
2. Using a liquid applied white elastomeric coating on flat builtup roofs.
3. Adding foam board insulation on top of existing roof deck to increase thermal performance.
4. Installing a radiant barrier within an existing attic space.

Insulation

Insulation type and performance is both an energy consideration as well as a sustainable materials concern. Paramount to any insulation is its R-value per inch. This must be the most important factor of the material given that it is the purpose of the product. Most insulation however, is widely considered to have unsustainable traits due to the fact that popular types like glass fiber and rigid foam board are synthetic in nature, have high embodied energy, and an unrecyclable makeup.

Alternative insulations are becoming available though. Cellulose insulation is a good alternative to glass fiber as it is typically made of shredded, chopped, or disaggregated recycled newsprint and has the lowest embodied energy of all insulations. Although relatively new, it has been adapted to deter pests through boric acid treatment and products have recently come on line with binders that resist settling in vertical applications. Cellulose insulation has an R-value of 3.7 per inch which is comparable with glass fiber insulation.

For insulation mounted to the exterior of framing, a more rigid product is required. Rigid insulation is typically used in applications with space limitations such as atticless designs. These types are also used in applications where the roof assembly does not provide enough room within the framing cavity. There are many types of rigid insulation including Molded Expanded Polystyrene (MEPS or beadboard), Extruded Expanded Polystyrene (XMEPS), and Polyisocyanurate. Below is a brief description of each:

1. Molded Expanded Polystyrene(MEPS) (beadboard)
    a. Requires added "vapor diffusion retarder"[126]
    b. R-values of 3.8-4.4 per inch
2. Extruded Expanded Polystyrene(XMEPS)
    a. More expensive than MEPS
    b. Better suited for roofs or wall panels

---

[124] Eley ibid. 6-1.
[125] Ibid. 6-2.
[126] Ibid. 6-4.

c. Excellent resistance to moisture absorption
d. R-5 per inch

3. Polyisocyanurate
    a. High initial R-value of R-9 and can reduce over time to between R-7 and 8

Figure 38 Insulation Cost[127]

Type of insulation	Material Cost ($/ft²)	Material Cost ($/"R-value")
Batt or blown insulation (5.5 inches, R-19)	$0.40	$0.02
Extruded Expanded Polystyrene (3 inches, R-15)	$1.35	$0.09
Polyisocyanurate (2 inches, R-14)	$0.95	$0.07

Radiant Barriers

"Radiant barriers are reflective materials that reduce the amount of heat radiated across an air space… At least one reflective side must face an air space to be effective."[128] There are many types of radiant barriers with varying application and performance:

1. Flexible sheets
    a. Potential for best performance
        i. Can be installed with air gap on both sides and may have low emissivity on both faces
2. Laminated to roof deck products
3. Liquid Applied
    a. Do not perform as well as others

Since a typical R-value cannot be assigned to a radiant barrier an emissivity rating has been developed to describe effectiveness. They range between a rating of 0 and 1. The lower the number indicates a better performance. Less than .1 will comply with Hawaii's energy code definition of an acceptable radiant barrier.[129]

Figure 39 Radiant Barrier Cost[130]

Type of Radiant Barrier	Material Cost ($/ft²)
Flexible Sheet	$0.15 to $0.20
Insulated Radiant Barrier	$0.40 to $0.60
Laminated Deck	$0.10 to $0.20 (added to wood panel cost)

[127] Ibid, 6-10.
[128] Ibid, 6-5.
[129] Eley Associates, "Hawaii Commercial Building Guidelines for Energy Efficiency." 6-5 – 6-6.
[130] Ibid. 6-10.

Roof Membranes

Roof membranes are desired to provide water resistance for the roofing assembly. However, they are also the first barrier to thermal loads of the sun. Roof membranes are desired to have a high emissivity and high reflectance to perform well. Typically roofing color has a large impact on performance. Lighter colors (white) will perform the best. Typically, the lighter colors tend to cost more but that cost can typically be made up through a reduced required thickness in insulation. White elastomeric coatings and white single ply membranes typically have high reflectance and high emmittance.[131]

Roof Assembly Considerations

Hawaii Energy Code requires a maximum Heat Gain Factor of .05.

RHGF=(U-Value) x (absorvity) x (Radiant Barrier factor; .33 if included, 1 if not)[132]

Hawaii Energy Code - Compliant Assembly Types are contained it Eley Associates study on cool roofs.

1. Low Slope (Refer to Commercial Building Standard 6-13 – 6-20 and references)
2. Sloped Roofs (Refer to Commercial Building Standard 6-21 – 6-24 and references)

Conclusions

It is the intentions of this study that the preceding research will be utilized to provide a basis of knowledge which can be put forward in the design portion of the project. The passive approaches to construction specifically with reference to retrofit will become the backbone of this effort. Utilizing these concepts will allow for further understanding of the building system as a whole. Together with the design portion of the project, putting these concepts into action in a whole building analysis software will begin to shed light on order of magnitude energy savings possible within a Hawaiian retrofit setting.

[131] Ibid. 6-7 – 6-8.
[132] Ibid. 6-10.

7

Active Offset Design Strategies for Commercial Hawaiian Retrofits

Passive first should be every architect's motto. But the reality is every design that aims for modern environmental comforts will need to rely on active offsets to complete the design. Architect's need to have a strong background in efficient active design as well as passive, even though other parties will ultimately be responsible for realizing the specifics of the design. While laying out a design approach, rules of thumb for determining the optimum active systems to compliment passive performance is necessary. The following is a description of active systems which complement progressive passive approaches.

Electric Lighting

Electric lighting design can have a large impact on electricity consumption even after all daylighting strategies have been incorporated. It is important for an architect to understand lighting systems. Mounting styles – i.e. surface mounted, recessed, suspended lighting approaches all have their own benefits to consider, and each can have opportunities in an existing building retrofit for efficiency. Guidelines for the end resultant illumination are the same as daylighting in many cases. Having optimum lighting levels and types ensures that occupants are getting the right kind of light for specific tasks.

Lighting accounts for between 15 & 45% of total electricity used in commercial buildings in Hawaii.[133] Efficient Lighting reduces heat gain which will also save on cooling. Lighting type improves visual comfort and overall quality of light through appropriate illumination and contrast as well as control of reflectance and glare.

IECC 2009 provides the base standard for efficient lighting in Hawaii. The IESNA Lighting Handbook can also be referenced. See below for recommended illuminance levels based on different types of tasks.[134]

---

[133] Eley Associates. "Hawaii Commercial Building Guidelines for Energy Efficiency."4-1.

[134] Associates, "Hawaii Commercial Building Guidelines for Energy Efficiency." 4-6.

Figure 40 Recommended Illuminance

Category	Description	Recommended Illuminance (fc)
Orientation and simple visual tasks	Public spaces	3
	Simple orientation for short visits	5
	Work spaces where simple visual tasks are performed	10
Common visual tasks	Performance of visual tasks of high contrast and large size	30
	Performance of visual tasks of high contrast and small size, or visual tasks of low contrast and large size	50
	Performance of visual tasks of low contrast and small size	100
Special visual tasks	Performance of critical visual tasks with very small or very low contrast elements	300–1000
Source: *IESNA Lighting Handbook, 9th edition,* chapter 10, p. 13.		

Color Rendering

"Light sources should have a minimum color-rendering index (CRI) of 75 for most interior spaces."[135]

"For areas where accurate color rendering is more critical (retail spaces, art rooms, exhibition spaces), select a source with a CRI of at least 80. The latest, more efficient "second-generation" or "premium" T-8 lamps, T-5 lamps and most compact fluorescent lamps have CRI in the range of 82–86."[136]

Lamps

Typically the light source has a great deal to do with both energy use and quality of light. Incandescents have historically been the most popular lighting source due to good color rendering, point source control, instant starting, and inexpensive dimming. They are however one of the least efficient lighting types. Other disadvantages include low efficacy, short lamp life, high maintenance costs, and a narrow range of color choices. Halogens provide a better performance in almost every area, but not enough. In an energy efficiency design, incandescents should be avoided in most places and are best used as accents.[137]

---

[135] Ibid. 4-7.
[136] Ibid.
[137] Ibid. 4-7 – 4-8.

Florescent lights with color temperature of 3500 deg K to 4100 deg K or higher are the most compatible with daylight.[138] Linear fluorescents are typically the most popular efficient commercial lighting option. These fixture types are widely available, more cost effective than LED fixtures, and provide almost any mounting style. Compact fluorescents have become very popular due to their interchangeable nature with incandescent bulbs.

Figure 41 Linear Florescent Lamp Types[139]

Type of Lamp	Advantages & Disadvantages	Applications
T-12	Relatively antiquated technology. Supplanted by newer technologies.	Some low temperature applications, such as food storage or display areas.
T-8	Advantages include higher efficacy, more design options, better color rendering than T-12s. Newly available "premium" T-8 lamps offer higher color rendition, higher maintained lumens, and a 20% increase in lamp life over standard T-8s; very cost effective.	Most general lighting applications, including classrooms, offices, libraries, outdoor and industrial spaces.
T-5	Similar performance to T-8 lamps, but more compact lamp envelope (5/8-in. vs. 1-in. diameter). T-5 luminaires should be well shielded to minimize glare. Electronic ballasts are necessary to achieve expected lamp life and performance.	Smaller profile luminaires. Especially effective in indirect luminaires, cove lighting systems, and wall washers.
T-5 High Output (T-5HO)	One T-5HO lamp produces nearly the equivalent light as two standard T-8 lamps, but somewhat less efficiently. May allow designer to increase the spacing between direct/indirect luminaire rows, compared to a typical T-8 design, which allows use of fewer lamps and/or fewer luminaires, reducing lighting costs. Currently more expensive than T-8 designs.	Like standard T-5 lamps, but may allow even smaller luminaires or better optical control and projection.

Linear florescent lighting can and should be used in most space types today. They provide a long life, high efficacy, good color performance, and low operating costs.[140] Many of the disadvantages of past linear florescent fixtures have been remedied through the use of electronic ballasts. Types of linear florescent bulbs are listed and described below. T-8 lamps are typically the most used lamp types. They are typically considered the most efficient. T-5's produce more light, but are generally only used in places where space is at a premium due to the fact that they cause glare issues if not shielded correctly.

Compact florescent fixtures offer a large list of reasons for use. Advantages include[141]:

2. Excellent Color Rendering
3. Quick Starting
4. Large palette of configurations enhances flexibility
5. Higher efficacy
6. Color selection
7. Longer lamp life
8. Dimming ballasts available but may be expensive

138 Ibid. 3-14.
139 Ibid. 4-9.
140 Ibid. 4-9.
141 Ibid. 4-10.

As listed above, the main reason for fluorescents is they provide a substitute for incandescent lighting which can be easily switched out when bulbs burn out and require no additional fixture install. Compact florescent fixtures are good candidates for[142]:

1. Task lighting,
2. Accent lighting
3. Wall washing
4. Supplementary task lighting
5. Portable task lighting
6. Medium to low level lighting such as lobby, corridors, restrooms, storage rooms, and closets
7. Outdoor corridors, step lighting, entry lighting

Currently there is another known lighting option that is more efficient than fluorescents, LED's. LED's have been on the market and studied for mass use in buildings for some time now. However, they have not become as effective as fluorescents due to availability, pricing, and fixture options. LED's have however been proven as the best option to producing colored light. They are the best options for exit signs and decorative lighting today.[143] LED's continue to be developed / streamlined for standard lighting based on advantages including controllability and long life.

Ballasts

Electronic high frequency ballasts have become the standard due to their superior operating capabilities when compared to mechanical ballasts. Electronic high frequency ballasts reduce flicker, noise, and available in a wide variety of factor ratings which allow the designer to tune light levels on the ballast specification.

Reduced Light Output (RLO) ballasts can be used in spaces where lower lighting levels can be acceptable to save power. They reduce the light output of the bulb and save the energy that would have been used in a more efficient way than if dimmed with a standard dimmer. These can be applicable in corridors, restrooms, storage areas, and similar spaces.

There are 2 types of ballasts - rapid start and instant start. Rapid start are typically considered to be the most efficient type of ballast and are typically specified for ballasts with a T-8 lamp. Instant start allow efficiency for more frequent switching. Programmed instant start are optimized for use with occupancy sensor controls. Instant starts are also the only ballasts rated for use with a T-5 lamp. [144]

Dimming ballasts are available but generally more expensive. They increase performance by optimizing space appearance, occupant satisfaction, and system flexibility. Dimming fluorescent ballasts should be considered in all cases requiring high energy performance and light level controllability.[145]

[142] Ibid. 4-11.
[143] Ibid. 4-12.
[144] Ibid. 4-10.
[145] Ibid.

Lighting Controls

The way lighting is controlled is a great way to increase efficiency. The most efficient systems performance can be easily doubled by careless control. Occupant control has been cited under LEED as a benefit, it offers the chance to let occupants turn on/off lighting as it is needed. This is a very effective and cost conscious approach to controllability. However, it only works for the energy cognizant occupant. It implies a level of education and prioritization on the part of the user. This is shown by a study of over a 1000 people performed by the Interface Corporation at their conference in Maui. When educated at how to save energy during the conference, the property's energy use fell 22% in 6 days.[146] In this way, the end user of the space must be understood to maximize efficiency and cost. In areas where the occupants cannot be counted on to use light efficiently, then a reliable occupant sensor system should be used to maximize efficiency. Commissioning of complex controls is a must to ensure that they are operating in the manner in which they were expected.

Control options for lighting include:

1. Switches
2. Manual Dimmers
3. Occupancy Sensors
    a. Passive
    b. Infrared
    c. Ultrasonic
4. Time Controls
5. Photoelectric Controls
6. Energy Management Systems

> "Manual controls cost less than automatic controls. Automatic controls typically have higher installation and maintenance costs, but can save a significant amount of energy in large buildings by ensuring that the optimum amount of illumination is provided in public spaces where manual controls may not be used effectively.
>
> The choice of dimming versus switching can have major first-cost implications, especially in retrofit situations. Special dimming ballasts are required for fluorescent and HID lamps, but the cost of fluorescent dimming (or controllable) ballasts is about twice that of equivalent non-dimming ballasts. HID dimming ballasts can be much more expensive. Multi-level ballasts, either fluorescent or HID, are less expensive than equivalent dimming ballasts, but may not give users the feeling of total control."[147]

---

[146] Amory B. Lovins and Rocky Mountain Institute, *Reinventing Fire* (White River Junction, VT: Chelsea Green Publishing, 2011).

[147] Eley Associates, "Hawaii Commercial Building Guidelines for Energy Efficiency." 4-34.

Mounting Styles

The are 3 typical styles of light mounting: recessed, surface mounted, and suspended lighting. Of the 3, suspended lighting seems to be the most preferred, due to their high functionability and ability to provide uniform illumination downward as well as on the ceiling. This helps to decrease contrast and significantly brighten one's perception of space by lighting all interior space.

Suspended Pendant Mounted Lighting

1. For use in rooms having at least 9.5' high ceilings. Must have at least 1' from ceiling with 18" or more preferred.
2. Allows for "direct/indirect distribution and at least 75% luminaire efficiency, using T-8 premium or T-5 lamps and electronic ballasts and a connected lighting power of 0.8 to 1.1 W/ft^2."[148]
3. Allows a "semi-indirect or indirect distribution and at least 85% luminaire efficiency, using T-8 premium or T-5 lamps and electronic ballasts and a connected lighting power of 0.8 to 1.3 W/ft^2"[149]
4. Costs range from $42-60 per lineal foot installed. Dimming ballasts range from $14-18 per lineal foot.[150]

Recessed Lighting

1. "Use recessed lighting in low-ceiling spaces where pendant mounted lighting is inappropriate or when the budget is limited. Use fluorescent lens troffers with at least 78% luminaire efficiency, T-8 premium lamps and electronic ballasts, and a connected lighting power of 0.9 to 1.1 W/ft^2."[151]
2. "Recessed troffer lighting systems generally offer excellent efficiency, but usually with some loss of visual comfort. They make excellent use of the low-cost, widely available T-8 lamps. Systems operating at about 1.0 W/ft^2 will generate between 50 to 60 footcandles maintained average, with very good uniformity."[152]
3. "Recessed lighting systems will cost about $140 per luminaire for basic, white reflector luminaries with #12 lens, two premium T-8 lamps, and electronic ballast. A dimming ballast will add about $45–$55 to each luminaire."[153]

[148] Ibid.4-20.
[149] Ibid.
[150] Ibid. 4-22.
[151] Ibid. 4-24.
[152] Ibid. 4-25.
[153] Ibid.

Surface Mounted

1. "Use surface-mounted lighting in rooms that do not have recessed or suspended lighting systems. There are several possible circumstances:
    a. Ceiling height is 8.5 ft or less, preventing use of suspended luminaires.
    b. Ceiling cavity is impenetrable because of, for example, the presence of asbestos or roof insulation.
    c. The space design employs a hard ceiling surface, such as concrete, that is impenetrable or has only a moderate reflectance."[154]
2. "When using surface-mounted lighting, there are two good choices:
    a. Use short stem-mounted semi-direct fluorescent luminaires having at least 65% efficiency, using T-8 premium lamps and electronic ballasts and a connected lighting power of 1.1 to 1.2 W/ft^2.
    b. Use surface-mounted fluorescent lens troffers having at least 78% efficiency, using T-8 premium lamps and electronic ballasts and a connected lighting power of 0.9 to 1.1 W/ft^2."[155]
3. Surface-mounted lighting systems will cost about $240 per luminaire for basic, lensed, white reflector direct luminaires with .125 in. lens, two premium T-8 lamps and an electronic ballast. Aluminum surface luminaires will probably cost a bit more, perhaps $280 each. A dimming ballast will add about $45–$55 to each luminaire.

Plug Loads

Optimization of plug loads is becoming an increasingly important piece of the overall aggregated energy consumption pie. Even though energy efficiency is increasing and subsequent consumption for individual devices continues to move downward, the quantity of devices plugged into the wall keeps going up. So much so, that overall plug load averages in buildings continue to rise. The resultant effect is that plug loads are continually becoming a larger and larger piece of the overall aggregate energy.

Plug loads become even more important when considering the heat gain they provide to an interior. This gain is something that ultimately adds to the total load which the building's HVAC system needs to cool. For this reason, lowering plug load consumption typically provides more savings than just the delta in outlet consumption and is one of the easiest ways to reduce a building's energy consumption – often without capital expense needed by a building owner.

A typical plug load for an open office space can be given a rough estimate of 1to 1.1 W/SF. DesignBuilder provides a default of 1.0935 W/SF. But one must be careful with plug load estimates. They tend to vary greatly, reports of plug loads for open office have been cited at 1.8 W/SF. On the low side, a best practice solution can go as low as .39W/SF.

[154] Ibid. 4-27.
[155] Ibid.

Figure 42 – Example Baseline and Best Practice Plug Load Energy Densities Taken from Individual Building Audit and Retrofit[156]

Space Type	Baseline EPD (W/sf)	Energy-Efficient Equipment EPD (W/sf)	Energy-Efficient Equipment & Changed Workstation Setup EPD (W/sf)
Open Office	1.81	0.56	0.39
Private Office	0.55	0.22	0.15
Courtroom	0.42	0.35	-
Conference Room	0.40	0.23	-
Lobby	0.26	0.10	-
Reception	0.05	0.02	-
Break room	18.2	17.25	-
Computer Lab	1.89	0.72	-
IT/Server Room	20.5	20.5	-
Resource Room	10.95	4.95	-
Task Lights (*)	0.34	0.14	-

Dehumidification

Dehumidification of indoor air is a prime concern in Hawaii's climate. Most often temperature control is seen as the prime function conditioned space, but this is not the case in the Hawaiian climate. Optimal humidity is typically considered to be between 40 and 60% for good indoor air quality. This means that in a Hawaiian climate, 93% of the time the air needs to be dehumidified.

The energy demand for dehumidification is so costly in a typical conditioned setting that the reheat portion of the system is minimized. Because of this, the air enters the interior at an uncomfortably cool temperature, ultimately leaving occupants unhappy with the space. HVAC systems are typically sized for peak loads and efficiencies during partial load situations are not realized. Mitigating these realities can be as simple as piggy backing dehumidification strategies on traditional HVAC systems when adhering to a cooling based system. Dessicant systems provide another approach in which vapor is extracted directly from the air without cooling. Each dehumidification system provides different results, but methods can often provide a system which uses only half the amount of energy to condition interior air.

[156] Tolga Tutar, "Validating the Impact of Plug Load Reduction on Achieving Deep Energy Retrofits" (Pennsylvania State University, 2012), 74.

Figure 43 - Estimated Annual Energy Performance of Dehumidification Systems[157]

System Specifications	KWh			Savings		
	Conventional System (base case)	Run-around System	Dual-path System	Conven-tional System (base case)	Run-around System	Dual-path System
CAV, 1000 cfm, 10% OA	11,993	5998	5923	0	50%	50%
CAV, 1000 cfm, 20% OA	12,315	6236	5887	0	49%	52%

Notes: The following data and assumptions were used in the calculations.

- System location: Honolulu
- System type: Constant air volume (CAV)
- Space setpoint: 73°F DB, 60% RH
- Airflow: supply air 1000 cfm, outside air 100 cfm, return air 900 cfm
- Space loads: total 1.92 ton, sensible load ratio 81%
- Space load variation: sensible load changes, latent load constant
- Operating hours: Monday to Friday, 8 AM to 6 PM, total 2860 hrs/yr
- Electric reheat is used whenever needed
- Fan heat increases air temperature by 1.5°F, no return air temperature rise due to duct heat loss
- Efficiency: cooling system total 0.8 kW/ton, chiller 0.6 kW/ton
- Four typical load conditions are calculated: 100%, 75%, 50% and 25%
- TMY2 weather data for Honolulu
- Run-around loop effectiveness 50%

HECO offers subsidies for qualifying strategies under the Commercial and Industrial Customized Rebate (CICR). Technologies that save energy and demand service can receive$125 per kW of peak demand reduction and $.05 per kWh for a year of energy savings. If unproven technologies used, may be paid over a period of 5 years on metered savings.[158]

157 Ibid, 7-7.
158 Ibid, 7-9.

Since many of the dehumidification techniques often work by providing alterations to the conventional cooling system with electric reheat, This method must be understood to explain the efficient nature of the climatically sensible alternates that follow.

Description of Typical HVAC Systems

Conventional Cooling Systems with Reheat

A typical cooling system with electric reheat operates by drawing in mixed air (indoor and outdoor) to be pushed across a cooling coil which is cold enough to chill the air to a point where the humidity condenses into water. When this happens the water drops out of the air and is dehumidified. Since the air typically needs to be cooled past a temperature considered comfortable, it must then be reheated and supplied to the interior space. It is this cooling/reheat cycle that is key to the complexity of the air conditioning process.[159]

The cooling coil is typically filled with cold water supplied by a chiller plant. The cooling coil can also be a direct expansion refrigerant coil. Reheat to required supply air temperature is often needed at typical low-load conditions and provided by a separate source electric reheat. Peak loads typically need the least reheat.

Method of cooling

1. Pass air across a cooling coil cold enough to condense water vapor
2. Reheat to required supply air temperature

This method often uses double the amount of energy because of overcooling and reheating of the supply air.

[159] Associates, "Hawaii Commercial Building Guidelines for Energy Efficiency." 7-10.

Figure 44 Energy Performance of a Conventional System, Constant Air Volume with 10% Outside Air[160]

Load%	Cooling Ton	Reheat kW	Total kW	Hours	Outside Air cfm	Outside Air DB	Outside Air WB	Supply Air cfm	Supply Air DB	Supply Air WB	KWh
100%	2.60	0.00	2.63	225	100	87	75	1000	56	55	592
75%	2.09	1.09	3.31	1396	100	82	70	1000	61	58	4621
50%	1.98	2.88	5.02	897	100	77	66	1000	66.5	59.4	4503
25%	1.92	4.57	6.66	342	100	72	64	1000	71.7	61.9	2278
Total											11,993

Load %	Cooling Ton	Reheat kW	Total kW	Hours	Outside Air cfm	Outside Air DB	Outside Air WB	Supply Air cfm	Supply Air DB	Supply Air WB	KWh
100%	2.95	0.00	2.91	225	100	87	75	1000	56	55	655
75%	2.28	1.09	3.47	1396	100	82	70	1000	61	58	4844
50%	2.03	2.88	5.06	897	100	77	66	1000	66.5	59.4	4539
25%	1.92	4.57	6.66	342	100	72	64	1000	71.7	61.9	2278
Total											12,315

Figure 45 Energy Performance of a Conventional System, Constant Air Volume with 20% Outside Air[161]

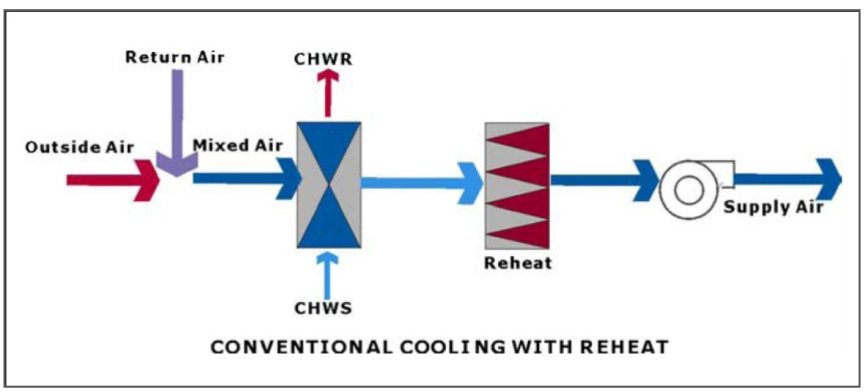


Figure 46 – Conventional Cooling with Reheat[162]

[160] Ibid., 7-13.
[161] Ibid., 7-13.
[162] Ibid., 7-11.

Run-around Coil Systems

Run-around coil systems begin with a relatively conventional system with electric reheat. A pre-cooling coil is introduced before the main cooling coil. The pre-cooling coil's chilled fluid is supplied by the downstream reheat. Once the mixed intake air drops heat and on the precooling coil, that heat is transferred to the reheat via circulating fluid where it is cooled and again returned to the pre-cooling coil. The reciprocal nature of energy transfer provides a much higher level of efficiency since both heat and cool cycles are fed by the same energy supply.[163]

Recommendations for Use

1. Install in applications with large dehumidification requirements
2. When air must be reheated after passing the cooling coil

Method of cooling

1. Upstream pre-cooling coil cools air
2. Main cooling coil cools air further and condenses humidity into water
3. Downstream reheating coil reheats air
4. Circulating fluid pumped to transfer heat from incoming air to the reheat instead of using an expensive external source to reheat air

Run-around systems can have a significant impact on heating and cooling capacity in new and retrofitted HVAC designs.

1. Energy savings can range from 50% for a normal loop and 65% for a high performance loop
2. Typically double the cost of a conventional system ($4.50 to 5.00/cfm), but with downsizing of chiller and cooling tower, it will be very close

[163] Ibid., 7-14.

Figure 47 Energy Performance of a Run-around System, Constant Air Volume with 10% Outside Air[164]

Load %	Cooling Ton	Reheat kW	Total kW	Hours	Outside Air cfm	Outside Air DB	Outside Air WB	Supply Air cfm	Supply Air DB	Supply Air WB	KWh
100%	2.60	0.00	2.72	225	100	87	75	1000	56	55	612
75%	1.78	0.00	2.07	1396	100	82	70	1000	61	58	2890
50%	1.16	0.00	1.57	897	100	77	66	1000	66.5	59.4	1408
25%	1.10	1.65	3.18	342	100	72	64	1000	71.7	61.9	1088
Total											5998

Load %	Cooling Ton	Reheat kW	Total kW	Hours	Outside Air cfm	Outside Air DB	Outside Air WB	Supply Air cfm	Supply Air DB	Supply Air WB	KWh
100%	2.95	0.00	3.00	225	100	87	75	1000	56	55	675
75%	1.93	0.00	2.19	1396	100	82	70	1000	61	58	3057
50%	1.18	0.00	1.59	897	100	77	66	1000	66.5	59.4	1426
25%	1.07	1.65	3.15	342	100	72	64	1000	71.7	61.9	1077
Total											6236

Figure 48 Energy Performance of a Run-around System, Constant Air Volume with 20% Outside Air[165]

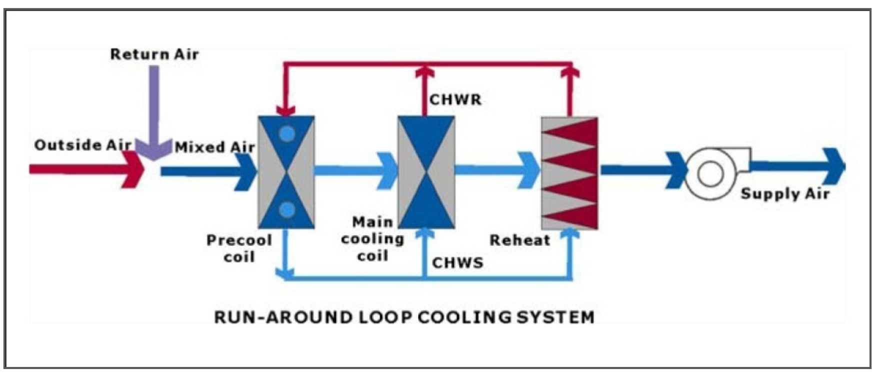


Figure 49 – Run-Around Cooling System[166]

[164] Ibid., 7-16.
[165] Ibid., 7-16.
[166] "Hawaii Commercial Building Guidelines for Energy Efficiency," 7-14.

Heat Pipe Systems

Heat pipe systems work in a similar manner to run-arounds in that they have a separate sealed entity that runs around the main cooling coil. Heat pipe systems use a hermetically sealed refrigerant loop to transfer heat/cool back and forth between the pre-cooler and the reheat. The refrigerant's properties allow it to phase change between liquid and solid using a wicking action to power the pump pushing the refrigerant around the loop.[167]

Recommendation

1. Install in applications with large dehumidification requirements
2. When air must be reheated after passing the cooling coil

Method of cooling

1. Upstream precooler
2. Main cooling coil
3. Downstream heat pipe
4. Hermetically sealed heat pipe is used to cool air on intake and reheat after humidity is removed. Refrigerant inside the pipe vaporizes as it cools the air and liquefies as it reheats, creating a more efficient transfer of energy

Costs

1. Heat Pipe loop for a cooling system is approximately $2.50/cfm
2. Simple payback of 2 to 3 years when replacing a system requiring reheat

Benefits

1. Removes 50% to 100% more moisture than systems without heat pipes.
2. Saves energy compared to systems that provide similar amounts of dehumidification.
3. Simple system with no moving parts or external connections makes it basically maintenance free.
4. Can be applied to an existing system
5. Reduces size requirements of a new system

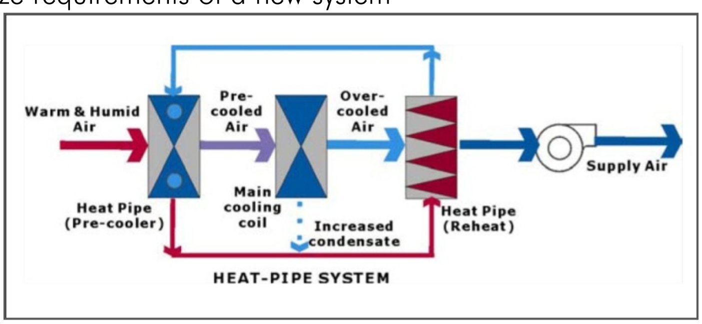


Figure 50 – Heat Pipe System[168]

---

[167] "Hawaii Commercial Building Guidelines for Energy Efficiency.", 7-17.

[168] "Hawaii Commercial Building Guidelines for Energy Efficiency," 7-17.

Dual Path Systems

A dual path system decouples sensible and latent cooling based on how the air is delivered to the system. Outside air is generally warmer and has more moisture than interior return air. Therefore it can be treated differently to increase efficiency and then mixed together before being introduced to the space as supply air. In this system, outside air is introduced to a cooling coil chilled between 40 and 42 degrees for dehumidification. The return air is run past a second coil which only need to be cooled to 50 to 60 degrees for sensible cooling. With the temperature difference, the chilled water or direct expansion can be utilized by both coils before being returned to be cooled again. If the outside air does not reflect enough of the overall percentage of mixed air, a portion of the return air can be mixed with outside air before dehumidification. This system is able to avoid reheat by decoupling the latent and sensible cooling.[169]

Recommendation

1. Install in applications with large dehumidification requirements due to high outside air ventilation rates
2. When air must be reheated after passing the cooling coil

Method of cooling

1. Coil to cool outside air
    a. Primary coil
    b. 42-45 deg for dehumidification
2. Separate coil to cool inside air
    a. Sensible cooling of already cool and dry air
    b. Chilled water (warmed from latent cooling) comes from outside air coil at 50-60 deg
3. Some return air is allowed to bypass RA cooling coil
    a. Remixes with air cooling coil air
4. Return air and cooled outside air can be mixed to appropriate temperature and humidity

Benefits

1. If properly designed, it will avoid reheat process
2. Decoupling latent and sensible cooling provides for efficiencies
3. Reduces the installed cooling tons over a conventional single-path system
4. Provides direct control of ventilation air quantity for improved indoor air quality
5. Provides good humidity control at all times, including part load. Moisture is removed at its source, regardless of building load.

Costs

1. Installation of system – $5-6 /cfm

[169] "Hawaii Commercial Building Guidelines for Energy Efficiency.", 7-19 – 7-20.

Figure 51 Energy Performance of a Dual Path System, Constant Air Volume with 10% Outside Air[170]

Load %	Cooling Ton	Reheat kW	Total kW	Hours	Outside Air cfm	Outside Air DB	Outside Air WB	Supply Air cfm	Supply Air DB	Supply Air WB	KWh
100%	2.60	0.00	2.69	225	100	87	75	1000	56	55	605
75%	1.79	0.00	2.04	1396	100	82	70	1000	61	58	2848
50%	1.61	0.00	1.90	897	100	77	66	1000	66.5	59.4	1704
25%	0.90	0.91	2.24	342	100	72	64	1000	71.7	61.9	766
Total											5923

Load %	Cooling Ton	Reheat kW	Total kW	Hours	Outside Air cfm	Outside Air DB	Outside Air WB	Supply Air cfm	Supply Air DB	Supply Air WB	KWh
100%	2.95	0.00	2.97	225	100	87	75	1000	56	55	668
75%	1.98	0.00	2.19	1396	100	82	70	1000	61	58	3057
50%	1.23	0.00	1.59	897	100	77	66	1000	66.5	59.4	1426
25%	0.87	0.84	2.15	342	100	72	64	1000	71.7	61.9	735
Total											5887

Figure 52 Energy Performance of a Dual Path System, Constant Air Volume with 20% Outside Air[171]

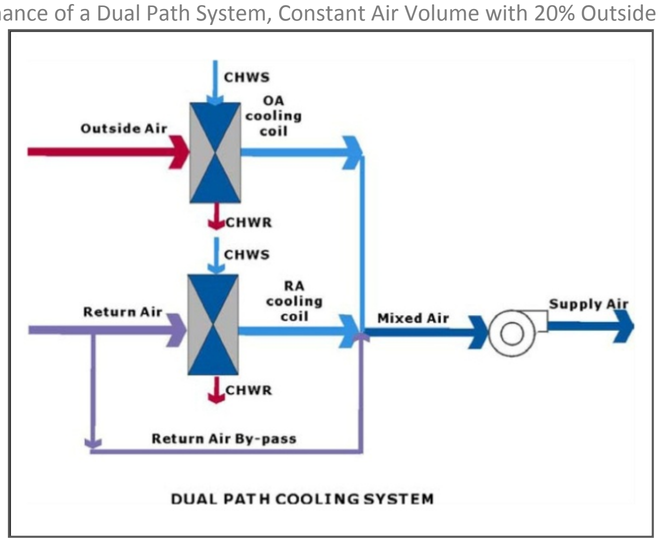


Figure 53 – Dual Path Cooling System[172]

170 Ibid., 7-23.
171 Ibid., 7-23.
172 "Hawaii Commercial Building Guidelines for Energy Efficiency," 7-20.

Desiccant Systems

Dessicant systems do not dehumidify by cooling. They remove water vapor from the air through absorption. These materials can absorb between 20 and 40% of their dry weight in water vapor from the air. Dessicants are available in liquid and solid forms, but solid are more typical.

Recommendation

1. Install in applications with large dehumidification requirements
2. When low interior humidity levels are desired that would be difficult to achieve with cooling-type dehumidification
3. Applicable in situations where one of the following applies[173]
    a. Low indoor Humidity needed (dew point below 50°F)
    b. High latent load fraction (greater than 25%)
    c. High outside air fraction (greater than 20%)
    d. High electrical cost and low gas costs
    e. Available heat source from waste heat, steam, hot water or gas for regeneration of desiccant

Method of cooling

1. Humid taken in intake
2. Passes through a filter
3. Air passes through desiccant material
    f. Desiccant slowly rotates as air passes through it
4. Materials absorb moisture from air
5. Air passes through rotary heat exchanger and increases dry bulb temperature
6. Air passes supplementary cooling coils to cool air to correct temperature and enters the interior
7. Indoor air re-enters on opposite side of unit through the reactivation stream.
8. Passes through filter
9. Passes through heat exchange
10. Rotating desiccant wheel is reheated
11. Hot dry air passes over moist desiccant picking up moisture on its way out of the building
12. Heat recovery system often put in place at exhaust

Benefit

1. Last 10,000-100,000 hours before needing replacement (approximately 10-15 years)
2. Supplementary cooling is smaller because it only needs to address sensible cooling needs
3. Use very little electricity – typically run on natural gas
4. Economic benefit from low humidity
5. Decouples latent cooling from sensible cooling for precise control of humidity independent of temperature.
6. Lower operating cost. Cooling system runs more efficiently to produce chilled water with higher temperature for sensible cooling.

---

[173] "Hawaii Commercial Building Guidelines for Energy Efficiency.", 25-26.

7. No wet coils or draining/cleaning requirement. Dry duct systems help avoid microbial and fungal growth associated with sick building syndrome.
8. Dehumidification process can use low-grade heat from natural gas, steam, hot water and solar energy.
9. Provide supply air with dew-point temperature below the practical limits of cooling technology.

Favorable to desiccant systems

1. High moisture loads with low sensible load
2. Need for more fresh air
3. Exhaust air available for desiccant post cooling
4. Low thermal energy cost with high electrical demand charges
5. Economic benefit to dry duct work
6. Low-cost heat available for desiccant regeneration

Cost

1. Large Commercial - $5/cfm
2. Smaller units (less than 1000 cfm) - $8/cfm
3. Can reduce HVAC electricity 30-60%

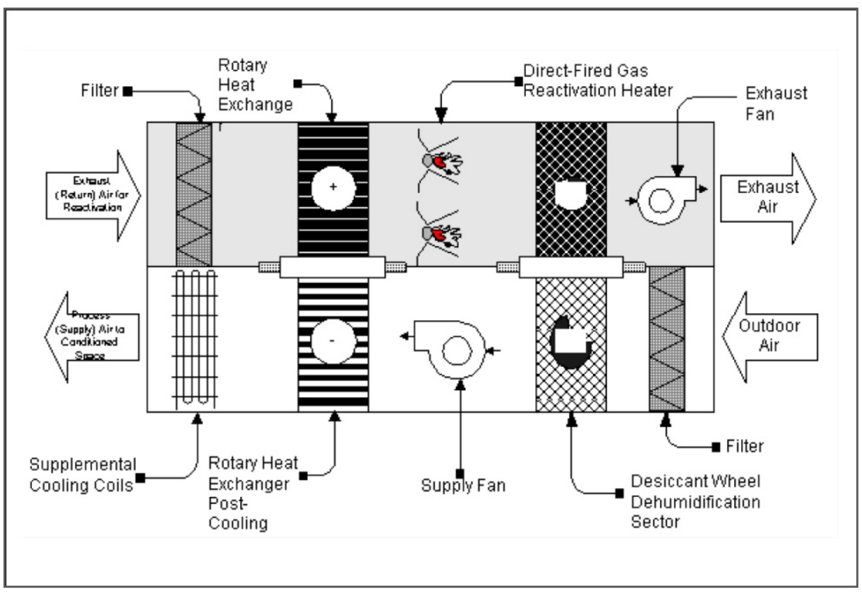


Figure 54 – Desiccant System[174]

Conclusions

The strategies outlined in this chapter are meant to inform the final design portion of this study. Although the strategies depicted vary significantly, this outline will help to develop a body of knowledge in reference to active systems. It will help to more quickly select systems applicable to the project at hand as needed.

[174] "Hawaii Commercial Building Guidelines for Energy Efficiency," 7-24.

8

Site Introduction & Existing Conditions

In the context of Honolulu, the benefit of an energy retrofit for efficiency is compounded. Honolulu has historically shown the highest energy prices in the nation. This is mostly due to its relative isolation from the rest of the world and the fact that non-renewable energy sources must be shipped to the island to be manufactured into a usable energy source. A focus on methods of energy efficiency in the Hawaiian context will continue to offer high levels of environmental and financial benefit for the life of the property.

This study's design focus will aim to become a model for Hawaiian office buildings to follow. For this reason, the property selected looked to be of a common type to the Honolulu context. It looked to be a property which utilized popular building types and systems to the Honolulu Context. It will also need to be located on the leeward side of Oahu to take on the most popular climatic constraints. The property needed to be of an age that major systems are considered to be nearing the end of their useful life and thus ripe for retrofit. Selection of a property indicative of this place, will make it possible to create approaches that can be propagated around the island.

Existing Building Parameters Desired

- Leeward Oahu Location (Honolulu or Kapolei areas)
- Construction Type will most likely want to be a concrete structure (or other typical Hnl construction type)
- Mechanical cooling system before retrofit will most likely want to be Nearing end of life or time for retrofit
- Office or Office Component to Program
    - Typical office Energy Intensity Cited at 22.82 kWh/SF-y. Higher than average energy intensity would be desired.
- Relative size will look to be over 40,000 SF

As discussed earlier, a basic understanding of energy consumption will be needed in order to begin to analyze existing conditions and compare to an eventual solution. Of particular value would be a site that has begun to sub-meter energy consumption. Detail of this sort can help in the calibration process, giving the designer insight as to where individual chunks of energy are being used.

Existing building as-builts were obtained in order to set up an accurate model. Having such documentation provides a jumping off point for calibration of the energy model and subsequent analysis of the space.

Building Data Required

- Available Energy Data for building's existing energy performance
- Available As-built documentation

Search Outcome & Property Description:

Ultimately, the following property was selected for further analysis as it was seen as the best option available to meet the most criteria above.

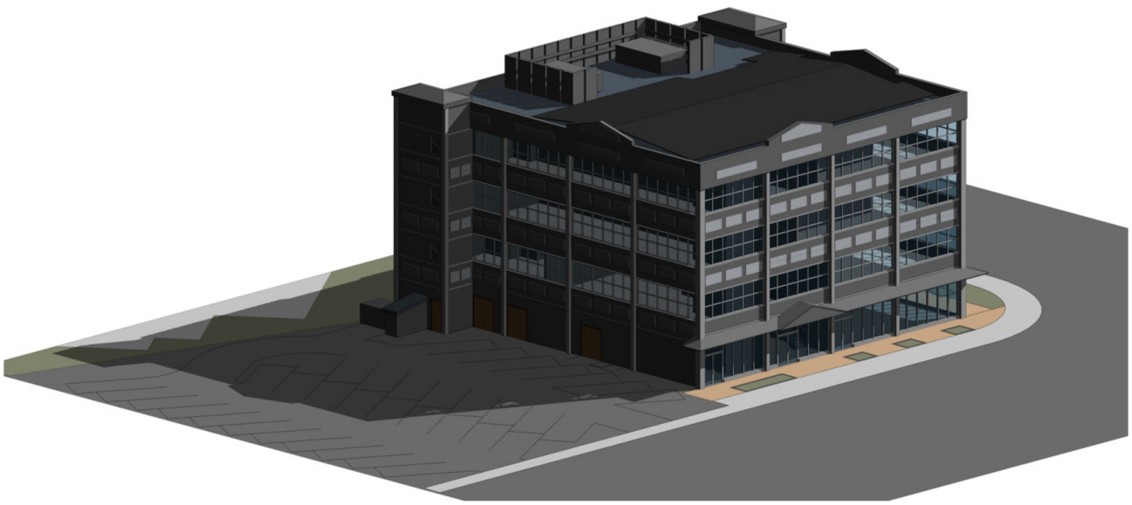
401 Kamakee – Mixed Use: Office & Retail Bldg

Figure 55 - West Perspective

Figure 56 - South Perspective

- Kakaako Mauka District(401 Kamakee)
- Approximately 25,000 SF
- 3 Floors Office & 1 Floor Retail
- Concrete/Steel Midrise
- 55% Glazing Ratio on 3 Sides
- Varying Age of Mechanical Equipment

Figure 58 - North Axon



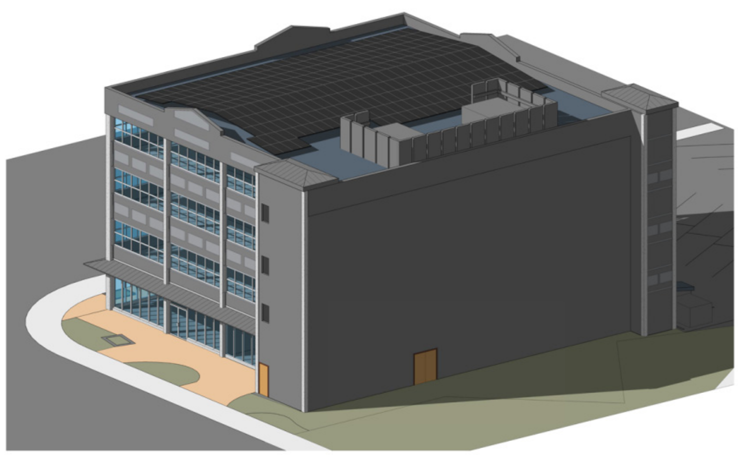


Figure 57 - South Axon

History

The building was originally the headquarters for EE Black Construction Contractors. Its original structure was built as 2 stories in 1958. The ground floor was almost exclusively parking and the 2nd floor contained offices for the group. Shortly after, 2 more floors of the same dimensions were built in 1961. [175]

Figure 59 – Original Building Facade

From Top Left to Bottom Right:

Mauka (Northeast) Elevation; Makai (Southwest) Elevation; Parking Entrance; Interstitial Space Between Facades

[175] Charles Chan, "E.E. Black Building Property Due Diligence Report," (Honolulu: Architects Hawaii Limited, 1993).

The original building's façade utilized a continuous gold anodized perforated metal screen to help mitigate direct heat gain in the interior on the three sides with glazing. This screen element was held off from the true wall by a catwalk system which attached back to the concrete structure.

The neighborhood underwent a transformation over the next 30 years, transitioning from its industrial roots to a much more urbanized context. In 1993 the building was purchased by the current owner which looked to convert the structure to a more standard urban mixed-use office typology, retrofitting it to include ground floor retail and removing the upper floor window screens which were considered detracting from the interior's rental value. The remaining façade was given a facelift to make it more presentable. These improvements are, in essence, what is visible from the street today.

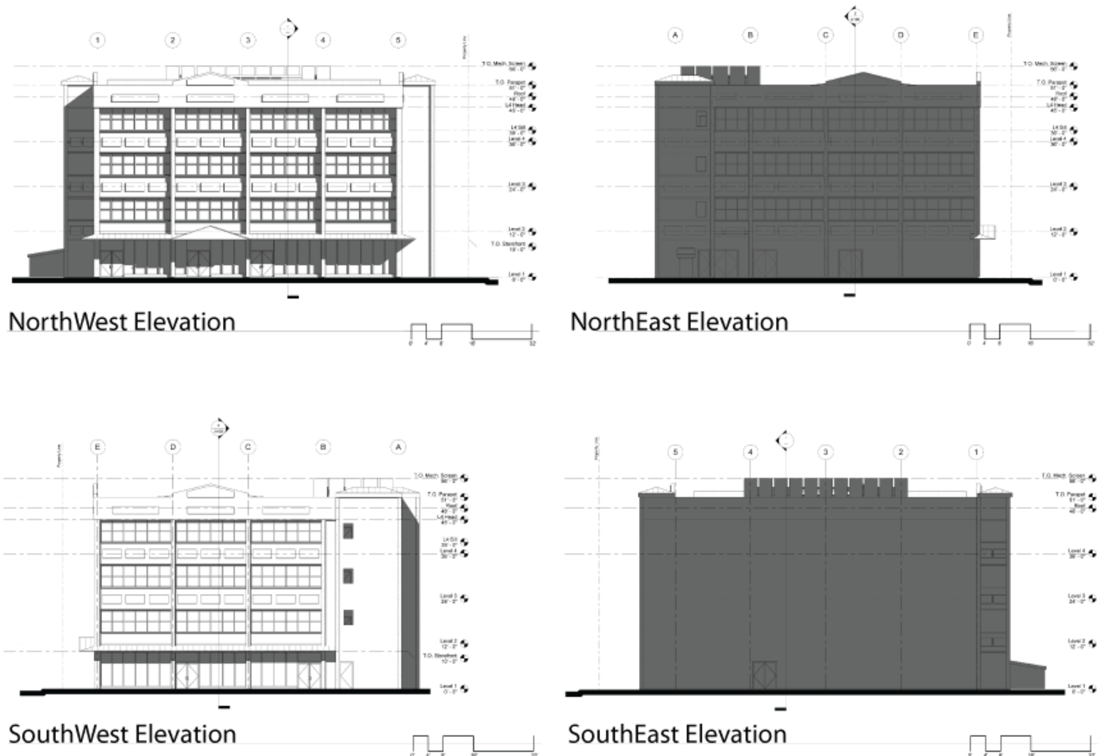


Figure 60 - EB Elevations

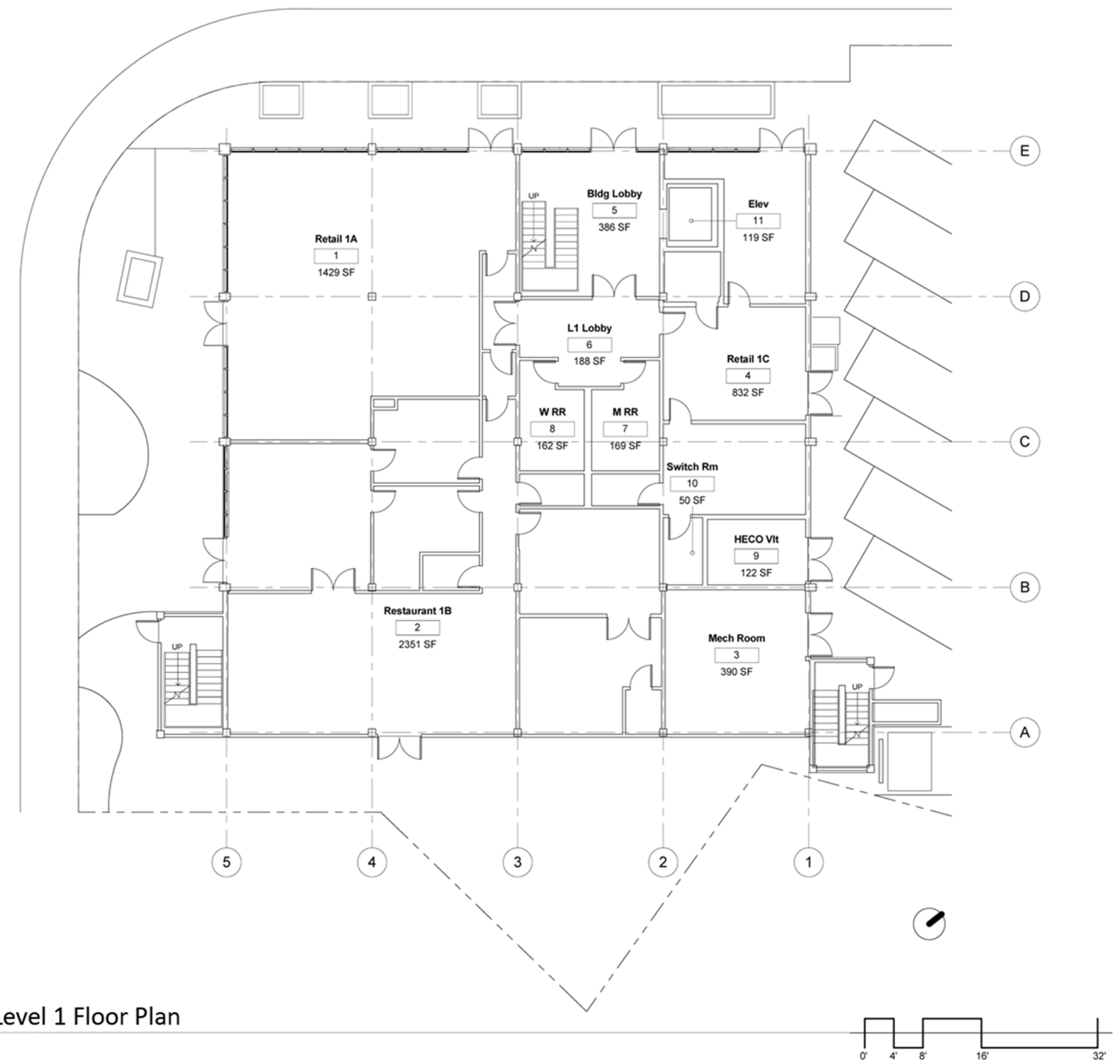
Rentable Area

The owner utilized the 2nd floor for his medical practice but has since retired and renovated that portion of the building in 2003. Two new tenants, a marketing firm and a spa, currently rent that floor. The 3rd and 4th floors are a mix of small office tenants, typically renting just enough space for one or two occupants. These floors offer a great deal of opportunity for rework of interior partitions - both for increased usable square footage and for increased access to daylight and the outdoors which has been proven to be a desired amenity.

For these reasons, the study will focus on the 4th floor first to show benefit of their renovation. That benefit will be applied to the other floors where possible to come to the full design package.

The 3rd and 4th floors show significant signs of age and it is obvious that they were built and added to over time without the same care and attention to detail that would be expected in an office improvement today. In some cases, interior partitions have been placed in a somewhat haphazard way, making due with the existing HVAC duct layout. You can see, in the following photos, the wall is bisecting the vent to allow airflow into each room on either side of the partition. The electrical wiring was noted as needing replacement in the '93 diligence report. Since that time, it has not seen improvement and is still in need of service.

Utility elements like restrooms and exit stairs have been pushed to the southeast wall of the floor plate against what used to be a zero setback line when the structure was built. Due to the deep floor plate in both directions, 3rd and 4th need to supply a large proportion of circulation space to accommodate egress requirements. Improving this condition would trigger significant action to ensure that exit egress comes up to code.



Level 1 Floor Plan

Level 1 Floor Area Summary

		Square Footage	
Leasable Retail Areas	Ext NA	1,251	
	1A	1,489	
	1B	941	
	1C	881	SubTotal
	1D	1,412	4,723
Building Common Areas	HECO Vlt	152	
	Switch Rm	56	
	Mech Rm	418	
	Emr	67	SubTotal
	Bldg Lobby	297	990
Floor Common Areas	L1 Lobby	200	SubTotal
	4 RRMs	386	586
NonRentable Area	Stair 1	163	
	Stair 2	144	
	Lobby Stair	114	SubTotal
	Elevator	88	509
Level 1 Total		6,808	

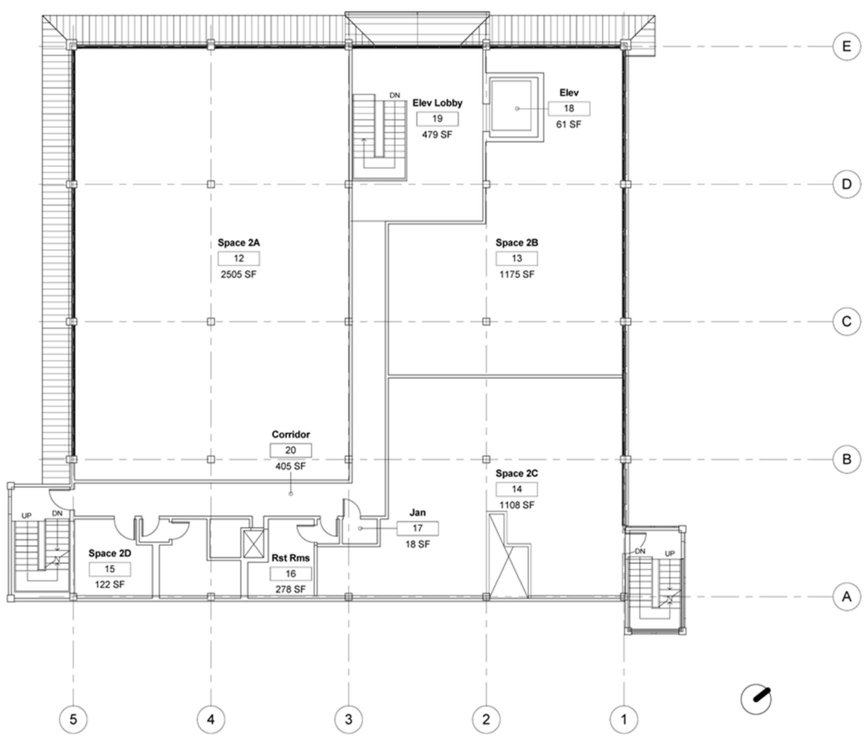
Figure 61 - EB Level 1 and SF Breakdown

The first floor currently houses street front retail tenants including one restaurant which takes advantage of the rear patio as extra seating. These shops, especially the restaurant, tend to be a draw for the tenants upstairs as they allow easy access to food and shopping.

Level 2 Floor Area Summary

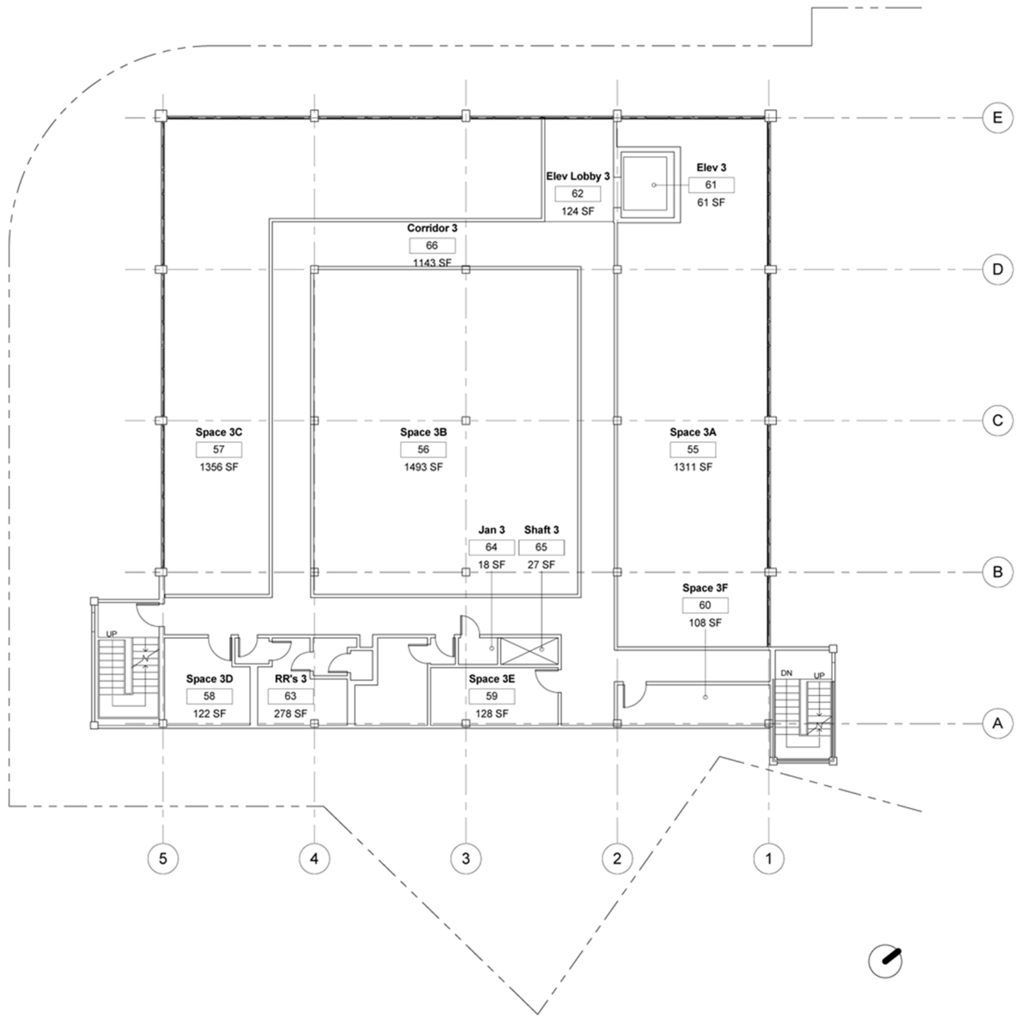
		Square Footage	
Leasable Office Areas	2A	2,575	
	2B	1,220	
	2C	1,152	SubTotal
	2D	129	5,076
Floor Common Areas	Janitor	25	
	2 RRMs	314	
	Elev Lobby	400	SubTotal
	Corridor	386	1,125
NonRentable Areas	Stair 1	163	
	Stair 2	144	
	Lobby Stair	114	
	Elevator	88	SubTotal
	Shaft	68	577
Level 2 Total		6,778	

The second floor takes advantage of its lobby stairway access to minimize egress required circulation. Because the of the revision, all tenant space has access to daylighting and rentable space is increased.



Level 2 Floor Plan

Figure 62 - EB Level 2 and SF Breakdown



Level 3 Plan

0' 4' 8' 16' 32'

Level 3 Floor Area Summary

		Square Footage	
Leasable Office Areas	3a	1,318	
	3b	1,497	
	3c	1,380	
	3d	129	
	3e	138	SubTotal
	3f	112	4,574
Floor Common Areas	Janitor	25	
	2 RRMs	314	
	Elev Lobby	133	SubTotal
	Corridor	1,310	1,782
NonRentable Areas	Stair 1	163	
	Stair 2	144	
	Elevator	88	SubTotal
	Shaft	29	424
Level 3 Total		6,780	

3rd Floor – Predominantly Office

Small Tenants around the perimeter made up of compact individual offices with ample daylight and outdoor view access. The interior side of the corridor is composed of misc. office spaces as well as specialty commercial spaces.

Figure 63 - EB Level 3 and SF Breakdown

Level 4 Floor Area Summary

		Square Footage	
Leasable Office Areas	4a	950	
	4b	1,861	
	4c	1,274	
	4d	129	SubTotal
	4e	339	4,553
Floor Common Areas	Janitor	25	
	2RRMs	314	
	Elev Lobby	221	SubTotal
	Corridor	1,223	1,783
NonRentable Areas	Stair 1	163	
	Stair 2	144	
	Elevator	88	SubTotal
	Shafts	49	444
Level 4 Total		6,780	

4th Floor – Predominantly Office Use

Small Tenants around the perimeter made up of compact individual offices with ample daylight and outdoor view access. The interior side of the corridor is composed of misc. office spaces as well as specialty commercial spaces.

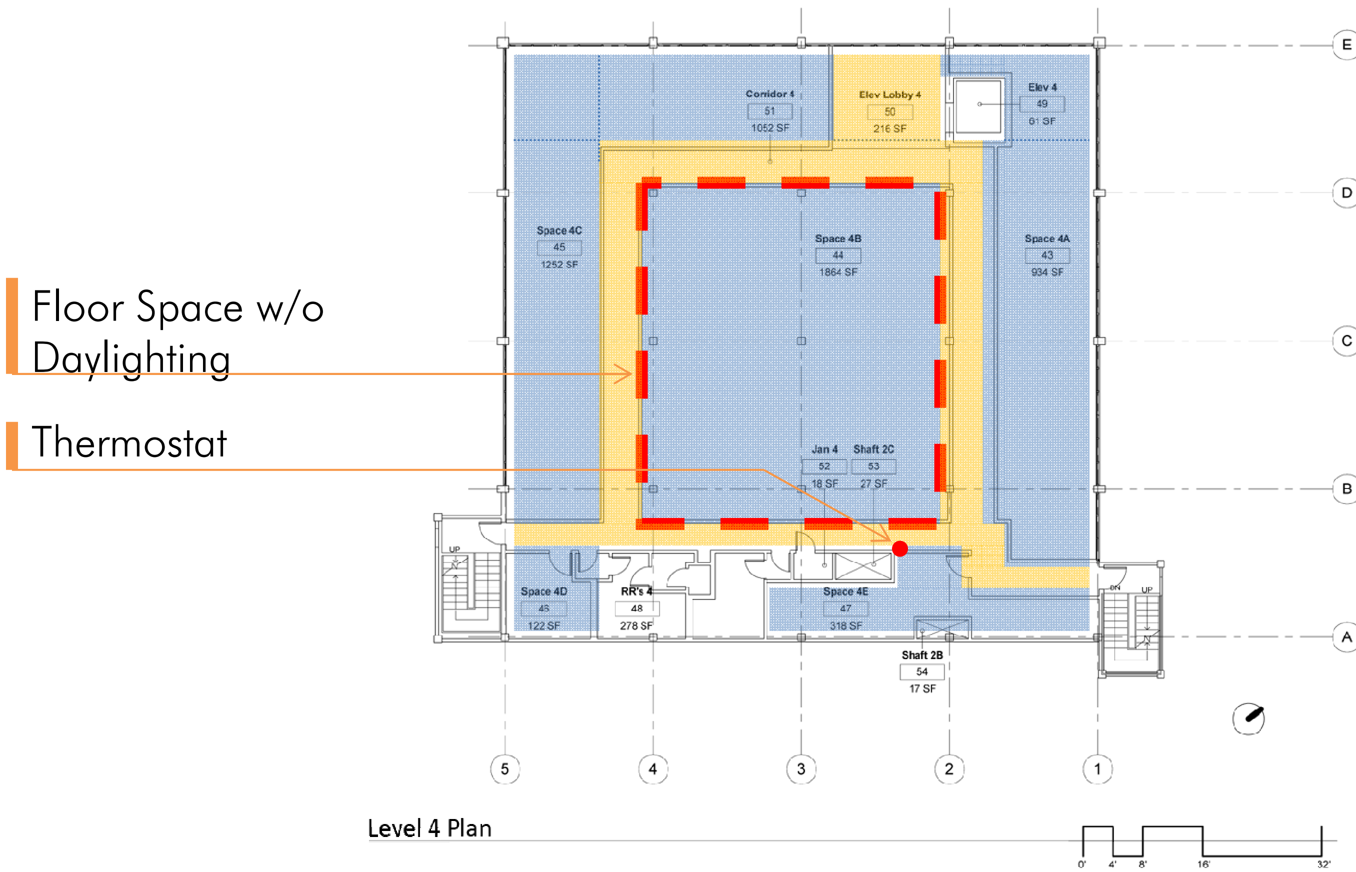


Figure 64 - EB Level 4 and SF Breakdown

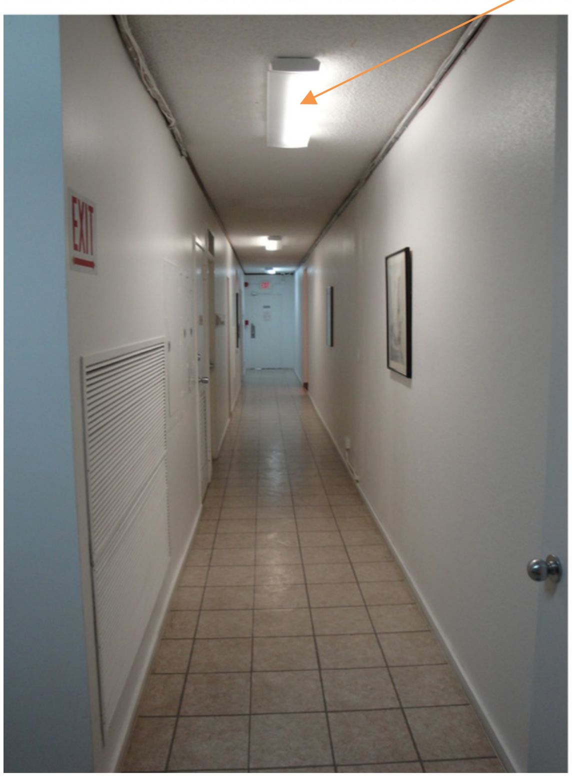


Figure 65 - Images of 3rd and 4th Floor Interiors.

From Top to bottom right:

Hallway Partition Wall Bisecting Supply Air Vent;

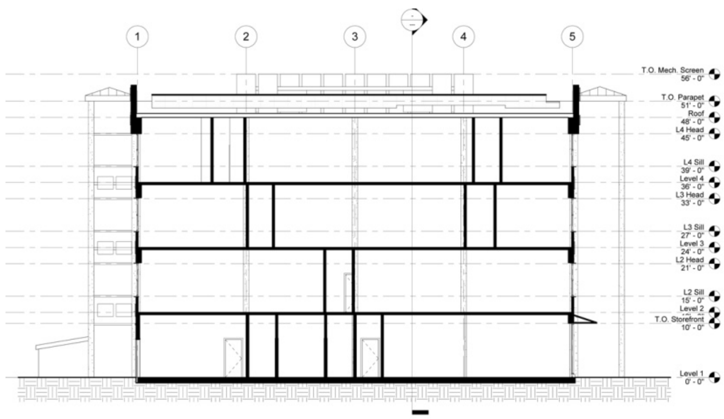
Elevator Lobby Area;

Rear Hall Along Restrooms;

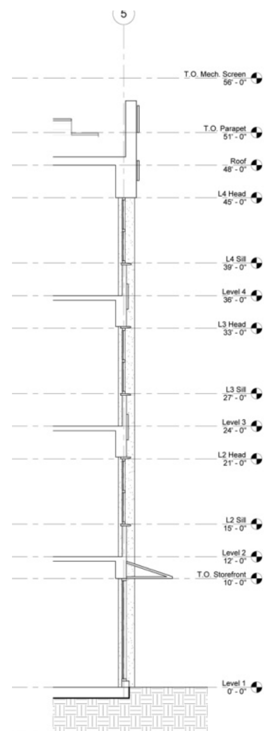
Typical Office Corridor

Occupancy

The building owner enjoys the fact that much of the building is geared towards small tenants. He feels that marketing toward this niche is the safest route given these spaces are easily filled in the event of vacancy. He rarely has less than 95% space occupancy and much of the time it is at 100%. This is well above the market average which is currently seeing upwards of 15% vacant[176].



Building Section



Wall Section

Figure 66 - Building and Facade Sections

Construction

The existing construction is comprised of a steel frame structure with 20' x 20' bays forming an 80' x 80' square building. The building's perimeter consists of concrete columns and beams. Full height concrete walls exist at the elevator shaft and 2 sides of the makai stair. The SE wall is a precast concrete infill wall. The typical floor framing consists of 2 1/2" concrete topping slab over light gage metal decking.

A seismic check of the concrete walls showed that the building did not conform to current code in 1993 due to lateral and seismic load deficiencies. The current building is susceptible to a twisting motion in the event of an earthquake or hurricane.[177] The same report recommends the addition of structural cross bracing @ interior bays to remedy concerns.

Facade

The exterior facade is comprised of a 1'-0" thick concrete headers that extends to the next level above (3'-0"). This face provides ample structural support as well as thermal sink for the interior. Below the windows are 2 1/2" precast concrete panels which are clipped to the floor slab as necessary.

176 "Honolulu Office Vacancy Rate Rises to 14.9%," *Pacific Business News*(2012).
177 "E.E. Black Building Property Due Diligence Report," 3.

Existing windows (55% of 3 sides of the building) are the original single pane glazing with a steel sash frame. They have been retrofit with a direct applied highly reflective film installed on the interior face. This film gives the assembly a relatively low solar heat gain, but discourages from daylighting.

Roofing consists of a built up roofing system, which is relatively white in color. The system appears to be aging in place and some minor ponding was evident on the roof.

Electrical Wiring

The electrical system is in need of rewiring. The '93 report recommended its replacement and has not been undertaken. Currently, the wiring is surface mounted to the ceiling in the 3rd and 4th floors. This could be having a significant effect on the efficiency of the wiring throughout the building.

Triggers

Many of the Right-Timing Triggers for a Deep Retrofit are present in the property. As discussed earlier, these points are common in most retrofit situations and often help to give additional incentive to proceed.

Redevelopment/Repositioning – Additional Amenity. Although not required by the owner, the property currently provides little in the way of tenant amenity besides the access to the shops on the first floor. The property's leasable value can be significantly increased through the addition of a few amenities. This approach should help to bring the office space to a higher product to lease to tenants. Furthermore, some of the central tenant spaces have no access to daylighting. Repartitioning the spaces could bring higher costs per square foot by providing access to daylight and the outdoors in all rentable space. Repartitioning would have the added benefit of increasing usable rent space which provides a direct increase in revenue.

Window Replacement –The Current Glazing is the original single pane steel sash assemblies installed in the building. They are over 50 years old and an extreme detriment to potential daylighting levels and thermal gains. Although retrofitted with a window film, it appears to have aged in place and is highly reflective, blocking usable daylight from entering the space.

Upgrades to Meet Code / Safety – Structural Bracing. The structural System was found to be structurally deficient in a 1993 due diligence report provided for the building.[178] Although the structure is an existing non-compliant condition, there is the possibility that the building is susceptible to an unwanted twisting response in the event of earthquake or hurricane. A retrofit of the building would be able to be coupled with strategies to address the stabilization and code compliance of the structure.

End of Life Replacement – Electrical Wiring Replacement. Similar to the structural concerns, the electrical system is the original system which has been loosely added onto throughout the decades. Often times, electrical lines are surface mounted and substandard. With the revised

[178] "E.E. Black Building Property Due Diligence Report," Struct 3.

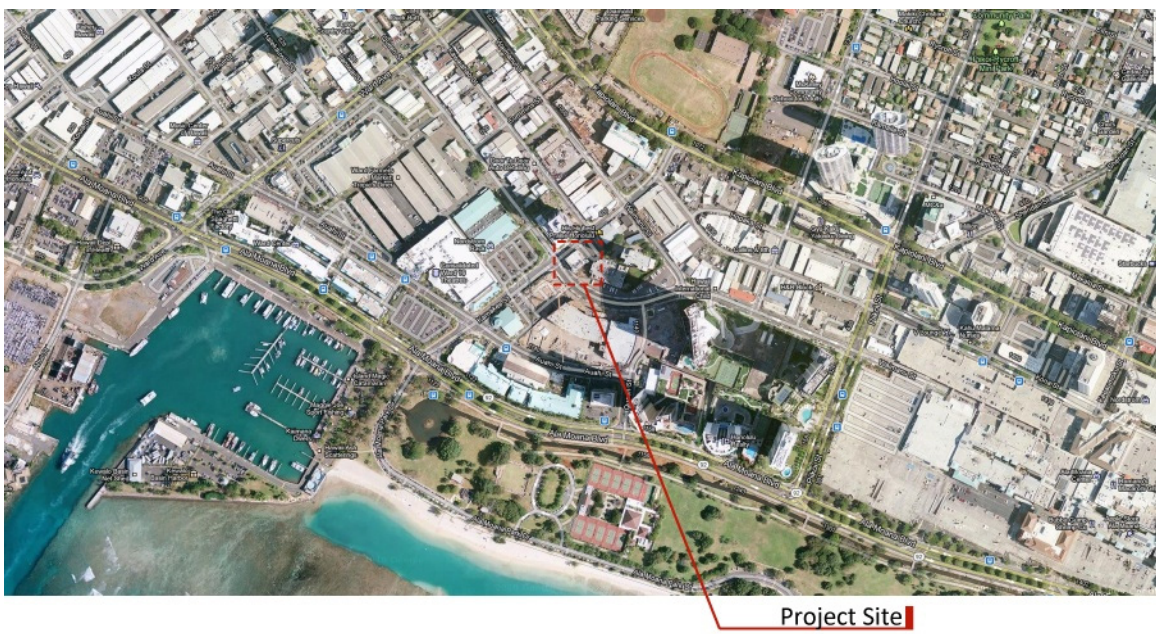
layout, comes the opportunity for a much needed electrical renovation of all wiring (along with lighting).

<u>HVAC Duct Replacement and Upgrade.</u> The current HVAC equipment is at varying ages. Holes in ducts are being plugged due to rust – implying energy inefficiency and condensation problems. Furthermore, the current ducting system and zoning was intended for an open layout. Air supplies are bisected by walls and thermostats and/or temperature monitoring is not provided for each of the orientation zones making thermal comfort difficult.

Existing Site Conditions

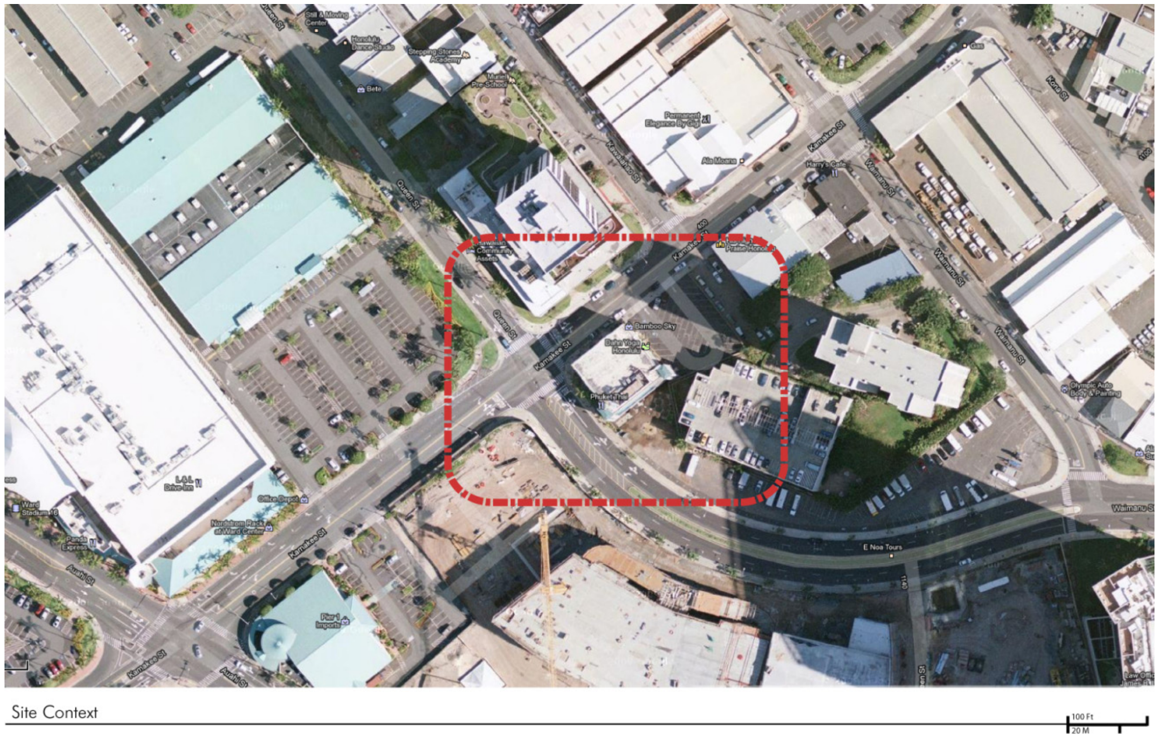
Currently, the surrounding site is beginning to dwarf the 50 year old structure. Development of the Ward Retail shops on the Makai (Sea), the Kapiolani Corridor to the north, and the Multifamily condo towers on the east have made the property a sought after location, and thus the potential for high value.

Figure 67 – Site Vicinity Map - Image Courtesy of Google Maps

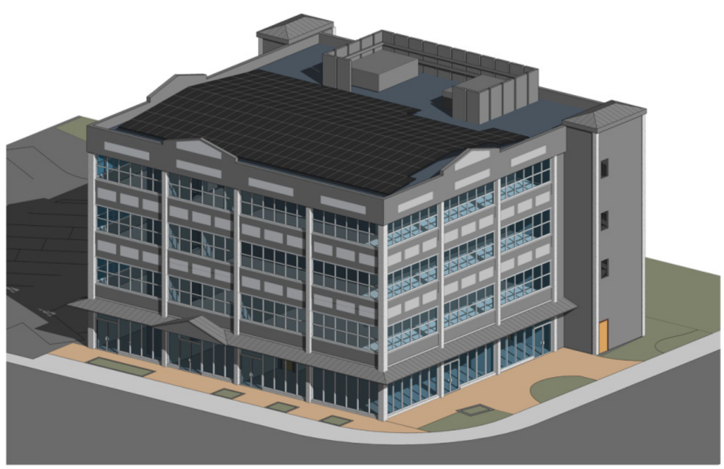


Zooming in on the property's surroundings, it becomes clear that although the larger surroundings have become very dense, the local surroundings are a relatively smaller scale in comparison.

Figure 68 – Site Context Map – Image Courtesy of Google Maps



This context has many implications. Part of this is opportunity for natural ventilation given its relatively open corridors towards the predominant winds on the site. Further local analysis of wind patterns will be required to determine if local conditions and the building geometry will allow for considerable comfort within the interior.



West Axonometric View

9

Environmental Analysis

Thermal Comfort begins with an analysis of local temperatures. In Honolulu, min/max swings from day to night are typically relatively small with ranging from about 10-15°F in the colder half of the year to 10°F in the warmer half. Throughout the year, typically some portion of the day will automatically be in the comfort zone without mechanical heating or cooling. Given that 43% of a typical office space currently goes to the cooling of a space, and offices are typically air conditioned for 100% of occupied hours, significant gains in efficiency can be made simply by utilizing outdoor air when in the comfort zone.

This site's closest weather station is located at Honolulu International Airport 5 miles away, with a similar relationship to the ocean - less than a mile away from the south coast of Oahu.

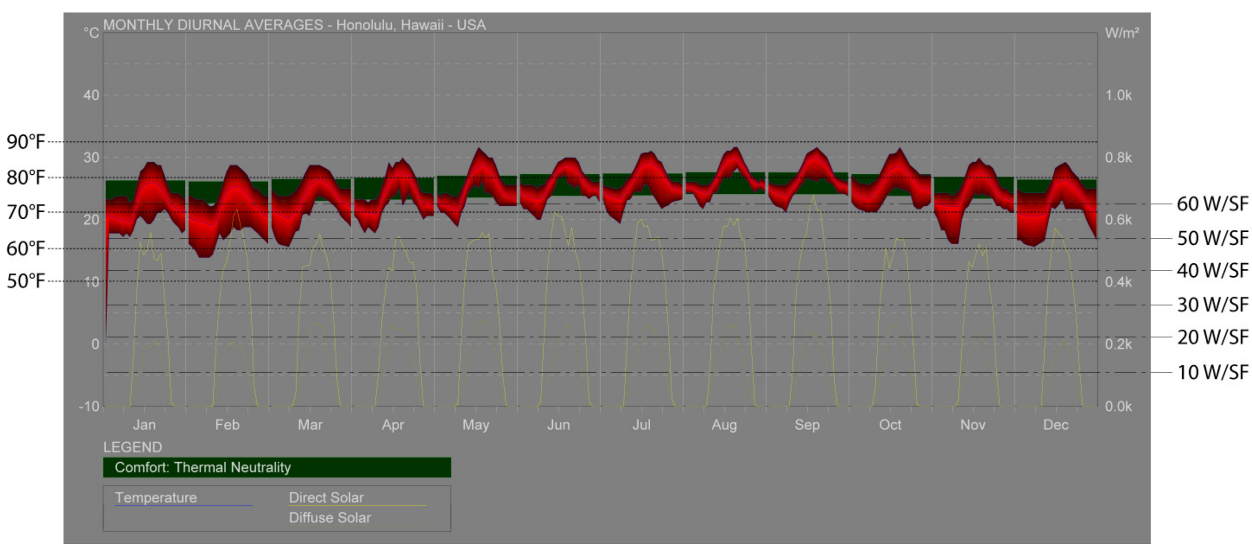


Figure 69 - Honolulu Monthly Diurnal Averages with Comfort Underlay

As discussed earlier in the research, temperature is a function of a few different variables including ambient air temperature and radiant. Analyzed together, they form an average, operative temperature, which is what is experienced by occupants.

However, temperature is just part of the thermal comfort puzzle. Humidity and air speed also factor in to determine comfort. This can be seen in the Psychometric analysis of the data below. A standard comfort level is depicted by blue. This window is increased when natural ventilation is introduced (depicted by the cyan line). As you can see, natural ventilation has the ability to bring occupants into the comfort zone for a good portion of the year (approximately 6 months).

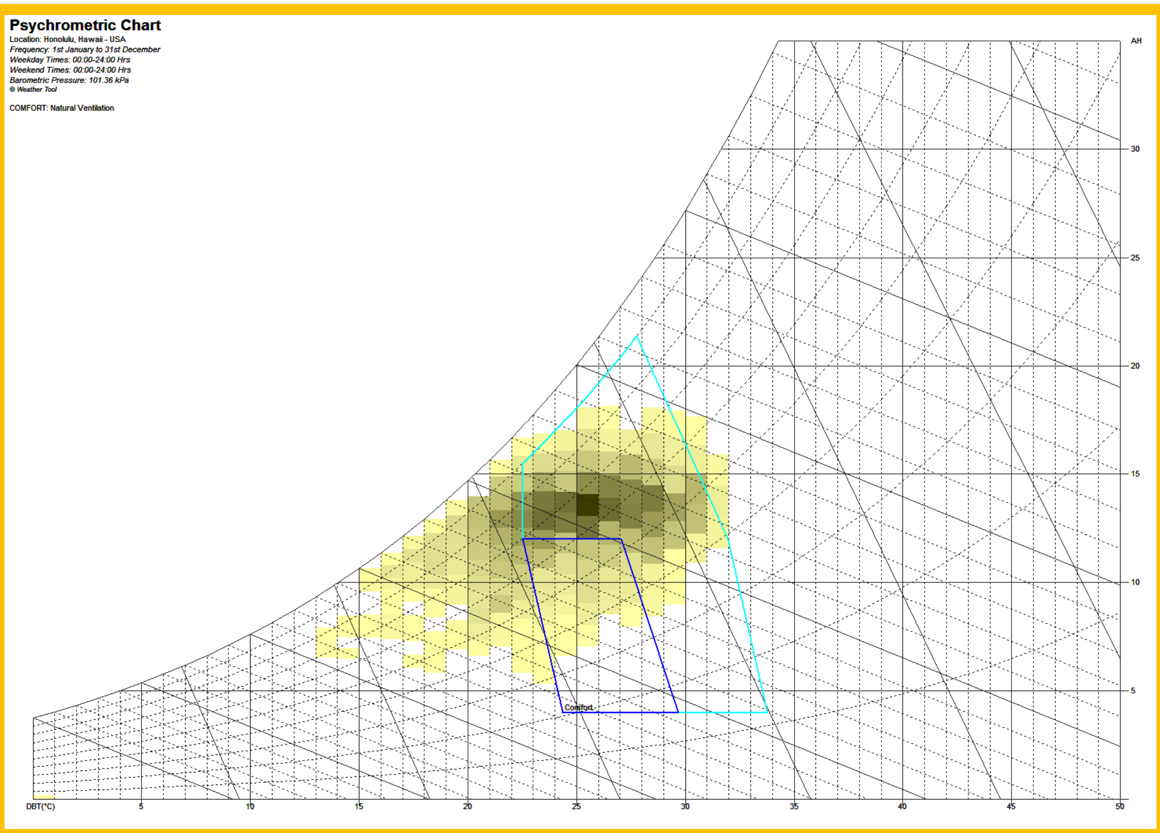


Figure 70 - Honolulu Annual Comfort Levels Plotted on the Standard Comfort Window with Natural Ventilation Adjustments

High humidity levels are of paramount concern when considering air conditioning systems in a Honolulu climate. Relative humidity daily averages range from 63-74%. Although a comfort-RH comparison will vary based on temperature, this is generally considered to be higher than desired for indoor air quality as well as for maintaining thermal comfort. Due to this fact, any efficient air conditioning system for this climate must be able to remove humidity from air in order to create an acceptable solution.

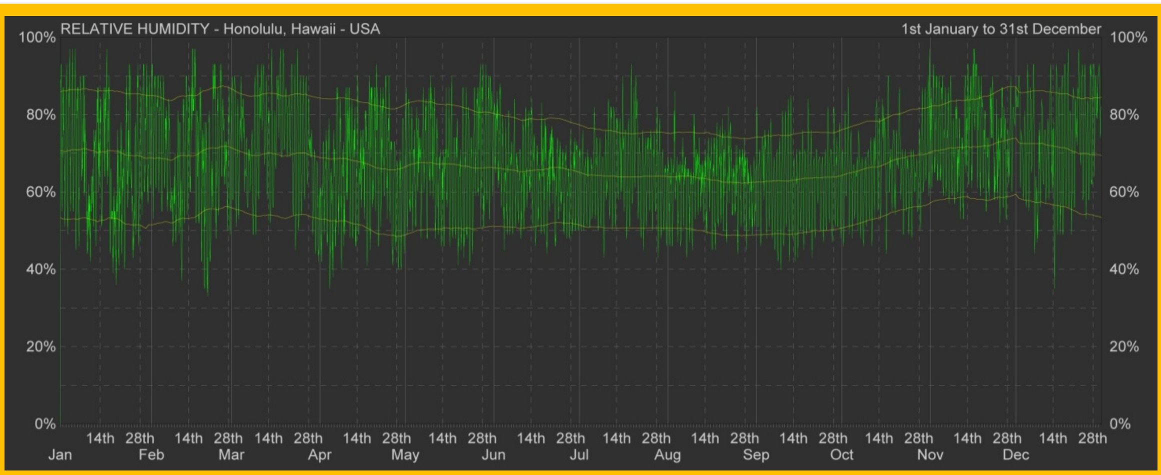


Figure 71 – Annual Relative Humidity For Honolulu

In order to develop a highly efficient comfort solution for Honolulu, heat and humidity will need to be addressed in the most efficient manner. Unfortunately cross ventilation alone does not adequately address humidity concerns because it does not have the capacity to remove water vapor from the air or mitigate mold growth. It also cannot remove heat from the air.

The weather data provides the necessary insight into the sites macro conditions in order to begin to analyze the micro-climate. Utilizing this data, a simulation of the local vicinity can be set up and more thoroughly analyzed.

The site environmental analysis needs to focus on the local microclimate where ever possible. Where site specific data is not available, existing conditions must be inferred from local weather stations. Temperature, Humidity, Solar Exposure, as well as exposure to Natural Ventilation become extremely important to the site analysis because they represent natural energies that when harnessed, can remove loading requirements on the existing structure.

Solar Exposure

Building Orientation

The existing building is oriented 52° off the East/West axis posing an interesting problem for external measures (See the shading analysis in the Analysis and Design Chapter). This is one issue that can be handled in concept design or planning (in the case of an urban setting). Unfortunately, once built off axis, mitigation of direct beam solar radiation becomes much more challenging, more costly, and material intensive. The extent of shading can be seen in the building's original design and is the reason for the extensive gold anodized screen which was demolished during a remodel in the 1990's to create more of a connection with the outdoors.

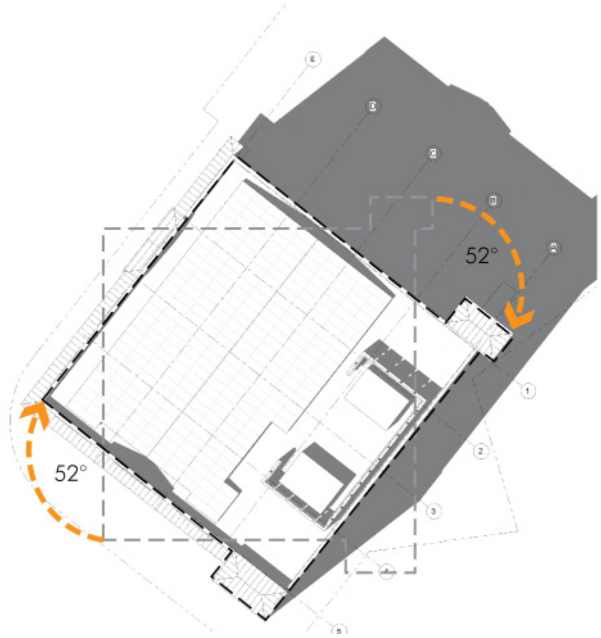


Figure 73 - Building Orientation

Figure 72 - Building Orientation

Sun Path

Solar paths have a wide range of fluxuations throughout the year. Altitudes range from approximately 95° (beyond overhead) at Noon on June 21st to 44° at Noon on December 21st. Sunrise and Sunset Azimuths also vary by about 55° annually. They are 25° North of the E/W in June and 30° South in December.

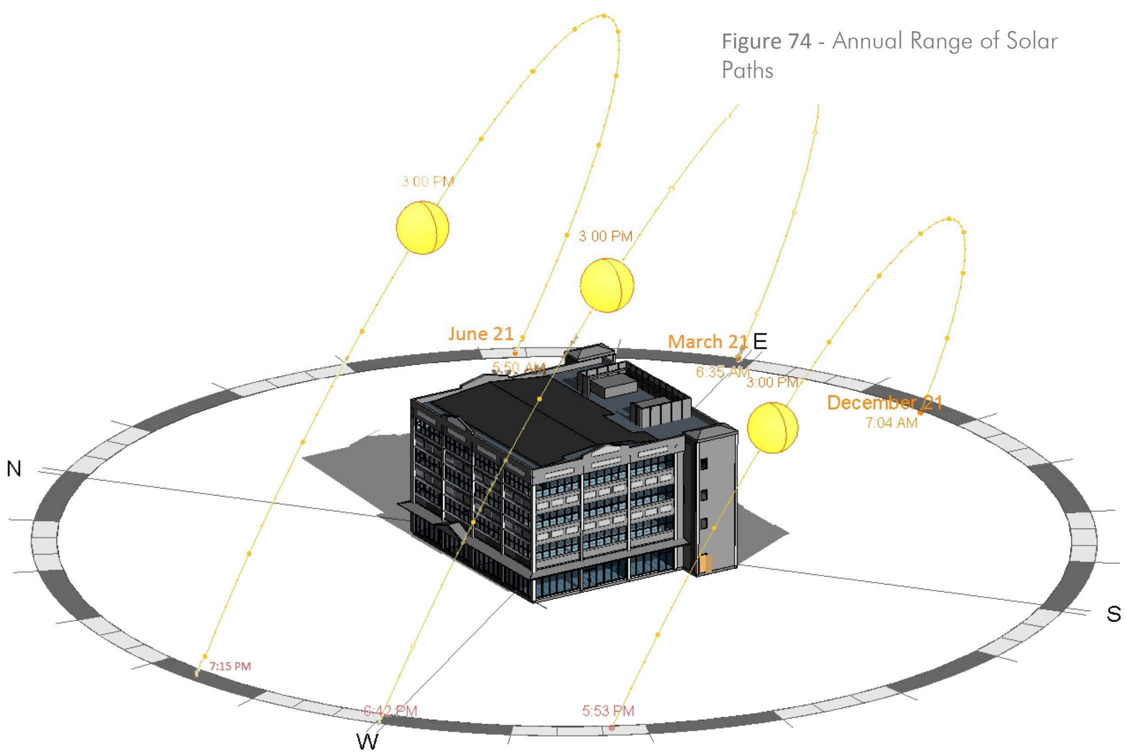


Figure 74 - Annual Range of Solar Paths

Exposure to Natural Ventilation

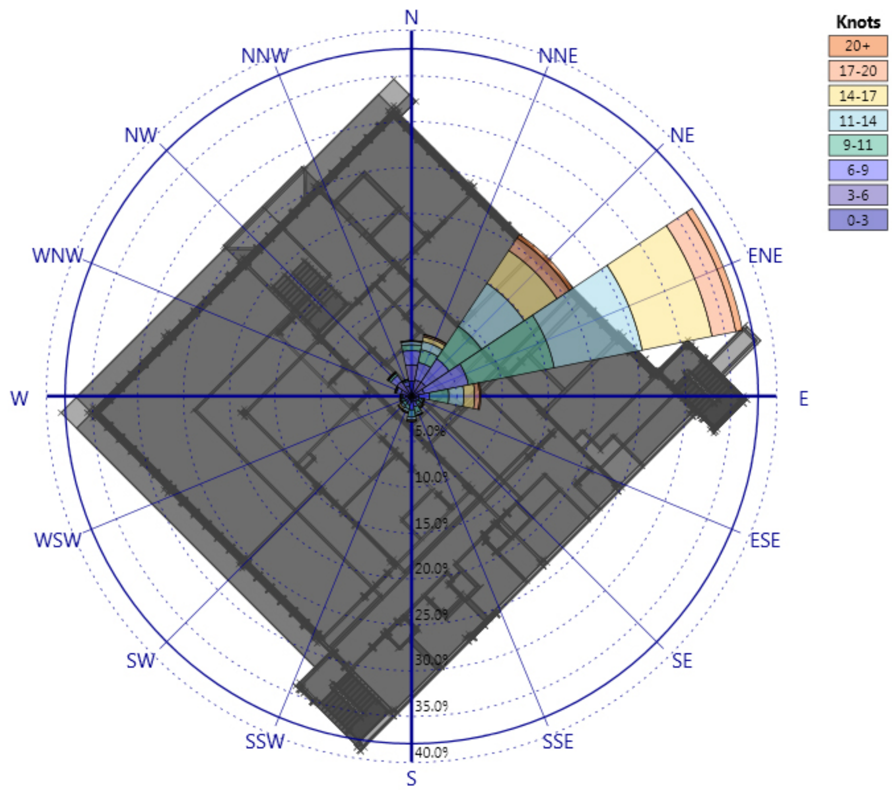


Figure 75 - Wind Rose Depicting Predominant Winds Effecting the Existing Structure

Predominant Winds and Macro Analysis

Wind measurements taken at the nearest weather station show a macro analysis of the wind's exertion on the building. Predominant winds are out of ENE (Approximately 60° Clockwise from North) and are primarily focused on the NE and SE facades. Velocities with the highest frequency range from 10-20 MPH (15-35 KM/Hr).

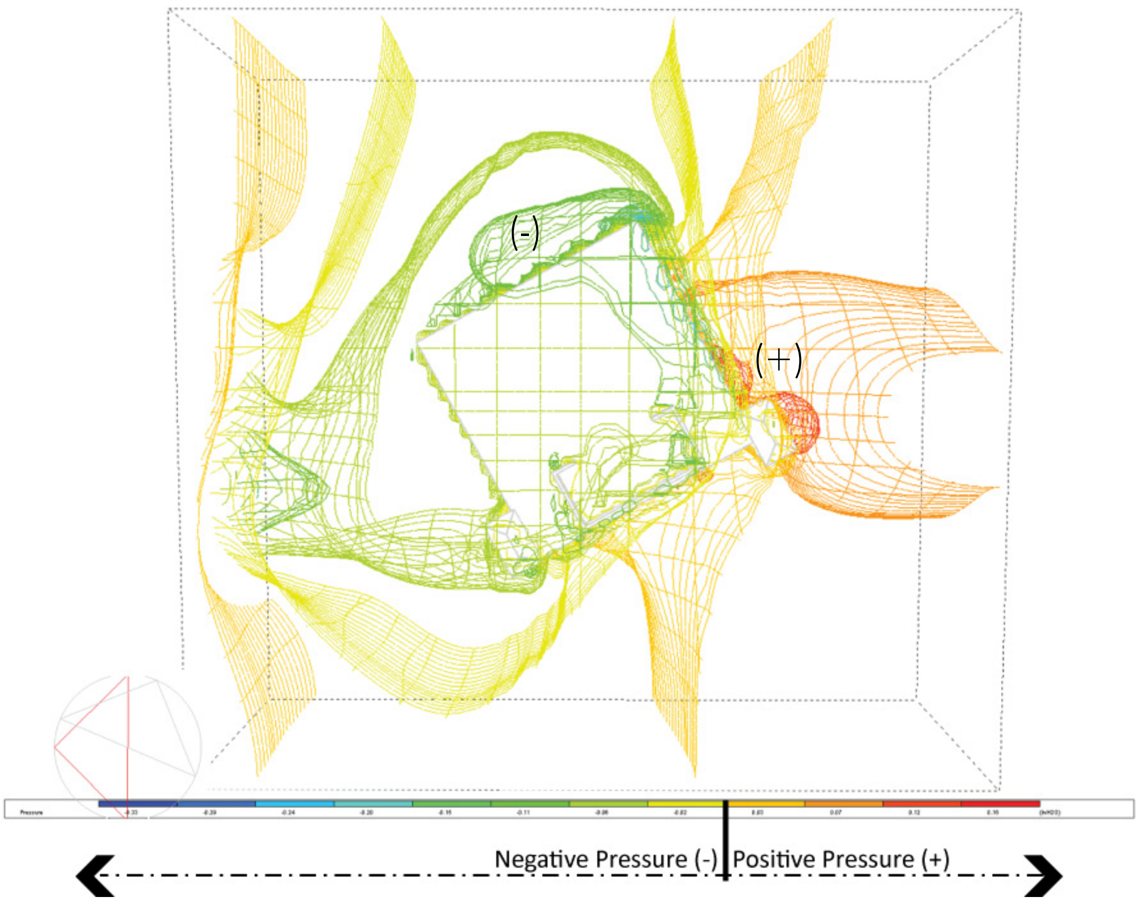


Figure 76 - Effects of Wind Pressure on Building Exterior

An external CFD analysis shows how air flow interacts with the building. Utilizing predominant wind directions and velocities (1640 Ft/Min), we can see that the relative shape and size of the building creates positive pressure pockets on the NE facade of the building closest to the stairwell. Conversely, negative pressure area lies on the NW facade centered around the existing stacked lobby areas. This means that any efforts to naturally ventilate the space will have the strongest intake at the NE and the strongest exhaust on the NW during predominant wind conditions.

Environment Analysis Conclusion

Understanding the site constraints and physical interaction of the building and elements is important to understand in any energy retrofit. When focusing on passive measures, it is essential. This understanding will be utilized throughout the rest of the process to come to an optimized result.

10

Model Calibration & (E) Performance

For the purposes of this process, an energy model will need to be created which closely mimics the performance of the actual existing structure. "The development of calibrated building energy simulation (BES) models involves a process of using genuine as-built information, surveys, and measured data to update the input parameters of the initial simulation model so that it closely represents the real operation of the building."[179]

Creating the Model

For this project, limited as-built documentation based on improvements made in the early 1990's were obtained as well as documentation after the current ownership took hold of the property. This includes tenant improvements and the remodel of the 2nd floor in 2003. The '93 renovation documents as well as the due diligence report conducted at the time of purchase were helpful in representing the correct thicknesses and construction types involved.

In some cases, it would be necessary to sub-meter individual systems to maintain the highest level of accuracy and lowest perceived risk. Due to time limitations of the project and the fact that the building has sub-meters installed by the electrical company, project specific monitoring of energy use was not undertaken. In this case, historical energy bills were helpful in determining the correct consumptions for individual systems given the amount of meters found to be operating in the field - (6).

On-site observation of existing conditions were helpful in verifying conditions expressed in the documentation and identifying active technologies like lighting and HVAC.

[179] Marcus Keane Paul Raftery, and Andrea Costa, "Calibration of a Detailed Simulation Model to Energy Monitoring System Data: A Methodology and Case Study," in *Building Simulation 2009* (Glasgow, Scotland2009).

Analysis of Energy Bills

Creating a calibrated energy model begins with a thorough analysis of the building's past energy consumption. Essentially, this information will become the baseline for which results are compared against. The following is a summation of 401 Kamakee's energy consumption from the period ending 8/24/2011 through 7/23/2012 spanning one year of time.

401 Kamakee Energy Consumption Analysis										
	Square Footage	Annual Total								
		kWh	kBtu	kWh/SF (EUI)	kBtu / SF	Cost	Cost/SF	#Days	KWH/Day	$/Day
1st & 2nd Floor		107,080	365,357			$35,462		364	294.41	$97.53
1st & 2nd Floor		131,480	448,610			$42,259		364	358.21	$114.81
1st & 2nd Total	13586	**238,560**	**813,967**	**17.56**	59.91	$77,720	$5.72			
3rd Floor Lighting	6780	32,492	110,863	4.79	16.35	$11,165	$1.65	364	88.37	$30.44
3rd Floor AC	6780	81,171	276,955	11.97	40.85	$27,863	$4.11	364	222.99	$76.59
4th Floor AC	6780	69,231	236,216	10.21	34.84	$24,544	$3.62	364	190.71	$67.61
4th Floor Lighting	6780	21,461	73,225	3.17	10.80	$7,626	$1.12	364	58.96	$20.96
Total	**27146**	**442,915**	1,511,226	**16.32**	56	**$148,918**	**$5.49**			

30 Day Example 7/23/2012 (Ex Energy Bills)						
	KWH	Cost	Cost/SF	#Days	KWH/Day	$/Day
1st & 2nd Floor	9440	$3,218.69		33	286.06	$97.54
1st & 2nd Floor	12800	$4,208.91		33	387.88	$127.54
1st & 2nd Total			$0.55			
3rd Floor Lighting	2676	$953.25	$0.14	33	81.09	$28.89
3rd Floor AC	6556	$2,315.02	$0.34	33	198.67	$70.15
4th Floor AC	5063	$1,902.53	$0.28	33	153.42	$57.65
4th Floor Lighting	1356	$514.56	$0.08	33	41.09	$15.59
Total	**37,891**	**$13,113**	**$1.39**			**$397.36**

Figure 77 - EB Energy Bills

Description of Sub-meters

The 1st & 2nd floors have 2 meters - each servicing a portion of each floor. Unfortunately, it has not been clear which systems are served by each meter. For this reason, the totals of the first two meters have been grouped to avoid confusion.

The 3rd and 4th floor meters for "Lighting" and "AC" were clearly designated by management on the bill summary for each floor. What was not clear is which meter is servicing the plug loads for the floor.

PV Onsite Generation

The Newly Installed PV array was installed in the beginning of 2012 and has been recorded by HECO since April of 2012. With the data shown, the array is looking to produce about 22% of the power needed for the building

Onsite PV Generation

	KWH	Payment	Pay/ Int.SF	(N) Rate	#Days	KWH/Day	(N) $/Day
30-Apr	6632	$1,253.45	$0.05	$0.24	25	265.28	$63.14
21-May	7882	$1,489.70	$0.05	$0.24	20	394.10	$93.80
20-Jun	10141	$1,891.65	$0.07	$0.24	30	338.03	$80.45
23-Jul	11506	$2,149.63	$0.08	$0.24	33	348.67	$82.98
23-Aug	11398	$2,687.72	$0.10	$0.24	31	367.68	$87.51
24-Sep	9893	$2,354.53	$0.09	$0.24	32	309.16	$73.58
24-Oct	7972	$1,872.34	$0.07	$0.24	30	265.73	$63.24
26-Nov	7432	$1,743.82	$0.06	$0.24	33	225.21	$53.60
24-Dec	5305	$1,262.59	$0.05	$0.24	28	189.46	$45.09
24-Jan	6191	$1,473.46	$0.05	$0.24	31	199.71	$47.53
22-Feb	6740	$1,604.12	$0.06	$0.24	29	232.41	$55.31
22-Mar	7708	$1,834.50	$0.07	$0.24	28	275.29	$65.52
Ave	8233	$1,801.46	$0.07		27	336.52	$80.09
Total	98800	$21,617.51	$0.80		350		

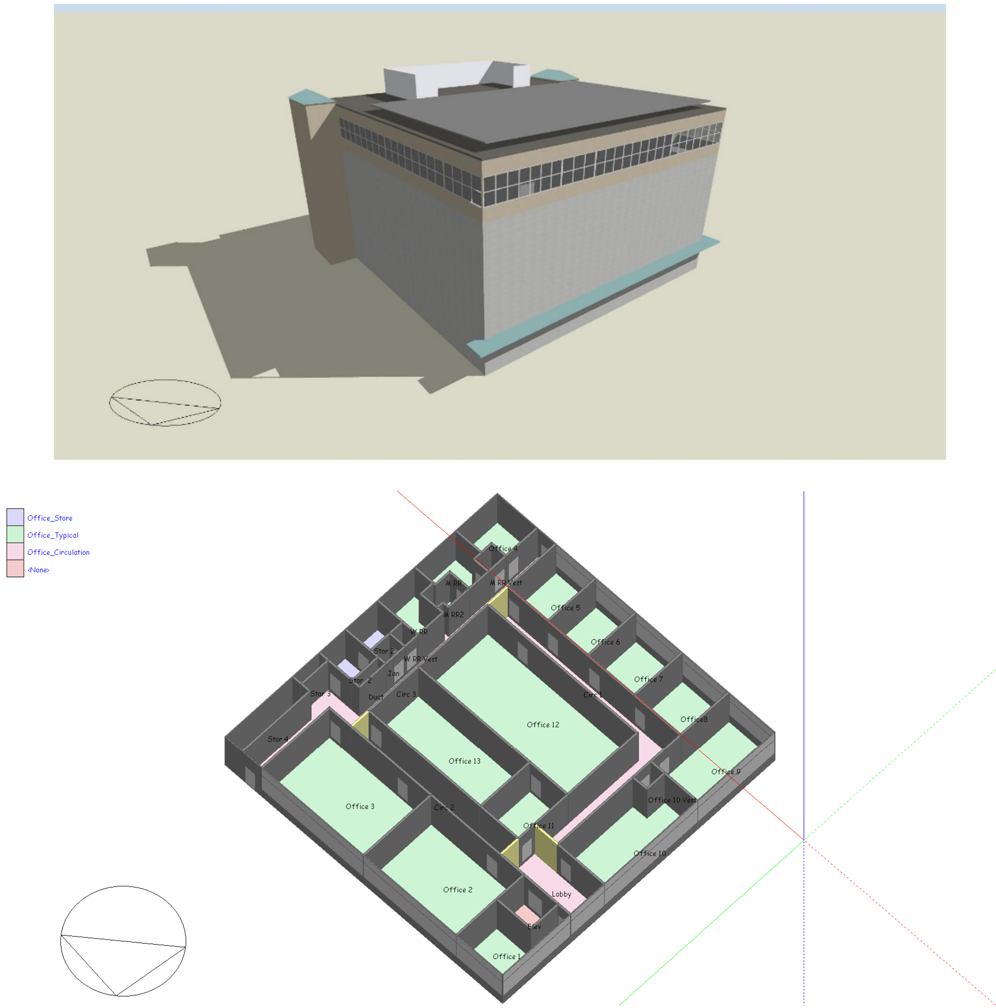
Figure 78 - EB PV Generation

Model Complexity and Makeup

Whole Model ---> Individual Floor as a "go-by"

The calibration process began with the intent of providing the most accurate "all inclusive" model possible for the whole building. The preliminary idea was that 1 building model would be able to provide the bulk of results. This approach resulted in a level of complexity that was not needed for the analysis, given the level of sub-metering and system zoning contained in the building which were isolated to each floor. For these reasons, an alternate approach, shown below, was developed to look at one floor at a time. This way, floors could be isolated allowing concentration on independent systems. The floors below were replaced with adiabatic surfaces to most closely simulate the 4th floor's heat transfer from below.

Figure 79 - Energy Model Geometry



Model Calibration and Setup

The following is a description of the model and its settings. Care is taken to explain the setup for clarity of process.

Activity and Zoning

Activity Settings explain the zone's predominant use. Some internal loads like heat produced by occupants, equipment, and hot water demand are specified here. The simulation software, Designbuilder, provides templates for typical programming. In this model, "Generic Office Area" is designated the default. Default office densities and metabolic rates were used. Due to the lightweight nature of dress in Hawaii, the clothing setting was adjusted to .5 clo's year around. Hot water loads remain at the default rates. The HVAC setpoint is set at 71° based on the setpoint in the actual building. Equipment is estimated at 110% of average at 1.2W/SF.

This was the predominant activity zone utilized. Other supporting zone types include Circulation, Restrooms, and Storage. The elevators and duct spaces are set to be unconditioned and are not tracked for comfort.

Zoning Activities

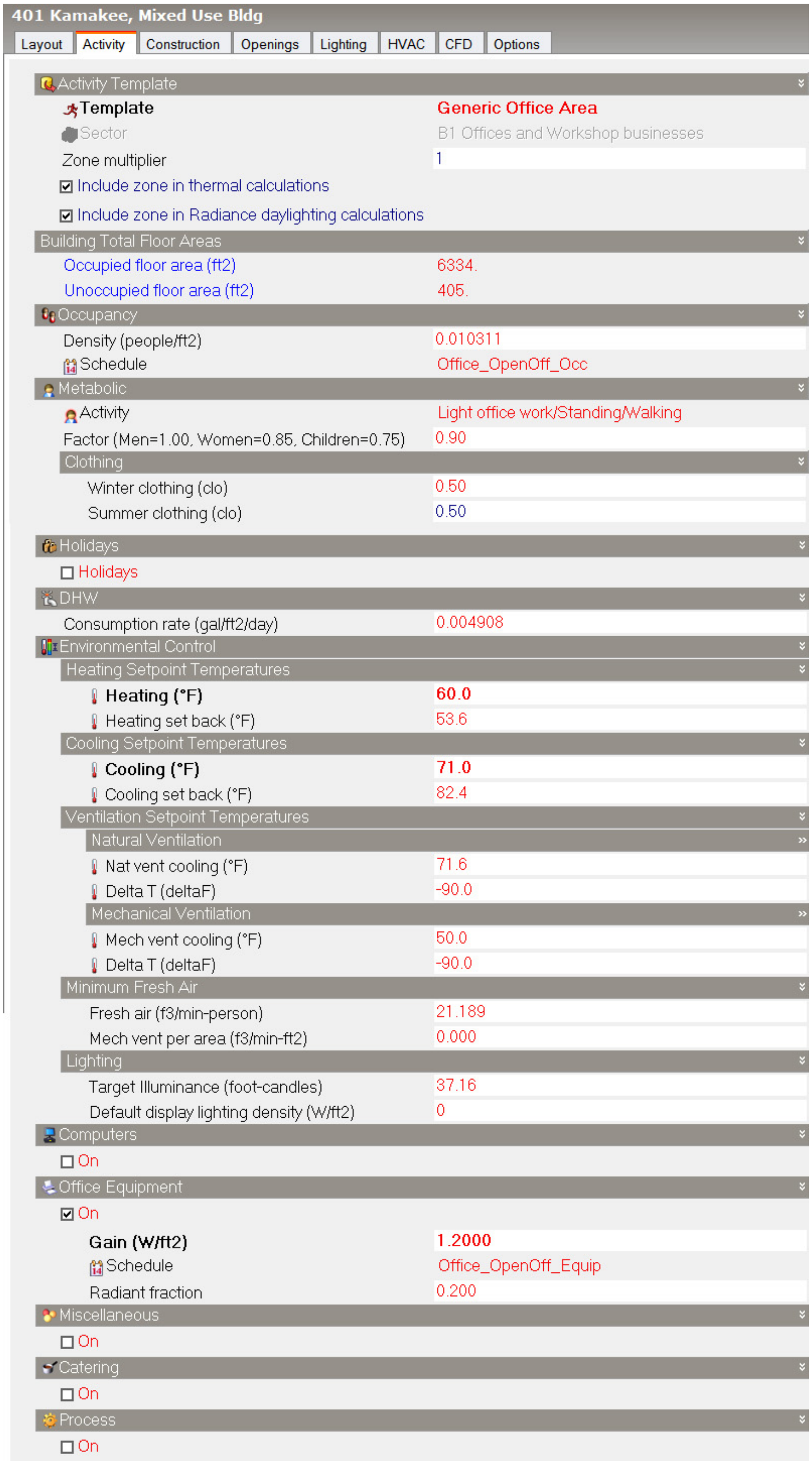


Figure 80 - Activity Setting Dialogue

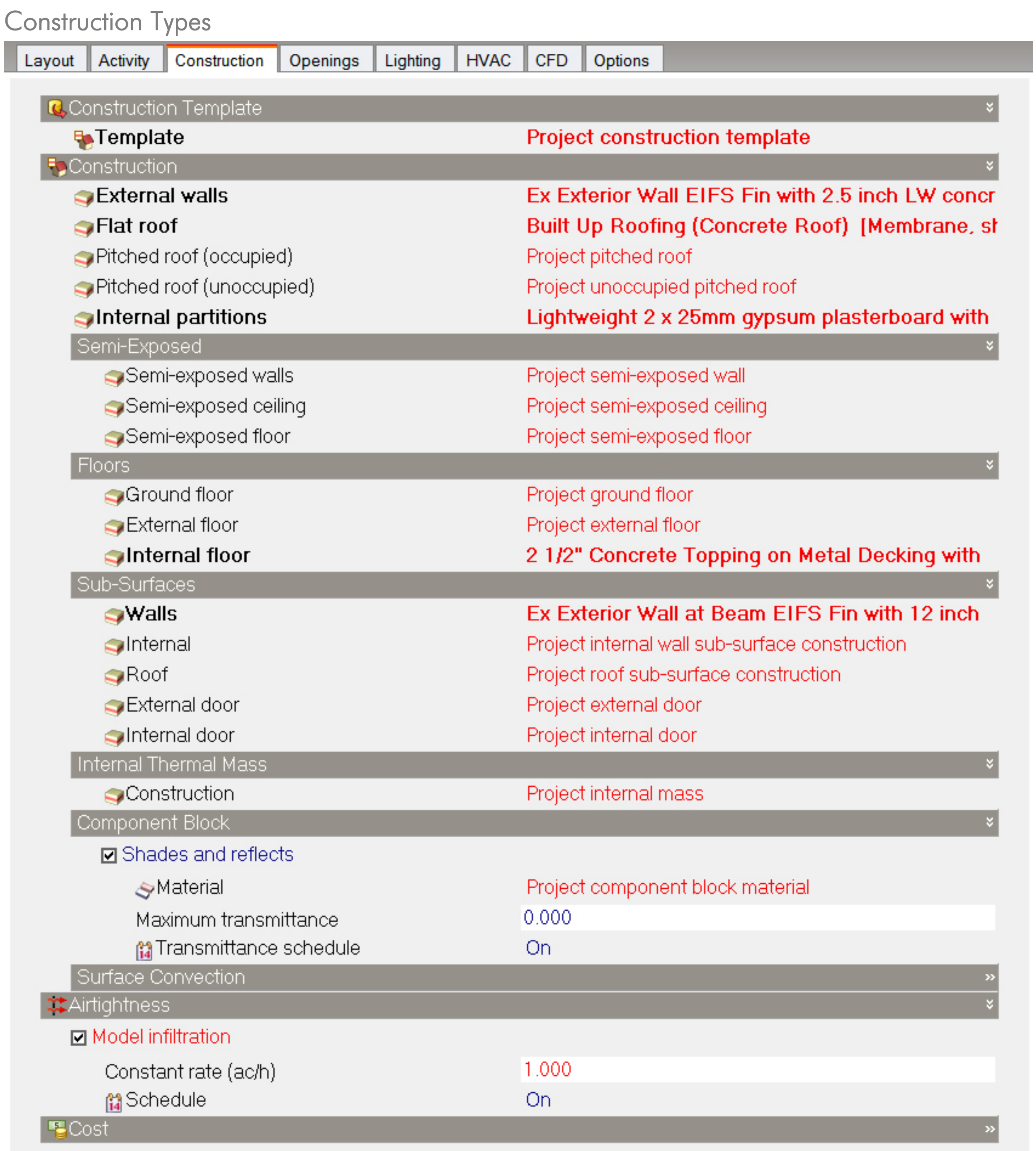


Figure 81 - Construction Types Dialogue

Construction Types are setup through the building, block, zone, or element level based on the typical dialogue above. In this model, custom templates for a typical construction type are set up at the building level. This designates the correct construction assemblies for the bulk of the building. Further explanation for each of the construction types follow for more info.

Model Infiltration is set at 1 air change per hour (AC/H) to mimic rates found in older buildings. The infiltration setting is a rate, which represents the tightness of the walls, windows and roof in how they perform together. Infiltration rates for aged in place existing buildings are generally considered to be higher than new construction. This is due to technology advancements, and newfound attention to the topic during construction in newly constructed projects. A study by the US DOE shows that a rate of .2 CFM/SF on wall areas of positive pressure can be a viable air change rate in existing buildings.[180] That figure calculates to about 1 AC/H for this building's particular floor size and volume.

Typical Facade Wall Below Window

The wall section above represents the typical section through the window wall below the window sill. This wall is made up of a 2 ½" precast concrete panel system with direct applied cementitious finish. On the interior side, a furred gypsum board finish with a painted interior face is modeled.

Typical Facade wall above window (beam)

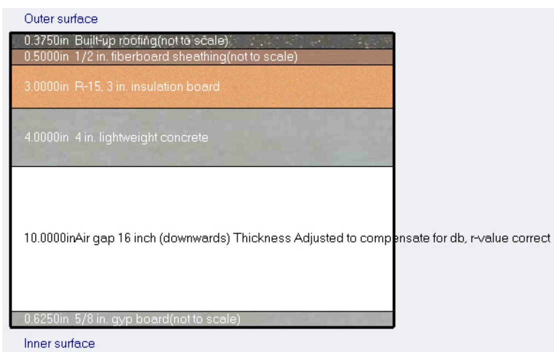
The wall section above the window on the same wall is modeled as a 12" thick concrete beam from top of window to underside of slab above. The exterior finish is a direct applied cementitious finish similar to below the window. Since this is a typical head of wall condition, this wall type is modeled as the typical "Wall Sub-Surface" for the building as seen in the template above.

180 J. Wiley, Benefield J., & Johnson, K., "Green Design and the Market for Commercial Space," *The Journal of Real Estate Finance and Economics* Vol 41, no. Number 2: 20.

Mural Wall at Rear of Building

Similar to the wall type under the window sill, the rear wall on the Southeast of the structure utilizes a precast concrete panel system, this time 8" thick. The interior side of the wall is painted and furred gypsum board finish.

Existing Roof Type

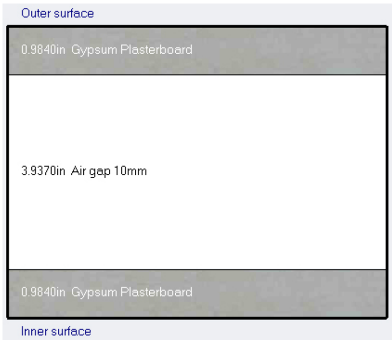


The roofing is composed of a 2 ½" concrete slab on metal deck. On the interior side the dropped ceiling is modeled with a gypsum finish. On the exterior side, a template for built up roofing is utilized over ½" fiberboard substrate over R-15 rigid insulation board. The insulation board was estimated as not forensic research was allowed to be conducted onsite.

Floor

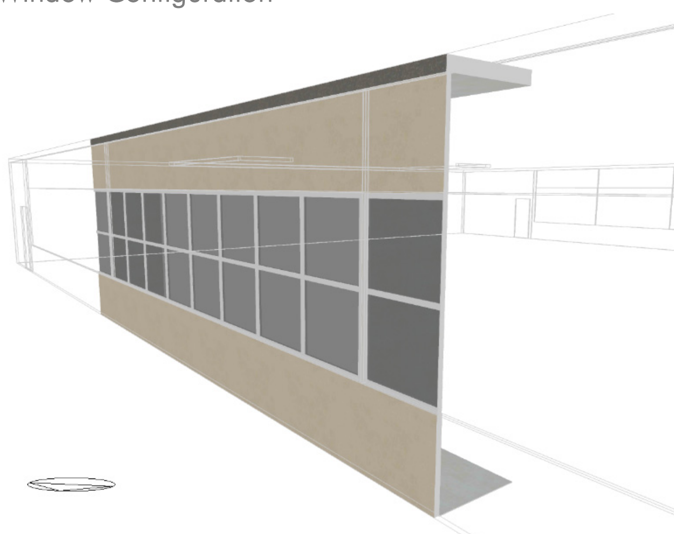
The floor, similar to the roof, is composed of a 2 ½" concrete slab on metal deck. On the interior side the dropped ceiling is modeled with a gypsum finish.

Interior Partition



Interior walls are modeled as a standard stud wall with gypsum board finish at either side.

Window Configuration



Windows are composed of the original single pane clear glass assemblies with metal sash framing. A window muntin divides the 6'0" High assembly in half. Vertical metal sash muntins divide the glass at 3'-0" o.c. to create a gridded assembly across the façade's exterior and interior faces. The windows have been retrofitted with a highly reflective film, which blocks a good deal of light.

Glazing

In modeling the existing glass, a thicker single pane 6mm was utilized. For the window tint retrofit, a selection with a low VLT (.1) and low SHGC (.245) was selected to mimic early tinting strategies. With this strategy, a low amount of heat gain is allowed into the building, but this is coupled with a result which does not allow for high levels of daylighting. The steel material was used to model the frame and muntins. Dimensions were input based on field observation.

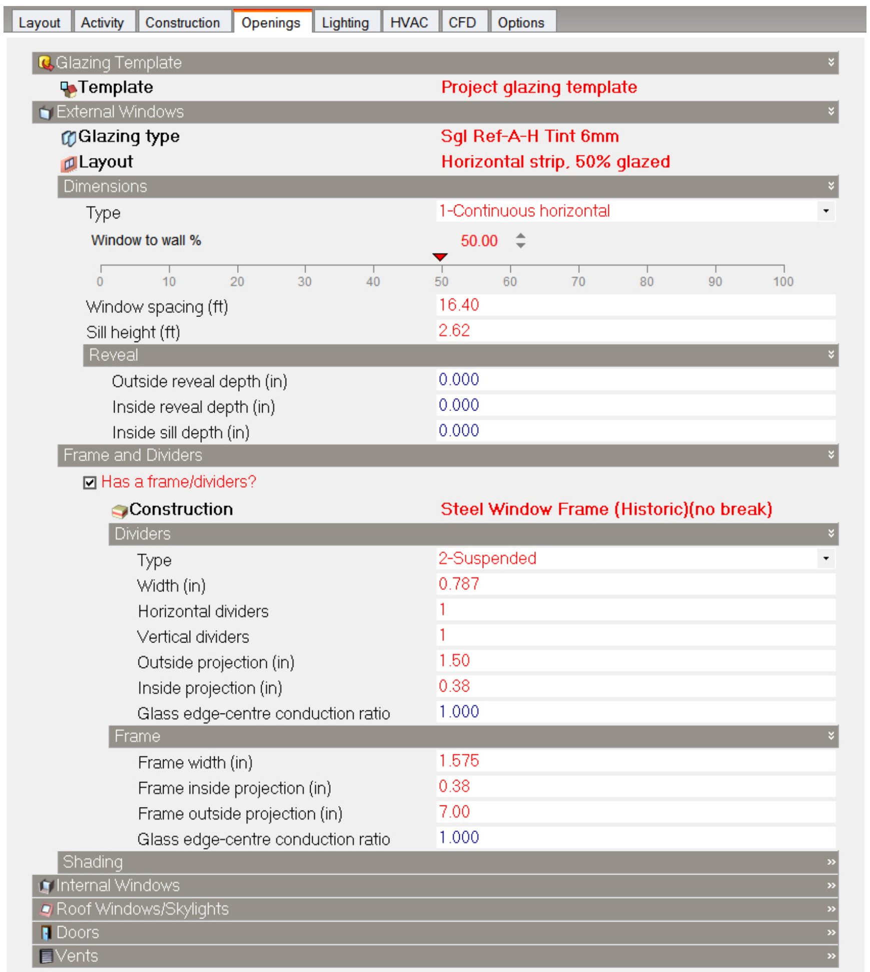


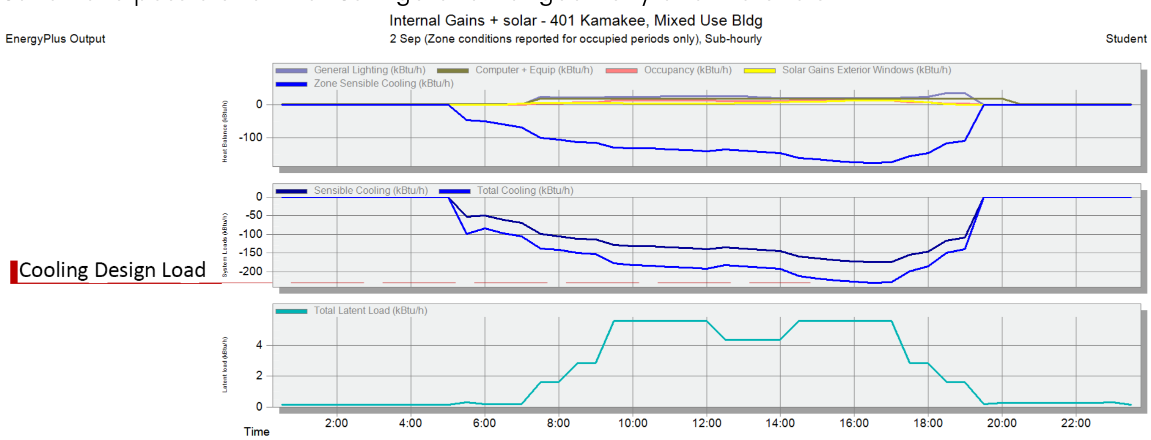
Figure 82 - Glazing Dialogue

HVAC Settings

Cooling Design

Cooling design loading is verified with the existing HVAC system to provide a "sanity check" for the loading requirements of the model. In this case, the existing Carrier unit was found to be a logical choice to cool the floor based on a comparison of cooling design loading and equipment capacity.

Cooling design loads are specified by analyzing the summer design week for the building. Looking at the summer design week's loading requirements allows the designer to find the maximum cooling loads necessary to cool the building. The summer design week is specified in the weather file utilized. Since a cooling design week assumes the worst conditions such as clear sky solar gains and full internal gains such as lighting, plug loads, and occupancy, along with no wind[181], it can be assumed to provide the worst loading conditions possible for that configuration of geometry and materials.



Time	2:00	4:00	6:00	8:00	10:00	12:00	14:00	16:00	18:00	20:00	22:00
General Lighting (kBtu/h)	0.00	0.00	0.00	21.45	24.25	26.70	21.07	20.15	24.70	0.00	0.00
Computer + Equip (kBtu/h)	0.93	0.93	0.93	18.42	18.57	18.57	18.57	18.57	18.57	17.56	1.00
Occupancy (kBtu/h)	0.15	0.14	0.41	3.75	13.20	13.20	10.26	13.20	6.72	0.34	0.31
Solar Gains Exterior Windows (kBtu/h)	0.00	0.00	0.00	5.71	4.56	4.01	6.73	12.46	8.00	0.00	0.00
Zone Sensible Cooling (kBtu/h)	0.00	0.00	-49.71	-105.26	-131.24	-139.80	-145.54	-173.00	-145.94	-0.36	-0.40
Sensible Cooling (kBtu/h)	0.00	0.00	-49.58	-105.27	-131.24	-139.80	-145.54	-173.00	-145.94	-0.36	-0.40
Total Cooling (kBtu/h)	0.00	0.00	-84.16	-141.43	-182.49	-192.39	-192.87	-227.16	-186.51	-0.47	-0.52
Total Latent Load (kBtu/h)	0.15	0.15	0.18	1.61	5.60	5.60	4.38	5.60	2.84	0.25	0.28

Figure 83 - Cooling Design Simulation Results

[181] Diego Ibarra and Christoph Reinhart, "Getting Started," in *Building Performance Simulation for Designers - Energy: DesignBuilder // Energy* (Harvard Graduate School of Design, 2009), 36.

A total cooling capacity of about 250 kBtu/h as a result when compared to the Carrier unit's net cooling capacity of 270 kBtu (Below) shows that the model results are within expectations of the original designed loads and that the existing unit seems to be about 10% higher than the cooling design calls for the existing conditions. The chart below shows cooling capacity criteria for the existing roof top unit.

HVAC

Further analysis of this data below shows that the CoP (EER/3.412) would expect to be about 2.5. This data is helpful in setting up the HVAC settings. It is worth noting that an EER of 10 (CoP of 2.93) is now required by 2009 IECC under the prescriptive approach.

50TJ WEATHERMAKER®

Single Package Rooftop
Standard Efficiency
Electric Cooling Units
15 to 25 Tons

ARI* Capacity Ratings / Physical Data

Size	Nominal Capacity (Tons)	Net Cooling Capacity (Btuh)	Total Power kW	EER	Sound Ratings (dB)	IPLV	Weight (lbs)	Dimensions (ft-in)		
								Length	Width	Height
016	15	178,000	19.8	8.9	88	9.6	1500	6'-11 1/2"	7'-2 1/8"	3'-9"
020	18	188,000	21.3	8.8	88	9.8	1650	6'-11 1/2"	7'-2 1/8"	3'-9"
024	20	220,000	25.1	8.7	94	8.9	1775	6'-11 1/2"	7'-2 1/8"	3'-11 1/4"
028	25	270,000	30.9	8.7	94	9.2	1850	6'-11 1/2"	7'-2 1/8"	3'-11 1/4"

LEGEND
db — Dry Bulb
EER — Energy Efficiency Ratio
IPLV — Integrated Part-Load Values
wb — Wet Bulb

Figure 84 - Existing RTU Loading Data: 25 Ton Unit

Due to the fact that the original space was planned and built as an open floor plan, the existing HVAC system on the 4th floor currently operates as a single zone. Unfortunately renovations which added partitions over the years did little to acknowledge the fact that there is only one thermostat controlling air delivery on the floor. The resultant condition is a floor plan with 16 distinct zone conditions controlled by one thermostat at the rear corridor of the building (see site intro for diagram). This means that at just about any given time, one of the zones will be in discomfort, but the rear hall is typically a well-maintained thermal environment. All in all, there is much that can and should be done to improve the functionality of this space.

The HVAC in the model is meant to reflect this condition. It is modeled with the Unitary Single Zone template. Per the CoP calculations above, it was set at 2.5.

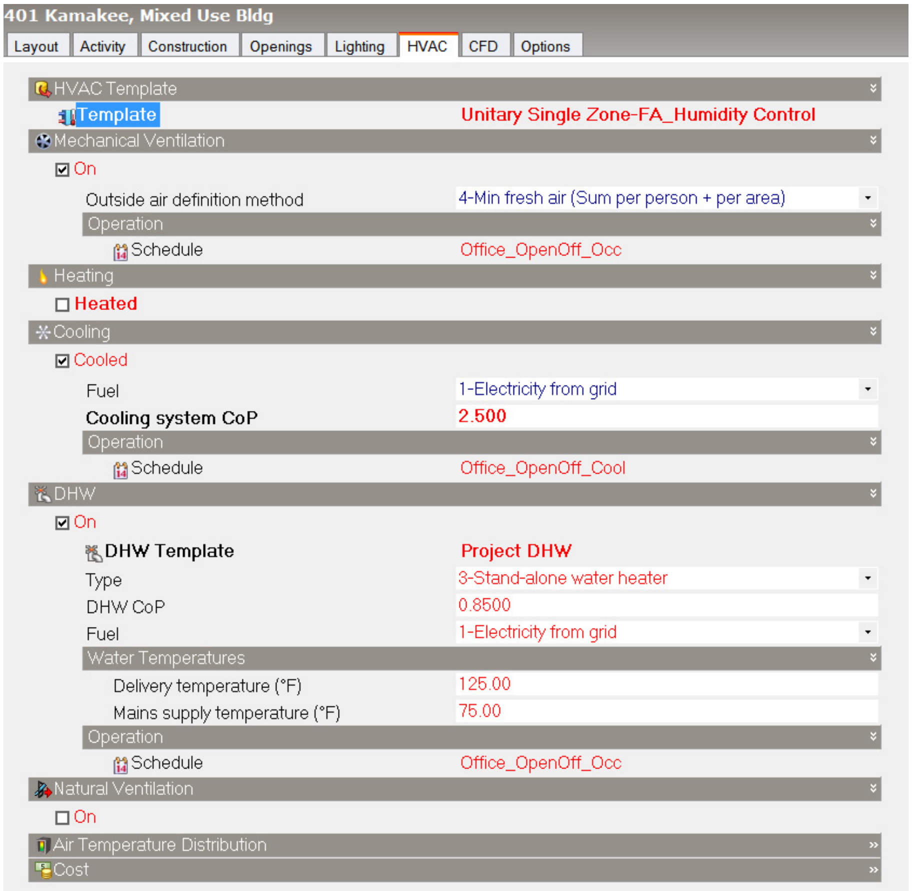
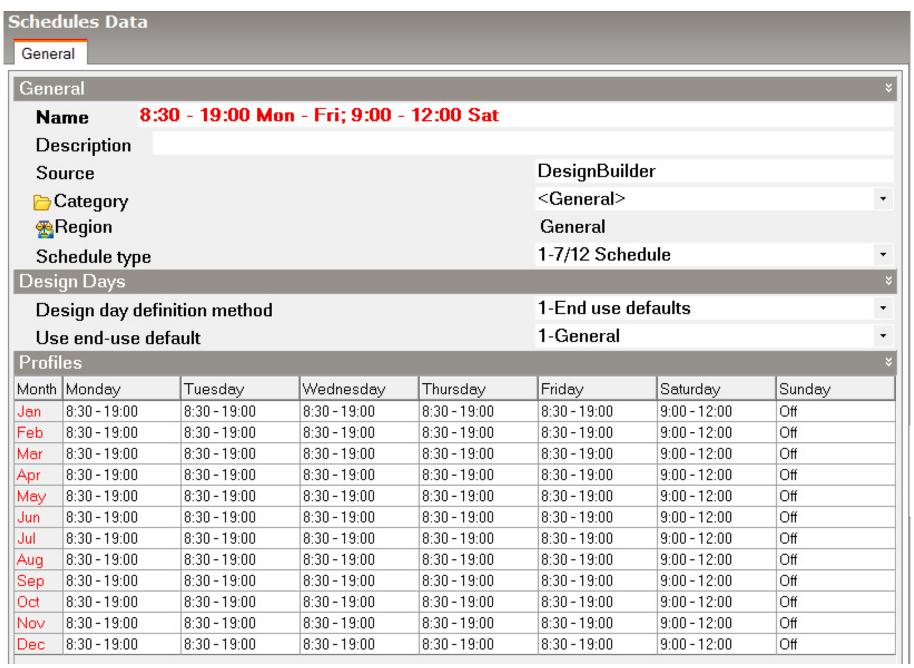


Figure 85 - HVAC Tab for existing conditions



Month	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
Jan	8:30 - 19:00	8:30 - 19:00	8:30 - 19:00	8:30 - 19:00	8:30 - 19:00	9:00 - 12:00	Off
Feb	8:30 - 19:00	8:30 - 19:00	8:30 - 19:00	8:30 - 19:00	8:30 - 19:00	9:00 - 12:00	Off
Mar	8:30 - 19:00	8:30 - 19:00	8:30 - 19:00	8:30 - 19:00	8:30 - 19:00	9:00 - 12:00	Off
Apr	8:30 - 19:00	8:30 - 19:00	8:30 - 19:00	8:30 - 19:00	8:30 - 19:00	9:00 - 12:00	Off
May	8:30 - 19:00	8:30 - 19:00	8:30 - 19:00	8:30 - 19:00	8:30 - 19:00	9:00 - 12:00	Off
Jun	8:30 - 19:00	8:30 - 19:00	8:30 - 19:00	8:30 - 19:00	8:30 - 19:00	9:00 - 12:00	Off
Jul	8:30 - 19:00	8:30 - 19:00	8:30 - 19:00	8:30 - 19:00	8:30 - 19:00	9:00 - 12:00	Off
Aug	8:30 - 19:00	8:30 - 19:00	8:30 - 19:00	8:30 - 19:00	8:30 - 19:00	9:00 - 12:00	Off
Sep	8:30 - 19:00	8:30 - 19:00	8:30 - 19:00	8:30 - 19:00	8:30 - 19:00	9:00 - 12:00	Off
Oct	8:30 - 19:00	8:30 - 19:00	8:30 - 19:00	8:30 - 19:00	8:30 - 19:00	9:00 - 12:00	Off
Nov	8:30 - 19:00	8:30 - 19:00	8:30 - 19:00	8:30 - 19:00	8:30 - 19:00	9:00 - 12:00	Off
Dec	8:30 - 19:00	8:30 - 19:00	8:30 - 19:00	8:30 - 19:00	8:30 - 19:00	9:00 - 12:00	Off

Figure 86 - HVAC Operation Schedule

The schedule for the floors is based on the building's operation hours. The HVAC system begins to run at 8:30am and runs through 7:00pm M-F. For Saturday and Sunday, there is a manual override switch to can turn on the unit. To simulate this condition a 4 hour block on Saturday is cooled representing about a ¼ of the overall weekend hours.

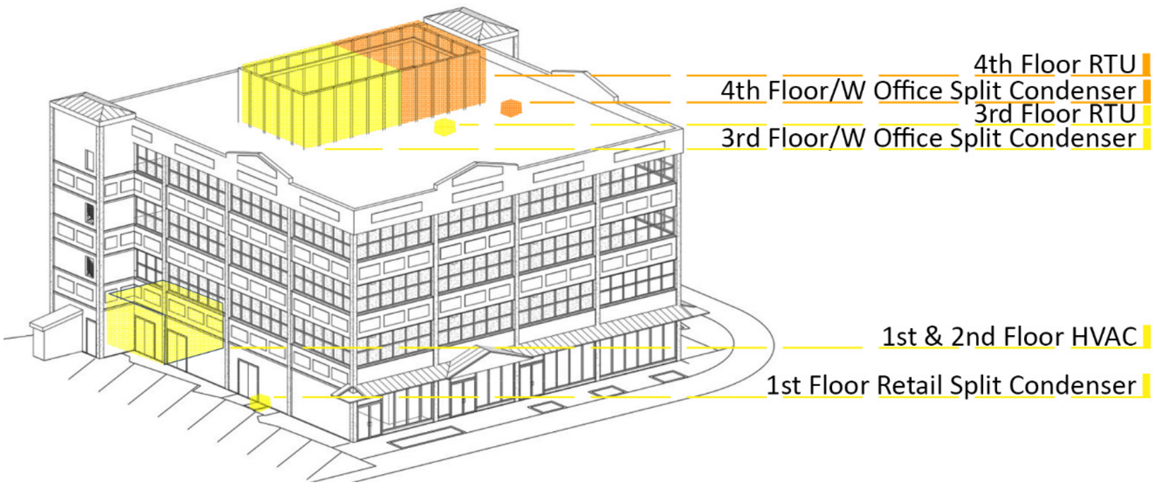


Figure 87 - HVAC Location Diagram

On the 4th floor, the Carrier unit described above is supplemented by a small split system in the West Corner office (seen below). This system was put in place due to tenant complaints that the space was more uncomfortable than the rest of the zones. As shown in the Cooling Design simulation, the Carrier unit has enough capacity for the entire floor. Unfortunately lack of temperature monitoring, is resulting in the low comfort level seen in the west office (and other offices around the perimeter).

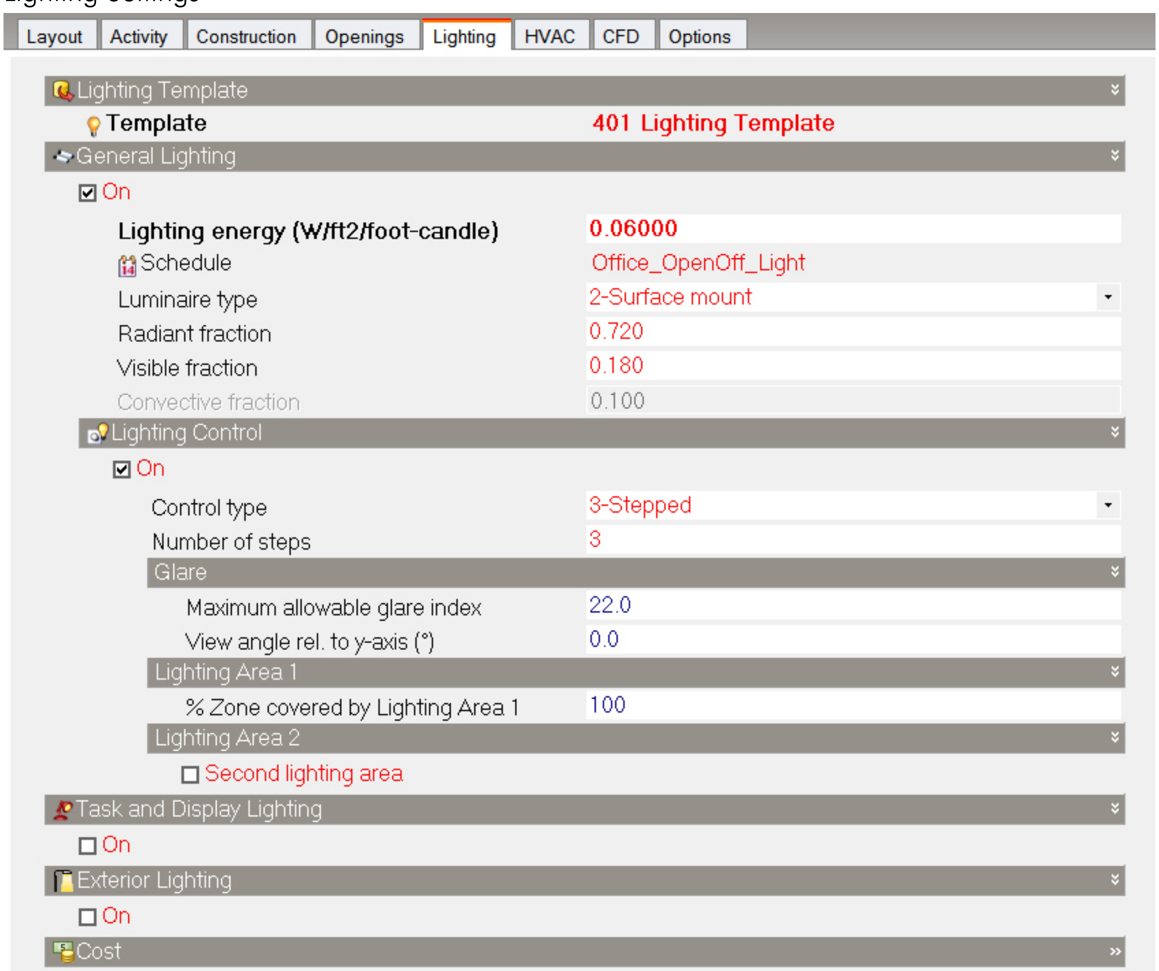
Cooling*	
Rated Capacity	16,200 Btu/h
Minimum Capacity	3,100 Btu/h
SEER	16.0
Total Input	2,070 W

* Rating Conditions (Cooling) - Indoor: 80ºF (27ºC) DB, 67ºF (19ºC) WB; Outdoor: 95ºF (35ºC) DB, 75ºF (24ºC) WB.

Figure 88 - Split System Servicing the West Office

This split system is modeled input in Designbuilder by altering the West office zone to a split system template.

Lighting Settings



Energy Consumption Results

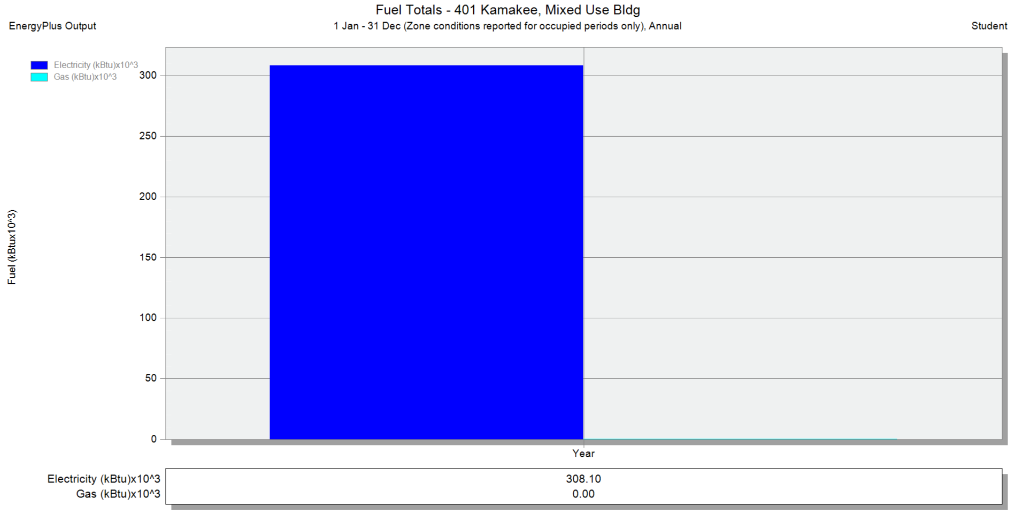


Figure 89 - Results of Calibration Annual Test : Total Electricity Consumption

401 Kamakee Energy Consumption Analysis — **Energy Bills**

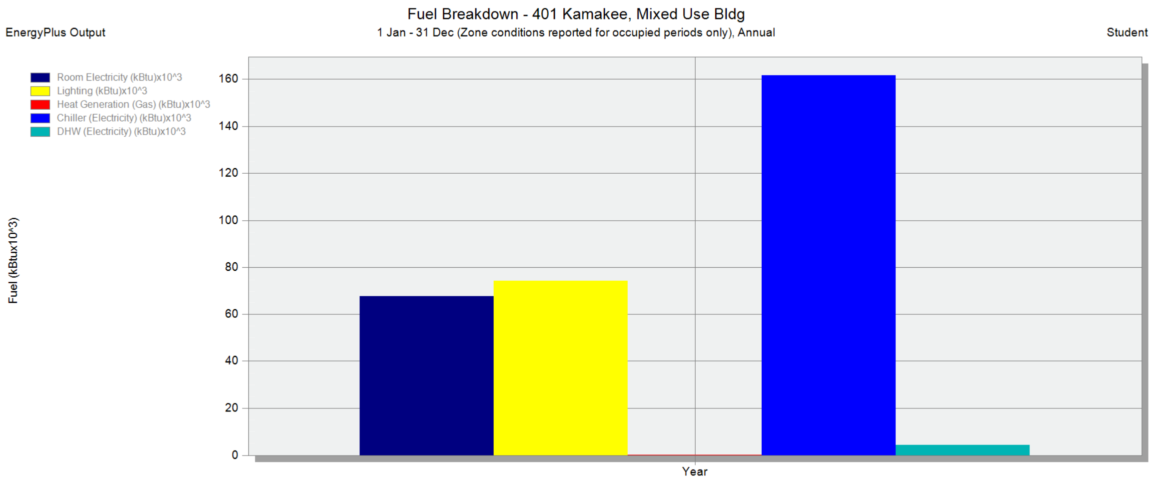
	Square Footage	Annual Totals (Ex Energy Bills)					
		kWh	kWh/SF (EUI)	kBtu	kBtu / SF	#Days	KWH/Day
4th Floor AC & Plug Loads	6780	69,231	10.21	236,216	34.84	364	191
4th Floor Lighting	6780	21,461	3.17	73,225	10.80	364	59
Total 4th Floor Energy	6780	90,692	13.38	309,441	45.64	364	249.67

401 Kamakee Energy Simulated Consumption Analysis — **Calibration**

	Square Footage	Annual Totals (Simulated Consumption)					
		kWh	kWh/SF (EUI)	kBtu	kBtu / SF	#Days	KWH/Day
4th Floor AC & Plug Loads	6780	68,507	10.10	233,746	34.48	365	188
4th Floor Lighting	6780	21,791	3.21	74,350	10.97	365	60
Total 4th Floor Energy	6780	90,298	13.32	308,096	45.44	365	247.39

Figure 90 - Comparison of Metered Energy Use to Simulated Energy Use

Annual consumption of the baseline calibration model comes to within a ½% of the annual consumption as displayed in the energy bill analysis. Ultimately it was a final adjustment to the HVAC's CoP(2.5) was utilized to bring the consumption as close as possible to the actual metered use.



Room Electricity (kBtu)x10^3	67.82
Lighting (kBtu)x10^3	74.35
Heat Generation (Gas) (kBtu)x10^3	0.00
Chiller (Electricity) (kBtu)x10^3	161.59
DHW (Electricity) (kBtu)x10^3	4.35

Figure 91 - Results of Calibration Annual Simulation : Aggregate Energy Consumption By Active System

Looking at the breakdown of fuel consumption, we can see that the building's agregated power is similar to the typical consumption of a Honolulu office space which was shown earlier in the research with an understading that the elevator power supply happens on the 1st floor.

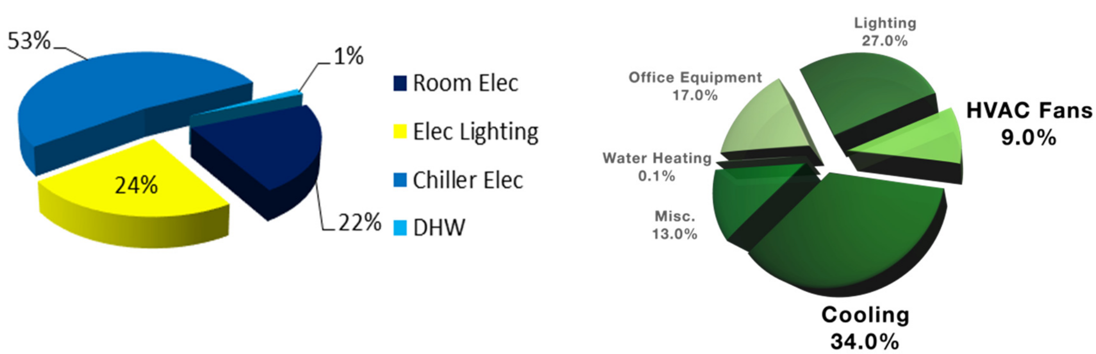


Figure 92 - EB Calibrated Simulation Comparison to Typical HI Office Consumption

By establishing an appropriate base case building, the first step in evaluating low-energy design and other sustainability strategies is accomplished. Furthermore, goals for resource use and costs are set relative to the base case.

45.44 kBtu/sf/Yr = 80th Percentile of HNL Buildings

It is necessary to note that the existing EUI for the 4th floor and the overall building is relatively low. Noted at 45 kBtu/SF/Yr, this level is estimated to be in the 80th percentile of HNL office buildings before improvements are undertaken. However, consumption on other floors are higher, meaning that the overall building performance would be worse off. Furthermore, Discomfort is found to be very high and would not pass current code with this model. Increasing comfort as-is will undoubtedly raise energy consumption. This externalized energy debt will need to be understood and solved with the energy saving measures. This will lessen the overall impact on energy savings. The low energy consumption seen, has been achieved through some preliminary improvements – installed and operational adjustments in the past few years. This means that much of the "Low hanging fruit" that would be seen as savings in a truly ripe retrofit will not be possible here.

Determining the Existing Comfort Levels

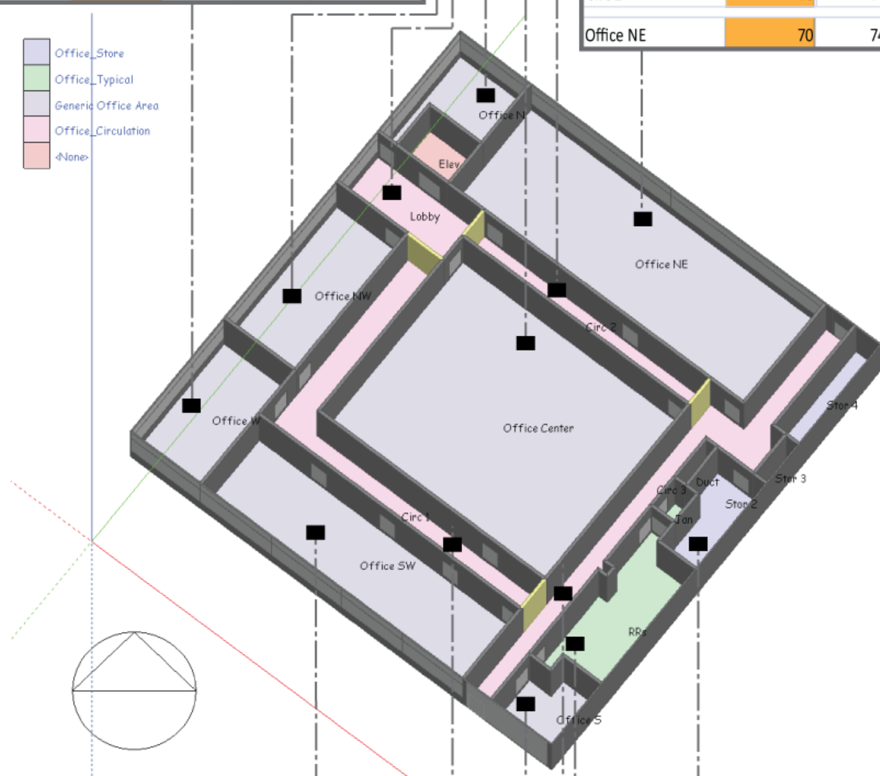
Due to the preceding comfort concerns, it is necessary to review comfort levels in the existing configuration and floor area to understand its performance. Although it is believed that comfort is suffering with the existing system and layout, discomfort readings are logged at approximately 40% of operating time. This is believed to be more extreme than the actual case.

Significant effort was put into calibrating the discomfort hours to something that could be more accurate, however, this was not able to be achieved using the "simple" HVAC configuration. Humidity control is not a function of this type of template. Sensitivity tests to the air changes per hour showed that some improvement could be seen with those adjustments, but not enough to make a difference. Further efforts were undertaken to begin to develop a "compact" and "detailed" HVAC scheme. However, these quickly became too technical for the typical architectural professional to undertake. To truly calibrate, a mechanical engineer would need to be consulted to obtain the necessary temperature settings for the various HVAC equipment.

	Relative Humidity %	Op Temp °F	Fanger PMV	Discomfort Hrs (all clothing)
4th Floor Total/Ave	**70**	**73**	**-0.71**	**1371**

	Relative Humidity %	Op Temp °F	Fanger PMV	Discomfort Hrs (all clothing)
Lobby	72	73	-0.52	1409
Office NW	69	74	-0.81	946
Office W	67	75	-0.70	658

	Relative Humidity %	Op Temp °F	Fanger PMV	Discomfort Hrs (all clothing)
Office N	65	75	-0.72	475
Office Center	72	74	-0.82	1312
Circ 2	73	73	-0.62	1479
Office NE	70	74	-0.77	1033



	Relative Humidity %	Op Temp °F	Fanger PMV	Discomfort Hrs (all clothing)
Office SW	69	75	-0.73	897
Circ 1	74	73	-0.62	1595
Office S	68	74	-0.95	691

	Relative Humidity %	Op Temp °F	Fanger PMV	Discomfort Hrs (all clothing)
Stor 2	73	73	-0.64	1167
RRs	70	76	-0.43	5903
Circ 3	74	72	-0.64	1609

Figure 93 - Annual Zone Comfort Analysis in Existing Conditions

Initial Steps Forward

Issues with the PMV and Humidity Control can be addressed in many ways. Exterior heat gains around the perimeter can be mitigated as they try to enter the building through a window, wall, or roof retrofit. The additional loading could also be cooled more efficiently by introducing additional thermostats or a VAV air delivery retrofit. Understanding the difference between these 2 choices – the active and the passive measure retrofits – is the essence of this study. The passive strategies look to mitigate the heat load before entering the building without the use of energy. The active looks to alter the loading afterwards with applied energy. Both sets of strategies are expensive and invasive endeavors. One has the resultant effect of using energy to offset loading and one does not. In order to adapt to a more environmentally responsible way of addressing applied efficient design, this project will look for ways to make more of the passive strategies viable before subscribing the outcome to energy consuming measures.

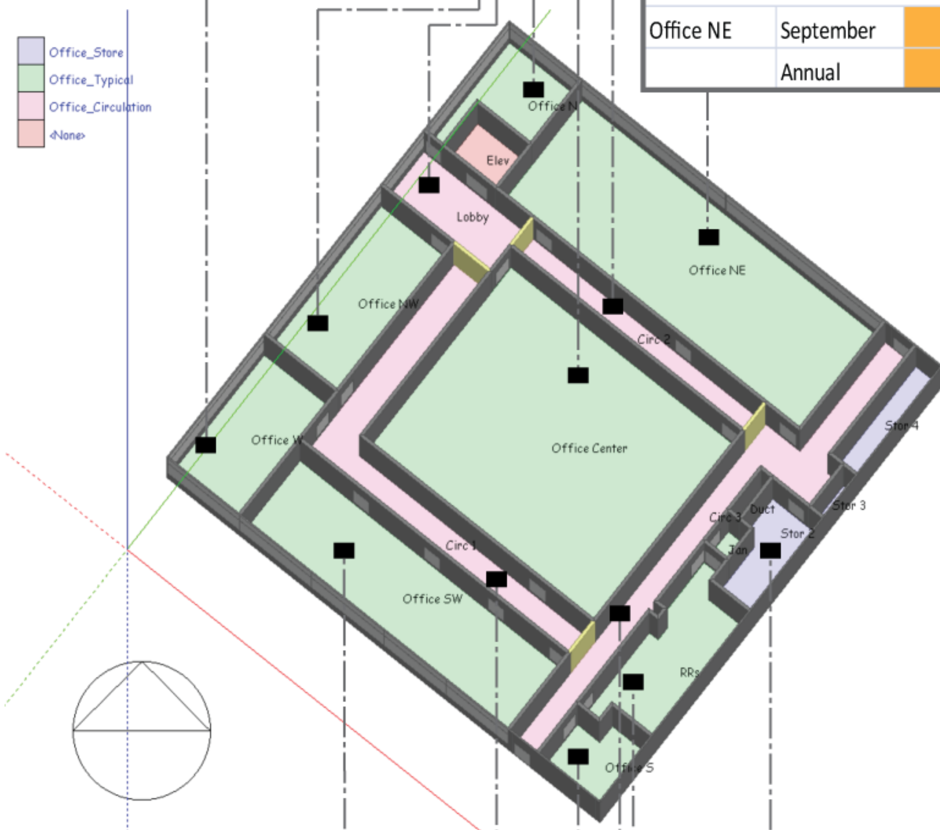
In order to accomplish this, its important to see how the existing building would react as-is, if all of the active systems were turned off. From a comfort perspective, both thermal and visual, this would be considered a worst-case scenario to begin to compare other passive measure's performance impacts. This will also help to explain the extent of the impact the active systems are currently providing. If the same or similar conditions can be met with passive measures, then it would make sense to see how attainable they are.

This test, turning the HVAC off, was conducted to see the resultant comfort levels. See the following:

4th Floor Existing Conditions Comfort Analysis With HVAC Off

	Date/Time	Fanger PMV	Discomfort hrs (all clothing)
Lobby	September	2.3	252
	Annual	1.6	2867
Office NW	September	2.5	720
	Annual	1.6	8177
Office W	September	2.5	720
	Annual	1.6	8138

	Date/Time	Fanger PMV	Discomfort hrs (all clothing)
Office N	September	2.1	720
	Annual	1.3	7954
Office Center	September	3.2	720
	Annual	2.5	8654
Circ 2	September	2.6	252
	Annual	2.1	3056
Office NE	September	2.4	720
	Annual	1.8	8249



	Date/Time	Fanger PMV	Discomfort hrs (all clothing)
Office SW	September	2.7	720
	Annual	1.9	8318
Circ 1	September	2.6	252
	Annual	2.0	3044
Office S	September	2.3	720
	Annual	1.6	8323

	Date/Time	Fanger PMV	Discomfort hrs (all clothing)
Stor 2	September	1.8	210
	Annual	1.2	2297
RRs	September	2.3	720
	Annual	1.6	8408
Circ 3	September	2.2	252
	Annual	1.6	2962

Figure 94 - Comfort with HVAC turned off

The resultant environment shows that 40% of hours have at least one zone that is uncomfortable. This equates to about40% of operating hours with unacceptable levels of thermal comfort.

Conclusion

Working through a model calibration allows the designer to understand how the building is functioning and realize what some of the driving factors for energy consumption and comfort are within the existing conditions. For instance, we can see by the walk through and the simulation effort that the single thermostat on the floor cannot be enough to service the many different types of loading going on within the building. Some type of additional HVAC control is needed in order to increase comfort.

Also, we can see that the glazing and tint retrofit, as modeled, is hampering interior daylighting strategies. Any retrofit to reduce lighting electricity consumption should be coupled with some sort of glazing retrofit. It could be as simple as installing a new tint with better VLT properties. However, to see deep savings, new windows would need to be installed to take advantage of the last 50 years of technological advances in glazing and window frames.

In producing the calibrated model, we see that there is much room for improvement.

11

Analysis & Design

Initial Set of Efficiency Measures

With the research cited in the previous sections, possible Efficiency Measures have been outlined and will be evaluated with reference to the specific property when selected. Efficiency Measures Implementation strategies vary widely based on occupant type, existing building condition and building use. Possible Efficiency Measures include:

1. Contemporary Efficient Use of Space
   a. Location of Program by volume
   b. Optimized Access to Daylight
   c. Correct Sizing of Space per Occupant per Function
2. Inspiration of Natural Ventilation
   a. Cross Ventilation
   b. Stack Ventilation
3. Optimized Cooling and Dehumidification Systems for Efficiency and Comfort
   a. All Natural Cooling with Mechanical Dehumidification Assist
   b. Mixed Mode System
   c. Efficient Mechanical System
4. Optimized Control of Thermal Comfort
   a. Automatic Controls for Natural Ventilation
   b. Occupant Controls for Natural Ventilation
   c. Automatic Controls for Active Conditioning
   d. Occupant Controls for Active Conditioning
5. Properly Protected and Optimized Daylighting
   a. Provide Natural Toplighting
   b. Optimize Window Size for Daylight
   c. Provide Direct Beam Protection of Apertures
   d. Provide Interventions for Deeper Daylighting Penetration
6. Properly Protected and Optimized View Windows
   a. Provide Direct Beam Protection of Apertures
7. Optimized Electric Lighting for Efficiency and Quality
   a. Provide Lamping Substitutions
   b. Provide Fixture Substitution

    c. Provide Rezoning of Fixture Locations for Daylight and General Efficiency
8. Optimized Electric Lighting Controls
    a. Rezone Lighting Controls for switching
    b. Provide Automatic Occupancy Sensor Controls
    c. Install Dimmers
9. Efficient Equipment
    a. Provide Energy Star Rated Equipment
    b. Revised Data / Software Server Solutions
10. Efficient Use of Plug Loads
    a. Optimized Quantities
    b. Automatic Shutdown
11. Optimized Glazing
    a. Window Retrofit
    b. Window Replacement
12. Optimized Cool Roof System
    a. Membrane Replacement
    b. Introduction of Radiant Barrier and Air Barrier
    c. Optimized Insulation
13. Optimized Exterior Wall System
    a. Optimized Window-Wall Ratio
    b. Introduction of Radiant Barrier and Air Barrier
    c. Optimized Insulation
    d. Optimized Durability for Weather Protection

Energy Design Process

As seen above, the initial set of potential efficiency measures is extensive. Furthermore, each measure has the potential for consideration of multiple solution types in order to come to an optimized version of that particular measure. The result of this analysis is sure to be an extensive list of options for final consideration. For this reason, it is necessary to have a clear understanding of how each measure will be judged in order to move past individual measures to bundles and the eventual technical potential outcome.

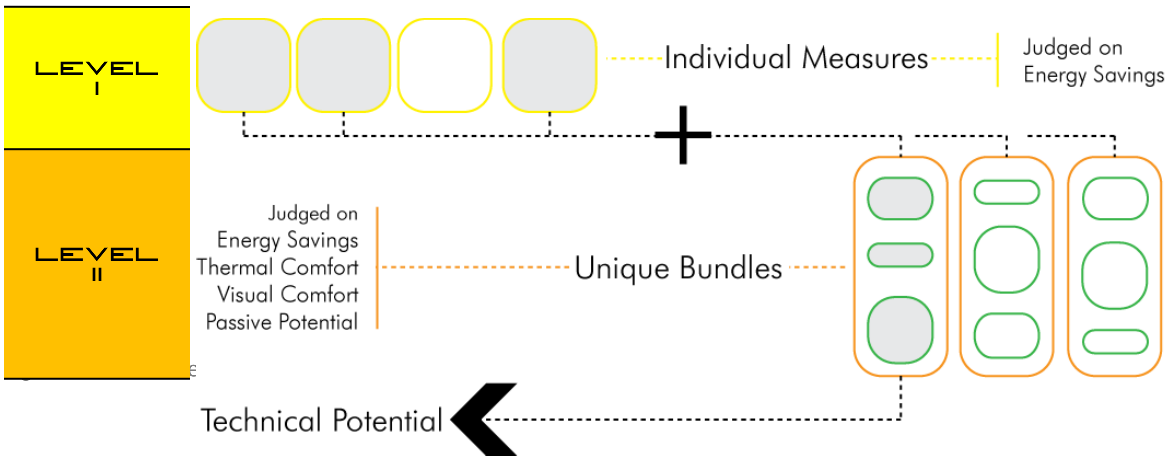


Figure 96 – Energy Modeling Process

A framework was developed to isolate and group straight forward measures as well as more complex symbiotic relationships between measures. The initial analysis endeavors to test each measure as applied to the existing conditions independently in the first level of simulation. This will show its individual impact on the space. Once all iterations are performed, top performing iterations of each measure are selected for a "Level 1 Base Improvements Package" where a clear benefit is present.

Using those base improvements mentioned above as a starting point, a second round of simulation is necessary to flush out some of the more complex options. In this round, the remaining measures with potential benefit are retested in a manner that all unique combinations of remaining measures are simulated independently. Then they are compared to a much more complex set of judging criteria. The best performer based on the criteria will ultimately become the Technical Potential solution.

Development of Final Judgment Criteria

As discussed in the Model Calibration chapter, it is not enough to only utilize energy reduction as a metric for judging the effectiveness of measures. With an approach such as this, you can end up sacrificing thermal comfort or even committing yourself to a sustained energy consumption solution, when a more passive route is possible. For these reasons, a system of reviewing each measure is provided to understand and weigh each bundle against the other. This system is made up of a set of indicators which can be weighed independently and ultimately accumulated to come to a final score between 0 & 100. The indicators selected are following; they have been given weights based on their perceived importance to the final outcome of the project:

40%	Energy Savings
35%	Thermal Comfort
20%	Passive Visual Comfort
5%	Passive Potential

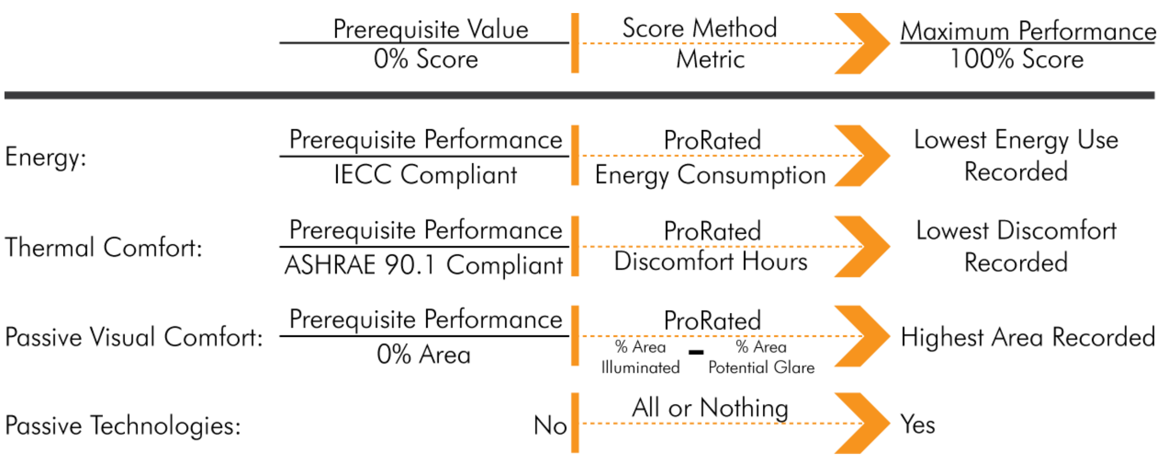


Figure 97 - Decision Making Scoring Criteria

In weighing these indicators, it is important to understand each individual factor's prerequisite requirement. When present, this value should be the minimum level allowable for acceptance.

For energy, IECC compliance became the prerequisite at 234,888 kBtu/annually.

The thermal comfort prereq. Uses ASHRAE 90.1's reference to a maximum of 300 discomfort hours.

Since access to daylight became a key strategy in the improvements package, it was selected as an important indicator to track. Since there is no code requirement for daylight, LEED V3's IEQ 8.1 standard for determining daylit area was utilized. This standard has notable flaws in reference to glare control and limited tested times. It was however, the most readily available and accepted analysis method to determine daylit area. In the event that another more accurate standard for daylight comfort is developed, it could replace the LEED standard. Since daylight is not a code requirement and the LEED threshold of 75% area is not realistic for many existing buildings, no prerequisite is required for this criteria.

The passive potential score refers to methods of providing thermal comfort. It give passive types of thermal comfort a small advantage given that they would not subscribe to an energy consuming future. This ensures that if results are close, the passive approach would win.

In all cases, the best performing iteration was considered to get the maximum score possible. Measures are scored in this manner to avoid having the overall importance of each criteria minimized by being compared to an unobtainable value.

Once understood, the difference between the optimum level and prerequisite can become a scale that can be scored based on its margin surpassing the prerequisite.

Level 1: Development and Selection of Base Component Package

Individual Parametric Analysis

For the initial level of simulation, each potential measure will need to be modeled and tested independently. Where ever possible Parametric Analysis will be used to test strategies to find an optimum solution. When strategies tested are more complex, a "Shoebox" energy model can be utilized to get relative results quickly. This approach is an initial, oversimplified energy model of a building in which the actual building (or part of the building) is represented as a rectangular box. At this early point one should already work with actual climate data, building type, usage patterns, and utility rates for the projects (if known). The shoebox energy model is especially valuable. Because it can be built very quickly and can therefore be used to inform early design decisions to optimize building energy performance.[182]

Optimization is another approach that may be available in the near future. This tool, still in beta in Designbuilder, allows the designer to enter multiple goals like CO2 output, Daylighting, Financial Cost, and Discomfort Hours to test for different strategies like window/wall ratio, glazing type, infiltration levels, etc with thresholds. This has the potential to expedite analysis. However, this tool currently seems to lack the level of functionality needed to provide meaningful results.

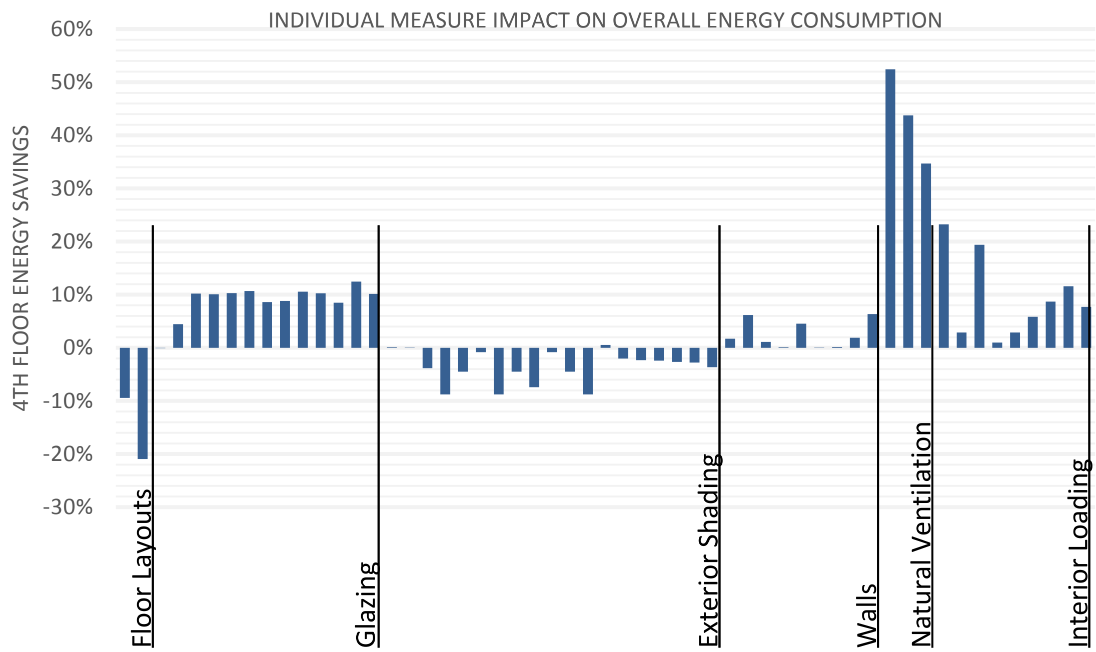
Individual Component Test Results

To simplify analysis of the strategies explored, the resulting data from the Designbuilder testing is compiled into a single spreadsheet for further analysis. These results are on the following sheets. An expanded description of the results for each topic follows afterward.

[182] "Tutorial #2: Load Schedules" (Harvard Graduate Scool of Design, 2012), 6.

Individual Measure Impact	Sub Type	Energy				Comfort			
		Total Consumption	Energy Savings			Thermal			Visual
		Annual kBtu	Annual kBtu	Annual kWh	% Savings	PMV (Fanger)	Discomfort Hours	Rating	% Daylight Area Illu
Baseline (Exisitng Conditions)		308098				-0.71	1370.7		0
IECC Compliant		234888	73210.00	21456.62	23.76%	-0.79	1074.44		
Baseline (HVAC Off)		146512	161586.00	47358.15	52.45%	2.5	3266		0
Space Use Modifications									
Interior Partition Reconfig									
1 Midsize & 4 Small		Carried to Final Round							0
2 Midsize Tenants		337142	(29044.00)	(8512.31)	-9.43%	-0.63	1390.6		0
Open Floor Plan		372594	(64496.00)	(18902.70)	-20.93%	-0.57	1287.74		0
Roof Area									
Raised PV to 12' Over Deck		308323	(225.00)	(65.94)	-0.07%	-0.71	1368.93		0
Envelope Reconfig									
Infiltration									
Optimized Infiltration (.2 ACH)		294407	13691.00	4012.60	4.44%	-0.73	689.67		0
Fenestration Wall (Top Performers)									
Glazing Type (224 tested / top 9 shown)	Trp LoE Film (55) Clr 6mm/6mm Air	276628	31470.00	9223.33	10.21%	-0.75	1475.05		0
	Trp LoE Film (55) Clr 6mm/13mm Air	277017	31081.00	9109.32	10.09%	-0.75	1473.5		
	Trp LoE Film (66) Bronze 6mm/13mm Air	276349	31749.00	9305.10	10.30%	-0.75	1491.29		
	Trp LoE Film (55) Bronze 6mm/13mm Air	275194	32904.00	9643.61	10.68%	-0.77	1511.53		
	Dbl LoE (e2=.1) Tint 6mm/13mm Air	281536	26562.00	7784.88	8.62%	-0.73	1437.14		
	Dbl LoE (e2=.1) Tint 6mm/13mm Arg	280917	27181.00	7966.30	8.82%	-0.73	1442.41		
	Dbl LoE Spec Sel Tint 6mm/13mm Arg	275563	32535.00	9535.46	10.56%	-0.76	1487.92		
	Dbl LoE Spec Sel Tint 6mm/13mm Air	276430	31668.00	9281.36	10.28%	-0.75	1497.87		
	Dbl LoE Spec Sel Clr 6mm/13mm Arg	281915	26183.00	7673.80	8.50%	-0.72	1425.35		47.5
	Serious 57/24	269682	38416.00	11259.09	12.47%	-0.78	1534		34
	Serious 62/35	276820	31278.00	9167.06	10.15%	-0.75	1470		40.3
Glazing Frame Type	Thermal Break	307731	367.00	107.56	0.12%	-0.71	1371.77		
	No Break (Contemporary Frame)	307869	229.00	67.12	0.07%	-0.71	1370.63		
Fenestration Roof		Roof Fenestration Simulation Inconclusive (not working properly)							
Top Lighting Area Percentage (30%)	Double Pane Low-e	308323	(225.00)	(65.94)	-0.07%	-0.71	1368.93		0
Top Light Glazing Type		Not Simulated							
Top Light Window Frame		Not Simulated							
Fenestration Shade Projection/Daylighting									
100% Coverage White Steel Shading System (Ex Floor Plan)		322404	(14306.00)	(4192.85)	-3.84%	-0.72	1376		0
100% Coverage White Steel Shading System (Open Floor Plan)	Transmittance: 0	405308	(32714.00)	(9587.92)	-8.78%	-0.57	1293.59		0
	Transmittance: .5	389339	(16745.00)	(4907.68)	-4.49%	-0.57	1288.51		0
	Transmittance: 1	375638	(3044.00)	(892.15)	-0.82%	-0.57	1286.85		
100% Coverage Glass Shading System (Open Floor Plan)	Transmittance: 1	405311	(32717.00)	(9588.80)	-8.78%	-0.57	1293.48		0
	Transmittance: .5	389340	(16746.00)	(4907.97)	-4.49%	-0.57	1288.44		0
	Transmittance: .2	400241	(27647.00)	(8102.87)	-7.42%	-0.56	1279.58		0
100% Polycarbonate Shading System (Open Floor Plan)	Transmittance: 1	375642	(3048.00)	(893.32)	-0.82%	-0.57	1286.82		0
	Transmittance: .5	389335	(16741.00)	(4906.51)	-4.49%	-0.57	1288.48		0
	Transmittance: 0	405312	(32718.00)	(9589.10)	-8.78%	-0.57	1293.48		0
1' Horizontal (Ex Int)		306396	1702.00	498.83	0.55%	-0.72	1387.46		0
2' Horizontal (Ex Int)		314314	(6216.00)	(1821.81)	-2.02%	-0.72	1378.44		0
3' Horizontal (Ex Int)		315258	(7160.00)	(2098.48)	-2.32%	-0.72	1387.29		0
5' Horizontal (Ex Int)		315538	(7440.00)	(2180.54)	-2.41%	-0.73	1402		0
Light Shelf 3Ft Exterior (Ex Int)		316227	(8129.00)	(2382.47)	-2.64%	-0.72	1375.99		0
Light Shelf 5Ft Exterior (Ex Int)		316631	(8533.00)	(2500.88)	-2.77%	-0.72	1383.81		0
Light Shelf 5Ft Exterior (Open Int)		383795	(11201.00)	(3282.83)	-3.64%	-0.58	1295.69		0
Opaque Construction - Walls									
Insulation All Ext Walls (All Walls R45)		302770	5328.00	1561.55	1.73%	-0.73	1419.84		0
Insulation + Infiltration Adjustments		289029	19069.00	5588.80	6.19%	-0.75	731.18		0
Radiant Barrier w/ Air Gap in Wall	Barrier Alone	Approx308000							0
	Barrier w Modest Adj to Infil (.8 AC/H)	304632	3466.00	1015.83	1.12%				0
Opaque Construction - Roof						-0.72	1244.88		
Insulation Variation - Roof (R-84Total)	9" Polyiso added	307718	380.00	111.37	0.12%	-0.71	1374.27		0
Insulation Variation - Roof (84)+infil	9" Polyiso added	294076	14022.00	4109.61	4.55%	-0.73	692.26		0
Radiant Barrier w/ Air Gap in Roof	Under Concrete	307936	162.00	47.48	0.05%	-0.71	1371.62		0
	Under Concrete Adjustment to Infil (.6)	301084				-0.72	1089.69		
	Above Deck	307914							
	Above Deck Adjustment to Infil (.6)	301063				-0.72	1090.01		
Green Roof		307630	468.00	137.16	0.15%	-0.71	1375.18		0
Insulation Variation - All Exterior		302294	5804.00	1701.06	1.88%	-0.74	1425.77		0
Insulation Variation - All Exterior + Infiltration		288538	19560.00	5732.71	6.35%	-0.75	736.31		0
Envelope Reconfig + Operation									
Cross Natural Ventilation		146549	161549.00	47347.30	52.43%	2.1	3188.67		
Cross Ventilation (1 Midsize + 4 Small)		Carried to Final Round							
Cross Ventilation (2 Midsize Tenants)		173273	134825.00	39514.95	43.76%	1.44	3122.02		0
Cross Ventilation (Open Floor Plan)		201193	106905.00	31332.06	34.70%	1.34	3101.99		0
Stack Natural Ventilation		Carried to Final Round							
Internal Equipment/Loading									
Lighting Type	Suspended+.018W/SF/FC	236440	71658.00	21001.76	23.26%	-0.81	1581.41		0
Lighting Controls (Linear)		299211	8887.00	2604.63	2.88%	-0.72	1393.05		0
Plug Load Optimization (.4)		248308	59790.00	17523.45	19.41%	-0.6	1541.48		0
Water Heater Setpoint Adjustment	90° F	305056	3042.00	891.56	0.99%	-0.71	1370.7		0
HVAC Setpoint Increase	1° F	299187	8911.00	2611.66	2.89%	-0.55	1484.52		0
	2° F	290140	17958.00	5263.19	5.83%	-0.39	1604.85		0
	3° F	281297	26801.00	7854.92	8.70%	-0.23	1714.52		0
	4° (75°F)	272390	35708.00	10465.42	11.59%	-0.07	1842.25		0
Additional Thermostats	Not Addressed								0
VAV Retrofit (IECC Compliant)	Addressed but Thermostats not able to be	284384	23714.00	6950.18	7.70%	-0.71	1370.7		0

Figure 98 - Level 1 Simulation Summary Graph



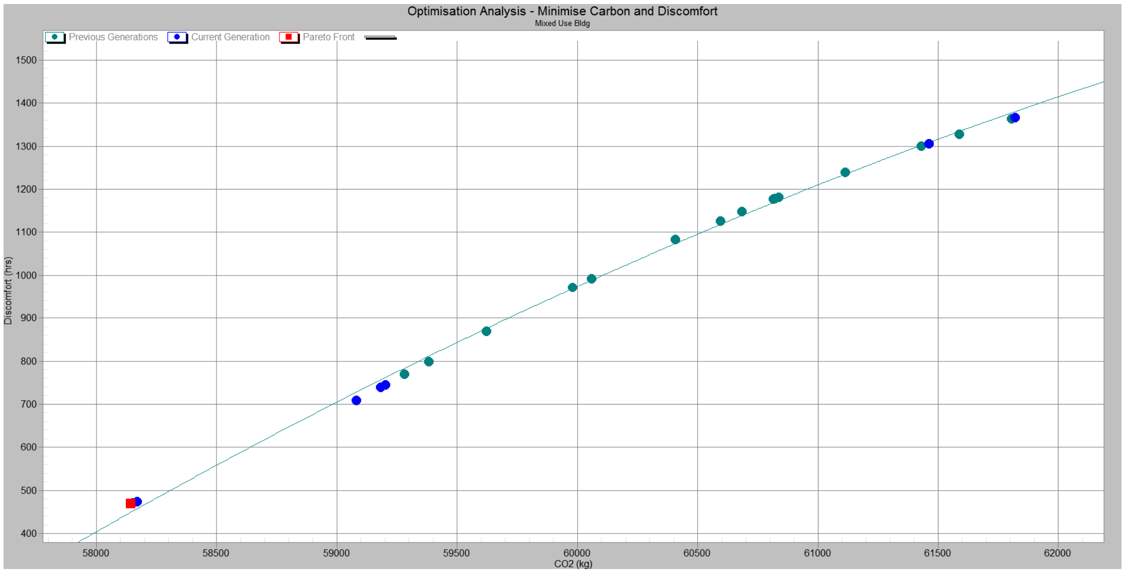
Facade Optimization

At the center of this study is a desire to begin to understand the impact of passive measures on the overall energy consumption of a building. This is not any more straight forward than the in the testing of alternative facade components to mitigate the loading of the exterior environment. The following is a synopsis of the measures tested to optimize the exterior facade.

Infiltration

Infiltration rates in existing buildings are generally considered to be higher than in current standards in new construction. Hawaii is no exception to this rule. It is generally well understood that buildings today are designed to be tightly built. This wasn't the case in the past as some practitioners wanted their buildings to "breathe." As long as the interior of the building is air conditioned, then low infiltration rates should be a prime design directive. This can be seen in an optimization test ran to compare insulation adjustment to infiltration rates on this project. The results of the test showed that adjustments in R-Value made little difference in the resulting CO2 levels. They vary greatly within the top results. Infiltration is the driving factor.

Figure 99- Optimization Analysis for Infiltration and R-Value Adjustments



Wall Insulation-Infiltration Optimization Results (Top Rankings)				
	Insulation (R-Value)	Infiltration (AC/H)	CO2	Discomfort
1	27.762	0.013	128185.8	1035.419
2	9.932	0.014	128205.2	1038.004
	29.404	0.014	128205.2	1038.004
	29.404	0.014	128205.2	1038.004
	0.547	0.014	128205.2	1038.004
	29.951	0.014	128205.2	1038.004
	29.404	0.014	128205.2	1038.004
3	29.326	0.016	128241.4	1042.488

For purposes of this analysis, a best practice level of .2 AC/H was assumed based on a DesignBuilder default: excellent level. Individual results based on this level of Infiltration are below.

Simulated Savings for 4th Floor - 13,691 kBtu's Annually (4.44% of total baseline load)

Passive Potential - Positive - No Investment in Active Technology

Cooling effect on PMV - Good - .02 Decrease in PMV

No Effect on Visual Comfort

Wall Testing

Walls were tested for 2 types of measures besides infiltration, increased insulation and radiant barriers. Both were found to have little impact on overall consumption. This is partly due to the fact that the building is deep and square in nature. Configurations such as these are considered relatively efficient at insulating the center space from heat gain.

Ultimately, the measure adding 9" of Polyiso Insulation was chosen due to its minor improvement in energy consumption. However, in a package short of a "Technical Potential" solution, this measure would most likely be one of the first not to be included. However, in reality, this retrofit of added insulation would provide the added benefit of sealing any cracks and improving infiltration. This alone makes it a worthwhile endeavor.

Simulated Savings for 4th Floor - 5328 kBtu's Annual (1.73% of total baseline load)

Passive Potential - Positive - No Investment in Active Technology

Cooling effect on PMV - Good - .02 Decrease in PMV

No Effect on Visual Comfort

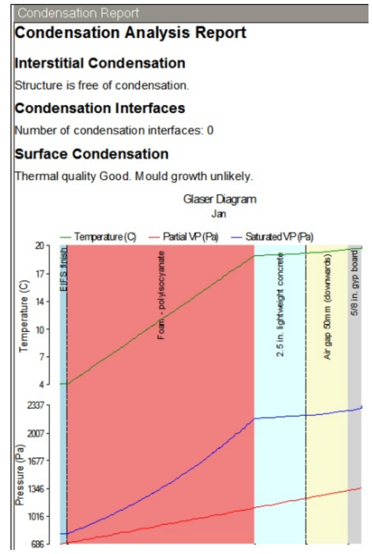


Figure 100 - Base Improvement for Wall Under Window

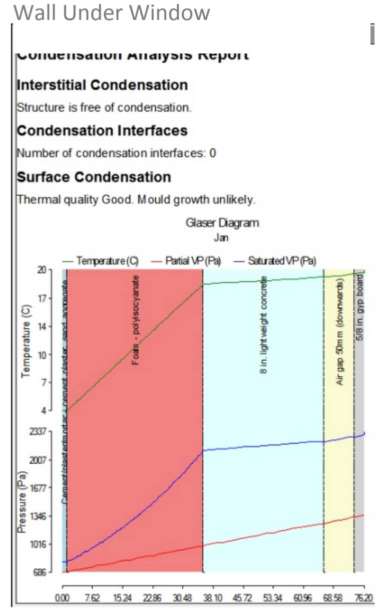


Figure 101 - Base Improvement for SE Wall

Roof Testing

Similar to the wall testing, roof interventions were slightly successful at providing results. This is partly due to the photovoltaic array which along with power generation, has the added affect of shading the roof with a substantial airspace between it and the deck. Existing performance is helped due to the fact that the existing roofing system is a Built Up roofing type with rigid insulation already underneath. In any case, the technical potential model will need to reflect a best case condition. Adding 9" of Polyiso Insulation provided the best results of the approaches tested.

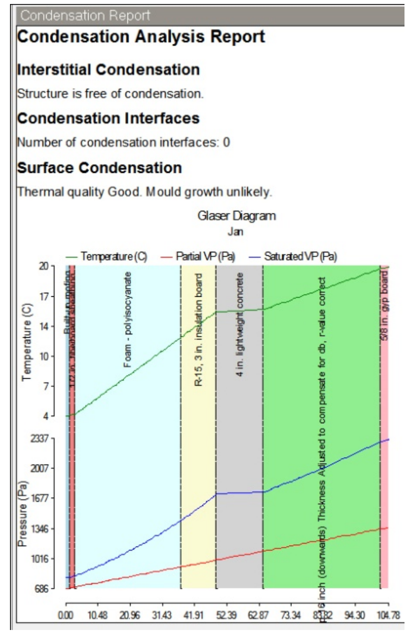


Figure 102 - Base Improvement for Roof

Simulated Savings for 4th Floor - 380 kBtu's Annual (.12% of total baseline load)

Passive Potential - Positive - No Investment in Active Technology

Neutral effect on PMV - Good

No Effect on Visual Comfort

Windows

When looking for a high performance window assembly, it's important to start with the glazing. In Hawaii, without exterior shading, it's important to look for a window with a low Solar Heat Gain Coefficient (SHGC) first and then a high Visual Light Transmittance (VLT). This will ultimately ensure that the least amount of heat load is being introduced to the interior with the added benefit of increased daylighting. This will reduce HVAC Loading, increase thermal comfort, reduce electric lighting loads (when lighting controls are in place), and bring added visual comfort associated with increased daylight within the space. Typically, looking for a high Efficacy (VLT/SHGC) is a good place to start.

This study tested 225 glazing types utilizing the "shoebox" method. This approach uses a simplified box of the same construction types in the same climate. This decreases test time and gives a performance rating relative to the other glazing types. This method is helpful in coming to a shortlist of successful items to test more in depth. Below is a graphic showing the range of the glazing performance within the shoebox test.

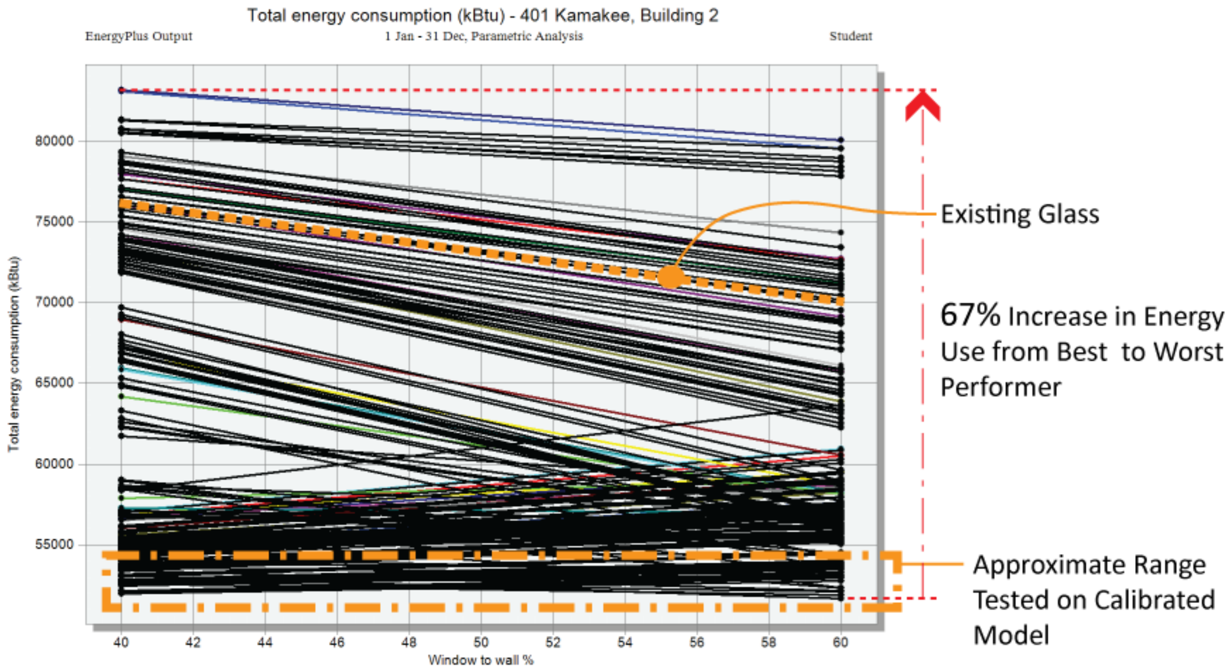
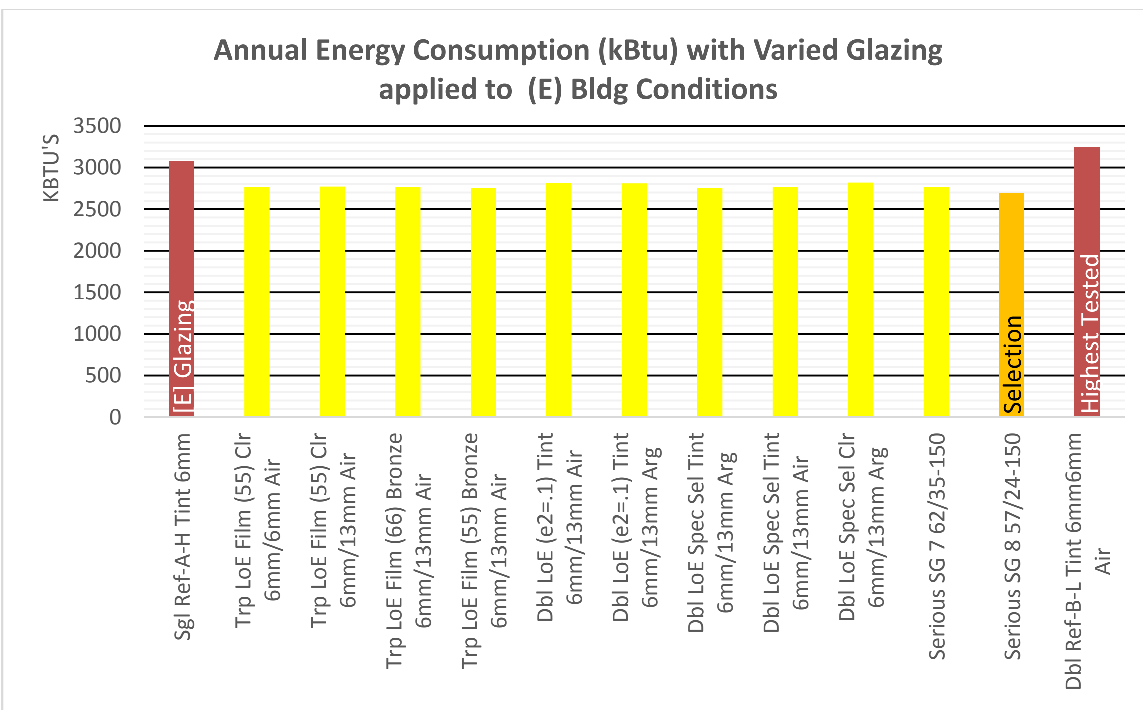


Figure 103 - "Shoebox" Parametric Study of 225 Glazing Types

The highest and lowest performing glazing types were then inserted into the calibrated model and tested independently to show which would perform the best in the existing conditions. The graph and chart below show performance of the best (and worst) glazing types when inserted into the calibrated model.

Figure 104 - Glazing Optimization Results



Of the 9 final glazing types, 5 types stood out as possible candidates for use. The most efficient, "Trp LoE Film (55) Bronze 6mm/13mm Air," provided a bronzed finish which has a tendency to retain heat and cause increased radiant temperatures near the windows. It also has a very low VLT, similar to the original glazing. The second most efficient glazing ("Dbl LoE Spec Sel Tint 6mm/13mm Arg") performed very well, but still had a very low VLT. Of all of the top glazing performing glazing types considered, the "Dbl LoE Spec Sel Clr 6mm/13mm Arg" was considered for its high efficiency & efficacy (VLT/SHGC).

Figure 105 – Final Glazing Characteristics

		Glazing Properties					Individual Results			
		SHGC	VLT	Efficacy	U-Factor	Low-E	Energy Consumption (kBtu)	% Saved	Fanger PMV	Disc Hr
	Baseline Glazing Results (Sgl Ref-A-H Tint 6mm)	0.245	0.1	0.41	0.923	No	308098	0.00%	-0.71	1370.7
Top Energy Consumption Performers										
Top Performer	Trp LoE Film (55) Clr 6mm/6mm Air	0.297	0.455	1.53	0.302	Yes	276628	10.21%	-0.75	1475.05
Top Performer	Trp LoE Film (55) Clr 6mm/13mm Air	0.303	0.455	1.50	0.213	Yes	277017	10.09%	-0.75	1473.5
Top Performer	Trp LoE Film (66) Bronze 6mm/13mm Air	0.242	0.322	1.33	0.215	Yes	276349	10.30%	-0.75	1491.29
Final Consideration	Trp LoE Film (55) Bronze 6mm/13mm Air	0.21	0.274	1.30	0.213	Yes	275194	10.68%	-0.77	1511.53
Top Performer	Dbl LoE (e2=.1) Tint 6mm/13mm Air	0.369	0.444	1.20	0.312	Yes	281536	8.62%	-0.73	1437.14
Top Performer	Dbl LoE (e2=.1) Tint 6mm/13mm Arg	0.364	0.444	1.22	0.264	Yes	280917	8.82%	-0.73	1442.41
Final Consideration	Dbl LoE Spec Sel Tint 6mm/13mm Arg	0.274	0.408	1.49	0.235	Yes	275563	10.56%	-0.76	1487.92
Top Performer	Dbl LoE Spec Sel Tint 6mm/13mm Air	0.282	0.408	1.45	0.288	Yes	276430	10.28%	-0.75	1497.87
Final Consideration	Dbl LoE Spec Sel Clr 6mm/13mm Arg	0.416	0.682	1.64	0.235	Yes	281915	8.50%	-0.72	1425.35
Final Consideration	Serious SG 7 62/35-150	0.35	0.62	1.77	0.14	Yes	276820	10.15%	-0.75	1470
Selected	Serious SG 8 57/24-150	0.24	0.57	2.38	0.13	Yes	269682	12.47%	-0.78	1534

Ultimately, 2 products from Serious glazing became finalists due to their superior energy savings stemming from a low SHGC as well as relatively high VLT. These products - considered super-windows - are double glazed, low-e, and argon filled, but their extreme ratings stem from highly insulative thermally broken frames as well as suspended film in between the panes.

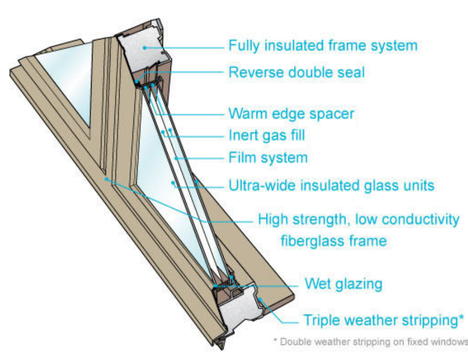


Figure 106 - Anatomy of a Serious Window

Simulated Savings for 4th Floor - 26,123 kBtu's Annually (12.47% of total baseline load)

Passive Potential - Positive - No Investment in Active Technology

Cooling effect on PMV - Good - .07 Decrease in PMV

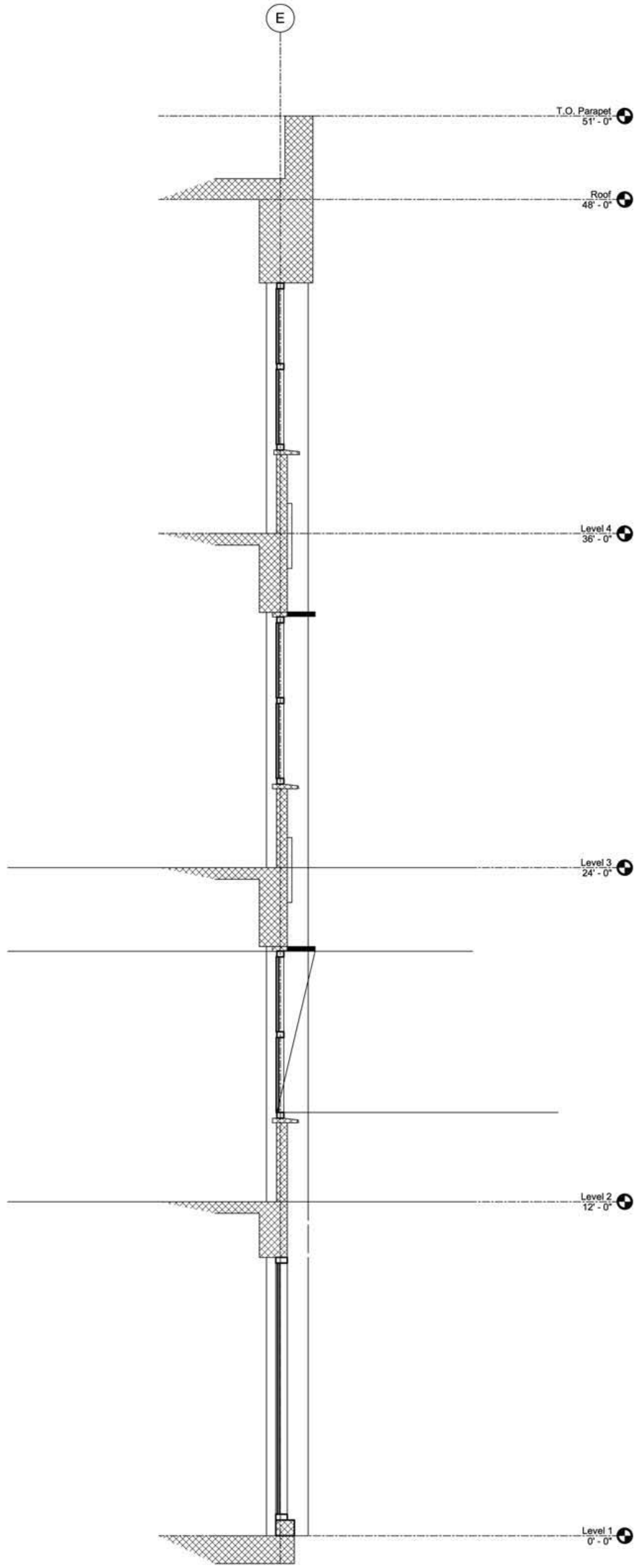
Large Effect on Visual Comfort - From 0 to 34% of floor area acceptably daylit by LEED standards.

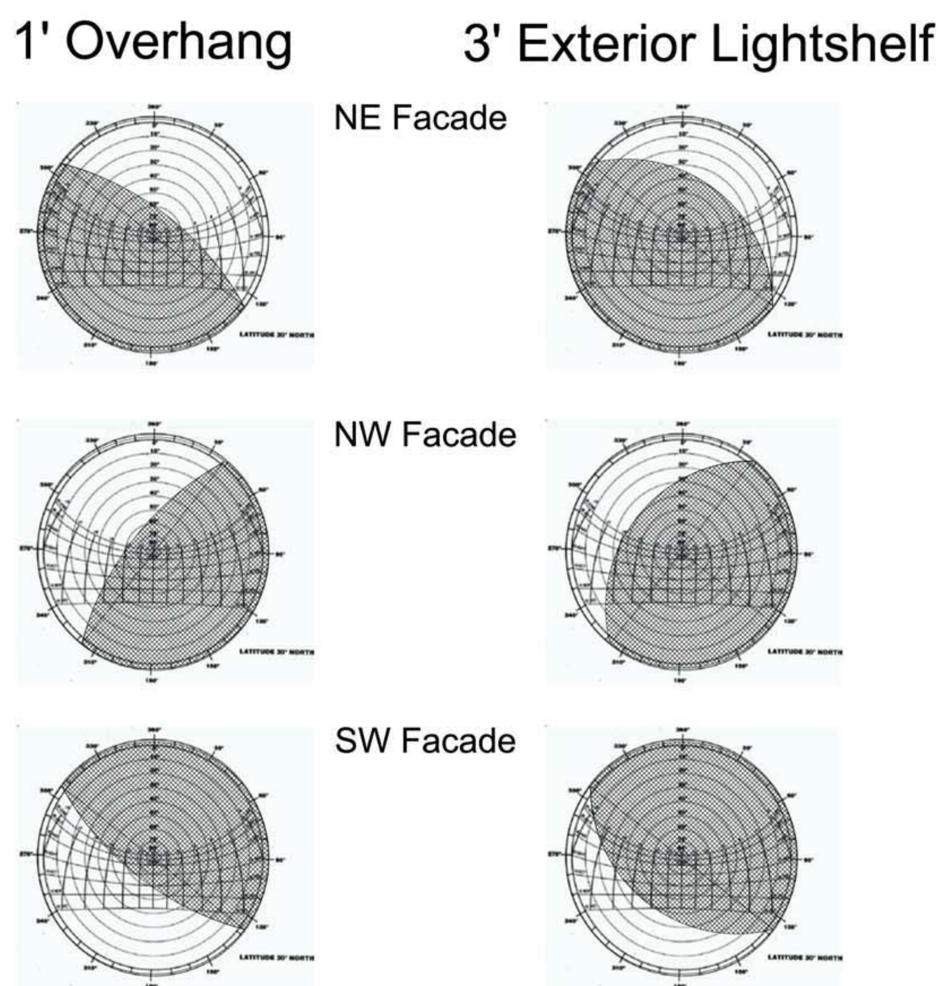
Exterior Shading

For the individual analysis portion of the project, exterior shading systems for energy savings were not compatible with existing conditions. All but one of the shade types tested, had a negative effect on energy use. The existing tint type on the windows had a very high Solar Heat Gain Coefficient, keeping the interior somewhat cooler than other glass. It is estimated that the exterior shades were effective in blocking out daylight and increasing loading from electric lighting given that the existing conditions are already on light sensors. This condition created a net increase in energy consumption.

For exterior shades to be effective in lowering energy consumption, an alternate glazing type allowing a high level of daylight would be needed. Exterior shades are very effective in situations where higher levels of solar heat gain are present. They also have significant benefit with respect to glare mitigation which involves shielding from direct beam penetration through apertures. For these reasons, exterior shading was carried over to the second level of testing to provide additional improvement to the new glazing type.

Shades tested included horizontal overhangs, horizontal lightshelves, and a scheme of mostly vertical shades for 100% coverage. Many variations beyond what was tested are possible, but in the interested of meeting time constraints, the most successful of these 3 popular methods of shade design were chosen to be tested in the Level 2 portion of simulations.


E
T.O. Parapet 51' - 0"
Roof 48' - 0"
Level 4 36' - 0"
Level 3 24' - 0"
Level 2 12' - 0"
Level 1 0' - 0"


1' Overhang
3' Exterior Lightshelf
NE Facade
NW Facade
SW Facade

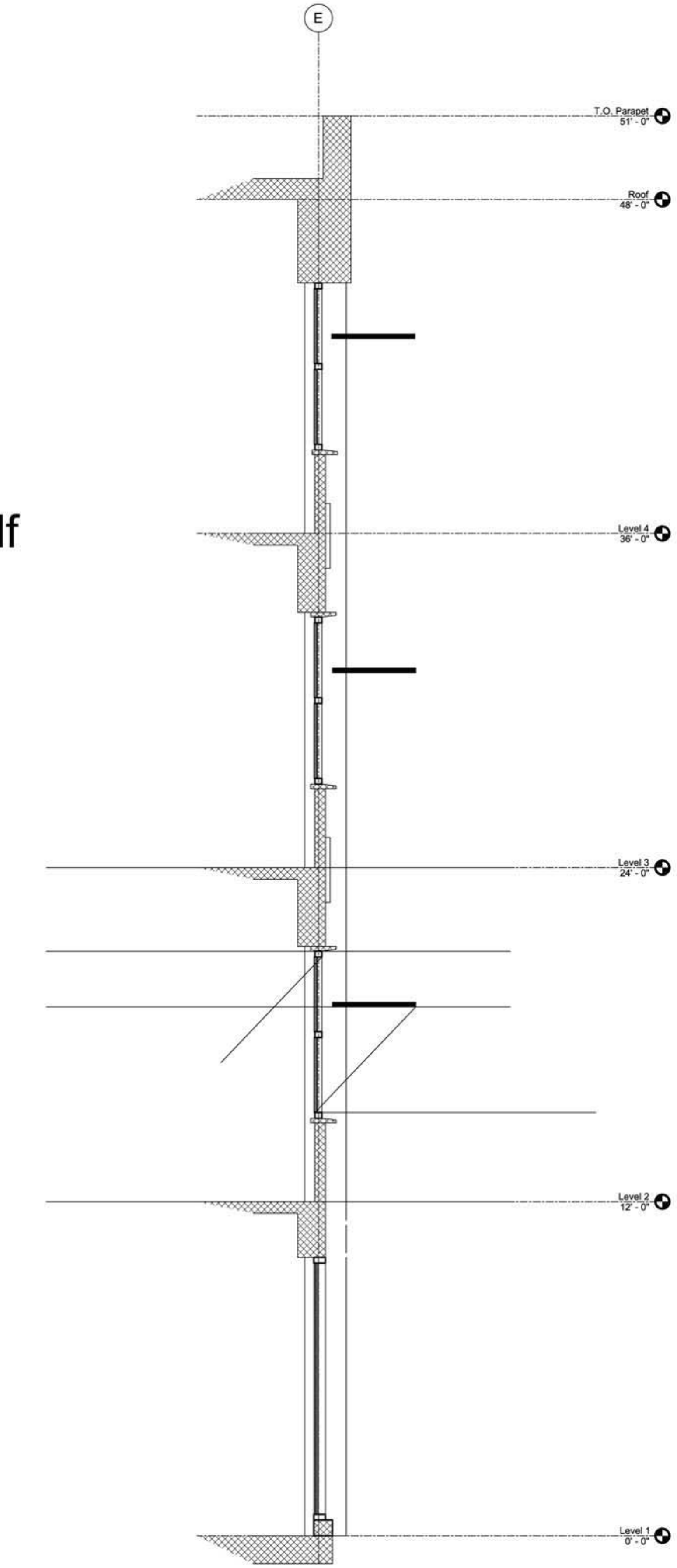
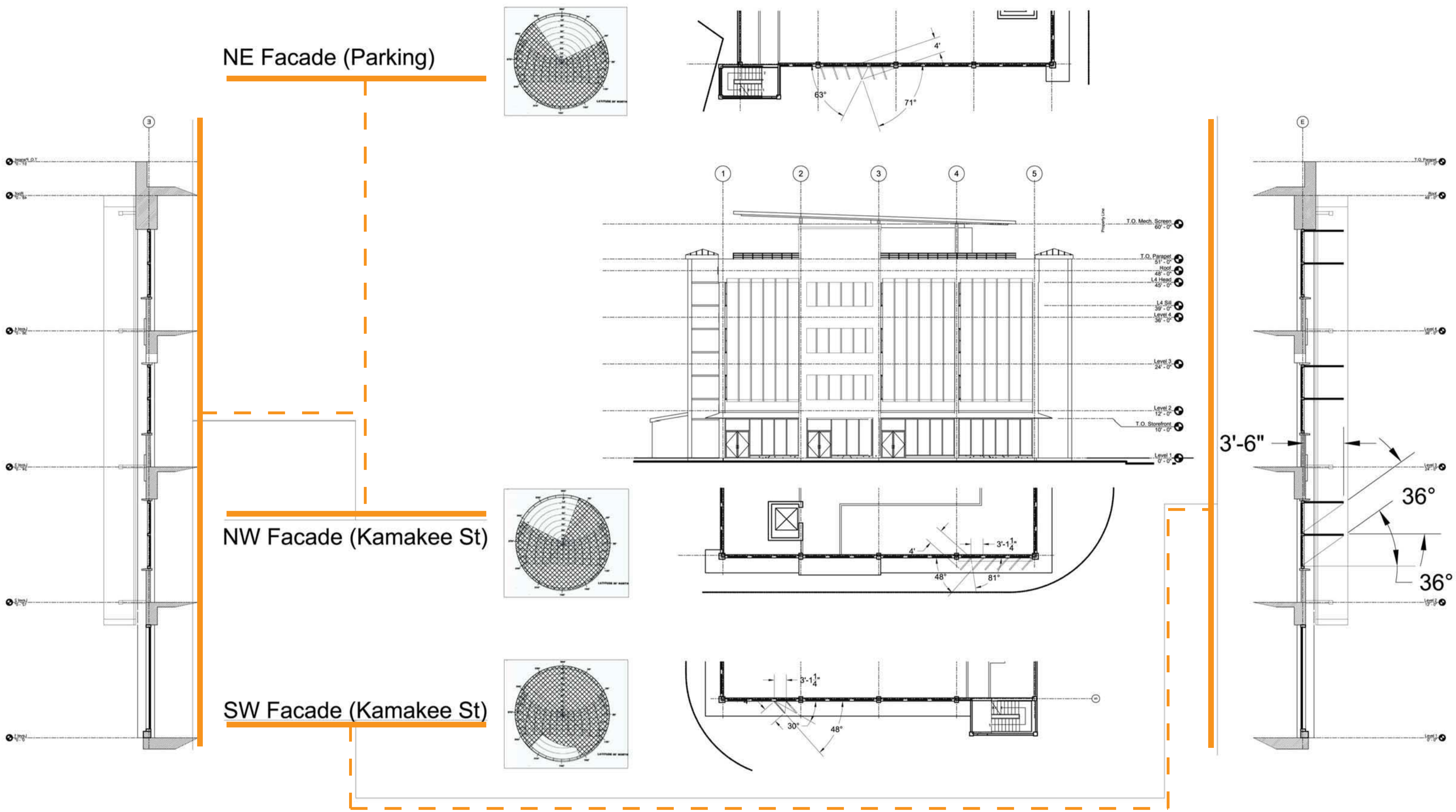

E
T.O. Parapet 51' - 0"
Roof 48' - 0"
Level 4 36' - 0"
Level 3 24' - 0"
Level 2 12' - 0"
Level 1 0' - 0"

Figure 64 - Scheme for 100% Shade



Natural Ventilation Strategies

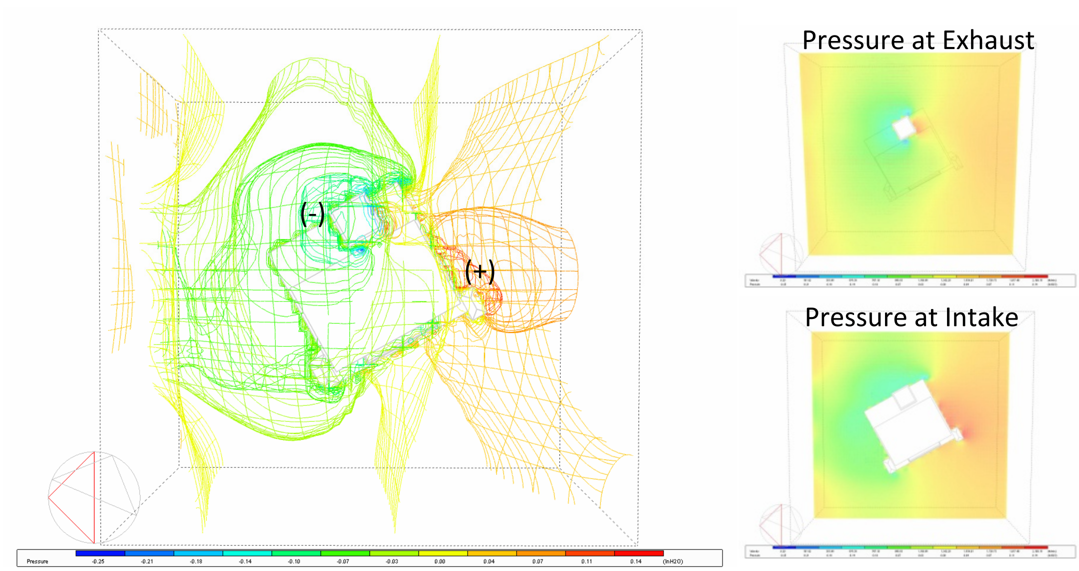
As mentioned earlier in the research, Hawaii's climate has a great deal of potential to take advantage natural ventilation concepts, including cross ventilation and stack effect. These concepts create comfortable conditions and cut off the use of air conditioning for some or all of operating hours. For simulation purposes, a continuous 70% open area was utilized for glazing bays to simulate awning windows.

Initial natural ventilation simulations were unsuccessful due to the high frequency of interior partitions across the space. This would not allow for cross ventilation of the floor plate or the application of an effective stack approach to ventilation. Furthermore, for natural ventilation to reach high levels of comfort, a best practice facade must also be in place to reduce heat loading from the interiors. Floor plans were modified to an open scenario early on to try to attain better results. Early CFD and simulation for spaces were not able to reach high comfort.

Natural Ventilation Strategies center around providing cross ventilation situations with openings on at least 2 sides of the building and creating pressure differential between the two effectively providing a ventilation current across the space. As mentioned previously, it is necessary to couple this approach with a reconfiguration of the interior partitions to provide this type of relationship with the façade.

Stack Ventilation Strategies look at providing a solar chimney to use vertical displacement temperature differentials to accelerate natural ventilation velocity rates within the interior. This was accomplished by providing a 30' tower above the Lobby area. Operable outlet windows are provided on the Northwest and Southwest Facades where negative air pressure pockets are seen. This causes a suction effect into the chimney to effectively accelerating air velocities in the interior space.

Figure 107 - External CFD Analysis of Stack Effect Tower Intervention



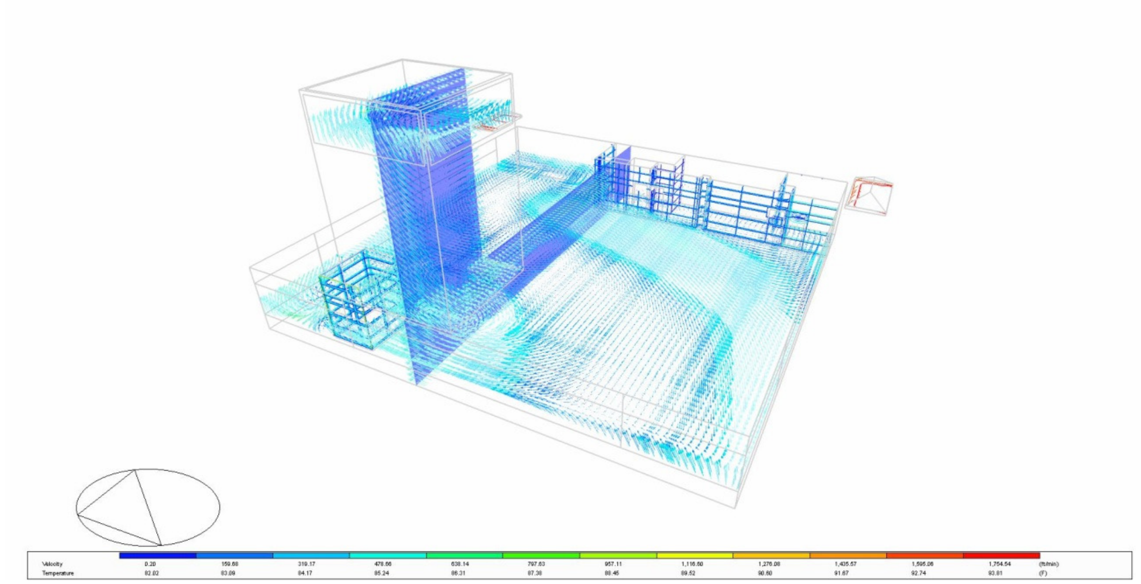


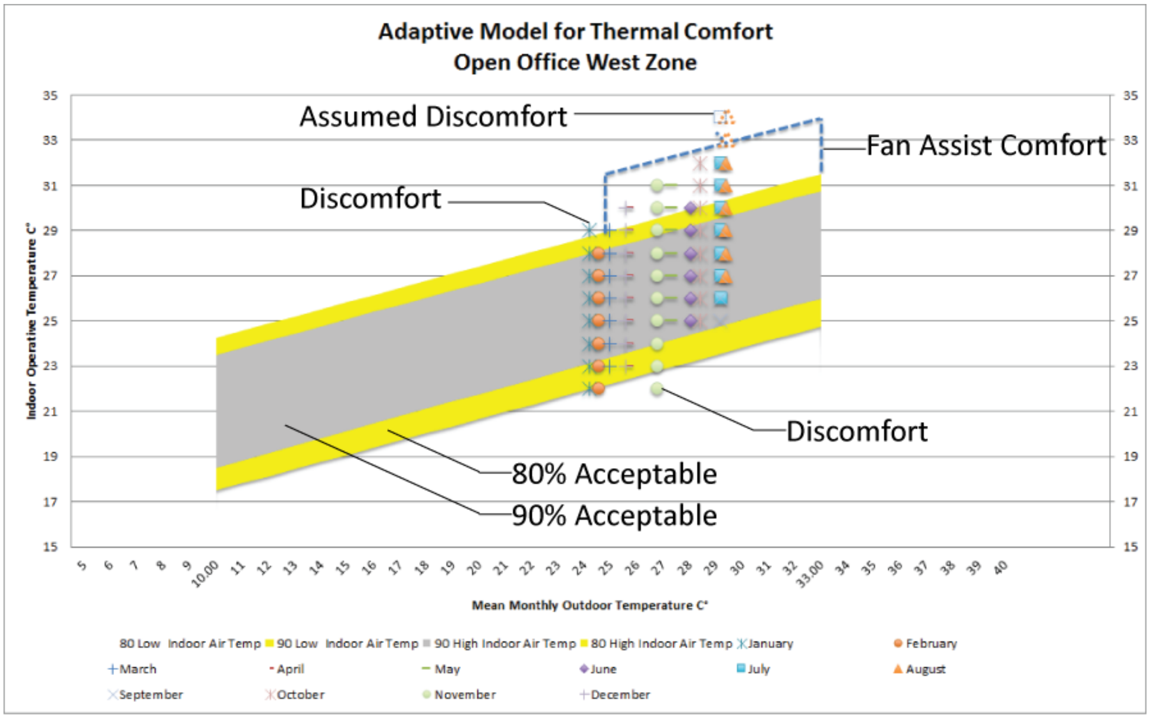
Figure 108 - Interior CFD Analysis of Open Floor Plan with Stack Effect Intervention

Stack ventilation through solar chimney becomes increasingly more complex than cross because it involves funneling air to one point to evacuate rather than allowing it to flow freely across the space. This stack vent method proposed,is more of a hybrid of cross and stack, allowing air to cross ventilate in portions of the floor plate.

While this strategy is only simulated on the 4th floor, it has potential to create increased air velocities to the spaces below as well. By providing analysis for the fourth floor, a worst-case scenario is depicted since providing access to the lower floors would effectively increase the chimney height for the spaces below and as such the chimney's effectiveness.

In analyzing comfort for natural ventilation, it is possible to use the Adaptive Model for Thermal Comfort to determine comfort levels. A discomfort hour quantity similar to the ASHRAE 90.1 limit of 300 was utilized to determine acceptable comfort hour quantities. See the following for an example of how interior and exterior temperatures are compared to determine comfort. Since DesignBuilder does not specifically analyze for an Adaptive Model for Thermal Comfort output, data from DB was exported and analyzed via spreadsheet to come to discomfort hour quantities. As such, zones were not able to be compared hour by hour to come to an exact discomfort hour count. Quantities given, however, should be within +/-10-20% of the actual count.

Figure 109- Adaptive Model Example



Adaptive Model For Thermal Comfort
Zone By Zone Analysis

	Confirmed	Assumed % DH	Total
Discomfort Hours (80%)	15.75	34.83	50.58
Comfort from Fans	324.25	68.97	393.22

Indoor Operative Temperature

Interval Start (°C)	22	23	24	25	26	27	28	29	30	31	32	Row
Interval End (°C)	23	24	25	26	27	28	29	30	31	32	32	Total
January	21.75	55	43.5	51.25	38.75	38.25	19.75	7.75	0	0	0	276
February	10.75	25.75	48.5	48.75	37.25	34.75	33.25	0.5	0	0	0	240
March	3.5	20.25	23.75	37.75	55.5	48	48	15	0.25	0	0	252
April	0	5.75	24.25	47	58.25	50	55.75	21.25	1.75	0	0	264
May	0	0	0	11.5	26.75	44.75	75.25	72.75	39.5	5.5	0	276
June	0	0	0	0.5	15.5	49.25	62.5	78	31	3.25	0	240
July	0	0	0	0	0	13	49	55.5	81.25	63	14.25	276
August	0	0	0	0	0	10.25	38	45	52.75	69.25	48.75	264
September	0	0	0	1	6.5	20.75	46.5	61.5	67.25	26.25	22.25	252
October	0	0	0	3.25	15.75	32	47.5	57.5	62.25	38.5	19.25	276
November	2	6.5	15.75	38	38	50	47.75	26	25.25	2.75	0	252
December	2	23.5	49.5	59.75	44.5	38.75	28	15	3	0	0	264

Mean Monthly Outdoor Temp

January	22.4833	22.4833	22.4833	22.4833	22.4833	22.4833	22.4833	22.4833	22.4833	22.4833	22.4833	22.4833
February	22.8056	22.8056	22.8056	22.8056	22.8056	22.8056	22.8056	22.8056	22.8056	22.8056	22.8056	22.8056
March	23.1667	23.1667	23.1667	23.1667	23.1667	23.1667	23.1667	23.1667	23.1667	23.1667	23.1667	23.1667
April	23.7556	23.7556	23.7556	23.7556	23.7556	23.7556	23.7556	23.7556	23.7556	23.7556	23.7556	23.7556
May	25.2333	25.2333	25.2333	25.2333	25.2333	25.2333	25.2333	25.2333	25.2333	25.2333	25.2333	25.2333
June	25.8667	25.8667	25.8667	25.8667	25.8667	25.8667	25.8667	25.8667	25.8667	25.8667	25.8667	25.8667
July	26.9	26.9	26.9	26.9	26.9	26.9	26.9	26.9	26.9	26.9	26.9	26.9
August	27.0611	27.0611	27.0611	27.0611	27.0611	27.0611	27.0611	27.0611	27.0611	27.0611	27.0611	27.0611
September	26.8722	26.8722	26.8722	26.8722	26.8722	26.8722	26.8722	26.8722	26.8722	26.8722	26.8722	26.8722
October	26.2166	26.2166	26.2166	26.2166	26.2166	26.2166	26.2166	26.2166	26.2166	26.2166	26.2166	26.2166
November	24.7611	24.7611	24.7611	24.7611	24.7611	24.7611	24.7611	24.7611	24.7611	24.7611	24.7611	24.7611
December	23.6889	23.6889	23.6889	23.6889	23.6889	23.6889	23.6889	23.6889	23.6889	23.6889	23.6889	23.6889

Internal Equipment and Fixture Loads

Design for energy efficiency in Hawaii typically becomes a heat mitigation problem. This is partly because the annual climate is slightly warmer than the human body would desire. But it is also spurred on by the heat loads that any indoor environment will need to mitigate in order to provide thermal comfort. As is pointed out in the Active Systems Chapter, anything that draws power will also provide a heat source. The heat generated will need to be cooled meaning that the efficiency of each of those systems is of extra importance in order to attain the highest levels of energy efficiency. For this reason, these factors are the first individual strategies which are tested.

Plug Load Optimization

For the purposes of this exercise, actual plug loads for the building in question were not able to be attained. However, the existing building's electrical wiring has been designated as needing replacement. Furthermore, no efforts to optimize the building's plug loads have been put into action. For these reasons, determining levels for the calibrated energy model used a slightly higher than average level of 1.2 W/SF. However, due to the state of the existing building's wiring, it would not be a surprise if it was higher.

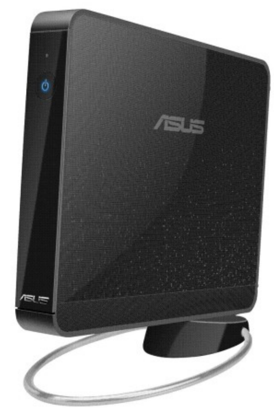


Figure 110 – Nettop Computer System, Part of a Best Practice Set of Office Equipment

In general, when it comes to energy efficiency, there is a very large difference between the standard energy consumption and best practice for plug loads. In a best practice situation, levels of .4W/SF are able to be attained. This is approximately 1/3rd of the original consumption and will have the added benefit of reducing heat gain to the interior. Minimizing these levels is one of the easiest ways to increase efficiency levels for the entire building.

From a building management perspective, these loads could be controlled in a proactive way through a tenant lease clause. Having them opt into buying only Energystar equipment or a predetermined list of best practice equipment would ensure that they adhere to guidelines and essentially lower the building's energy footprint with no capital expense on the part of the owner.

Simulated Savings for 4th Floor - 59,790 kBtu annually (19.41% of total baseline load)

Passive Potential - Neutral - Investment in Active Technology, or Technology can be replaced with best practice as devices need replacement. This is due to a short lifespan of plugload devices.

Warming effect on PMV - Bad - .11 Increase in PMV

No Effect on Visual Comfort

Lighting Type Optimization

Similar to Plug Loads, optimization of electric lighting has the added benefit of reducing the loading requirements on the thermal comfort system, weather HVAC or Nat Vent. Although it will work best with added measures for increased daylighting, an electrical lighting retrofit will almost always be a good investment when the existing system has been in place for some time. This is due to significant advancement in lighting technology.

Figure 111 - Suspended Linear Lighting Fixture

The system type specified is a suspended up-down fixture type which can reach wattage levels and visual comfort that the existing surface mounted fixtures cannot. With the revamp of the fixture type, will also come a rezoning of fixtures based on their proximity to daylight. Wattage levels specified for the Tech Potential solution are .018 W/SF/FC and Illuminance levels are slated at 37 FC/SF for an overall power consumption of about .66W/SF before lighting controls and daylighting are considered.

Simulated Savings for 4th Floor – 71,658 kBtu's Annually (23.26% of total baseline load)

Passive Potential - Negative - Investment in Active Technology. This measure will commit owner to energy consumption, but is necessary given the depth of the floor plate

Cooling effect on PMV - Good -.10 Decrease in Annual PMV

No Effect on Passive Visual Comfort. New lighting type will provide a more even illuminance than the old electric lighting system (Target 37 fc)

Lighting Controls Optimization

This is a minor improvement because the existing conditions were already retrofit with occupancy sensor control and switches. The additional controls put in place will allow lighting levels to dim in a linear fashion until they reach a point where they shut off based on daylighting levels present in the space. With the existing window types, this has very little impact due to the very low visible light allowed in the space by the existing tint. When coupled with the optimized glazing, better results should appear.

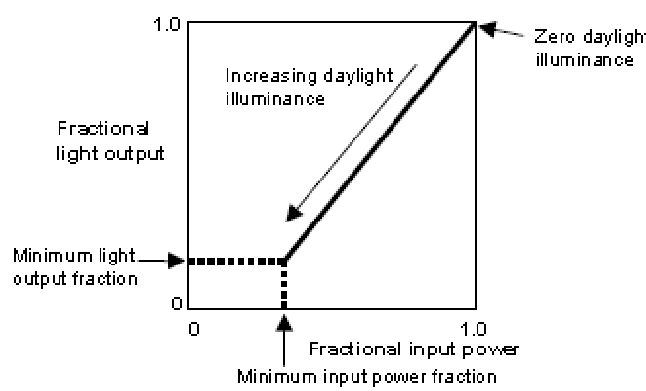


Figure 112 - Continuous Dimming Controls Description

Simulated Savings for 4th Floor - 8,887 kBtu's Annually (2.88% of total baseline load)

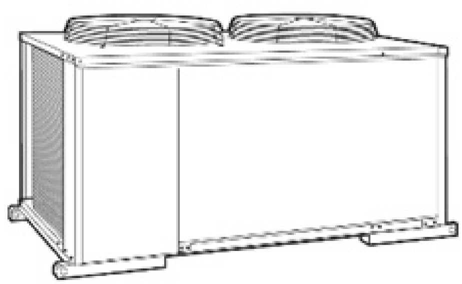
Passive Potential - Negative - Investment in Active Technology. This measure will commit owner to energy consumption

Cooling effect on PMV - Good -.01 Decrease in Annual PMV

No Effect on Passive Visual Comfort. New lighting controls will ensure a more even illuminance then the previous controls

IECC VAV HVAC Retrofit

IECC minimum recommendations for air conditioning system would be a large improvement to the existing power consumption. Retrofitting the cooling system to a variable air volume system with parallel fan-powered boxes and providing thermostats in each zone as recommended would provide necessary efficiency and local controllability not seen in the current conditions. Since thermal comfort has become a large part of determining the final package of improvements, this would be the status quo improvement if sticking with a more traditional commercial HVAC system. For these reasons, this becomes one of the options tested in the second level to determine thermal comfort.



Simulated Savings for 4th Floor – 23,714 kBtu's Annually (7.70% of total baseline load)

Passive Potential - Negative - Investment in Active Technology. This measure will commit owner to energy consumption

Cooling effect on PMV - Neutral

No Effect on Passive Visual Comfort.

Ceiling Fans

Ceiling fans are an excellent method to enhance the effectiveness of natural ventilation techniques. They have traditionally been used as a way to raise temperature setpoints in HVAC systems saving portions of energy by increasing convective heat loss from the body. Recently they have been proposed to work in the same manner within the Adaptive Model for Thermal Comfort by Richard de Dear.[183] In this proposal, the permissible range of operative temperature is allowed to be increased based on a steady increased movement of air.

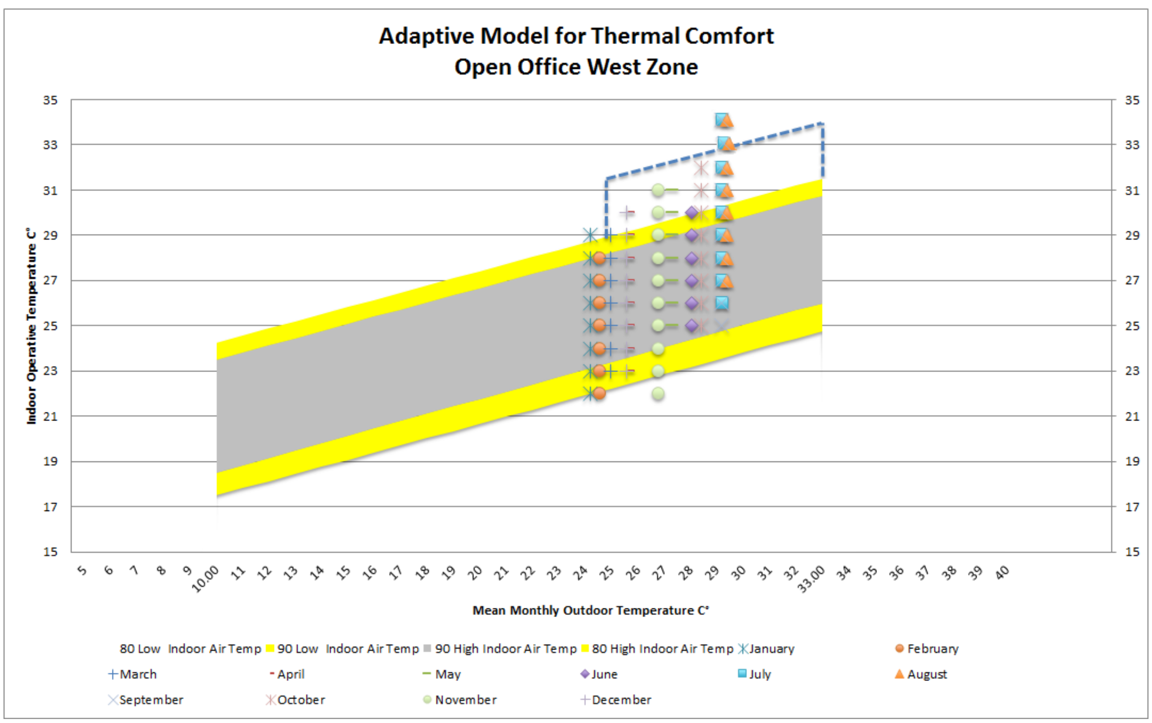
Figure 113 - Proposed Raise in Comfort Temperature Provided by Increased Air Speed[184]

Increases in Acceptable Operative Temperature Limits (Δt_o) in the Adaptive Comfort Standard (Figure 5.3) Resulting from Increasing Mean Air Speed Above 0.3 m/s (59 fpm).

Mean Air Speed 0.6 m/s (118 fpm)	Mean Air Speed 0.9 m/s (177 fpm)	Mean Air Speed 1.2 m/s (236 fpm)
1.2°C (2.2°F)	1.8°C (3.2°F)	2.2°C (4.0°F)

This research is still ongoing, but using ceiling fans to raise comfort temperature is a relatively well understood concept in the heat balance method. Similar conditions within an adaptive context have similar results, raising the allowable 80% and 90% comfort thresholds upwards.

Figure 114 - Example of Increased Comfort through Increased Air Speed



[183] PhD Richard de Dear, "Adaptive Thermal Comfort: Background, Simulations, Future Directions" (Las Vegas, 2011).
[184] Ibid.

Water Heater Setpoint Adjustment

As a relatively new IECC requirement, water heater setpoints are now set 90°F. This setting was previous varying at much higher temperatures. Given the intermittent use of water and the low need for it to be hot, especially in bathrooms, this was recommended to be adjusted to a setpoint to conserve.

Simulated Savings for 4th Floor – 3,092 kBtu's Annually (.99% of total baseline load)

Passive Potential - Negative - Investment in Active Technology. This measure will commit owner to energy consumption

Cooling effect on PMV - Neutral

No Effect on Passive Visual Comfort.

Determining Symbiotic Strategies

Key to the success of any Deep Energy Retrofit is finding opportunities to maximize the impact of the capital investment made. In this project's case, a few concepts emerge which have the opportunity to both increase owner revenue and provide a new tenant lifestyle.

Revamp 4th Floor Layout - Prototype for other floors

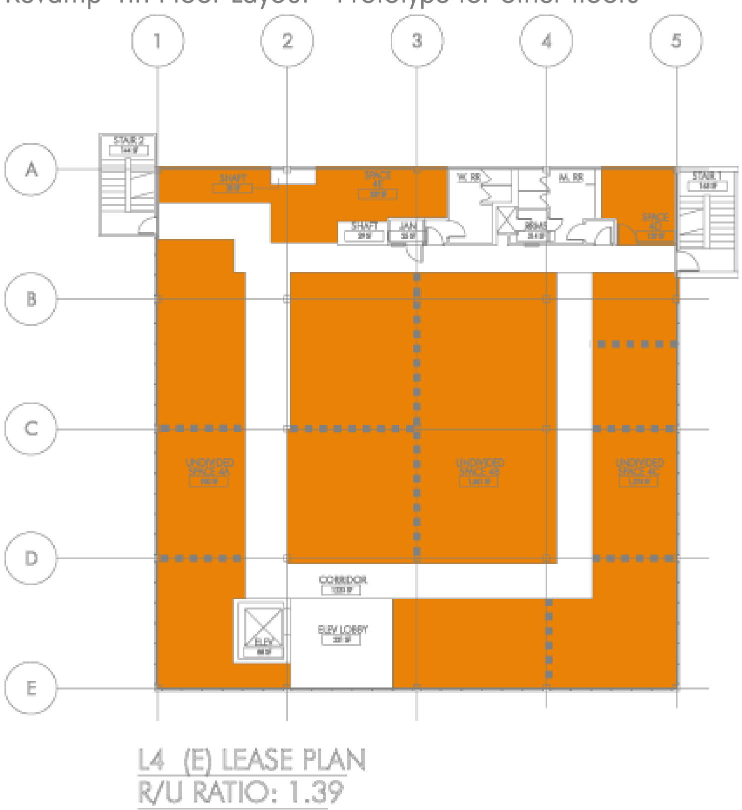


Figure 115 - Existing Floor Layout

In the existing layout, access to daylight is unavailable in some spaces. Rental space of this type is substandard in the market today. Study after study shows that connection to the outdoors increases perceived comfort and relaxes occupants. Studies show that daylight, as long as heat gain and glare are mitigated properly, is much more efficient to the overall energy consumption than electric lighting.

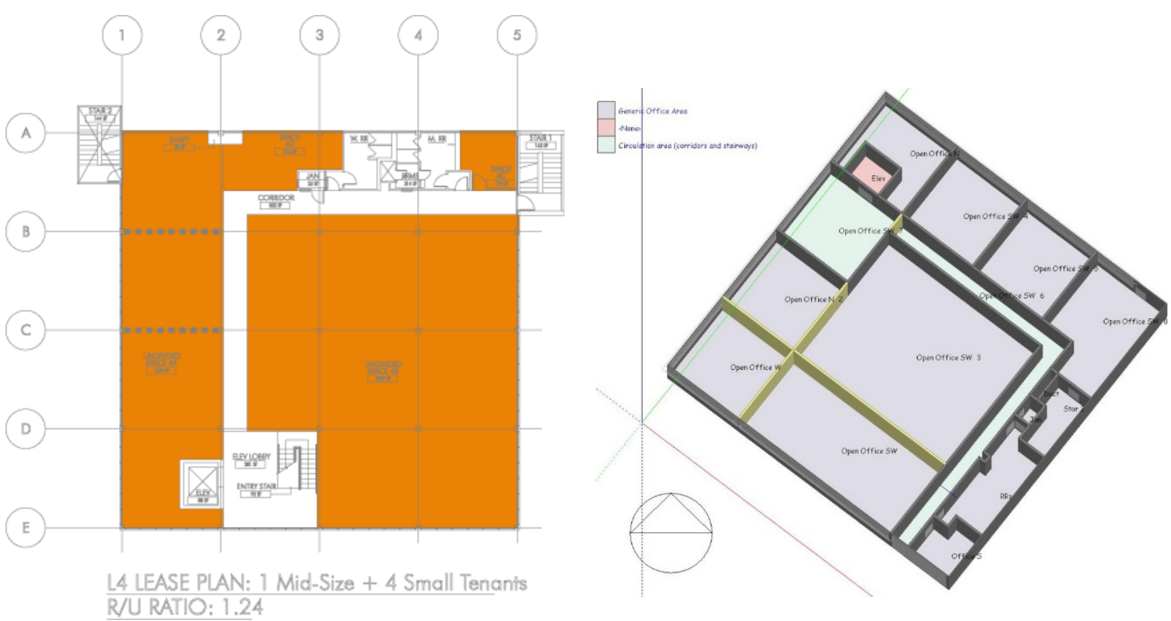
Taking these considerations into account, a revamp of the existing 3rd and 4th floor plan types should become a prerequisite strategy. This revamp will need to ensure that all tenants have access to daylight within their space. An improvement such as this is likely to make the overall rentable square footage more valuable as well as increase rentable square footage.

One major barrier kept this from occurring in the previous renovations: access to egress. Egress will require 2 separate paths to the exterior. By extending the lobby stair to the 4th floor, a more compact circulation layout can be accomplished. A similar effort has already been undertaken on the 2nd floor during a rehabilitation in 2003. By reconfiguring the space, this approach has the added the benefit of significantly increasing usable area on each floor due to the fact that significantly less space is needed to navigate to an exit.

Fortunately, a stairwell connecting the first and second floors already exists in the front lobby. Extending this stair to the 3rd and 4th floors could ultimately suffice as an egress exit and create a code compliant condition.

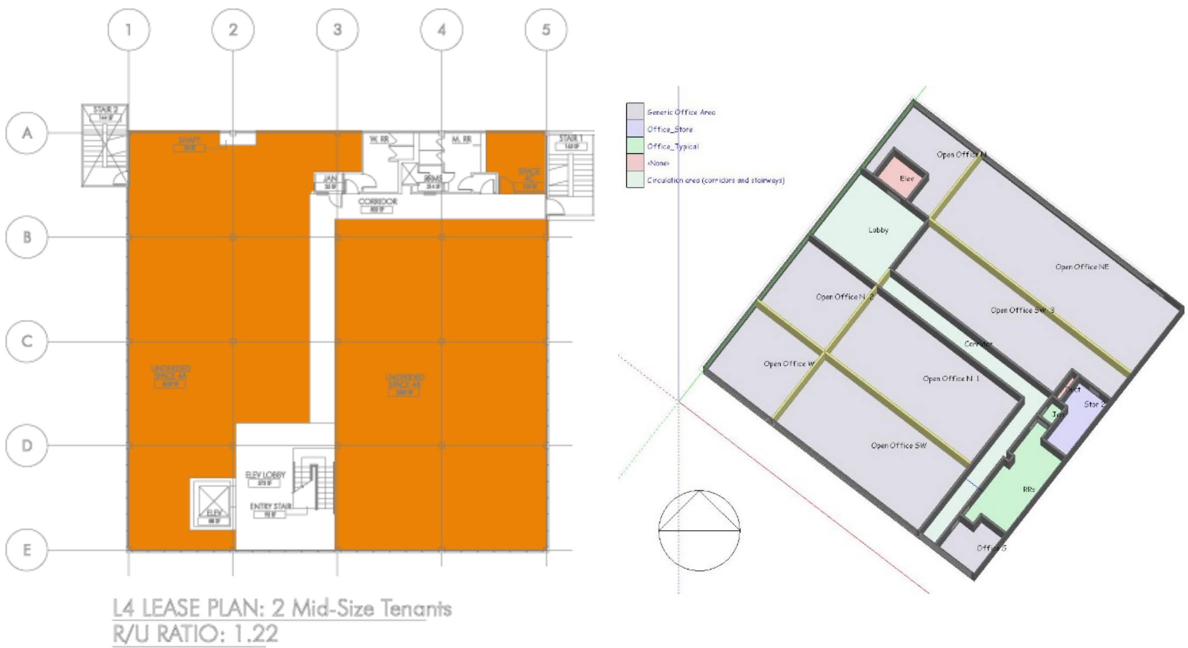
Utilizing this approach, 3 floor layout schemes, displayed in the figures below, were added to the list of variables to be tested with the understanding that 1 of the 3 layouts would ultimately be utilized. Below are further details for each of the layouts as well as examples as to how the spaces could be used by tenants.

Figure 116 - 1 Mid-Size + 4 Small Tenants



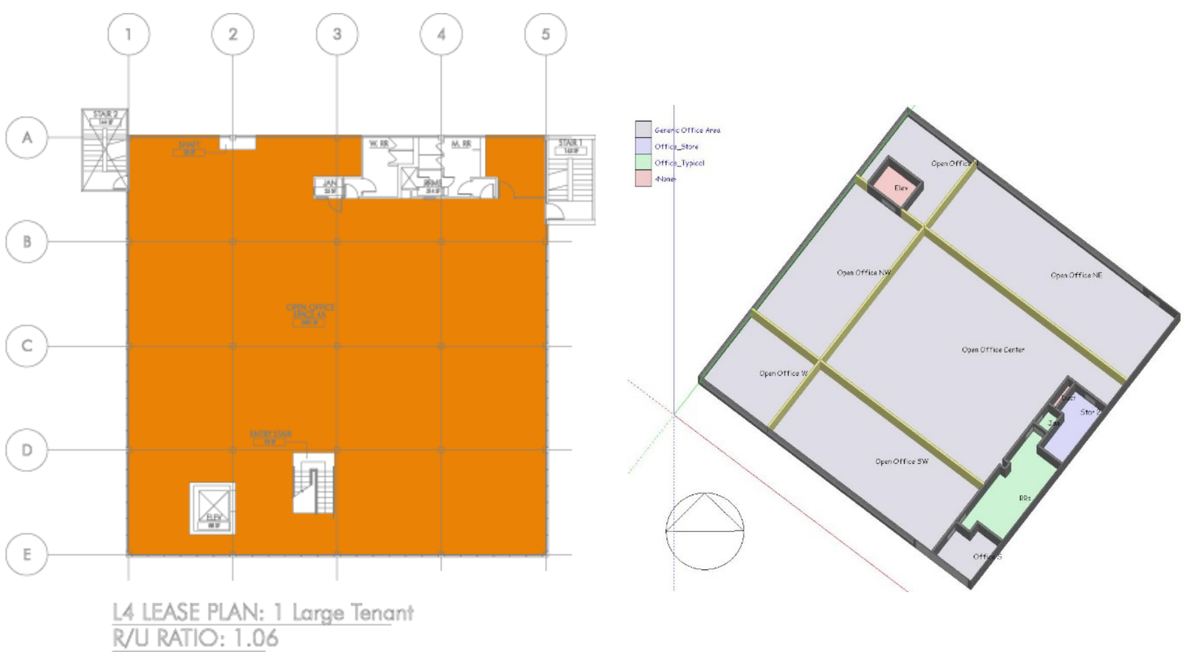
- 571 Additional SF

Figure 117 - 2 Mid-Size Tenants



- 571 Additional SF

Figure 118 – Open Floor Plan



- 1341 Additional SF

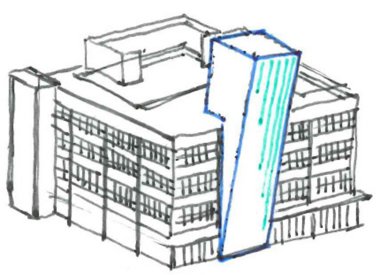
Explore Vertical Neighborhood Concept

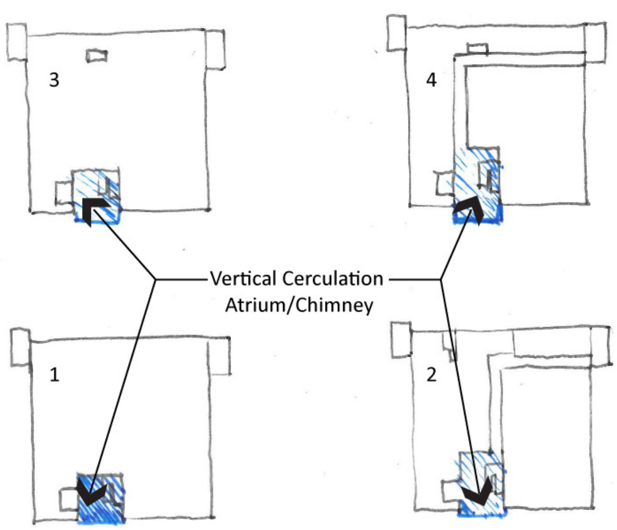
The extension of the lobby stair creates an opportunity to further unify the tenants of the building and encourage social interaction and community by creating a vertical atrium connection. This intervention will solidify a new identity for the building and encourage exploration of the floors and their tenants.

This effort will also provide the opportunity to extend the stair all the way to the roof, allowing for a roof deck improvement to take place. A roof deck in this instance can provide reprieve from the interior space and allow tenants to move to a new venue to work remotely. It would also provide a venue for pau hana events which would be a great draw for tenants considering the views from the rooftop.

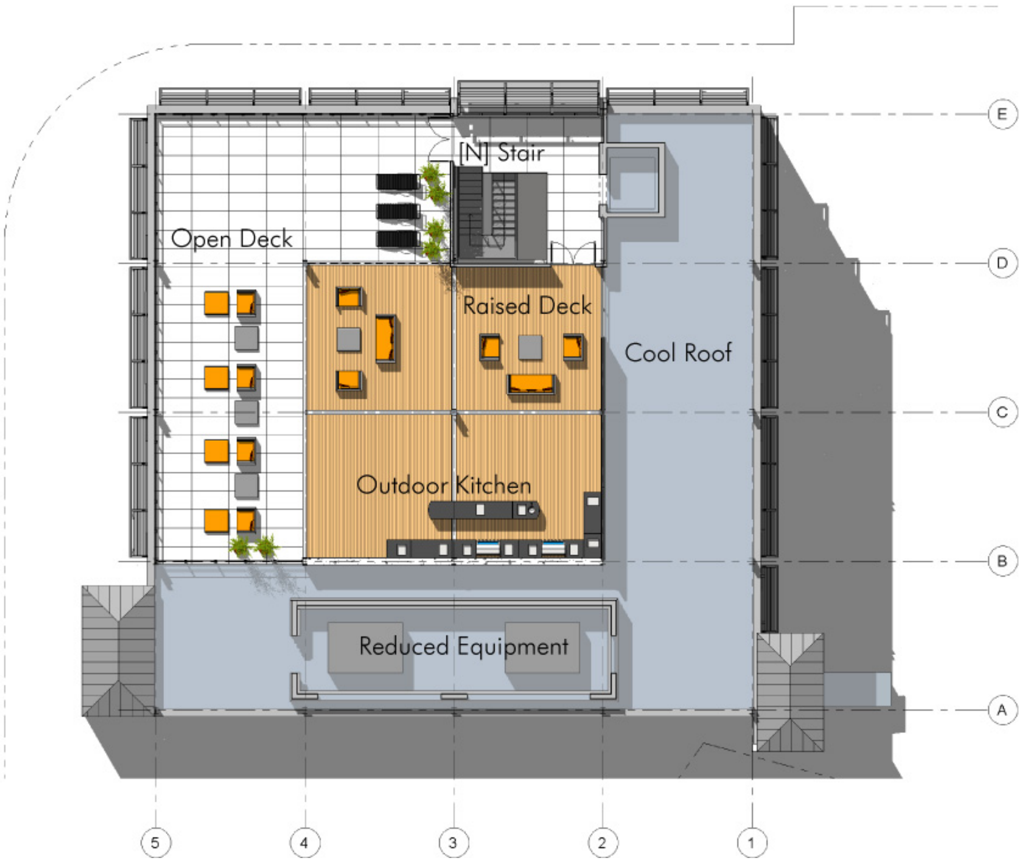
In the event that a stack ventilation scheme is chosen as the most energy efficient option, the vertical atrium space would be the most viable location for a solar chimney (as shown in the preceding stack effect discussion). Vertical movement of air and people would combine allowing tenants and other occupants to experience building science in action.

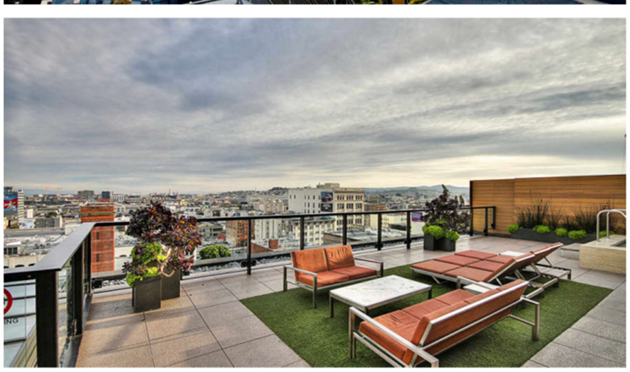
This one act would become the heart of the building – both socially and physically – and at the same time make a statement to the outside neighborhood that 401 Kamakee is not only a part of this neighborhood's past, but a benchmark for future ways of doing business.





Occupiable Roof Deck





Access to the roof provided by the [New] stairway would continue to the roof. A roof deck would piggyback on other improvements, providing a whole new level of amenities.

Currently the roof deck houses the 3rd and 4th floor HVAC equipment, other miscellaneous equipment, and an expansive solar PV array that takes up about ¾" of the total roof area. Equipment still needed after improvements will remain in the rear of the rooftop and the PV array will be lifted to become a shade structure for the occupiable portion of the new deck.

The new occupiable portion of the deck will be part outdoor office, part outdoor lounge, and part outdoor kitchen to provide function for all times of the day and night. The roof deck is envisioned as a major driving point for a higher level of tenant focused on having an office that is both a place of business and indicative of a contemporary office lifestyle.

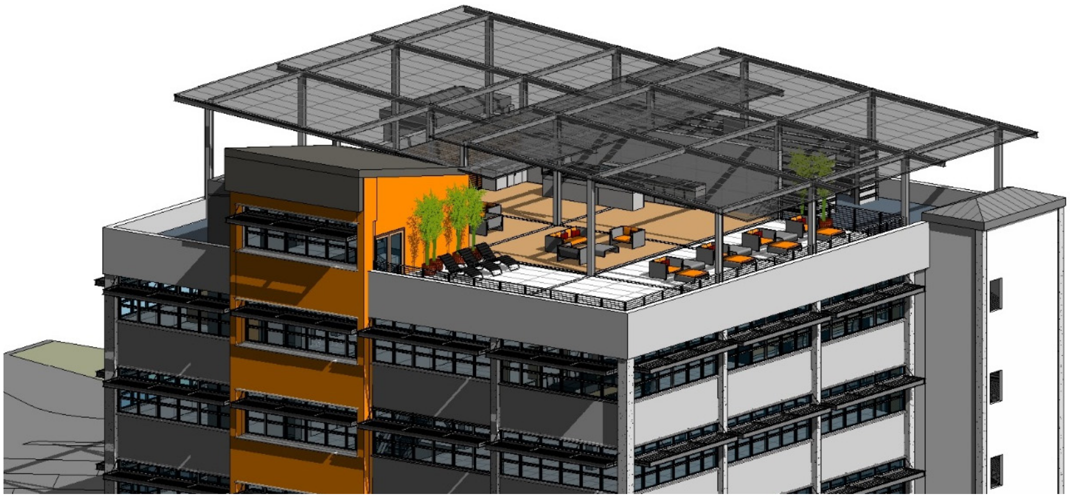
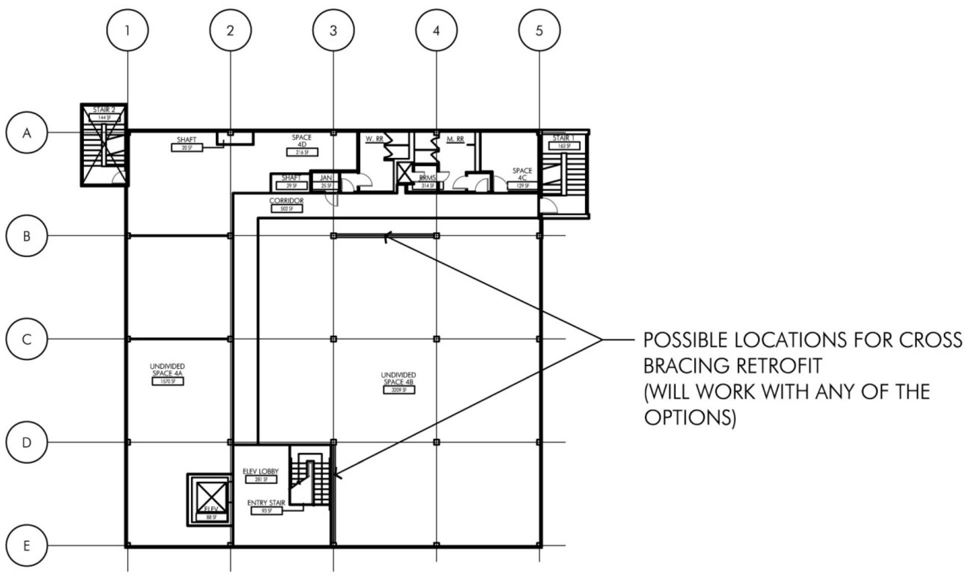


Figure 119 - Roof Deck Axon

Access to the roof is required by current code in buildings 4 stories and higher. So while this would not be required to be undertaken by the local jurisdiction as a part of the improvements, it would none the less, become a current code compliant condition.

Structural Retrofit

Although no major beams will need to be disrupted in the improvements, retrofitting for a new stairway at the lobby will also mean the penetration two floor slabs and the roof in order to realize all of the improvements. Since the structure has been deemed structurally deficient as sited in the '93 property report,[185] a structural retrofit will be needed to stabilize the structure. A continuous roof to foundation cross bracing effort was recommended in the property report. Utilizing this approach and providing stabilized bays in each direction on each floor will provide enough stability to provide for the previous structural needs as well as the new penetrations for the lobby stair and atrium. The cross bracing elements, when properly placed, can provide some space division as well as visual accent to the spaces. Placement will need to be carefully considered to reinforce space usability in the final tenant space.



Electrical Retrofit

Similar to the structural concerns, the electrical wiring is the original system which has been loosely added onto throughout the decades. Often times, electrical lines are surface mounted and substandard. With the revised layout, comes the opportunity for a much needed electrical renovation of all wiring.

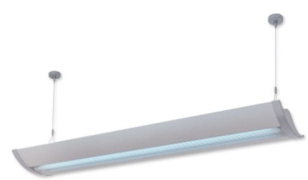
[185] Chan, "E.E. Black Building Property Due Diligence Report," Struct 3.

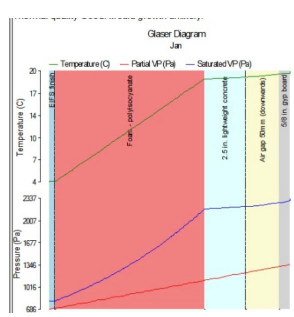
Level 2: Determining the Final Technical Potential Package

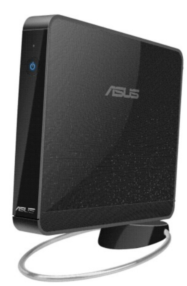
The preceding are all examples of variables to be considered for a final Technical Potential Solution. In order to take the next step toward a final bundle of measures, optimized versions of variables with beneficial effects to energy consumption, and thermal comfort were automatically included in a "base improvements" package to serve as a starting point for final determination of the technical potential package.

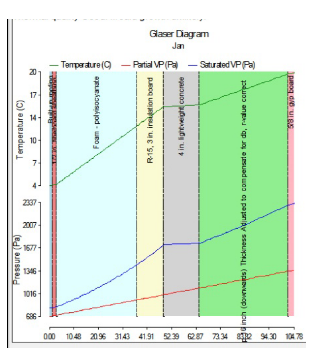
Level 1 Package - Base Improvements

- Window glazing is improved to provide Dbl LoE Serious 57/24 Arg filled glazing type. Window frames are to include a thermally broken section.
- Exterior Walls - 9" Polyiso Insulation Foam added to exterior face of concrete panels. Exterior to be refinished with a cementitious coating.
- Roofing - 9" Polyiso Insulation Foam added to roof deck. Roof membrane to be replaced with a reflective finish.
- Infiltration is updated to .2 AC/H based on the improvements to the envelope.
- Plug Loads are revised to .4W/ SF
- A new Suspended Lighting System is installed producing .018W/SF/FC (37FC target). Linear-off lighting controls couple these new fixtures. Fixtures and controls are zoned accordingly to be optimized to these levels.
- Water heater Setpoints adjusted to 90°F









Level 2 Package – Matrix Bundles

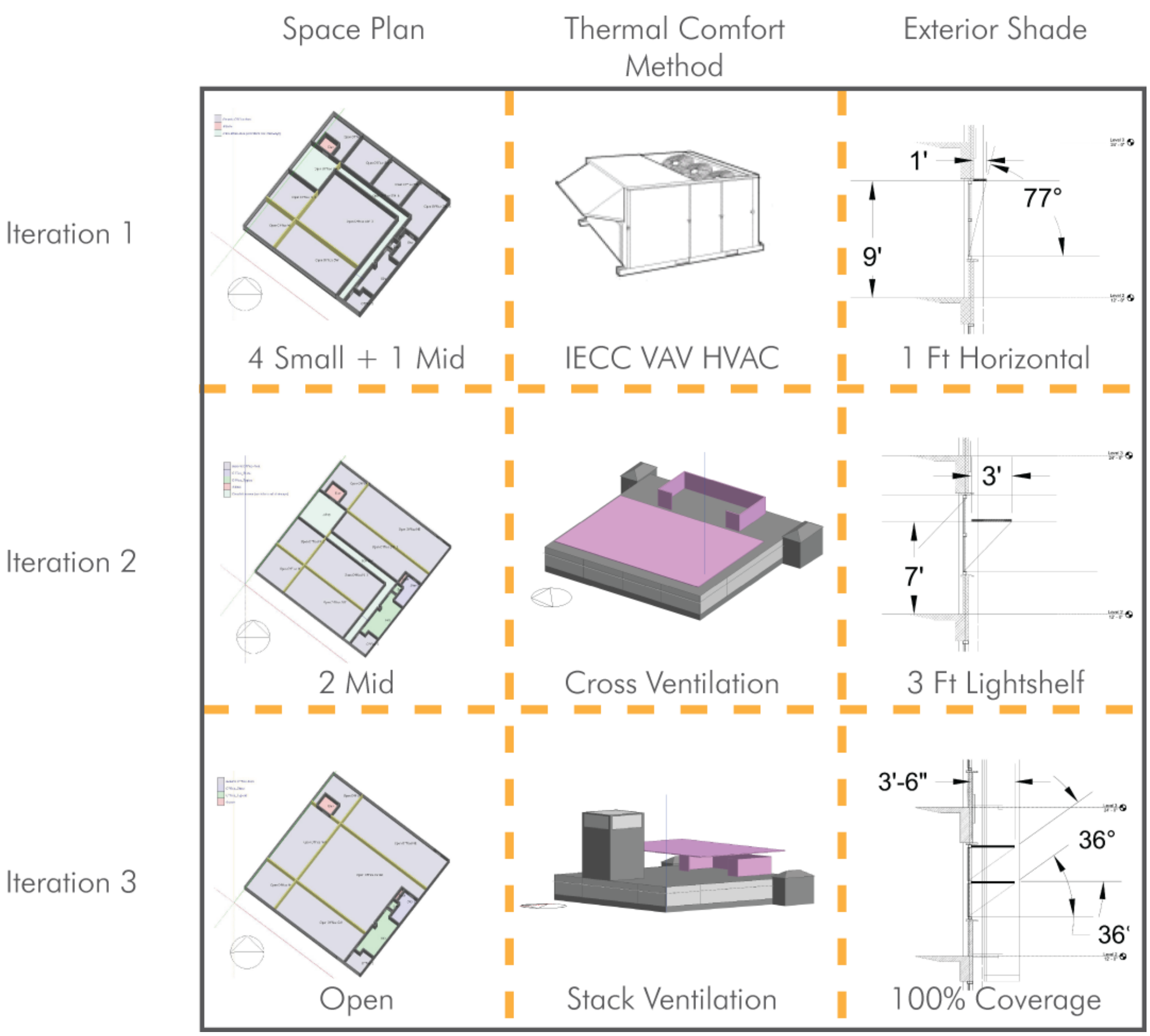
To flush out some of the more complex energy relationships, unique configurations of the remaining variables are determined. Components to be tested in this round are:

Floor Layout (3 Variations - Open/2 Mid-size Tenants/4 Small + 1 Mid-size Tenants);

Method for Internal Comfort (IECC VAV HVAC / Cross Ventilation / Stack Ventilation);

Exterior Shading Method (1Ft Horizontal / 3Ft Lightshelf / 100% Coverage).

Figure 120 - Level 2 Bundle Matrix



Each combination of these 3 factors are tested with the base improvements to find the optimum resulting package. Results are then scored based on the criteria outlined at the beginning of the chapter. The next sheet shows the results of these tests.

			Energy Consumption	Simulated Energy Savings			Simulated Comfort			Scoring							
							Thermal		Visual	Energy		Thermal Comfort		Passive Visual Comfort		Passive	**Total Score %**
Level 2 Simulations			kBtu	kBtu	kWh	%	PMV (Fanger)	Adjusted Discomfort Hours	% Daylight Area Illuminance								
Unique Packages										% Score	Score	% Score	Score	% Score	Score	Score	
Exisitng Conditions Baseline			308098				-0.71	1370.7	0.00%		Weight		Weight		Weight	Weight	
IECC Code Compliance			234888				-0.79	1074.44			40% of Total		35% of Total		35% of Total	5% of Total	
Baseline (Turn HVAC Off)			146512	161586	47358	52.45%	2.5	3266	0.00%		Score		Score		Score	Score	
All Finalists have Optimized Walls, Glass, Roof, and Interior Loading			132784	175314	51382	56.90%	-0.92	1524.06									
Floor Layout	**Method of Thermal Comfort**	**Exterior Shading**															
Small Tenants + Mid	IECC Compliant VAV HVAC	1 Ft Horizontal Overhang	125769	182329	53438	59.18%	-0.93	200	31.10%	57.64%	23.05	44.25%	15.49	88.35%	17.67	0	**56.21**
		3ft Horizontal Exterior Light Shelf	124341	183757	53856	59.64%	-0.95	200	25.30%	58.39%	23.36	44.25%	15.49	71.88%	14.38	0	**53.22**
		100% Coverage (.5) Transmittance	122838	185260	54297	60.13%	-0.96	200	0.00%	59.19%	23.67	44.25%	15.49	0.00%	0.00	0	**39.16**
	Nat Vent	1 Ft Horizontal Overhang	45590	262508	76937	85.20%	0.95	127	29.90%	99.99%	40.00	76.55%	26.79	84.94%	16.99	5	**88.78**
		3ft Horizontal Exterior Light Shelf	46258	261840	76741	84.99%	0.92	89	24.00%	99.64%	39.85	93.36%	32.68	68.18%	13.64	5	**91.17**
		100% Coverage (.5) Transmittance	46619	261479	76635	84.87%	0.9	80	20.00%	99.44%	39.78	97.35%	34.07	56.82%	11.36	5	**90.21**
	Stack	1 Ft Horizontal Overhang	45581	262517	76939	85.21%	1.06	720	37.40%	99.99%	40.00	0.00%	0.00	106.25%	21.25	5	**66.25**
		3ft Horizontal Exterior Light Shelf	46392	261706	76702	84.94%	1.04	713	32.70%	99.56%	39.83	0.00%	0.00	92.90%	18.58	5	**63.41**
		100% Coverage (.5) Transmittance	46901	261197	76552	84.78%	1.01	725	10.60%	99.30%	39.72	0.00%	0.00	30.11%	6.02	5	**50.74**
2 Midsize Tenants	IECC Compliant VAV HVAC	1 Ft Horizontal Overhang	124252	183846	53882	59.67%	-0.92	200	35.20%	58.44%	23.38	44.25%	15.49	100.00%	20.00	0	**58.86**
		3ft Horizontal Exterior Light Shelf	122054	186044	54526	60.38%	-0.94	200	27.60%	59.60%	23.84	44.25%	15.49	78.41%	15.68	0	**55.01**
		100% Coverage (.5) Transmittance	120798	187300	54894	60.79%	-0.95	200	0.10%	60.26%	24.11	44.25%	15.49	0.28%	0.06	0	**39.65**
	Nat Vent	1 Ft Horizontal Overhang	45679	262419	76911	85.17%	0.96	2170	34.20%	99.94%	39.98	0.00%	0.00	97.16%	19.43	5	**64.41**
		3ft Horizontal Exterior Light Shelf	46737	261361	76601	84.83%	0.93	95	26.60%	99.38%	39.75	90.71%	31.75	75.57%	15.11	5	**91.61**
		100% Coverage (.5) Transmittance	47600	260498	76348	84.55%	0.9	74	0.00%	98.93%	39.57	100.00%	35.00	0.00%	0.00	5	**79.57**
	Stack	1 Ft Horizontal Overhang	46382	261716	76705	84.95%	1.08	752	41.70%	99.57%	39.83	0.00%	0.00	118.47%	23.69	5	**68.52**
		3ft Horizontal Exterior Light Shelf	46748	261350	76597	84.83%	1.05	745	34.30%	99.38%	39.75	0.00%	0.00	97.44%	19.49	5	**64.24**
		100% Coverage (.5) Transmittance	47581	260517	76353	84.56%	1.02	752	11.20%	98.94%	39.57	0.00%	0.00	31.82%	6.36	5	**50.94**
Open Plan	IECC Compliant VAV HVAC	1 Ft Horizontal Overhang	129246	178852	52419	58.05%	-0.94	200	34.30%	55.80%	22.32	44.25%	15.49	97.44%	19.49	0	**57.30**
		3ft Horizontal Exterior Light Shelf	126944	181154	53093	58.80%	-0.96	200	26.60%	57.02%	22.81	44.25%	15.49	75.57%	15.11	0	**53.41**
		100% Shade Cov	126275	181823	53289	59.01%	-0.97	200	0.00%	57.37%	22.95	44.25%	15.49	0.00%	0.00	0	**38.43**
	Nat Vent	1 Ft Horizontal Overhang	50716	257382	75434	83.54%	0.92	133	33.40%	97.28%	38.91	73.89%	25.86	94.89%	18.98	5	**88.75**
		3ft Horizontal Exterior Light Shelf	51092	257006	75324	83.42%	0.89	78.75	25.80%	97.08%	38.83	97.90%	34.26	73.30%	14.66	5	**92.76**
		100% Shade Cov	52708	255390	74851	82.89%	0.86	199	0.00%	96.23%	38.49	44.69%	15.64	0.00%	0.00	5	**59.13**
	Stack	1 Ft Horizontal Overhang	50608	257490	75466	83.57%	1.21	634	40.50%	97.34%	38.94	0.00%	0.00	115.06%	23.01	5	**66.95**
		3ft Horizontal Exterior Light Shelf	50960	257138	75363	83.46%	1.19	804	33.90%	97.15%	38.86	0.00%	0.00	96.31%	19.26	5	**63.12**
		100% Shade Cov	51838	256260	75106	83.17%	1.17	609	11.00%	96.69%	38.68	0.00%	0.00	31.25%	6.25	5	**49.93**

In review of the 27 unique packages and how they fared in performance, it is possible to begin to draw conclusions as to each of the level 2 measures' performance in relation to each other and where symbiotic relationships occurred.

Space Plans were found to have relatively little impact on any of the scoring criteria as an average across simulated bundles. While a floor plan option was selected, a switch of floor plans the floor plan layouts between the tested options, would have relatively little impact on the overall score achieved.

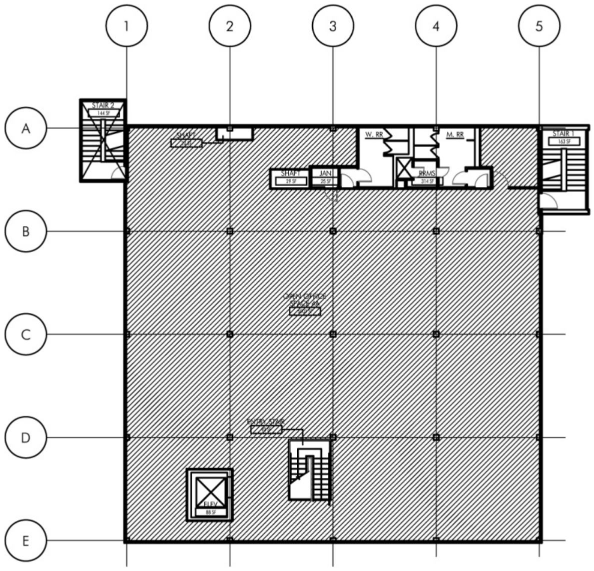
Method of providing thermal comfort had significant impacts on energy consumption and thermal comfort scoring. Cross and stack ventilation options both showed an average of 84% energy savings over the existing conditions. The IECC HVAC retrofit showed an average of 59% savings. Thermal comfort results were a large separator in the scoring. The HVAC option (simple template) had trouble with humidity control. So comfort was inconclusive and estimated at 200 discomfort hours to remain a viable option. The stack ventilation option's lobby zone became a problem due to direct beam from skylight and increased discomfort enough to disqualify it. Further development of this approach might prove to have better results if the heat gain in the chimney could be controlled to high elevations. Cross Ventilation became the clear favorite under adaptive model for thermal comfort when coupled with significant shading & ceiling fans.

When looking at exterior shading elements performance, energy consumption is relatively similar across options as average across simulated bundles (.09% of each other). This differences within this variable type occurred in thermal comfort and daylighting performance. Each of these strategies, 1Ft Overhang, 3Ft Lightshelf, and 100% Coverage option, was chosen because it has a significantly different approach. This can be seen in the comfort:daylight comparison. The 1Ft Overhang solution provides little direct beam protection, but allows a 35% average area of daylight to occur. Where it gains in daylight, it suffers in slightly in comfort. The 100% Coverage scheme performs slightly best in thermal comfort, but suffers greatly in reference to daylight averaging 5.88% area. The 3' Lightshelf is a good compromise on both with an average of 347 discomfort hours and 28% daylit area. For this reason it is by far the best option of these 3 criteria.

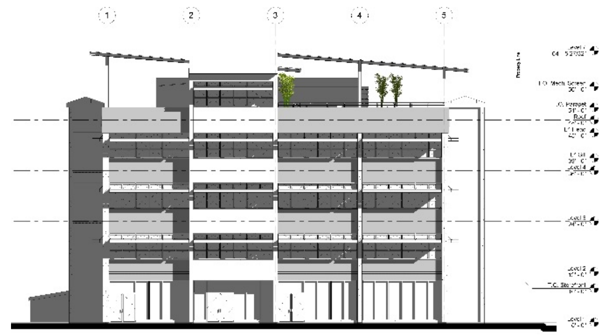
Taking all of this into consideration, the open floor plan with cross ventilation and 3Ft lightshelf bundle receives the best score.

38.83 of 40 on Energy / 34.26 of 35 on Thermal Comfort / 14.66 of 20 for Daylight / 5 of 5 for Passive Potential

Total Score of 92.76 of 100



L4 LEASE PLAN: 1 Large Tenant
R/U RATIO: 1.06



- Spatial Layout: Open Plan
- Thermal Comfort Provided Predominantly with Cross Ventilation supplemented by Ceiling Fans in the main spaces and mechanical ventilation in restrooms
- Exterior Shading: Addition of 3' Horizontal Overhang & Ligthshelf at 7’-0” Aff
- Exterior Walls - 9" Polyiso Insulation Foam added to exterior face of concrete panels. Exterior to be refinished with a cementitious coating.
- Roofing - 9" Polyiso Insulation Foam added to roof deck. Roof membrane to be replaced with a reflective finish.
- Window glazing is improved to provide Dbl LoE Serious 57/24 Arg filled glazing type. Window frames are to include a thermally broken section.
- Infiltration is updated to .2 AC/H based on the improvements to the envelope.
- Plug Loads are revised to .4W/ SF based on a best practice equipment package

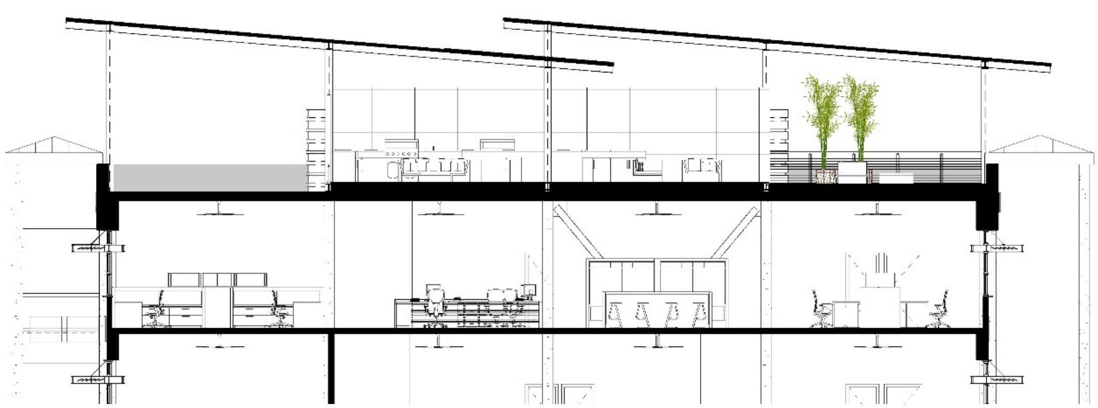


Figure 121 - Section of Technical Potential Package Applied to Building

- A new Suspended Lighting System is installed producing .018W/SF/FC (37FC target). Linear-off lighting controls couple these new fixtures. Fixtures and controls are zoned accordingly to be optimized to these levels.
- Water heater Setpoints adjusted to 90°F

7.53 kBtu/sf/Yr = 100th Percentile of HNL Buildings

(Moisture Control/Elevator Loads/Exterior Lighting are not included in this EUI)

Final Energy Savings: 83.42%

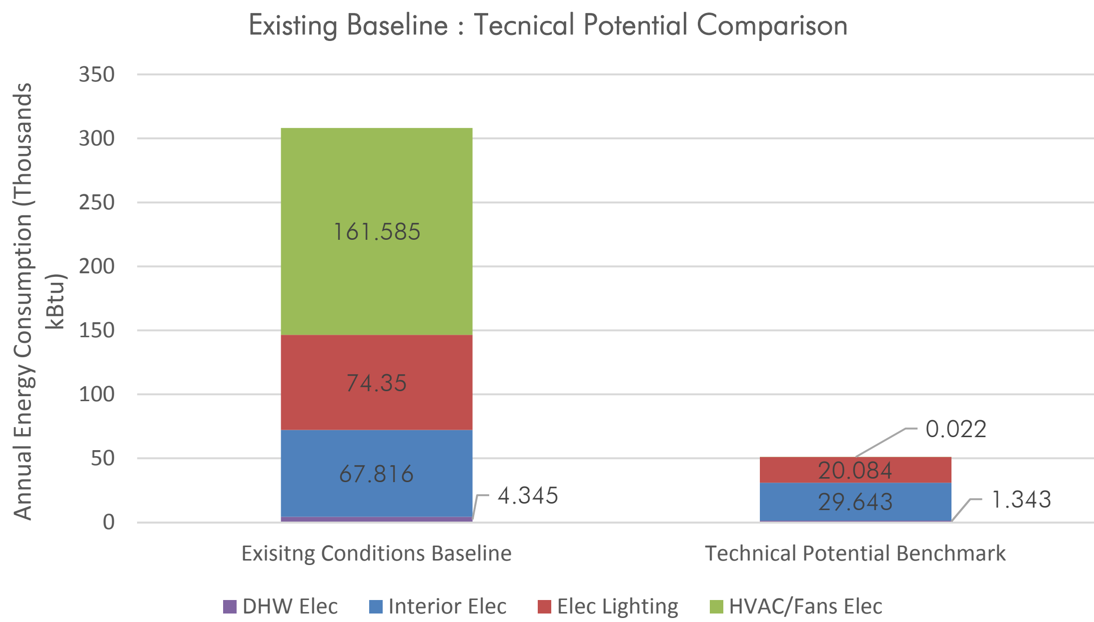
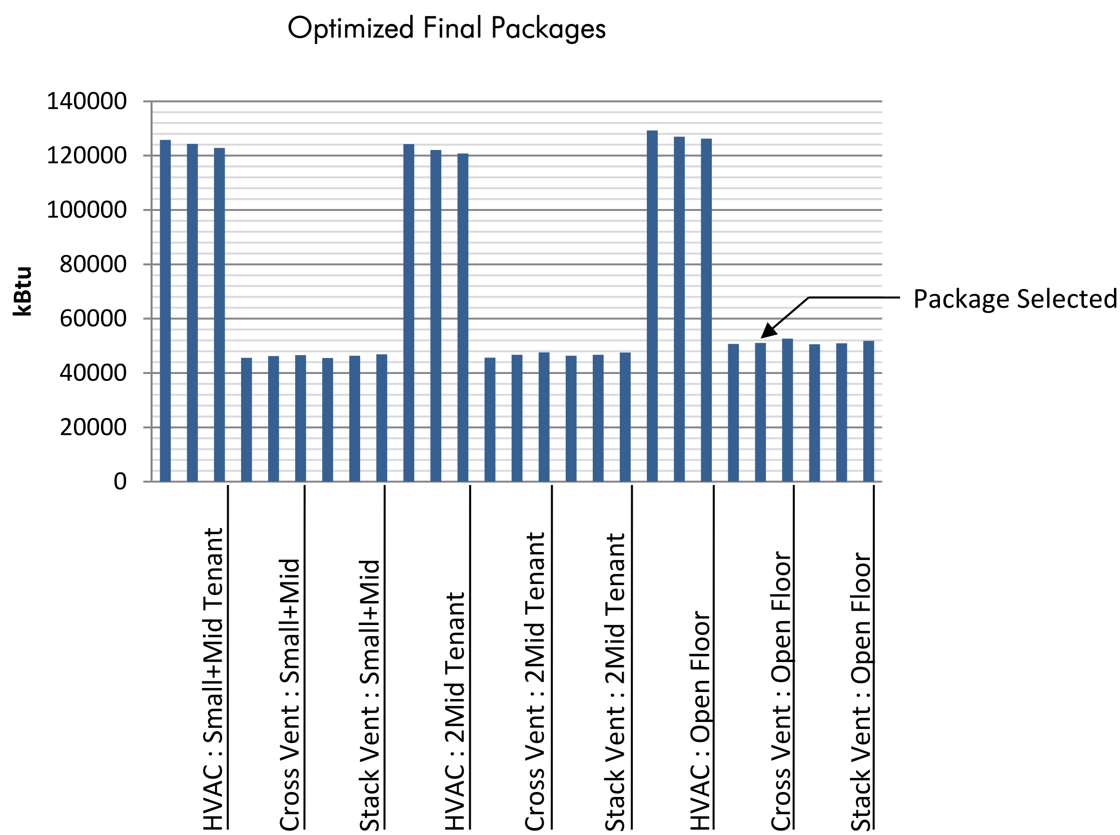


Figure 122 – Before and After Energy Consumption Comparison

Figure 123 - Results of Level 2 Bundle Analysis



Additional Benefits / Amenities

- Additional Usable Square Footage
- Occupiable Roof Deck and Events Space
- More Flexible Egress System through Continuation of the Lobby Stairwell to the 3rd, 4th Floor, & Roof
- New electrical Wiring
- Previously Recommended Structural Retrofit

Thermal Comfort Recap

Natural Ventilation schemes were tentatively weeded out until bundled with ceiling fans. The act of adding the fans had the benefit of enlarging the comfort window just enough to make them a viable outcome. As it would turn out, the calculated discomfort levels in the cross ventilation schemes turned out to be much lower than even the HVAC schemes. It is worth noting that the 100% shade option generally offered higher comfort than the 3' Lightshelf option, but the slight comfort advantage seen there was outweighed by the additional daylight seen in the lightshelf option. Additionally, comfort from fans was able to reclaim over 300 hours for comfort.

4th Floor Open Floor Plan Comfort Analysis With Natural Ventilation

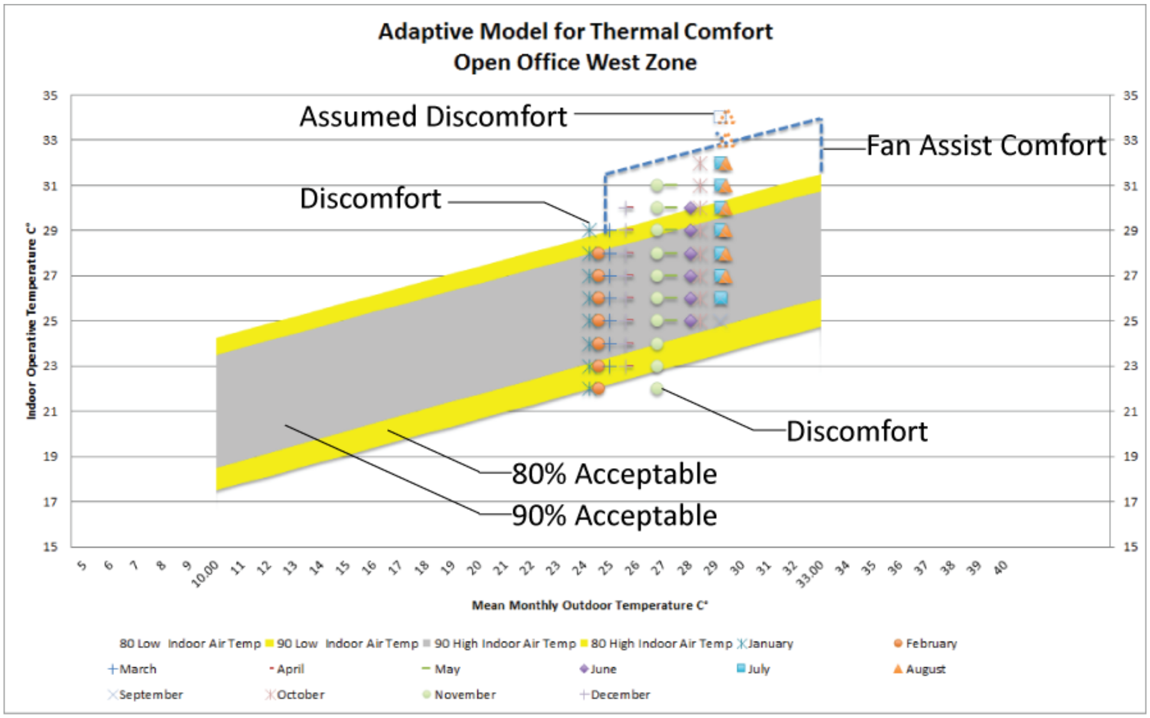
Whole Building Comfort:

Date/Time	Fanger PMV	Discomfort hrs (all clothing)
Annual		Estimate 79

	Date/Time	Fanger PMV	Discomfort hrs (all clothing)
Open Office W	Annual	1.2	51

	Date/Time	Discomfort hrs (all clothing)
Open Office NE	Annual	28

Figure 124 - Method of Estimating Discomfort by Adding Worst zones of 2 Main Orientations



Adaptive Model For Thermal Comfort
Zone By Zone Analysis

	Confirmed	Assumed % DH	Total
Discomfort Hours (80%)	15.75	34.83	50.58
Comfort from Fans	324.25	68.97	393.22

Indoor Operative Temperature

Interval Start (°C)	22	23	24	25	26	27	28	29	30	31	32	Row
Interval End (°C)	23	24	25	26	27	28	29	30	31	32	32	Total
January	21.75	55	43.5	51.25	38.75	38.25	19.75	7.75	0	0	0	276
February	10.75	25.75	48.5	48.75	37.25	34.75	33.25	0.5	0	0	0	240
March	3.5	20.25	23.75	37.75	55.5	48	48	15	0.25	0	0	252
April	0	5.75	24.25	47	58.25	50	55.75	21.25	1.75	0	0	264
May	0	0	0	11.5	26.75	44.75	75.25	72.75	39.5	5.5	0	276
June	0	0	0	0.5	15.5	49.25	62.5	78	31	3.25	0	240
July	0	0	0	0	0	13	49	55.5	81.25	63	14.25	276
August	0	0	0	0	0	10.25	38	45	52.75	69.25	48.75	264
September	0	0	0	1	6.5	20.75	46.5	61.5	67.25	26.25	22.25	252
October	0	0	0	3.25	15.75	32	47.5	57.5	62.25	38.5	19.25	276
November	2	6.5	15.75	38	38	50	47.75	26	25.25	2.75	0	252
December	2	23.5	49.5	59.75	44.5	38.75	28	15	3	0	0	264

Mean Monthly Outdoor Temp

January	22.4833	22.4833	22.4833	22.4833	22.4833	22.4833	22.4833	22.4833	22.4833	22.4833	22.4833	22.4833
February	22.8056	22.8056	22.8056	22.8056	22.8056	22.8056	22.8056	22.8056	22.8056	22.8056	22.8056	22.8056
March	23.1667	23.1667	23.1667	23.1667	23.1667	23.1667	23.1667	23.1667	23.1667	23.1667	23.1667	23.1667
April	23.7556	23.7556	23.7556	23.7556	23.7556	23.7556	23.7556	23.7556	23.7556	23.7556	23.7556	23.7556
May	25.2333	25.2333	25.2333	25.2333	25.2333	25.2333	25.2333	25.2333	25.2333	25.2333	25.2333	25.2333
June	25.8667	25.8667	25.8667	25.8667	25.8667	25.8667	25.8667	25.8667	25.8667	25.8667	25.8667	25.8667
July	26.9	26.9	26.9	26.9	26.9	26.9	26.9	26.9	26.9	26.9	26.9	26.9
August	27.0611	27.0611	27.0611	27.0611	27.0611	27.0611	27.0611	27.0611	27.0611	27.0611	27.0611	27.0611
September	26.8722	26.8722	26.8722	26.8722	26.8722	26.8722	26.8722	26.8722	26.8722	26.8722	26.8722	26.8722
October	26.2166	26.2166	26.2166	26.2166	26.2166	26.2166	26.2166	26.2166	26.2166	26.2166	26.2166	26.2166
November	24.7611	24.7611	24.7611	24.7611	24.7611	24.7611	24.7611	24.7611	24.7611	24.7611	24.7611	24.7611
December	23.6889	23.6889	23.6889	23.6889	23.6889	23.6889	23.6889	23.6889	23.6889	23.6889	23.6889	23.6889

Figure 125 - Adaptive Model for Thermal Comfort West Zone Discomfort Calculation Breakdown

Visual Comfort Recap

The scheme selected was able to provide daylight to 25% of the floor area per the LEED V3 IEQ 8.1Credit with views to the outside environment well maintained.

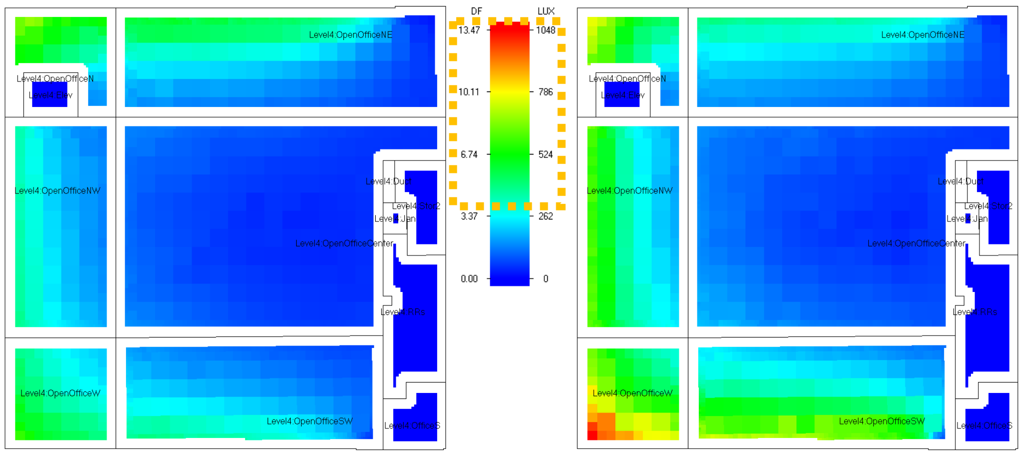


Figure 126 - 9AM Equinox of Tech Potential ***(left)***

Figure 127 - 3PM Equinox of Tech Potential ***(right)***

Adapting Strategies to the Remainder of the Building

While this study has focused on the 4th floor as a prototype, many of the energy improvements proposed will also be helpful on other office floors. Level 3 is currently almost identical to that of level 4, so it could easily be expanded to be part of the same retrofit. This floor would most likely see a very slight improvement over the 4th floor consumption projection given the fact that it would not have to deal with the heat gains from the roof that the 4th floor would. Since level 2's interior was recently renovated, its improvement could be limited to a façade retrofit similar to above. Given that the consumption levels between the 3 floor plan layouts showed only minor differences in consumption, this would have little impact on the overall performance. The ground floor retail could utilize an energy retrofit, but strategies applicable to retail are much different than office. It would require a slightly different approach therefore the findings of the 4th floor analysis would not apply to the first floor.

All in all, given the results on the 4th floor, it would be likely that the 2nd floor would be able to attain the same EUI at 7.53 kBtu/sf/Yr. With an adjustment for a 2 mid-size tenant floor plan, the 2nd floor would be able to realize an EUI of 6.89 kBtu/sf/Yr with approximately 16 more discomfort hours annually.

12

Economic Benefit

After determining the Technical Potential bundle for the project, it is necessary to begin to understand what kind of financial benefits will follow it. For the designer, understanding these benefits are imperative because they will ultimately become a set of metrics that a client is using to validate strategies pursued. For this reason, this research has focused on quantifying benefits that stem from the improvements to display an order of magnitude understanding of a viable $ Benefit/SF. Ultimately this benefit analysis would need to be compared to a $ Cost/SF but understanding the benefits allow designers to perform their own sanity check on the packages they are putting forward before cost analysis is undertaken.

Benefits are displayed in a range from cost savings stemming from energy, to revenue generators such as new amenities and increased usable square footage, to property value increases, to more qualitative benefits that are realized through the occupant's interaction and use of the improved space. All of these benefits have their own credible place within a deep energy retrofit analysis, however realizing each type of benefit will require different paths. For this reason, benefits have been separated accordingly by who will be the direct beneficiary.

In a true investment audit, this benefits quantification effort would ultimately be followed by a construction and operational cost breakdown to determine the package's worth as an undertaking. Since determining construction cost is often a significant scope of work to undertake, this research makes the point that a designer can use the benefits analysis to gage if they are one the right track; i.e. are the benefits expected in line with costs for similar projects? This question needs to be considered before sending to a full cost:benefit analysis which would be conducted by a qualified consultant.

Present Benefit Quantification

Benefits are calculated in line with an investment grade audit standard utilizing the LCCAide Tool Published by Rocky Mountain Institute and final values are presented in a "Present" value format. This means that all benefits take into account a discount rate (the rate which would be sought in any other investment undertaken by the client). Providing benefit in this format allows the metric to ultimately become more comparable with the initial costs of construction.

Values are based on the retrofit of the 3 office floors and are based on a 20 life cycle cost.

For the purposes of this research, a discount rate (also known as Internal Rate of Return or Hurdle Rate) range of 6 -10% was utilized to determine the present value range of each of these benefits. In an actual investment grade audit of an improvements package, a specific hurdle rate would be determined as a BAU profit that must be met. This rate is typically determined by the client's expectations for return on investment. In this case, it is thought to be more effective to display a range of potential benefits based on a range of potential Discount Rates.

Inflation is specified as an additional 1.5% in addition to the discount rate.

The LCCAide tool uses the DOE standard escalation rates for energy.

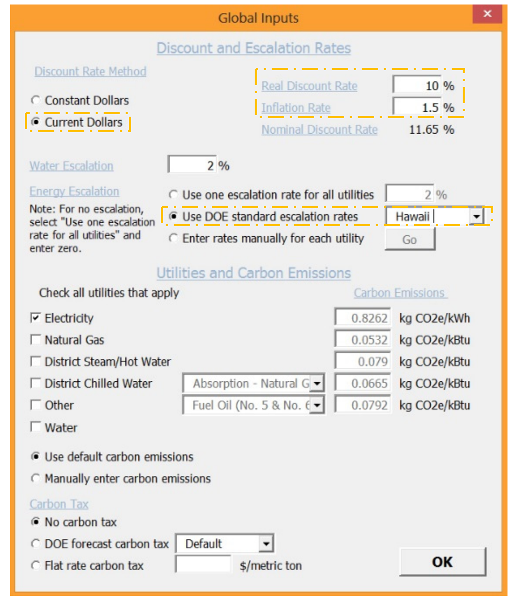
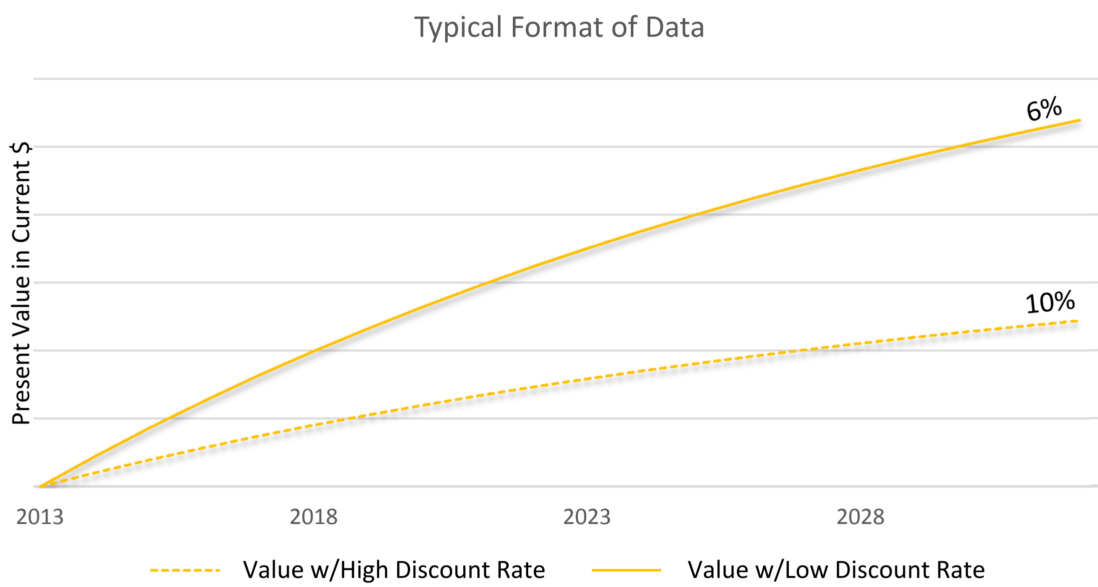


Figure 128 - LCCAide Dialogue Displaying Controlling Financial Variables



It is also necessary to mention that for the purposes of this research, the economic present benefit was not a driving factor in the selection of the final technical potential solution, but rather the package was selected based on its performance, followed by a summation of the benefits that would stem from its implementation. This approach puts emphasis on finding the most efficient package possible with today's construction techniques and technologies rather than the most economically beneficial.

What follows is a summation of the economic benefits that where found.

Direct Owner Benefit

Typically owner benefit can be defined as improvements that generate revenue or increase capital value. It does not include costs (like energy) that would typically be passed straight through to a tenant and paid as part of a Common Area Maintenance Agreement.

Property Value Increase by meeting Green Building Certification

*Value for the property was taken from county records for purposes of this exercise.[186]

[(E) Property Value] x [(+)X%]

All of the packages put forward, if pursued on a building wide level, will comply with levels needed for an Energy Star and/or LEED rating. Having an Energy Star or LEED rated building has many benefits including a proven record of property value increase. This particular value should not typically be grouped with the other owner values as it will only be realized in the event that the property is sold. Much more value can be realized by operating the property for the 20 year life span of the improvements.

Taken from the Value Beyond Cost Savings Chart in Chapter 5 (as are most benefits in this chapter), Energy Star was shown to add 5.8-26% to the property value. This value add would occur 1 year after the improvements were put in place since Energy Star Certification requires 1 year of recorded performance before certification is given. For this reason, the added value needs to be discounted for the length of construction and 1 year of operation as is seen below in the figure below. Assuming that the whole building is able to meet EnergyStar certification, as it would in a whole building renovation of this depth, a present value of $273,403 to $1,271,847 would be added to the property. Little change between a 6 & 10% discount rate is apparent due to the fact that the value is only projected 1 year into the future. LEED Certification has been shown to add between 9.9 and 25%. Improvements listed within this project would undoubtedly be enough for certification. Since Energy Star provided both the high and low benefit increase, its benefits are shown below.

[186] Department of Planning and Permitting, "Honolulu Land Information System," (Honolulu: City and County of Honolulu, 2013).

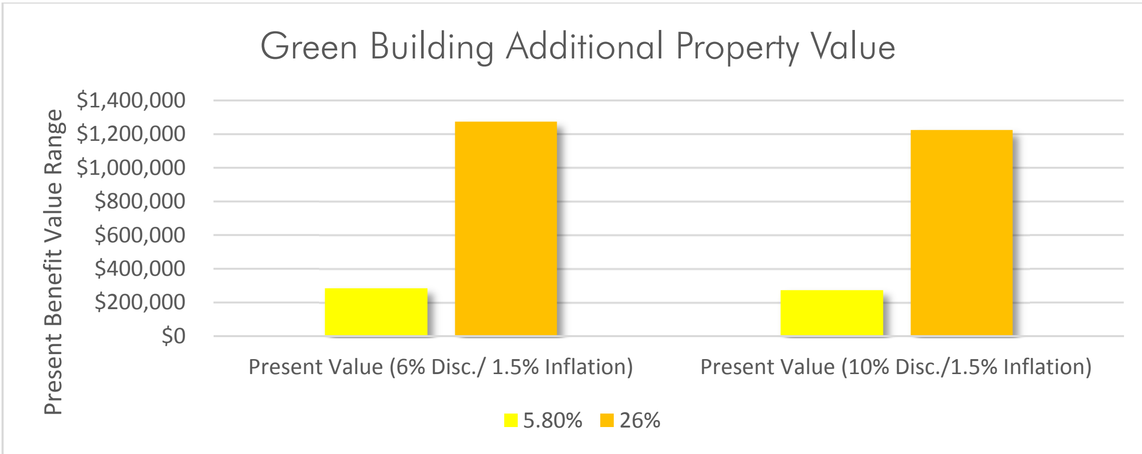


Figure 129 - Green Building Additional Property Value

Rental Rate Increase Justification

Key to the argument of an energy retrofit is its ability to inspire additional value to tenants. This results in warranted increases in rental rates. Building owners have been able to realize higher rents based on these monikers. These referenced percentage rates have been applied to this property to show its potential uptick in value.

Determination of Value:

[(E)$/SF] x [SF] x [(+)X%] x [12 Mos]

- Energy Star: Increase by 3-15.2%
- LEED Certification: Increase by 5-17.3%

	Annual Revenue Increase	Present Value (6% Disc./ 1.5% Inflation)	Present Value (10% Disc./1.5% Inflation)
Energy Star Rent Increase	$10,983.60	$111,204.00	$83,870.00
	$55,650.24		
LEED Rent Increase	$18,306.00		
	$63,338.76	$641,303.00	$483,672.00

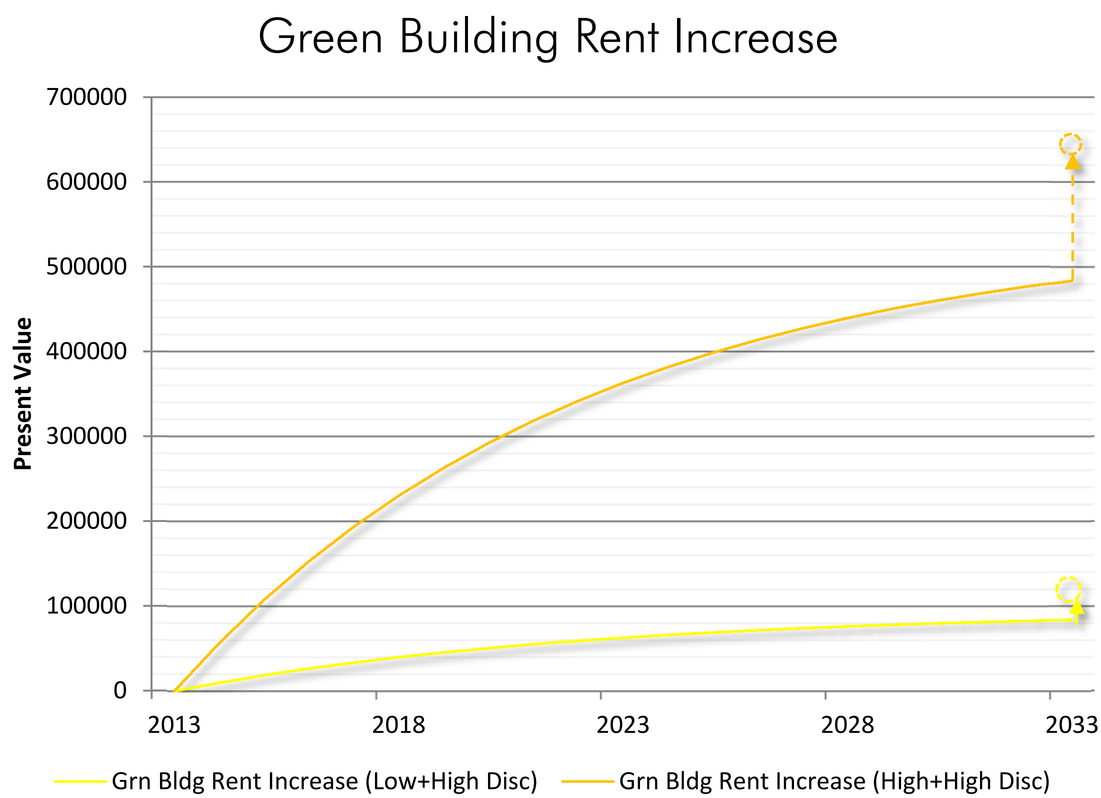


Figure 130 - Green Building's Effect on Rent Revenue

Occupancy Rates

Energy Star and LEED bring a few other notable benefits to the property. These certifications help to build a reputation as being green friendly, something that can help considerably with tenant marketing efforts as well as retention. Energy Star buildings see a 1.3-11% increase in occupancy rates. LEED buildings see 8-18% increase in occupancy. This building currently does not see a need for rate increase but if it could use the full 18%, this would translate to a present value between $36,341 and $667,253.

Usable Square Footage Increase Value

Through a reworking of the interior space on the 3rd and 4th floors, additional rentable space is realized. This, in essence, is new square footage that can be rented out for additional revenue.

Determination of Value:

[SF] x [Rate] x [12 Mos]

	Annual Revenue Increase	Present Value (6% Disc./ 1.5% Inflation)	Present Value (10% Disc./1.5% Inflation)
Usable Square Footage Increase	$53,380.80	$540,477.00	$407,629.00

Amenity Deck Value

Value for the amenity deck is estimated at the same level of revenue as the rest of the space. This additional revenue would ultimately be charged as building common space and split between all of the tenants.

Determination of Value:

[SF] x [Rate] x [12 Mos]

	Annual Revenue Increase	Present Value (6% Disc./ 1.5% Inflation)	Present Value (10% Disc./1.5% Inflation)
Roof Deck Amenity	$63,360.00	$641,526.00	$483,840.00

Tenant Value

Energy Cost Savings

Energy cost savings was the original inspiration for deep retrofit financial justification. However, as can be seen from the data below, even in a retrofit reducing energy cost by over 80% and averaging current rates of $.33 kWh, energy cost savings alone would not offer enough impetus to inspire a retrofit if based on their value alone. Additional cost savings must be sought in order to justify enough life cycle savings to pursue a Deep Energy Retrofit.

Determination of Value

[EUI] x [SF] x [$/kBtu]

	Annual Revenue Increase	Present Value (6% Disc./ 1.5% Inflation)	Present Value (10% Disc./1.5% Inflation)
Energy Cost Savings	$76,406.00	$746,935.00	$563,196.00

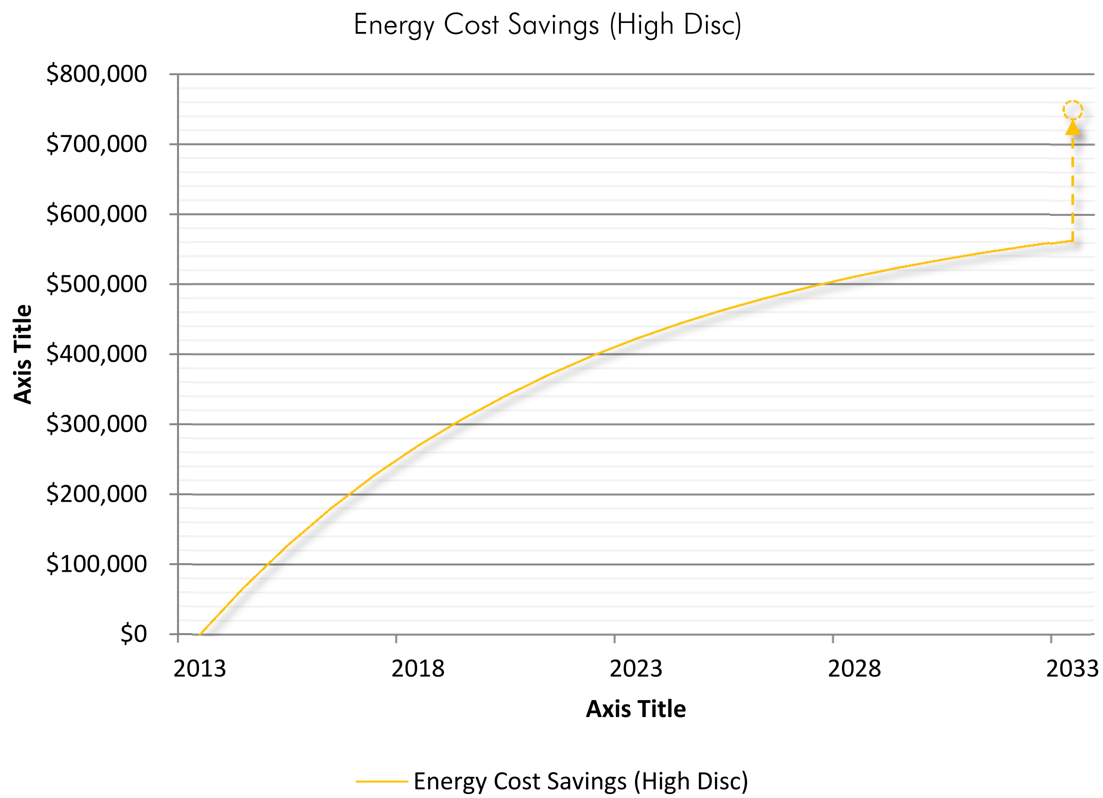


Figure 131 - Technical Potential Energy Savings NPV

Productivity Gains

The largest benefits stem from increases in productivity. This is because salary is by far the largest expense an office has. Any action that makes a staff more efficient will quickly become a large impact on the office's bottom line. This can be seen in the comparison between the few productivity adding strategies and the aforementioned values.

Determination of Value:

[(+)X%] x [Salary Rate] x [Occupant Load] x [SF]

	Annual Revenue Increase	Present Value (6% Disc./ 1.5% Inflation)	Present Value (10% Disc./1.5% Inflation)
Natural Ventilation	$817,930.39	$8,281,614.00	$6,246,012.00
	$1,510,025.33	$15,289,137.00	$11,531,102.00
High Performance Lighting	$33,556.12	$339,757.00	$256,246.00
	$2,189,536.73	$22,169,246.00	$16,720,096.00

Decrease in Absenteeism

Reduction in Absenteeism is a relatively small benefit in comparison to increase in productivity, however it represents a much more solid indicator. If people choose to come to work more often, it would follow that they are happier to be there - a great benefit for the building owner to be able to tout to potential tenants.

Determination of Value:

[(+)X%] x [Salary Rate] x [8 Ave Sick Days Annual/260 Ave Workdays] x [Occupant Load x SF]

	Annual Revenue Increase	Present Value (6% Disc./ 1.5% Inflation)	Present Value (10% Disc./1.5% Inflation)
Natural Ventilation	$183,268.03	$1,855,605.00	$139,501.00
Daylighting	$38,718.60	$392,023.00	$295,665.00

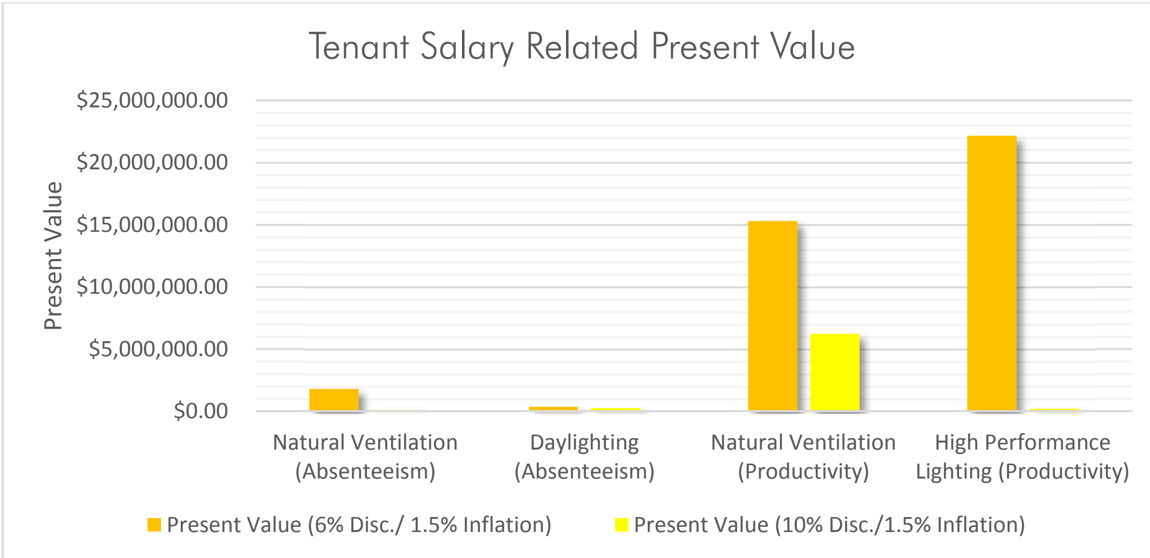


Figure 132 – Salary Related Benefits Associated with Technical Potential Package

Analysis of Total Benefit

Figure 133 - Owner / Tenant Value Break Down

Operational Total Benefit	Annual Revenue	Present Value (6% Disc./ 1.5% Inflation)	Present Value (10% Disc./ 1.5% Inflation)	$ Benefit/SF (6% Disc./ 1.5% Inflation)	$ Benefit/SF (10% Disc./ 1.5% Inflation)
Owner Total Benefit (Low)	$127,724.40	$1,293,207.00	$975,339.00	$63.58	$47.95
Owner Total Benefit (High)	$180,079.56	$1,823,306.00	$1,375,141.00	$89.64	$67.61
Tenant Total Benefit (Low)	$1,149,879.13	$11,615,934.00	$7,500,620.00	$571.09	$368.76
Tenant Total Benefit (High)	$3,997,954.68	$40,452,946.00	$29,249,560.00	$1,988.84	$1,438.03
Total Benefit (Low)	$1,277,603.53	$12,909,141.00	$8,475,959.00	$634.67	$416.71
Total Benefit (High)	$4,178,034.24	$42,276,252.00	$30,624,701.00	$2,078.48	$1,505.64

Capital Benefit	Property Value Increase				
Property Value Increase (Low)	$305,254.00	$283,720.00	$273,403.00	$13.95	$13.44
Property Value Increase (High)	$1,368,380.00	$1,271,847.00	$1,225,598.00	$62.53	$60.26

Given that all markets are different and the statistics that derive the values above are based on markets from around the nation, this study will utilize the low percentages whenever a range is present. With this in mind, it becomes clear that traditional owner benefits range from $1,293,207 to $975,339 depending on the discount rate selected. This works out to between $63 and $47 / SF of construction cost. While this would typically be a sizable budget for capital improvements, it clearly falls short of a Deep Retrofit that would be associated with the Technical Potential package posed. Given that Hawaii typically has some of the highest construction costs in the country, more value must be derived in order to make the package viable.

When tenant value is added in, value per SF ranges from $634 to $416. This makes for a much more viable budget to realize such an extensive bundle of improvements. It should allow for plenty of profit after some time.

Benefit Type and Path to Realization

Primary to understanding energy and green building benefits is an acknowledgment of who will reap the reward of the improvements made. By stepping back from the viewpoint of energy performance metrics and looking at the situation in the same manner a developer or building owner might, interesting industry barriers emerge which begin to show why higher levels of efficiency are typically not pursued.

Typically Developers and Property Owners have had a hard time justifying energy improvements financially. This is caused by the overwhelming benefit being realized by the tenant and not the developer or building owner. Currently perceived value at point of sale or point of lease is typically much lower than is actually realized by the tenant rent rates. Therefore ownership is much more hesitant to invest in these types of improvements because they feel they may not be able to recoup.

Up until recently, there has not been any examples of improvements such as these being marketable to tenants. However, this is changing. With the birth of green building certifications like LEED and Energy Star, market analysis is able to track increases in capital value and rent rates based on obtaining these monikers. More helpful though are studies that are beginning to emerge showing rises in staff output based on the incorporation of specific strategies. These help to show measures that have significant impact and minor impact.

What studies are finding is that rises in productivity far outweigh total owner benefits and energy cost savings. This can easily be seen in the benefits above where tenant benefits range from around 7 to 20 times more beneficial. Nationally, this trend is so much the case that productivity is quickly becoming the focus of the green retrofit discussion. Current owner benefit often leaves the bulk of the potential value on the table and thus hinders our overall carbon potential. We need to continue to work toward recognizing these unrecognized costs. Awareness is first, and benefit studies such as these help to spread the word and ensure that ownership is reviewing their potential for increased revenue.

13

Conclusions

Concluding results of this research display an aggressive attempt to reduce energy consumption. Careful consideration is taken to ensure that high standards for thermal and visual comfort are maintained. However the resulting package asks for a level of participation from occupants in order to achieve this comfort. This path is pursued for one reason – to understand best practice energy systems at a building level. Once this solution is known and agreed upon, it will become easier to attain and much larger progress at a city and regional scale can be pursued.

Focused on the incremental, as well as the iterative, the research provided serves as a tool to find best practice energy systems for an office in a subtopic climate. Integral to this solution was discovering the relationships that make highly efficient building solutions a possibility. By beginning with the testing of each individual measure's impact independently in the context of the existing structure, strategies were either found to be beneficial in this context and included in a base improvements package, discarded, or found to be incompatible with the with existing conditions and saved for another round. Once the base package was established, additional results and insight were obtained by revisiting some of the less successful strategies from the first round and grouping them into unique packages to find successful energy synergies.

Within the framework above, it was important to find a place to interject some of the synergistic benefits that come along with a Deep Energy Retrofit. Where items are repaired and/or replaced, great care should be taken to realize the maximum viable benefit – energy or otherwise – associated with the strategies. In this particular case, code compliance egress and structural upgrades are all able to be accomplished by piggy backing on energy improvements already being made. Coupled with the system's improvements, are spatial layout upgrades to increase rentable area and quality of space. Amenities like the occupiable roof deck / event space, and additional connection to the outdoors through increased views and operable windows elevate the office class rating. And finally, the retrofit of the space allows the building to rebrand itself as a contemporary, flexible, and collaborative environment, enforcing community, and allowing tenants to live out their professional lives.

Miscellaneous benefits of the package are tabulated at $47/SF for owner & $368/SF for tenant. Quantification of these benefits is undertaken as a means to justify the market value benefit of the deep retrofit process and will ultimately begin to offset the construction cost of the project. The benefits listed could also be coupled with any other means not mentioned to become part of a viable outcome. As a part of a technical potential exercise, this project did not seek to be the most economically viable package possible, but rather, the most efficient possible within acceptable comfort thresholds. In the event this project was realized, the technical potential package would ultimately need to evolve to an implementable minimum to become completely viable in current market conditions.

Comparison of Milestone Packages

Important to the discussion of a Deep Energy Retrofit is the concept of relative energy use. We are currently in a state of flux when considering allowable limits of energy consumption. What is acceptable by today's standards will undoubtedly be both unattractive and non-compliant as society shifts mindsets and regulatory codes to more efficient levels. We will need to understand the differences between standards as we continue to move to higher and higher levels of efficiency.

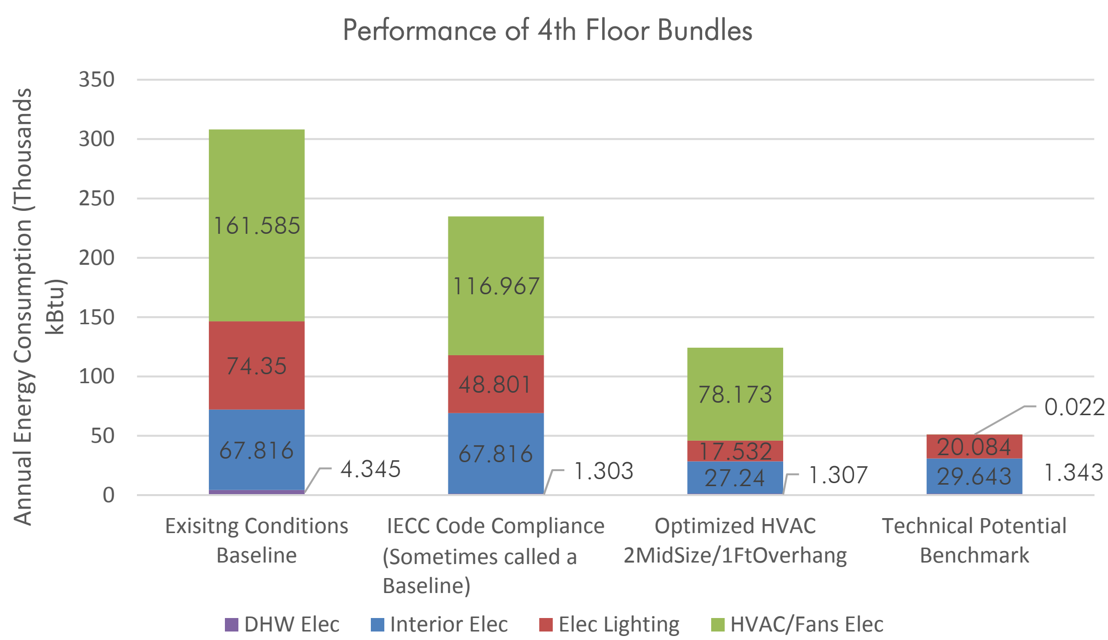


Figure 134 - Energy Consumption Comparison of Milestone Bundles

The difference stemming from use of Benchmarks, Baselines, and Generalized Targets in a design process can wield very different end results when setting energy goals. It's important to understand the difference between these terms when setting goals for a project. It's also important to understand what's physically possible to accomplish before setting goals based on financial and other constraints - even if the answer ends up being that what's physically possible is not accomplishable. Understanding the lowest energy use possible is an important step that allows the design team to keep a frame of reference to the end result.

This research was able to find that significant energy improvements are possible even when the existing baseline consumption is seen as mildly efficient in comparison to other properties. In reflecting on this project, the existing 4th floor power consumption was considered relatively low at the outset of the project. This consumption level (for the 4th floor) seems to be at or around the 80th percentile of Honolulu office. However recent migrations in energy code requirements toward higher levels of efficiency mean that it would not comply with today's compliance standard. Furthermore, given that code compliance is the worst performance allowed to be built, the study was able to show that much lower consumption levels are possible - weather a natural ventilation solution is pursued or not. 48% less energy use was seen in the best performing HVAC case while a 78% reduction was seen in the technical potential solution. This is taking into account maintaining high levels of comfort and significant project specific constraints like a bad solar orientation and significantly large window to wall ratios. All of this shows that retrofits for energy efficiency can be a significant source of power reduction if pursued in the right manner.

Another consideration are these package's relation to a Net Zero energy solution. In this project's case, the building's rooftop had already been retrofitted with a PV system covering roughly 75% of the roof area. Maintaining this array and applying the bulk of the 4th floor improvements to the 2nd and 3rd floors (also office), the building would be on track to achieve a Net Zero Energy rating. Together with a 56% reduction to the ground floor retail space, the building would become Net Zero without needing to use any more of the roof area for PV.

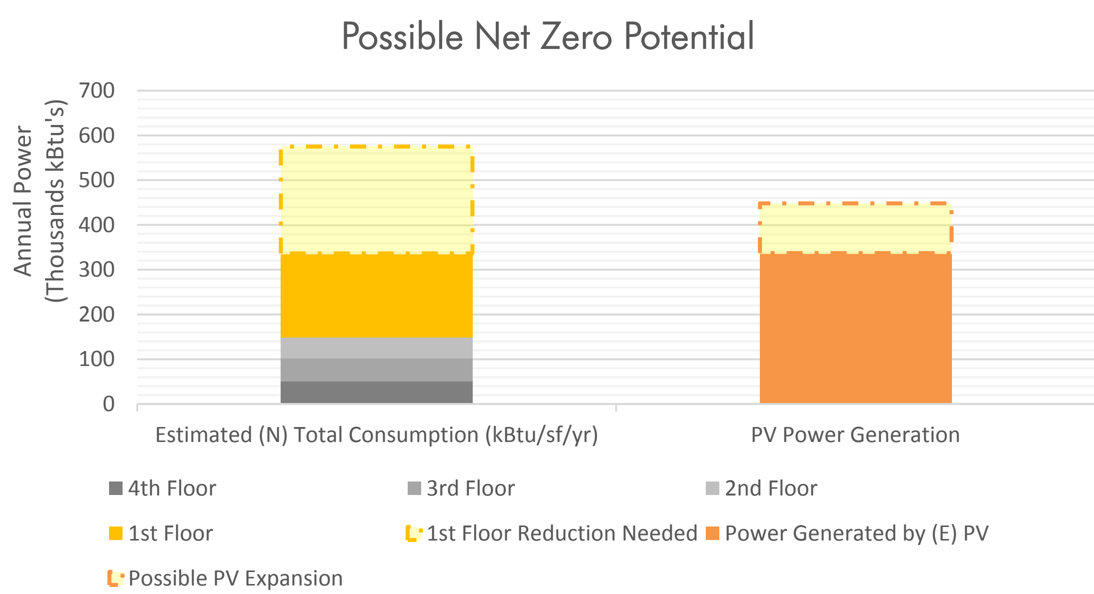


Figure 135 - Net Zero Consumption Possibilities

Technical Potential Package

The resulting technical potential package is able to show savings of 83% over the existing energy use and move the property to the 100th percentile of Honolulu's Building Stock. To accomplish this reduction in consumption, the following package of measures is proposed:

- Spatial Layout: Open Plan
- Thermal Comfort Provided Predominantly with Cross Ventilation supplemented by Ceiling Fans in the main spaces and mechanical ventilation in restrooms
- Exterior Shading: Addition of 3' Horizontal Overhang & Ligthshelf at 7'-0" Aff
- Exterior Walls - 9" Polyiso Insulation Foam added to exterior face of concrete panels. Exterior to be refinished with a cementitious coating.
- Roofing - 9" Polyiso Insulation Foam added to roof deck. Roof membrane to be replaced with a reflective finish.
- Window glazing is improved to provide Dbl LoE Serious 57/24 Arg filled glazing type. Window frames are to include a thermally broken section.
- Infiltration is updated to .2 AC/H based on the improvements to the envelope.
- Plug Loads are revised to .4W/ SF based on a best practice equipment package
- A new Suspended Lighting System is installed producing .018W/SF/FC (37FC target). Linear-off lighting controls couple these new fixtures. Fixtures and controls are zoned accordingly to be optimized to these levels.
- Water heater Setpoints adjusted to 90°F

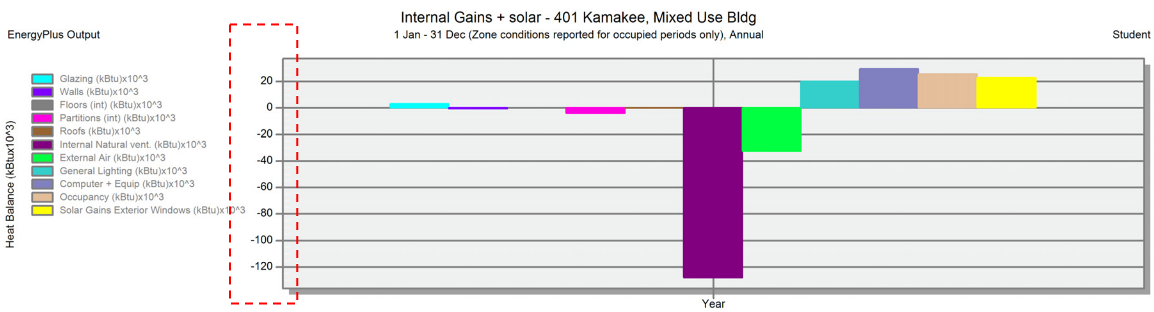
Furthermore the package proposed offers the perfect opportunity to incorporate much needed capital improvements, modernization of the office, and additional amenities. Such Improvements include:

- Additional Usable Square Footage
- Occupiable Roof Deck and Events Space
- More Flexible Egress System through Continuation of the Lobby Stairwell to the 3rd, 4th Floor, & Roof
- New electrical Wiring
- Previously Recommended Structural Retrofit

The proposed package offers significant advantages on environmental, economic, and social levels. By focusing on a best practice energy solution, we are at once able to minimize, even closely negate the building's carbon footprint. This, if it became the popular response to retrofit, would eventually make a zero carbon future possible for the Hawaiian Island's office building stock. The act is economically responsible, both in its cost saving and value increases, but also in the resilience and independence that follows its implementation – reducing the client's responsibility to subscribe to an energy system that will constantly tax all efforts for other types of progress. Finally, the act is socially responsible because in the process of weaning itself off carbon based energy, it is also improving existing interior environments for tenants and visitors alike to enjoy. By focusing on improving an energy situation, much, much more is accomplished in the process.

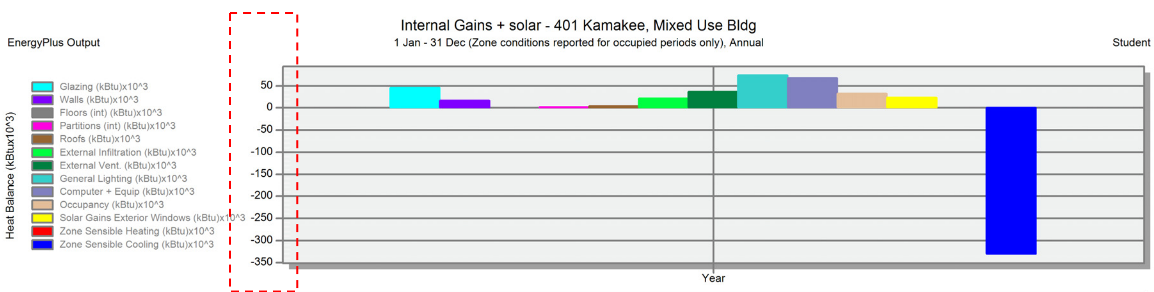
This technical potential consumption reflects the addition of a multitude of optimized systems working together to at once minimize the solar and internal loading of the interior while maximizing the efficiency of the remaining electrical load offsets. As is seen in the following solar and internal loading charts, loading from existing levels to the technical potential solution is reduced in every major area to a point where the largest energy load (cooling) can be accomplished in a much more efficient manner (elevated natural external ventilation). This results in an environment with an extremely low EUI.

Figure 136 - Technical Potential Facade and Internal Gains



Glazing (kBtu)x10^3	2.98
Walls (kBtu)x10^3	-0.58
Floors (int) (kBtu)x10^3	0.03
Partitions (int) (kBtu)x10^3	-4.05
Roofs (kBtu)x10^3	-0.22
Internal Natural vent. (kBtu)x10^3	-128.22
External Air (kBtu)x10^3	-32.46
General Lighting (kBtu)x10^3	20.08
Computer + Equip (kBtu)x10^3	29.64
Occupancy (kBtu)x10^3	25.72
Solar Gains Exterior Windows (kBtu)x10^3	22.78

Figure 137 - Existing Facade and Internal Gains



Glazing (kBtu)x10^3	45.65
Walls (kBtu)x10^3	16.55
Floors (int) (kBtu)x10^3	0.01
Partitions (int) (kBtu)x10^3	1.61
Roofs (kBtu)x10^3	3.31
External Infiltration (kBtu)x10^3	21.65
External Vent. (kBtu)x10^3	36.83
General Lighting (kBtu)x10^3	74.35
Computer + Equip (kBtu)x10^3	67.82
Occupancy (kBtu)x10^3	33.02
Solar Gains Exterior Windows (kBtu)x10^3	23.99
Zone Sensible Heating (kBtu)x10^3	0.00
Zone Sensible Cooling (kBtu)x10^3	-330.71

Promising Strategies

Lighting levels in the existing condition, a surface mounted fluorescent layout with motion sensors in common areas and direct switch controls in offices, were considered relatively efficient. However, with an upgrade to a suspended up down fixture type with photo sensor controls, over 23% of total energy consumption is saved over the existing conditions through direct savings to electric lighting and reductions in HVAC loading. This revised lighting power level of .018 w/sf/fc can reach energy levels saving 42% of lighting power over current IECC standards.

Plug loads are another often overlooked source of energy savings. Over time this type of loading is proving to have an increasing effect on overall energy consumption, due to an ever increasing pool of electrical devices. .4 W/sf for open office have been shown to be an effective level when best practice equipment is utilized. Since existing loads were estimated at 3x this level, the original energy consumption was able to be reduced over 19% simply from this one revision. These savings stem from direct plug load reductions and reductions in required cooling load to the HVAC.

The replacement of windows to a Serious double pane low-e window assembly w/suspended film between panes was able to save 1/8th of the overall energy as a stand-alone improvement. It did this while significantly improving daylighting to the space. With the lightshelf and open floor plan, the resulting package was able to bring natural daylighting to over 25% of the floor area by LEED standards – a significant improvement upon the existing conditions.

Perhaps the biggest success of this project is the fact that summing up all of the load reductions in the envelope and interior make it possible to pursue a natural ventilation strategy for 100% of the operating hours. As mentioned early on, air conditioning in the typical Honolulu office space takes up 43% of the total energy use. As determined in this building's calibrated model, the measure pursuing cross ventilation was able to finally negate the HVAC load (with the exception of ceiling fans), originally estimated at 53% of the total consumption.

The adaptive model for thermal comfort is important to this strategy because it is able to effectively enlarge the occupant's comfort window. This enlarging is in direct response to occupants receiving more control over their environment by allowing them to operate windows and monitor ventilation rates and indoor temperatures. By allowing this level of control and acknowledging the fact that occupants have some local control of their comfort (how they dress, if they have fans on, etc.), a more varied comfort window is realized. This broader definition of comfort allows more people to effectively control their local comfort as opposed to the heat balance method which dictates that all people in all climates are comfortable in the same conditions: a notion that has been proven erroneous time and time again.

The addition of ceiling fans to the natural ventilation scheme was integral in achieving an acceptable thermal comfort level. By using the standard proposed by DeDear[187] to expand the Adaptive Model for Thermal Comfort window, over 390 potential discomfort hours were moved to comfort in the solution's worst performing zone. Ceiling fans were the final improvement needed to ensure that the cross ventilation schemes shifted from unacceptable options to the some of the best performing schemes in regards to thermal comfort.

Remaining Challenges and Steps Forward

Undoubtedly, meeting the energy level proposed would be a challenge to bring to fruition while maintaining thermal and visual comfort. The following is a summation of the challenges remaining and how they might be remedied in future efforts.

Noted Challenges in Annual Simulation

Specific to this project, active HVAC solutions were particularly problematic in estimating discomfort. This stems from the utilization of a "Simple" HVAC template within the DesignBuilder simulations. Utilization of this this approach to HVAC simulation was able to achieve relatively reliable energy consumption estimates, but unable to provide the necessary humidity control that is needed in a humid climate such as Honolulu's. Results from analysis showed constantly low PMV ratings (a function of being too cool) and high humidity levels.

Attempts to move to a "Detailed" or "Compact" energy template proved to be too technical for an architect in training. Thermal comfort results from the Level 2 HVAC packages were ultimately estimated to be an acceptable level of 200 discomfort hours given the lack of control included in the software program's simple template and the general understanding that much higher levels of comfort (per the heat balance standard) are able to be achieved with the IECC compliant system specified. While this was a notable shortcoming of the study, the addition of humidity control to the package would not have increased the package's score enough to make up the difference between it and the chosen technical potential package. In any case, much the same as an integrated design process promotes, future efforts would need to involve an engineering team early on in the design process to ensure accuracy of results.

Process

The proposed 2 level simulation scheme is a viable approach to determining the most effective bundle of measures. Moving through preliminary measures in the first level of testing allows one to begin to grasp the magnitude of effectiveness for each given strategy. It also lets one begin to reflect on strategies that are universally beneficial improvements and ones that look to be dependent on other strategies. Through this train of thought the method of determining final thermal comfort, exterior window shading, and interior space layout variables were identified as dependent upon other measures for optimization. By isolating the

[187] Richard de Dear, "Adaptive Thermal Comfort: Background, Simulations, Future Directions" (Las Vegas, 2011).

"universally beneficial" strategies and applying them to unique packages of the dependent approaches, the most efficient instance is determined.

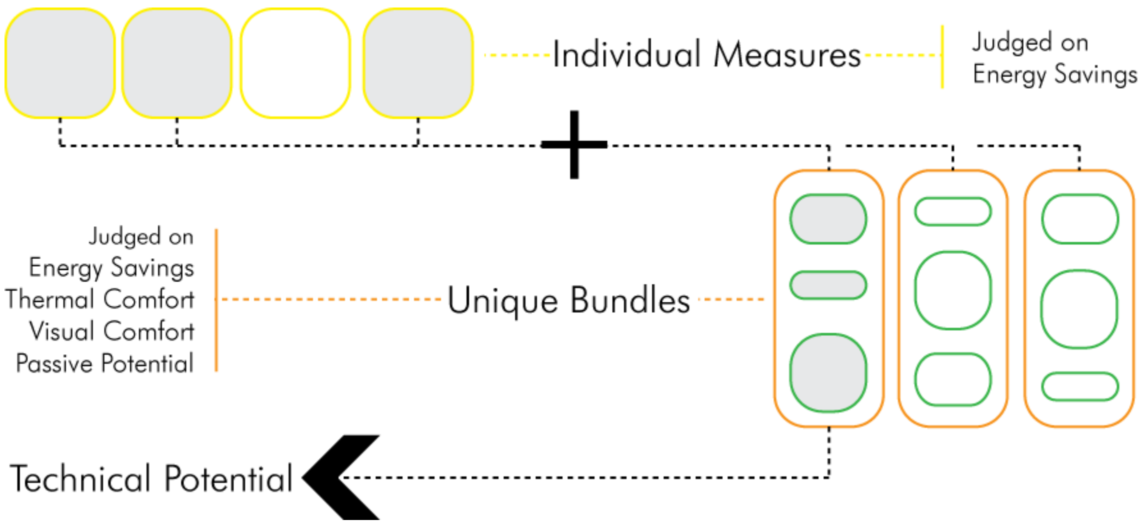


Figure 138 - Simulation Framework

The above process is one of the strengths of this research's findings. However, there is much progress that can be made in the speed in which the optimized package is found. This process involved managing some 60+ energy model files to come to the solution, each taking significant time to set up and simulate. Although the tool is in its preliminary beta test stages, DesignBuilder's optimization tool is one possible solution to this limiting time constraint. The tool allows the user to set parametric variables to be tested. Once fully developed, it has the potential to allow the user to set up multiple variables, like variable glazing, insulation, and even more complex strategies like method of thermal comfort, and shading systems and run all of the tests in one model to more effectively determine an optimized solution. This tool has the potential to significantly improve the workflow of the simulation process.

Another concern lies in the 80' depth of the building in both directions. This creates a situation that is typically considered less than optimal for cross ventilation. Due to time constraints, the selected solution was unable to be tested with respect to a detailed CFD analysis. The final package was tested on an annual level looking at overall air changes and discomfort hours. What is not understood is how airflow will move through the space consistently. Ensuring an acceptable level of air change to all spaces in a 100% naturally ventilated scheme involves analyzing the interior space in detail for air circulation. This analysis, more than likely would identify space and time where supplemental mechanical ventilation backup is necessary to maintain acceptable levels of circulation. Due to the fact that ceiling fans are planned for the space, circulation of air is relatively ensured but further analysis would be able to show if the necessary air changes are being achieved throughout the space. Ultimately, if this was the chosen package for final implementation, it would need to be understood under specific wind conditions and would involve a detailed interior CFD analysis.

Design and Technical Advancement

Some of the most challenging aspects of the proposed solution involve how to handle humidity and moisture mitigation. Natural Ventilation will provide a new set of concerns for consideration. Since it is open to the elements, a high humidity climate will require some need to control moisture buildup in an efficient but responsible way. If left unchecked, the building could become a haven for mold.

Figure 139 - Technical Potential Monthly Average Relative Humidity

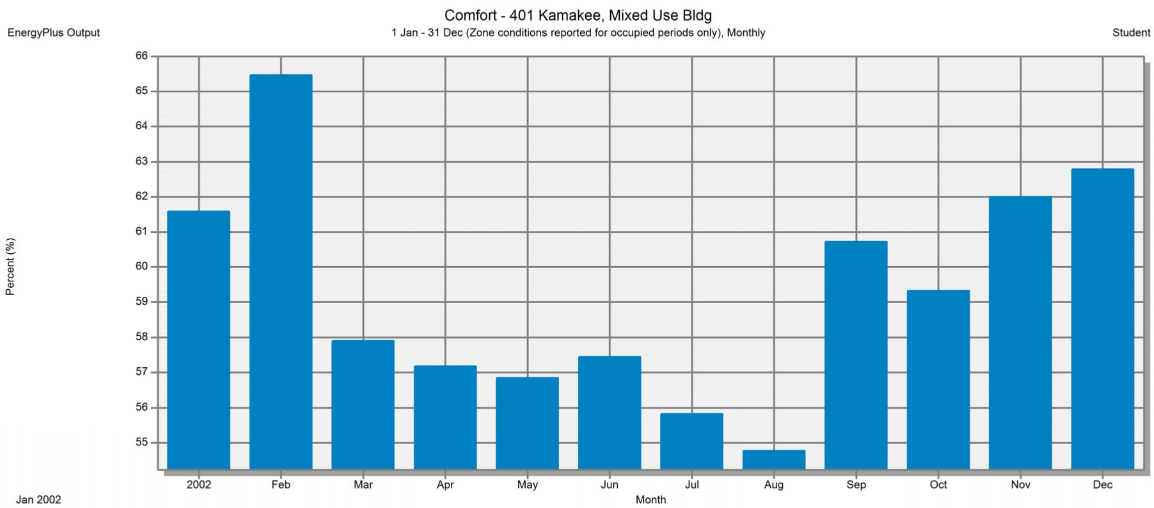
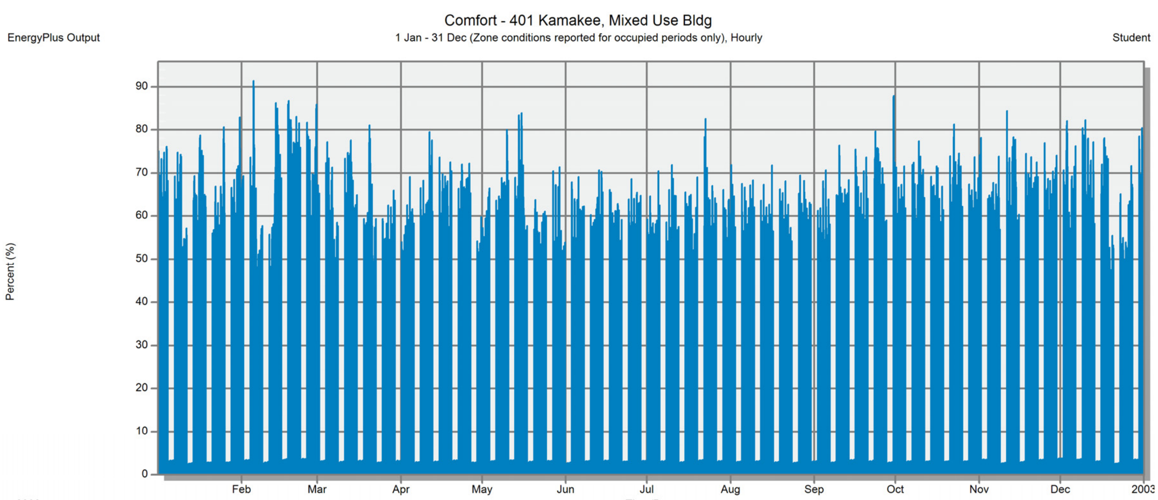


Figure 140 - Technical Potential Annual Hourly Relative Humidity



Average monthly humidity levels for the space seem to be acceptable for some of the year. Closer look at the hourly levels, shows that levels vary greatly in daily and even hourly levels. These are unacceptable by typical standards for much of the year. Relative humidity is shown in the figures above and they help to understand, but fluxuations of this type can be a good indicator of a high likelihood for condensation, which depends on surface dew point temperatures being hit. It is true that the proposed Adaptive Model for Thermal Comfort does not require tracking of humidity to maintain thermal comfort. But realization of this scheme would require some mitigation of moisture to remedy health concerns that follow high levels being allowed to constantly build up. Such a system would typically aim to interrupt the mold cycle which requires a 72 hour window to begin to take hold.

The current package does not attempt to propose a system to mitigate the mold growth cycle. Systems put in place strictly for dehumidification purposes would require the assistance of engineering team to design a solution to meet the needs of the building. This system would be an additional unknown energy load and is not accounted for in the proposed technical potential package.

Market Understanding and Acceptance

The solution proposed is only accomplishable with significant investment in the property. Reducing loads enough to realize a natural ventilation scheme involves a renovation of the envelope as well as interior equipment; all of which traditionally add significant heat to the interior and would then need to be cooled. Reaching the level of passive and active heat mitigation discussed will require a level of trust in both the designers to realize the proposal and the ability of the owners themselves to recoup these significant cost investments. Both would need to be accomplished in order to become a popular solution for the islands.

The benefits portion of this research was able to identify significant financial savings and revenue generating effects associated with the proposed technical potential bundle. The majority of this benefit though, is realized through the tenants and the productivity increases they are likely to see once the improvements are put into place. This creates a barrier for building owners and investors because there is currently no effective way to transfer this value from tenant to owner and developer. It creates a situation where property owners are unwilling to implement deeper improvements because there is no mechanism to ensure that the tenant benefits seen will serve to repay the owner's investment. For the technical potential package proposed to become a reality, either the building owner needs to be the tenant, or tenants will need to pay a premium based on the types of productivity increases that stem from improvements.

Historically this has been the owner's excuse for not investing in efficient technologies, but this is not the case anymore. We are evolving to a much more aware culture. Subsets of business owners (tenants) are beginning to recognize the benefits of an energy efficient work place. As such there is more and more demand for this type of product and therefore a rental premium.

Green leasing offers one such approach to achieving higher performance buildings. In this type of owner/tenant relationship, each party enters with the understanding that they are achieving a higher level of environmental stewardship as well as indoor environment. This type of lease will outline conditions that must be maintained including indoor environmental conditions, energy consumption, and a litany of other possibilities. Leases of this type typically involve a higher level of owner tenant coordination and understanding, but have been met with success in their early stages.

Some adaptation will need to occur in relation to interior environmental expectations. We have come to expect the narrow comfort windows which follow the heat balance method in the last half century. It has gotten to the point that heat balance is the industry standard and many are closed minded to the idea that a natural ventilation solution is possible. These strategies have not been widely used to achieve a commercial level of comfort in near history. The technical potential solution provided would require ownership to accept a level of uncertainty while the design is built and calibrated. The experimental nature of this system would require the design team to follow through on the constructed result to determine if comfort levels are actually being experienced. This would need to be corrected as necessary to ultimately achieve the comfort sought.

Tenants would need to understand that they would be subscribing to a natural ventilation solution, something that is typically not seen in ordinary lease situations. Part of this acceptance would be some more exposure to the elements which would require them to operate windows in a responsible and active manner to achieve comfort. It would also mean they would need to dress accordingly while in the space. It should be noted however, that the majority of people actually end up preferring this method of comfort as long as planned implemented in a responsible manner.

Bundling for Economics & Implementable Minimum Package

As is explained earlier in the research, a technical potential solution is rarely a viable package for implementation. In most cases, additional steps of identifying and mitigating project specific physical constraints, working with cost/value impacts, and incorporating aesthetic and functional requirements are often needed to bring a project to fruition. These steps have not been addressed in this design process as depicted.

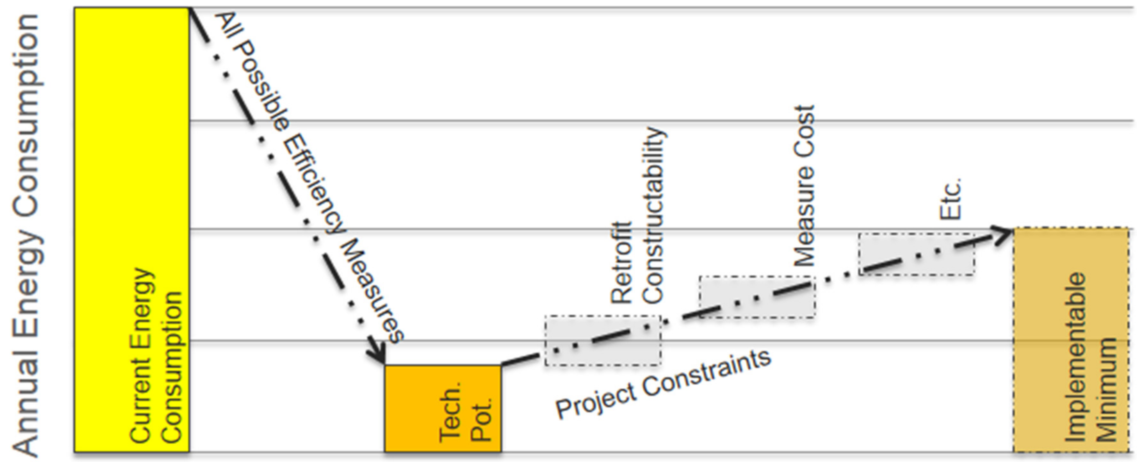


Figure 141 - Diagrammatic Process Showing Steps of a Deep Retrofit Process

Since the value portion of the economic plan has been started, steps forward would require a full construction and operational cost analysis to determine the cost:benefit ratio. Once this is understood, the team must come to an agreement of how much each benefit will actually be worth in implementation. This helps to finalize client expectations for energy related outcomes and helps the design team to come to a working budget.

With a budget to target, teams can isolate priorities and find further synergies in pursuit of the final implementable minimum. It is this time that more expensive measures not providing meaningful payback, may be dropped from the final package. Further testing is required to ensure that energy efficiencies are maintained as much as possible. Eventually, the team will reach a set of measures which is believed to be attainable and economically viable.

The figure below from Rocky Mountain Institute shows a similar analysis in which the team puts together bundles of measures. The bundle closest to the x-axis on the positive side represents the implementable minimum package.

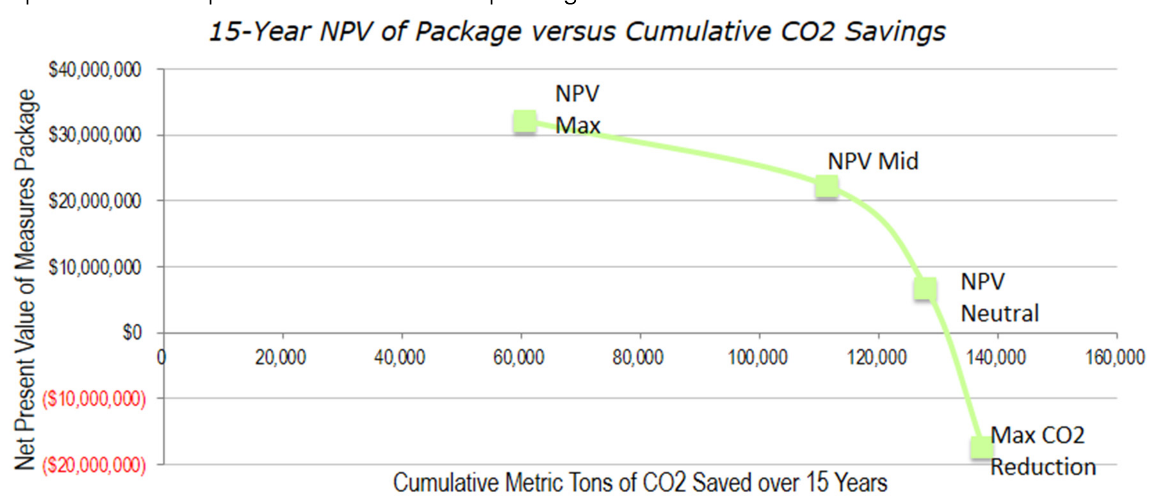


Figure 142 - Example Comparison of Net Present Value and CO2 Savings

Steps leading to the Implementable Minimum are a function of implementation cost (construction), operational cost, and timing. Grouping synergistic measures often helps to keep cost low and boost financial benefits like energy savings enough to become economically viable. "Right-Timing" the implementation of measures can help to ensure the larger existing items are allowed to realize their planned life span.

Closing Thoughts

We should look to a time when the technical potential solution is the expected outcome. It was Paul Hawken that first said that until the most sustainable solution is also the cheapest, we will not have met our goal. The strategies put forward in this study seek to find a method within the retrofit industry to do just that. Through a concerted effort to find an optimized energy consumption and a method to realize it through a true recognition of the value involved, we can make this most sustainable solution a possibility and even a reality.

By approaching a Deep Energy Retrofit with an integrated design team including an Architect, a passive first method can ensure the deepest results are achieved. Through whole building analysis, with tailored results to client needs, and simulated energy modeling, the most effective package is found and realized.

The construction industry today is primed and ready for a new type of service and product. The industry is still reeling from the effects of the previous recession. Popularization of services associated with the Deep Energy Retrofit would give a much needed boost, although it will require some alternate methodologies to become effective in delivering the results it touts. Diffusion of Innovations theory dictates that the transference of knowledge with respect to this Deep Energy Retrofit innovation will take some time to become the standard. But as time moves by, this product will undoubtedly get streamlined and become the standard of practice. Those that focus on refining approaches early have the most potential to stake claim to the benefits involved with these services.

Much the same that we were once unaware of the potential of the sustainability concept, we are now beginning to realize the potential that follows a thorough understanding of high performance energy design. This key niche of architectural design has the potential to at once stop the harmful effects of a subscription to dirty energy and make our systems more financially resilient. Together, the pursuit of energy decarbonization through technical potential efficiency and clean power generation are one of the most important steps in the adaptation to a sustainable built environment.

FAIA, Hillary Brown. "Toward Zero Carbon Buildings." In *The Post Carbon Reader: Managing the 21st Century's Sustainable Crises*, edited by Richard Heinberg and Daniel Lerch. Healdsberg: Watershed Media, 2010.

Administration, U.S. Energy Information. "2003 Commercial Buildings Energy Consumption Survey: Sample Design " U.S. Department of Energy, http://www.eia.gov/emeu/cbecs/2003sample.html.

Alsup, Frank. "Measuring Deep Retrofit Impact." Boulder, Colorado: Rocky Mountain Institute, 2012.

Amory B. Lovins and Rocky Mountain Institute. *Reinventing Fire*. White River Junction, VT: Chelsea Green Publishing, 2011.

Architecture2030. "2030 Goes Code." Architecture2030, http://architecture2030.org/hot_topics/2030-goes-code.

Architecture, Adrian Smith + Gordon Gill. *Toward Carbon Zero: The Chicago Central Area Decarbonization Plan*. Mulgrave: Images Publishing Group Pty Ltd, 2011.

ASHRAE. "Ashrae Standard 55: Thermal Environmental Comfort for Human Occupancy." Atlanta: ANSI, 2010.

Associates, Eley. "Hawaii Commercial Building Guidelines for Energy Efficiency." Honolulu: Energy, Resources & Technology Division, Dept. of Business, Economic Development and Tourism, State of Hawaii, 2004.

Bendewald, John Zhai Nicole LeClaire & Michael. "Deep Energy Retrofit of Commercial Buildings: A Key Pathway toward Low-Carbon Cities." *Future Science* (2011): 425-30.

Brager, Richard de Dear & G.S. "Developing an Adaptive Model of Thermal Comfort and Preference." *ASHRAE Transactions* Volume 104 (1), (1998): pp.145-67. Published electronically 01-01-1998. http://escholarship.org/uc/item/4qq2p9c6.

Building Programs Unit, Architectural Energy Corporation. "Rethinking Percent Savings:The Problem with Percent Savings and the New Scale for a Zero Net-Energy Future, Cs 08.17." Architectural Energy Corperation & Southern California Edison, 2009.

Capehart, Turner, and Kennedy. *Guide to Energy Management*. Sixth Edition ed. Lilburn, GA: The Fairmont Press, Inc., 2008.

"Cbecs Status." http://www.eia.gov/consumption/commercial/.

Chan, Charles. "E.E. Black Building Property Due Diligence Report." Honolulu: Architects Hawaii Limited, 1993.

Council, U. S. Green Building. *Green Building Design and Construction*. Washington DC: U. S. Green Building Council, 2009.

"Day-Lighting: Top-Lighting." In *Veridis*: Wentworth Institute of Technology.

"Daylighting: Design Strategies." Natural Frequency, 2013.

Dear, Richard de. "Adaptive Thermal Comfort: Background, Simulations, Future Directions." Las Vegas, 2011.

DeKay, G.Z. Brown & Mark. *Sun, Wind, & Light Architectural Design Strategies*. 2nd Edition ed. New York: John Wiley & Sons, Inc., 2001.

Divison, Reasearch and Economic Analysis. "Renewable Energy in Hawaii." edited by Economic Development and Tourism Department of Business. Honolulu: State of Hawaii, 2011.
Eichholtz, P., Kok, N., & Quigley, J. . "Doing Well by Doing Good? An Analysis of the Financial Performance of Green Office Buildings in the USA. ." http://www.rics.org/site/scripts/download_info.aspx?downloadID=19&fileID=5763.
FAIA, Hillary Brown. "Toward Zero Carbon Buildings." In *The Post Carbon Reader: Managing the 21st Century's Sustainable Crises*, edited by Richard Heinberg and Daniel Lerch. Healdsberg: Watershed Media, 2010.
Fuerst, F., & McAllister, P. "Green Noise or Green Value? Measuring the Effects of Environmental Certification on Office Values." American Real Estate and Urban Economics Association, http://sallan.org/pdf-docs/Fuerst_HPB_Value.pdf.
Fuerst, F., & McAllister, P. "New Evidence on the Green Building Rent and Price Premium." Henley University of Reading, http://www.immobilierdurable.eu/images/2128_uploads/Fuerst_New_paper.pdf.
G. Brager, P. Alspach, and D. H. Nall. "Natural Vs. Mechanical Ventilation and Cooling." *RSES Journal*, no. February (2011): 18-22.
Gurtekin PhD, B., Hartkopf PhD, V., & Loftness FAIA, V. "Building Investment Decision Support (Bids)." Carnegie Mellon University Center for Building Performance and Diagnostics.
Heschong Mahone Group, Inc. "Daylighting in Schools : An Investigation into the Relationship between Daylighting and Human Performance." California Energy Commission, 1999.
Heschong Mahone Group, Inc. . "Daylight and Retail Sales." California Energy Commission, 2003.
"Honolulu Office Vacancy Rate Rises to 14.9%." *Pacific Business News* (2012). Published electronically 8/25/2012.
"Indoor Air Quality Scientific Resource Bank: Impacts of Indoor Environments on Human Performance and Productivity." Lawrence Berkely National Laboratory, http://www.iaqscience.lbl.gov/performance-summary.html.
Initiative, Hawaii Clean Energy. "Hawaii Clean Energy Initiative." http://www.hawaiicleanenergyinitiative.org/.
Institute, Amory B. Lovins and Rocky Mountain. *Reinventing Fire*. White River Junction, VT: Chelsea Green Publishing, 2011.
Institute, Rocky Mountain. *High Performance by Integrative Design*. Boulder: Rocky Mountain Institute, 2010.
http://blog.rmi.org/RMIReportHighlightsOpportunitiesBuildingEnergyModeling.
Joseph W. Lstiburek, Ph.D., P.Eng., Fellow ASHRAE. "Prioritizing Green: It's the Energy Stupid." *www.buildingscience.com*, 2008.
Kats, Greg. "The Costs and Financial Benefits of Green Buildings: A Report to California's Sustainable Building Task Force." California's Sustainable Building Task Force, 2003.
KPMB. "Displacement Ventilation." Integrate Design Consortium, http://manitobahydroplace.com/Integrated-Elements/Displacement-Ventilation/.
Lechner, Norbert. *Heating, Cooling, Lighting Design Methods for Architects*. 2nd Edition ed. New York: John Wiley & Sons, Inc., 2001.
Lstiburek, Joseph W. "Prioritizing Green: It's the Energy Stupid." *Insight*, no. 007 (2008).
Miller, N. & Pogue, D. . "Do Green Buildings Make Dollars and Sense?" http://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd= 4&ved=0CEQQFjAD&url=http%3A%2F%2F**Error! Hyperlink reference not valid.**.
Miller, N.; Spivey, J.; & Florance, A. "Does Green Pay Off?" Costar, http://www.costar.com/josre/pdfs/CoStar-JOSRE-Green-Study.pdf.

Paul Raftery, Marcus Keane, and Andrea Costa. "Calibration of a Detailed Simulation Model to Energy Monitoring System Data: A Methodology and Case Study." In *Building Simulation 2009*. Glasgow, Scotland, 2009.

Permitting, Department of Planning and. "Honolulu Land Information System." Honolulu: City and County of Honolulu, 2013.

Pivo, G.; Fisher, J. "Income, Value and Returns in Socially Responsible Office Properties." University of Arizona, http://www.u.arizona.edu/~gpivo/Pivo_Fisher_Investment%20Returns%20from%20RPI%203_3_09.pdf.

Reinhart, Diego Ibarra and Christoph. "Getting Started." In *Building Performance Simulation for Designers - Energy: DesignBuilder // Energy*: Harvard Graduate School of Design, 2009.

Research, Pike. "Retrofit Industry Needs Assessment Study." In *Retrofit Depot*, edited by Rocky Mountain Institute. Boulder: Pike Research, 2010.

"Retrofit Initiative: Technical Potential." edited by Rocky Mountain Institute. Boulder, 2012.

Richard de Dear, PhD. "Adaptive Thermal Comfort: Background, Simulations, Future Directions." Las Vegas, 2011.

"Rmi Report Highlights Opportunities for More Effective Building Energy Modeling." Rocky Mountain Institute,

"Royal Bank of Scotland Americas Headquarters by Roger Ferris + Partners, United States." In *Top Box Design*.

"Solar Chimney." Integrated Design Consortium, http://manitobahydroplace.com/Integrated-Elements/Solar-Chimney/.

"Timing a Deep Energy Retrofit." Rocky Mountain Institute, http://www.retrofitdepot.org/TimingDeepEnergyRetrofit_More.

Tutar, Tolga. "Validating the Impact of Plug Load Reduction on Achieving Deep Energy Retrofits." Pennsylvania State University, 2012.

"Tutorial #2: Load Schedules." Harvard Graduate Scool of Design, 2012.

"What Is the Effect of Eco-Labeling on the Office Occupancy Rates in the USA?" Henley University of Reading, http://www.rics.org/site/scripts/download_info.aspx?fileID=5749&categoryID=523.

"Why Deep Retrofits?" Rocky Mountain Institute, http://www.retrofitdepot.org/WhyDeepRetrofit.

Wiley, J., Benefield J., & Johnson, K. "Green Design and the Market for Commercial Space." *The Journal of Real Estate Finance and Economics* Vol 41, no. Number 2 (Pgs. 228-43.

Appendix A_2009 IECC Compliant Power Consumption Levels

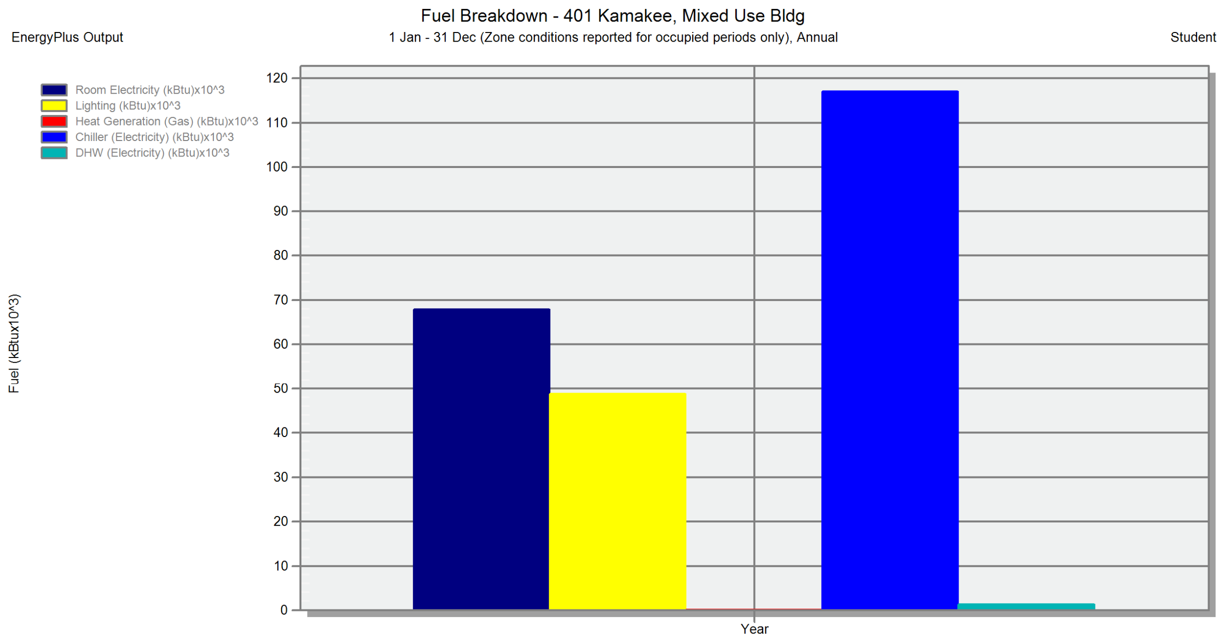
The existing calibrated model was improved to IECC compliant levels in order to come to a benchmark minimum allowable energy consumption in comparison with the final bundles. Below is a list of model adjustments based on Table 506.5.1 from the 2009 IECC. These values are current code for new construction some extensive retrofits and their resultant maximum energy consumption would be the maximum energy consumption outcome preferred in a deep energy retrofit of this property.

Roof	Type: Insulation entirely above deck U-factor: .063 Solar Absorbance: .75 Emittance: .90
Walls, Above Grade	Type: Steel Frame Wall U-factor: .124 Solar Absorbance: .75 Emittance: .90
Floors, Above Grade	Type: Joist/Framed Floor U-factor: .282
Doors	Type: Swinging U-factor: .7
Glazing	Adjustment to 40% of Wall Area (a decrease of 15%) U-factor: 1.2 SHGC: .4 External Shading: None
Glazing Frame	U-factor: 1.2
Infiltration	.35 AC/H
Interior Lighting	1 W/SF Lighting Controls on Timer Based on Occupancy Hours
Direct Hot Water	Setpoint Adjusted to 90°F
Cooling System	Adjusted to a Variable Air Volume System with Parallel Fan-powered Boxes Cooling Type: Chilled Water Assumed but not specifically modeled with Simple HVAC Settings Utilized * CoP: 2.93 (EER of 10) Thermostats: Would be Required in Each Zone, but were Unable to be Specifically Modeled with Simple HVAC Settings Utilized

Final outcomes of the annual simulation are as follows:

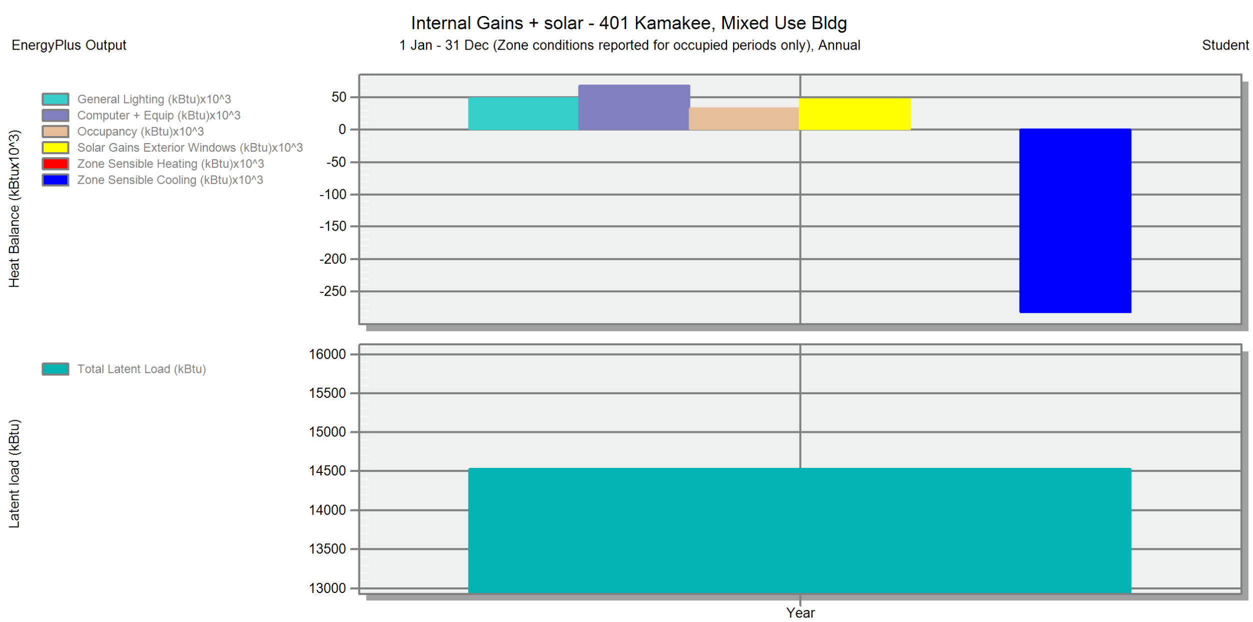
Annual Energy	234,888 kBtu
Discomfort Hours	1074 Hours

Figure 143 - Fuel Breakdown of IECC Compliant Version of 4th Floor



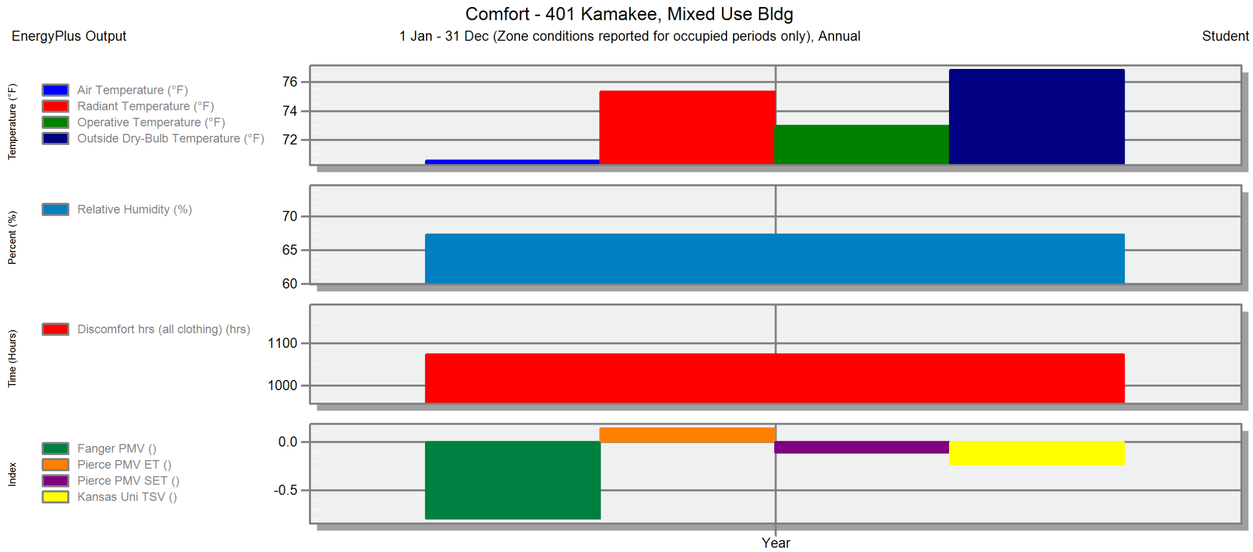
Room Electricity (kBtu)x10^3	67.82
Lighting (kBtu)x10^3	48.80
Heat Generation (Gas) (kBtu)x10^3	0.00
Chiller (Electricity) (kBtu)x10^3	116.97
DHW (Electricity) (kBtu)x10^3	1.30

Figure 144 - Internal Gains of IECC Compliant Version of 4th Floor



General Lighting (kBtu)x10^3	48.80
Computer + Equip (kBtu)x10^3	67.82
Occupancy (kBtu)x10^3	32.98
Solar Gains Exterior Windows (kBtu)x10^3	46.67
Zone Sensible Heating (kBtu)x10^3	0.00
Zone Sensible Cooling (kBtu)x10^3	-282.39
Total Latent Load (kBtu)	14531.10

Figure 145 – Comfort Summary of IECC Compliant Version of 4th Floor



Air Temperature (°F)	70.62
Radiant Temperature (°F)	75.33
Operative Temperature (°F)	72.97
Outside Dry-Bulb Temperature (°F)	76.85
Relative Humidity (%)	67.35
Discomfort hrs (all clothing) (hrs)	1074.44
Fanger PMV ()	-0.79
Pierce PMV ET ()	0.14
Pierce PMV SET ()	-0.12
Kansas Uni TSV ()	-0.24