Simulation strategies for healthcare design
To achieve comfort and optimize building energy use

Shruti Narayan
Isabelle Lavedrine
Maurya McClintock
Arup, 901 Market Street, Suite #260
San Francisco, CA 94103

ABSTRACT

The principle purpose of a building design is to provide conditions for human comfort through the optimization of solar control, daylight performance, and subsequent provision of supplemental heating, ventilating, air-conditioning and lighting systems. Medical facilities are a building sector where there is an inherent concern for occupant well-being and comfort while still being mindful of operational energy efficiency. Façade configurations are the most important interface to the external environment, and they play a significant role in setting occupant comfort levels within the space. This paper therefore focuses primarily on solar control aspects of façade system alternatives and their impact on minimizing energy use and optimizing comfort within the space. This is achieved through a proposed design process that utilizes comfort simulation alongside operational energy saving calculations to validate and refine, integrated architectural, envelope interior planning and perimeter zone supplemental mechanical and lighting systems from a holistic perspective. The paper illustrates the use of this process on four recent healthcare projects in California. It also highlights the importance of design team interaction from an early stage, in this scenario; the success of this process was due to the participation of the architect, mechanical engineer, façade consultant and the energy analyst from the schematic design stage.

INTRODUCTION

Hospitals and medical facilities as described above are one building sector where there is an inherent concern for occupant well-being and comfort while still mindful of operational energy efficiency. The design teams and clients for these projects should feel strongly that the quality of the interior spaces created and the resulting comfort of the occupants and patients that inhabit those spaces should be crucial design drivers particularly with healthcare environments.

As such, the design/analysis process for this study to achieve the above was to:

- Estimate the expected energy consumption for the proposed design.
- Use this 'baseline' energy consumption level to assess a variety of options for mechanical system components and exterior façade elements on the overall energy use of the hospital.
- Conduct a thermal comfort analysis of specific building areas to verify that the energy consumption and life-cycle cost options would create comfortable environments with regard to factors such as solar heat gain and air distribution. (while life cycle cost calculations are quantitative, with numerical results, it is equally important to understand the resultant, subjective, comfort of the building's occupants related to the same design decisions being assessed from the quantitative perspective. Occupant comfort can be addressed through qualitative analysis.)
- Add up all of the 'costs' - both financial (initial construction, long-term energy, operational, and maintenance costs) and humane (impact on environmental comfort) to establish both a life-cycle cost and life-cycle assessment (that includes both qualitative and quantitative impacts) for each option, or combination thereof.

The ultimate goal of this process was to determine the highest level of building performance achievable with the lowest possible life cycle cost, the best design for the building at an acceptable balance of first-cost, life-cycle cost and human comfort.

This paper will highlight this design process, illustrated through the use an integrated sustainable environment assessment accomplished for the Valley Specialty in Santa Clara, Valley Health Care in Fairoaks and Gilroy and Sutter Hospital in Mills Peninsula projects.

DESIGN PROCESS

The design process in addition to assessing the long term energy cost savings and related simple payback of specific ECM's (Energy Control Measures): combined external shading/ high performance glazing/daylight sensors or combined performance façade systems coupled with optimized mechanical systems, also assessed the impacts of all the ECMs on thermal comfort, visual task acuity and enhanced daylight penetration. The comfort analysis concentrates specifically on perimeter zone where a number of design challenges originate: controlling solar radiation, controlling sunlight and glare, maximizing daylight penetration and providing both thermal and visual comfort. The analysis was carried out for each perimeter zone orientation for the peak design times for the mechanical system and depicts the impact inter-related external climate and façade configurations have on solar control, thermal comfort, visual comfort and the mechanical system design and control.

A four way approach as described was adopted to study fenestration design impacts on thermal load and comfort: Solar Control, Daylighting, Thermal Comfort and Energy cost analyses were performed.

While the final energy cost analysis was performed for the resulting total building energy use, initially the solar control, daylighting, and comfort analysis concentrated specifically on the perimeter zone where a number of design challenges originate; controlling sun light penetration and solar gain, maximizing daylight penetration yet controlling glare, and providing both thermal and visual comfort. The initial analyses were carried out for each perimeter zone orientation for the peak design times for the mechanical system (corresponding to the time of maximum combined internal loads and external heat gains) in addition to these times daylighting was also assessed for times of low angle sun penetration for each orientation. These analyses depict the impact the inter-related external climate and façade configurations have on solar control, thermal comfort, visual comfort and the mechanical system design and control.

Based on the combined simulation results, recommendations were made for façade components (glass types and sunshade dimensions) inclusion of daylight dimming systems, thermostat set-points and air supply temperatures and rates to both optimize the mechanical system design and enhance comfort conditions to meet ASHRAE standard.

Simulation Tools

Simulation tools DOE2(interface: Visual Doe, eQuest) Radiance and Oasys ROOM were used in combination to guide the design process. Oasys ROOM (an Arup proprietary software tool) was used to assess the thermal comfort response to different design alternatives. Radiance was used to predict visual comfort and daylight penetration. DOE 2 and eQuest were used to obtain the resulting operational energy savings.

Thermal Comfort and ROOM

ROOM Analysis: A single zone model simulates the impacts of the exterior environment, wall material layers, mechanical system type and method of air/ temperature distribution on thermal comfort. The result is a contour plot designation of the Percentage of Persons Dissatisfied (PPD) within that space. The PPD result represents a statistical measure of the number of people out of one hundred that would be uncomfortable (dissatisfied) with the environment shaped by the resultant parameters of each of the cases. The parameters considered within the measurement of PPD are:

- Air temperature
- Relative humidity
- Radiant surface temperature
- Air movement
- Subjective, human parameters (such as level of clothing, activity level, position inside space, etc.)

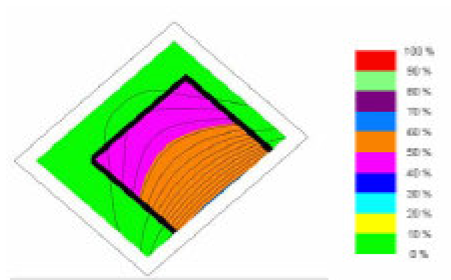

Fig. 1: Plan view of comfort (PPD) contours in a 'typical' perimeter zone for the facade.

The different colors within the contour plan correspond with the legend to allow evaluation of the Percentage of Persons Dissatisfied.

note:

- The comfort criteria to be met to follow ASHRAE standard 55
- Recommend design limits: *general* discomfort up to 10% dissatisfaction (green)
- Recommend design limits *local* thermal discomfort up to 15% dissatisfaction (yellow)
- Where the above is achieved, the space designed would then provide a thermal environment acceptable to at least 80% of the occupants.

- The peak time used for the comfort analysis is the peak load time for the space. (Time: Northeast July, 10:00 Southeast September, 12:00, Northwest July, 19:00 and Southwest September, 17:00)

The Thermal Comfort Assessment described in this section was performed to help the project design team understand the resultant levels of thermal comfort achieved in typical perimeter zone patient rooms due to:
a. Different external shading and internal blind configuration options – their ability to reduce solar gains, thereby reducing cooling load requirements while providing a thermally comfortable environment.
b. Inter-related mechanical system delivery options (air supply rate, air supply temperature, thermostat set point etc.)
c. Different internal load configuration alternatives and their impact on mechanical system design and perceived thermal comfort.
It should be noted that:
a. The thermal comfort simulation assesses the worst case scenario (no building self-shading) for each façade type and orientation. The spaces are assumed to be in mid floors and heat gain or loss through the floor or roof is not considered. All calculations considered façade configurations that include glazing self-shading due to the 1'-3" inset of the window. For all cases the glass type Viracon VE1-52 remains constant and the window configuration composed of one lower window (5' high x 6' wide) and one adjacent upper window (2' high x 6' wide).
b. The simulation assesses the patient room as a single entity/zone. The potential to contain façade loads to the family waiting area directly adjacent to the window and provide conditioning to the patient area of the room as a semi-separate zone was not addressed specifically in the simulation process.
c. Two types of patient rooms (annotated 'tower face' and 'patient rooms') were simulated due to the different type of external shading systems associated with each area.
d. The thermal comfort analysis was carried out for the hours around the critical peak time (the time corresponding to the peak design load for the mechanical system) as determined and defined by the project mechanical engineer. This critical peak design time corresponds to the time when the combination of internal loads and external heat gains is at its maximum. (By optimizing shading for times of peak external load, solar loads can be reduced, mechanical systems can potentially be down-sized and operational savings achieved while still providing a thermally comfortable interior. Moreover, if comfortable conditions can be maintained at these worst times, it can be assumed that thermal comfort can be achieved at all other times).

<u>Daylighting and Radiance</u>

Radiance is a daylighting simulation tool used to simulate realistic quantitative as well as qualitative lighting distribution within a space. The daylight contour plots overlaid on luminance rendering and false color images aid in an understanding of the implications of different façade treatments on potential solar control and daylight penetration thus helping with complex design decisions.
Daylight Contour Plots: The following are luminance plots, the contour lines for illuminance (total visible light on a surface) values are included, to indicate quantitatively what light levels can be expected.

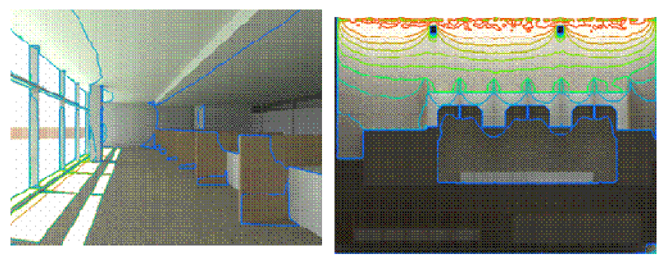

Fig. 2: Sectional Perspective image of the building with contour lines highlighted.

False Color Renderings: False color images more easily explain how sunlight and solar gain is controlled. In these images, for example, one can more easily visualize the effect of shading devices and fritted glass.

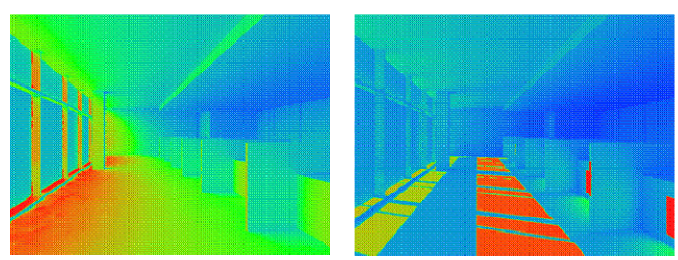

Fig. 3: External shades block incoming sunlight reducing the bright red area of direct sun penetration, Fritted glass dims the sunlight penetration intensity changing the color from red to orange.

<u>APPROACH</u>

The combined Solar Control Analysis, Daylighting and Thermal Comfort assessment described helped the project design team understand the resultant levels of thermal comfort and daylight penetration achieved in typical perimeter zone patient rooms due to:
1. Different external shading and internal blind configuration options – their ability to reduce solar gains,

thereby reducing cooling load requirements and the ultimate impact on perceived thermal comfort.
2. Inter-related mechanical system delivery options (air supply rate, air supply temperature, thermostat set point etc.)
3. Different internal load configuration alternatives and their impact on mechanical system design and thermal comfort.

By optimizing shading for times of peak external load, solar loads can be reduced, mechanical systems can potentially be down-sized and operational savings achieved while still providing a thermally comfortable interior. Moreover, if comfortable conditions can be maintained at these worst times, it can be assumed that thermal comfort can be achieved at all other times.

Alongside resulting operational energy/cost saving and life cycle cost analysis for different combinations of façade and mechanical system components the thermal comfort and daylighting analysis will facilitate a more holistic understanding of integrated façade and mechanical system performance and thus better informed decision making.

<u>SOLAR CONTROL ANALYSIS</u>

Shading masks were used initially to optimize external shading configuration and dimensions in order to obtain the best shade coverage at time of high priority (corresponding to times of high solar loads) without significantly impacting view and transparency.
The shading masks and three-dimensional sun patch diagrams provide an understanding of the sun penetration to be expected inside the spaces studied, for a given external shading configuration. The amount of shade coverage provided on the window (over the hours per season) should be read on the shading mask diagram and correlated to the specific amount of shadow (shown in blue) on the sun penetration diagrams.
The hourly sun penetration diagrams for the Sutter Hospital rooms indicate sun penetration into the space (in yellow) through the afternoon hours of 2-5pm in September. The dark blue indicates the shadow cast by the external shading device during these times. Comparison of the blue shadow cast by the shading device between the seasonal afternoon hours represented illustrates the increased protection from direct solar gain the shade provides during the time of peak load in September (compared to the time of peak solar penetration, November for example) for this perimeter zone orientation.
Similarly, the shading mask diagram for this orientation and exterior shading device design indicated not only maximum sun penetration in afternoon hours during all seasons (also illustrated in the hourly sun penetration diagrams) but also illustrated the effectiveness of the horizontal and vertical shading device in providing shade to the interior during the mid-day hours particularly during the summer and swing seasons when most needed.

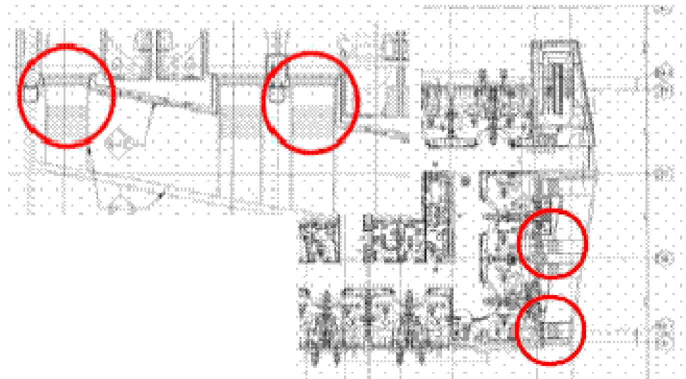

Fig. 4: Plan of the areas studied on Sutter Hospital, identifying 'typical' perimeter zone for the facade. (SouthWest Orientation)

At the corner bay, the shading device studied provides close to 50% shading during the time of peak load. This 50% coverage could be achieved by widening the horizontal shade past the edge of the window.

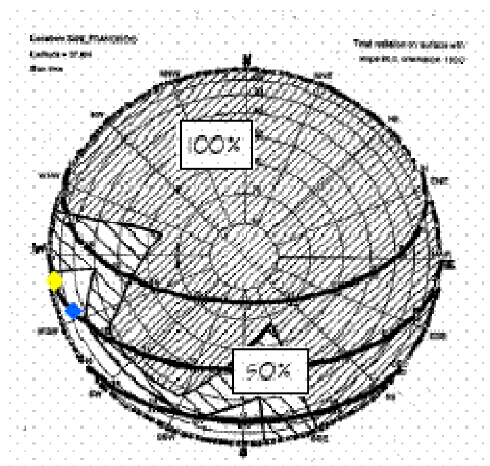

Fig. 5: A shading mask study of proposed external shading device.

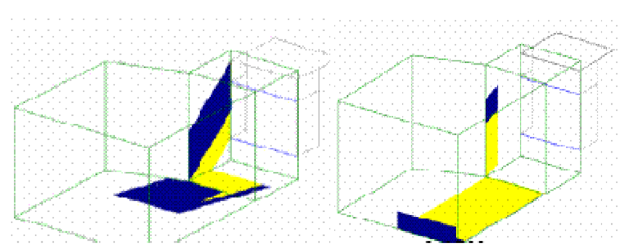

Fig. 6: ROOM solar penetration at 2-3pm September (corresponding with the peak AC load) and at 2-3pm November,(corresponding with the peak solar penetration of low sun angles).

DAYLIGHTING

To illustrate the solar control, natural daylight penetration and enhanced interior visual environmental effect of the proposed façade component alternatives sunlight/daylight simulation was run over a series of consecutive hours for two different times of the year and under different sky conditions. The impact of some façade components were visually subtle, different illuminance scales were therefore introduced for the false color and daylight contour images to better express the enhanced performance provided. The fully glazed façades of the Valley Health projects posed concern for potential impact of uncontrolled solar gain penetration on thermal comfort and associated sunlight penetration on visual comfort and glare due particularly at times of low-angle sun penetration in the late afternoon hours of autumn and winter. The results were presented as foot-candle levels in three formats: lighting level contours overlaid on both a sectional perspective and plan view of the space, and false color images of the sectional perspective which utilize the color variation across the surfaces to express lighting level and intensity variation.

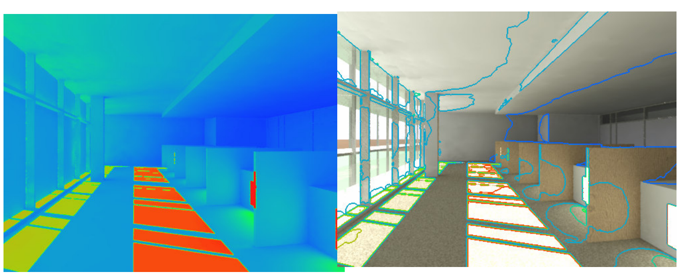

Fig. 6: Radiance image highlighting the solar penetration at 2pm November, with shading.

The effect of the exterior shading at eliminating direct sunlight penetration is indicated by the blue stripes introduced into the red and yellow patches on the floor. The corresponding light levels contours aided in determining the availability of natural ambient light to initiate exploration of daylight-dimming controls to reduce electric lighting use and the associated operation energy and cost savings.
In addition, the effect of the exterior shading at increasing the illuminance of directly adjacent surfaces (reducing contrast and associated glare) can be seen most easily on the ceiling of the other reception/waiting area sectional perspective contour images (above). Even with external shading control the contour images indicated the natural light levels in the hallway adjacent to be 20-25fc.
The external shading system proposed was not only effective at controlling direct sunlight penetration, particularly during the summer months, but was also effective at increasing the illuminance of directly adjacent surfaces, reducing contrast and associated glare. The control of direct sunlight in the waiting area and at the reception desk and daylight penetration in the hallway behind results in natural daylight levels during both sunny and overcast days indicating that daylight-dimming controls for electric lighting in these areas may be worth exploring, affording associated operational energy and cost savings.

THERMAL COMFORT

Thermal and daylighting models of typical patient room spaces were assessed for Peak Time of the day, for the months of July, September and November depending on orientation to ascertain the inter-related external climate, façade configuration and mechanical system impacts on thermal comfort within these spaces. Initially the mechanical system and set point parameters were held constant across all of the façade configuration cases. Then a variety of potential thermostat set-point, or air supply temperature with a potential to optimize the mechanical system design or enhance comfort conditions were evaluated. Note that the desired target comfort level for occupants is an average of not more than 10% PPD, however, an increased average of 15% PPD was accepted as long as no point within the occupied area had a PPD greater than 20%. Iterations were performed to assess the model for the different shading options according to the various alternatives. The inputs were modified in terms of the thermostat set-point to achieve an acceptable limit of 10-15% Percentage of People Dissatisfied. In orientations and alternatives where the PPD was 0%; an attempt was made to increase the PPD hence decreasing the system load. Additional alternatives were also assessed to demonstrate allowing the temperature in the room to increase during certain times of the year to maintain acceptable levels of thermal comfort.

As an example the Baseline hourly comparison for the Sutter Health Project showed that the shading is adequate to provide protection from sun penetration during the afternoon hours during the peak cooling season (September.) The (purple-30-40% PPD at 2-3pm and orange-40-50% PPD at 3-4pm in September) are localized and contained. While these patches of discomfort near the fenestration penetrated deeper into the space in later season months, they were less intense (yellow/lt. blue-20-30% PPD 2-3pm in November) and in these winter seasons a bit of warm solar penetration would often be welcome.

With interior blinds drawn, the intensity of the localized discomfort patch at the window at 2-4pm in September is reduced (from 40-50% PPD to 10-20% PPD.) It was worth noting that the rest of the room stayed well within the 0-10% PPD range indicating that the thermostat set point could possibly be increased or conditioned air supply volume reduced, providing thermal comfort at reduced mechanical system operation.

Varying the ACH illustrated that 4ACH at 60°F supply would reduce the amount of cooling energy required while still providing a thermally comfortable environment. Note that in comparing 58°F supply to 60°F supply the general room comfort went from yellow/green-0-20% PPD to green-0-10% PPD --effectively the space was too cold at 58°F--).

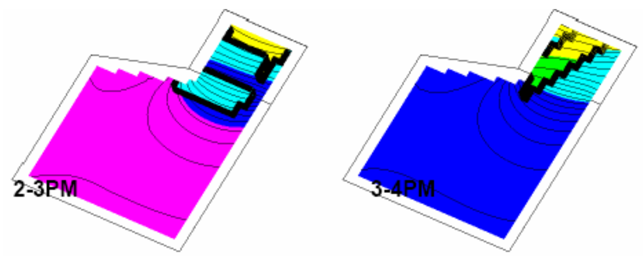

Fig. 10: ROOM image highlighting the thermal comfort contours at 2-3pm September, corresponding with the peak AC load. (6 ACH/ supply temperature 58 degF)

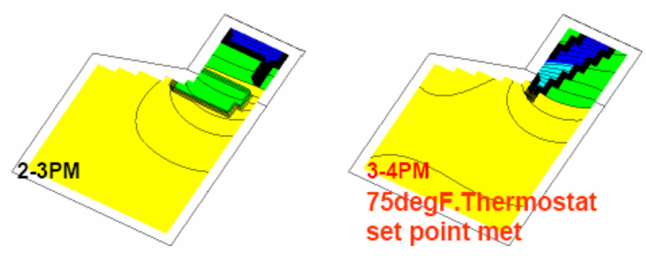

Fig. 11: ROOM image highlighting the thermal comfort contours at 2-3pm September, corresponding with the peak AC load. (6 ACH/ supply temperature 62 degF)

The results obtained from this analysis indicated that external shading, high-performance glazing and internal blinds would be required to achieve an acceptable ASHRAE level of comfort in the visitor nook adjacent to the window during the worst-case design hours/season. And, operational energy cost savings could be afforded by this façade system over a large portion of the year if the mechanical system could be designed to accommodate either varying conditioned air supply rates (a variable-air-volume system.) and/or varying the AC thermostat set-point temperature (increasing the AC set-point for large portions of the summer and swing season afternoon hours and decreased heating set-point temperatures throughout the morning hours when direct solar gain is present.)

LIFE CYCLE COST ANALYSIS

The potential to realize cost savings through a life cycle cost analysis is particularly significant for healthcare facilities. "Hospitals have unique and intensive energy use requirements. In addition to the need for lighting and heating 24 hours a day, hospitals demand extensive energy for ventilation, equipment, sterilization, laundry, and food preparation. Every year, U.S. hospitals spend an average of $1.67 per square foot in electricity costs, and another 48 cents per square foot on natural gas," making them one of the most energy-use intensive of all commercial or institutional building types" (Commercial Building Performance: Healthcare Facilities, Sector Fact Sheet, Consortium for Energy Efficiency, 2005).
In California, with our high cost of energy and strict health and safety regulations, these energy cost figures can be significantly higher. With this immense allocation of resources, even a small improvement in system performance can yield substantial savings in yearly energy costs - potentially providing the financial capacity to hire additional staff or purchase vital life-saving equipment.
In addition, "The purpose of architecture is to shelter and enable man's life on earth and to fulfill his belief in the nobility of his existence." [Eero Saarinen]. Particularly with hospitals and healthcare projects there is increasing pressure and desire to create and maintain healthy interior environments for hospital patients, staff and visitors. Thus it is important in any life-cycle assessment process to include not only financial/cost issues and analysis but also the related qualitative issues, benefits and challenges. Occupant Thermal comfort is one facet of healthy interior environments that is closely related to mechanical ventilation, cooling and heating and their associated energy and cost. As such, this report includes thermal comfort qualitative analysis as an integral component of the life-cycle assessment.

CASE STUDY

Following two case studies are used to highlight the process implemented and its impacts.

Case Study:1

Mills- Peninsula health services hospital replacement hospital was one of the hospitals studied using this methodology. Following is an extract from this study highlighting the measures studied, implemented and their impact on the energy cost savings.
Two different DOE2.1E studies were conducted to aid with exterior shading design. In the first study a single patient room was modeled in order to estimate the peak cooling load and peak supply air flow rate for each orientation (NE, SE, SW, NW) of these rooms with different shading

configurations. This first study showed a fairly significant impact on peak loads in these perimeter rooms form the overhang shading.

The second shading study evaluated the impact of exterior shading on whole building energy and peak electric demand. This study indicated modest impact on energy costs both for constant volume and variable air volume HVAC systems.

AEC (Architectural Energy Corporation) further studied the impact of optimized overhang design on reducing peak supply flow in patient rooms.

In all of the above cases, the internal loads were adjusted to represent design loads determined by the mechanical engineer for the patient room. Assumptions include equipment power density of 1.35 w/s.f., lighting power density 1.3 w/s.f., and 4 people.

As expected, reducing the ventilation rate reduces the fan and cooling energy significantly. In addition, there is less reheat required thus savings in gas cost is a significant part of the total. The magnitude of savings is greatest when the minimum ventilation setpoint is reduced from 6 ACH to 4 ACH. Additional savings are achieved when the minimum ACH is reduced to 2 ACH, although not in the same magnitude as when reduced from 6 ACH to 4 ACH. This implies that for most hours 4 ACH is adequate to meet the loads, with a few additional hours when only 2 ACH is needed to meet the loads.

Thus, in theory the VAV boxes can be set to supply minimum of 2 ACH. However, the practical and indoor air quality (IAQ) implications of having it set to 2ACH will need to be determined by the mechanical engineer. Once a VAV system is installed there is no additional cost associated with setting the VAV boxes to desired minimum positions.

Adding VAV controls in additional zones also has a significant impact, with energy savings between $73,000 and $191,000 per year depending on minimum ventilation set-points. However, reducing the min ACH to 2 ACH at night in these zones has relatively marginal savings indicating that there are only a few hours in these spaces where the load is low enough to be satisfied by 2 ACH.

Description	Southwest	Northwest	Northeast	Southeast
	ACH	ACH	ACH	ACH
Without Any Shades *	10.22	8.16	7.14	9.56
Without Overhang **	9.9	7.81	6.76	9.24
With Overhang ***	8.25	6.86	6.03	7.46

* all exterior shades removed.
** includes exterior fins and window recess shading that are in the base design
*** adds exterior overhang shading.

Fig 12: ACH calculations

<u>Case Study:2</u>

Valley Health Center at Fairoaks was one of the hospitals studied using this methodology. Alongside qualitative assessment of daylight and thermal comfort impact of façade system alternatives, energy analysis was used to assess related total building energy savings potential and life-cycle cost simple payback for a number of integrated envelope, mechanical and lighting/electrical alternatives alone and in combination.

The following are the Energy Control Measures assessed for potential energy savings and life-cycle cost, simple payback.

List of ECM (Energy conservation measures) implemented:

ECM 1 Implement shading devices on the building glazing.

ECM 2 Replace the standard double-pane glass with high performance clear glazing and high performance fritted glazing.

ECM 3 Reduce building LPD by 20% and install occupancy sensors to control lighting in offices, and exam, storage and restrooms.

ECM 4 Reduce building LPD as appropriate via implementing daylight harvesting controls in the Lobby & Waiting areas.

ECM 5 Implement a strainer cycle/water-side economizer on the 100% outside air unit to reduce chilled water demand.

ECM 6 Install a VFD Chiller.

ECM 7 Replace cartridge filters with electrostatic filtration in all air handling units.

ECM 8 Combined Measure 1: ECM 1 + ECM 2 + ECM 3 + ECM 4.

ECM 9 Combined Measure 2: ECM 1 + ECM 2 + ECM 3 + ECM 4 + ECM 6.

ECM 10 Combined Measure 1: ECM 1 + ECM 2 + ECM 3 + ECM 4 + ECM 7.

ECM 11 Combined Measure 2: ECM 1 + ECM 2 + ECM 3 + ECM 4 + ECM 6 + ECM 7.

The Title-24 performance method along with the EnergyPro version 3.9 (Healthcare) software program was used to evaluate all ECMs for this report. Note that this "Standard" building is based on the Savings by Design Healthcare program, and that the results would be different from results derived using the "Standard" building used for Title-24 compliance calculations. The baseline has been modified in this version of EnergyPro to use a constant volume air handling system as the standard building design.

The facility is located on an existing campus, which is served by the utility, Pacific Gas & Electric, under the E-20P electric rate schedule and under the GNR-2 natural gas rate schedule.

Valley Health Center at Fair Oaks								
	Annual *Savings* (over base case)							
	Electricity			Natural Gas		Total	Estimated	Net simple
	Use [kWh]	Demand [kW]	Cost [$]	Usage [therms]	Cost [$]	Cost [$]	cost. [$]	payback [years]
ECM1	58,124	6	$9,200	3,327	$2,910	$12,110	$413,000	34
ECM2	60,910	6	$9,666	3,370	$2,930	$12,596	$131,500	10
ECM3	13,412	3	$2,007	-98	-$87	$1,920	$30,525	16
ECM4	30,432	8	$4,961	520	$464	$5,425	$21,100	4
ECM5	-16,556	23	$156	900	$797	$953	$9,750	10
ECM6	54,578	28	$9,647	0	$0	$9,647	$30,762	3
ECM7	182,544	19	$21,348	-1,251	-$1,094	$20,254	$52,500	3
ECM8	**98,467**	**17**	**$15,735**	**1,983**	**$1,707**	**$17,442**	**$596,125**	**34**
ECM9	**148,028**	**44**	**$24,346**	**1,983**	**$1,707**	**$26,053**	**$626,887**	**24**
ECM10	266,760	34	$35,357	973	$823	$36,180	$648,625	18
ECM11	**314,015**	**62**	**$43,643**	**973**	**$823**	**$44,466**	**$679,387**	**15**

Code	**Measure Description**
ECM 1	shading devices.
ECM 2	high performance and high performance fritted glass.
ECM 3	reduce LPD by 20% and install occupancy sensors.
ECM 4	daylight harvesting controls in Lobby & Waiting areas.
ECM 5	strainer cycle/water-side economizer.
ECM 6	VFD Chiller.
ECM 7	electrostatic filtration in all air handling units.
ECM 8	ECM 1 + ECM 2 + ECM 3 + ECM 4.
ECM 9	ECM 1 + ECM 2 + ECM 3 + ECM 4 + ECM 6.
ECM 10	ECM 1 + ECM 2 + ECM 3 + ECM 4 + ECM 7.
ECM 11	ECM 1 + ECM 2 + ECM 3 + ECM 4 + ECM 6 + ECM 7.

Fig 13: Energy cost summary table

CONCLUSION

This design/simulation process applied to the four healthcare projects above provided essential client understanding of human perception consequences of potential design decisions and, alongside financial payback justification, facilitated buy-in to design refinement from a holistic occupant satisfaction and cost savings perspective. This process is recommended as a starting point in the design, it has been applied to several projects in the firm and it has shown significant improvement to the design while demonstrated the strength of an integrated design process.