1. The west façade of the Jerry Yang and Akiko Yamazaki Environment and Energy Building.

Y2E2:

The Jerry Yang and Akiko Yamazaki Environment and Energy Building, Stanford University, California

“Y2E2 is much more than a building; it is a symbol of what is possible in our transition to sustainability. It is designed for problem-solving, designed to conserve, designed to inspire, and designed to teach.”

Jeffrey Koseff, Perry L McCarty Director of the Woods Institute for the Environment.

Kurt Graffy Janette Lidstone Cole Roberts
Brandon G Sprague Jake Wayne Armin Wolski

Background

As noted elsewhere in this edition of *The Arup Journal*[1], Einstein is said to have observed that “we can’t solve problems by using the same kind of thinking we used when we created them”. Stanford University’s Jerry Yang and Akiko Yamazaki Environment and Energy Building (Y2E2) exemplifies a new kind of thinking aimed at providing watershed solutions in the areas of environment, technology, and energy. Completed in early 2008, Y2E2 is the first element in Stanford’s new Science and Engineering Quad 2 (SEQ2). Masterplanned by Boora Architects Inc, SEQ2 will deliver over 500 000ft² (46 450m²) of interdisciplinary teaching and research space in four highly sustainable buildings.

Stanford believes that finding solutions responsive to today’s multifaceted environmental challenges requires experts from a range of fields to work together in an interdisciplinary environment, sharing their different insights. Y2E2 therefore provides accommodation based on research focus, not academic department. These focus areas include “sustainable built systems”, “climate and energy systems”, “oceans and estuaries”, “fresh water”, “energy”, and “land use and conservation”.

The building accommodates researchers from biology, law, medicine, education, anthropology, and economics, as well as two departments (Civil and Environmental Engineering and Environmental Earth Systems Science), two interdisciplinary teaching programmes, and four centres and institutes including the Woods Institute for the Environment with its strategic collaborations (the Center for Ocean Solutions, the Natural Capital Project, and the Food Security and Environment Project).

Y2E2 sets a benchmark in cutting-edge university and research facilities. Representing Stanford’s new interdisciplinary initiative for the integrated study of energy and natural systems made it imperative that the building itself be a model of sustainability and energy efficiency. The design team, including Arup and Boora, pursued architectural forms and building systems that would meet this sustainable goal and provide the space needed for each research focus - the connective areas allowing collaborative work, and spaces where laboratory researchers can link with the social scientists responsible for absorbing and disseminating research insights.

Stanford entered the Y2E2 design process with strong ideals that would ultimately guide subsequent work on SEQ2. These were that the university could no longer "do business as usual", and needed to:

- break down the long-standing traditions that maintain barriers between academic disciplines
- create opportunities for engineers to work alongside economists, policy makers, and biologists
- have a shared language and common vision for housing its new interdisciplinary programmes
- emphasise opportunities through organisational design
- blur traditional boundaries between disciplines
- engineer greater success in creating spaces that support people and their work.

It is fitting that an integrated team of architects, engineers, landscape designers, and contractors working on behalf of a visionary client should deliver a building dedicated to such integration.

Atria

Within the SEQ2 masterplan, Y2E2 is one of the two larger buildings, a pair of L-shapes mirroring each other across the central open space. Ranged along the centre of the horizontal element in Y2E2's L-shape are three atria, with a fourth near the top of the vertical of the L.

Measuring 81ft (24.7m) from basement to highest point, all four atria extend the full height of the building, allow the integrated disciplines to collaborate and connect, be inspired and curious, and remain transparent and open to daylight, view, and outside air (Fig 2).

The extensive use of glass at all levels, and the design's sensitivity to sightlines, reveal laboratory work, flexible seminar classes, administrative activities, and social gatherings, making all the building occupants visible to visitors and, most importantly, visible to each other (Fig 3).

The atria are not simply areas to cross, but destinations in themselves. Stairways and all interior corridors pass through them, supporting their vitality, while the spaces clustering around, including lounges, touch-down stations, kitchens, seminar rooms, wayfinding stations, social entries, and casual seating, host the interactive work of the occupants.

The atria's openness to light, sound, airflow, and temperature variation established itself early in the project as both a critical key to the project's success and as overlapping performance challenges to be solved by the fire, lighting, acoustics, and mechanical engineering teams in Arup.

Working with Boora, Arup's overall task was to create spaces that are both comfortable for the occupants and form an integral part of the building's passive ventilation and smoke release schemes.

The requirements were often contradictory, but certain priorities for successful realisation of the atria became obvious:

(1) Their upper portions needed to vent to the roof exterior so as to function properly as part of the natural ventilation scheme, with sufficient open area to provide the airflow needed.

(2) As the atria also form part of the passive smoke release design, additional surface area had be allocated in their upper portions beyond the louvre areas established for the natural ventilation system.

(3) Their tops needed to be visibly transparent to bring light into the interior, requiring a significant portion of the atrium structures above the roof to be glazed.

(4) These first three priorities effectively determined the acoustic strategies required for occupant comfort.

2. Section through atrium.

3. The glazed conference rooms give direct views to the exterior and other people working.

Laboratories

The 54 000ft^2 (5000m^2) of laboratories in Y2E2's basement house multiple departments, each with unique research and teaching programmes. There are nine environmental labs (two environmental fluid mechanics, three environmental engineering, one structures, and three remaining labs to be used by future research recruits). Specific needs for these research programmes include:

- wet laboratory benches with fume hood workstations
- constant temperature rooms
- noisy equipment work rooms
- undergraduate teaching wet laboratory
- reverse osmosis testing facility
- fluid mechanics wave flumes with water reservoir trench system and laser-based measurement systems
- fluid mechanics teaching laboratory
- sustainable building systems research and testing facility
- sustainable building systems classroom.

The floor plan was compartmentalised into three basement control areas to allow chemical inventory flexibility. Open interchangeable wet laboratory spaces allow research programmes to expand and contract. Four large-scale flumes of different configurations (three are around 40ft/12.2m long) incorporate measurement stations using lasers.

The sustainable building systems research labs included a large-scale material baking oven and weathering simulation equipment.

4.

Multi-tasking fume hoods

A research community focused on environmental solutions must also be a solution itself, doing more with less. One of Y2E2's many innovations is the design for lab fume hoods that enables them to perform double duty. With light and ventilation systems demanding so much energy from buildings, they are often the first systems studied for reduction or optimisation opportunities.

Fume hoods are very ventilation-intensive, demanding much energy to contain and limit exposure to airborne hazards. Each may require as much volumetric air flow as a 600-700ft^2 (56-65m^2) room. They are often grouped in a single space shared by multiple labs, which requires a great deal of air coming in and going out above and beyond that needed for ventilation

The Y2E2 design locates the fume hoods in the open lab where they serve as air returns for the ventilation system. Instead of double ventilating spaces – one system for the labs and a second for the shared fume hood rooms – the design economises with the fume hoods multi-tasking.

The lungs of the building

The atria act as the building's lungs, passively drawing air through natural buoyancy and cross-driven pressures up and out of the louvres near the apex. Evenly positioned throughout the building, they are integrated into the layout allowing direct connection and ease of natural ventilation for all the perimeter offices on every façade.

Ironically, the greatest challenges in the atria natural ventilation integration were control of the high rates of strong, buoyant airflow, and assurance of thermal comfort in the well-daylighted third floor. Both challenges are discussed later. Additional obstacles fell to Arup's fire, lighting, and acoustic teams to address.

Fire and smoke

California fire safety codes require smoke control in atria interconnecting three or more storeys. Instead of providing the usual mechanical exhaust systems, however, Arup's fire engineers and Stanford chose to capitalise on Y2E2's natural ventilation design, which would allow openings between the first floor and the basement to supply natural light and visual connection to the lowest level.

Not all atria are appropriate for naturally ventilated smoke control systems; a reasonable height limit is needed to ensure adequate buoyancy. A smoke control system may not be necessary for a short, two-storey atrium, whilst a fire may not provide enough heat and buoyancy to drive smoke out of natural ventilation openings in a tall, six-storey atrium. However, as the team worked through the early design phases, preliminary calculations showed that the Y2E2 atria were within the necessary range.

After preliminary calculations, the team gave the architect and the mechanical engineers an estimate of ventilation opening sizes, which was then used in design development. CFD modelling enabled the fire team to determine the smoke development and tenability of the space as well as the benefits of venting (Fig 5).

Analysis of numerous models, with varying sizes of ventilation opening, showed that the amount and size of these for make up air was just as significant as the amount and size of exhaust air vents. As the design was finalised, the fire engineers requested more and more make up air ventilation.

Since Boora wished to maintain a maximum amount of louvres and grills on the façade, the fire team proposed using automatically opening exterior doors under fire alarm conditions. This additional make up air opening helps the smoke evacuate the space via natural means.

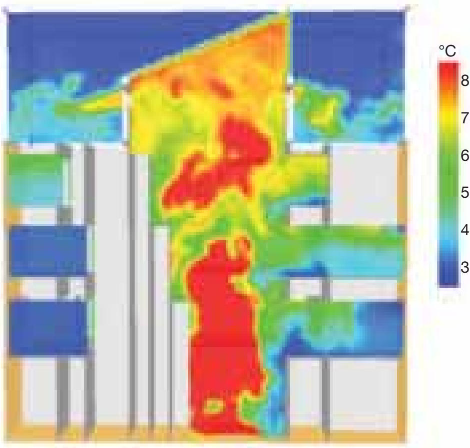
In exploring different fire scenarios, the team found that a basement fire might have insufficient buoyancy to vent its effluent out of the tops of atria of this height. The solution would normally involve more ventilation openings, but this conflicted with the Y2E2 architectural goals, so consideration was given to closing off the basement from the first floor. This achieved the goal of fire separation of the basement laboratory space from the atrium, but the faculty committee insisted on maintaining the opening.

Since natural lighting was important for these basement areas, a structural, fire-resistance rated glass floor was also considered. Cost ruled this out, so Arup found a third alternative - a horizontal fire shutter that would close on smoke or fire detection. By providing this between basement and first floor, the fire rating was maintained, and the challenging fire scenario in the basement eliminated. Since the shutter can be kept open during normal conditions, daylight can still reach the basement level.

This final fire engineering solution was all-important as without daylight the atria as whole entities, let alone their lowest levels, would not give an appropriate environment, or send the right message, for Stanford's sustainable, integrated research and teaching facility.

As part of the commissioning process, the authorities required live hot smoke testing, the success of which surprised even the fire marshal.

5. CFD image showing fire and smoke distribution.



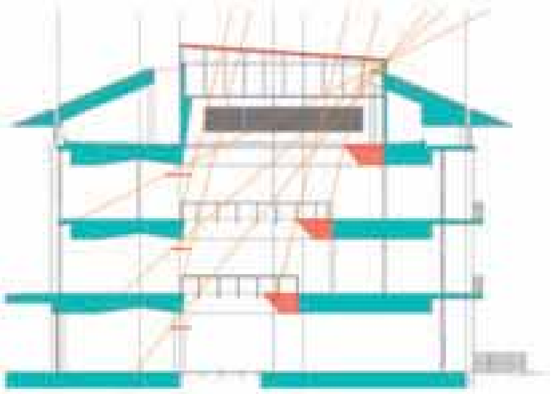
6. Light and people.

Light quality

Just as the atria serve the architectural intent by forming junction points between the building's social and intellectual activities, so they are also interfaces between the built and the natural environment. The abundance of natural light in each atrium serves as a visual clue to the building's energy story, but the light has to be controlled in a visually comfortable manner as well as utilised to the full at each level. Abundant natural light also impacts thermal comfort, and to balance these factors was imperative (Figs 6, 7).

Early in the design process, Arup's lighting engineers studied the atria shape and form in respect of the sun's path through the sky. Based on angle studies in conjunction with the architectural team, three of the atrium openings were refined to be widest near the top of the building, and narrowest at the base. This allows the floor at each level to extend a little below the opening in the floor above, with more floor space at the south sides of each atrium. These receive abundant ambient light, as direct solar light primarily lands at the north. The south sides are thus ideal locations for meeting rooms with glass walls, open to ambient light and visually connecting to the building's activities.

With the shape defined, the architectural programme for the atria was refined to include common workspaces, meeting rooms, and informal gathering spots. With so many activities needing to occur in areas with abundant sunlight, controlling glare and maintaining visual comfort were critical concerns for Arup.



7. Natural light penetration and floorplate modifications at the atria.

The atrium glazing was originally designed to incorporate etched photovoltaics (PVs), not only to generate electricity but also to mitigate the heat and glare of the direct sunlight.

In concert with the mechanical and CFD analyses, extensive modelling was used to quantify the daylight incident to the atria at different times of the year. A 3-D virtual daylight model for a typical atrium was created and used as follows:

- Daylight factors were calculated for each floor, gauging penetration into the building's core.
- Illuminance studies provided data on peak light levels where direct sun was incident.
- Luminance studies on surfaces in the atria informed contrast ratios and material finish choices.

Each played a specific role. The daylight factor analysis showed how much electric lighting in and around the atria could be dimmed or switched off to conserve energy. Together with this, the illuminance studies identified the light levels available at the different floors, under varying sky conditions. And because the space was to accommodate both social and academic informal meetings, it was essential to provide a base level of illuminance for comfort.

The integrated PV panels in the atria glazing were later value-engineered out of the project in favour of three types of roof-mounted PV technology, and the studies had to be repeated to advise on new glazing parameters. A level of frit on the glass was found necessary to mitigate the sunlight's intensity, as with meeting rooms and workspaces adjacent to the atria, direct sunlight on its vertical faces would potentially cause glare to occupants. The frit cuts light intensity, while maintaining brightness and connection to the natural environment. In turn, however, thermal comfort in the atria had to be reviewed. The level of frit was ultimately established through combined daylight and mechanical studies to optimise both visual and thermal comfort, the latter dictating a frit pattern that sufficiently mitigates incident heat from the upper levels.

Acoustic quality

Solutions were also needed to manage the way sound interacts in the open spaces. Arup's acoustic strategy had two defining boundaries: the atria would be (1) open externally, and (2) visually transparent. These established the direction for the means to achieve the acoustic targets. Being open to the outside via louvres for the mechanical system, and via motorised glazing for smoke extraction, the upper portions of the atria were vulnerable to rooftop mechanical system noise.

This meant that control of mechanical system noise from the rooftop-mounted supply and laboratory exhaust fans would have to be at the units themselves, as the atrium envelope would provide minimal sound isolation at best (louvres closed) and at worst, none (louvres open). Also, the portion of the atrium envelope not operable was primarily glazing, with minimal sound isolation value.

Acoustic modelling to map potential noise levels on the roof, using the fans and exhaust stacks as simple acoustic sources, indicated the extent of the challenge, particularly for adjacencies to the atria. Specific calculations and analysis of the mechanical systems themselves indicated the range of mitigation required.

The usual acoustic barriers were ruled out early in the analysis. Initial modelling indicated that barriers between the atria cupola louvres and the mechanical systems could impede the airflow required for natural ventilation extract or for the smoke extract system. The variables thus became location of the devices relative to the atria, selection of quieter units, or sound mitigating elements such as silencers or noise-reducing enclosures. Arup's final solutions included each of these:

- The exhaust stacks from the laboratory exhaust fans were relocated to avoid acoustic "hot-spots" on the roof from multiple stacks close to each other and to the atrium.
- The supply fans were changed from the standard single-fan air-handling units (AHUs) to a "fan-wall" unit - multiple smaller fans in a single housing supplying the same air volume as the standard fans, but with markedly reduced vibration and low-frequency fan noise.
- Intake silencers were put at the supply fan inlets, close to the atria louvres.
- Silencers were installed in the exhaust fan ductwork.
- The exhaust fans themselves were installed in sound-isolating enclosures.

On the atria interiors, room acoustic requirements were again bound by openness and transparency requirements, effectively establishing "go/no-go" zones for provision of acoustic treatment. Acoustic treatment in the atria was needed to reduce reverberation time and diminish occupancy noise and break-in noise from the building services systems.

Preliminary studies indicated that, without acoustic treatment, the room would be highly reverberant. Opportunities for treatment were, however, limited due to the lack of available wall-space and restrictions to putting acoustic banners at the tops of the atria (blocking light), along the sides of the upper atrium cupolas (blocking air flow at the louvres), or on the floor (more difficult to keep clean than hard floors).

An acoustic model was built of a "typical" atrium (all four are slightly different), and sound "sources" placed at various locations within. Arup's acoustic engineers wanted to determine, for a given source location, which surfaces in the room were acoustically "open" to that source. By analogy, if the acoustic source represented lighting, the team wanted to see which surfaces would be "illuminated" and which would remain dark. Those surfaces illuminated by a particular source location would be the first choice for placing acoustic treatment to control the direct and early reflected energy from that source. By absorbing and reducing these sound energies efficiently, control of the reverberant energy was also optimised.

Repeating this for sources at each floor level adjacent to the atria and at the atrium floor levels themselves yielded a list of surfaces that were prime locations for acoustic control of reverberation and occupant-generated noise. By vetting the effectiveness of the various room surfaces for acoustic accessibility to the direct and early sound energy from the sources, Arup could work with Boora, prioritising and focusing on a specific palette of surfaces for treatment.

8. Room acoustic requirements were again bound by openness and transparency requirements.

Process and receptacle loads

Process and receptacle loads are quickly gaining attention as the greatest energy consumers in high-performance buildings, approaching 70% in some cases. This is especially true where lighting, conditioning, and ventilation energy use is extremely low, and in buildings with intense process loads, eg science and laboratory programmes. Y2E2 was estimated to have a non-regulated end-use proportion of over 50% if no actions were taken to reduce the loads.

Historically, such loads have been considered by the energy design standards and design professions to be "non-regulated" and outside the control or influence of engineers. The USGBC's LEED® rating system for example, prior to its most recent version release, awarded all energy points only on "regulated" loads, effectively ignoring a large energy-consuming end-use in many buildings.

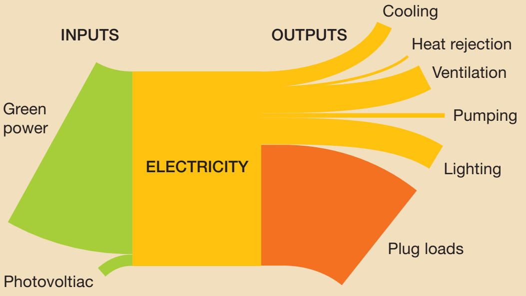
Realising the impact of these loads on Y2E2's performance, Arup argued strongly for both better understanding of the potential opportunity and the need for more informed design criteria, and the team expended significant effort identifying and characterising the equipment planned for the building. Discussions with the incoming occupants and Stanford focused on opportunities for reducing these loads, including:

- occupant habit, education, and load budgeting
- proper sizing through appropriate design margins and diversity (instead of typically excessive assumptions)
- establishment of a preferential purchasing/leasing policy where standards exist (eg EnergyStar V4, EPEAT)
- informing laboratory equipment manufacturers about a preferential purchasing intent
- consumer alliances with the University of California and other university partners
- optimising the number and location of equipment for shared use.

The benefits were identified to include:

- reduced first cost by \$1-\$2/W/ft²
- operational cost savings on a direct basis/W/hr avoided
- improved occupant comfort in naturally ventilated areas.

9. Energy flow, highlighting the potential opportunity and risk of high plug loads in Y2E2.



Natural ventilation

Stanford's temperate climate is ideal for the passive conditioning and ventilation of buildings by natural airflow (Fig 10), and over the past half-century the campus had incorporated natural ventilation in several buildings that could have otherwise have been mechanically conditioned. Not all were successful, however, and from the start of Y2E2's design the team was challenged to find a meaningful solution that incorporated lessons from the past successes and failures.

Arup studied existing buildings on the campus and gathered feedback from past and present occupants and designers.

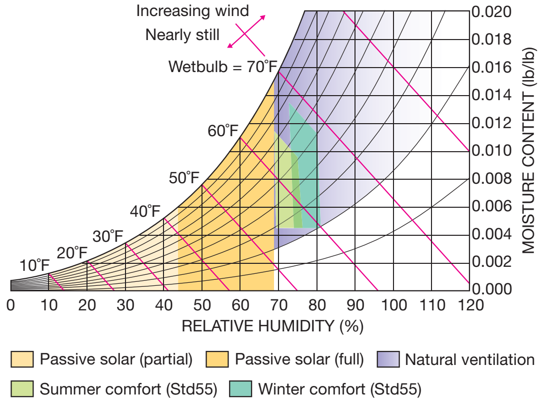
Over 30 lessons from this study were then applied to the design and operational intent of the Y2E2 natural ventilation system, including:

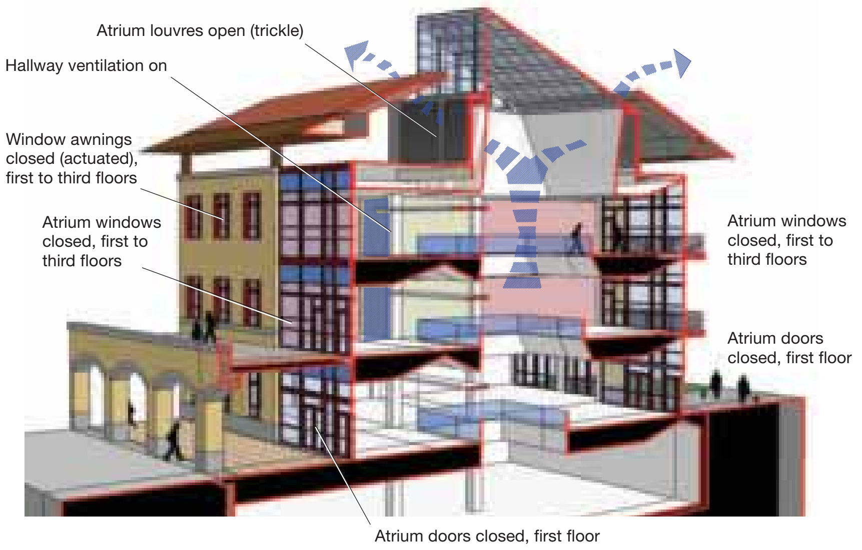
- seeking opportunities for passive redundancy (no single point of failure)
- avoiding poor quality and low-bid design/ construction practices
- ensuring maintenance and facility personnel buy-in
- clarifying occupant expectations, programme assumptions, and education
- capitalising on the reduced risk of north and east solar orientations.

Adaptive comfort and transitional zones

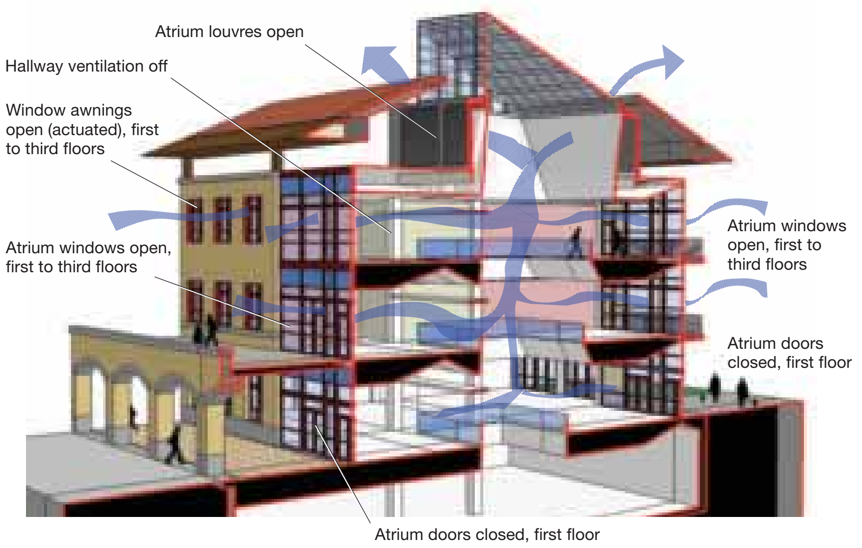
Early in masterplanning SEQ2 and the conceptual development of Y2E2, the team developed a scheme of "thermal transitioning". By providing a progressive transition from areas with the most intense temperature and sunlight and greatest occupant transience to those of least temperature variance and regular occupancy, the team could reduce energy consumption from air-conditioning but still ensure a comfortable workplace. As occupants pass from the unprotected open quadrangle, to the shaded outdoor arcade, to the naturally ventilated indoor atria, and finally into their offices and meeting areas, they move gradually toward increasing comfort, reduced thermal variation, and more regular occupancy.

10. Bioclimatic psychrometric chart, showing climate and natural ventilation comfort potential at Stanford.





11. Natural ventilation control scheme in cooling mode at temperatures above 82°F. In this mode the building management system (BMS) closes actuator-controlled windows and initiates messages to occupants to manually close their windows.



12. Natural ventilation control scheme in night flush mode, in which the BMS opens actuator-controlled windows and initiates messages to occupants to manually open their windows.

As the occupants expressed a desire for operable windows and natural ventilation, Arup summarised for them the implications of newly-released adaptive comfort criteria based on work by Brager and deDear[2]. Occupants who could control their own environment and had a direct connection to the outdoors were shown conclusively to be more tolerant of temperature variation. Through computational analysis Arup was able to demonstrate that select offices with adequate solar protection could maintain comfortable conditions with no mechanical cooling or forced ventilation.

Solar response

Recognising that effective passive conditioning and ventilation were possible with the four atria, and occupant buy-in, Arup and Boora worked to optimise the façade and space layout. The application of natural ventilation as opposed to mechanical conditioning corresponded strongly to solar orientation. After more detailed analysis, the team decided that the north and east-facing areas abutting the perimeter wall and receiving the least solar gain could be purely naturally ventilated. South and west areas would function in a mixed mode, with supplemental active chilled beams and operable windows.

The building's operable windows were designed as recessed (or "punched") windows and then treated, based on orientation, to minimise solar gain and enhance natural light penetration. North-facing windows have vertical and horizontal mullions near flush with the glass. East-facing windows have vertical mullions that extend the depth of the recess and work in concert with that recess to shade the glazing from oblique sun angles. West-facing windows have extended vertical and horizontal mullions, whilst south-facing windows have extended horizontal sunshades in place of the horizontal mullions. The south-facing sunshades protect the glass and deflect light into the room through transom windows.

Control

Given the potential strength of airflow through all the atria openings, a strategy was needed to manage the velocity while maintaining enough passive draw during warm, windless conditions to move adequate air through the building.

The result was a combination of motorised and manual operable windows combined with motorised louvres.

Through the building management system (BMS), the motorised windows open and close when interior temperatures reach a pre-set point relative to outdoor temperature, providing fresh air to all levels of the atria as well as cooling the corridors. Simultaneously, manually operable windows and ceiling fans provide and circulate fresh air to and through offices at occupant discretion. The release for all air entering the building in both ways is in the glass atria caps, which have louvres on all four sides. A rooftop wind speed and direction monitor tells the building which louvre dampers need to open and close.

In windy conditions, louvres downwind of the atrium cap open, creating negative pressure to draw air out of the building which in turn creates more draw to pull more air out. When there is no wind, all louvres open. For further control, the atria louvres can modulate their positions.

14. Rooftop motorised louvres.

Occupant control of the operable windows was a source of significant discussion and analysis during the project design. Numerous control strategies were assessed for cost and benefit, including motorised building control with occupant override, manual control with contact strip lock-outs, and visual indicators.

Due to the commitment of the occupants and lowest first cost considerations, visual indicators in the form of BMS-initiated messages to occupant computers were selected for Y2E2, along with a move-in user guide for all the occupants.

This is the first of nine major buildings under construction at Stanford, and it is important to note that successive projects have elected to incorporate manual windows with contact strip lock-outs due to differences in occupancy commitment and Arup's recommendations to minimise the potential for energy leakage in mixed mode areas.

Night flushing

With a typical day-to-night temperature swing of <25°F, Y2E2 benefits from the ability to circulate nighttime air through the building fabric and release heat accumulated during the day. To facilitate the effectiveness of night flushing in the natural ventilation (and mechanical ventilation) sequences, thermally massive floor surfaces have been exposed in many areas. The digital control system combines readings from internal and external temperature sensors and then uses the motorised windows to allow cool air in.

Arup provided two options for night flushing control: one of sophisticated and optimal performance which, among other features, anticipates the next day's temperature based on the previous day's (or weather forecasts), and a simplified version based on instantaneous temperature readings and a single interior setpoint.

Active chilled beam technology

While relatively new in North America, active chilled beam systems are proven and popular in Europe and elsewhere. Unlike traditional "all-air" conditioning systems that provide both ventilation and cooling through a primary duct or ducts, active chilled beam systems decouple ventilation from conditioning, transferring most of the cooling and heating loads from the less efficient air distribution system (fans and ductwork) to the more efficient water distribution system (pumps and piping). The benefits are typically:

- reduced energy consumption and operating costs
- Smaller AHUs and ductwork (typically 60-80%)
- reduced floor-to-floor height (or conversely an increase in glazing head height and resulting daylight penetration)
- increased chilled water system output due to higher return water temperatures.

The building's ventilation air is supplied to the active chilled beam terminal units by the central air-handling system. This ventilation air is cooled or heated to partially handle the temperature-driven sensible loads; in the summer it is cooled/dehumidified enough to handle all the internal moisture-driven latent loads.

The ventilation air is introduced into the active chilled beam through a series of nozzles or holes - up to nine nozzles/ft (28 nozzles/m) of beam. Air passing out of the nozzles induces or "pulls" room air up into the active chilled beam and in turn through a water coil. Induced room air is cooled and/or heated by the water coil to the extent needed to control the room temperature. Induced room air is then mixed with the ventilation air and the mix discharged into the room.

In general, the central system is designed to circulate only so much air as is needed for ventilation and dehumidification; the active chilled beams provide the additional sensible cooling and/or heating required through the induced room air and water coil. The amount of primary air circulated by the central system is thus dramatically reduced, along with the size of the AHUs and ductwork.

Fan energy has been shown to be often second only to lighting in the energy consumption of typical commercial buildings in North America. Active chilled beam systems dramatically reduce the fan energy due to the relatively small amount and low pressure of the primary air circulated by the central system.

13.

Daylighting

The campus benefits from abundant sunlight; the average direct solar insolation level of 5.4kWH/m² actually exceeds that of more southerly locales such as Houston, Texas, and is very consistent throughout the year. But although this ample sunlight is available, the team faced significant challenges:

- The masterplan dictated a building cross-section of 80ft (24.4m), ie 30-100% wider than the ideal of 40-60ft (12.2-18.3ft).
- The building's square footage, combined with the campus height limit, dictated that an entire floor would need to be below grade, forming a basement.
- The demands of faculty offices forced the partitioning of the interior with walls.
- The building's passive natural ventilation and energy efficiency goals required a high degree of solar control, especially on the west and south exposures.

The full design team worked to develop responses that included:

- skylighting the building core using the atria
- façade and room treatments to control sunlight and extend it into the interior
- seamless integration with dimmable lighting and task lighting
- basement light wells along the south exposure
- material selection to promote translucency in the interior.

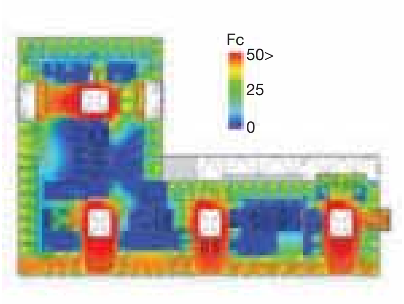
The result is a building with significant views and transparency, daylighting for approximately 60% of the occupied floorplate (including the basement level), and very little artificial lighting during the day. Indeed, during a campus-wide power outage six months after opening, many occupants failed to realise any disruption.

15. The atria deliver light to all floors including the basements.

Modelling of multiple physics

Over 60 computational models were created and run for Y2E2, reflecting 2500+ hours of computer time and ancillary analysis. This enabled the team to develop successfully many of the building's critical design elements, including the atria, naturally ventilated perimeter, daylighting systems, passive smoke evacuation, and range of energy-saving technologies. The models were also critical to cost/benefit decision-making, helping to ensure that capital investments were well informed.

16. Daylighting + illuminance model (level 2).



Daylight modelling allowed the team to better understand the effect of daylight harvesting techniques and the scope of dimming controls for the artificial lighting system. Thermal comfort modelling clarified the daylighting and ventilation requirements, to the benefit of future occupants. Acoustic modelling helped to mitigate issues of noise break-in to the atria from the rooftop mechanical systems, and examined the effect of the rooftop visual screening parapet for reflection of rooftop mechanical noise into the quadrangle below. Finally, the atrium interior acoustics were modelled to establish the locations, amount, and type of treatments needed to control background noise levels and reverberance in the atria and adjacent spaces.

Computational modelling for Y2E2 included:

- daylight (Boora, Arup) (Fig 16)
- energy (Arup)
- natural ventilation CFD (Arup)
- lab stack exhaust (Ambient Air Technologies)
- passive smoke evacuation CFD (Arup)
- Comfort CFD (Arup)
- rooftop noise mapping (Arup)
- atria acoustics (Arup).

Skylighting

By delivering light to all floors including the basement, the atria optimise the abundant daylight that penetrates the building, with the glass caps distributing natural light by reflecting it off wall surfaces. The building is designed to bring this direct sunlight down to the basement level for those using the labs, while lighting the floors above.

Side lighting

In addition to top-down light distribution, the team worked to optimise the amount and intensity of natural light entering through the perimeter. The design maximised Y2E2's length east-west, providing significant north and south façade exposure. Tailored shading and glazing strategies were used for each façade exposure. Vertical mullion caps on the east and west façades aid in shading. This, combined with high performance low-e glazing, was used to control the admittance of direct sunlight and the associated heat gains.

The north façade glazing uses high performance low-e glazing as well; however, visible light transmittance (VLT) here is highest, direct sunlight not being a concern on this face of the building. The high VLT maximises the ambient daylight available to the north- facing rooms, without compromising visual comfort. By contrast, the south façade receives significant direct sunlight throughout the year.

With Palo Alto's predominantly clear sky climate, a strategy combining external sunshades and internal light shelves optimised the distribution of daylight in the rooms on the south side, and integrated with the reduced loads needed by the building's mixed mode mechanical system.

In addition to thermal shading, the external sunshades block direct sunlight entering the windows for much of the year. In winter, when the sun is at low altitude angles, the glazing below the sunshades has a relatively low VLT, to mitigate intensity of direct sunlight. Internal light shelves help distribute daylight into the spaces by reflecting incident direct sunlight off the ceiling. The light shelves are in the same horizontal plane as the external sunshades, above which the windows extend far enough to permit the required daylight. Higher VLT glazing above the shades maximises the available direct sunlight to the top of the light shelf, enhancing the reflected light. Lower level roll-out shades have been installed on the south and east for conditions that cannot adequately be addressed by fixed shades and light shelves alone. Additionally, the light shelves continue past the edges of each window to aid in mitigating direct sunlight through the high VLT glazing.

The energy strategy

Energy provision was addressed through a step-by-step storyline that simultaneously organised, simplified, and prioritised the University's investment (Fig 17). The energy story emphasised load reduction, passive operation, and efficiency (steps 1-3); sought out energy recovery opportunities (step 4); included self-generation (step 5); and allowed for successful carbon-neutral operation (step 6).

As a result, Y2E2 is predicted to use 50% less energy* and achieve a return on investment of up to 36%, as well as be more enjoyable to visit. In response to its success, Stanford University has since mandated that this energy and sustainability performance be pursued on all subsequent buildings in SEQ2. Energy used in buildings generates an estimated 70-75% of Stanford's carbon emission, the remainder from vehicles. With the energy reduction projected for Y2E2, the design and those it inspires will greatly reduce Stanford's carbon footprint.

A complete list of strategies implemented in each step is shown on the right. Select examples have been extracted and summarised as follows:

Step 1: Reduce

Office loads: Receptacle loads directly consume electrical energy and indirectly increase the energy consumption of conditioning systems. As a result, they were a highly leveraged opportunity at Y2E2 for integrated cost savings and further energy efficiency. Repeated efforts were made during the design to rationalise receptacle load assumptions, establish budgets for future use, and allow the University to commit to a procurement policy for campus-wide performance improvement.

Reduce leakage: Spray-in insulation, typically in a thin layer into open wall, ceiling, and floor cavities, expands to about 100 times its original volume, forming an air barrier. It is then trimmed flush with the framing members before drywall is installed.

Step 2: Make passive

Mixed-mode operation: Although approximately a third of the floorplate is purely naturally ventilated (no supplemental cooling), the remaining non-lab areas of the building a mixed-mode operation that allows building occupants to open their windows during temperate conditions.

Step 3: Make efficient

Chilled beams heat and cool the conditioned non-lab areas of the building; active chilled beams utilise the more efficient water distribution system (pumps and piping) instead of the less efficient air distribution system (fans and ductwork).

Step 4: Recover

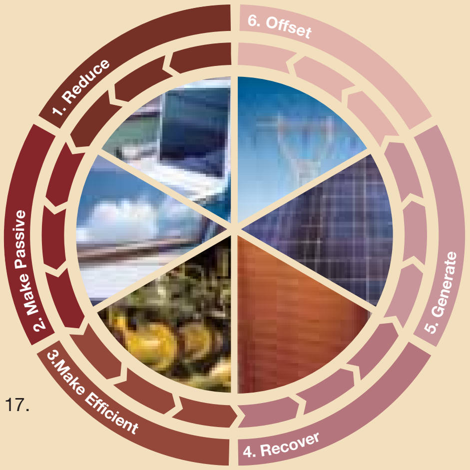
Heat pipe: Laboratory exhaust air is used to pre-condition incoming air. Using a physically separated passive solution that does not depend on moving parts avoids cross-contamination and significantly reduces maintenance.

Step 5: Generate

Monocrystalline PV: Y2E2 features a PV system with space for four arrays, of which three are installed on the south-facing roof. They produce 12.5-14.5kW at their peak and could deliver 16.5-18.5kW with the fourth system installed.

Step 6: Offset

Community reinvestment: This being a laboratory building, full site generation was not feasible. The desire to achieve carbon neutral operation has prompted the campus to seek further opportunities through purchased offsets and community reinvestment.



17.

1. Reduce
- office loads
- office size
- education
- lighting power
- lab process loads
- lab airflow rates
- hood density
- insulation
- reduce leakage
- shade
- punch windows
- thermally break
- low-E glazing.

2. Make passive
- incorporate atria
- naturally ventilate
- mixed-mode operation
- expose mass
- daylight
- transfer boots
- light shelves
- open interior
- translucent interior
- light colours.

3 Make efficient
- chilled beams
- radiant floor
- low pressure air
- ceiling fans
- daylight dimming
- monitoring
- cogeneration service
- water-cooled computer rooms.

4. Recover
- heat pipe.

5. Generate
- monocrystalline PV
- polycrystalline PV
- amorphous thin film PV
- fuel cell tie-in (future).

6. Offset
- purchased offsets
- community reinvestment.

Photosensors adjust the electric lighting in offices adjacent to the façades in response to the available daylight, giving appropriate levels for task lighting under any daylight condition. Translucent partition walls allow the daylight harvested in the perimeter spaces to spill into adjacent corridors, providing a visual connection to the outdoors, as well as an architectural link to the bright, daylit atria.

Complementary daylighting and task lighting

The engineered light shelves and exterior shades optimise the provision of daylight in the building, but the electric lighting must be tuned to work harmoniously with variations in natural light, creating a holistic and non-distracting system. Y2E2 does just this. A combination of task lighting and architectural lighting work seamlessly with the daylight. A combination of indirect and direct architectural lighting in the offices achieves the minimum recommended illuminance levels. Additional LED task lights or LED under-cabinet fixtures add supplemental lighting to meet users' needs. Architectural lighting power densities are very low, and the LED task lighting operates with only 6W.

The architectural lighting is controlled through a combination of photosensors and occupancy sensors, the former controlling the lighting in response to available daylight while the latter ensure that the architectural lighting turns off when occupants leave the room. Reports from staff indicate that the task lighting is the source of choice when no natural light is available, and that the architectural lighting in private offices is typically not required. The translucent partitions also allow a level of ambient light into offices from adjacent corridors.

18. Engineered light shelves and exterior shades optimise the provision of daylight in the building,

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* Energy comparison uses a baseline significantly more rigorous than the national average (ASHRAE 90.1-2004). Saving predictions are 42% including process loads and 56% excluding process loads.

The water strategy

As a campus in a Mediterranean climate with frequent water shortages - and recognising that water would soon be a limiting factor in its continued development - Stanford chose to aggressively pursue both water efficiency and alternative water sources.

To address the water performance goals meaningfully, the team took a similar approach to that for energy; a step-by-step storyline that simultaneously organised, simplified, and prioritised the University's investment (Fig 19). This emphasised reduced water use in (1) landscaping and (2) the building; (3) reclaimed water use; (4) greywater capture and storage; (5) rainwater capture and storage; and (6) water use offsets.

The building is thus predicted to consume 2M gallons less water per annum and achieve 90% reduction in fixture potable water use*. Partly resulting from the Y2E2 and SEQ2 work, Stanford has invested in a reclaimed water system to serve over 2Mft^2 (186 000m^2) of development and reclaim approximately 60 000 gallons of water per day for non-potable use.

A more complete list of strategies implemented in each step is shown on the right. Select examples have been extracted and summarised as follows:

Step 1: Reduce site use

Native and low water-consuming vegetation were incorporated, historic oak trees were saved and replanted, planted areas were minimised in favor of high benefit zones, and the little water needed for irrigation is sourced from rainwater captured in the gravity-fed Felt Lake reservoir.

Step 2: Reduce building use

Low water consumption WCs (1.28gal/flush) and urinals (0.125 gal/flush) were installed. Also, one waterless urinal was installed in each men's toilet room. Since the campus central energy facility (CEF) evaporates water in cooling towers to condition the campus buildings, savings from reduced cooling load were three to six times the savings from building fixtures.

Step 3: Reclaim water

Water for cooling in the CEF is captured, treated, and piped for laboratories and flushing. Designed under a separate project, but concurrent with Y2E2, was Stanford's on-site water treatment plant and site piping system. To help sustain itself within the natural limits of its environment, and to contribute to the conservation of potable water resources, this recycled or CEF water Is piped into Y2E2 specifically for flushing water closets and urinals (as well as potential use in laboratories if quality is deemed sufficient).

Step 4: Greywater capture

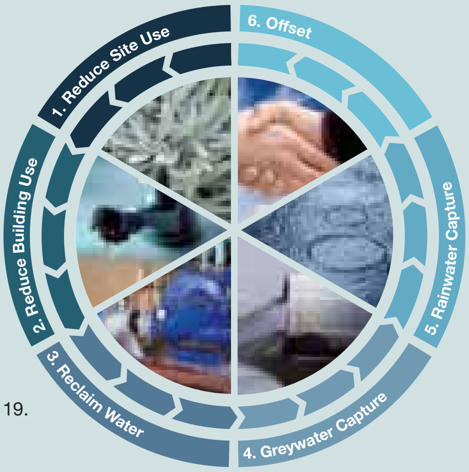
The team carried a greywater capture and treatment option for the early project phases, but once the reclaimed CEF water was confirmed, this option was eliminated.

Step 5: Rainwater capture

Although a below-grade stormwater capture, storage, and treatment system was designed in, it was deleted during early construction phases. A successor building (the Stanford Graduate School of Business) is, however, incorporating a similar rainwater capture element.

Step 6: Offset

The team recognised that some potable water would always be consumed and that better leverage could be achieved by reinvesting in other campus buildings and the surrounding community. In exploring a net zero water operation the team has considered further such opportunities.



19.

1. Reduce site use
- native and low water consuming vegetation
- historic oak trees saved and re-planted
- planted areas were minimised
- water for irrigation sourced from rainwater captured.

2. Reduce building use
- low water consumption WCs
- savings from reduced cooling load.

3. Reclaim water
- Water used for cooling is captured, treated, and piped through campus for laboratories and flushing.

4. Greywater capture
- A greywater capture and treatment option for the early project phases was undertaken. Once reclaimed water from the CEF was confirmed, greywater capture was eliminated.

5. Rainwater capture
- A future phase, below grade capture, storage and treatment system was included.

6. Offset
- Community reinvestment.

Cost

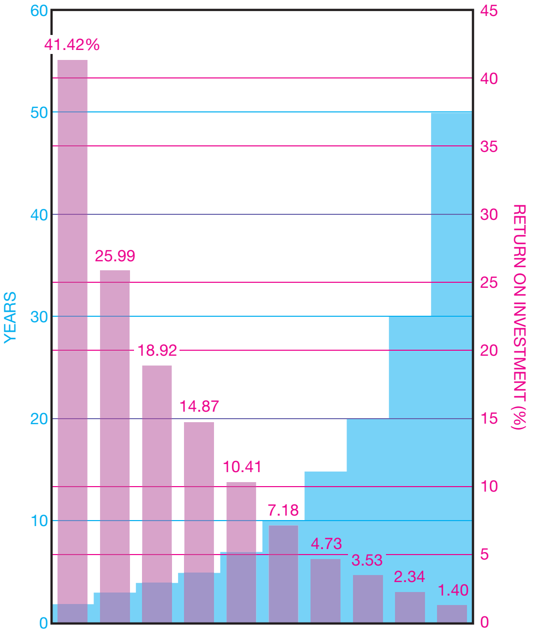
In an era of global economic development and trade, increased material demand has dramatically inflated construction costs. If demand is the first factor in the numerical rate of inflation, time is the second factor of the compounded inflation rate. Design teams are under pressure to innovate, as shorter building delivery time means reduced cost. "Faster = cheaper" is a new mandate for design/construction teams. At the same time, when the built environment is implicated in 40% of all US energy use, and energy generation, use, and conversion are in turn implicated in rising greenhouse gas emissions, building design and construction must meet increasingly high quality levels and performance targets.

The sustainability premium

During the design and construction of Y2E2, the team closely tracked and discussed the sustainability premium associated with the project. Individual design elements were broken out of the cost estimate and summed to establish a net sustainability premium (Fig 20). Its progression started from an early estimate of a 9% premium to a final estimate of a 0.9-4.6% premium. This range, agreed at the conclusion of the project in lieu of a single number, reflected the integrated design.

So much of the design served multiple functions that the assignment of a particular design element to the sustainability sum would have suggested a false accuracy. Instead, the range allowed for both liberal and conservative estimates. The resulting knowledge was more valuable than if a single % premium had been agreed.

Stanford's commitment to sustainability was demonstrated when the initial high estimate of 9% did not result in a reduction in the project goals. Instead, the team



20. Return on investment versus paybacks.

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* Calculated in comparison to the Energy Policy Act of 2005.

was encouraged to work through the ensuing phases, reducing the premium but maintaining the aspirations. Between the first and final estimates, misunderstandings of the design intent were resolved, inaccuracies in the cost estimate were addressed, the design team improved and optimised the design, the contractor suggested enhancements, and the owner made some value-based decisions.

12+% return on investment

To encourage sustainable design practices and a high return on their investment, the Stanford board of trustee's life-cycle policy mandates that any strategy that pays back in 10 years or less must be pursued. Those that will pay back in 10+ years will be considered at the discretion of the project team. Y2E2 will recover the marginal costs of measures in its design in just six years, well under the 10-year benchmark and yielding 12+% return on investment. This cost recovery will come from savings due to less energy use as well as reduced first costs in select integrated systems (Fig 21).

Integrated design/construction team

Stanford's compressed schedule reduced the time available to design and construct each building from four to two years, and so an integrated team of architects, landscape designers, engineers, university stakeholders, contractors, and subcontractors address each building comprehensively, overlapping programming, design and construction phases to deliver each project as rapidly as possible.

The involvement of construction manager/general contractor Hathaway Dinwiddie enabled real-time costing and ensured that the contractors were invested in the design from the outset. This enabled tremendously valuable constructability counsel and secured contractor buy-in during design in support of the project goals.

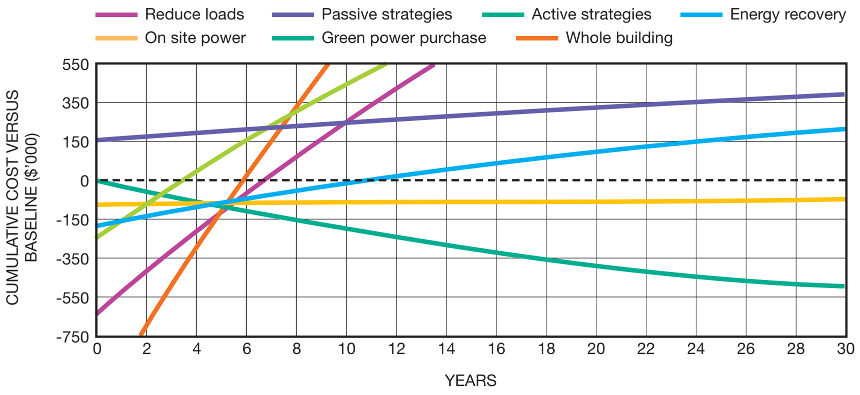
Cost savings on the precast concrete skin

The façade of limestone tiles preset in precast panels gives a consistent campus architectural expression. Importantly, it also enabled project delivery within its modest cost/ft^2 target and aggressive schedule, as it reduced construction time by over 40%.

Using these panels was significantly quicker than traditional hand-setting, installation being completed in eight weeks instead of the customary 20-24 for hand-set limestone. Much of the material cost inflation was avoided; also, fewer workers and less equipment were needed to install the panelised limestone, further reducing costs. This accelerated process imposed little critical path impact on other trades, as field crews were not on site for a long time installing panels.

The precaster further reduced costs by incorporating as many elements as possible into the panels. Window connections to them, and hardware to attach the metal window sunshades, were all installed in the plant, eliminating the need to do this on site. Additionally, because the limestone veneer and architectural detail elements were incorporated in the panels, extra steel support was not needed, further reducing overall costs for the exterior cladding.

21. Cost payback (intersection with the horizontal axis) for the six energy steps, as well as a "whole building" sum.



Conclusion

Officially dedicated on 4 March 2008, the Y2E2 building is named for Stanford Trustee Jerry Yang, co-founder of Yahoo! Inc, and his wife Akiko Yamazaki, who together pledged $75M to enhance interdisciplinary programmes at Stanford. The result is a fitting tribute to this philanthropic couple and the perfect workplace for the environmental and energy specialists who inhabit it.

Kurt Graffy is an Associate Principal of Arup in the San Francisco office, and the Americas regional skills leader for audio and audiovisual. He led the acoustics team for the Y2E2 design.

Janette Lidstone is a marketing specialist for Arup in the San Francisco office.

Cole Roberts leads the Energy and Resources business in Arup's San Francisco office. With Alisdair McGregor he led the project management/direction of Arup's Y2E2 design team, and also led the energy/sustainability assessment.

Brandon G Sprague is Communications Director at Boora Architects, Inc.

Jake Wayne is a lighting design consultant of Arup in the San Francisco office, and was a member of the lighting design team for Y2E2.

Armin Wolski is an Associate Principal of Arup in the San Francisco office, and led the fire safety design for Y2E2.

Credits

Client: Stanford University **Architect:** Boora Architects, Inc **MEP, energy/sustainability, fire/life safety, and acoustic consultant:** Arup - Key Anderson, Engin Ayaz, Peter Balint, Andrew Coles, Angus Deuchars, Joseph Digerness, Michael Dimmel, Jason Edling, Larry Encarnacion, Chris Field, Anthony Fresquez, Kurt Graffy, Gene Joves, Amit Khanna, Susan Lamont, Shaun Landman, Jun Lautan, Isabelle Lavadrine, Kathryn Lee, Dee Lindsay, Alisdair McGregor, Afaan Naqvi, Shruti Narayan, Tim Pattinson, Jason Prodoehl, Benedicte Riis-Duryea, Cole Roberts, Norman Romabiles, Geza Szakats, Larry Tedford, Jake Wayne, Matthew Williamson, Armin Wolski, James Woods, Darren Woolf **Structural engineer:** Middlebrook + Louie **Civil engineer:** BKF **Wind consultant:** Ambient Air **General contractor:** Hathaway Dinwiddie Construction Co **Landscape architect:** Hargreaves Associates **Electrical contractor:** Cupertino Electric Inc **Mechanical contractor:** ACCO **Laboratory consultant:** CAS Architects, Inc **Plumbing contractor:** Hellwig Plumbing + Greene Engineers **Controls contractor:** ICS Controls Inc **Illustrations:** 1, 3, 4, 6, 8, 14-15, 18, 22 Tim Griffith; 2 Boora Architects; 5, 7, 9, 11-12, 16-17, 19 Arup; 13 TROX®; 10, 20-21 Nigel Whale.

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Acknowledgment

We are grateful to Boora Architects for supplying some of the content for this article; Boora's collaboration has been invaluable throughout the life of this project.

About Arup

Arup is a global organisation of designers, engineers, planners, and business consultants, founded in 1946 by Sir Ove Arup (1895-1988). It has a constantly evolving skills base, and works with local and international clients around the world.

Arup is owned by Trusts established for the benefit of its staff and for charitable purposes, with no external shareholders. This ownership structure, together with the core values set down by Sir Ove Arup, are fundamental to the way the firm is organised and operates.

Independence enables Arup to:

- shape its own direction and take a long-term view, unhampered by short-term pressures from external shareholders
- distribute its profits through reinvestment in learning, research and development, to staff through a global profit-sharing scheme, and by donation to charitable organisations.

Arup's core values drive a strong culture of sharing and collaboration.

All this results in:

- a dynamic working environment that inspires creativity and innovation
- a commitment to the environment and the communities where we work that defines our approach to work, to clients and collaborators, and to our own members
- robust professional and personal networks that are reinforced by positive policies on equality, fairness, staff mobility, and knowledge sharing
- the ability to grow organically by attracting and retaining the best and brightest individuals from around the world - and from a broad range of cultures - who share those core values and beliefs in social usefulness, sustainable development, and excellence in the quality of our work.

With this combination of global reach and a collaborative approach that is values-driven, Arup is uniquely positioned to fulfil its aim to shape a better world.

22. The west face of Y2E2 both suits the Stanford historical character and works with the natural environment, as window louvres, a shaded arcade, and green space improve the experience for visitors.