PROJECT REPORT

NEW BUILDING EFFICIENCY EVALUATION AT UC DAVIS

At Gallagher Hall, UC Davis, California

Western Cooling Efficiency Center-UC Davis

October 31, 2012

WESTERN COOLING EFFICIENCY CENTER

UCDAVIS
UNIVERSITY OF CALIFORNIA

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ABOUT THE WCEC

The Western Cooling Efficiency Center was established along side the UC Davis Energy Efficiency Center in 2007 through a grant from the California Clean Energy Fund and in partnership with California Energy Commission Public Interest Energy Research Program. The Center partners with industry stakeholders to advance cooling-technology innovation by applying technologies and programs that reduce energy, water consumption and peak electricity demand associated with cooling in the Western United States.

ABOUT SPEED

The State Partnership for Energy Efficient Demonstrations (SPEED) program drives the market adoption of energy efficient technologies as a part of California's commitment to a clean energy future. Managed through the California Institute for Energy and Environment (CIEE), SPEED has been highly successful in conducting more than 100 demonstrations and other technology-transfer projects to showcase the benefits of best-in-class technology solutions in installations across the state. SPEED is a program of the Public Interest Energy Research (PIER) program of the California Energy Commission.

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1. OVERVIEW

Gallagher Hall and Conference Center at UC Davis

DEMONSTRATION ENERGY HIGHLIGHTS	
Source EUI (Gallagher Hall)	101 kBTU /sq. ft.
Source EUI (CBECS Building Average)	180 kBTU /sq. ft
% of total energy supplied by Solar Energy	20%
Source EUI savings vs. similar buildings	**49% (Compared to CBECS average)**

Gallagher Hall and Conference Center is an 86,000 square-foot building at the University of California Davis. The building, opened in 2009 houses the Graduate School of Management and contains a mixture of classrooms, office space and conferencing facilities. The building is located outside of the central campus and does not have access to the campus district heating and cooling systems. This presented a challenge to the designers – but also an opportunity to think creatively and design a building for high efficiency from the ground up. The result was a building design that achieved LEED Platinum recognition. Many systems and design features made this possible, but most can be grouped into three main categories – the radiant heating and cooling system, the dedicated outside air system, and the solar management features.

Solar loading is reduced with an innovative architectural rain screen on the building walls with solar exposure. The stone facade is separated from the main building envelope by up to 10 inches, which shields the envelope from solar radiation, and provides an insulating air bubble around the building. Spectrally reflective window film, a reflective white roof, and architectural window shading further reduces the solar load on the building. Solar panels on the roof generate a portion of the power used on site, when power generation exceeds demand the excess power is sold back onto the grid for others to use.

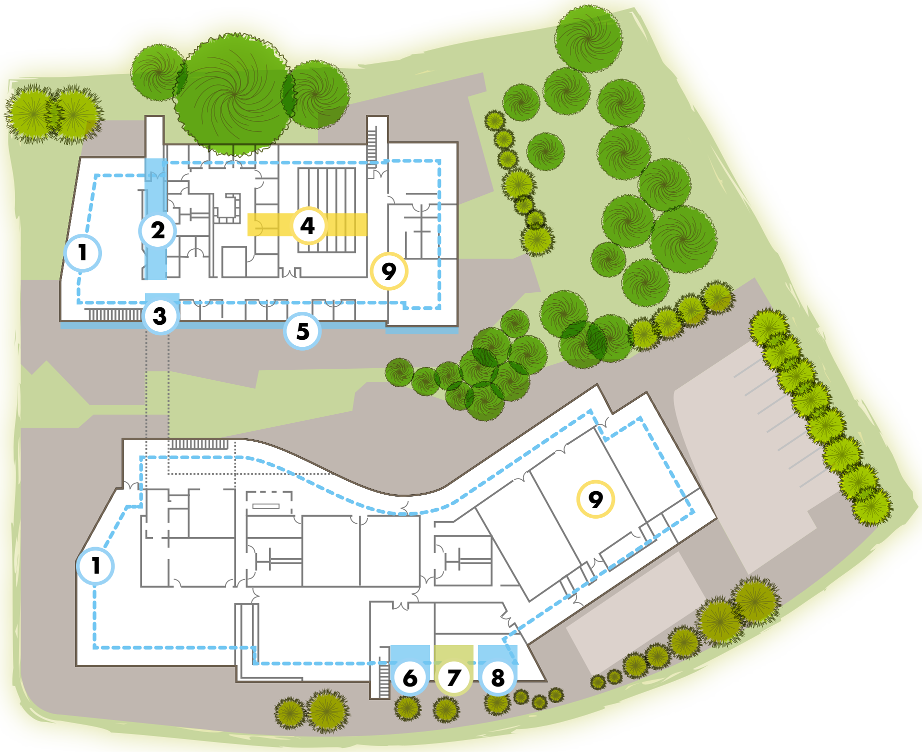
Gallagher Hall utilizes an innovative ground-coupled hydronic system to manage its space heating and cooling needs. By moving water instead of air, this system distributes thermal energy much more efficiently than a forced air system in a typical building. Heating and cooling is delivered through the cement slabs in the floor and ceiling, which act as large area radiant surfaces.

Eighteen miles of tubing are buried 16 feet beneath the building to exchange heat with the earth. This ground source heat exchanger provides a source of nearly constant temperature water for the conditioning equipment, and in some conditions can even be pumped directly through the building without additional heating or cooling energy. For additional cooling capacity the system includes an evaporative fluid cooler and chiller. A high efficiency condensing gas boiler and heat pump can provide additional heat.

Since the bulk of heating and cooling is provided by the radiant system, air distribution can be limited to only what is needed for indoor air quality. A network of sensors throughout the building monitor carbon dioxide concentrations and control the amount of fresh air according to demand. The dedicated outside air handlers take advantage of California's arid climate by cooling air with a high efficiency indirect evaporative system plus DX cooling when additional capacity is required. In humid conditions an active desiccant wheel removes moisture from the ventilation air to ensure that water does not condense on the radiantly cooled surfaces. Displacement ventilation techniques introduce fresh air at floor level through under-floor plenums on the upper floors.

**Compared to modeled building standards from a national average of this building type*

2. DESIGN & TECHNOLOGY



GALLAGHER HALL TECHNOLOGY MAP

LEGEND

1. Radiant system
2. Displacement Ventilation
3. Operable Windows
4. Light Well
5. Rain Screens
6. Chiller & Heat Pump
7. PV Inverters
8. Boiler/Hot Water Heater
9. Solar Panels

Figure 1: Gallagher Technology Map

MAIN TECHNOLOGIES AT GALLAGHER HALL

RADIANT HEATING AND COOLING

1. Radiant System
2. Chiller & Heat Pump
3. Ground Loop
4. Evaporative Fluid Cooler
5. Efficient Condensing Boiler

DEDICATED OUTSIDE AIR SYSTEM

6. Air Handler with Indirect Evaporative Cooling
7. Displacement Ventilation
8. Operable Windows

SOLAR MANAGEMENT

9. Solar Photovoltaic Panels
10. Photovoltaic Power Inverters
11. Rain Screen/Window Shading
12. Light Well Natural Lighting

Figure 2: Main technologies at Gallagher

Solar Management and Envelope Treatment

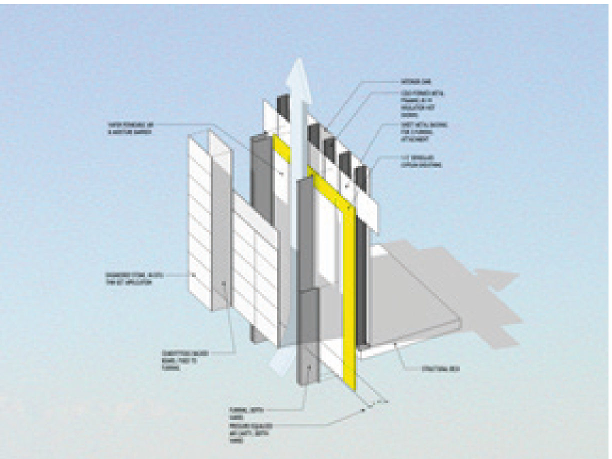
The northern valley California location experiences long summers that are dry and cloudless. Typically the last rains of the year will end in May and do not begin again until October. In the summer temperatures will typically exceed 100F for multiple days making air conditioning peak loads quite extreme. Due to these climatic conditions, solar management is an important consideration to reduce loads and multiple design elements were incorporated to take advantage of the abundant sunlight or to mitigate its effects.

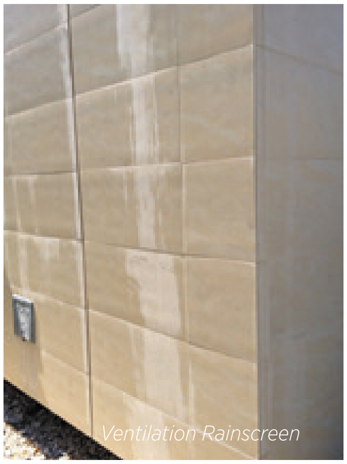
Solar Gain Management at Gallagher

SOLAR SHIELDING

Gallagher Hall uses passive solar shading elements around many of its windows to stop sunlight from directly entering windows when unwanted. Passive solar shading can be designed according to season and time of day to allow sunlight to enter the widow opening during winter months, or early morning and late afternoon, while blocking sunlight during summer months. The entrance of the building also exhibits the use of passive solar shading in its use of parallel grates that block light during the high noon hours, but allowing for unobstructed views perpendicular to the windows.

In addition to the architectural shading techniques, the windows were also treated with a solar control film. The product used blocked UV light, 85% of visible light, and rejected 71% of incident solar energy. This results in a solar heat reduction of 64%. With the large window areas on the exterior of the building this reduction is significant. In especially high solar isolation areas, such as the roof level conference room, patterned opaque window films were also used to the block sunlight.





Ventilation Rainscreen

VENTILATION RAINSCREEN

A second feature designed to mitigate the intense summer solar radiation and reduce the building load was the ventilated rain screen. The rain screen serves as the visible finished exterior of the building and is covered with a façade of stone in the high traffic sides of the building, such as the front entrance, and a similarly colored synthetic fiberboard façade on the rear and side walls. The rain screen forms what amounts to an offset solar shield offset from the wall by 4 inches on shaded building sides to 10 inches on the sunlit sides. The space has an open bottom and top allowing air to pass between the shield and the building. In this way an insulating layer of air is always present between the sun exposed exterior rain screen and the exterior wall. The insulating properties of this area are further enhanced because a portion of the previously conditioned air exhausted from the building flows through this space and is kept close the exterior of the building. This has the effect of heating the building when the weather is cold, and cooling the building when the weather is hot.

SOLAR PV ONSITE GENERATION

Solar PV array at Gallagher

Onsite solar PV generation was instrumental in allowing the building to achieve LEED Platinum certification and also displaces a portion of the electricity needed to be supplied by the grid. Yearly, the PV system generates roughly 3 times more power during summer months than during winter months.

Figure 3: Solar Production 2013

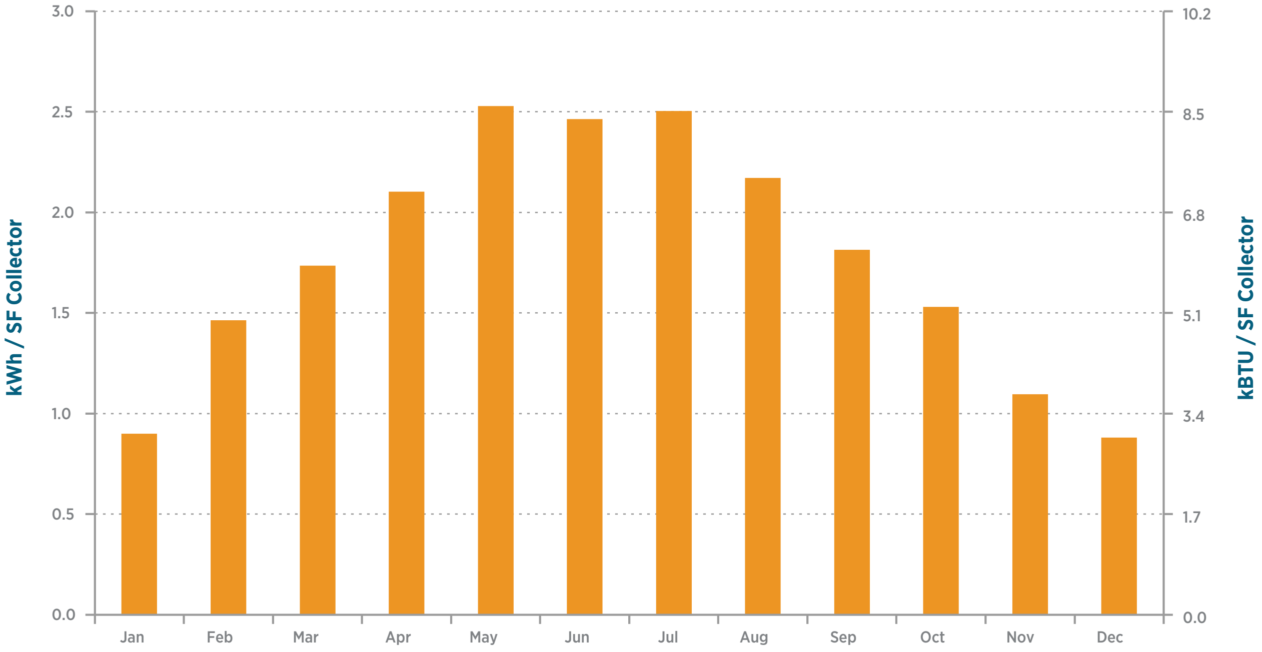
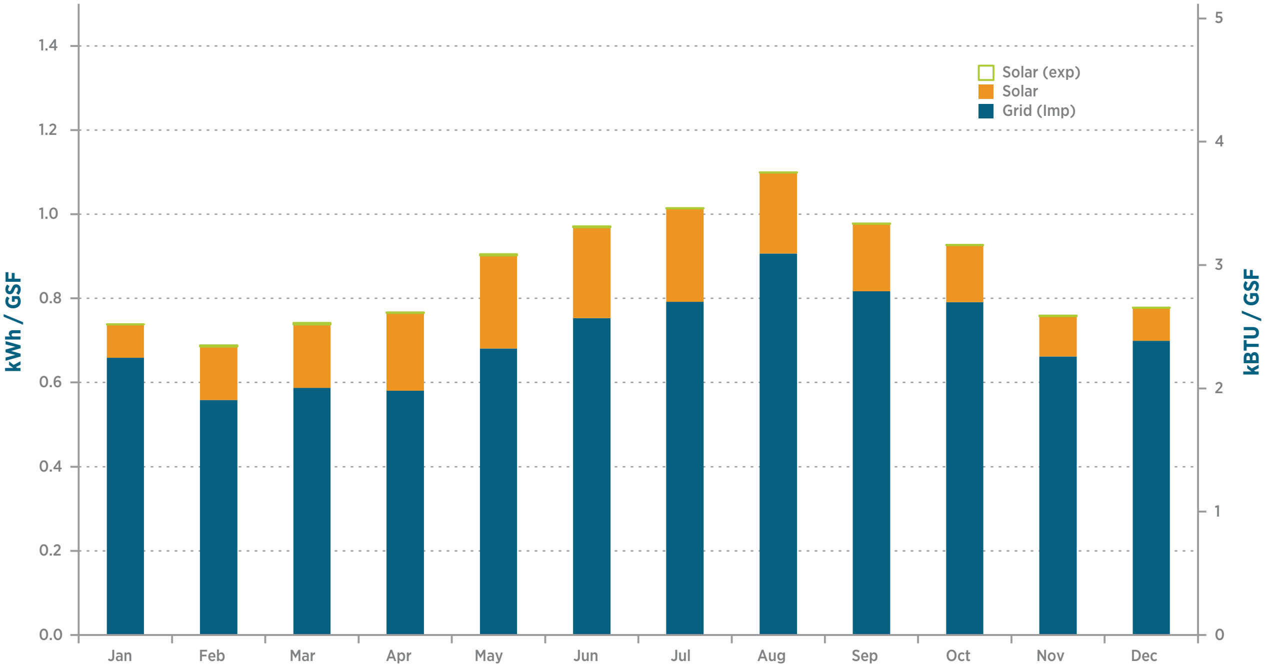


Figure 4: Electrical Consumption



The PV system generates roughly 20% of the total electricity used onsite, and can contribute up to 30% of electrical energy needed in summer months. The use of PV is especially advantageous in warm sunny climates because conditioning loads coincide well with peak solar production.

The solar production was able to be utilized onsite for all but a very small percentage of the year, only about 0.25% was exported the grid.

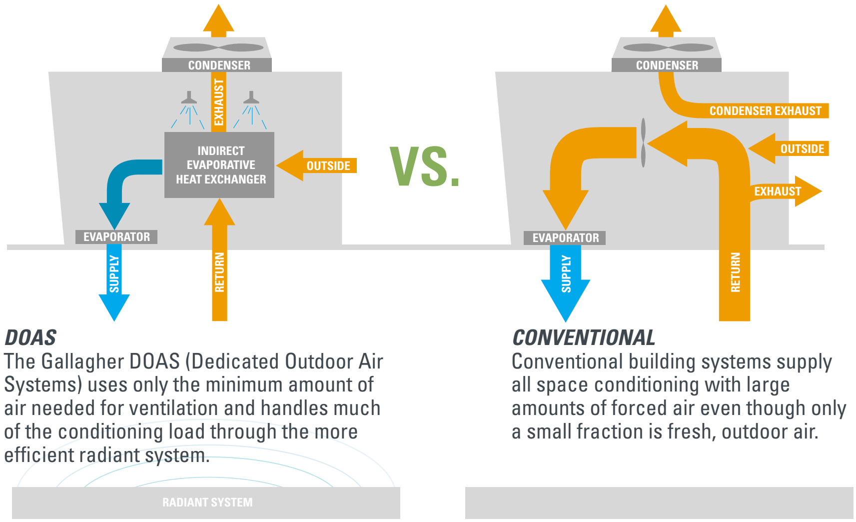
Building Conditioning System

Gallagher is a good example of a Dedicated Outside Air System (DOAS) ventilation design. Systems incorporating DOAS will attempt to separate sensible heating and cooling loads from latent loads associated with fresh air ventilation. The building makes use of a hydronic radiant system to provide building sensible heating and cooling needs, and a dedicated outside air system providing 100% outside air for building air quality needs. By de-coupling the ventilation latent loads from the sensible building conditioning loads, the ventilation system can be designed to move the least amount of air possible based solely on ventilation. Conventional forced air systems will circulate 4 to 5 times more air than that needed for fresh air ventilation to ensure that a consistent temperature is maintained in all conditioned spaces. However, moving excess air to maintain consistent temperatures is an energy intensive process that can be eliminated with the DOAS system.

DEDICATED OUTSIDE AIR SYSTEM WITH EVAPORATIVE COOLING

Ventilation needs are provided by three Munters Oasis EPX air handling units located on the roof of Gallagher Hall and the Conference Center. These advanced air handling units incorporate a heat exchanger section that serves to recover energy in the winter, and serves as an indirect evaporative cooling section in the summer to precool the outside air. After the outside air is preconditioned it can be mechanically cooled or heated further to achieve the desired supply air temperature needed. Two of the units also contain a desiccant wheel to maintain an acceptable humidity level inside the building so that the radiant cooling system can operate without condensation.

Figure 5: Dedicated outdoor air systems versus conventional systems

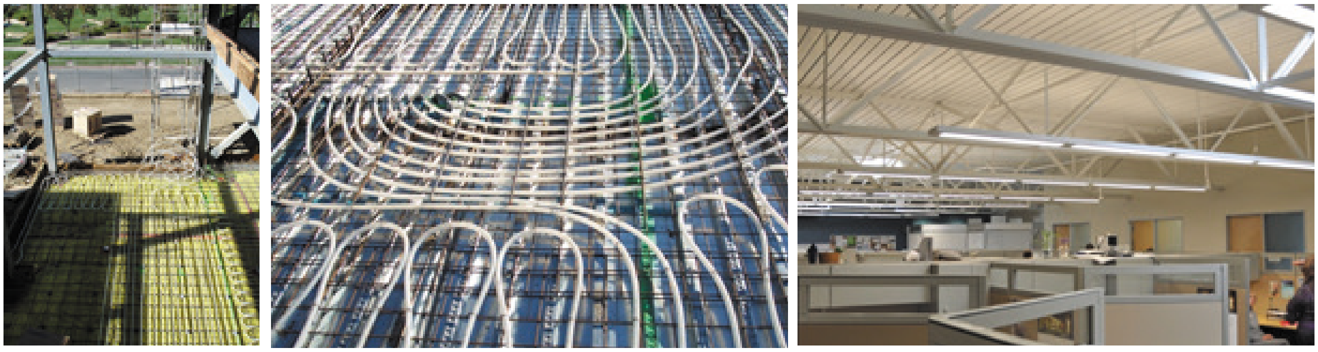


DOAS
The Gallagher DOAS (Dedicated Outdoor Air Systems) uses only the minimum amount of air needed for ventilation and handles much of the conditioning load through the more efficient radiant system.

CONVENTIONAL
Conventional building systems supply all space conditioning with large amounts of forced air even though only a small fraction is fresh, outdoor air.

Munters Oasis EPX Dedicated Outdoor Air Systems at Gallagher

GROUND COUPLED HYDRONIC RADIANT SYSTEM



In conjunction with the three DOAS air handling units, Gallagher hall has a hydronic radiant system to handle much of the sensible conditioning load of the building. On the first floor, the floor slab is the radiant surface, and on the upper floors the ceiling is the radiant surface. Pumps in the mechanical room circulate water through each of the zones of the radiant system and the water is heated and cooled by a combination of equipment located in various mechanical rooms throughout the building. Cooling loads are serviced by a chiller coupled to an evaporative cooling tower and the ground loop or by directly coupling the building loop to the ground loop. Heating loads are serviced by a heat pump coupled to the ground loop and a high efficiency condensing boiler.

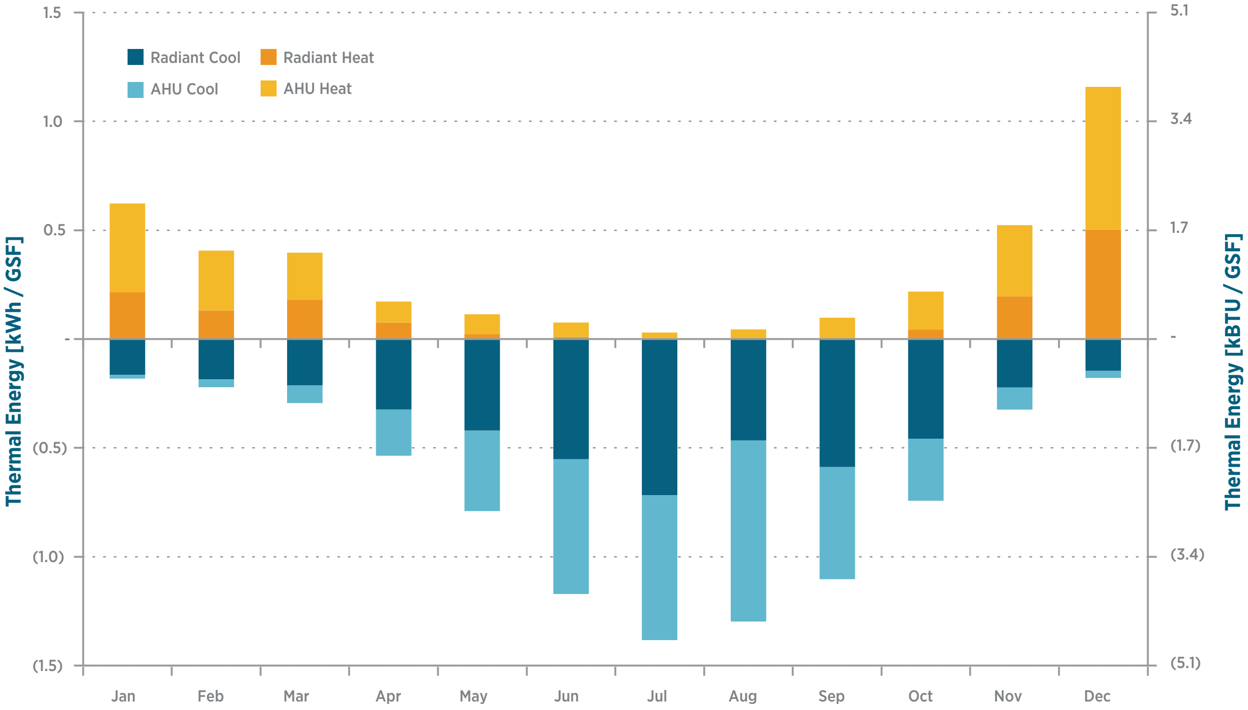
Many of the systems used in Gallagher have been tried before separatley, however the way that Gallagher implements the systems may make it unique. The design of the system allows for flexible operation in any of four cooling modes of progressively higher capacity and one heating mode that can make varialbe use of the heat pump and high efficiency boiler. This flexibility allows for a large amount of building optimization.

Another important design element of Gallagher Hall is the large thermal mass provided by the floor and ceiling slabs through which the radiant hydronic system runs. The large mass of the radiant surfaces are used to shift heating and cooling demand from the typical peak hot afternoon hours to early morning hours. This shift in demand times during cooler operating hours increases the overall efficiency of the cooling system and reduces energy use during typical peak hours of operation.

Upon examination it was found that in the three year period under study, the dessicant wheels have never been needed. This is not completely unexpected in that summers are extremely dry, with the last rains typically falling in March or April when cooling is not necessary for most of the building. In the winter, when relative humidity is the highest, and rain is common, there is no cooling load. While condensation concerns remain an important consideration, this suggests that radiant cooling systems are well suited to this climate zone, and potentially other hot and dry climate zones in California.

BUILDING THERMAL LOAD SHARE

Figure 6: Building Thermal Load 2012/2013



An analysis of the split between conditioning load between AHU and the radiant system was also performed. It was found that the split was greatly affected by the season. During shoulder seasons the load is primarily handled by the radiant system with AHU thermal conditioning taking a more prominent role during seasonal peaks. A baseline cooling load is observed to exist even in winter months. Investigation revealed this to be primarily due to the loads generated by computer server rooms located within the building that require continual cooling, even in winter months.

Building Operation

Operating programs for Gallagher are continually being adjusted to maximize occupant comfort and also to deal with unanticipated equipment downtime. Due to these circumstances, significant changes in building and equipment load profiles can be seen from year to year.

The building load plot for cooling reveals how chilled water is delivered throughout the day during different times of the year. In summer 2012, an aggressive strategy of pre-chilling the radiant slabs was programmed. In summer 2013 a strategy of continuous cooling throughout the day was followed. It can be noted that chilled water is called for throughout the year, even in the middle of winter, due to the cooling needs of the server rooms.

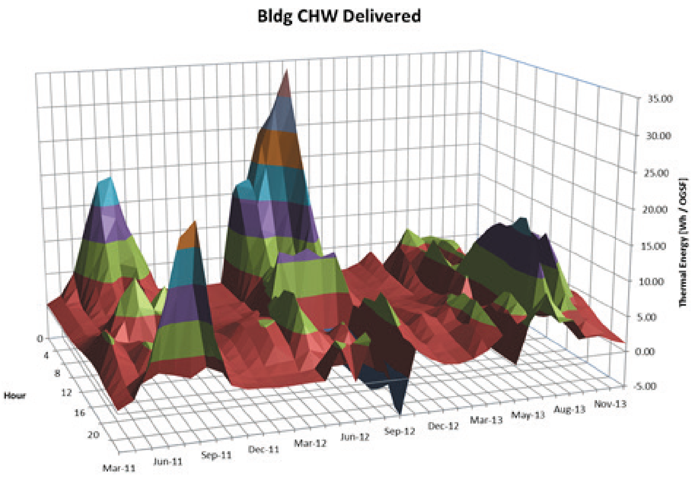


Figure 7: Building chilled water delivered from March 2011-November 2013

During winter months, the heat pump starts operation shortly before the building opens, but similar to the chiller operation, does not operate after noon. There is a significant reduction in heat pump operation in the 2012/2013 winter attributable to mechanical difficulties and a shift to boiler heat.

Two distinct patterns of operation can be seen for chiller operation over the three years shown. During the summer of 2011 and summer 2012 a control strategy that takes advantage of the slabs thermal mass was employed. In these years, the chiller starts operating late in the night or early morning, and slowly reduces its load as the slab cools. After noon, only minimal chiller operation is needed in order to provide cooling to the building. In the afternoon, during the hottest hours of the day, and when the load on the grid is peaking, the building is using very little cooling energy. Mechanical issues forced a change in operation for the 2013 year, and this year shows more even usage of the chiller.

The heat pump makes similar use of the slabs thermal storage capabilities. Most of the heating is performed during the night with nearly no heating taking place during the day. The 2012/2013 winter show significantly less heat pump usage due to mechanical issues which forced more heat to be supplied by the high efficiency boiler.

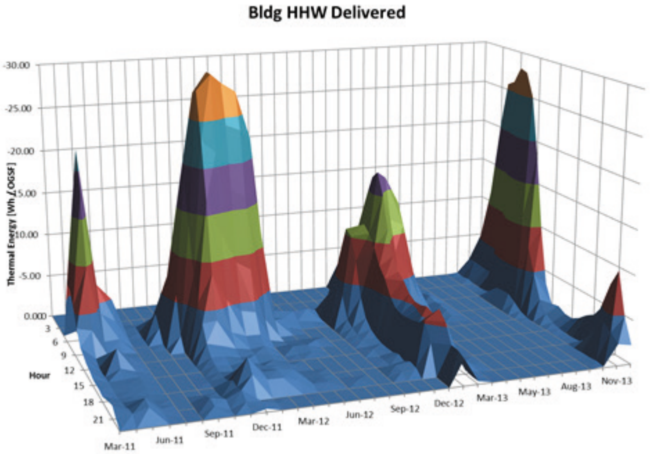


Figure 8: Building hot water delivered from March 2011-November 2013

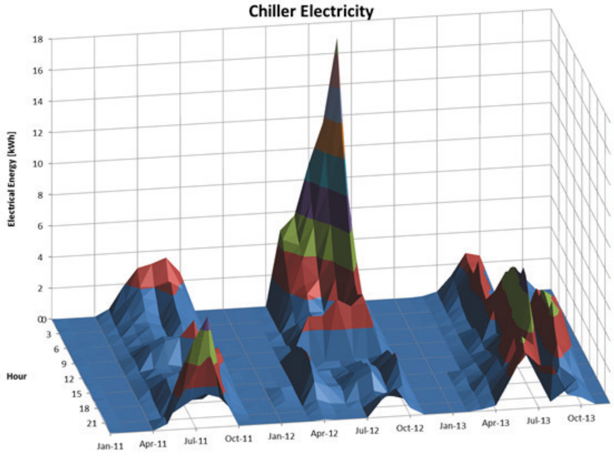


Figure 9: Chiller electricity usage from March 2011-November 2013

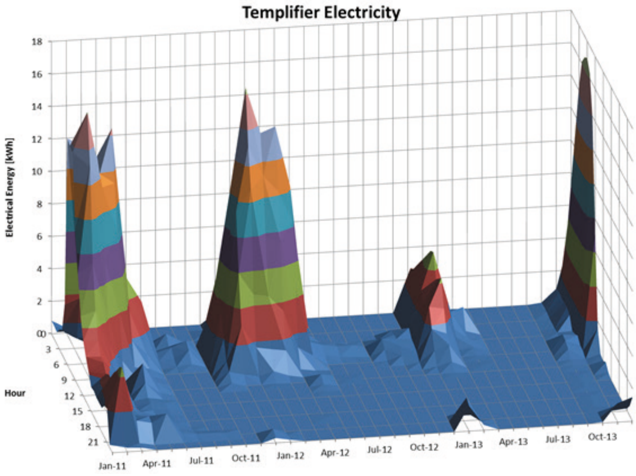
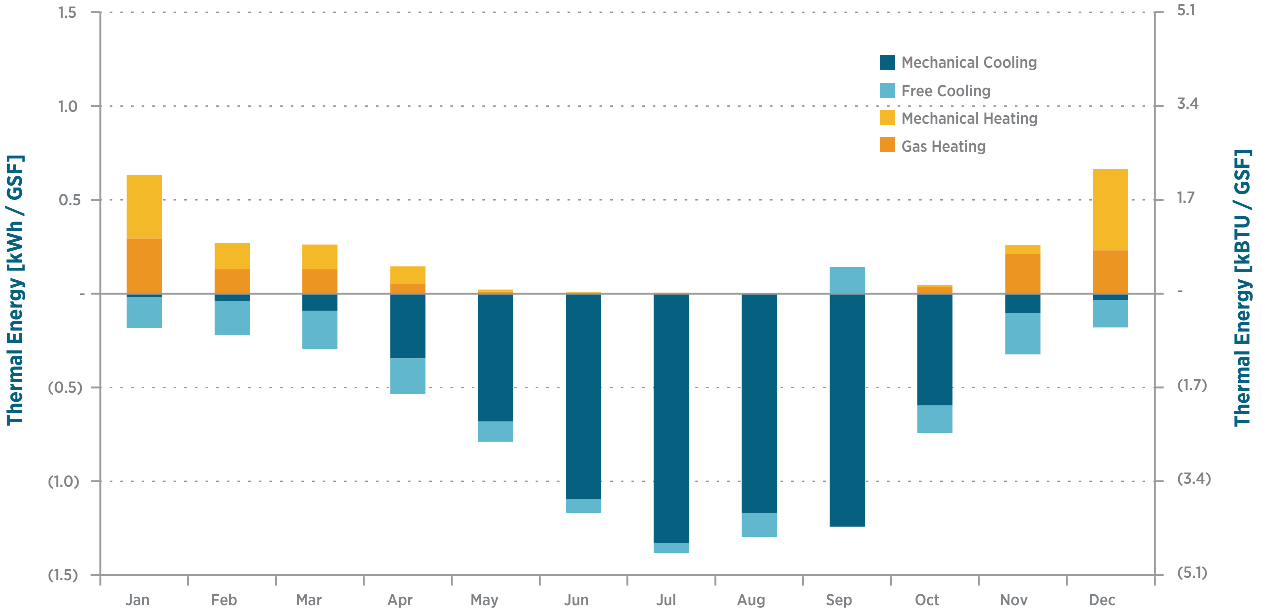


Figure 10: Templifier electricity usage from March 2011-November 2013

Figure 11: Building Thermal Load 2012/2013



Building Conditioning and Ventilation Equipment

An examination of the equipment used to handle the conditioning load over the year found that for heating loads, the heat pump is able to handle much of the load without needing to engage the boiler. The heating loads for the latter part of the year are handled completely by the boiler due to a heat pump failure. The design of the heating system allows for the boiler to completely handle heating needs for the building without requiring heat pump operation. Besides for the redundancy this allows for in the case of a heat pump failure, it also allows the load to be shifted between electrical and natural gas fuel sources based on what is the most cost effective at the moment.

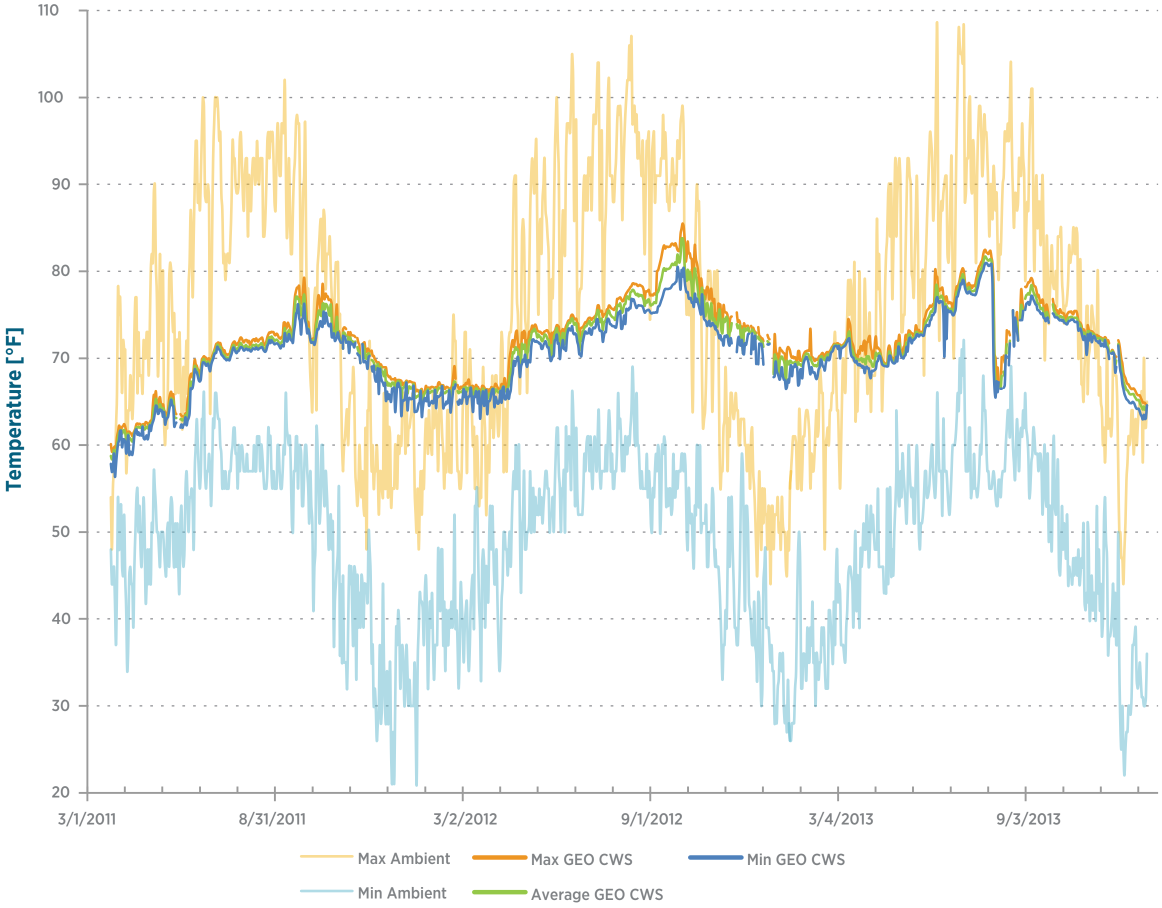
As previously stated, computer server room cooling necessitates year round cooling of portions of the building. The source plot reveals that during winter months this cooling load can be entirely handled by the direct coupling between the ground loop and the building cooling loop. With the onset of summer, and a subsequent increase in cooling load, the ability for the building to be cooled by direct coupling with the ground loop diminishes and the chiller must be used to drive building heat out of the building. By October, the cooling loads have decreased enough to allow some of the load to be ground coupled again.

GROUND LOOP THERMAL SINK

The geo-exchange field is a horizontal slinky tube design that covers roughly the same area as the building footprint. This design is economical in that excavation of the area was needed in order to lay the foundation for the building, so little additional cost was incurred by installing the geo-exchange field at the same time. The field is separated into 4 parallel loops that can be individually isolated from the system in the event that a leak occurs in any one loop.

The field shows an excellent ability to act as a sink for the thermal loads and shows only a modest 2 – 5 °F difference in max and min water temperature over the course of a day. The data seems to indicate that there has been a slow rise in ground temperature over the years. This could be due to an asymmetric heating and cooling load coupled with dry ground conditions. This demonstrates the importance of planning for symmetrical loading of the field.

Figure 12: Ground Loop Temperatures





HEATING AND COOLING EQUIPMENT

Thermal energy from the ground loop is transferred to the building via a heat pump and a chiller. A 145-ton capacity McQuay chiller is used to cool the building loop and transfers building heat to the ground loop. Similarly a 165-ton McQuay heat pump, called a Templifier by the manufacturer, transfers ground loop heat to the building. These two devices where designed to the be the primary machines for maintaining occupant comfort when the ground loop temperature wasn't at an appropriate temperature to provide for building conditioning directly.

In addition to the chiller, a 75-ton PowerCold evaporative fluid cooler rejects additional heat from the ground loop during peak heating periods. Auxiliary heating equipment includes an Aerco 757kBTU high efficiency condensing boiler and 2 high efficiency condensing hot water heaters.

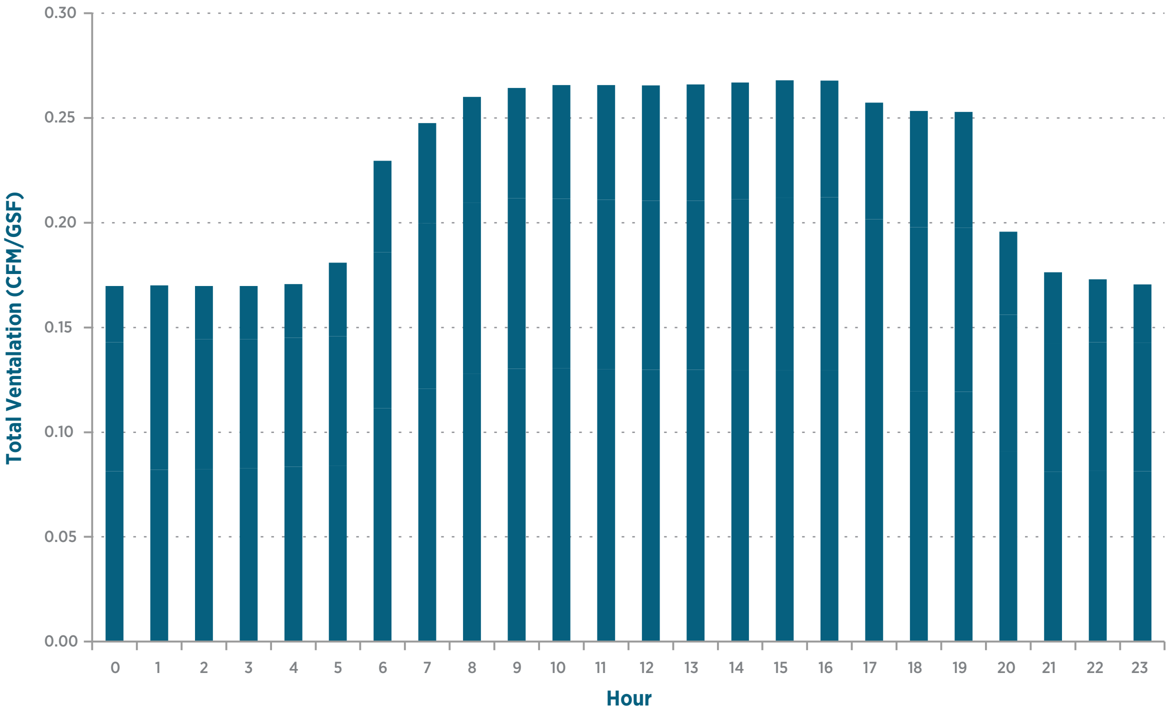
Ventilation and Indoor Air Quality

Proper control of ventilation air represents a large opportunity for savings in buildings. Fan power used to circulate and distribute conditioned air consumes a significant portion of HVAC energy. Anything that can be done to reduce the amount of air circulated will have a direct energy savings benefit. Additionally anything that can be done to reduce the amount of outside air introduced to a space will have energy benefits because this air needs to be conditioned. The goals of energy savings by reducing ventilation airflow must always be balanced with the need to provide sufficient air to achieve acceptable indoor air quality.

DEMAND CONTROL VENTILATION

Gallagher's DOAS design philosophy attempts to balance energy savings with indoor air quality by supplying only the amount of air needed. The air handlers are 100% outdoor air units, and do not waste any energy recirculating indoor air and are not used for the primary purpose of thermal distribution. Sensors located throughout the building continually monitor CO2 levels and adjust air delivery based on meeting set point requirements. In this way, an unoccupied room will call for less air than a fully occupied room, and energy savings will be maximized while still achieving the required fresh air ventilation.

Figure 13: Building Ventilation Delivered over 10-month monitoring period



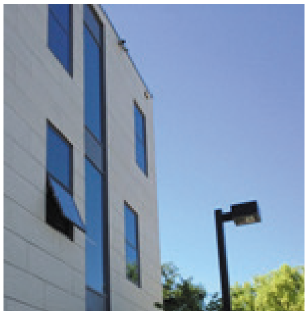
DISPLACEMENT VENTILATION

Gallagher hall utilizes under-floor plenums to direct neutrally conditioned ventilation air to the occupied space. The raised floor on the upper floors allows low velocity air to slowly displace the room air at ground level where it is removed by exhaust ducts at the ceiling level. A portion is also directed to the exterior of the building between the exterior wall and the rain screen and increases the effective envelope insulation.

OPERABLE WINDOWS

The ventilation design of Gallagher makes it possible to employ natural ventilation through operable windows. Because the exhaust ventilation is driven by demand as measure by CO2 concentrations, during favorable weather conditions windows can be opened to allow for fresh air to enter the building. The building control system measures indoor and outdoor temperature and humidity conditions, as well as mechanical equipment demands and notifies occupants when it is appropriate to open their windows.

Figure 11 illustrates the hours that the operable window indicator shows that it's appropriate to open the windows. As might be expected, the windows are permitted to be open the most in the fall and the spring. January and July are the months with the least amount of operable windows hours. Looking on a monthly basis, the hours when the windows are allowed to be operated correspond primarily with prevailing outside temperature conditions. During the summer, early morning hours seem to predominate. In spring and fall, the operable hours are more fully distributed across the day.



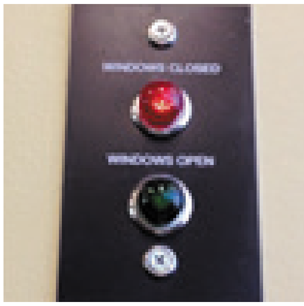
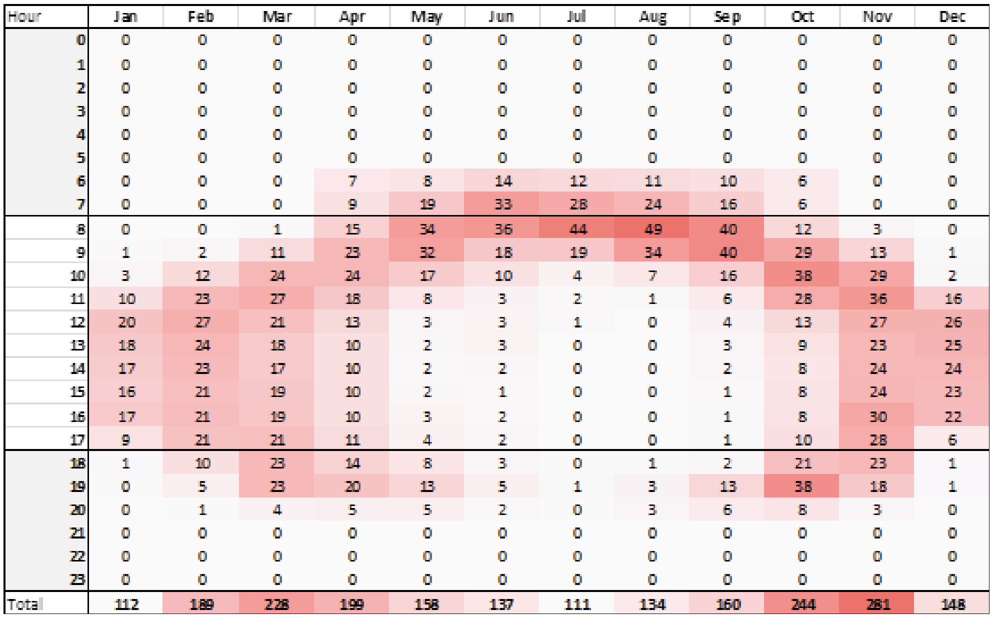


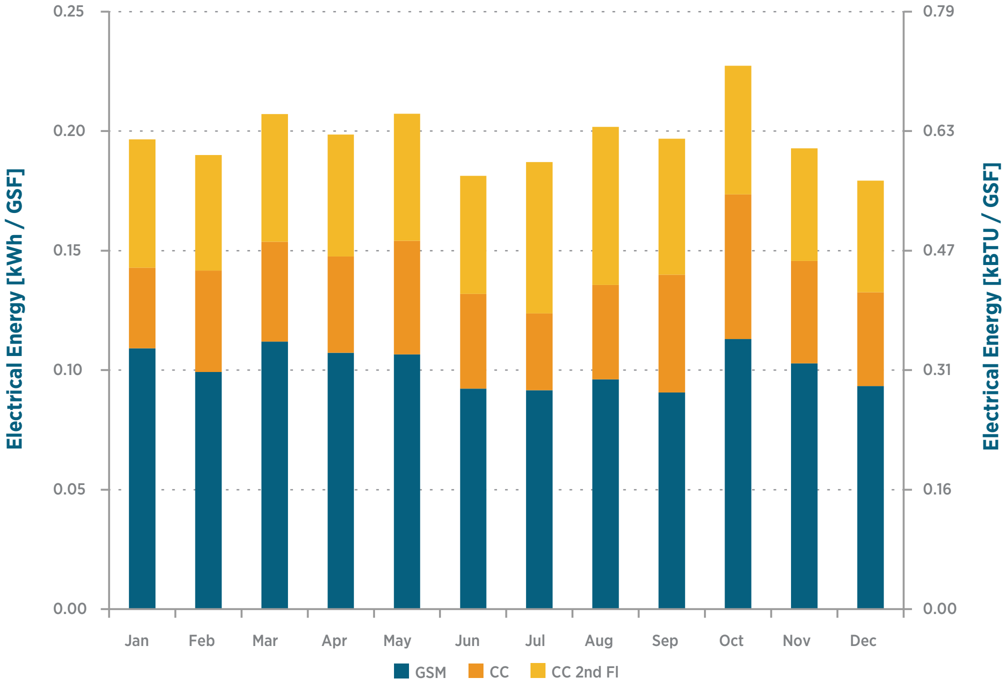
Figure 14: Heat map that shows when the operable window indicator notifies building tenants to open the windows



Hour	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
0	0	0	0	0	0	0	0	0	0	0	0	0
1	0	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0	0	0
6	0	0	0	7	8	14	12	11	10	6	0	0
7	0	0	0	9	19	33	28	24	16	6	0	0
8	0	0	1	15	34	36	44	49	40	12	3	0
9	1	2	11	23	32	18	19	34	40	29	13	1
10	3	12	24	24	17	10	4	7	16	38	29	2
11	10	23	27	18	8	3	2	1	6	28	36	16
12	20	27	21	13	3	3	1	0	4	13	27	26
13	18	24	18	10	2	3	0	0	3	9	23	25
14	17	23	17	10	2	2	0	0	2	8	24	24
15	16	21	19	10	2	1	0	0	1	8	24	23
16	17	21	19	10	3	2	0	0	1	8	30	22
17	9	21	21	11	4	2	0	0	1	10	28	6
18	1	10	23	14	8	3	0	1	2	21	23	1
19	0	5	23	20	13	5	1	3	13	38	18	1
20	0	1	4	5	5	2	0	3	6	8	3	0
21	0	0	0	0	0	0	0	0	0	0	0	0
22	0	0	0	0	0	0	0	0	0	0	0	0
23	0	0	0	0	0	0	0	0	0	0	0	0
Total	112	189	228	199	158	137	111	134	160	244	281	148

3. OTHER EFFICIENCY FEATURES

Figure 15: Lighting loads

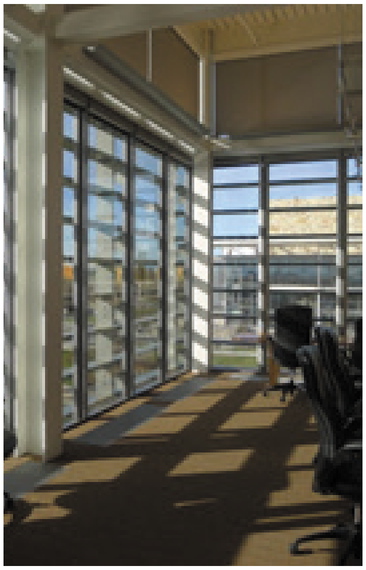


Lighting

The GSM utilized a combination of readily available energy efficient light sources, occupancy controls and natural daylight in its energy efficient design. Electric light was comprised mostly of linear fluorescent and LED lamps. Where required by 2008 code, occupancy controls were included to further reduce lighting loads when spaces are vacant. The inclusion of a light well allows for plentiful indirect natural light to supplement electric light during the day without the majority of the solar heat gain associated with direct sunlight. As compared with today's energy efficiency code requirements and readily available LED lighting, the GSM's lighting could be easily improved. The almost continuous increase in the efficacy (efficacy is the measure of light produced by a light source such as a lamp divided by the amount of energy it took to create the light. Efficacy is measured as lumens per watt) of LED's has caused a continuous reduction in the cost of LED luminaires. LED luminaires are typically more efficient than standard light sources and are also typically cost effective in new construction. Additionally, today's California Energy Efficiency code requires the use of occupancy controls throughout the majority of commercial spaces as well as electric daylight harvesting (Electric daylight harvesting is the use of photo sensors in day lit spaces to reduce the energy use in the space by dimming the electric light) controls for a number of space with natural daylight in the form of windows or skylights. Additionally, the recent development of networked lighting controls compatible with building automation systems will result in the development of smart buildings which utilize occupancy, daylight, temperature and other data streams to optimize the energy use of the building. The inclusion of these kinds of controls at the GSM could further improve its building efficiency.

Landscaping & Water Usage

The landscaping around the building has been carefully chosen to require little irrigation and to have a low impact on water usage. As one example, UC Verde Buffalograss, developed by scientists at UC Davis and UC Riverside, was included in the landscaping of the new Maurice J. Gallagher Hall and helped the building meet its LEED certification goals. UC Verde grass needs only about 25 percent the amount of water used for other turf grasses. In addition to being water-efficient, UC Verde grass is also extremely tough and dense with strong disease and insect resistance, which reduces the need for chemical applications, weeding or other maintenance. Because the grass variety grows very slowly in comparison to other varieties, it also needs to be mowed far less frequently.
(http://sustainability.ucdavis.edu/progress/water/index.html)



4. BUILDING PERFORMANCE

Building Energy

An analysis of the building's electrical and natural gas usage reveals that the GSM relies primarily on electrical energy for the majority of its energy needs. This is expected due to the significant portion of space heating that is covered by the ground source heat pump system. Analyzed on a source energy basis it becomes even more apparent that the natural gas energy used on-site is only a small percentage of the buildings total energy footprint.

Figure 16 shows the breakdown of electrical energy only for the building. In this context HVAC loads account for the major portion of electrical energy used. Lighting accounts for roughly a quarter of the buildings energy use. Plug loads, and the unclassified portion of building electrical usage, which is also largely plug loads and a rooftop package air conditioner serving the top floor conference room, account for the remaining quarter of building energy electrical usage.

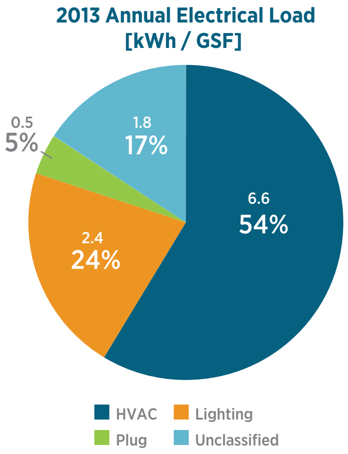


Figure 16

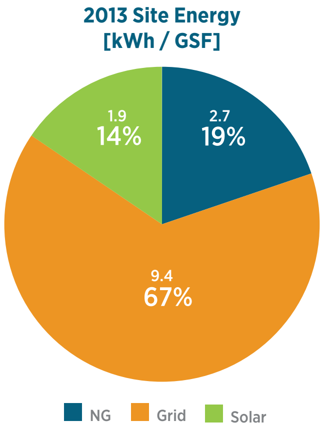


Figure 17

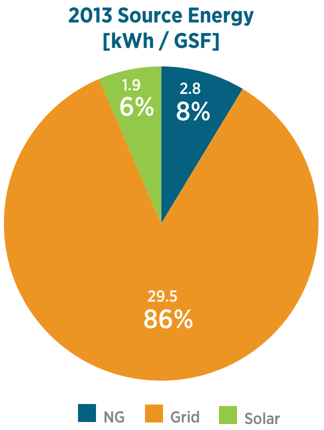
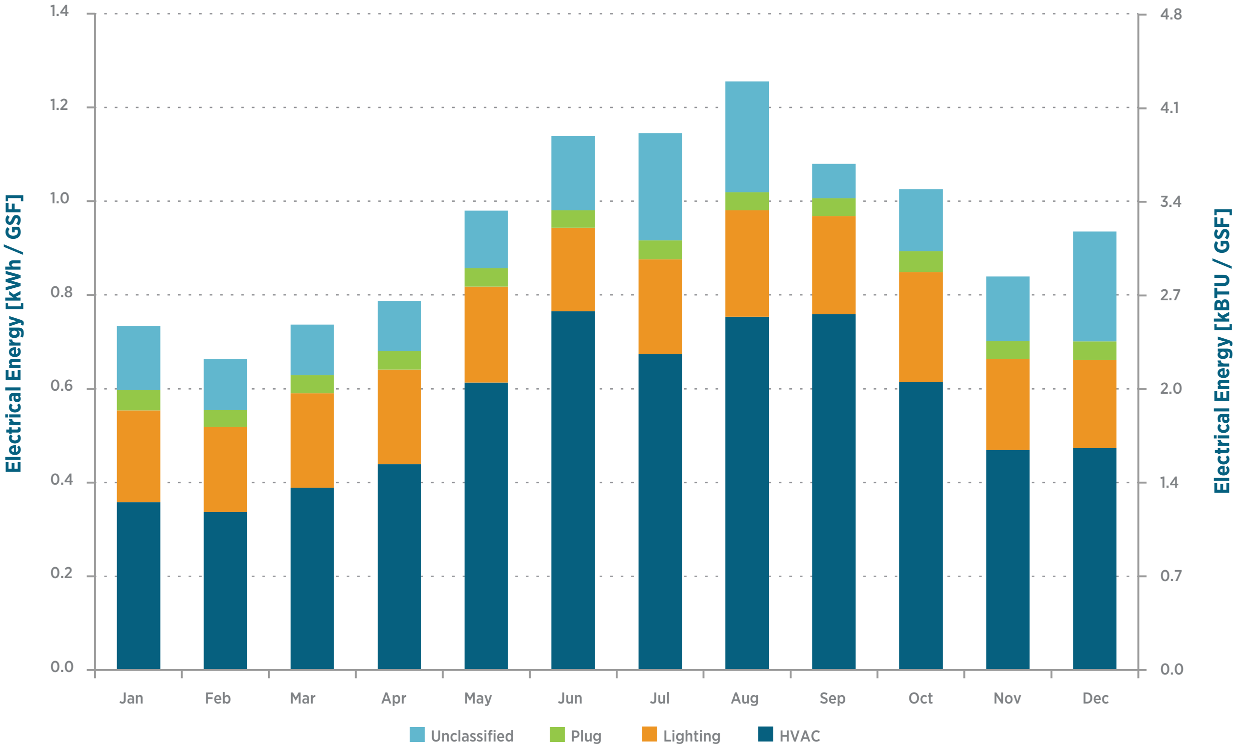


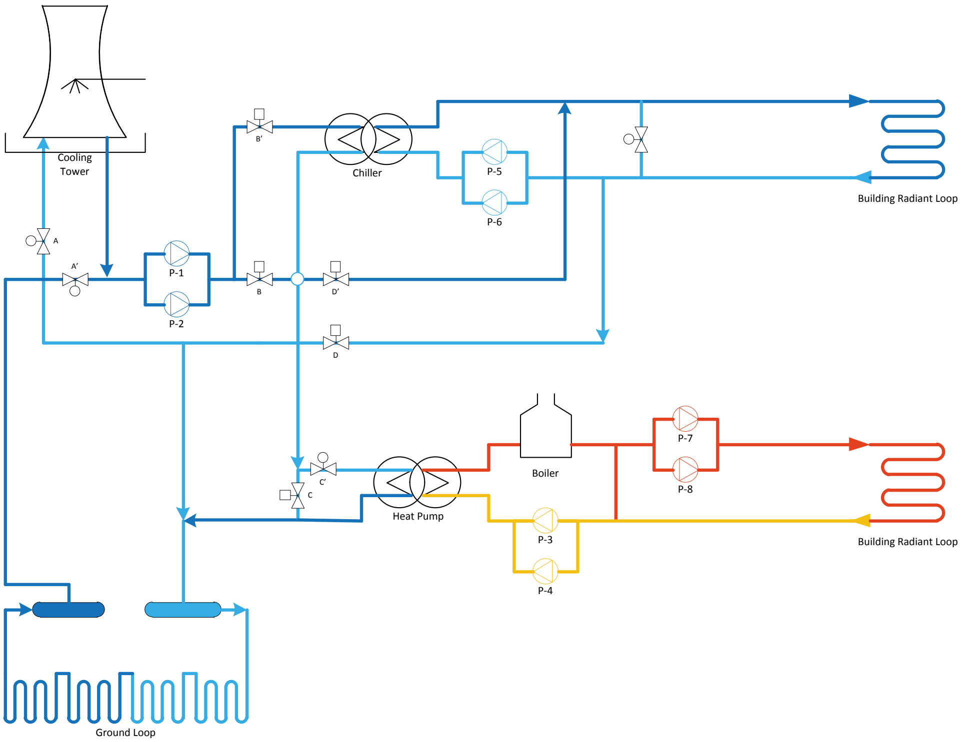
Figure 18

Figure 19: Electrical loads



A further breakdown of electrical loads on a monthly basis highlights the seasonal change in building electrical loads. HVAC loads increase in the summer when hot weather necessitates greater use of the chiller and vapor compression cooling systems. Lighting and plug loads are roughly constant throughout the year.

Figure 20: HVAC operations diagram



HVAC Operation

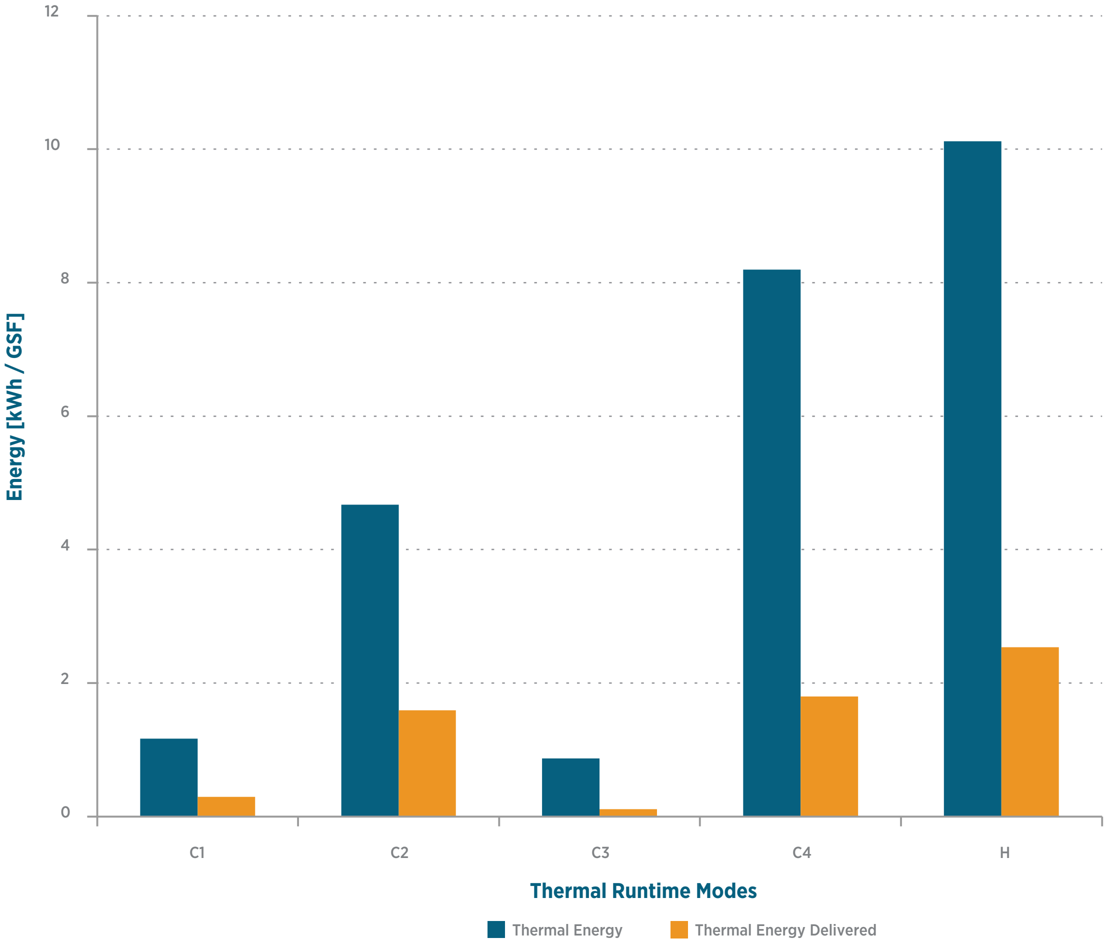
The hydronic system utilized at Gallagher has two main functions of operation – heating and cooling. Heat is rejected to two places, the ground via the horizontal loop field installed under the building and to the atmosphere via the evaporative fluid cooling tower. When temperatures are favorable, and cooling demands are low, fluid that circulates through the building can be pumped directly to the ground loop or the cooling tower and heat can be rejected to either of these places directly without any assistance from the chiller. As cooling demands increase the chiller is brought online to increase the capacity of the systems and to overcome unfavorable temperatures differences between the conditioned space and heat rejection sink.

The heating system is simpler in design and operates in a single mode. A heat pump draws heat from the water loop and rejects that heat to the building radiant loop. If the temperature of the water produced by the heat pump is too low, a boiler is used to boost the water temperature to that which is needed to supply the needed capacity to the building. If desired the heat pump can be disabled and the boiler can be used alone to supply building heat.

Within the cooling function there are 4 modes of operation with increasingly energy intensive cooling strategies and increasing cooling capacity. There is a single heating mode, but this mode can be called simultaneously with any of the 4 cooling sub-modes. The final mode is heating only mode. In practice, the building never enters the heating only mode because data centers within the building constantly require cooling. The mode of operation that is chosen is based on conditioning demand, ambient temperature, water loop temperatures, season, and other factors managed by the building management system (BMS).

The building operates in two different seasonal modes – summer and winter. All nine modes of operation are allowed regardless of the season, but the season does dictate operation parameters such as set point temperature of the occupant space and the dynamic behavior of the radiant surfaces. A graphical representation of equipment used for each mode is shown in APPENDIX A.

Figure 21: HVAC Energy use by mode



HVAC energy broken out by mode is shown in Figure 21. The plot shows total thermal energy delivered to the building from the primary radiant and AHU systems. The majority of cooling energy delivered to the building is in the C4 mode.

Comparative Performance

Figure 22: Building site energy

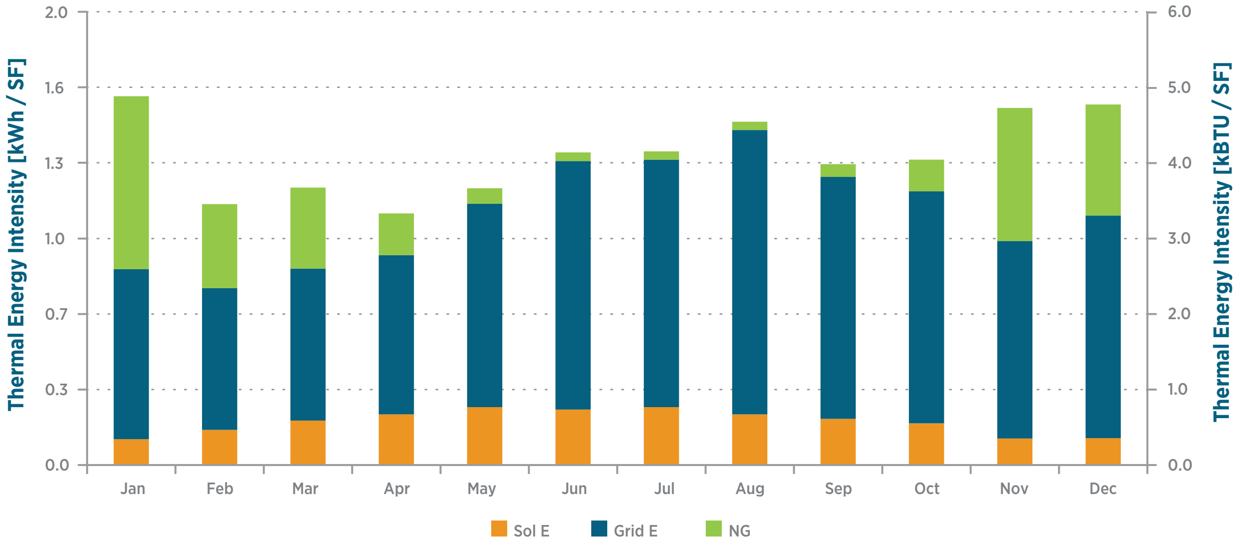
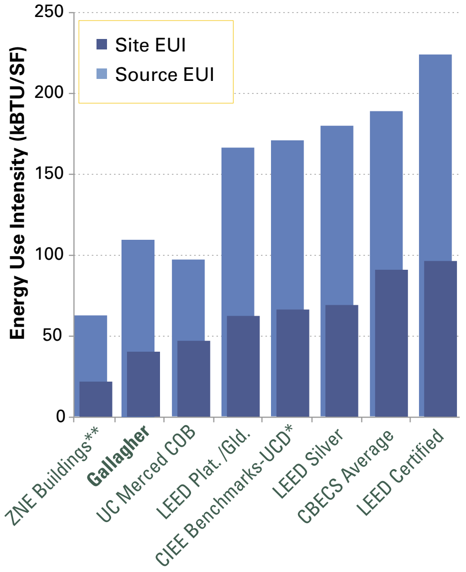


Figure 22 - EUI shows the site energy utilized by the building broken out on a monthly basis. Solar energy production and grid electricity follows seasonal patterns with both peaking in the summer time. Showing that the solar energy produced helps to offset the summer electrical usage peak. Natural gas energy, as expected peaks in the winter months.



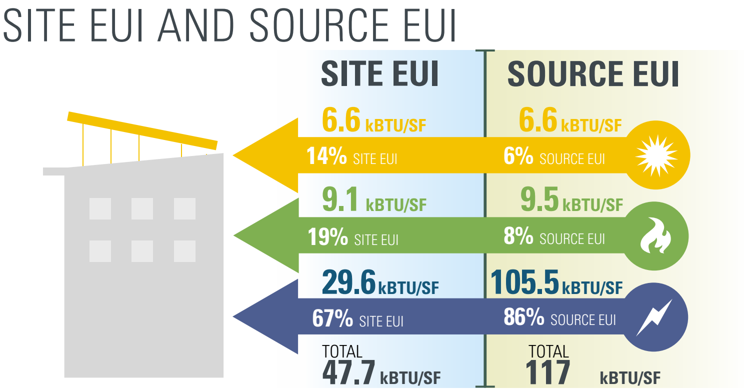


Figure 23: Site EUI and Source EUI

The final figure shows the overall building performance expressed as site and source EUI. Gallagher hall compares favorably with other buildings of its class.

Ongoing Issues

Since its completion in 2010, the Graduate School of Management and Conference Center (GSM) has experienced many failures and problems with its mechanical systems. UC Davis Design and Construction Management issued a report in late 2013 detailing these issues.

AIR HANDLERS

The three air handlers that serve Gallagher Hall are of a complex design that includes DX cooling with a bypass, hot water fan coils, and evaporative precooling. Additionally, two of the air handlers also have desiccant wheels with reactivation furnace. These systems have experienced multiple refrigeration leaks and have released refrigerant into the ventilated space. They have also experienced multiple compressor failures. It is suspected that harmonic vibration is causing the condenser pipes to crack, and that this failure is causing subsequent compressor failure. An additional concern is that the leaking refrigerant and oil into the supply air stream may be coating the desiccant wheels and inactivating them.

A high frequency of evaporative section pump, and switch failures has also been observed. No less than 6 pumps have been replaced between the 3 units, each showing signs of overheating. The design of the evaporative section does not allow the pump to be fully submerged and this has likely led to premature failure. Failures in the seal between the air and water side of the indirect evaporative pre-cooler section have also been observed.

The failure of the air handlers, while not trivial, seems to be confined to a component-level issue and does not represent a fundamental system design failure. Munters has been cooperating with the University to rectify these issues.

EVAPORATIVE FLUID COOLER

The fluid cooler used in the system is manufactured by PowerCold. The unit employs a proprietary heat exchanger composed of multiple polymer tubes collected into bundles. Over the course of only a few years an increasing number of these tubes cracked and failed. The tubing cannot be replaced, and leaks need to be isolated from the rest of the system by zip ties. This has had the effect of progressively reducing the capacity of the system. Of greater concern, is the discovery that the unit already included damaged and abandoned tubes at time of delivery. The company that manufactured this unit was sued by the SEC, and subsequently went out of business. All indications

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** CIEE. Benchmark-based, Whole-Building Energy Performance Targets for UC Buildings, March 2014. 1999 Energy Baseline Benchmark for UC Davis Campus.*

*** NBI. 2014 Getting to Zero Status Update, January 2014. Average of all Net-Zero Buildings.*

suggest that these failures will continue to occur. As with the air handlers this failure appears to be isolated to the component level, and does not indicate a systemic failure of the building.

CHILLER AND HEAT PUMP

The chiller and heat pump are of similar construction and made by McQuay. They utilize Danfoss TurboCor compressors with magnetic bearings. They both receive condenser water from a geothermal ground source loop under the building and/or the fluid coolers mentioned above, depending on the mode of operation.

Since commissioning the chilled water loop, it has exhibited a systemic problem that has prevented proper operation of the chiller. In short, the system was designed without a means by which to control the incoming water temperature to the chiller, and the swing in this temperature has caused instability and short cycling. The water temperature issue has been corrected with the addition of controls, piping and valves in the main mechanical room. The short cycling issue appears to be related to light loads added to the system by a server room located within the building. The light load of the server room and the low thermal capacity of the system cause the chiller to short cycle. This issue was mitigated by forcing the system to operate in ground loop free cooling mode when there are only low loads present.

In August of 2013 the single turbo compressor on the chiller experienced a failure. Investigation revealed that the chiller had experienced 41,000 start/stop cycles in only 7,060 hours of operation and the short cycle is suspected to have played a role in this component failure.

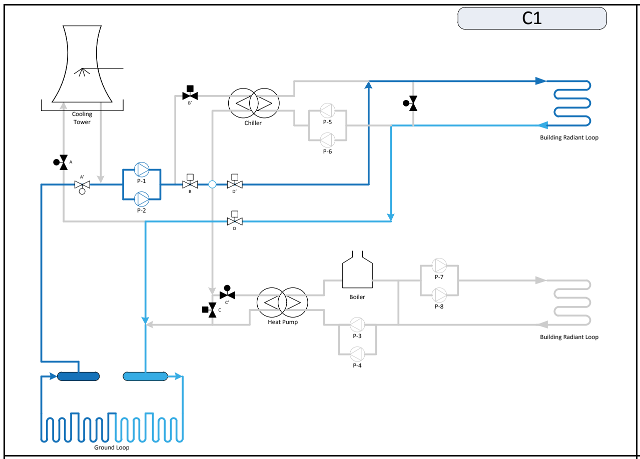
GROUND SOURCE AND FLUID COOLER CAPACITIES

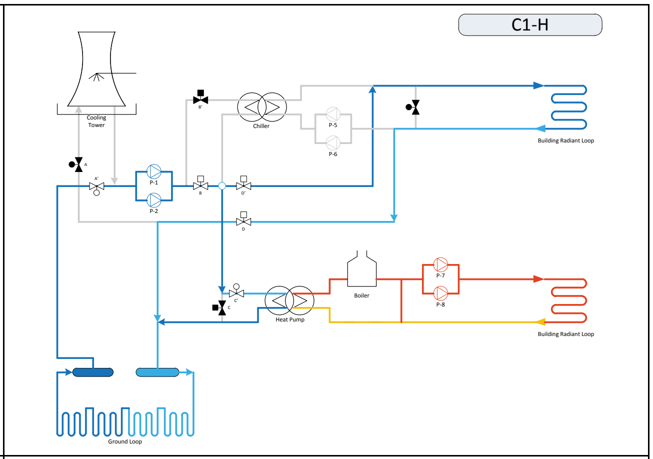
The ground source and fluid cooler were originally designed and sized to deliver 100 tons of cooling from the ground source and 50 tons of cooling from the fluid coolers. During construction though, it became apparent that the ground loop could only provide 75 tons of cooling capacity, so the fluid coolers were increased to provide the remaining 75 tons. As designed, the ground loop temperature was to remain cooler than about 70 degrees. However trend data has revealed that this temperature has exceeded this design temperature, and on a longer time scale appears to be trending upward. This is likely due to many factors including asymmetrical heat addition and extraction from the loop, and undersized loop, and dry soil conditions.

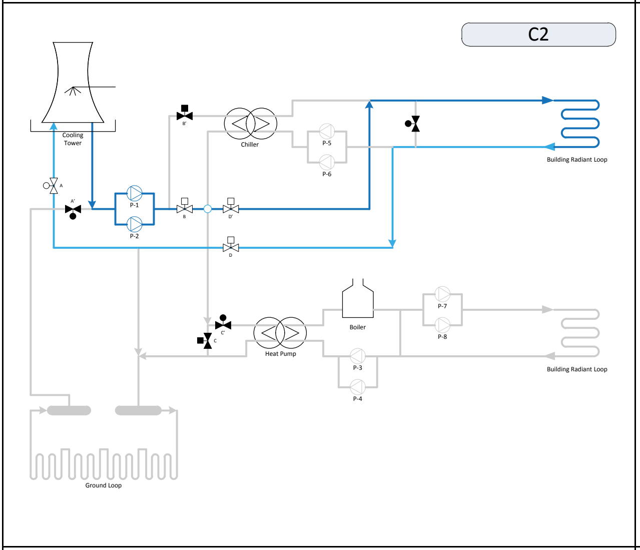
Technology Potential

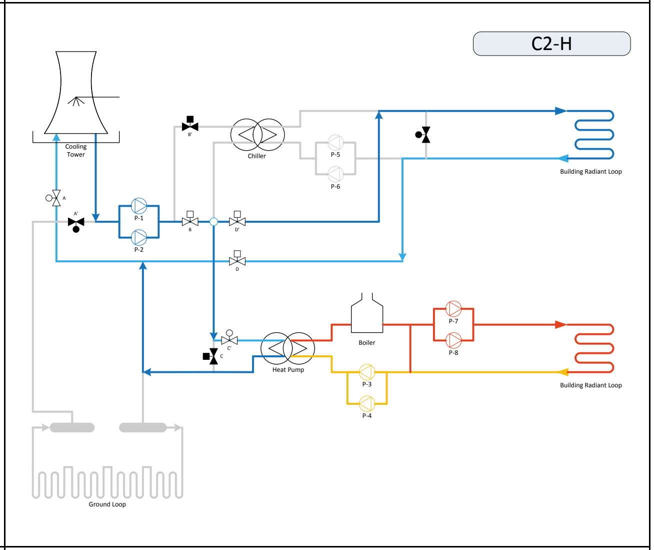
Gallagher Hall has demonstrated promising and effective technologies for the next generation of energy efficient campus construction. By utilizing design elements that incorporate radiant heating and cooling with dedicated outdoor air systems, the building has achieved impressive low energy performance. The use of a ground thermal geo-exchange loop has enhanced the energy efficient operation of the building heat pump and chiller, and has allowed these pieces of equipment to deliver highly efficient performance by lowering the required temperature lift required between source and sink, even when outdoor air conditions are at extremes. The geo-exchanger has also made possible some amount of seasonal thermal energy storage which effectively allows the heat stored in the earth during the summer to increase the efficiency of the building heating system in the winter, and vice versa. With further development the systems demonstrated at UC Davis Gallagher hall could be successfully incorporated into new building construction, and some aspects may even be appropriate for retrofit into existing buildings.

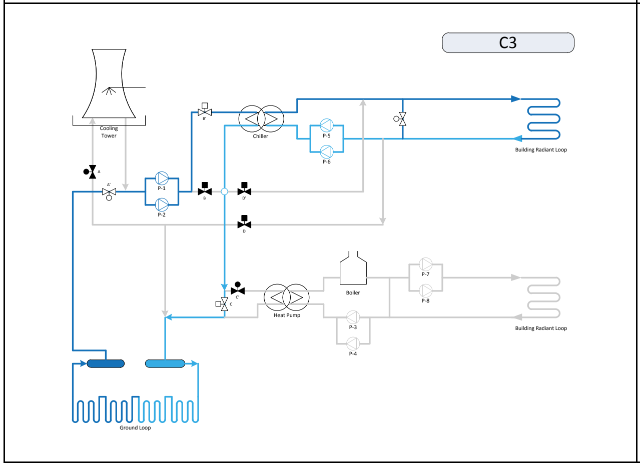
5. APPENDIX A: MODES OF OPERATION

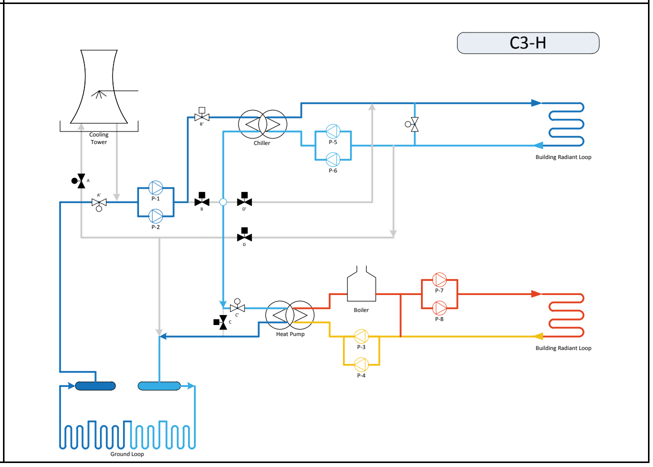












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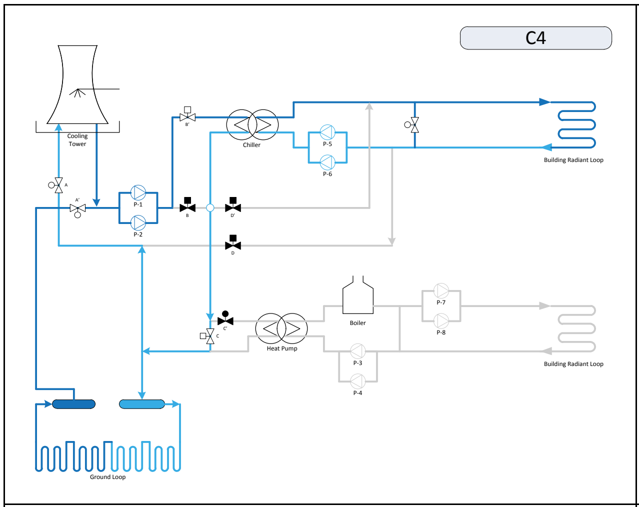
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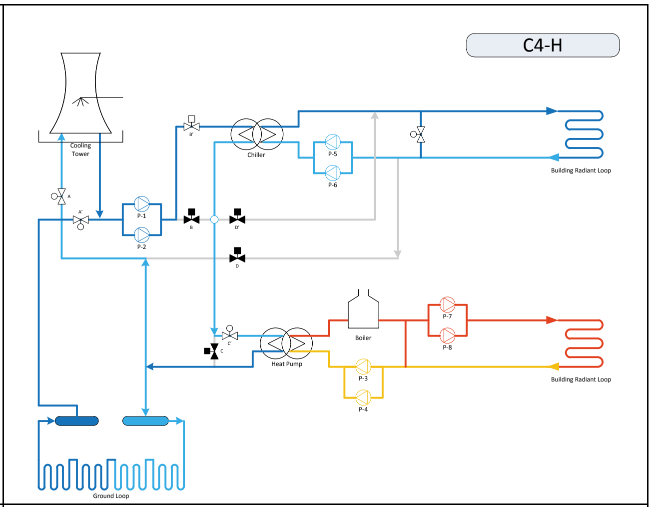
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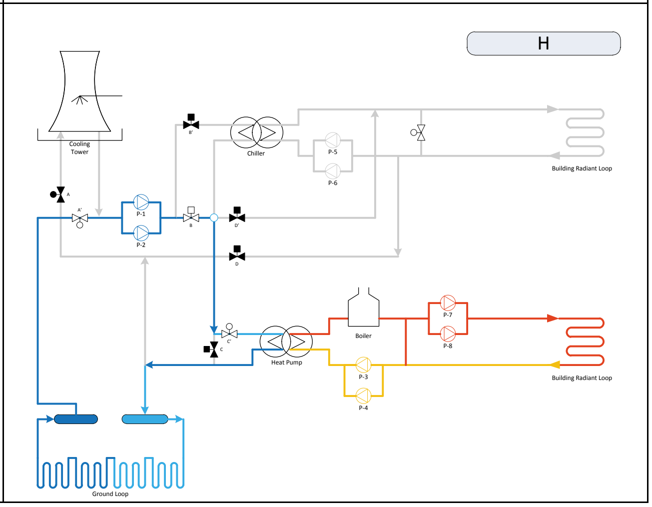
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AHU1 - GSM - Des Champs PV-EPX (3,955 SF served)

- 340kBtu / hr Heat
- 240kBtu / hr Cool
- Cool Eff: 260kW
- 12,000 CFM

AHU2 - CC - Des Champs PV-EPX (766 SF served)

- 430kBtu / hr Heat
- 300kBtu / hr Cool
- Cool Eff: 260kW
- 15,000 CFM

AHU3 - CC - Des Champs PV-EPX (2,108 SF served)

- 340kBtu / hr Heat
- 240kBtu / hr Cool
- Cool Eff: 260kW
- 12,000 CFM