TTP 289A

THE PATH TO NET ZERO ENERGY (ZNE)

Robert Mondavi Institute (RMI) BUILDING

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EXECUTIVE SUMMARY

The purpose of the study was to recommend a suitable technology that could provide chilled water at the temperatures required for process loads at the Robert Mondavi Institute (RMI) building, in order to remove this load from the campus central heating and cooling plant (CHCP), which was forced to provide chilled water during the winter only to satisfy the needs from the RMI building. By providing a localized solution for chilled water consumption at the RMI building, the central heating and cooling plant (CHCP) will be able to operate at a higher efficiency, generating energy and economic savings.

In this study, the needs of RMI building were identified according to their specific purpose loads through a series of meetings and interviews with the lab managers working in the building. It was established that the RMI building currently requires water at 40^0F for the processes at the dairy lab and at the food pilot plant. The operation of the CHCP was also analyzed and possible economic savings were determined for a future scenario where the provided temperature for chilled water during the colder months would be of 50^0F, which would allow the CHCP plant to operate at a higher efficiency during the winter.

To satisfy the needs of all clients, the study was conducted and various technologies were analyzed according to the users priorities. An onsite electric chiller of 30 tons was recommended as the solution for providing better service at RMI building and saving energy at the CHCP. From the economic analysis in this study, the savings on energy will be $47.634 over the period of three years. The installation of an electric chiller is economically viable and will contribute to the overall energy savings of the University.

BACKGROUND

The 32,000-square-foot teaching and research complex, located within UC Davis Robert Mondavi Institute for Wine and Food Science, was officially opened on January 28, 2011. It is the one of the world's most environmentally sophisticated and technologically advanced facilities for making wine, brewing beer, and processing foods and dairy products. It was financed entirely by private philanthropy — no state or federal funds were used. The campus received more than $20 million in private support to construct and equip the complex [1].

It is the first such building to receive LEED® (Leadership in Energy and Environmental Design) Platinum certification, the highest rating for environmental design and construction awarded by the U.S. Green Building Council [1].

The south wing of the complex is home to the August A. Busch III Brewing and Food Science Laboratory, which include the Anheuser-Busch InBev Brewery, the California Processing Tomato Industry Pilot Plant for processing and the Dairy Processing Laboratory. The complex's north wing houses the new Department of Viticulture and Enology Teaching and Research Winery [1].

The new winery, brewery and food-processing complex was designed to serve as a test bed for production processes and techniques that conserve water, energy and other vital resources. Its environmentally friendly features include onsite solar power generation and a large-capacity system for capturing, processing and conserving rainwater. The stored rainwater is used for landscaping and toilets. The building maximizes the use of natural light, outside air and temperatures during day and night to provide a confortable building temperature. The building also houses rooftop photovoltaic cells, which allows it to become positive net zero in terms of energy [1].

The air heating and cooling system for the building also utilizes steam and chilled water provided by the Central Heating and Cooling Plant (CHCP). The complex also requires water at different specified temperatures for different process loads, which are also currently maintained by using the chilled water and steam provided by the CHCP.

I. Problem description:

The CHCP provides chilled water at around 40°F and steam at around 350°F across the University steam and chilled water distribution system. During the Winter, when the air cooling systems of the buildings require very low energy, most of the chilled water pumped by the CHCP returns through the bypass valve which results in very small temperature difference between the supply and the return chilled water. As a result, the efficiency of chillers goes down and the cost of chilling the water goes up. Because of this, it is desirable to run the chillers at higher temperature (around 50°F) in winter so that the efficiency of chillers does not decrease.

The RMI building is the only building on the University campus that requires 40°F chilled water all year long because of its specialized process loads, which makes it mandatory for the CHCP to provide chilled water at this temperature even though it is more inefficient.

This conflicting nature of efficiency and necessity provides a challenge for energy savings and providing services to the University. The main purpose of this study was to determine whether a new onsite chilling system could provide better service at the RMI building and save the operating cost at the CHCP (Figure 1), and to supplement the current energy project underway, the student team will look into additional innovative technologies that could be applied to this building to achieve ZNE.

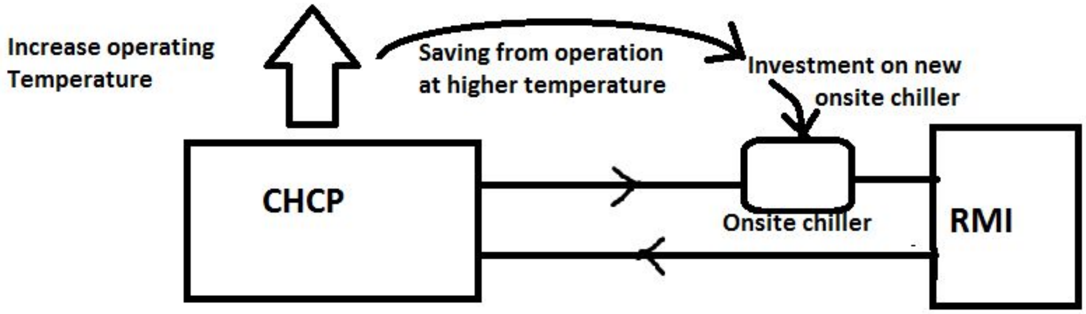

Figure 1. Proposed localized solution for the RMI building

II. Clients

a. Central Heating and Cooling Plant (CHCP)

CHCP provides chilled water and steam for the building air-cooling systems at the UC Davis Campus and for the Health Science District (HSD). Currently, there are four large boilers and three chillers in the CHCP. All the chillers that were originally in the CHCP were substituted in the past 5 years with three high efficiency 2,500 tons electric chillers. There are two boilers that were constructed in 1967, which are very inefficient, old and have high maintenance costs. The third boiler was constructed in the 1990 decade and the fourth one was installed in 2009. The 10,350-ton chilled water plant was constructed sometime after 1999, and includes two electric chillers, two cooling towers, a thermal energy storage tank, and pipelines connecting the plant to the campus chilled water distribution system [2].

b. Milk Processing Laboratory

The Milk Processing Lab is an invaluable resource to bring the bench-top research carried out at the FST Department to the translational stages in which all the important milk components can be safely isolated and tested for bioactive activity. It was designed to be highly flexible to allow the exploration of wide range of concepts, processes, packaging and products. All the instruments require minimum consumption of energy and water and can reach steady state quickly while producing little waste. The lab is currently equipped with a raw-milk cooling tank, cream separator, milk pasteurizer, milk homogenizer, ultraclean milk filler, a complete dairy analyzer (LactoScope) and a membrane separation system [3].

c. Food Processing Pilot Plant

The California Processing Tomato Industry Pilot Plant handles a broad spectrum of food products, including tomatoes, olives, peaches, prunes and has a flexible setup for teaching, research, outreach and contract work [4].

d. Brewery

The Brewery is part of "The August A. Busch III Brewing and Food Science Laboratory", which is 11,500 ft^2 and houses the brewery with a dry storage, mill room, records room and controlled-temperature room, as well as the food processing pilot plant and the milk processing laboratory mentioned above, classrooms and an analytical laboratory. The brewery is an authentic, reduced-scale facility, similar in size to smaller commercial brewing operations.

The winery, brewery, and food science laboratory building is the world's first LEED Platinum-certified facility in their respective domains. LEED stands for Leadership in Energy and Environmental Design and has become the hallmark of sustainability in the architecture and construction world [5].

III. Objectives

Determine the requirements from each client regarding the temperatures and flows of chilled water in order to provide a better service that can satisfy the needs of them all.

Propose a localized solution that could provide chilled water at the required temperatures and flows to the RMI building that is efficient and generates energy savings.

Evaluate the economic feasibility for the proposed technology for chilled water generation on site.

IV. Literature Review

Technologies:

a. Electric Chillers:

Electrical chillers use a motor driven compressor to chill the refrigerant. Generally, the refrigerants used are HCFCs, CFCs, HFC, etc. These refrigerants are greenhouse gases. CFC was phase out of production in January 1st, 1996 because of issues of ozone layer depletion [6].

Table 1: Comparison of refrigerant alternatives for electric chillers [6]

Criteria	HCFC-123	HCFC-22	HFC-134a	Ammonia
Ozone Depletion Potential	0.016	0.05	0	0
Global Warming Potential (Relative to CO_2)	85	1,500	1,200	0
Ideal kW/ton	0.46	0.50	0.52	0.48
Occupational Risk	Low	Low	Low	Low
Flammable	No	No	No	Yes

The electrical chillers can be classified according to the compressor used:

i. Reciprocating Compressor Chiller:

The compressor in reciprocating compressor uses pistons in cylinders to increase refrigerant pressure. The number of piston-cylinder varies from 1 to 12, which unload in pairs as load decreases. These types of chillers dominate the market in small tonnage systems. [7]

ii. Centrifugal Compressor Chillers:

Centrifugal chillers are aerodynamic type chillers. They move fluid by converting kinetic energy to pressure energy. The compressor encases a refrigerant in a decreasing volume during the compression process. Centrifugal chillers are best suited for big chilling system because of the compressor variable volume load characteristics. They are generally quieter, require less maintenance and have less vibration than reciprocating compressors [7]. The main advantages of a centrifugal compressor are high flow rates capabilities and good efficiency characteristics [8].

iii. Screw Compressor Chillers:

Screw compressors are more compact than either centrifugal or reciprocating compressor. It consists of two matching helically grooved rotors, which turn, compressing the refrigerant gas as it passes from one end of the screws to the other. They are suited for lower temperature applications. [7]

iv. Scroll Compressor:

Scroll Compressor uses two spirals, one within the other to compress refrigerant. Often, one of the scrolls is fixed and the other orbits eccentrically without rotating, thereby trapping and compressing the pockets of fluids between the two spirals. The scroll compressors are very quiet and efficient. [9]

b. Absorption Chiller: [10]

An absorption Chiller is a green technology that cools water using energy provided by a heat source. This technology differs from conventional chillers in the sense that it uses thermochemical absorption process to cool water instead of the mechanical process used in conventional chillers. In addition absorption chillers use water as refrigerant instead of chlorofluorocarbons.

The absorption chiller system uses water as refrigerant and lithium bromide as absorbent. Thus in the absorber the lithium bromide absorbent absorbs the water refrigerant and the solution of water and lithium bromide is formed. This solution is pumped to the generator to be heated. The water refrigerant gets vaporized and moves to the condenser where it is heated while lithium bromide flows back to the absorber where it further absorbs water coming from the evaporator. [10]

Absorption chillers are generally classified as direct or indirect fired and as single, double or triple effect. In directly fired units, the heat source can be gas or some other fuel that is burned in the unit. Indirect fired units make use of heat energy brought from somewhere else in the fluid.

i. Single effect: In a single effect absorption chiller, the fluid transfers through four major components of the chiller-evaporator, absorber, generator and condenser once. The thermal efficiency of single effect chiller is low and they are frequently used to tap the waste heat energy.
ii. Double effect: In a double effect absorption chiller, the fluid transfers through two condensers and two generators to provide more refrigerant boil-off from the absorbent solution. It has higher efficiency than a single effect chiller.
iii. Triple effect: In a triple effect absorption chiller, the refrigerant vapor from the high and medium temperature generators is condensed and the

heat is used to provide heat to the next lower temperature generator. The triple effect chillers are under development and they promise substantial performance improvements.

The advantages of absorption chillers are:

- Elimination of use of CFC and HCFC refrigerants.
- Quiet, vibration free operation.
- Lower pressure systems with no large rotating components.
- High reliability
- Low maintenance

The limitations of absorption chillers are:

- Cost is the primary constraint.
- Low thermal efficiency.
- Requires greater pump energy compared to electric chillers.
- Requires larger cooling tower capacity.
- Cooling up to 41-48^{0}F.

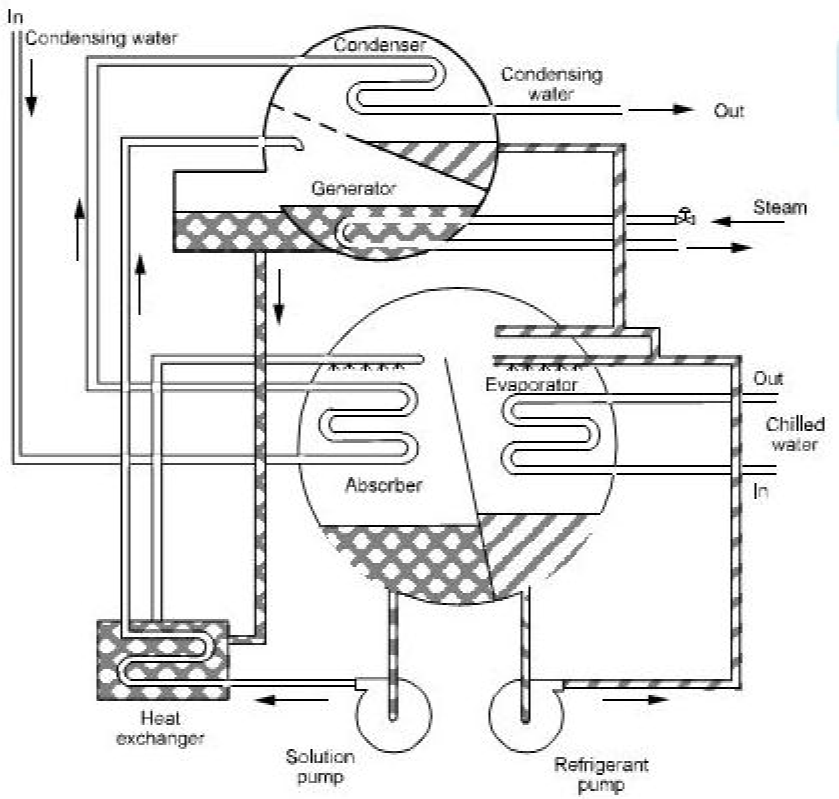

Figure 2: Working cycle of an absorption chiller [10]

c. Adsorption Chiller: [13]

Adsorption chiller is a green technology, which cools water by using a heat source. The adsorption chiller uses water as refrigerant and permanent silica gel as an adsorbent. The silica gel has a very long life (around 30 years), which provides a long lifetime for these types of chillers. The evaporator section cools the chilled water by the refrigerant water being evaporated by adsorption of the silica gel in one of the two adsorption chambers. The adsorption chiller can produce chilled water temperatures of less than 38°F using hot water temperatures ranging from 194 to 122°F. The hot water regenerates the silica gel in the second of two adsorbent chambers. The water vapor released from the silica gel by hot water is then condensed in the condenser section.

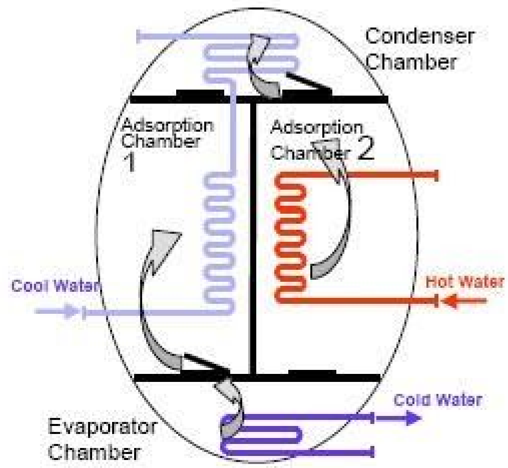

Figure 3: Working cycle of an Adsorption chiller

The advantages of adsorption chillers are:

- Tap water can be used as refrigerant,
- Very long life time,
- Do not need compressors,
- No vibration or noise,
- Chilled water up to 39°F can be delivered
- High energy efficiency.
- Reduction of carbon footprint.

The capacity of adsorption chillers is very large and not appropriate for small capacities since from the different quotations obtained for adsorption chillers for this project, the minimum capacity for a chiller found was of 110 ton.

d. Water-to-water heat pump [14]

The water-to-water heat pump is a green technology, which can be used to cool and heat the water using the same equipment simultaneously. The R-410A is used as the refrigerant. The basic principle of a water source heat pump is the transfer of heat into water from the space during cooling or the transfer of heat from water in space during heating. It is designed to operate between 20°F to 90°F in cooling and 30°F to 120°F in heating for source and 60°F to 120°F in heating and from 30°F to 110°F in cooling for entering load temperatures.

METHODOLOGY

The overall approach of the project was divided in 4 phases: the first one consisted of defining the needs of the clients to better understand the problem at hand; the second one entailed estimating the capacity of chilled water that should be provided; the third phase involved the evaluation of the possible solutions and the selection of a technology that could provide the chilled water required; and the last phase consisted of an economic evaluation of the solution proposed.

I. Phase I – Interviews and data collection at the RMI laboratories

Phase I of the project was the one that involved the most data collection, thus, taking more time to be developed. It was intended to gather the most accurate data as possible, so meetings were scheduled with each of the clients to define what their requirements are and what they were really looking forward to with this project.

The following interviews were made to ensure that each of the clients would be interviewed at least once and several emails were exchanged to confirm their expectations, their needs and equipment specifications:

- April 22nd, 2013 @ RMI Building: Joshua Morejohn (CHCP), Wyatt L. Kennedy and Tom (R&A Engineering Solutions) and Tamy.
- April 25th, 2013 @ D-Lab: Joshua Morejohn (CHCP), Anil, Claudia and Tamy.
- May 7th, 2013 @ Milk Processing Lab: Dr. Juliana Nobrega (MPL), Anil, Claudia and Tamy.
- May 20th, 2013 @ Food Pilot Plant: Scott McCarthy (Food Pilot Plant), Anil, Claudia and Tamy.
- May 20th, 2013 @ Brewery: Candace Wallin (Brewery Manager), Anil,

Claudia and Tamy.

II. Phase II – Data collection and analysis for chilled water consumption

The following phase of the project was to estimate the total flow of chilled water necessary for all the process loads and the equipment in the labs. With an estimated flow rate for chilled water, different technologies could be evaluated for providing a local solution to the RMI building.

The amount of chilled water required for process loads in the three labs in the RMI building was estimated by combining the information from all the labs of the flow-rates used by each equipment and process and the amount of hours each equipment was used in one day. On the other hand, the use of the equipment in each lab is highly variable in terms of time and flow consumption, which is inconvenient for estimating the optimal flow of chilled water required for satisfying all the labs at all times.

To better determine the amount of chilled water used for process loads at the RMI labs, an energy and mass balance for the total chilled water consumption for the entire RMI complex was performed. The total flow of chilled water that is provided from the campus loop to the RMI building is being used for air-cooling and process loads, and it is constantly monitored in combination with measurements from its inlet and outlet temperatures (Figure 4). The airflow that is provided to the RMI building for cooling purposes is also constantly monitored in combination with the temperature in which the air is being supplied into the building and the ambient air temperature (Figure 4). The data for all these measurements was collected from January 1st 2013 to May 24th 2013 every 15 min.

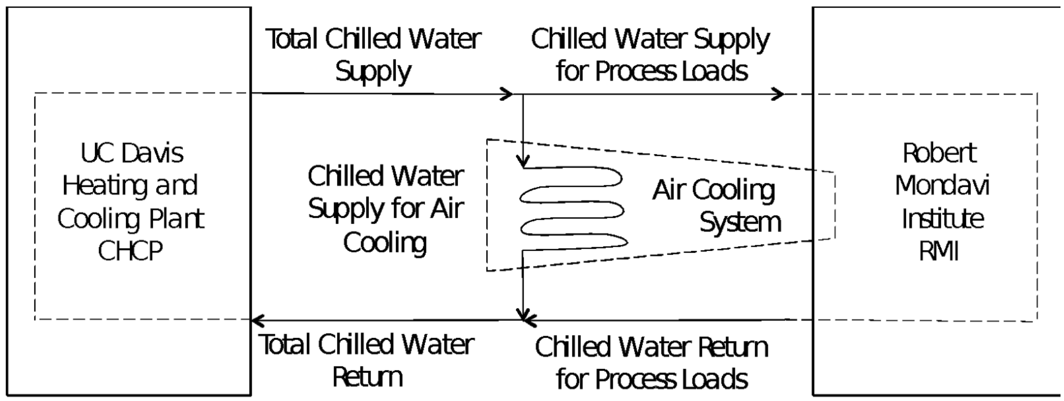

Figure 4. Chilled water loop and air-cooling system at the RMI building

From an ideal energy balance of the measured data the flow rate of chilled water that was required for air cooling was calculated (Equation 1), and by subtracting this value from the total chilled water flow coming into the RMI building the flow of chilled water for process loads was estimated. A 20% of losses for the air-cooling system at the RMI building were assumed to estimate the total flow of chilled water for process loads.

It should be noted that the RMI building has a winery wing that uses chilled water and was not included in the calculation for chilled water loads for the labs but is included in the total balance for chilled water use at the RMI building.

$$v_a \bullet \rho_a \bullet Cp_a \bullet \left(T_{ambient\ a} - T_{supply\ a}\right) \cdot t = v_w \bullet \rho_w \bullet Cp_w \bullet (T_{w\ in} - T_{w\ out}) \cdot t \qquad (1)$$

III. Phase III – Technology selection through an evaluative matrix

After the estimations for total consumption of chilled water at the RMI laboratories were determined, the following phase of the project was to evaluate possible solutions that could provide the RMI laboratories with the required chilled water flows and temperatures.

To select the most appropriate technology for providing chilled water to the laboratories, an evaluative matrix was presented to all four clients who had to rank the importance and relevance for a list of parameters, to determine which were a priority for them so it would be possible to evaluate each technology. The parameters evaluated were: the cost of the technology, the energy savings provided by installing the technology, how “green” or environmentally friendly the technology was, the footprint, the ease of use and the availability of the service provided by the technology.

IV. Phase IV – Data collection for energy and economic savings

The last phase of the project consisted of a brief Economic Analysis of the technology selected during phase III to find the energy savings provided by it and its feasibility based on the results that were encountered. Several assumptions and considerations were made in this phase because of the lack of time and availability of data.

RESULTS AND DISCUSSION

I. Phase I – Defining the needs of all clients

The findings from the interviews were the following:

a. UC Davis Central Healing and Cooling Plant: The campus facilities want to reduce the energy consumption of their cooling plant during the colder months of the year (November through March) by increasing the temperature of the chilled water provided to the campus loop from 40°F to 50°F, since during these months the temperature difference between the outside air and the comfort temperature required inside the buildings on campus is lower than during the warmer months of spring and summer. By increasing the temperature of the chilled water provided to the campus by 10°F, the chillers in the heating and cooling plant can operate more efficiently or could even not be required to operate at all since the return water could be stored and re-circulated into the loop without involving further cooling. However, the CHCP is currently required to provide chilled water at 40°F or lower to the entire campus loop just to satisfy the needs for chilled water by the laboratories located in the RMI Building to be used for their processes. For this reason, campus facilities is considering the alternative of installing a local technology that can provide for the chilled water requirements directly in the RMI Building so that the chilled water loop for the campus can modify their supply temperatures to what best suits the requirements for air cooling while generating energy savings.

b. RMI – Milk Processing Laboratory: This laboratory requires chilled water at 39 to 40°F to cool down their dairy products. The chilled water is used by a milk cooling tank, two heat exchangers, a skim milk tank and a pasteurizer. The water consumption however is highly variable because the experiments are not performed on a constant basis during each quarter. Since the cooling water is not in contact with the products the use of a closed chilled water loop for the equipment could be beneficial to reduce the amount of chilled water that is currently being consumed in the lab.

c. RMI – Food Processing Pilot Plant: This laboratory is currently using chilled water for two equipment, a freeze dryer used 7 to 14 days with a week apart between processes and a high pressure food processor used 4 times per month for 2 days a week. The freeze dryer can operate with water temperatures up to 65^{o}F, but for the high pressure food processor the range of operating temperatures for cold water is unknown. Also this laboratory is considering on purchasing a pasteurizer that would require chilled water at 40^{o}F, so a connection with a localized chilled water loop would solve this requirement.

d. RMI – Brewery: This laboratory is not currently connected to the chilled water loop, since this lab was designed based on their old lab, which was not connected to any loop. They have a glycol refrigerant loop to provide their necessary cooling. However, tap water is being used for cooling some of the smaller brewing equipment, which is inefficient since the tap water is at higher temperatures than what the cold water is required to be (50^{o}F), generating a higher consumption of water to compensate for the lack of colder temperatures.

II. Phase II – Energy and Mass Balance for Chilled Water at the RMI Building

Based on the information from all the labs of the flow-rates used by each equipment and process and the amount of hours each equipment was used in one day, a result of 15 GPM of required chilled water flow was obtained, equivalent to 6.25 Tons of refrigeration (Appendix A). From the estimations for total flow of chilled water provided to the RMI building and from the energy and mass balance performed for the entire building, the flow required for process loads was estimated to be of 28 GPM on average and 54 GPM for peak flow, equivalents to 12.5 and 22.5 Tons of refrigeration respectively, which is a higher value than what was determined directly from the labs consumption. The reason for this difference between the two estimated consumption values is that the winery wing chilled water consumption was not included in the calculations for chilled water loads for the labs but is included in the total balance for chilled water use at the RMI building. From the estimations, two final scenarios were selected for the total capacity that would be required from the technology chosen, one that could satisfy the average requirements of chilled water flow of 10 Tons and one that could satisfy the peak flow requirements of 30 Tons.

III. Phase III – Technology Selection

The final results of the evaluative matrix ranked the parameters in the following order of importance (Appendix B):

1. Availability
2. Ease of use
3. Cost of the technology
4. Energy Savings
5. Footprint
6. How "green" the technology is

The technologies considered as possible solutions for this project were a conventional chiller and the three following 'green' technologies: a solar thermal silica gel-water adsorption chiller, a solar thermal lithium bromide-water absorption chiller, and a water-to-water heat pump. From these options, the three green technologies suggested are able to provide heating and cooling simultaneously, which could be beneficial for the laboratories since they require water at high temperatures (120 to 160^{o}F) for their process loads, but would reduce the ease of use of the technology since chilled water and hot water might not be needed simultaneously and additional storage tanks and pumping systems would be necessary. The green technologies also have a higher cost than a conventional chiller and a lower availability of the service because in order to generate chilled water a heat source is required. Since the parameter of how green the technology is was ranked the lowest by the clients, and from the previous considerations, it seemed reasonable to select a conventional chiller as the technology to use since chilled water would be available constantly, it would be an easy to use equipment and the costs of the technology would be lower than for the other options. All of the technologies proposed would generate similar energy savings from the campus heating and cooling plant point of view, since they will all provide a solution for chilled water consumption locally at the RMI building, but from an operation point of view, for the conventional chiller to have equivalent energy savings as the green technologies, it would be required that it operates with solar power. Finally quotations for 10 ton and 30 ton conventional chillers were acquired (Appendix C).

IV. Phase IV – Economic Analysis

By installing a conventional chiller at the RMI building the campus heating and cooling plant would be able to provide chilled water up to 50^{o}F during autumn and winter to the entire campus, increasing the efficiency of the plant as explained by the client. Currently, during summer and spring, the campus cooling and heating plant requires both their plants (TES and CHCP) to operate simultaneously due to the large demand of chilled water flows, with combined energy consumption for both plants of 0.70 Kw/ton on average. During the colder months of the year when the chilled water requirements are much lower, only the TES plant operates with an energy consumption of 0.79 Kw/Ton on average (Figure 5). The campus heating and cooling facilities would like to have the option of varying the flows and temperatures of chilled water provided to campus during the colder months to allow the TES plant to operate at a higher efficiency and reduce its energy consumption to 0.70 kw/ton (Figure 6).

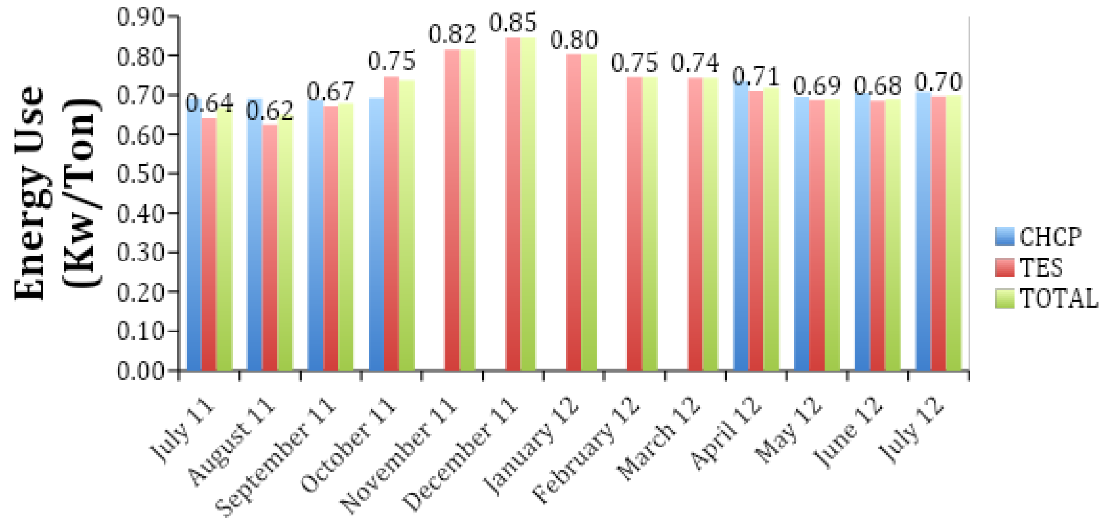

Figure 5. Current energy use scenario for campus heating and cooling plant

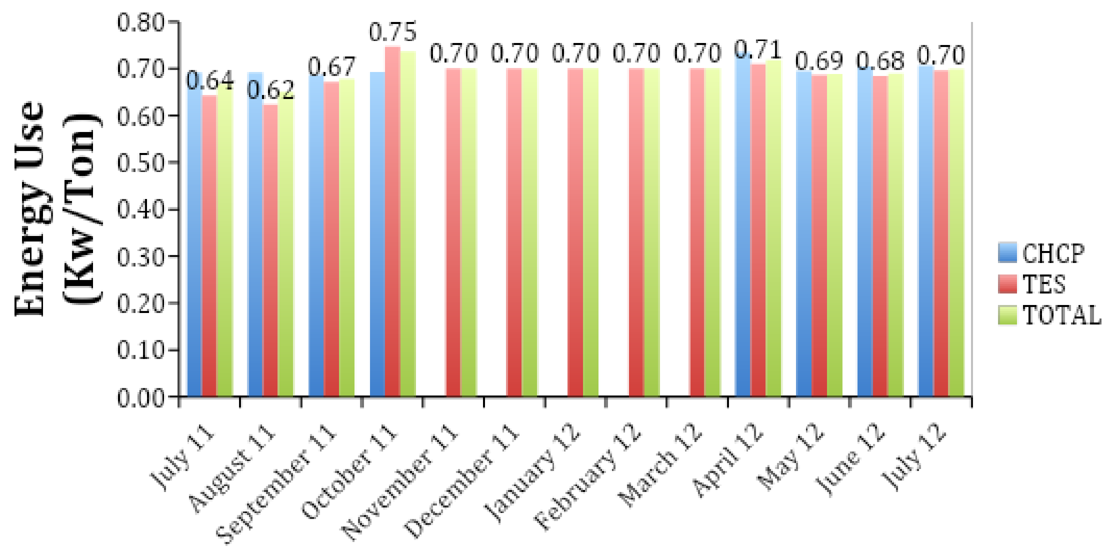

Figure 6. Predicted energy use scenario for campus heating and cooling plant

For the predicted scenario for the campus heating and cooling plant, by reducing the energy use of the TES plant from 0.79 Kw/ton to 0.70 Kw/Ton on average, from the months of November to March, the campus heating and cooling plant could save up to $30.548 per year (Appendix D).

By installing a 10 Ton or a 30 Ton conventional chiller at the RMI building, which from the obtained quotations have respectively the prices of $11.910 and $32.600, assuming that installation costs represent 35% of the full price, a payback time of 3 years, and no operation costs since the RMI building uses solar power to generate its own electricity, the calculated savings provided by the 10 and the 30 ton chiller options would be of $75.565 and $47.634, respectively, over the 3 year period.

Even though further economic analysis would be required, the estimated initial savings prove that by installing a chiller at the RMI building to provide a localized solution for chilled water, extensive economic and energy savings could be achieved.

CONCLUSIONS AND RECOMMENDATIONS

Throughout the quarter several different challenges were faced. Having only three months to develop a project of such scale is too little time. However, it was possible to get to some conclusions based on research, the interviews and the assumptions that were made.

The conventional chiller seems to be the technology that supplies the requirements established by all the clients effectively and works in accordance with the available budget that was determined by the calculations. It is simple, traditional, does not need too much space to be installed and meets the necessities of the labs described by the Evaluative Matrix.

On the other hand, several assumptions were made to get to the results this study got to. The consumption and economic scenarios should be further analyzed to choose the one that fits the current and future demands more accurately.

Further work would involve obtaining more accurate data, in a broader period of time, through more interviews and maybe some on-site observations. A mass and energy balance should be evaluated for summer and autumn also. It would also be good to interview the people who are in charge of the winery and try to add their numbers to the calculations, shaping them better.

It should also be analyzed a more efficient use of the labs that were listed in this study. The current chilled water consumption is very high for the final use that the clients described to be doing. At the same time, according to the Evaluative Matrix, it is possible to see that “how ‘green’ the technology is” is not a relevant factor for them. A different approach and increasing the awareness of the clients and the users to the benefits of more efficient lab practices and using a greener technology could have a significant impact on the energy savings provided by this new technology.

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APPENDICES

Appendix A

Estimation of chilled water consumption for each of the labs at the RMI building, except for the winery wing.

I. Milk Processing Lab

Equipment	Volume (gal)	Flow (GPM)	Hours Used/Day	Water Consumed (gal)
Sprinkman Heat Exchanger 1	100	7	2	840
Sprinkman Heat Exchanger 2	100	7	2	840
Sprinkman Heat Exchanger 3	25	7	2	840
Gea Niro Soax Homogenizer		0.88	2	105.6
TOTAL				2625.6

II. Food Processing Pilot Plant

Equipment	Volume (gal)	Flow (GPM)	Hours Used/Day	Water Consumed (gal)
Freeze dryer Virtis		7.5	24	10800
High Pressure Food Processor Avure		10	4	2400
TOTAL				13200

III. Brewery

Equipment	Volume (gal)	Flow (GPM)	Hours Used/Day	Water Consumed (gal)
2 Stage Plate & Frame Heat Exchanger		7	8	3360
Tube & Shell Heat Exchanger 1	5	7	1	420
Tube & Shell Heat Exchanger 2	5	7	1	420
Tube & Shell Heat Exchanger 3	5	7	1	420
Tube & Shell Heat Exchanger 4	5	7	1	420
TOTAL				5040

IV. Final estimations for chilled water consumption for the RMI laboratories

Water consumed/day=	20865.6	gal
Minutes/day =	1440	min
Average Consumption	14.49	GPM

V. Estimations of Chilled water consumption for the energy and mass balance performed for the entire RMI building

Chilled Water for Process Loads (GPM)	Energy Recovery Scenario		
	100%	80%	60%
Average Consumption	35.17	28.14	21.10
Peak Consumption	67.43	53.94	40.46

Appendix B

Evaluation matrix for technology selection

Parameter	Milk Lab			Brewery		
	Importance	Relevance	Sub-Totals	Importance	Relevance	Sub-Totals
Cost of the technology	5	3	15	5	3	15
Energy Savings	5	5	25	3	3	9
How 'green' the technology is	3	3	9	1	1	1
Footprint	3	3	9	4	4	16
Ease of Use	5	5	25	5	5	25
Availability	5	5	25	5	5	25

Parameter	Food Pilot Plant			CHCP - Facilities		
	Importance	Relevance	Sub-Totals	Importance	Relevance	Sub-Totals
Cost of the technology	5	3	15	5	5	25
Energy Savings	3	3	9	5	5	25
How 'green' the technology is	3	3	9	4	5	20
Footprint	5	5	25	3	1	3
Ease of Use	5	5	25	4	2	85
Availability	5	5	25	4	4	16

Parameter	TOTAL
Cost of the technology	70
Energy Savings	68
How 'green' the technology is	39
Footprint	53
Ease of Use	83
Availability	91

Appendix C

I. Quotation for a 10 ton chiller

TEMPTEK — Economy Priced Auxiliary Equipment For Industry — phone: 317-887-6352

Home | About Us | Products | Contact Us |

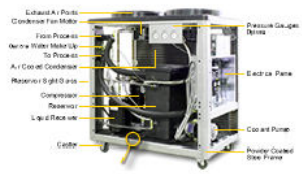
Products Links

- Temperature Control Units
- Liquid Chillers: Portable
- Liquid Chillers: Central
- Pump Tank Stations
- Cooling Towers
- Vacuum Loaders
- Desiccant Dryers
- Material Granulators

PORTABLE CHILLER

10 Tons : Specifications : Features : Options

Typical unit appearance shown.



List Prices for the CFD-10A:
(includes CF Chiller Control)
- **$11,910** (230/3/60)
- **$11,910** (460/3/60)
- **$Consult Factory** (575/3/60)

(Quote # 130605-58636)

Contact Temptek at
317-887-6352
for more information about purchasing and shipping.

SPECIFICATIONS

Model: CFD-10A

(2) **CAPACITY**	
TONS:	10
KW:	35.1
COMPRESSOR	
HP:	10
TYPE:	Scroll
PROCESS PUMP	
HP:	2
GPM:	24
PSI:	48
TYPE:	Centrifugal
CONSTRUCTION:	Stainless Steel
CONNECTION SIZES	
TO:	1-1/4"
FROM:	1-1/4"
WATER MAKE-UP:	1/2"
AIR-COOLED CONDENSER	
TYPE:	Fan
CFM:	10,000
(3) AMBIENT:	95 °F
(4) **FULL LOAD AMPERAGE**	
230/3/60:	55
460/3/60:	27
575/3/60	22
TANK CAPACITY	
HOLDING:	25 gal
LID:	Standard
AUTO MAKE-UP:	Optional
DIMENSIONS	
Height:	60"
Width:	34"
Depth:	56"

FEATURES

FRAME CONSTRUCTION:
- Powder coated steel upright frame
- Galvanized steel cross frame
- Powder coated steel lift-off cabinetry
- Lift-off top panel
- Thermoformed ABS front fascia
- Compact physical size
- Castors - for portability

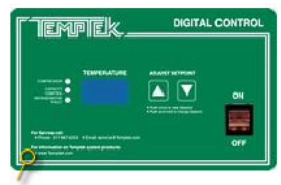
REFRIGERANT CIRCUITS:
- Scroll compressors
- Air-cooled condenser with finned tubes
- Propeller fan(s) induced air flow
- Refrigerant sight glass with moistureindicator
- Filter-drier
- Liquid line solenoid valve
- Thermostatic expansion valve
- Brazed plate evaporator

COOLANT CIRCUIT:
- High Flow Centrifugal pump
- Large capacity insulated non-ferrous reservoir
- Reservoir level sight glass
- Automatic water make-up system
- Standard NPT process fittings

PRESSURE GAUGES:
- Refrigerant high pressure
- Refrigerant low pressure
- Coolant pressure

ELECTRICAL:
- Process pump motor starter

INSTRUMENT



M1 Series (standard instrument)
- Continuous To Process temperature display
- Selectable Setpoint temperature display
- Illuminate ON/OFF power switch
- Soft touch Setpoint selection keys
- Bright and easy-to-read LCD Temperature display window
- Machine Status with Compressor and Capacity Control indicating lights
- Basic Machine Diagnostics with Refrigeration Fault indicating light

OPTIONS

REFRIGERANT CIRCUIT:
- Compressor CPR valve (for setpoints above 65°F)

COOLANT CIRCUIT:

II. Quotation for a 30 Ton chiller

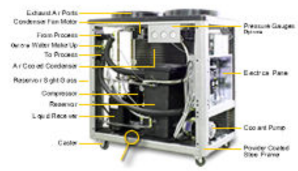
Products Links

- Temperature Control Units
- Liquid Chillers: Portable
- Liquid Chillers: Central
- Pump Tank Stations
- Cooling Towers
- Vacuum Loaders
- Desiccant Dryers
- Material Granulators

PORTABLE CHILLER

30 Tons : Specifications : Features : Options

Typical unit appearance shown.



List Prices for the CF-30A:
(includes CF Chiller Control)
- $32,600 (230/3/60)
- $32,600 (460/3/60)
- $Consult Factory (575/3/60)

(Quote # 130605-68986)

Contact Temptek at
317-887-6352
for more information about purchasing and shipping.

SPECIFICATIONS

Model: CF-30A

(2) **CAPACITY**	
TONS:	30
KW:	105.5
COMPRESSOR	
HP:	15 x 2
TYPE:	Scroll
PROCESS PUMP	
HP:	5
GPM:	72
PSI:	57
TYPE:	Centrifugal
CONSTRUCTION:	Stainless Steel
CONNECTION SIZES	
TO:	2"
FROM:	2"
WATER MAKE-UP:	1/2"
AIR-COOLED CONDENSER	
TYPE:	Blower
CFM:	30,000
(3) AMBIENT:	95 °F
(6) SP:	
(4) **FULL LOAD AMPERAGE**	178
230/3/60:	89
460/3/60:	72
575/3/60	
TANK CAPACITY	65 gal
HOLDING:	Standard
LID:	Optional
AUTO MAKE-UP:	
DIMENSIONS	96"
Height:	58"
Width:	70"

FEATURES

FRAME CONSTRUCTION:
- Powder coated steel upright frame
- Galvanized steel cross frame
- Powder coated steel lift-off cabinetry
- Lift-off top panel
- Thermoformed ABS front fascia
- Compact physical size
- Castors - for portability

REFRIGERANT CIRCUITS:
- Scroll compressors
- Air-cooled condenser with finned tubes
- Centrifugal Blower induced air flow
- Refrigerant sight glass with moistureindicator
- Filter-drier
- Liquid line solenoid valve
- Thermostatic expansion valve
- Brazed plate evaporator

COOLANT CIRCUIT:
- High Flow Centrifugal pump
- Large capacity insulated non-ferrous reservoir
- Reservoir level sight glass
- Automatic water make-up system
- Standard NPT process fittings

PRESSURE GAUGES:
- Refrigerant high pressure
- Refrigerant low pressure
- Coolant pressure

ELECTRICAL:
- Process pump motor starter

INSTRUMENT

M1 Series (standard instrument)
- Continuous To Process temperature display
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- Illuminate ON/OFF power switch
- Soft touch Setpoint selection keys
- Bright and easy-to-read LCD Temperature display window
- Machine Status with Compressor and Capacity Control indicating lights
- Basic Machine Diagnostics with Refrigeration Fault indicating light

OPTIONS

REFRIGERANT CIRCUIT:
- Compressor CPR valve
(for setpoints above 65°F)

COOLANT CIRCUIT:

Appendix D

Economic Analysis

I. Current Scenario

Month	CHCP			TES			TOTAL		
	Kw/Ton	Ton-h	Cost $	Kw/Ton	Ton-h	Cost $	Kw/Ton	Ton-h	Cost $
July 11	0.69	2.70E+06	$134,530.19	0.64	2.69E+06	$124,399.59	0.67	5.39E+06	$258,929.78
August 11	0.69	1.94E+06	$96,343.84	0.62	2.96E+06	$132,715.37	0.65	4.89E+06	$229,059.21
September 11	0.69	2.13E+06	$105,348.27	0.67	2.80E+06	$135,359.50	0.68	4.93E+06	$240,707.77
October 11	0.69	5.11E+05	$25,464.29	0.75	2.27E+06	$122,246.72	0.74	2.78E+06	$147,711.01
November 11	0.00	2.24E+03	$0.00	0.82	9.82E+05	$57,630.46	0.82	9.84E+05	$57,761.67
December 11	0.00	0.00E+00	$0.00	0.85	7.59E+05	$46,230.60	0.85	7.59E+05	$46,230.60
January 12	0.00	1.39E+03	$0.00	0.80	8.37E+05	$48,447.53	0.80	8.39E+05	$48,527.78
February 12	0.00	8.88E+02	$0.00	0.75	9.27E+05	$49,784.45	0.75	9.28E+05	$49,832.14
March 12	0.00	3.44E+04	$0.00	0.74	9.99E+05	$53,405.08	0.74	1.03E+06	$55,244.07
April 12	0.74	7.32E+05	$38,758.96	0.71	1.47E+06	$74,958.25	0.72	2.20E+06	$113,717.20
May 12	0.70	1.12E+06	$56,042.69	0.69	2.46E+06	$121,765.04	0.69	3.58E+06	$177,807.74
June 12	0.70	1.11E+06	$56,478.57	0.68	3.18E+06	$156,693.12	0.69	4.29E+06	$213,171.68
July 12	0.71	1.03E+06	$52,302.29	0.70	3.13E+06	$156,642.35	0.70	4.15E+06	$208,944.64
TOTAL COST									$1,847,645.29

* Cost of energy = 0.072 $/Kwh

* Average Annual usage = 0.70 Kw/Ton

II. Predicted Scenario

Month	CHCP			TES			TOTAL		
	Kw/Ton	Ton-h	Cost $	Kw/Ton	Ton-h	Cost $	Kw/Ton	Ton-h	Cost $
July 11	0.69	2.70E+06	$134,530.19	0.64	2.69E+06	$124,399.59	0.67	5.39E+06	$258,929.78
August 11	0.69	1.94E+06	$96,343.84	0.62	2.96E+06	$132,715.37	0.65	4.89E+06	$229,059.21
September 11	0.69	2.13E+06	$105,348.27	0.67	2.80E+06	$135,359.50	0.68	4.93E+06	$240,707.77
October 11	0.69	5.11E+05	$25,464.29	0.75	2.27E+06	$122,246.72	0.74	2.78E+06	$147,711.01
November 11	0.00	2.24E+03	$0.00	0.70	9.82E+05	$49,479.69	0.70	9.84E+05	$49,479.69
December 11	0.00	0.00E+00	$0.00	0.70	7.59E+05	$38,271.63	0.70	7.59E+05	$38,271.63
January 12	0.00	1.39E+03	$0.00	0.70	8.37E+05	$42,196.90	0.70	8.39E+05	$42,196.90
February 12	0.00	8.88E+02	$0.00	0.70	9.27E+05	$46,734.05	0.70	9.28E+05	$46,734.05
March 12	0.00	3.44E+04	$0.00	0.70	9.99E+05	$50,365.97	0.70	1.03E+06	$50,365.97
April 12	0.74	7.32E+05	$38,758.96	0.71	1.47E+06	$74,958.25	0.72	2.20E+06	$113,717.20

May 12	0.70	1.12E+06	$56,042.69	0.69	2.46E+06	$121,765.04	0.69	3.58E+06	$177,807.74
June 12	0.70	1.11E+06	$56,478.57	0.68	3.18E+06	$156,693.12	0.69	4.29E+06	$213,171.68
July 12	0.71	1.03E+06	$52,302.29	0.70	3.13E+06	$156,642.35	0.70	4.15E+06	$208,944.64
TOTAL COST									$1,817,097.27