2016-2017 ENERGY EFFICIENCY AUDIT

For Mt. San Antonio Gardens

Roberts Environmental Center

Roberts Environmental Center at Claremont McKenna College

Energy Analysis Team

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INTRODUCTION

Lauren D’Souza ’18, Student Manager

Last year, the Energy Analysis Team at the Roberts Environmental Center began its partnership with Mt. San Antonio Gardens with an analysis of the Gardens’ current residential HVAC systems and evaluation of nine proposals for solar arrays for the Gardens’ campus. The final report and presentation culminated in the Mt. San Antonio Gardens Conservation Plan, announced by Gardens CEO Maureen Beith on July 27, 2016.

The Conservation Plan is split into two phases. In the first phase, the Gardens will begin to reduce energy consumption around the campus by (1) a multi-year project to replace the old air conditioners and adding insulation where feasible in the cottages, (2) improving the efficiency of the central HVAC system, and (3) gradually replacing many of the single pane windows and doors with double panes throughout the complex.

The second phase entails the installation of a large solar array to the campus. The Board of Trustees has decided to hold off on choosing a proposal until the phase one energy conservation efforts are complete. After that, the Gardens will solicit new proposals to ensure that the array is not larger than necessary, given new reductions in energy usage.

Under the direction of resident Sam Tanenbaum, the team from the Roberts Environmental Center decided to continue its partnership with the Gardens. The team chose four new areas of inquiry that would contribute to energy efficiency at the Gardens and further reduce energy usage for Phase One of the Conservation Plan.

In the residential area, the team assessed the possibility of insulating the cottages (Section 1) and analyzed the cottages’ hot water heater tanks and the savings for switching to a tankless model (Section 2). For the whole campus, the team measured the lighting levels in large common areas to see if levels were too high and lights could be switched off (Section 3); the team analyzed the Gardens’ eight commercial ice machines and calculated savings for upgrading to more efficient models (Section 4).

Given the changes that the analysis may produce, the team thought it pertinent to distribute a survey regarding the changes to gauge resident sentiment, as the Gardens is reluctant to implement changes that would incur resident complaints (Section 5).

1. INSULATION

Lillian Liang HMC '18

Introduction

Building insulation is a material installed in the walls, ceiling, or roof of a building to help it retain heat. By preventing heat transfer into or out of a building, insulation can help keep warm buildings warm and cool buildings cool. Consequently, insulating a building often leads to lower heating and cooling loads, lower energy bills, and greater comfort for residents. Window type (single or double-pane), building leaks, and building geometry are other factors that may impact heat transfer into or out of a building.

Many of the cottages at the Gardens are old - some built as early as 1961 - with little to no insulation and single pane windows. Because the older cottages have poor heat retention, air conditioners and heaters may have to work harder than they need to maintain the residents' desired temperatures, thus incurring unnecessary energy consumption and costs for the Gardens. In this section of the report, the team provides data to inform the Gardens' adoption of cottage insulation in their Conservation Plan. Our calculations of possible energy savings show that the payback period for insulating a cottage is likely to be less than four years.

Heat Transfer Model 1: Response of Cottage to Changing Temperature

Analysis in the insulation study was based on a physical model of heat flow into a building given an oscillating outdoor temperature proposed by Sam Tanenbaum. The time constant t_0 was chosen as a parameter of interest, and in the model, represents the time delay it takes for a cottage to peak after the outdoor temperature has peaked. Thus, the higher t_0 is, the better the temperature inside a home remains stable despite large fluctuations in outdoor temperatures. When t_0 is less than 2 hours, it approximately equals the time delay; however, as the time delay increases, t_0 caps at 6 hours. t_0 depends on the following parameters:

1. Mass (M)
2. Specific heat (C)
3. Surface area of the building in ft^2 (A)
4. R-value of the insulation (R) in (°F • ft^2) / (BTU/hr)[1]

[1] An R-value is a measure of resistance of a building material to heat passage, and therefore is usually the metric used to describe quality of insulation.

$$t_0 = MCR / A$$

This relationship confirms that the more massive, difficult to heat, or well-insulated a home is (the higher its mass, specific heat, or R-value), the higher the t_0 value, and the less indoor temperatures will fluctuate with changes in outdoor temperature. Likewise, the larger the surface area of the building is, the lower the t_0 value, and the more easily heat can escape from the home, and the more indoor temperatures will fluctuate with changes in outdoor temperatures. In other words, a well-insulated home will have a high t_0 and a poorly-insulated home will have a low t_0.

The heat-flow model reveals a theoretical relationship between the time constant and temperature fluctuations shown in the equation below, where ω (omega) is the frequency of the oscillating outdoor temperature, and ΔT_i and ΔT_o are the differences between the maximum and minimum temperatures inside and outside the building, respectively.

$$\Delta T_i / \Delta T_o = 1 / (1+\omega t_0)$$

Note that as the time constant or frequency of the oscillating outdoor temperature increases, the smaller the change in indoor temperature compared to changes in outdoor temperature. Rearranging, this equation becomes:

$$t_0 = (\Delta T_o / \Delta T_i - 1) / \omega$$

In this study, time constant values were calculated from the above equation. It was assumed that outdoor temperatures fluctuate on a 24-hour cycle, so $\omega = 2\pi/24 = \pi/12$.

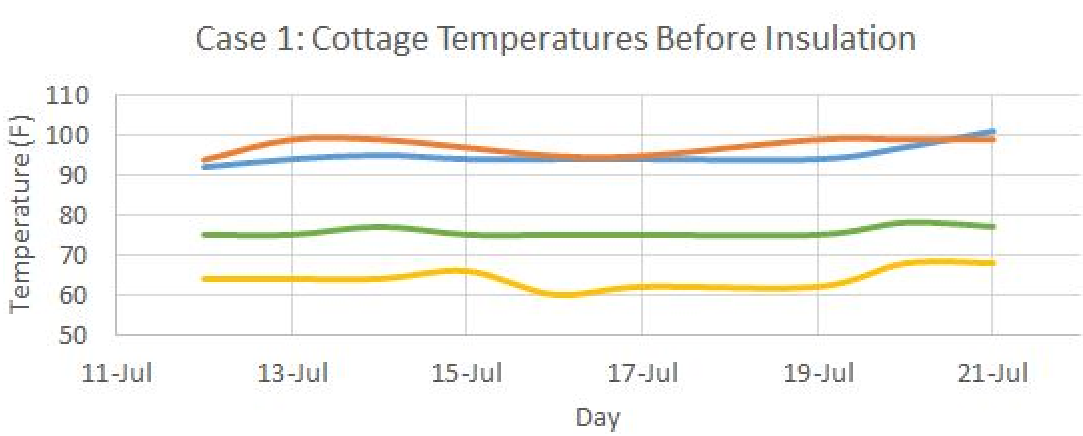
Results and Analysis: Resident-Collected Cottage Temperature Data

Residents of three cottages at the Gardens measured temperature over one to nine days both inside and outside of the cottage. Details of each case are described in Table 1.1. In all three cases, participating residents noted the minimum and maximum temperatures over the data collection period.

	BUILDING INFORMATION	DATES OF STUDY
Case 1:	**Ken & Marian Brown, *Cottage 916 W. Harrison*** Work done by HPM: Blown-in cellulose insulation (R-38 in ceilings, R-13 in walls); Fiberglass batts in crawl space with insulation around air return ducts Other factors: Ceiling fans and window fans	Pre-work: July 12, 2016 – July 21, 2016 Post-work: Sept. 18, 2016 – September 19, 2016, September 25, 2016
Case 2:	**Milt Wilson, *Cottage 892 W Harrison*** Double-paned windows; amount of insulation unknown	November 2, 2016 – November 3, 2016
Case 3:	**Stuart Oskamp, *Cottage 891 Bonita*** No insulation	November 2, 2016 – November 5, 2016

Table 1.1: Overview of the three sets of data used in this study.

Daily temperature data collected by Ken and Marian Brown in Case 1 is shown in Figure 1.1, both before and after insulation. Both before and after insulation, daily minimum temperatures hovered around 70-80 ℉. However, before insulation was installed, daily maximum temperatures in the home closely followed daily maximum outdoor temperature - some were recorded to be over 100 ℉. Remarkably, in post-insulation data collection, the maximum recorded daily temperatures remained at 80 ℉.



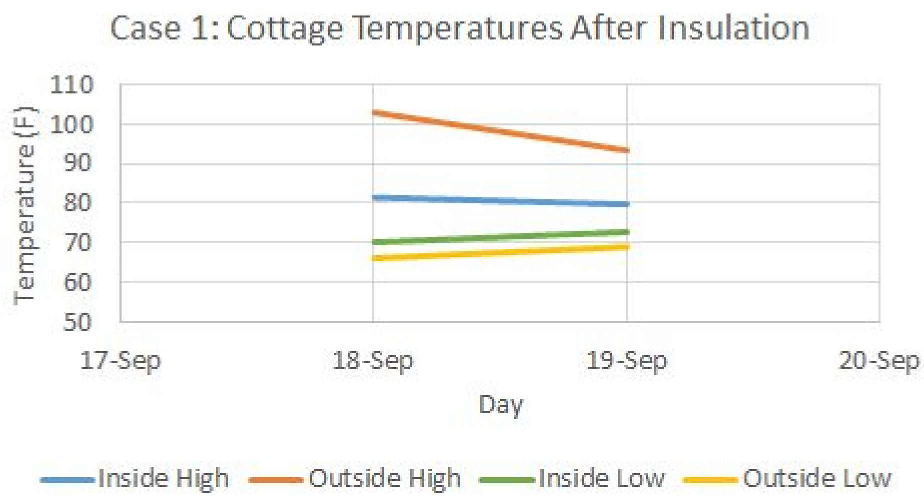


Figure 1.1: Temperature data collected in Case 1 before and after insulation. All data were collected with AC turned off.

The dramatic effect of insulation on cottage temperature can be more clearly seen in the hourly temperature data from Case 1, shown in Figure 1.2. The indoor temperature remained largely stable throughout the day despite the almost 100 ℉ outdoor temperature peak in the mid-afternoon. In all three cases, indoor temperatures measured with a thermostat at the wall were considered more accurate than those measured with a thermometer in the middle of the room.

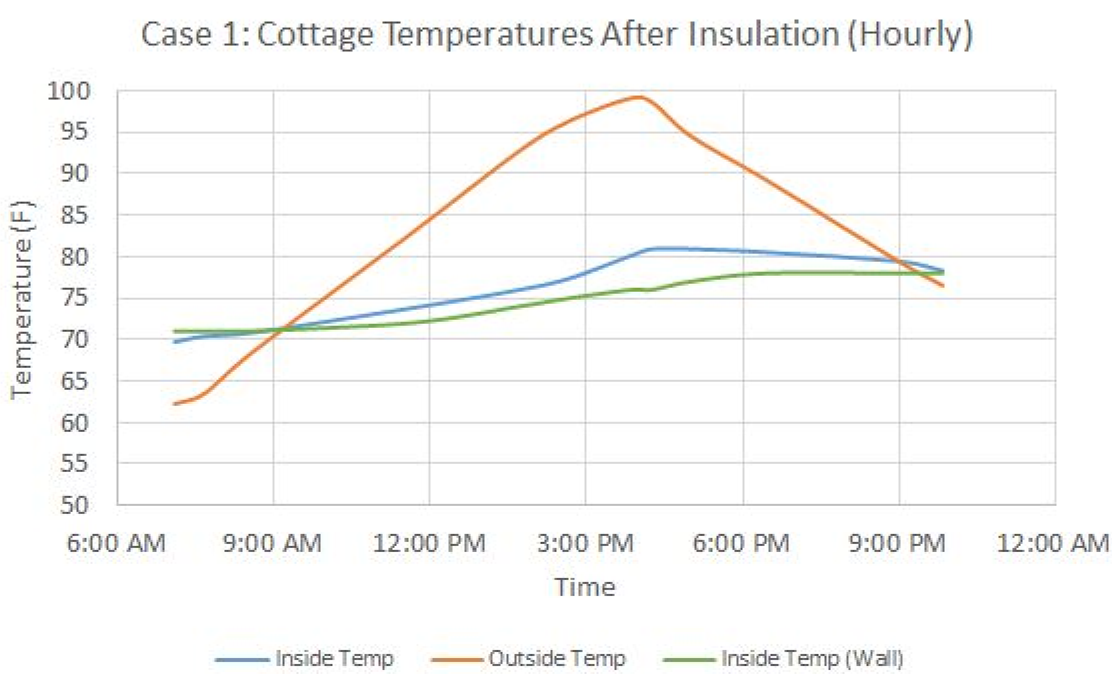


Figure 1.2: Temperature data collected in Case 1 after insulation, approximately every hour. This data was collected on September 25, 2016.

In Cases 2 and 3, Milt Wilson and Stuart Oskamp recorded temperature data approximately hourly, shown in Figures 1.3 - 1.4.

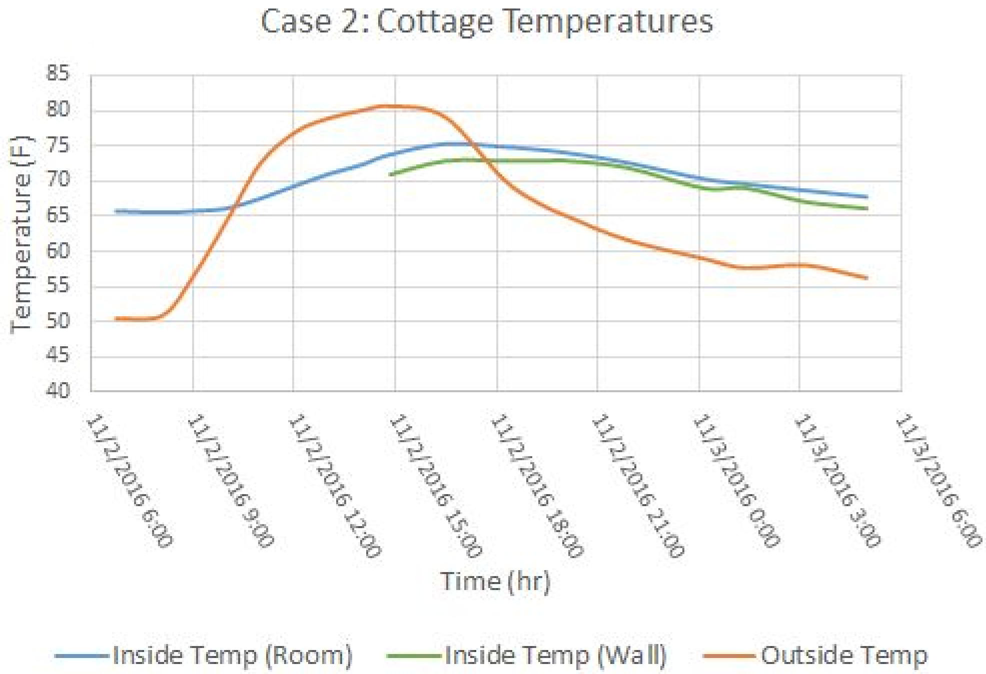


Figure 1.3: Temperature data collected in Case 2. Note that inside temperatures were measured both with a thermometer in the interior of the room and with a thermostat on the wall.

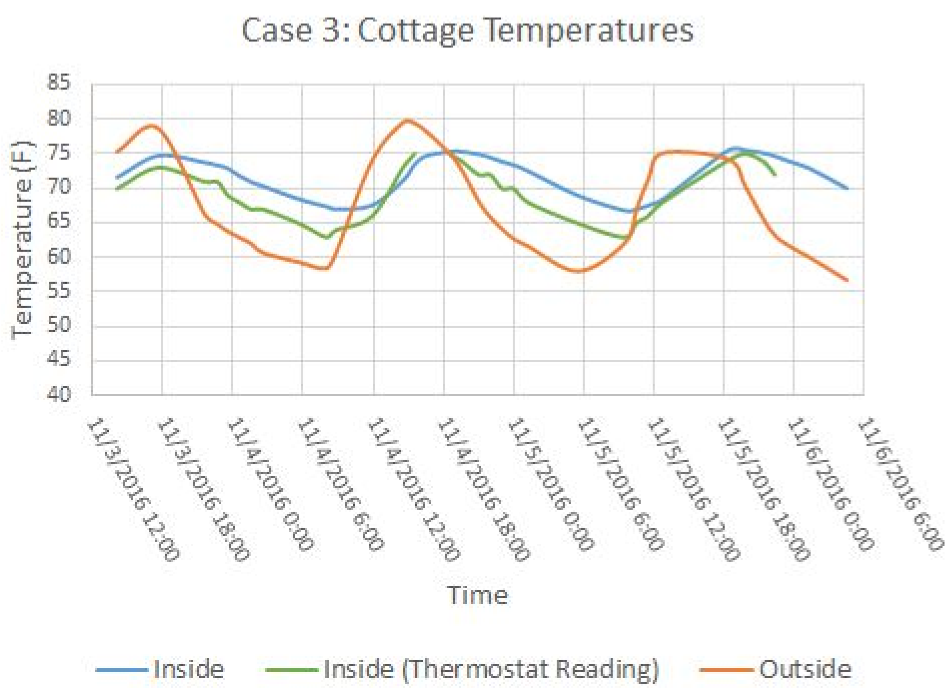


Figure 1.4: Temperature data collected in Case 3. Note that the outdoor thermometer broke for a portion of the initial readings, so data are only included for 11/3-11/5.

Figures 1.3-1.4 illustrate time delay, where peak indoor temperature occurred after outdoor temperature has peaked. The time delay illustrated in these graphs can be quantified with t_0. Though there is no standard or ideal t_0 value, the team still found it valuable to use t_0 as a comparative metric for cottage temperature responses with and without insulation. For each Case, t_0 was estimated and recorded in Tables 1.2 – 1.4.

Pre-Insulation											
DATE	7/12	7/13	7/14	7/15	7/16	7/17	7/19	7/20	7/21	**Avg.**	**Std. Dev.**
t_0	2.92	3.22	3.61	2.41	3.22	2.81	3.62	2.41	1.11	**2.81**	**0.78**
Post-Insulation											
DATE	9/18	9/19								**Avg.**	**Std. Dev.**
t_0	8.69	9.83								**9.26**	**0.81**

Table 1.2: Pre- and Post-Insulation Time constants calculated from data collected in Case 1.

In Case 1, time constants were calculated before and after insulation, providing an opportunity to evaluate the performance of the insulation. Case 1 revealed net time constants 3.3 times greater than prior to insulation, respectively, indicating that the insulation made the buildings more effective at maintaining a stable temperature.

CASE	DATES	t_0 (THERMOSTAT)	t_0 (THERMOMETER)
2	11/2/16	12.33	8.16

Table 1.3: Time constants calculated from data collected in Case 2. Indoor temperatures measured at the wall (thermostat) were considered more accurate than those measured in the middle of the room (thermometer.)

CASE	DATES	t_0 (THERMOSTAT)	t_0 (THERMOMETER)
3	11/3/16 – 11/5/16	1.53	2.64

Table 1.4: Time constants calculated from data collected in Case 3. Indoor temperatures measured at the wall (thermostat) were considered more accurate than those measured in the middle of the room (thermometer.) Data collected during outdoor thermometer malfunction in were discarded.

The time constants calculated in Cases 2 and 3 are shown in Table 1.3 - 1.4. Case 3 exhibited time constants similar to Case 1 pre-insulation case. Since Case 3 Cottage had no insulation, the results confirmed that the pre-insulation time constants for Case 1 were reasonable. Case 2 exhibited time constants similar to Case 1 post-insulation, indicating that the cottage, which had double-paned windows and an unknown amount of insulation, had better heat retention capabilities than a cottage without any insulation.

Heat Transfer Model 2: Impact of Insulation on HVAC

The potential financial benefits of insulation are substantial. Insulation impacts the energy load demanded by the HVAC units. Cottages that are not well-insulated have higher rates of air leakage and heat transfer via conduction through the walls. Thus, cottages with insulation experience decreased energy bills and may even be able to downsize their AC and heating units. Savings on heating and cooling from decreased loads were estimated using another heat transfer model proposed by Sam Tanenbaum.

Heat transfer by conduction through the walls (Q_c) and by air infiltration (Q_a) can be modeled by the following, with parameters listed in Table 1.5:

$$Q_c = A \bullet DD \bullet 24 / R$$

$$Q_a = n \bullet V \bullet C \bullet DD$$

PARAMETER	DESCRIPTION	VALUE FOR MODEL UNIT
Q	Heat loss or gain between the cottage and the environment (Btu)	Discussed in Results and Analysis.
$\Sigma A/R$	A is the area of each external surface of the building (ft^2), and R is the corresponding R-value for each surface ($ft^2 \cdot °F \cdot h/Btu$). The summation calculation takes into account the relative "weights" of the R-values for the materials given.	0.45 - ½" gypsum (sheetrock) 0.94 - ¾" plywood 0.81 - ½" wood siding 0.44 - Asphalt shingles 0.90 - Single-pane glass 1.72 - Double-pane glass, ¼" air space 2.04 - Double-pane glass, ½" air space 3.5 • width of blocks (inches) - Cellulose insulation 6 • width of blocks (inches) - Dense foam insulation

Degree Days (DD)	Degree Days describe the heating requirements of the building (°F·day). The units denote a fall of one degree below a standard average temperature for one day, and the value of the parameter varies by climate.	1700 DD - Heating (Pomona, CA) 1300 DD - Cooling (Pomona, CA)
Air Changes per Day (n)	Air change rate describes air supply flow and leakage in a building.	4 changes/day - tightly-sealed cottage 24 changes/day - loose sliding doors and windows
Volume (V)	Volume enclosed by the building (ft^3).	15,700 ft^3
Specific Heat (C)	Heat required to raise the temperature of one ft^3 of air by one degree (Btu/ (ft^3 •ºF)).	0.018 Btu/ (ft^3 •ºF)

Table 1.5: Parameters for heat transfer model.

The heat transfers Q_c and Q_a represent heat losses or gains from the cottage to the environment due to conduction and air infiltration. Theoretically, in order for the interior of the house to remain a relatively stable temperature despite these heat transfers Q_c and Q_a, the heating, ventilation, and air conditioning systems (HVAC) need to work to pump in or out the identical amount of heat in opposition to the loss or gain incurred. Once found, Q_c and Q_a can be used in conjunction with information about the HVAC efficiencies to find both energy consumption and cost for annual heating and cooling. In heating analysis, we assumed a natural gas cost of $6.00/MBtu and heating unit efficiency of 0.9 (Btu of heating per Btu from natural gas). After analysis was complete, we noted that the Gardens actually pays $10.00/MBtu for natural gas. In cooling analysis, we assumed electricity cost of $0.14/kWh (the peak rate), and AC unit efficiency of either SEER 6 (old) or SEER 14 (new).

Results and Analysis: Energy and Cost Savings from HVAC in a Model Cottage Unit

For all calculations, the team used a “model unit” based on the original floor plans in the Gardens’ residences pamphlet for a 1,250 sq. ft. Two Bedroom Cottage Model, as shown in Figure 1.5. The model unit had no attic, 10 ft. tall walls, and a roof pitch of 30°.

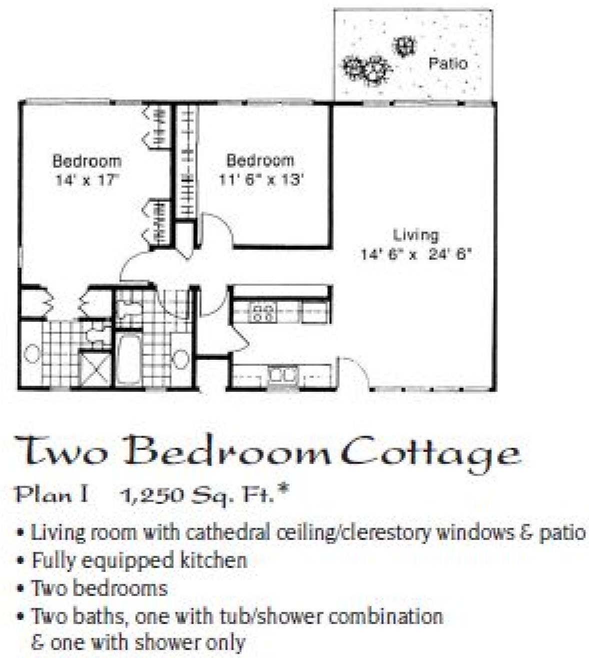


Figure 1.5: Floor plan for two bedroom cottage, the most common model in the Gardens. Floor plans can be found at the Gardens website (http://www.msagardens.org/residences/.)

Using the conduction and air infiltration heat transfer model, we calculated energy and cost saving outcomes for 10 insulation situations for the model unit, as shown in Table 1.7. The four model inputs that the team varied from trial to trial were:

1. AC SEER Rating (6 or 14)
2. Insulation Type (none, cellulose, dense foam)
3. Air Changes per Day (4, 14, 24)
4. Window Type (single pane, double pane - ¼" space, double pane - ½" space)

The team began analysis with the two most extreme insulation scenarios. The worst-case scenario (Trial 1) included old AC units, no insulation, extremely leaky walls, and single pane windows; the best-case scenario (Trial 10) included new AC units, dense foam insulation, tight walls, and double pane windows with a ½" gap. The eight intermediate trials explored various insulation situations between these two extremes, listed in order of increasing annual savings.

TRIAL	DESCRIPTION	AC SEER RATING	INSULATION TYPE	AIR CHANGES PER DAY	WINDOW TYPE
1	Worst Case	6	None	24	Single Pane
2	New AC	14	None	24	Single Pane
3	New AC, Double Pane Window 1/4"	14	None	24	Double Pane - 1/4" Air Space
4	New AC, Medium Leaks	14	None	14	Single Pane
5	New AC, Double Pane Window 1/2"	14	None	24	Double Pane - 1/2" Air Space
6	Old AC, 6" Cellulose Insulation	6	6" Cellulose	24	Single Pane
7	Old AC, 6" Dense Foam Insulation	6	6" Dense Foam	24	Single Pane
8	New AC, 6" Cellulose Insulation	14	6" Cellulose	24	Single Pane
9	New AC, 6" Dense Foam Insulation	14	6" Dense Foam	24	Single Pane
10	Best Case	14	6" Dense Foam	4	Double Pane - 1/2" Air Space

Table 1.7: Descriptions for various trials of model implementation.

Annual energy usage resulting from each scenario is shown in Table 1.8. The annual energy use in each case is compared to the "Worst Case" in the "Savings from Worst Case" column.

TRIAL	DESCRIPTION	HEATING (MBtu/yr)	SAVINGS FROM WORST CASE (MBtu/yr, %)		COOLING (kWh/yr)	SAVINGS FROM WORST CASE (kWh/yr, %)	
1	Worst Case	72.752	0.000	0%	9272.364	0.000	0%
2	New AC	72.752	0.000	0%	3973.87	5298.494	57%
3	New AC, Double Pane Window 1/4"	67.998	4.754	7%	3714.158	5558.206	60%
4	New AC, Medium Leaks	67.949	4.803	7%	3711.481	5560.883	60%
5	New AC, Double Pane Window 1/2"	67.179	5.573	8%	3669.444	5602.920	60%
6	Old AC, 6" Cellulose Insulation	26.303	46.449	64%	3352.312	5920.052	64%
7	Old AC, 6" Dense Foam Insulation	24.420	48.332	66%	3112.326	6160.038	66%
8	New AC, 6" Cellulose Insulation	26.303	46.449	64%	1436.705	7835.659	85%
9	New AC, 6" Dense Foam Insulation	24.420	48.332	66%	1333.854	7938.510	86%
10	Best Case	9.239	63.513	87%	504.650	8767.714	95%

Table 1.8: Heating and cooling energy consumption and energy savings for various trials of model implementation.

In a quote for a Gardens cottage, Home Performance Matters (HPM) reported a cost of $4,418.40 for installation of cellulose insulation, whose breakdown is described in Table 1.9. The plan would involve minimally invasive installation, requiring only small holes on the building exterior and interior ceilings into which insulation would blown at high pressure. For cottages getting their roofs replaced, ceiling insulation could be installed from the exterior, as well. HPM provided a mockup of the exterior wood siding with patching for the insulation holes, shown in Figure 1.6.

ESTIMATE	DESCRIPTION	SQ. FT.	STANDARD UNIT PRICE	DISCOUNTED UNIT PRICE	TOTAL PRICE	NOTES
1	Attic Insulation	364.0	$1.70	$1.36	$495.04	Loose-fill cellulose (R38) or Fiberglass Batts (R30)
2	Kneewall Insulation	123.5	$4.70	$3.76	$464.36	Fiberglass Batt insulation with Mylar Radiant Barrier (R19)
3	Wall Insulation	78.0	$20.00	$16.00	$1,248.00	Loose-fill cellulose (R38), blown in from exterior (R13). Includes finish patching, no painting
4	Cathedral Ceiling Insulation	750.0	$30.00	$2.40	$1,800.00	Does not include patching drywall or painting
5	Room Protection		$822.00	$411.00	$411.00	Per house protection cost
	TOTAL				**$4,418.40**	

Table 1.9: Cost of Insulation from Home Performance Matters (HPM) Professional Quote

Figure 1.6: HPM provided a mockup of the exterior wood siding post-installation. HPM includes patching for insulation holes in their installation process, though the Gardens plans to employ its own staff for painting.

Annual energy cost is shown in Table 1.10. The team assumed $0.14/kWh, the peak electricity rate, to be the cost of electricity, and $6.00/MBtu to be the natural gas cost. The Gardens currently pays for natural gas at a rate of about $10.00/MBtu. Based on current Gardens bills for natural gas, the savings for natural gas will be significantly larger than these estimates. Annual energy costs are compared to the “Worst Case” in the “Savings from Worst Case” column. Using these ideal cost savings, the team also calculated approximate payback periods for the $4,418.40 cost quoted by HPM.

TRIAL	DESCRIPTION	HEATING ($/yr)	COOLING ($/yr)	TOTAL ($/yr)	SAVINGS FROM WORST CASE ($/yr)	PAYBACK PERIOD (yr)
1	Worst Case	$485.02	$1,298.13	$1,783.15	$0.00	--
2	New AC	$485.02	$556.34	$1,041.36	$741.79	--
3	New AC, Double Pane Window 1/4"	$453.32	$519.98	$973.30	$809.85	--
4	New AC, Medium Leaks	$452.99	$519.61	$972.60	$810.55	--
5	New AC, Double Pane Window 1/2"	$447.86	$513.72	$961.58	$821.57	--
6	Old AC, 6" Cellulose Insulation	$175.35	$469.32	$644.68	$1,138.47	3.88
7	Old AC, 6" Dense Foam Insulation	$162.80	$435.73	$598.53	$1,184.62	3.73
8	New AC, 6" Cellulose Insulation	$175.35	$201.14	$376.49	$1,406.66	3.14
9	New AC, 6" Dense Foam Insulation	$162.80	$186.74	$349.54	$1,433.61	3.08
10	Best Case	$61.59	$70.65	$132.24	$1,650.91	2.68

Table 1.10: Heating and cooling costs and cost savings for various trials of model implementation. In our analysis, the team assumed an electricity cost of $0.14/kWh, the peak rate, and a natural gas price of $6.00/MBtu.

The team noted that the most dramatic drop in energy usage/cost arising from a single retrofit to the worst-case scenario cottage was in the addition of insulation. As shown in rows 6-7 of Table 1.10, the Gardens could potentially save over $1000 per year when compared to the worst case scenario in combined heating and cooling savings for a single model cottage. The analysis confirmed that dense foam insulation performed better than cellulose insulation; however, what impacted savings more substantially was that the house was insulated.

The second most dramatic drop in energy usage and cost from the Worst Case Scenario arose from updating the AC units. Updating AC units improved the cooling efficiency, drastically reducing the energy consumption and cost of cooling, as shown in row 2 of Tables 1.8 and 1.10. The team completed AC analysis last year to make recommendations on the SEER rating of new AC units for the Gardens, and plans are underway to update cottage units to SEER 14. The decreased energy load from installing insulation may enable further cost savings by decreasing the size requirements of the new SEER 14 AC units. Retrofit scenarios involving fixing leaks and replacing windows, as shown in rows 6-8 of both Table 1.8 and 1.10, would not lead to energy or cost savings quite as dramatic as those produced by adding insulation or new AC units.

Conclusion

1. Insulation, double-paned windows, and leak patching are cottage retrofits that may help buildings retain heat. Many of the cottages at the Gardens have little to no insulation and single pane windows. Home Performance Matters (HPM) quoted a cost of $4,418.40 for installation of cellulose insulation in a cottage.

2. Data from residents show that insulation significantly reduces the magnitude and increases the time delay of the temperature response of a cottage to fluctuations in outdoor temperature.

3. With simplifying assumptions, calculations on a “Model Cottage Unit” show annual savings of $1,184.62 and payback period as little as 3.63 years with the addition of 6” of cellulose insulation. Based on current Gardens bills for natural gas, the savings for natural gas will be significantly larger than these estimates.

4. Though not included in our analysis, the team noted that installing insulation may enable further cost savings by decreasing the required AC unit size.

5. Calculations on a “Model Cottage Unit” show that 6” of insulation has a larger impact on energy and cost savings than updating AC from 6 to 14 SEER.

2. HOT WATER HEATERS
Ellen Zhang '18

Introduction

The current water heater used in cottages of Mt. San Antonio Gardens is a 30-gallon conventional natural gas fired water heater manufactured by A.O. Smith. This model requires a storage tank heating the water 24 hours every day. This system creates a considerable amount of energy loss, due to several factors:

1. The first energy loss arises from firing the fuel. Natural gas usually has a 20% efficiency loss, because not all of the energy generated by the natural gas is converted into heat.
2. Energy loss also comes from the standby water in the storage tank: since the tank is outside the cottage and not well-insulated, heat is poorly retained.
3. Another energy loss occurs when the hot water moves from the tank to the faucet and bathroom. Because the tank is far away from the rooms, heat is lost along the pipes.

The energy loss is summarized by the Energy Factor (EF), which indicates the overall energy efficiency of a water heater.

Although the tankless water heaters also face the same energy loss as tank heaters when hot water travels through the pipe, the standby loss is eliminated since the hot water is only heated on demand when the faucet is turned on. Incoming cold water encircles the heat exchanger and leaves the heater at its set-point temperature. Therefore, tankless units usually have a higher EF than conventional ones.

Several assumptions were made to estimate the annual energy usage cost and payback period of installing tankless hot water heaters to replace the Gardens' conventional 30 gallon tank heaters.

- **Hot water usage level:** Low usage of hot water is 45 gallons per day; medium usage is 65 gallons per day; high usage is 85 gallons per day.
- **Water Heater:** Different types of water heaters are mentioned in the analysis.
  - "Conventional Water Heater" is the current model in the Gardens, a 30-gallon natural gas fired storage water heater with EF 0.63 (Brand: AO Smith GCB-30, outdoor).
  - "Tankless Unit 1" is a Tankless Water Heater Condensing 150,000 BTU with

EF 0.82 (Brand: Rinnai V65EN, Outdoor).
  - "Tankless Unit 2" is a Tankless Water Heater Condensing 160,000 BTU Natural Gas with EF 0.95 (Brand: ATI-240H-N, Indoor).
- **Natural Gas Price:** The gas price was as low as 60 cents per therm ($6 per million Btu) when the analysis was first done, so we used $6 per million Btu as a low gas price for comparison. Now that the price has increased to 100 cents per therm ($10 per million Btu). Considering that the price might fluctuate in the future, a higher gas rate of 120 cents per therm ($12 per million Btu) is used to estimate annual cost, annual savings, and payback period.
- **Hot Water Temperature rise:** Each water heater has a set heat temperature. A temperature rise of 55°F (heating the water from 50°F to 105°F) is used to estimate energy needed.

Natural Gas Input Comparison

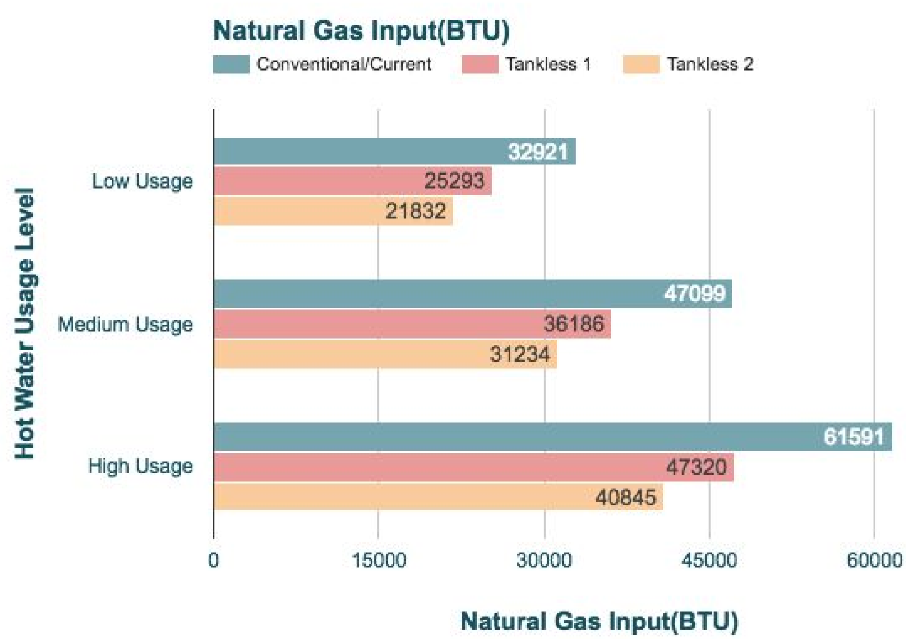


Figure 2.1: Comparison of natural gas input needed for three models of hot water heaters, based on daily usage.

Water Heater	Hot Water Usage Level		
	Low Use	Medium Use	High Use
Conventional/Current	32,921 Btu	47,099 Btu	61,591 Btu
Tankless 1	25,293 Btu	36,186 Btu	47,320 Btu
Tankless 2	21,832 Btu	31,234 Btu	40,845 Btu

Table 2.1: Natural gas usage (BTU) for three scenarios of usage and three types of hot water heaters.

Calculation Method:
Natural Gas Input (BTU) = Natural Gas Needed (BTU) / Energy Factor
Natural Gas Needed (BTU) = Gallons Used • 8.3 • Temperature rise
Natural Gas Input = (Gallons Used • 8.3 • Temperature rise) / Energy Factor
Note: 8.3 is used to convert gallons to pounds, since BTU is measured in pounds.

Given the same amount of natural gas needed to heat the water to the same temperature, the conventional uses the most amount of natural gas, while Tankless Unit 2 uses the least amount of natural gas regardless of the hot water usage level. Compared to the natural gas needed by a conventional storage water heater, tankless units can save up to 20,000 BTU of natural gas when hot water usage is high. Under the current low use condition, tankless unit 2 can save more than 10,000 Btu.

Annual Cost Comparison

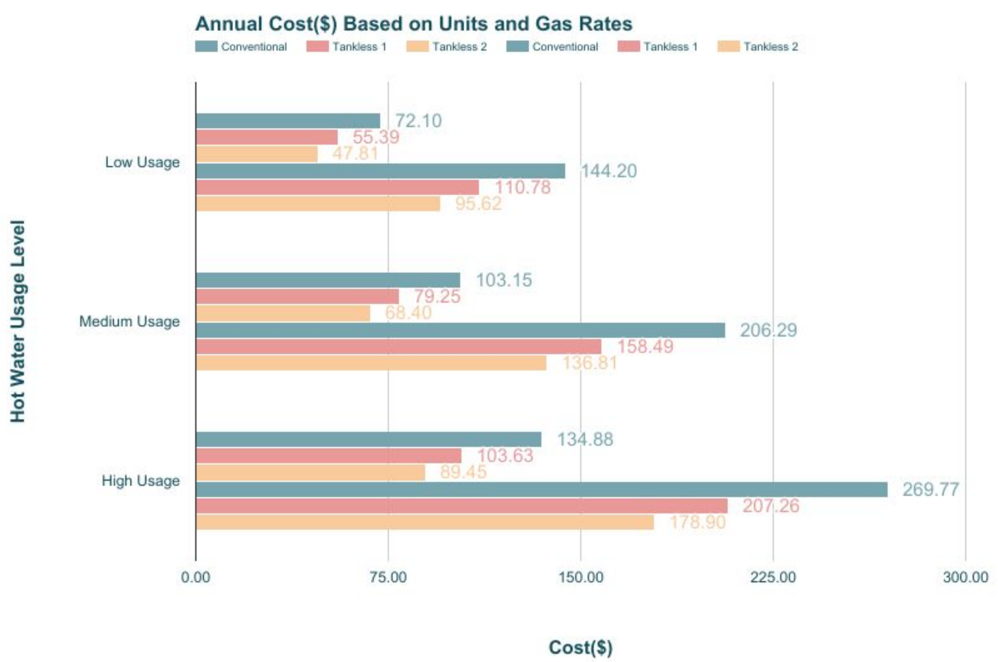


Figure 2.2: Comparison of annual cost needed for three models of hot water heaters, based on daily usage and high/low gas rates.

Gas Rate	Water Heater	Hot Water Usage Level		
		Low Use	Medium Use	High Use
Low Gas Rate (60 cents)	Conventional	$72.10	$103.15	$134.88
	Tankless 1	$55.39	$79.25	$103.63
	Tankless 2	$47.81	$68.40	$89.45
High Gas Rate (120 cents)	Conventional	$144.20	$206.29	$269.77
	Tankless 1	$110.78	$158.49	$207.26
	Tankless 2	$95.62	$136.81	$178.90

Table 2.2: Annual cost ($) for three scenarios of usage, three types of hot water heaters, and high/low gas rates.

Calculation Method: Annual Cost ($) = Natural Gas Input (BTU) • Gas Rate

The operation cost is based on the natural gas input. Since the natural gas input of conventional water heaters (EF 0.63) is the largest, its annual cost is also the greatest, especially when the demand for hot water usage is high. Currently, the annual cost of conventional heater is approximately 50% higher than the Tankless Unit 2 (EF 0.95) and 30% higher than the Tankless Unit 1 (EF 0.82). The cost of using tankless units is proportionally lower than using conventional water heaters when the cost of natural gas increases in the future.

Annual Cost Saving Comparison

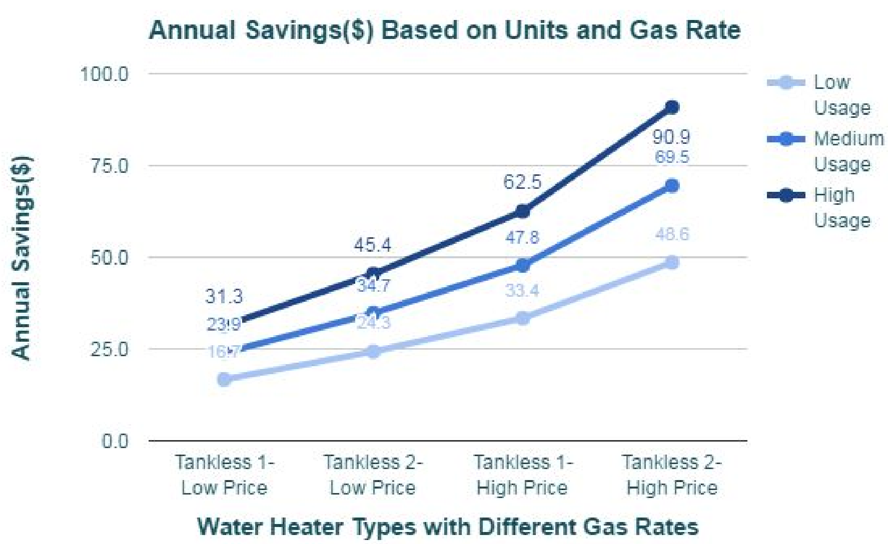


Figure 2.3: Annual savings ($) for two tankless water heaters given hot water usage and high/low gas prices.

Gas Rate	Water Heater	Hot Water Usage Level		
		Low Usage	Medium Use	High Usage
Low Gas Rate (60 cents)	Tankless 1 (EF0.82)	$16.7	$23.9	$31.3
	Tankless 2 (EF0.95)	$24.3	$34.7	$45.4
High Gas Rate (120 cents)	Tankless 1 (EF0.82)	$33.4	$47.8	$62.5
	Tankless 2 (EF0.95)	$48.6	$69.5	$90.9

Table 2.3: Annual savings ($) for two tankless water heaters given hot water usage and high/low gas prices.

Although it is counterintuitive, the more hot water is used, the more money is saved. Tankless Units 1&2 can save 87% annually when the water demand is high, while using Tankless Unit 2 (EF 0.95) can save even more of 45% compared to Tankless Unit 1 (EF 0.82). More money can be saved if the gas rates rise in the future. Under the condition of low water demand and low gas rate, the savings are only $16.8 and $24.3. Even if the price increases in the future, the saving is $33.4 and $48.6. The maximum saving occur when the price of gas rate and hot water usage are high. But in the case of Gardens, where each cottage lives only one or two elderly, the maximum saving of $90.9 seems unattainable.

Payback Periods of Tankless Water Heaters

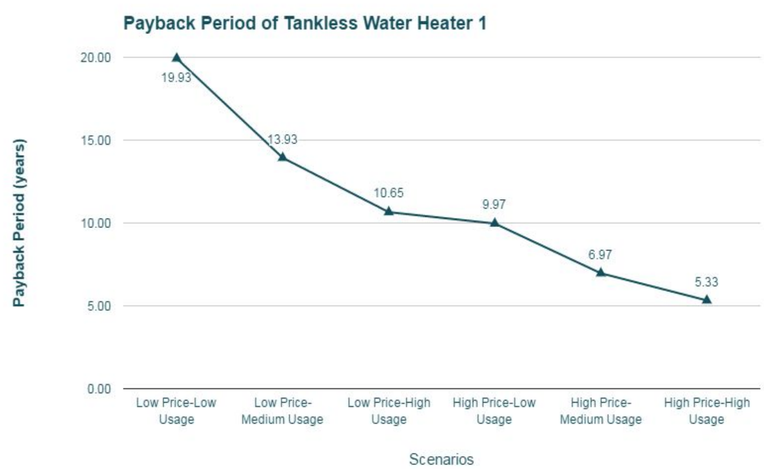


Figure 2.4: Payback periods of Tankless Water Heater 1 (EF 0.82) based on price of natural gas and daily usage.

	Hot Water Usage Level		
Tankless Water Heater 1	Low Use	Medium Use	High Use
Low Price (60 cents per therm)	19.93 years	13.93 years	10.65 years
High Price (120 cents per therm)	9.97 years	6.97 years	5.33 years

Table 2.4: Payback period (years) for Tankless Water Heater 1.

Calculation Method: Payback Period = (New Unit Cost – Old Unit Cost) / (Old Operation Cost – New Operation Cost)
Note: installation cost is not taken into account, because the Gardens' staff will help install.

The payback period for the energy efficient tankless water heaters is calculated from the savings of using Tankless Unit 1 (EF 0.82) and Tankless Unit 2 (EF 0.95). The payback period decreases when both the hot water usage and natural gas rate increases. The shortest payback period of 5.3 years is using Tankless Unit 1 (EF 0.82) when the gas rate is 120 cents per therm. Under low hot water usage, which fits the Gardens' situation, it takes as long as 20 years to pay back the investment when the price of gas is also low. It is most likely to experience the situation when the water demand is low, but gas rate is high. In that case, the payback period is almost 10 years.

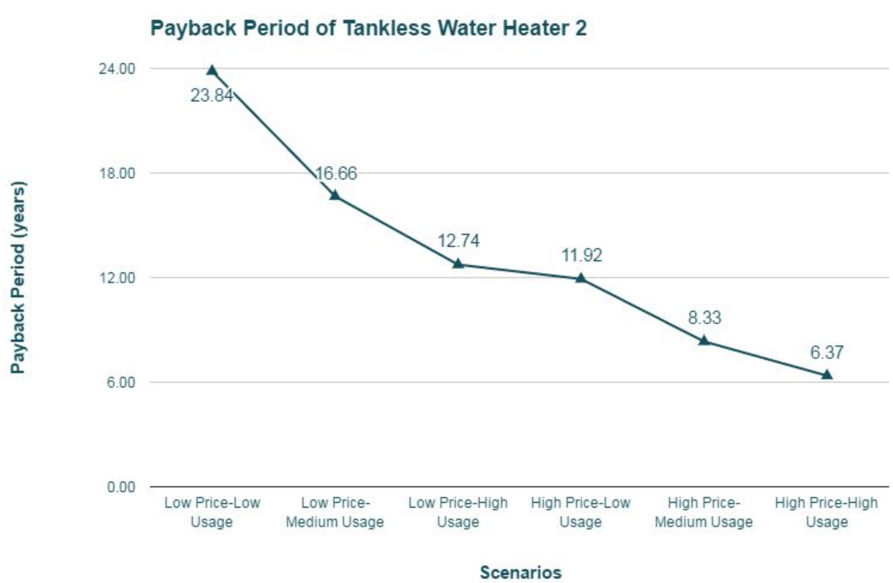


Figure 2.5: Payback periods of Tankless Water Heater 2 (EF 0.95) based on price of natural gas and daily usage.

	Hot Water Usage Level		
Tankless Water Heater 2	Low Use	Medium Use	High Use
Low Price-60 cents per therm	23.84 years	16.66 years	12.74 years
High Price-120 cents per therm	11.92 years	8.33 years	6.37 years

Table 2.5: Payback period (years) for Tankless Water Heater 2.

Similar to the analysis of using tankless 1, the shortest payback period of 6.4 years is using Tankless Unit 2 (EF 0.95) when the gas rate is 120 cents per therm. Compared to using the Tankless Unit 1 (EF 0.82), using the Tankless Unit 2 saves more money annually, but it also takes longer to pay back the price.The payback period of using the Tankless Unit 2 doubles when gas rate is lower. The ideal condition for the Gardens is low water demand and high gas rate, which yields to 12 years of payback period.

Conclusion

1. Tankless Water Heaters are much more efficient than the current conventional hot water heaters by saving up to 50% of annual operation cost.
2. Replacing the hot water heaters with tankless units saves $20.5 per year on average under the condition of low hot water demand and low gas rate.
3. The payback period of more efficient tankless units is about 22 years on average with the current usage of hot water and 11 years on average if the price of gas continues to rise.

3. CAMPUS-WIDE LIGHTING LEVELS
Anthony Burre '19 & Nova Quaoser '19

Methods

On Friday, November 4th, the Energy Analysis Team visited Mt. San Antonio Gardens to collect data on lighting levels, with the goal of finding out which areas (if any) were overlit and potentially energetically wasteful. Using a light meter to measure Lux (lumens per square meter), the team surveyed six different living spaces at the Gardens: the center and back of the dining hall, a corridor in D-building, and the kitchen, bathroom, and hallway of an apartment in D-building. Starting from the dining hall and ending outside residents' living quarters, lighting from each area was sampled three times and was averaged and compared to the Illuminating Engineering Society (IES) and the General Services Administration's (GSA) recommended levels in Table 3.1. The IES is primarily focussed on relaying information from lighting professionals to lighting consumers, whereas the GSA is a governmental agency tasked with delivering the best value in real estate and technology services to the American people.

Findings & Conclusion

The back of the dining hall, the D-Building Apartment bathroom, and the D-Building Apartment hall were outside their recommended lux levels, as shown in Table 3.1. However, The back of the dining hall was significantly less bright than the recommended level for a dining room, but it was also intended to have a different ambiance than the center of the dining hall, which was at a normal level. The D-Building Apartment bathroom was significantly brighter than the recommended levels at 556 lux.

According to Dr. Gary Heiting, O.D., an eye care professional with 25 years of experience in geriatric vision, people over the age of 60 need about three times as much ambient light to read, and they have more difficulty adjusting to new light levels. His research has shown that as people age, their pupils reduce in size and become less elastic.[2] Given that the bathroom is a place for reading miscellaneous labels and prescription bottles, the high level of light seems sensible. Similarly, the slightly elevated light level of 293 lux in the D-Building Apartment hallway effectively lessens the strain on the resident's eyes when walking between the kitchen and the bathroom by minimizing the change in brightness.

[2] Heiting, Gary. "How Your Vision Changes as You Age." *All About Vision*. AAV Media LLC, Jan. 2016. Web.

Overall, there is no reason to lower light levels in any areas of the Gardens, unless residents themselves complain about them. While some of the lights are outside the recommended range, this seems to have been done with a useful purpose in mind.

LOCATION	IES RECOMMENDATION (LUX)	GSA RECOMMENDATION (LUX)	AVERAGE SAMPLED VALUE (LUX)
Dining Hall, Center	300	200	216
Dining Hall, Back	300	200	52
D-Building Apartment, Kitchen	500	500	481
D-Building Apartment, Bathroom	100	200	556
D-Building Apartment, Bedroom Hallway	150	200	293
D-Building Apartment, Outside Hall	150	200	155

Table 3.1: Comparison of sampled light levels (average) to the recommended levels provided by the Illuminating Engineering Society (IES) and General Services Administration (GSA) recommended levels in various locations at the Gardens.

4. COMMERCIAL ICE MACHINES

Jafar Daniel ’20

Introduction

Mt. San Antonio Gardens currently has eight commercial ice machines around campus for residential use. The cottages, the homes on Taylor Road, and the Terraces all lack ice machines because residents have in-home ice makers in their refrigerators. The locations of ice machines are as follows:

- A building
- B building
- C building
- D building, second floor
- D building, third floor,
- D building, fourth floor
- F building
- Oak Tree Lodge

The calculations for initial electricity costs comes from a report done by Sam Tanenbaum on 10/25/16. Bob Pierce, Director of Plant Engineering and Projects at the Gardens, estimates that each machine uses about 1438 Watts while running, and each machines runs for about eight hours each day. Sam Tanenbaum calculated that all of the eight machines uses 92 kWh per day, or 33,600 kWh per year. Because the Gardens currently pay 15 cents per kWh, the current system costs the Gardens $5040 per year.

Pierce notes that the Gardens’ yearly energy bill is about $900,000, so the ice machines make up only about 0.56% of the total spending on electricity. However, there is some added cost for maintenance for older ice machines that could be eliminated. The current ice machines sometimes need repairs to eliminate the mineral buildup from water. With these factors in mind, the team conducted an analysis of several scenarios to replace the current ice machines in the Gardens.

Potential Replacement Options

One potential option for upgrading the ice machines is to purchase the Manitowoc UR-0140A, which runs at 11.3 kWh per 100 lbs. With a daily storage capacity of 122 pounds and assuming that they are used to full capacity, this machine runs at roughly 13.78 kWh per day. The Manitowoc model would cost the Gardens $5032 per year in operation costs. With an annual savings of $8, the payback period is roughly 230 years.

A much smaller model could be placed in lounges of the letter buildings—the Igloo ICE103 Counter Top Ice Maker. The Igloo model has a capacity of 2.2 pounds of ice at one time, and can produce up to 26 pounds in a 24-hour period. It runs on about 120W, and only costs about $120 for each machine. If the Gardens residents do not use much ice, but would still like a machine near their residence, these smaller capacity models save about $3785 in operation costs and have a payback period of three months.

Two other options are to keep the Gardens' current model of ice machines and remove all but one machine, or to remove all eight machines entirely. In these scenarios, the only savings would be from the reduced operation cost. The full list of calculations for each scenario can be found in Table 4.1 below.

REPLACEMENT OPTIONS	SAVINGS & RETURN ON INVESTMENT
Full replacement of all seven machines with newer ice machine model of the same capacity (Manitowoc UR-0140A NEO 26" Air Cooled Undercounter Regular Size Ice Cube Ice Machine)	• Current annual operation cost for 8 machines = $5040 • Annual operation cost for one new machine = $754 • 8 machines = $6035 • Annual savings = $5040 – $6035 = -$995 • Upfront purchasing cost for 8 machines: $14664 Payback period = (New unit cost) / (Old Operation Cost – New Operation Cost) = 240 years
Full replacement of all seven machines with significantly smaller model (Igloo ICE103 Counter Top Ice Maker)	• Current annual operation cost for 8 machines = $5040 • Annual operation cost for one new machine = $156.95 • 8 machines = $1255.6 • Upfront cost of purchasing 8 new machines = $968 • Annual savings = $3785 Payback period = 3 months
Removal of all but one machine	Annual Operation Cost Savings = $4410
Removal of all machines	Annual Operation Cost Savings = $5040

Table 4.1: Replacement scenarios for the Gardens' eight commercial ice machines, with their respective upfront purchasing

costs, operation costs, and payback period.

Survey Responses & Conclusions

In an initial survey of resident behavior distributed on November 22, 2016, the team was able to sample usage of ice machines. A few of the results are listed below.

The team received 119 responses to a question asking if residents use the ice machine available in their building. The responses were fairly split, with about 40% of residents saying that they do not use their ice machine, and 60% saying that they do. One resident responded that they do use the ice machine, but they “would not miss it if the machine was removed.” A few residents responded that they do not use it because they make ice in trays in their fridge; others said that they only used the ice machine if they are entertaining or have guests over.

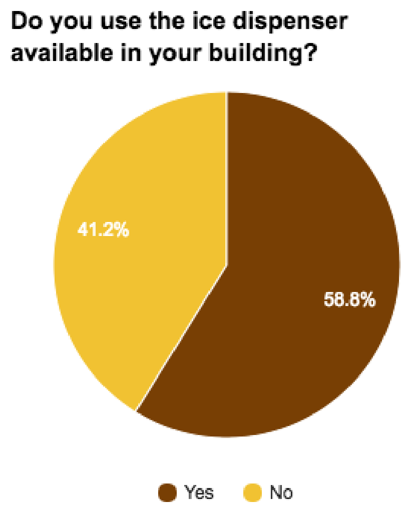


Figure 4.1: Percent of Gardens resident responses that indicated whether or not they use an ice machine.

Another question attempted to gauge how many residents used each ice machine, in the hopes of determining which to potentially eliminate. Only 84 residents answered this question, and the results showed that the only machine not in high use was the ice machine in Oak Tree Lodge. Obviously, a more thorough survey of the Letter Building residents should be disseminated before removal of any machine.

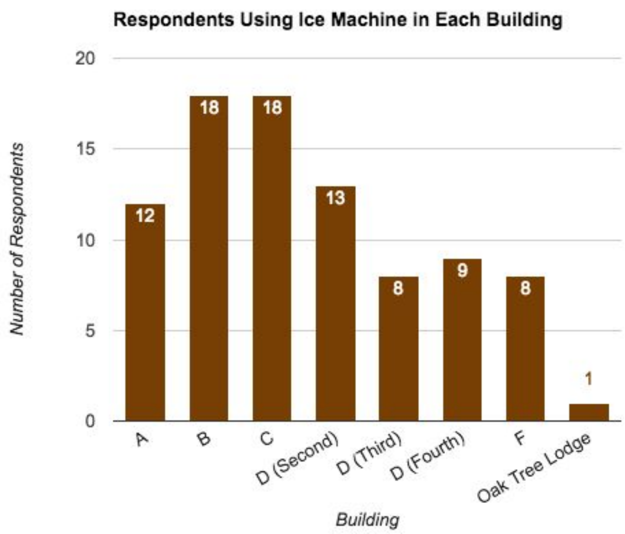


Figure 4.2: Number of respondents who use the ice machine available in each building.

Our recommendation depends on whether or not these ice machines are in use. If they are all in consistent use, we would not recommend installing new ice machines, as the payback period is far too long, the savings are a small fraction of the Gardens' overall energy bill, and the Gardens is hesitant to take any action that might lead to resident complaints. The results of the team's initial survey show no significant results that may lead to immediate action; many residents use the ice machines available, and removing them may cause residential complaints. We officially recommend that a more in-depth survey of only the Letter Building residents be conducted to more accurately determine usage of the ice machines.

Another option mentioned by resident Sam Tanenbaum was to simply promote the use of ice cube trays, as most Mt. San Antonio Gardens residents in the letter buildings own refrigerators.

5. GARDENS RESIDENT SURVEY
Lauren D'Souza '18 and Nova Quaoser '19

As discussed in section four, the team composed and distributed a two-page, thirteen question survey to approximately 400 residents via their mail room cubbies on November 22, 2016. The survey was broken into four sections: Ice Machines (for residents of Letter Buildings only), Energy Usage and Behavior, Preference Questions, and Feedback. A cover letter was also included to inform residents of the purpose of the survey and how their responses would be collated. To view the full survey, please see Appendix III. On December 2, 2016 (ten days following distribution), the team collected the surveys and analyzed the responses.

The survey aimed to gauge general trends in resident energy usage and sentiment on potential changes to the Gardens campus. In total, 182 residents completed the survey, although not every respondent answered each question. The figures below represent the responses for each question.

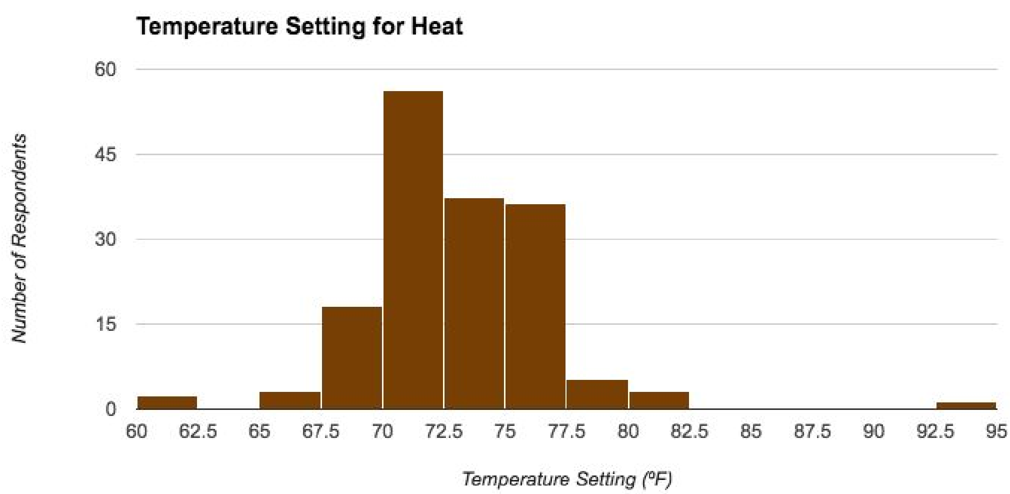


Figure 5.1: Typical temperature range when Gardens residents need heating. Question: "At what temperature do you typically set your thermostat when you need heat?" N = 168

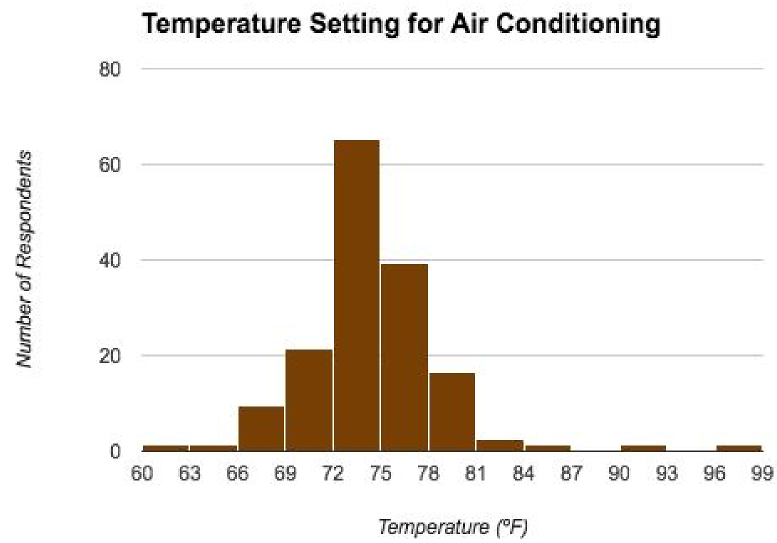


Figure 5.2: Typical temperature range when Gardens residents need air conditioning. Question: "At what temperature do you typically set your thermostat when you need air conditioning?" N = 165

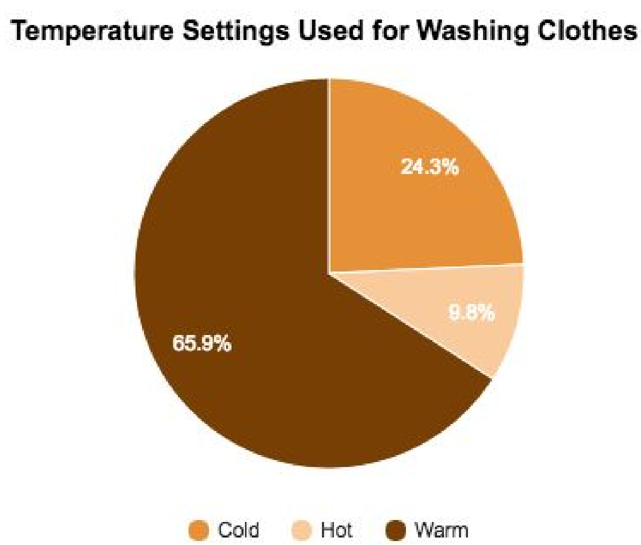


Figure 5.3: Temperature settings used for washing clothes. Question: "Which setting do you usually use when washing clothes?" N = 173

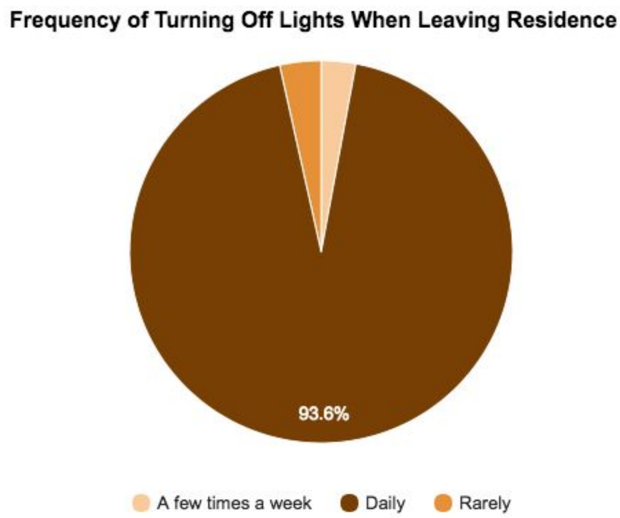


Figure 5.4: Percentage of residents who turn off all or most lights when leaving their residence. Question: "How often do you turn off all (or most) lights when you leave your unit?" N = 173

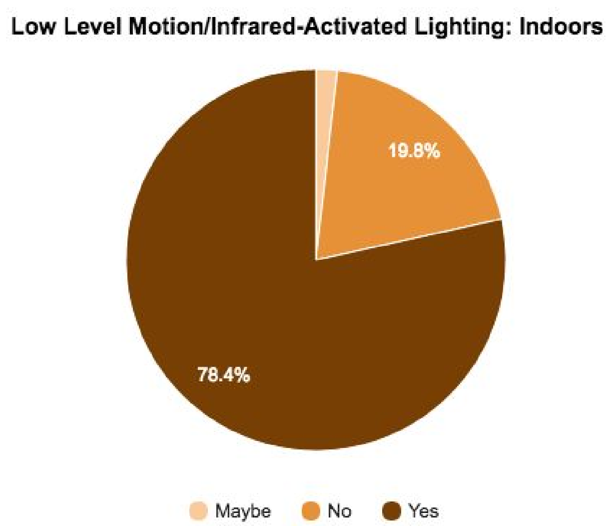


Figure 5.5: Percentage of residents in favor of and against having low-level motion/infrared-activated lighting in hallways, corridors, and common areas. Question: "Would you be comfortable with low-level lighting in corridors and common areas with motion or infrared sensors that turn on full lighting when someone enters?" N = 167

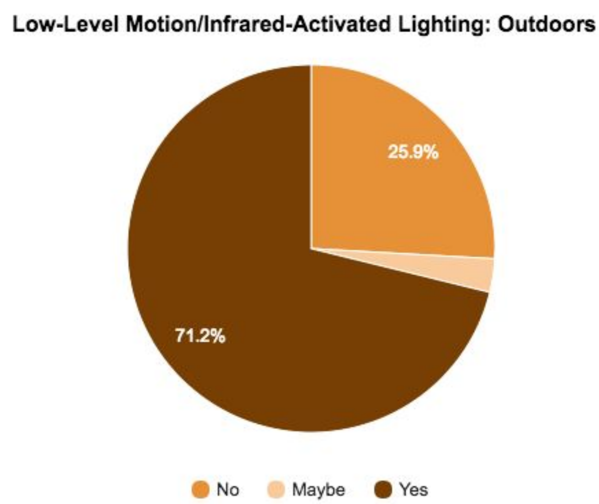


Figure 5.6: Percentage of residents in favor of and against having low-level motion/infrared-activated lighting in outdoor hallways and common areas. Question: “Would you be comfortable having low-level lighting in some outdoor areas and motion or infrared sensors that turn on full lighting when someone enters the area?” N = 170

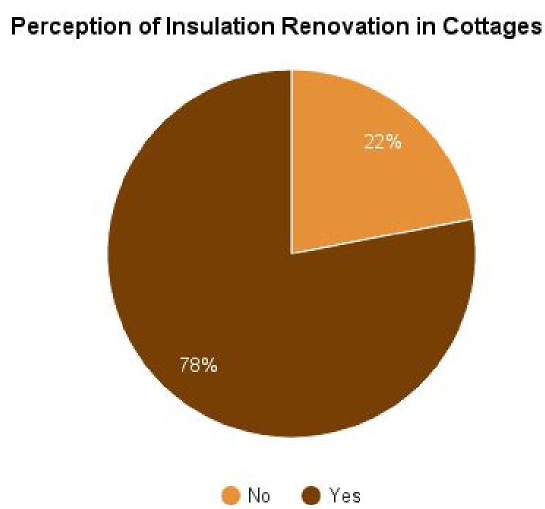


Figure 5.7: Percentage of residents in cottages in favor of and against moving out temporarily for an insulation renovation. Question: “If you live in a cottage, would you be willing to have insulation installed in walls and/or your ceiling if it requires you to move out while contractors work in your cottage for a few days?” N = 50 (note smaller sample)

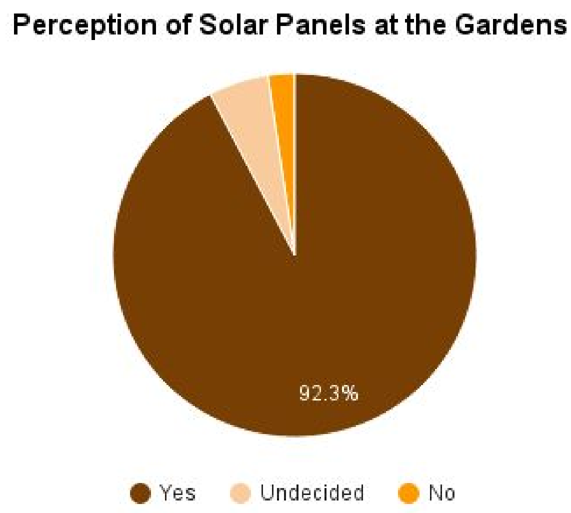


Figure 5.8: Percentage of residents at the Gardens in favor of and against installing solar panels. Question: "Would you favor having the Gardens install solar panels if they can provide some of our electricity at a lower rate than we currently pay?" N = 169

Our survey of the Gardens provided a quick surface snapshot into how residents were gauging some of the reforms being considered. It is important to note that our survey results in no way reflect a formal statistical conclusion on residents' support of specific practices or routine actions at the Gardens. Our results only allow us to demonstrate a general initial reaction by residents to the various questions posed in the survey. Given our decidedly large volume of responses to many questions, however, we conclude that the survey can help shed light on residents' thought processes more accurately than inaccurately. Furthermore, discrepancies in sample sizes from question to question are mainly a result of various questions applying only to specific residents and/or the fact that some residents decided not to respond.

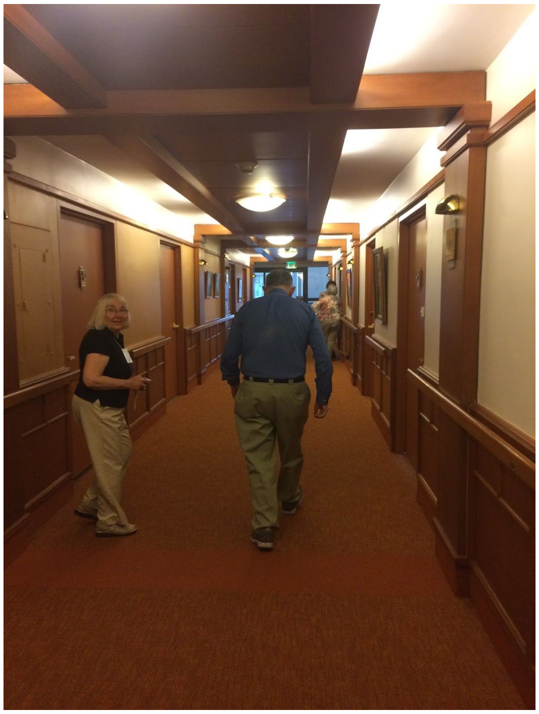
Moving to the conclusions of the survey, we noticed a surprisingly open mentality to many of the changes posed in the survey. Over 70% of residents were in favor of indoor and outdoor motion/infrared-activated lighting (78.4% and 71.2% respectively), and a whopping 92.3% of residents who responded were in favor of the Gardens adopting solar panels if they provided some electricity at a lower rate. This survey also gave us an interesting insight into how residents currently conducted routine practices such as laundry habits, lighting in their housing, and residents' temperature settings. Notably, it showed that residents at the Gardens consistently do practice good techniques, especially when it comes to turning off their lights when leaving their residence (93.2% do so daily).

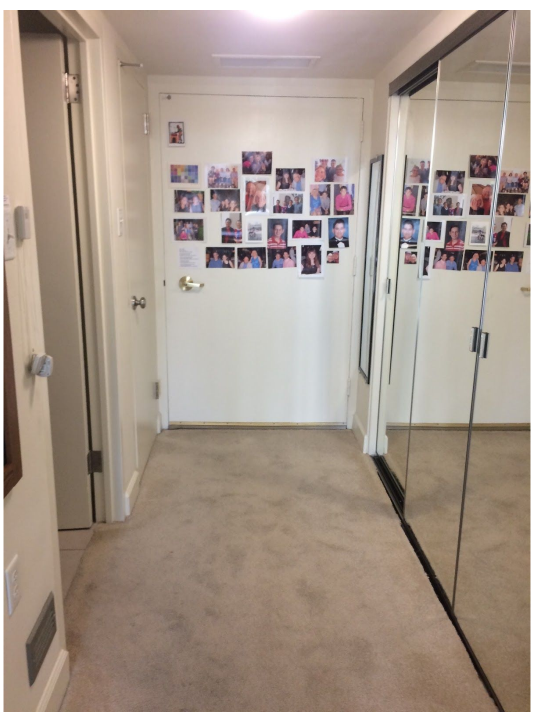
As our survey indicates, it seems that both the Board and residents at the Gardens are open to many proposed environmentally sustainable reforms when it comes to lighting and housing. To conclude, we are optimistic that the Gardens has and will foster an encouraging atmosphere when it comes to considering more sustainable practices.

ACKNOWLEDGMENTS

The team would like to express our sincerest gratitude for our advisor Sam Tanenbaum, for being an exceptional leader in the Gardens Energy Audit. He provided direction and advice for our team when we needed it, advocated for the project amongst the Gardens residents and Board, and connected our team to helpful people and resources from the Gardens to round out our research. In addition, we would like to thank Kristin Miller, Bill Ascher, and Liz Thomas from the REC for their valuable insight about our work and report. Finally, we would also like to extend thanks to the Gardens Residents who supported our Energy Audit, especially Ken & Marian Brown, Milt Wilson, and Stuart Oskamp, who spent substantial time and effort collecting cottage temperature data for the insulation study, and all the residents who participated in our energy use survey. This project would not be possible without the support of all the residents and board members at the Mt. San Antonio Gardens, who have repeatedly and enthusiastically shown support for energy conservation and sustainable projects.

APPENDIX I: Photos of Lighting Areas






APPENDIX II: Ice Machine Upgrades

Link: https://goo.gl/iXPblo Link: http://amzn.to/2loYFFa

Left: commercial model; Right: countertop model.

APPENDIX III: Gardens Resident Behavior Survey

Roberts Environmental Center at Claremont McKenna College
MT. SAN ANTONIO GARDENS ENERGY AUDIT - RESIDENT BEHAVIOR SURVEY

The Roberts Environmental Center is a research institute at Claremont McKenna College. Last year, the Energy Analysis team completed a consulting project with the Gardens on more efficient A/C units and various proposals for large solar arrays. This year, the REC team is continuing its partnership with the Gardens, and analyzing four areas of potentially increased energy efficiency. We have composed a survey to gauge initial data on energy using behavior. All responses to the survey are voluntary, anonymous, and non-binding. Your answers will be aggregated in our report and used for statistical purposes only. For example, the team will prepare figures on what percentage of respondents typically use hot water when washing their clothes.

The team will be presenting their findings at the Gardens shortly before that. We will keep all residents informed of our presentation date and our report will be available around campus after its completion. If you have questions, please feel free to reach out to myself, Lauren D'Souza (ldsouza18@cmc.edu) or our resident advisor, Sam Tanenbaum (tanenbaum@g.hmc.edu). Thank you so much for your participation. We look forward to hearing your comments!

Once you have completed the survey, please return to the "Energy Survey" box in the mail room cubby area. We kindly ask that you return the surveys by *Friday, Dec. 2*.

Best regards,
Lauren D'Souza CMC '18
Student Manager, Energy Analysis Team - Roberts Environmental Center

- **Ice Machines *(For residents of Letter Buildings and Oak Tree Lodge only.)***
  A. Do you use the ice dispenser available in your building? (circle one or explain)
  Yes No Other (please explain)

  B. If so, how often do you use it? (circle one)
  Daily A few times a week A few times a month Rarely

  C. Which ice machines do you use? (Check all that apply)

	A building		D building (third floor)
	B building		D building (fourth floor)
	C building		F building
	D building (second floor)		Oak Tree Lodge

- **Energy Usage and Behavior**
    A. At what temperature do you typically set your thermostat?
        1. When you need heat?
        2. When you need air conditioning?

    B. Which setting do you usually use when washing clothes? (circle one)
    Hot Warm Cold

    C. How often do you turn off all (or most) lights when you leave your unit? (circle one)
    Daily A few times a week A few times a month Rarely

- **Preference Questions**
    A. Would you be comfortable with low-level lighting in <u>corridors and common areas</u> with motion or infrared sensors that turn on full lighting when someone enters? (circle one or explain)
    Yes No Other (please explain)

    B. Would you be comfortable having low-level lighting in <u>some outdoor areas</u> and motion or infrared sensors that turn on full lighting when someone enters the area? (circle one or explain)
    Yes No Other (please explain)

    C. If you live in a cottage, would you be willing to have insulation installed in walls and/or your ceiling if it requires you to move out while contractors work in your cottage for a few days? (circle one or explain)
    Yes No Other (please explain)

    D. Would you favor having the Gardens install solar panels if they can provide some of our electricity at a lower rate than we currently pay? (circle one or explain)
    Yes No Other (please explain)

- **Feedback *(If you need more space, please attach another sheet to this paper.)***
    A. Have you observed anything that the Gardens is doing that might be wasteful of energy, e.g. outdoor lights left on 24/7?

    B. Do you have any other comments?