Analysis 2: Alternative Thermal Window Design

(8.1) Problem Statement:
In the first analysis, the cost and environmental impacts of the addition of solar PV panels to the roof of GrandView was determined. Keeping with the theme of solar energy and minimizing schedule impact and the fact that the building employed an advanced Henry air/moisture skin, it was determined that the windows installed in the residential units were not meeting the overall envelope purpose of saving energy. What would happen if alternative thermal window designs were substituted, and what affect would this have on conductive and solar heat gain relating to the cooling system?

(8.2) Research Goals:

The goal of this analysis is to compare the energy savings and environmental impact the substitution of more energy efficient windows has on the building. Three aspects of the windows will be analyzed and then combined to produce the final results. First, a low E glazing will be added to prevent solar heat gain through the windows as well as help with moisture control. Second, a more advanced double pane and triple pane system will be substituted to help lower the overall U-Value of the unit. Finally, the current aluminum frame will be replaced with a fiberglass insulated frame. It is my hope that the life cycle costs of the energy saved by this substitution will offset the initial investment.

(8.3) Background

Pairing energy efficient windows with an efficient building skin maximizes energy savings. The current skin of GrandView consists of a Henry Air and Moisture Barrier system, which was used to enhance the air leakage and insulation properties of the system.

Controlling moisture is critical to maintaining the durability of a building as well as the health of its occupants. When moisture condenses it can damage finish materials, reduce the R-value of insulation, and lead to decay. High moisture levels are necessary for the growth of molds and dust mites which can endanger human health.

The current windows account for 36% of the building's overall façade area. Low-E glass improves the energy efficiency of windows and can improve interior comfort and reduce the occurrence of condensation on windows. This glass allows high levels of natural light to enter the home, reducing the need for supplementary artificial lighting during the daytime. Solar control glass also reduces interior surface reflectivity which can prevent occupants from seeing outside at night. In some cases, using solar control glass can reduce cooling loads so greatly that cooling system capacity can be reduced or that glass area can be added without increasing cooling loads. It offers the greatest energy savings in areas where cooling costs are higher than heating costs.

The current window package for the residential portion of the building amounts to $1,875,430.00.

(8.4) Design Methodology

There are three fundamental elements of window design that affect the thermal performance:

- Glass – Affects the thermal loss out of the building and the solar gain into the building.
- Glazing – Affects the solar heat gain through the glass
- Frame - Affects the thermal loss out of the building through conduction and air loss.

The current window system that makes up the residential portion of the building consists of simple thermally broken frames and double pane glass, high solar gain glazing.

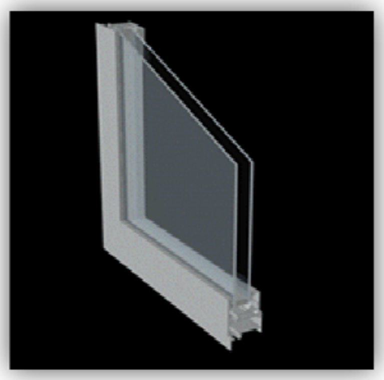


Figure 8.1: Double Glazed Aluminum Window

Existing Window Type: Double Glazed Clear with Aluminum Frame	
U-Factor	0.43
SHGC	0.58
VT	0.68

Table 8.1: Existing Window Type

In order to achieve better energy efficiency through solar and convective gain, the following two window types are going to be analyzed. The addition of a Low-E, low solar gain glazing will be applied to both a double and triple pane window system with a fiberglass frame. Fiberglass frames have a far better U-factor than aluminum frames when it comes to convective and solar heat transfer. The Low-E glazing will help lower the solar heat transfer as well as maximize light transmittance.

Figure 8.2: Double Glazed Fiberglass Window

Proposed Window Type 1: Double-Glazed with Low-Solar-Gain Low-E, with Fiberglass Frame	
U-Factor	0.26
SHGC	0.31
VT	0.55

Table 8.2: Design 1

Proposed Window Type 2: Triple-glazed with Low-Solar-Gain Low-E with Fiberglass Frame	
U-Factor	0.18
SHGC	0.26
VT	0.43

Table 8.3: Design 2

Definitions

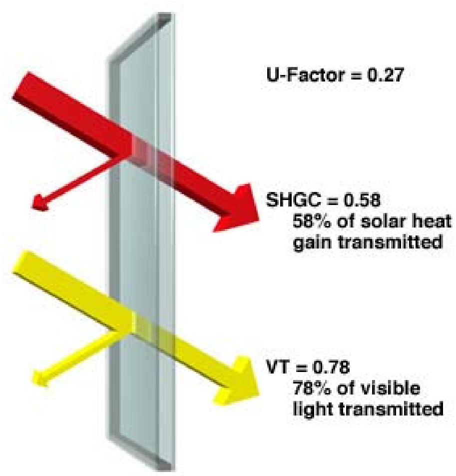


Figure 8.3: Solar Heat Gain Values

U-factor (U-value). A measure of the rate of non-solar heat loss or gain through a material or assembly. It is expressed in units of Btu/hr-sq ft-°F (W/sq m-°C). Values are normally given for NFRC/ASHRAE winter conditions of 0° F (18° C) outdoor temperature, 70° F (21° C) indoor temperature, 15 mph wind, and no solar load. The U-factor may be expressed for the glass alone or the entire window, which includes the effect of the frame and the spacer materials. The lower the U-factor, the greater a window's resistance to heat flow and the better its insulating value.

Solar heat gain coefficient (SHGC). The fraction of solar radiation admitted through a window or skylight, both directly transmitted, and absorbed and subsequently released inward. The solar heat gain coefficient has replaced the shading coefficient as the standard indicator of a window's shading ability. It is expressed as a number between 0 and 1. The lower a window's solar heat gain coefficient, the less solar heat it transmits, and the greater it's shading ability. SHGC can be expressed in terms of the glass alone or can refer to the entire window assembly.

Visible transmittance (VT). The percentage or fraction of the visible spectrum (380 to 720 nanometers) weighted by the sensitivity of the eye, that is transmitted through the glazing.

High-performance windows not only provide reduced annual heating and cooling bills; they reduce the peak heating and cooling loads as well. This has benefits for the homeowner, in that the size of the heating or cooling system may be reduced, and it also benefits the electrical utilities, in that load factors are reduced during the peak times in summer.

SOLAR AND MECHANICAL BREADTH

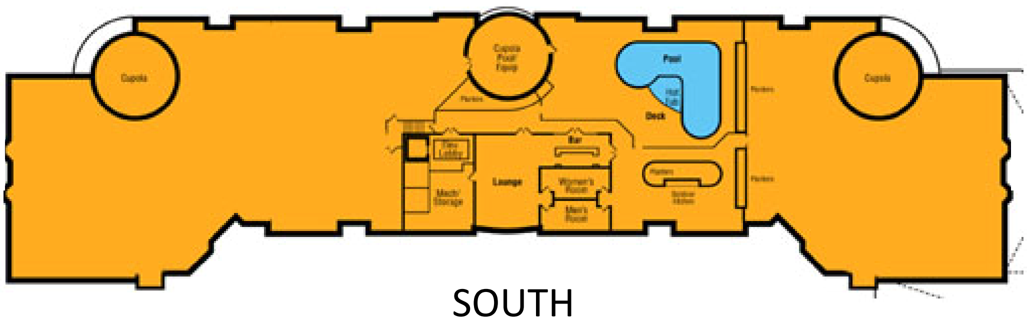
(8.5) Fenestration Heat Gain Analysis

In order to determine the heat gain through solar rays, building orientation, surface area of the windows, surface irradiance bust be determined. Utilizing previous calculations done by Todd Povell, the solar irradiance of each side of the building was determined. It is important to note that in order to create an accurate heat fenestration excel sheet, building orientation needed to be adjusted. In Grandview's case, the following changes needed to be made to the fenestration data provided.

North irradiance becomes GrandView's **East**
South irradiance becomes GrandView's **West**
East Irradiance becomes GrandView's **North**
West irradiance becomes GrandView's **South**

NORTH

WEST



EAST

SOUTH

Figure 8.3:

STEP 1	Determining Total Fenestration Area

In order to determine the area of fenestration, a simple hand take-off was calculated from the drawings. This area consists of all the windows and glass facades that are present in floors 2-12. The first floor is retail and has not been included in this analysis due to different window type and energy consumption requirements.

Window Area by Façade Face: **North** = 16380 ft^2 **South**= 14976 ft^2 **East** = 3159 ft^2 **West** = 3861 ft^2

STEP 2	Estimating Exterior Temperature

With this type of analysis, the exterior temperature is needed to determine whether heat will be transferred into or out of the building. Data for the DC area was found with the help of the National Oceanic and Atmospheric Administration (NOAA) and the United States Naval Observatory (USNO). Together they provided minimum, maximum and mean temps for the area along with sunrise and sunset times. Through these sets of data, a temperature gradient was determined for one day of each month (21^{st}). The data can be found in Appendix E.

STEP 3	Calculating Total Surface Irradiance

Now that the area of fenestration for each face of the building is known, surface irradiance for each face needs to be calculated. Fortunately, these calculations have been provided. It is important to note that a re-orientation of the irradiance was done in order to apply them to GrandView. The basic footprint is almost identical in orientation to the provided data. See the previous page for a detailed explanation.

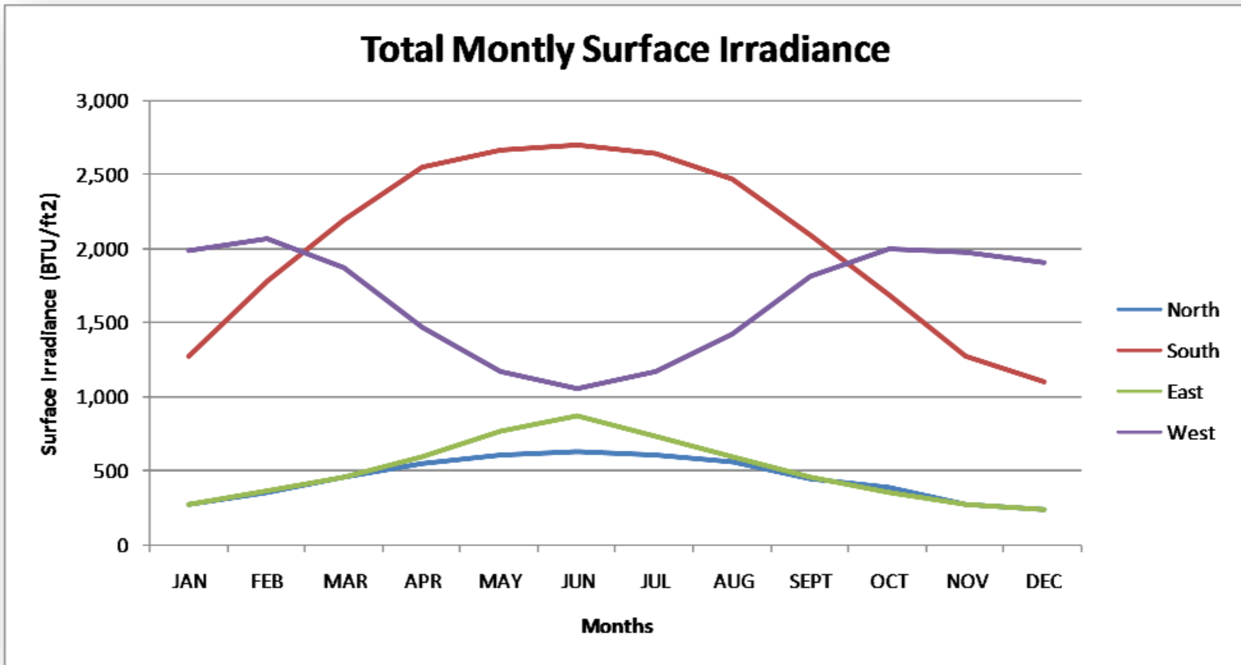


Figure 8.4: the southern facing façade gains the most solar energy while the north and east gains the least

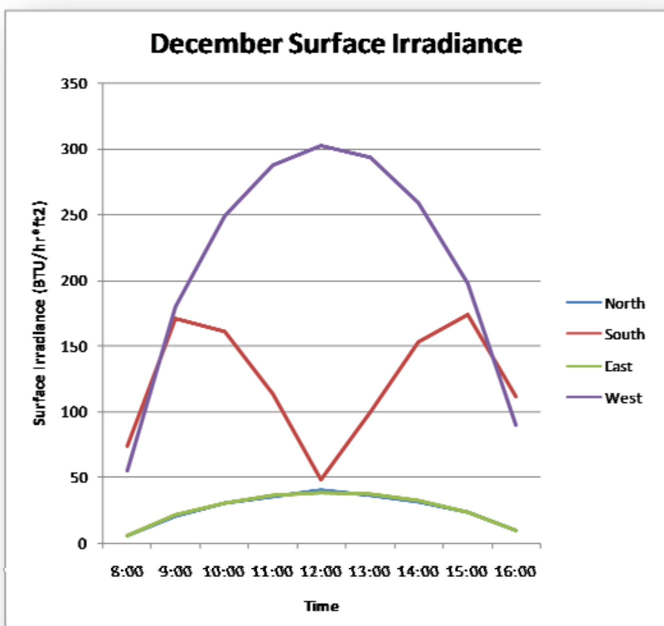


Figure 8.5:

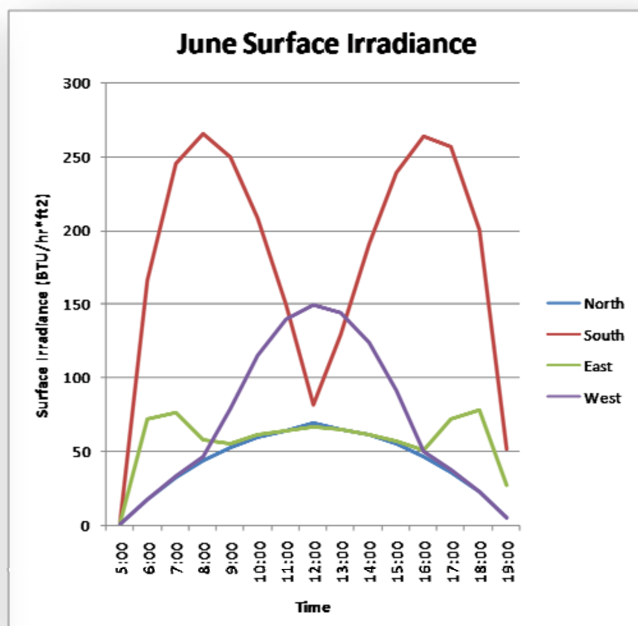


Figure 8.6:

STEP 4 | **Calculating Fenestration Heat Gain**

A fenestration is defined as the openings in a building's envelope including windows, doors, and skylights. The following analysis will only deal with windows.

In order to determine the instantaneous heat transfer through the window system, the following equation was utilized from the 2005 ASHRAE Handbook of Fundamentals (page 31.3, equation 1)

Equations

$$Q = Q_{cond} + Q_{sol}$$

$$Q = AU(T_{OUT} - T_{IN}) + SHGC(A)(E_T)$$

Definition of Terms

Q	Instantaneous Energy Transfer	BTU/hr
U	Overall Coefficient of Heat Transfer	BTU/(hr*ft^2*F)
A	Area of Fenestration	ft^2
t_{out}, t_{in}	Exterior and Interior Temperatures	F
SHGC	Solar Heat Gain Factor	-
E_t	Incident Total Irradiance	BTU / (hr*ft^2)

GIVEN | **Assumptions made for Cooling Load Analysis**

- The indoor air temperature was set at a comfortable 72 degrees F for the whole year. The scope of this breadth focuses specifically on the energy transfer through the windows, a constant temp. removes variables such as tenant's specific requirements. Because GrandView is a luxury apartment complex, it is assumed that cooling and heat loads would be constant.
- While the heating load was calculated in Appendix E, it was omitted for the sake of cooling load calculations. Only net heat gains through the windows were accounted for because variables such as computers, lights, humans, and mechanical equipment are essentially all part of the heating load.
- Both residential common windows and the large curved glass facades were taken into account. However, since the glass facades all face north, there is no significant solar heat gained through them as compared to southern facing windows.
- The two design types, double pane with Low-E glazing, and triple pane with Low-E Glazing were compared to the current window type. Cumulative Cooling Savings are based off of this comparison.
- It was also assumed that the windows were unobstructed, that is, no curtains or drapes were over them as to detract from solar gain. Also, in order to calculate the maximum energy possible. It is assumed that there is no cloud cover during the day. In reality, it is more than likely that a certain percentage of the calculated solar gain would be obtained.

The following page contains a condensed table of the Monthly Cooling Loads as found in Appendix E as well as a graphical representation of the Monthly Cooling Loads of Design 1 and 2 compared to the current window system shown in Figure 8.7. The Cumulative Monthly Energy savings of Design 1 and 2 can be found in Figure 8.8.

END BREADTH

(8.6) Cooling Load Cost and Life Cycle Analysis

Monthly Cooling Load Values

		Total Daily (Million Btu's)			Total Monthy (Million Btu's)			Total Savings (Million Btu's)	
Time	**Days**	**Current**	**Design 1**	**Design 2**	**Current**	**Design 1**	**Design 2**	**Design 1**	**Design 2**
JAN	31	14.6	6.0	4.1	454.1	185.0	128.1	269.1	326.1
FEB	29	19.3	7.9	5.5	560.9	230.0	159.3	330.9	401.7
MAR	31	24.2	10.2	7.1	748.8	316.3	219.0	432.5	529.8
APR	30	29.4	12.8	8.9	882.6	385.2	266.7	497.4	616.0
MAY	31	31.8	14.1	9.8	987.0	437.3	302.8	549.7	684.3
JUN	30	34.7	15.8	10.9	1040.3	472.8	327.4	567.5	713.0
JUL	31	36.1	16.7	11.6	1119.1	518.2	358.8	600.9	760.3
AUG	31	30.4	13.6	9.4	943.8	420.8	291.3	522.9	652.4
SEPT	30	26.8	12.0	8.3	805.1	359.1	248.6	446.0	556.5
OCT	31	21.1	9.1	6.3	654.4	282.3	195.4	372.0	458.9
NOV	30	15.9	6.7	4.7	477.4	201.7	139.7	275.6	337.7
DEC	31	13.0	5.3	3.7	402.7	163.5	113.2	239.2	289.5
			Yearly Totals		**9076.2**	**3972.4**	**2750.1**	**5103.8**	**6326.1**
				Percent Savings			**Percent Savings**	**56%**	**70%**

Table 8.4: Monthly Cooling Loads

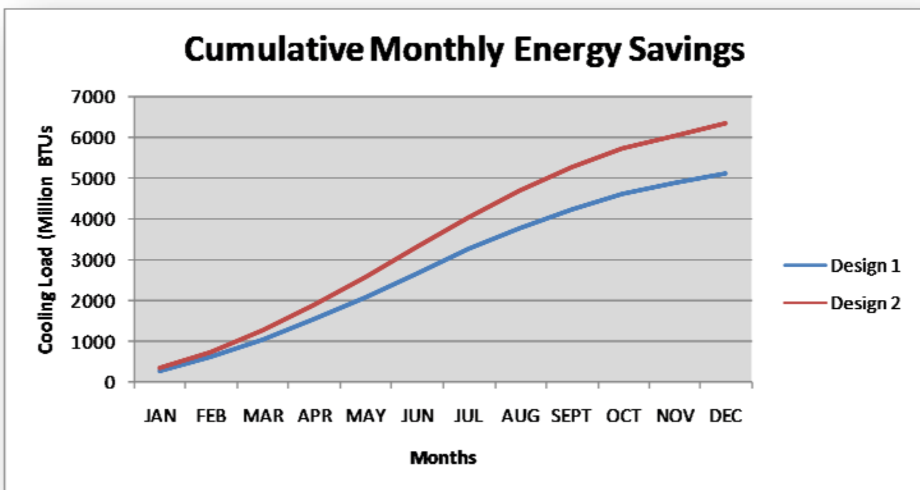


Figure 8.7: Cumulative Monthly Savings

Monthly Cooling Savings

Cumulative Savings (Million BTU's)

Design 1	**Design 2**
269	326
600	728
1033	1258
1530	1873
2080	2558
2647	3271
3248	4031
3771	4683
4217	5240
4589	5699
4865	6037
5104	6326

Table 8.5: Cumulative Cooling

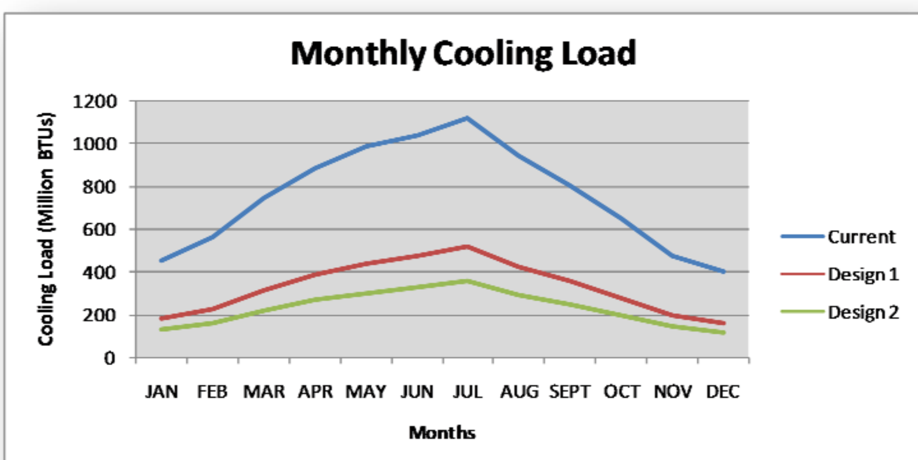


Figure 8.8: Monthly Cooling Load

Magic-Pak AHU Implementation

In order to reduce wall and floor penetrations, it is proposed that GrandView employ the use of individual Air Handling Units in each apartment. The MAGIC-PAK MCB model is design so it can have direct access to the outside though a penetration in the façade. Reducing the floor and wall penetrations needed for duct work would reduce the need for coordination between trades and save on material costs of duct work due to a smaller size.

Typically, these units are placed on a vibration reducing pad in a closet. The SEER Rating for this particular AHU is 11.4.

Advantages of a MAGIC-PAK System:

- Unobtrusive design – small footprint and
- wall-opening requirement
- Low operating sound levels
- Standard and high-efficiency cooling models
- Fully insulated cabinet
- Low installed, maintenance and life-cycle costs
- Individual Tenant Control

In order to determine the Cooling Load a SEER Rating of 11.4 is used to determine the efficiency of the cooling unit.

In *Table 8.4* the annual savings of both the single and double pane windows were established. These values can be applied to the following financial savings equation:

$/year = [(BTU/year)($/kWh)] / [(SEER)(1000w/kW)]

The higher the SEER rating, the lower the cooling cost.

Cost Comparison							
Design	Difference in Cost per SF	Area (SF)	Initial Cost Difference	Magic-Pak SEER	Annual Cooling Cost	Annual Cooling Savings	Percent Savings
Current	$ -	38,376	$ -	11.4	$ 109,870	$ -	0%
Design 1	$ 2.41	38,376	$ 92,486.16	11.4	$ 48,087	$ 61,783	56%
Design 2	$ 5.22	38,376	$ 200,322.72	11.4	$ 33,291	$ 76,579	70%

Table 8.6: Cost Comparison

An additional payback period of **1.5 years** would be required for the double pane fiberglass windows. The triple pane windows would require an extra **2.6 years**.

A life cycle analysis of ten years gives the following CO2 impact when considering 1 kwh = 3412 BTU's and 1 kWh = 1.6 lbs of CO2 equivalent of coal burned.

[redacted]

Table 8.7: CO2 Savings

According to the Sightline Institute, based on Boeing 747 emissions and the average occupancy of USA flights, every 2,062 miles travelled accounts for 1 ton of CO2 emissions per person.

A 1200 ton CO2 savings is equivalent of a 400 Passenger Boeing 747 making a round trip from DC TO LA. Therefore, over a period of ten years, installing Design 1 would be equivalent of canceling 10 round trip flights of a 747 across the country.

(8.7) Constructability and Schedule Review

In order to determine the feasibility of construction and the impact the installation of the panels would have on the design of the building, some key areas of constructability were looked at.

Window Weight
The weight of the window weight would only affect constructability for the triple pane windows. Since they are relatively heavier than the standard double pane, a structural analysis would need to be done in order to determine load impact.

Mounting
Mounting of the double pane fiberglass windows would be identical to the current double pane aluminum windows. However, the triple pane windows have a slightly different configuration that would need to be taken into account.

Moisture Control
Glazing provides an additional moisture control system that would be paired with the Henry AIR/Moisture building skin. In a residential unit, moisture can warp and ruin many aspects. Therefore, the substitution of a Low-E window type would help protect the building and reduce maintenance costs

Schedule Impact

The only impact that this type of window substitution would have is the installation time of the triple pane windows and a possibly larger lead time. Since they are heavier and have a different mounting layout than the double pane windows, they would be expected to take longer to install due to mobility and placement detail.

Results and Recommendations

Through this analysis the following overall results were determined:

- The substitution of a fiberglass, double pane window with a LOW-E glazing reduced the cooling costs by nearly **56%** and saved an annual **$61,783**. When considering the initial cost, an additional payback period of **1.5** years would be added to the overall payback period of 30 years.
- The substitution of a fiberglass, triple pane window with a LOW-E glazing reduced the cooling cost by nearly **70%** and saved an annual **$76,579**. When considering the initial cost, and additional payback period of **2.6** years would be added to the overall payback period of 30 years.
- The double pane window design prevented **1197 tons** of CO2 from entering the atmosphere per year.
- The triple pane window design prevented **1483 tons** of CO2 from entering the atmosphere per year.

It is my recommendation that GrandView install the double pane window design with the Low-E solar glazing. However, it is not necessary to use the fiberglass frame because the conduction through a frame of this type is minimal compared to the solar energy gain. Plus, aluminum frames are lighter and less expensive. While triple pane windows provide a slightly better result, in the long run they cost more and are much heavier. These types of windows would better be suited for a harsher environment that has a vastly different inside and outside temperature difference.

The use of a Magic-Pak AHU reduces the schedule impact when coordinating partition and floor penetrations. The ease of installation and small size makes it ideal for GrandView. It is my recommendation that these units continue to be used.

After going through the all of the calculations, it would have been more advantageous to analyze one specific aspect of the window rather than 3. I would have focused specifically on just the glazing and kept the double pane window with the aluminum glazing because the solar gain was the dominant heat transfer method.