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Final Report:

Reduction of Snow and Ice Accumulation on Stairs Through Heated Paneling

St. Francis Xavier University

Department of Engineering

Group 4:

Gavin Barter

Devin Sceles

Chris Brennan

Majd Al Zhouri

Katie Robinson

Submitted to:

Dr. Emeka Oguejiofor, P.Eng

Paul Dorion, P.Eng

Abstract

This report is based on the need for a system to effectively prevent snow and ice accumulation on stairways on the St. Francis Xavier University (StFX) campus. The current methods of snow removal are not adequate. Even on days when it does not snow, the stairs on campus are often coated in slush and ice, making them a hazard for students and faculty. Grounded on the research that demonstrates students were often falling and injuring themselves, this appeared to be a suitable project. In order to resolve this problem, many ideas were discussed before the final design of the Solar Step was formed. The final design is a safe and sustainable product that can eliminate snow and ice as it forms, thus eliminating the need for manual shoveling and preventing students and faculty from falling. As obstacles came up it was important to alter the design for the best possible outcome. A great deal of research was done to design the Solar Step, including the choice of materials, cost analysis, power and sunlight analysis. These topics and more will be further discussed in this report.

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Introduction:

Preliminary Ideas:

During the brainstorming phase of this project many ideas were discussed. A big focus was improving safety in everyday life. Before landing on the final idea of preventing snow and ice buildup, two main ideas were considered

The first idea was to design a hat for hikers to alert for help if they were to fall unconscious. It can be dangerous to hike alone, yet many people enjoy the solitude. The possibility of tumbling rocks or falling off the trail edge puts hikers at high risk. If injured and still conscious, most people can receive help with the use of their cell phones. What if they acquire a head injury and become unconscious though? It could take days to be found. To help keep them safe while alone, a hat in the style of a ball cap or toque would be designed with sensors sewn in. When the sensors are triggered by the user falling unconscious, they would send an alert to a designated emergency contact and by using GPS, send this contact the location of the injured person.

Several problems arose as this was discussed further. Research needed to be conducted to ensure this was not an already existing product. If a heart rate sensor were used, it would most likely need wires outside the hat, causing it to not be visually appealingly to wearer. Extensive research would need to be done on how to configure a GPS system. It was decided to continue brainstorming on different proposals.

The second idea was to improve the stretch of undivided highway between Antigonish and Cape Breton. This section is very dangerous for collisions with animals and other vehicles. Ideas to increase safety included creating an under pass for animals to prevent them from crossing the highway. This combined with fencing around the highway could decrease the number of collisions with wildlife. The other idea discussed was to double the highway, making it divided, thus reducing vehicle impacts.

The concerns with this idea were that it had been done before. As well as the fact that there are currently plans to double that section of the highway, making the issue already solved.

After several meetings of brainstorming ideas, the problem of slippery stairs on campus was brought to attention. After discussing the problem extensively, it was decided that this would be a suitable problem to solve.

Problem Definition:

When living in Canada during the winter, snowy conditions are no surprise. Based on reports from 2005-2015, Antigonish, Nova scotia receives on average 96.4mm, 72.3mm, and 77.4mm of precipitation during the months of December, January and February respectively (Climate and Weather, 2015). This produces a large amount of snow and ice buildup. If not properly dealt with, these conditions can jeopardize the student's and faculty's safety.

During the winter months, StFX maintains the campus walkways by using plows and snowblowers. The walking paths are cleared to a safe standard but the stairways on campus are a different story. The stairs must be manually shoveled, requiring more time and labor. Even after being shoveled, the stairs on campus tend to accumulate slush and ice causing students to slip and fall when walking to class.

To determine if this was a concern for StFX students a preliminary survey was conducted over a five-day span. The results shown in Figure 1.1 and 1.2 clearly validate the issue at hand. Out of 110 student responses, 70% of the students claimed to have fallen on stairs on campus. To measure the extent of impact falling had on these students, a follow up question was asked. 41.5% responded that they were slightly injured after falling and 10.4% answered that they were injured to the degree of needing medical attention. Based on these results, it was obvious that this was a problem that required an innovative solution.

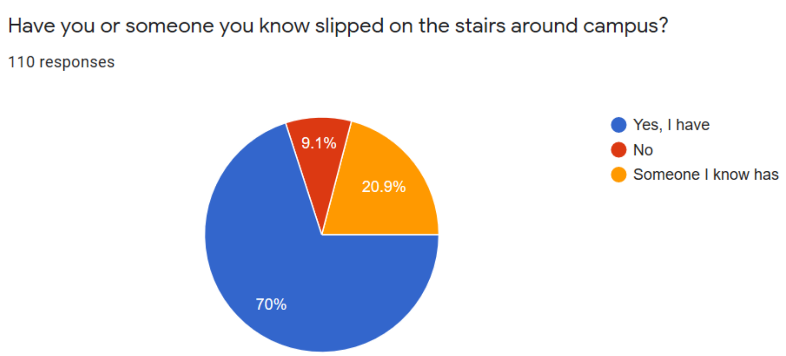

Figure 1.1 Results from the survey showing 70% of students have fallen on stairs on the StFX campus.

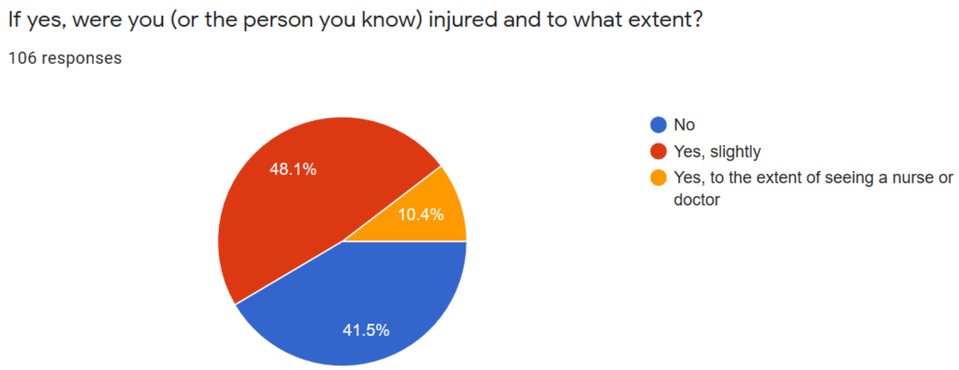

Figure 1.2 Results from the survey showing 41.5% of students have been injured on the stairs and 10.4% have need to seek medical assistance

Brainstorming:

The original resolution considered was to implement a heating system beneath the outdoor stairs around campus. By heating the stairs from beneath, it would be possible to melt snow and ice efficiently. After chatting with Professor Brittany MacDonald, P.Eng, it was found that common approaches to surface heating included electric heating or hydronic heating using glycol as the working fluid.

With both of these methods, large amounts of energy would be required to run the systems. To avoid this and keep the design sustainable, the possibility of using waste heat on campus was brought to attention. Research was completed on thermo-electric generators that could be used to convert the waste heat to electricity to power the heating of the stairs. Several Facility Management workers were contacted to locate the areas on campus where heat is expelled and unused.

When researched further, it was discovered the complexity of capturing heat and converting it to energy. The extensive work that would be necessary to complete this idea would require more in-depth analysis than previously thought. With the short nine-week timeline and the amount of work it would take to research and design a thermo-electric powered, in-surface heating system, it did not seem like a feasible idea. Another problem that arose was the fact that if implemented, the existing stairs would need to be removed and rebuilt with the heating system. This was not practical considering the expense to do so.

Proposed Solution:

With the original design turning out to be unrealistic, a new plan was envisioned. The new idea was to create a portable paneling system that could be placed on stairs during the winter months. The surface of the panels would be heated as snow and ice formed, eliminating the need for manual removal. As previously mentioned, sustainability is an important consideration. To keep the design environmentally friendly, it was decided to integrate solar panels into the surface to avoid using grid power, thus giving the device the title of the Solar Step.

To explain further, the Solar Step will be a thin panel that the consumer would lay across the problematic step. These panels will have wires within that will be heated slightly above zero degrees Celsius, as that is all it would take to prevent snow and ice accumulation (Henderson, 2014). On top of these wires will be the solar cells that will collect energy from the sun. This energy will be stored in a connected battery. Since this is a system that needs to withstand the weight of hundreds of people per day, the solar panels will be protected by a durable glass and all the elements will be surrounded in rubber. Figure 1.3 depicts what the system will look like and figure 1.4 shows an exploded view of the layering.

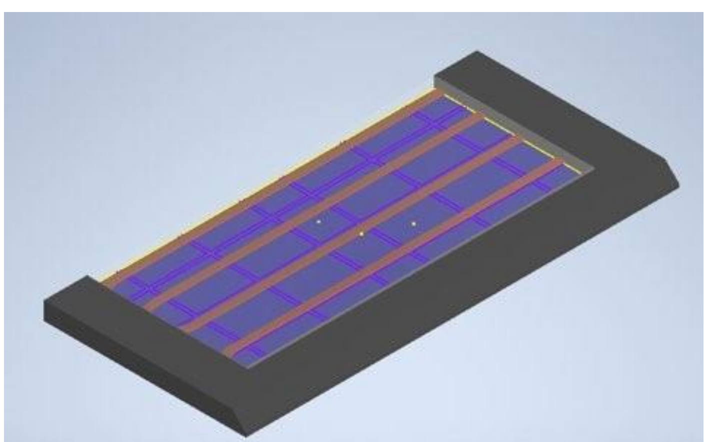

Figure 1.3 Inventor portrayal of the planned design for the Solar Step

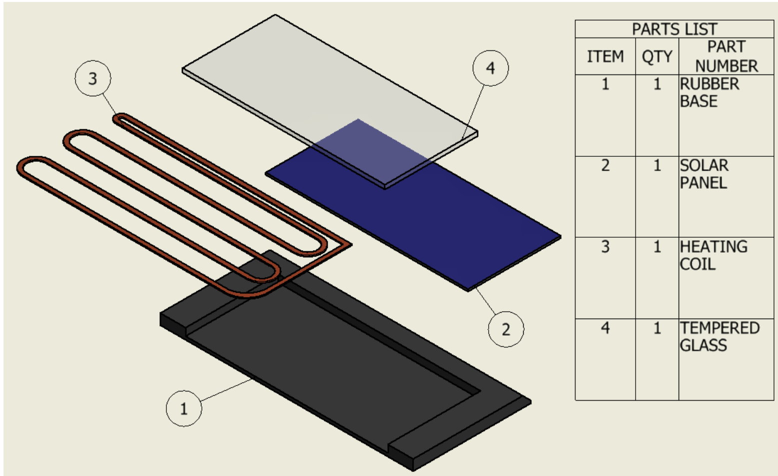

Figure 1.4 Exploded view of the Solar Step

Obstacles:

Loss of Traction on the Glass Surface:

An early concern for the design of the Solar Step was that the surface was going to be made of glass and when wet, this could possibly increase slippage on stairways. After researching ways to avoid this, a solution was found. The Solar Roadways project had a similar surface, also using tempered glass. To combat this issue, Solar Roadways performed tests on texturized glass surfaces and found that even when wet, this feature could safely stop a car traveling 80 mph (Glass). To avoid loss of traction, the glass surface of the Solar Step will be texturized, providing sufficient grip for the users.

Keeping the Solar Panels Clean:

Another obstacle that arose was the possibility of dirt gather on the surface and decreasing the solar power efficiency. With people walking on the surface all day, it is impossible for dirt not to accumulate. If the system needed cleaned often, it would defeat the purpose of eliminating manual labor to clear the stairs. As it turns out, uncleaned solar panels are only slightly less efficient, to the degree that it would not affect the power output enough to be a concern. Tests done by the Solar Roadway project concluded that when compared to a clean panel, a dirty one was only lagging power production by 9% (Glass). To further explain using theoretical numbers, if a clean panel were to produce 100 kW, a dirty panel would produce 91kW. Therefore, verifying dirt buildup will not be a significant issue.

Arrangement of the Heating Elements:

For the Solar Step to function as designed, there must be a certain measure of separation between each pass of the wire. It was therefore decided to loop the wire 5 times along the step in a "snaking" pattern as depicted in figure 1.5. This results in a 1.17-inch separation between the wires which provides the proper distribution of heat along the entire Solar Step, while also allowing sunlight to penetrate the step and reach the solar panels with ease.

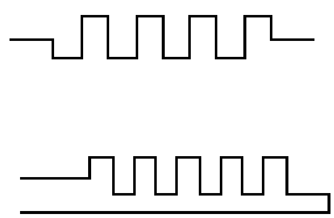

Figure 1.5: Different wire layouts

System Sensor:

When looking at the logistics of using the Solar Step, the question of whether the heating would need to be manually or automatically operated came up. To minimize energy cost and prevent any extra manual labor, it was decided to use a sensor system to initiate the heating cable. The system will include a moisture sensor and a temperature sensor. The combination of these sensors will activate the system when there is a temperature is below one degree Celsius and any moisture is present, including snow, ice and water. The Solar Step will rely on these two sensors to signal the controller to send power to the heating cables.

Analysis:

Materials:

One of the first steps to designing the Solar Step was to choose what the system should be made from. Each piece of the Solar Step had specific requirements that needed to be considered.

The top layer of glass needed to be extremely durable as countless students and faculty would be walking on it daily. Several types of glass were researched, including annealed, heat strengthened and tempered. Deciding to use tempered glass was quite simple as it is up to five times stronger than annealed glass (Glass). Tempered glass is common in everyday products such as cellphone screen protectors, making it a very accessible material that will work perfectly for the use in the Solar Step.

As shown in figure 1.4, the heating cables are positioned above the solar panel so that it is closer to its acting surface. Provided that snow melts at zero degrees Celsius and there would only be a need to melt 2-3 inches at a time, it seemed extensive to use an industrial heating element. Instead, a self-regulating, medium heating cable was much more fitting for the product. The Chromalox SRM/E Self-Regulating heating cable was chosen as it is very energy efficient, has freeze protection and runs on a 120V source. As stated, this cable is self-regulated meaning that it will never exceed the desired temperature and it has been implemented on rooftops and has proven to be successful in melting snow (Omega Engineering). Research found that common snow melting systems require 100 btu/ft^2 per hour (Snow Melting Systems). By completing calculations using common stair dimensions, seen in figure 1.6, if was found that a 15 W/ft cable would be required. This cable can melt 1.5 in of snow per hour.

Known measurements:

Common stair dimensions: 60in wide x 8in height x 11in depth

Length of coil estimated to be 9.84ft

100 btu/ft per hour will melt 1.5in of snow

Surface area of the panel: $60in \times 11in = 660in^2 = 4.58ft^2$

Conversion factor: $1\frac{btu}{hr} = 0.293W$

Btu/hr to W: $100\ \frac{\frac{btu}{hr}}{ft^2} = 29.3\frac{W}{ft^2}$

W/ft^2 to W: $29.3\ \frac{W}{ft^2} \times 4.58ft^2 = 134.227\,W$

W to W/ft: $134.227\,W \div 9.84ft = 13.64\frac{W}{ft} \approx \frac{15W}{ft}$

Therefore the cable needed is 15 W/ft

Figure 1.6 Calculations showing how 15W/ft was found

There were a few different options for the types of solar panels to incorporate into the Solar Step each with their own merits but ultimately, we decided on the thin film monocrystalline panel. These panels are light weight and heat resistant making a good fit for the requirements.

The choice of battery for this project is the most cost-effective option while also producing the required energy to operate the Solar Step. The lithium iron phosphate battery (LiFePO4) can operate in temperatures from 0 to -20, however when temperatures approach the –20 range there is an effect on the battery's efficiency shown in figure 1.7 (8Ah lithium).

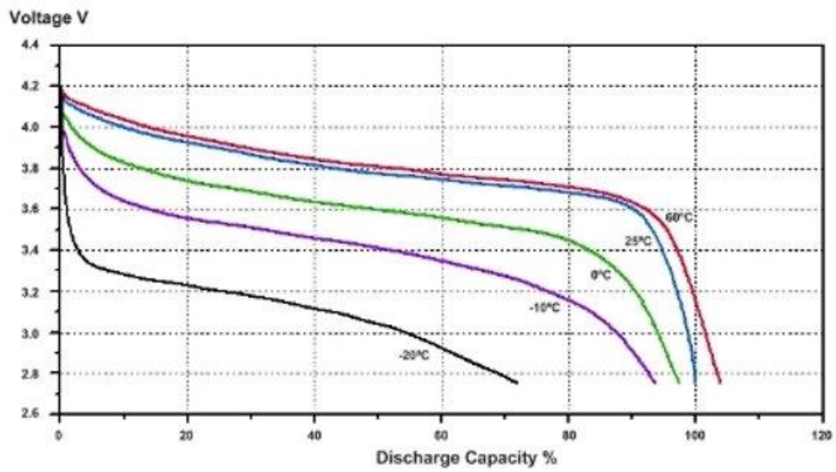

Figure 1.7: Change in discharge over time (8Ah lithium)

According to the government of Nova Scotia, it is predicted that in 2020 there will only be approximately 4 days in the year where temperatures go below –10 when not including windchill (Community of Nova Scotia). Therefore, the effect of efficiency should not be a problem. This battery type also fits our size requirements as they come in small sizes. Research found that LiFePO4 batteries can range from 3.2V-96V. For our product each step will have a 72V and a 48V lithium iron phosphate battery connected in series with one another to successfully output the required 120V needed to power the heating cables. Each battery will be compact enough to fit into its place under the solar panels in our design. Also, because the product tailors to people that are in favor of green and renewable energy, a lot of consumers may be concerned with the environmental effects of the Solar Step. Batteries are often considered harmful and difficult to recycle. However, the lithium iron phosphate battery and its contents can be safely recycled and discarded because of the basic elements it is made of (Sergio).

Sunlight and Power:

Solar panels operate best at peak hours of sunlight, which is not the same as total hours of sun during a single day. Some energy will still be produced during weaker hours of sunlight, but solar efficiency is based on the number of peak hours a panel will see on a given day. A peak solar hour is when the intensity of the sun reaches 1000 watts per square meter (Solar Reviews, 2020). As the sun will rise and fall over the course of the day, peak solar hours are calculated based on the total amount of solar irradiance received at an area, represented by how many hours of 1000 watt per square meter it receives (Solar Reviews, 2020). This will give the likely power generation for a panel.

The government of Canada meteorology sites tracked the number of bright sunlight hours from 1981-2010 to calculate the average bright sunlight hours per month over this period. Their tracking utilized a Campbell-Stokes sunshine recorder described below.

> It consists of a glass sphere that is 10 cm in diameter, mounted concentrically in a portion of a spherical bowl. The sun's rays are focused by the glass sphere on a card held in position by a pair of grooves in the bowl. The focused rays scorch the card or burn a trace right through it. The card size used depends on the length of the day and is available in three classes corresponding to the time of the year equinox, summer or winter solstice (Climate Change Canada, 2019).

This method of tracking may not perfectly match the 1000 watt per square meter calculation that produces an average of 3.5-4.5 solar hours in many regions (Solar Reviews, 2020). Using the data from the Sydney station, shown in figure 1.8 and 1.9, it is seen that the highest average hours is March with 4.287 hours, followed by February with 3.986 hours. The lowest month is December with 2.200 hours of bright sunlight. The total five-month average, given that these months are the most precipitation or the most frequent temperature drops, is 3.195. The Nappan station, seen in figure 1.8 and1.10, records a daily average of 4.448 hours in

March and 3.879 in February, with a minimum of bright sun hours in November of 2.540. The total five-month average is 3.289 hours.

The precipitation data shown in figure 1.11 for the Collegeville station, 13 km outside of Antigonish, shows that the total number of days (average) to expect precipitation over this five-month period is 32.7 days. November is the month with the least days of precipitation over this period, having an average of only 2.3 days. November is also a month with close to the minimum number of bright solar hours. There will be less days where the solar step will need to melt precipitation in November and the months with higher snowfall also have more average bright solar hours a day. Excluding November solar hours from the average, brings the average between the two stations above 3.4 bright solar hours, therefore 3.4 solar hours will be used in the calculations of energy.

Sydney Station:

$$January: \frac{91.0}{31} = 2.935\frac{hours}{day}, \quad February: \frac{111.6}{28} = 3.986\frac{hours}{day}, \quad March: \frac{132.9}{31} = 4.287\frac{hours}{day}$$

$$November: \frac{77.0}{30} = 2.567\frac{hours}{day}, \quad December: \frac{68.2}{31} = 2.200\frac{hours}{day}, \quad Total: \frac{15.975}{5} = 3.195\frac{hours}{day}$$

Nappan Station:

$$January: \frac{93.6}{31} = 3.019\frac{hours}{day}, \quad February: \frac{108.6}{28} = 3.879\frac{hours}{day}, \quad March: \frac{137.9}{31} = 4.448\frac{hours}{day}$$

$$November: \frac{76.2}{30} = 2.540\frac{hours}{day}, \quad December: \frac{79.3}{31} = 2.558\frac{hours}{day}, \quad Total: \frac{16.444}{5} = 3.289\frac{hours}{day}$$

Fig 1.8: Calculations of average bright solar hours per day

1981 to 2010 Canadian Climate Normals station data

Bright Sunshine

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year	Code
Total Hours	91.0	111.6	132.9	141.0	198.0	224.6	246.9	228.4	167.1	130.1	77.0	68.2	1816.7	D
Days with measurable	21.4	20.6	22.6	21.1	24.5	26.7	28.4	28.3	26.5	26.1	21.5	18.9	286.5	D
% of possible daylight hours	32.4	38.3	36.1	34.7	42.7	47.7	51.8	52.0	44.3	38.3	27.1	25.3	39.2	D
Extreme Daily	9.0	10.5	11.2	13.7	15.0	**15.4**	15.3	14.5	12.8	11.1	9.3	8.3		
Date (yyyy/dd)	1961/29	1964/28	1973/25	1961/29	1960/29	**1957/18**	1958/06	1961/01	1990/01	1994/07	1977/02	1964/15		

Fig 1.9: Bright Sunshine at Sydney A 1981-2010 average (Climate Change Canada)

1981 to 2010 Canadian Climate Normals station data

Bright Sunshine

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year	Code
Total Hours	93.6	108.6	137.9	146.5	186.0	208.5	229.7	218.0	161.1	130.7	76.2	79.3	1776.1	D
Days with measurable	21.1	20.3	21.4	20.6	24.5	26.2	27.4	28.1	24.8	23.9	18.6	18.8	275.7	D
% of possible daylight hours	33.1	37.2	37.4	36.2	40.2	44.4	48.4	49.8	42.7	38.4	26.7	29.3	38.6	D
Extreme Daily	9.3	10.6	12.0	13.9	14.6	15.0	**15.1**	14.2	12.7	10.4	8.9	8.3		
Date (yyyy/dd)	1957/30	1979/20	1985/27	1980/28	1999/16	1982/04	**1989/13**	1998/01	1997/06	1987/02	1951/06	1983/08		

Fig 1.10: Bright Sunshine at Nappan 1981-2010 average. (Climate Change Canada)

1981 to 2010 Canadian Climate Normals station data

Days With Snowfall

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year	Code
>= 0.2 cm	9.1	7.8	6.1	2.6	0.16	0	0	0	0	0.21	2.3	7.4	35.7	C
>= 5 cm	3.5	3.3	2.4	0.96	0.08	0	0	0	0	0.04	0.79	2.7	13.9	C
>= 10 cm	1.2	1.1	0.96	0.38	0	0	0	0	0	0	0.17	1.4	5.2	C
>= 25 cm	0.12	0.18	0.04	0.04	0	0	0	0	0	0	0	0.17	0.55	C

Fig 1.11: Collegeville snow precipitation average 1981-2010 (Climate Change Canada)

The calculation of a solar panel's watt rating is based on the number of solar cells spread over the panels area, the amount of solar irradiation expected and the solar panel's efficiency. This results in the expected watts per hour of bright sunlight. If a panel was rated for 120 watts and received 4 hours of bright sunlight a day, the expected output would be 480 watt-hours. This would the total output if there were no other factors that reduced the efficiency on the power generation. Figure 1.12 displays some possible sources of efficiency reduction for panels.

- Inverter losses (4% to 10 %)
- Temperature losses (5% to 20%)
- DC cables losses (1 to 3 %)
- AC cables losses (1 to 3 %)
- Shadings 0 % to 80%   (specific to each site)
- Losses at weak radiation 3% to 7%
- Losses due to dust, snow... (2%)

Fig 1.12: Sources of Efficiency Reduction (Photovoltaic-Software)

Solar panel calculations typically use an efficiency coefficient between 0.5 and 0.9, 0.9 being the most ideal conditions with the least losses. This number is calculated using a starting value of 0.9, which most solar panels claim to have under brand new and ideal conditions, by subtracting areas of efficiency reduction from it. As the operating temperature for the solar step will be close to zero degrees, the temperature coefficient of 0.38% per degree over/under 25° Celsius (Prostar Solar Power) will increase efficiency 9.5% as seen in figure 1.13. There will be no inverter between the panel and the batteries, so there will not be losses from an inverter. Anticipating a median cable loss of 2%, weak radiation loss of 5% and loss to dirt and dust of 2% results in losses of 9%. It is difficult to discern the exact losses due to shade, but too heavy of losses would result in this product being incompatible with the location. An initial value of 10.5% will be chosen. This results in a power coefficient of 0.80, seen in figure 1.14.

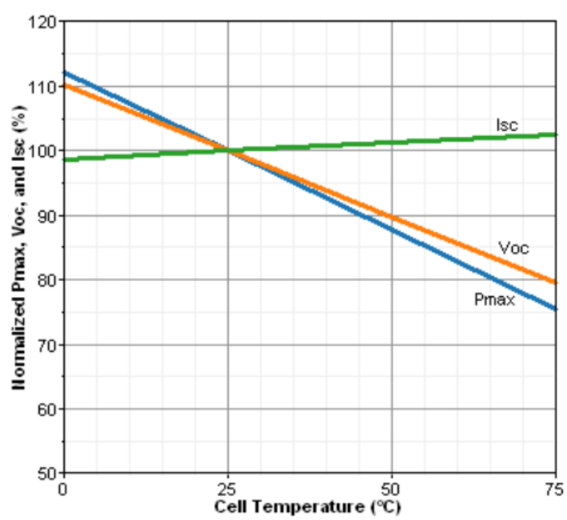

Fig 1.13: Chart of P-max per degree Celsius change (Homer Energy)

Power Coefficient:

$$0.90 - (0.02 + 0.05 + 0.02 + 0.105) + 0.095 = 0.80$$

Daily Watt-hours generation:

$$120\ watts * 3.4\ solar\ hours * 0.80\ power\ coefficient = 326.4\ Watt - hours$$

Fig 1.14: Calculations of the Power Coefficient and daily watt-hours

Using the 0.80 power coefficient calculated, an individual step consisting of a front and top covered panel bent at 90°, will generate 326.4 watt-hours per 3.4 bright solar hours a day on average. This number will vary based on the true amount of bright solar hours, the number of additional sources of efficiency reduction that may affect different sites (such as increased shade).

Cost Analysis:

*This analysis includes only the cost for the raw materials of the product and does not include manufacturing costs

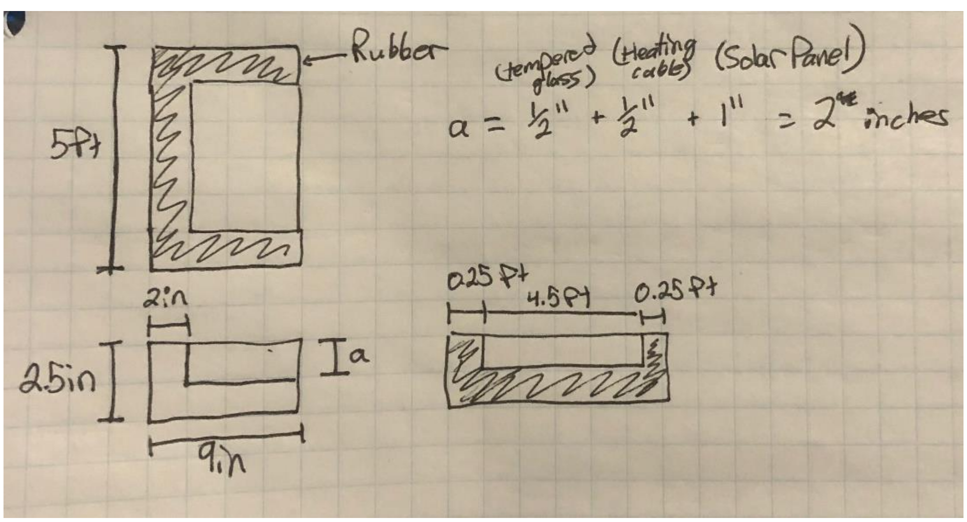

Figure 1.15: Crude drawing of Solar Step dimensions

Rubber:

Price=4.82USD/kg (Garside, 2020)

Volume of rubber/step = 0.0097339m^3

Density of rubber= 1522kg/m^3

(1522kg/m^3) (0.0097339m^3) = 14.815 kg

(14.815kg) (4.82) = **$71.41/step**

Heating Element:

Price = $1.56/ft (Omega Engineering)

Total feet required = 27.49ft (refer to fig 1.16)

Cost = (17.49ft) ($1.56/ft) = **$42.88/step**

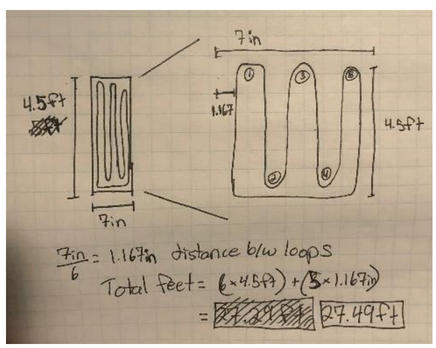

Figure 1.16: Dimensions for heating element arrangement

Tempered glass:

Area = 2.625ft^2 (refer to fig 1.14)

½"thickness supports 905.63 lbs

weight = 17.06 lbs

Price = **$97.23/step** (Glass Weight Calculator)

Battery:

Each step requires: 72V + 48V batteries in series

72V lithium iron phosphate = $234.00 (Battery Pack Pricing)

48V lithium iron phosphate = $129.00 (Battery Pack Pricing)

Price = **$363.00/step**

Solar Panel:

Monocrystalline solar panel (4.425’x1.77’x1/8”)

Price = **$225.00/step** (AIMS, n.d)

The total cost for a Solar Step = $799.52

Conclusion:

In short, the idea of the Solar Step was formed to prevent injuries and falling on campus. The goal was to find a new and innovative way to clear the stairways. This goal was met. With the final price being approximately $800 per step, it is unlikely the university would invest in the Solar Step. Although in end, the Solar Step may not be the most cost-effective solution, the required research and analysis was completed to demonstrate skills based on problem solving, innovating and designing. Clearly shown throughout the report, a large amount time, dedication and care went into this project. It has provided a great learning opportunity and has allowed real-world engineering skills to be taught. In the future, a system like the Solar Step could be possible.

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