# Heat Retention for Overhead Doors

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Saskatchewan Polytechnic / MET

# Heat Retention for Overhead Doors

For City of Saskatoon Access Transit Bus Depot

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# Executive Summary

In the winter months, overhead doors are a major cause of heat loss. As environmental concerns grow and energy costs rise, it is important to address this issue now. The City of Saskatoon is facing this problem to a higher degree at the Access Transit Bus Depot, which has 22 overhead doors. The purpose of this project was to propose solutions to minimize the heat being lost and provide relevant financial calculations to address payback period for each solution.

A site visit was conducted at the City of Saskatoon's Access Transit bus depot. What was discovered is that many of the seals are damaged and are not creating an effective seal. This was letting in air through infiltration as the doors were closed. Another identified issue was that to let the buses in and out, the doors had to be opened. When the doors were open, this was letting in a large amount of unheated outside air, reducing internal temperatures. There are two reasons for the large amounts of air when the doors are open. The first reason is that the doors are set on timers to automatically close after being open for 60 seconds, which is much longer than many need to be open for. The second reason is that since the doors are much taller than the Access Transit buses, they leave an extra four feet of headroom when they open, allowing more air in.

For every door, replacing the seals and adding weather stripping made of higher quality Kevlar will reduce heat loss drastically and can pay itself back in about 2 years. An air curtain is a device that blows a stream of high velocity air across the opening, reducing heat loss while the doors are open. Since air curtains have a very high initial cost, installing them on only two of the most frequently used doors will save a large amount of energy with a payback period of about 6 years. Finally, reducing the amount of time the doors are open and adjusting the door heights to only give an extra foot of headroom are both solutions that will lead to the largest reduction of heat losses with instantaneous payback periods.

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# Acknowledgments

We would like to express our deepest gratitude to Ravi Jassar, whose invaluable contributions and unwavering support greatly enhanced the quality of this report. Ravi’s expertise in Computational Fluid Dynamics (CFD) and his profound understanding of heat transfer principles were instrumental in generating meaningful insights. Without his generous assistance, this report could not have achieved its level of accuracy and comprehensiveness. We extend our heartfelt appreciation to Ravi Jassar for his unwavering support and mentorship throughout this endeavour.

We would also like to express our gratitude to the workers at the City of Saskatoon Access Transit Bus Depot, particularly Kathryn Theede, for their invaluable assistance with our project. Their dedication, expertise, and unwavering support have been instrumental in its success. We are deeply grateful for their contributions and commend their commitment to providing reliable transportation services. Thank you to the entire team for their exceptional efforts and for making a difference in our community.

# Introduction

During winter, overhead doors are commonly known to cause a massive amount of heat loss. The City of Saskatoon's Access Transit Bus Depot has 22 overhead doors, meaning that there is an abundance of heat loss related to the overhead doors. As seen in Figure 1, an average of 21% (Appendix A) of all natural gas bought for the Transit Depot is spent heating up the air that the doors let in when they are open, and an average of 13.5% (Appendix B+C) is spent when the doors are closed due to infiltration and conduction. The rest of the bill is being spent on heat that is conducted through the walls, roof and floor, or lost in other ways.

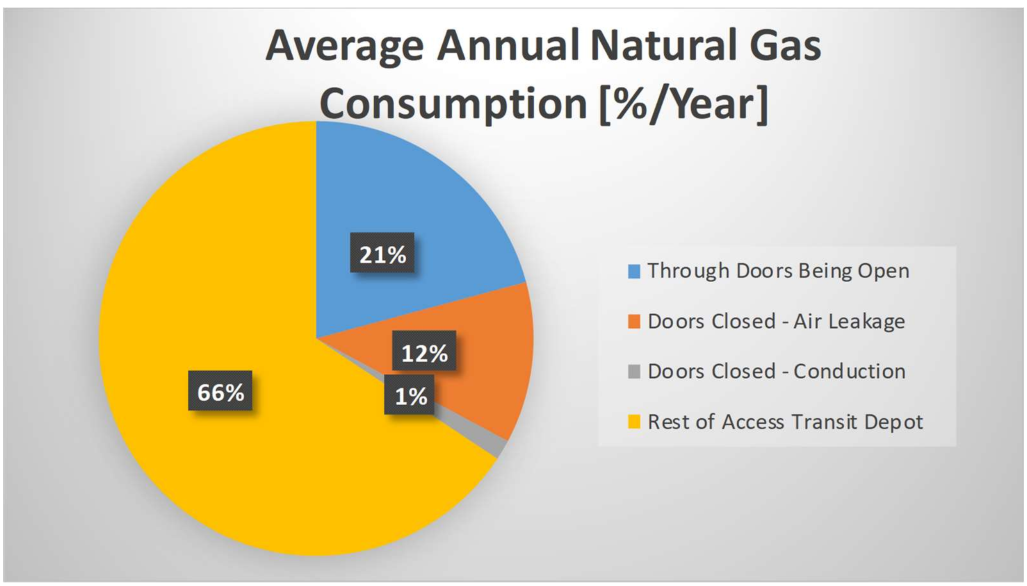



*Fig. 1. Pie Chart*

Saskatchewan Polytechnic was approached by the *City of Saskatoon* to propose this project. The purpose of this project was to discover, research, and propose several solutions that would minimize heat losses and improve building efficiency in relation to the overhead doors. Upon completion of the report, the City of Saskatoon will take the suggested solutions and make their decision for which solutions they will implement independently.

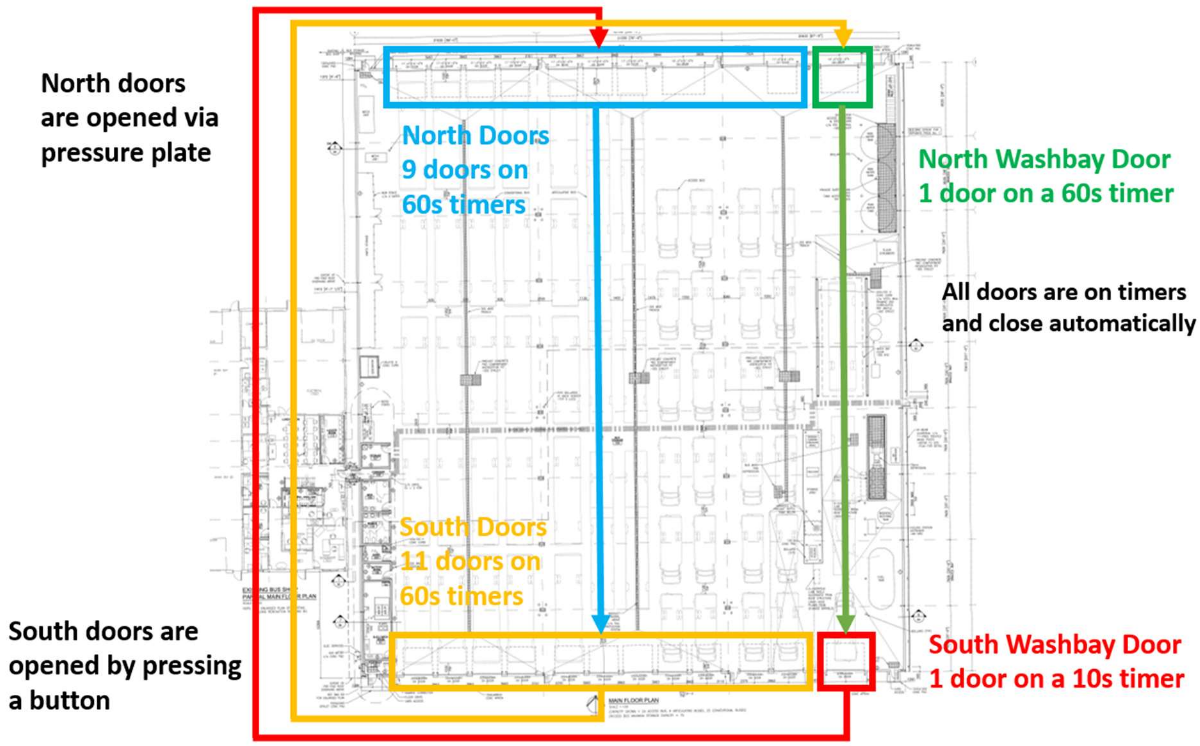



*Fig. 2. Bus Schedule Layout*

The majority of the heat loss happens during everyday operation. To let the buses in and out the doors must be opened which lets in unconditioned air. As shown in Figure 2, there are four different sections of doors that the buses go through. When following their routes, the buses will leave out the south doors (yellow). When a bus is finished following its route it will then enter through the north wash bay door (green) to get cleaned. After the buses are cleaned they will leave out the south wash bay door (red), and enter again to be parked through the north doors (blue). This is the daily routine for each bus, although sometimes they may not get cleaned. With 25 buses following this schedule, opening a door every time they leave or enter, it is easy to see why there is so much heat loss.

## Purpose

Energy efficiency is important especially today, since energy efficient buildings save money, lower carbon emissions, and create healthier places for people to live and work. Because the bus depot is heated using natural gas, energy efficiency is crucial to improve upon now since the prices of natural gas are only going to rise. The objective of this report is to propose solutions for minimizing overhead door heat loss while providing supporting evidence of their effectiveness, and to provide a resulting payback period for each solution.

For buildings, there are LEED Certifications that can be earned, with a LEED Certification meaning that the certified building is recognized by a global organization that specializes in building efficiency. The Access Transit bus depot is currently at the lowest level of LEED certification. This means that although they are taking steps in the right direction to be more energy conscious, there are still plenty of other ways to improve building efficiency.

## Project Scope

The solutions outlined in this report were considered only for the Access Transit bus depot, but after submission of the report, the City of Saskatoon may choose to apply proposals outlined in this report to other buildings that face similar problems with overhead doors. The amount of energy saved in comparison to the base case by each solution was to be calculated. In addition to this, different models and brands of products were to be considered and compared against each other, predominantly for installed products such as the seals, air curtains, and insulation.

The doors are to blame for a large portion of the heat loss, but there are still other thermal losses, such as the walls, roof, and floor. These were considered to be out of scope for this project. Since the main focus was the doors, solutions for any other losses were not considered.

Only solutions for the winter months were considered, because solutions to specifically improve heat retention were required. Based on historical values, minimal amounts of natural gas are spent on heating in the summer months. Because of this, the amount of natural gas consumed in the winter represents the amount of natural gas consumed annually.

For each solution proposed, a financial analysis including payback periods was to be performed.

## Methodology

For this report, a quantitative approach was chosen based on the practical nature of the study. Providing and selecting solutions that are reasonable, realistic and would have practical application if put into use was prioritized. Some qualitative aspects are still considered, since general principles that could be applied are being proposed as well.

The first research step was to examine the current state of the doors at the Access Transit bus depot. Several issues were identified, such as being able to see the seals let in air, and observing the doors opening and closing. People employed at the Access Transit bus depot were also interviewed, which helped collect additional information. A Fluke IR Thermometer was used to find required values, such as the indoor temperature of the depot. The imaging on the thermometer was also used to inspect the condition of the seals, many of which were damaged and letting in air. The leakage was then quantified by using ASHRAE standards for calculations.

The assumptions for outside temperature in Saskatoon were based on the Design Table shown in Appendix D for Saskatoon. This is accurate because ASHRAE is one of the most reputable sources for design conditions such as these. The calculations are based on an “average” winter instead of calculating for the worst case scenario, since an average winter is more accurate. A more realistic payback period was achieved this way, since it is never the worst case conditions every day. It was assumed that the city pays for heating through October through April which is 212 days of the year, and that no natural gas is spent on heating during the summer.

For the open door calculations and CFD simulations, an average wind speed from WindAtlas.com was used. Although ASHRAE has average wind speeds for Saskatoon, WindAtlas.com takes into account how the buildings and other structures affect the wind speed within city limits, while ASHRAE does not.

After a site visit, base case conditions for heat loss were replicated using CFD and hand calculations. The amount of heat saved after solutions were applied to the base case was then calculated, providing the effectiveness of each solution. CFD was especially utilized when considering solutions for when the doors were open, because of the increased amount of air movement.

For the financial information, the calculations are based to start during the winter of 2023-2024, using historical data to accurately predict future prices. Since increases in inflation and price were accounted for, if a solution is employed at a later date than 2024 the annual cost of natural gas and the carbon tax will be different for that year, since the first year of costs are associated with 2024.

Each potential solution was considered independent of each other, meaning that if several solutions are applied, the values in this report would not be representative of the actual scenario.

For all calculations relevant textbooks were referenced, using the procedures outlined within. Most procedures were sourced from either Cengel’s *Fundamentals of Thermal-Fluid*

*Sciences,* or the *2021 ASHRAE Fundamentals Handbook.* Because the researchers behind this project had previous classes and experience with heat transfer and energy concepts, many formulas for the calculations were created to be representative of the actual values at the Access Transit depot.

# Results/Data/Analysis

This section will discuss the solutions for which the research and calculations have been completed. There are two sections, one section for solutions to be used when the doors are closed, and another section for when the doors are open.

# Doors Closed

## Problem Definition

During a site visit on February 22nd, it was noted that a majority of the overhead doors had seals and weather stripping that were so leaky daylight was visible from the inside. Cold air could also be felt blowing in through the cracks around the edges of the doors, which caused the frost buildup that was apparent around most of the leaky areas. Appendix N shows a summary of the data collected that day. The results from Appendix N are significant because it shows that 18 of the 22 doors had obvious defects with the seals and weather stripping; these defects provide a gap for cold air to enter or warm air to escape in the building. It is shown in Figure 1 that when the doors are closed, they account for an average of 13.5% of the heating bill with 12% being related to infiltration and 1.5% to conduction. Air leakage into the building takes a higher priority, as it is instantly turned into a heating load. Figures 3 and 5 depict the door with the largest visible air gap while Figures 4 and 6 show the issues that were more common among all the doors.

*Fig. 3. Frost Accumulation on Door*

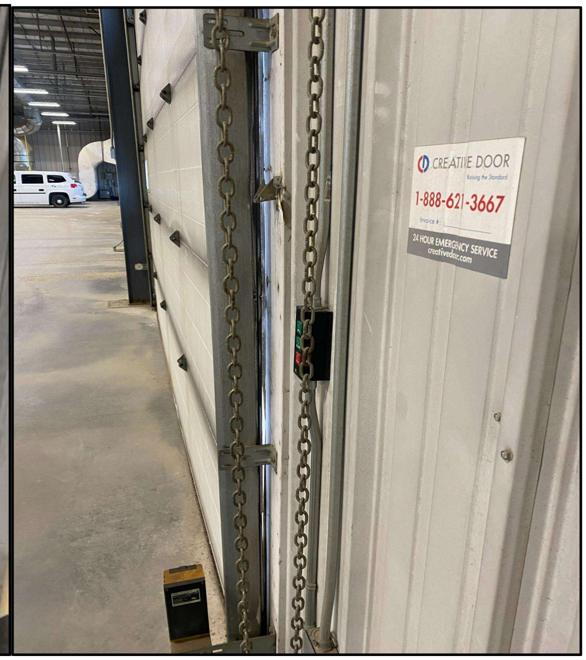



*Fig. 4. Leaky Weather-stripping*

*Fig. 5.  Frost Accumulation Blocking Door*

*Fig. 6. Damaged Corner Seals*

Air leakage into a building is more commonly referred to as infiltration. ASHRAE classifies infiltration through large gaps that have a short path into its own category called concentrated infiltration [1]. The leakage observed at the Access Transit bus depot while the overhead doors are closed can be put into this category of concentrated infiltration. Concentrated infiltration results in higher energy consumption, thermal discomfort and cannot be considered as good ventilation air [1]. Therefore the air leakage through the closed doors is an issue that needs to be addressed.

## Seals and Weather Stripping

As seen in Figure 5, ice buildup and uneven concrete can cause the doors to be misaligned and let in more air. Many of the seals are old, worn out, or damaged. The only solution for reducing infiltration is by simply replacing the seals that are along the bottom of the doors and the weather-stripping along the sides.

In its current state, the bus depot is losing 27 kW of energy (Appendix B) through infiltration alone. Replacing the seals and adding weather-stripping will reduce the amount of energy lost by more than half, bringing it down to 11.67 kW of energy lost.

When it comes to buying the materials, new seals and weather-stripping could be bought at any hardware store, but these seals and weather-strips are likely to just break and need to be replaced again soon. A company called *Snirt Stopper* was found that produces a heavy-duty seal for garage doors. Although these require more of a capital investment, they come with a 25 year warranty, something that many regular seals do not come with. 300 feet of bottom sealer and 900 feet of weather-stripping for the sides and tops of the doors is required. The cost is shown in Figure 7 in USD, meaning the price is closer to $8000 CAD.

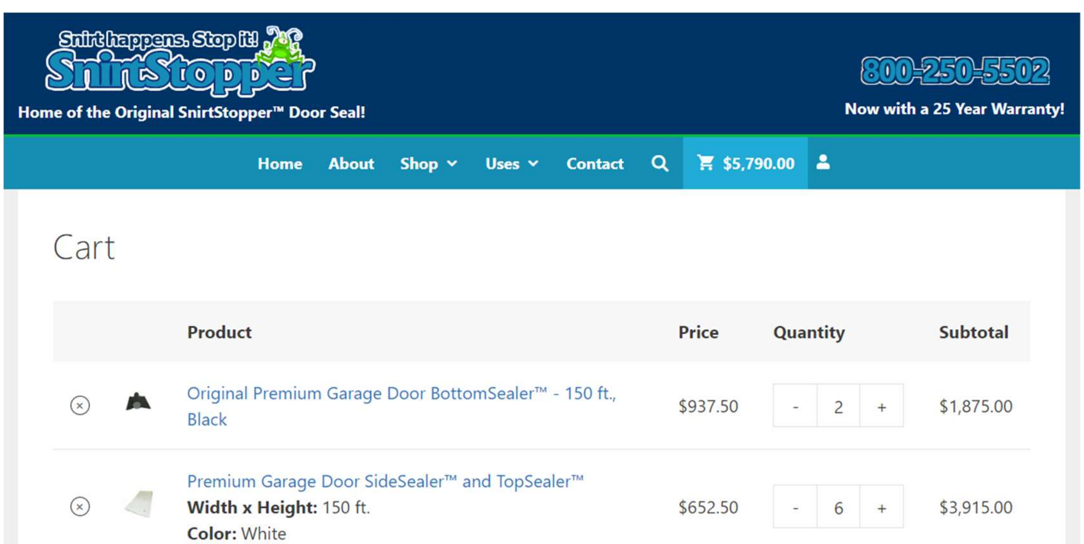



*Fig. 7. SnirtStopper.com Cart, Adapted from [4]*

These seals are also made out of Kevlar reinforced woven polyester that can stay pliable and resilient for years, even more so than rubber seals. As shown in Figure 8, the *Snirt Stopper* can fix even large gaps in garage doors. *Snirt Stopper* also makes weather-stripping which is made of the same heavy-duty material as the seals and is installed over top of existing, damaged weather-stripping as shown in Figure 9.


*Fig. 8. SnirtStopper Bottom Seals for Overhead Doors, Adapted from [4]*

*Fig. 9. SnirtStopper Weather-stripping Being Installed, Adapted from [4]*

It can seem hard to justify the higher capital investment of $8000 when compared to normal seals that can be bought at any hardware store for much cheaper. However, normal seals do not have a warranty, and are made out of comparatively weaker rubber. The *Snirt Stopper* seals that are being suggesting are well worth it in the long run because at the end of their 25 year warranty, they will have saved the City of Saskatoon approximately $367,000 (Appendix B). The seals and weather-stripping will take only 2.5 years to pay back, as shown in Figure 10.

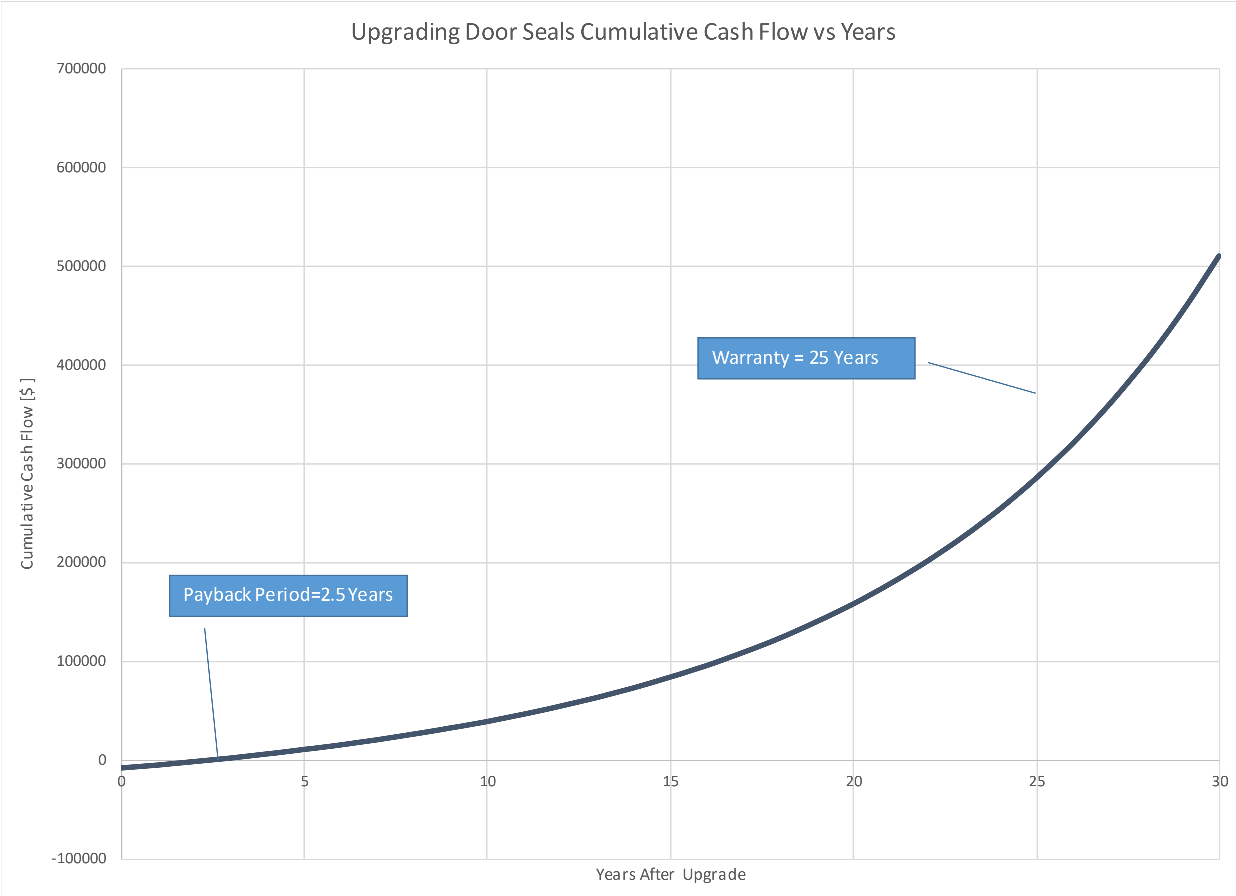



*Figure 10 - Seals and Weather-stripping Cumulative Cash Flow, Adapted from Appendix B*

Infiltration is the biggest problem to fix while doors are closed, meaning that investing in high quality seals will pay off in the long run, both for heat retention and money savings.

## Insulation

Although infiltration is the largest source of heat loss while the doors are closed, there is also heat being conducted through the doors. Many stores sell kits for garage door insulation which simply press onto door panels. These have potential to improve heat retention and efficiency by adding on to the R-Value of the garage door they are placed onto. These are made to be easily applicable, without the use of many tools as shown in Figure 11. As of now, the amount of heat being lost through the doors by conduction is close to 4 kW, which makes up 1.5% of the average annual heating bill (Appendix C).

*Fig. 11. Home Installation of a Garage Door Insulation Kit, Adapted from [6]*

Several different types of insulation including three different brands of foam insulation and one brand of reflective insulation were considered. The different types of insulation performed with varying amounts of effectiveness, and with varying lengths of payback periods.

The longest payback period was 22 years as seen in Table 1, and it belonged to the *Reach Barrier Reflective* kit, which also saved the least amount of energy. Since Saskatoon is in such a cold climate, considering reflective insulation is not very effective. Reflective insulation is better applied in warmer climates to reduce heat gain and cooling costs in the summer [2]. Although reflective insulation provides some heat retention, this is not its intended purpose so they do not have much use for reflective insulation here.

The shortest payback period was 11 years as also seen in Table 1, belonging to the *Owens Corning* insulation kit, with this kit also saving the most amount of energy. It saves a little more than 1 kW of energy, which is more than a quarter of all energy lost through conduction. Any insulation that increases R-Value will help fight against the cold, and will improve efficiency, even if marginally.

*Table 1. Comparison of Different Insulation Kits*

| Insulation Type | R-Value | # Needed | Price Per Kit | Total Cost | Energy Saved [W] | NG Saved [m3] |
|---|---|---|---|---|---|---|
| Cellofoam | 3.674 | 60 | $ 61.86 | $3,711.60 | 631.20 | 315.89 |
| Plymouth | 3.815 | 60 | $ 124.24 | $7,454.40 | 730.49 | 365.58 |
| Owens | 4.378 | 54 | $ 81.57 | $4,404.78 | 1063.20 | 532.09 |
| Reflective | 3.15 | 56 | $ 55.48 | $3,106.88 | 184.32 | 92.24 |

Most garage doors are only R-4 or R-8, but the doors at the Access Transit bus depot are R-16. This is very high for overhead door standards. Although for some applications insulation may seem like the right option, there is not much use for more insulation here.

The doors already have a high resistance against the cold outside and the shortest payback period for insulation is 11 years. The amount of energy saved by applying insulation is marginal compared to other solutions, so applying insulation cannot be considered as a feasible solution.

## Replacing Doors

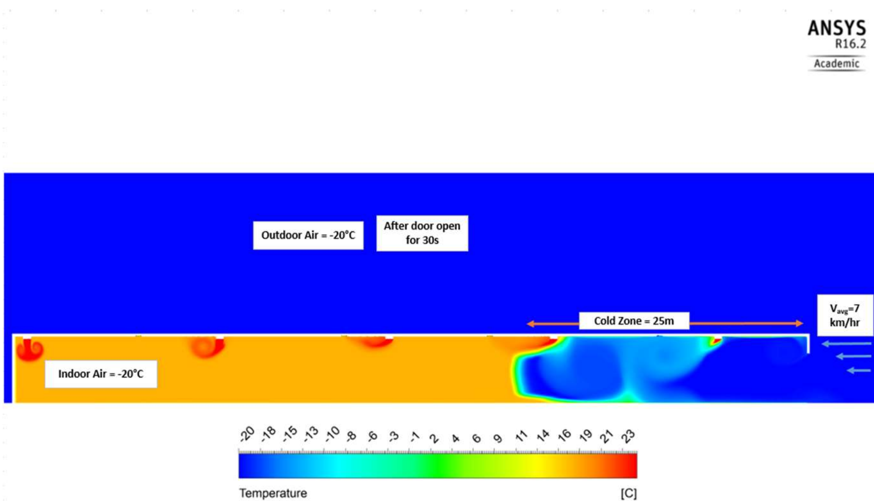
Replacing the doors was another considered solution. As shown in the previous section, the doors have no need for additional insulation because of their high R-value. Replacing the doors for a higher R-Value will only give marginal energy gains and since R-16 doors are already top of the line, better doors would have a much higher cost.

Since the doors are already in decent condition without much visible external damage, replacing the doors was not considered to be a feasible solution.

## Doors Open

### Problem Definition

When the overhead doors are open, they introduce an extremely large air gap to the Access Transit Depot. Any outdoor air that enters through this gap is instantly turned into a heating load. Figure 12 shows a CFD rendering of the side view of a temperature gradient across the Access Transit depot after a single overhead door was open for 30 seconds (Appendix E). This CFD result is significant because it shows just how large the cold zone is from having the doors open. Figure 12 shows that the cold outside air can infiltrate up to 25 meters into the building. Figure 13 shows a different angle of what Figure 12 is representing.



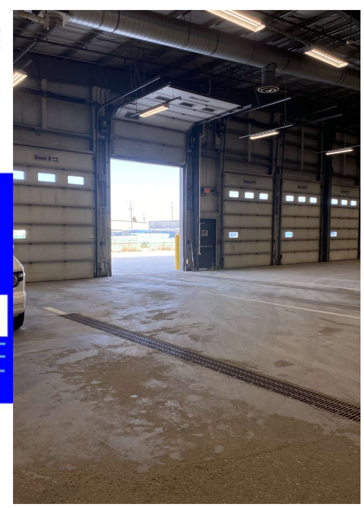



*Fig. 12. Side View of Open Door CFD Rendering*

*Fig. 13. Open Overhead Door*

From Appendix A, the amount of heat lost from the overhead doors being open was found to be around 21% of the annual heating. 21% is definitely a significant value and therefore the access transit depot would greatly benefit from a solution to reduce the amount of heat loss while the doors are open.

## Air Curtains

Air curtains are a popular piece of equipment that are used in many heat retention applications worldwide. The basic working principle of the air curtain is that it separates the indoor and outdoor environments while the overhead door is open. An air curtain achieves this by shooting a high velocity stream of air across the opening of the door, illustrated by Figure 13. The direction of the airstream can usually be adjusted 20° forwards or backwards to ensure optimal performance. Air curtains will either circulate room air or have an internal heater and shoot out heated air. The analysis done for the air curtains used a recirculating model since the heated models were not readily available in the high velocity configurations for the tall overhead doors at the Access Transit Depot.

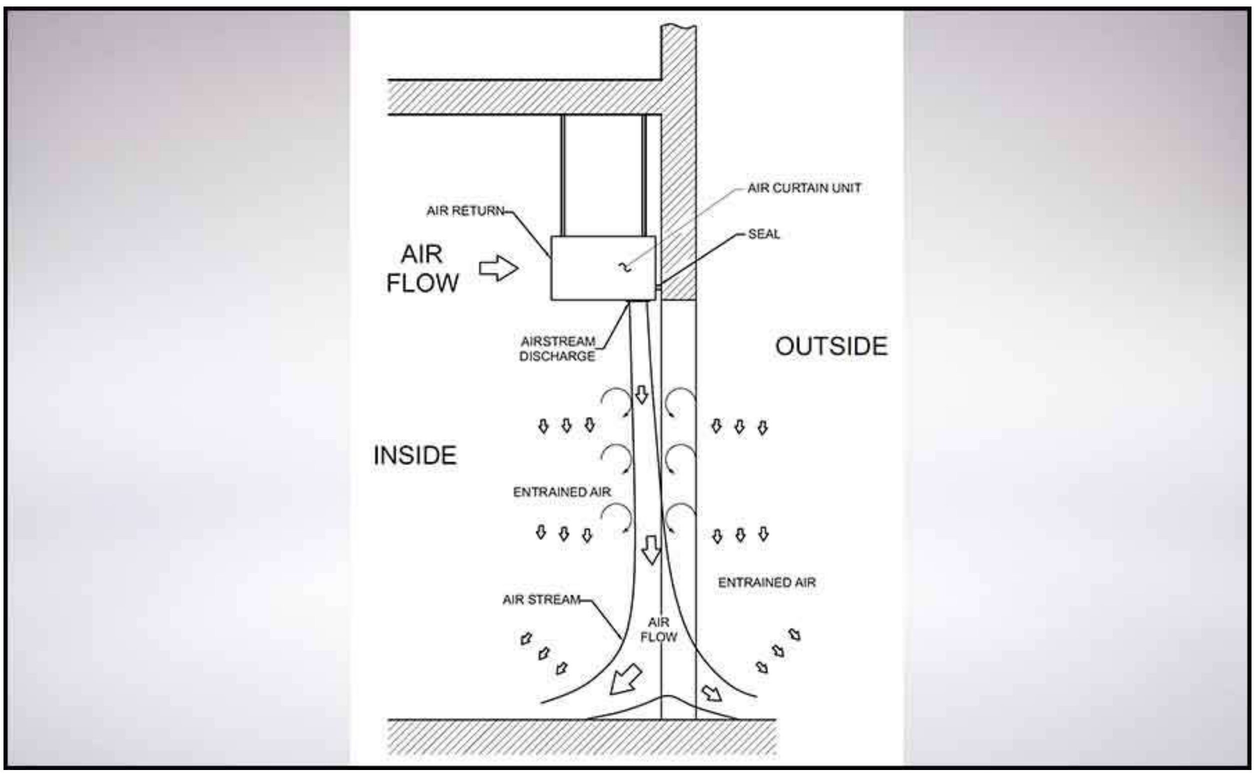



*Fig. 14. Diagram of Air Curtain Operation, Adapted from [5]*

Many sources claim air curtains are able to keep in upwards of 80% heat that would otherwise be let out [3]. No information was provided on how these sources were achieving these impressive numbers of 80% effectiveness. Therefore using CFD, a more representative effectiveness was determined that would help better analyze payback periods. The CFD simulation to find a new effectiveness compared the base case simulation shown in Figure 12 to a simulation with an air curtain installed as shown in Figure 15. The air curtain in Figure 12 uses values in the CFD to simulate a *Berner* high velocity air curtain that is meant for an 11ft x 14ft door and is available for sale from *Aklands Grainger*. However, the air curtain takes up some space so lowering the doors 2 feet to only open to 12 feet was also implemented with the air curtains.

Comparing the temperature gradients from Figure 12 and Figure 15, a more realistic thermal effectiveness was produced. For air curtains installed in the access transit bus depot, the actual effectiveness would be closer to 60%.

Appendix M.1 details on how this 60% value was calculated. Because the climate in Saskatoon is colder than the climate most air curtains are tested at, this leads to a lower effectiveness of the air curtains. This is due to the higher heat transfer rate that can occur through the airstream. The air curtain analysis also featured the average wind speed of 7 km/hour as a headwind, since wind is a common feature that these air curtains would have to deal with (Appendix K). Using unrealistic testing conditions with no wind being applied and idealized air curtain flow stream, an effectiveness of 80% could possibly be achieved. Because a realistic analysis was required, the calculated 60% effectiveness was utilized in financial calculations.

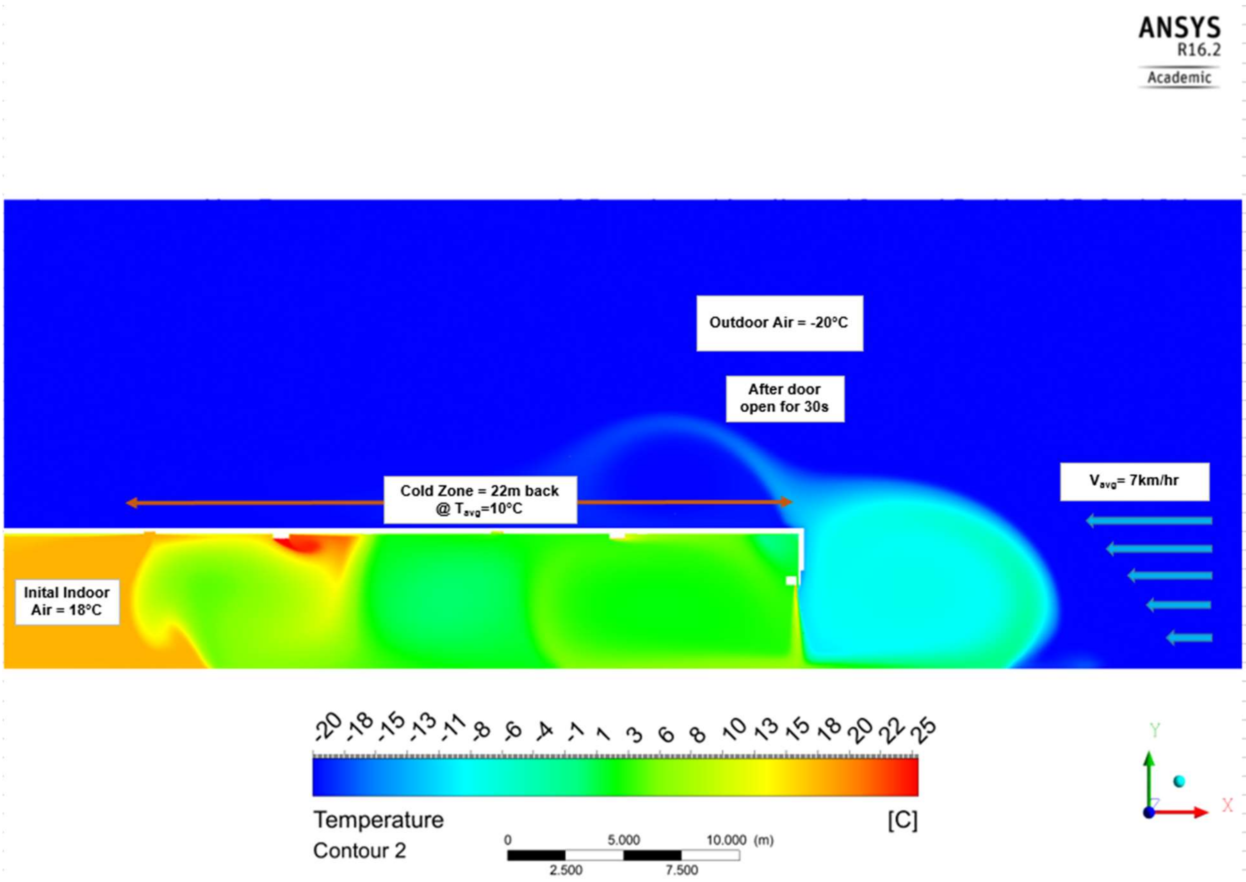



*Fig. 15. Berner High Velocity Air Curtain on Transit Depot, Adapted From Appendix K*

For the payback period, the cost inputs assumed that all 22 overhead doors in the Access Transit Depot had a *Berner High Velocity* air curtain installed and the savings were calculated based on the previously found 60% effectiveness. The results showed that a payback period of 14 years is possible with these air curtains installed on all overhead doors in the Transit Depot (Appendix M-1). During site visits at the Access Transit Depot it was noted that it would be very difficult to install air curtains on all doors since a majority of the doors are closely spaced together and would make installation of the air curtains challenging.

The two doors that do have enough clearance on the sides for air curtains to be installed are the wash bay doors. If air curtains are only installed on the two wash bay doors, the payback period becomes 6.5 years (Appendix M-2). The payback period becomes lower since the wash bay doors are the most frequently used doors. *Berner* provides a 5 year warranty on these air curtains, however they have been known to last up to 20 years trouble free [3]. Figure 16 shows the cumulative cash flow for the investment. More information on the financials is available in Appendix M.

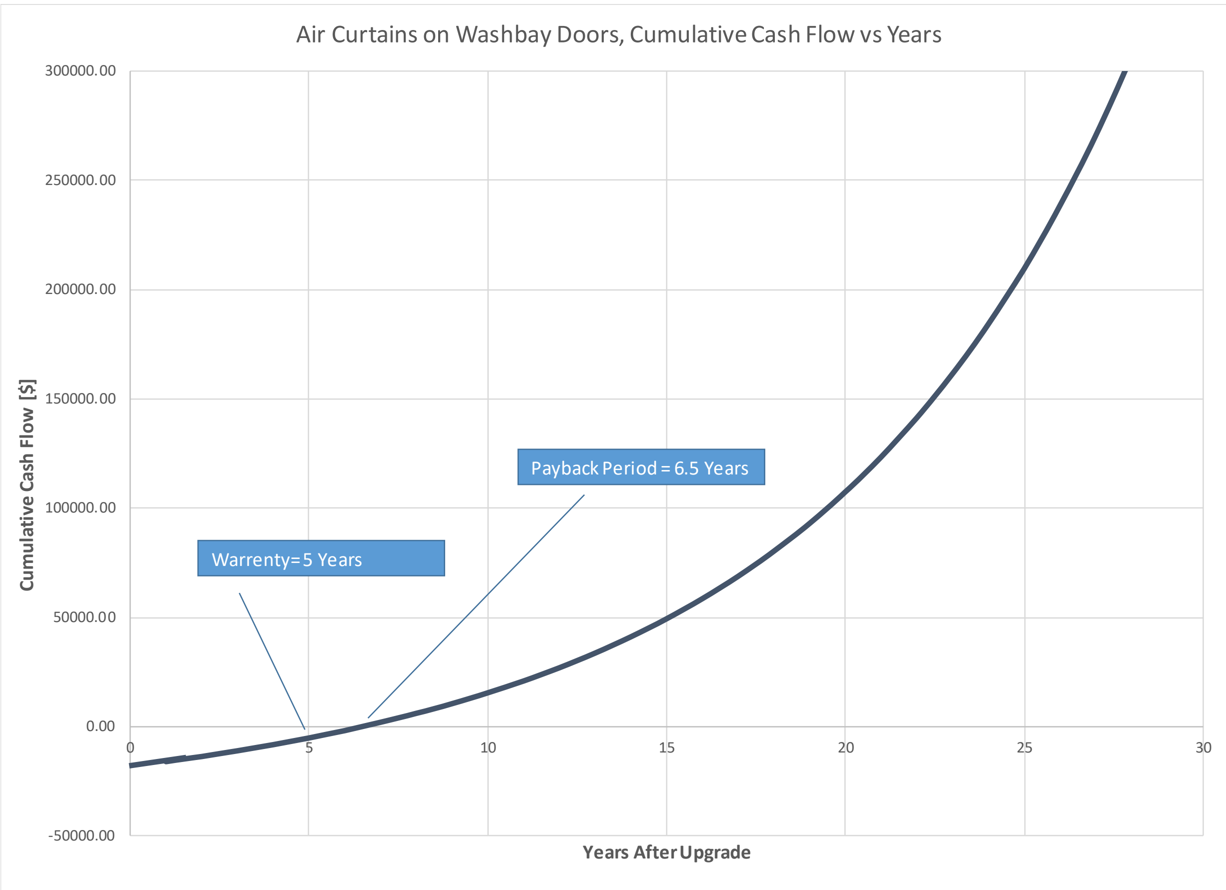



*Fig. 16. Wash bay Doors Air Curtains Cumulative Cash Flow, Adapted from Appendix M-1*

One important consideration with the air curtains is that if not installed or fitted properly, they will worsen the situation. If the air stream is angled too far out, this will worsen the situation by blowing the conditioned air outside, although for locations with higher wind speeds, a steeper air stream angle may be needed. Another problem that can arise with the air curtains is if too low of a velocity unit is installed, then the air curtain will actually create a nozzle near the bottom of the door and push more cold air inside the building as shown in Figure 17. A lower velocity air curtain was analyzed to represent the results in Figure 17.

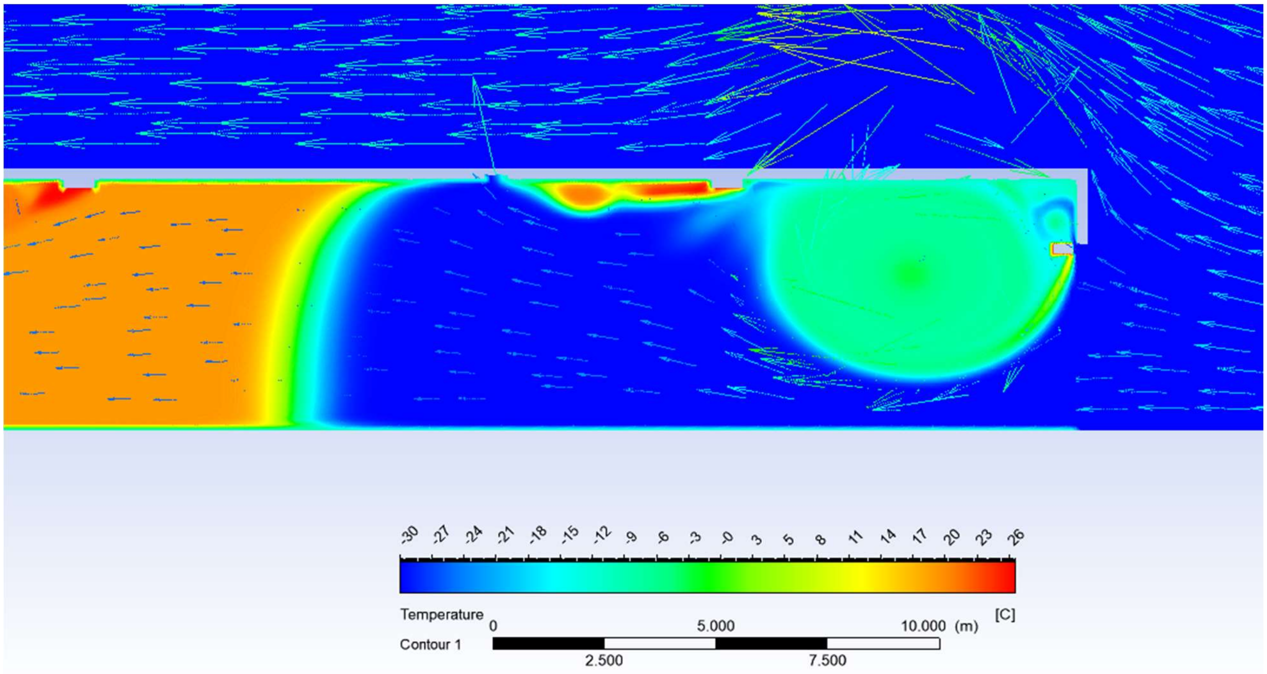



*Fig. 17. Air Curtain with Undersized Velocity, Adapted from Appendix K*

In conclusion, air curtains can be effective only if sized and installed properly like a *Berner High Velocity* air curtain. However there is some risk involved in installing air curtains in the Access Transit bus depot, since the warranties don't cover the life of the payback period.

## Door Timers

A stopwatch was used to time how long the doors would remain open for at the bus depot, since every door is set on timers to close automatically. Including opening and closing times, it was discovered that most of the doors were open for a total of 1 minute and 45 seconds, with only the south wash bay door being open for a total of 45 seconds. The doors being open for 1 minute and 45 seconds was deemed excessive, and that the amount of heat being lost from keeping the doors open for so long could easily be saved.

In the Opera-H specification sheet found in Appendix F-1, the setting that can be adjusted to fix this problem is the “Timer to Close” function. This function closes the door after an adjustable time delay once the door has reached its fully open position. The method to adjust these settings are shown in Appendix F. These specification sheets were given to us on site by the City of Saskatoon.

During an interview with one of the Access Transit drivers, it was learned that the south doors must be open for at least a minute once the door is completely opened. This is because the Access Transit bus drivers must get out of the bus, walk to the door to open it, then walk back, start the bus, and pull out. Because they have so much to do before driving out of the depot, the timers on the south exit doors will be left on 60 second timers.

Over on the north side, the doors are opened by pressure plates in the ground. It is being proposed to adjust the timers on the north entrance doors so that they close after being fully open for 30 seconds. Because the doors open when the drivers pull up and the drivers are already in the Access Transit buses, the doors do not need to be open for as long when entering the building.

By changing the north doors to close after 30 seconds, the amount of heat that will be saved is 12% of the annual heating bill or a 40% improvement over the base case opening scenario. This energy is being wasted by having the doors open for excessively long.

A suggestion not considered was installing fobs or sensors on the inside of the building which would enable the drivers to drive out without needing to get out of the buses. Giving the drivers the ability to open the doors without having to get out of the buses would allow the south door timers to be reduced down to 30 seconds as well. However, this was considered out of scope for this project, with the Access Transit bus depot's security policies not known.

By keeping the doors open for much longer than needed, the bus depot is losing a large amount of heat and money. Adjusting the hoists to close sooner will lead to increased savings and higher building efficiency.

## Door Height

Another issue regarding the doors is the height that each door opens to. Each door is opened to the full height of 14 feet, even though the Access Transit buses do not need that much room to safely leave. Drivers at site said that the tallest vehicle that enters and exits the Transit depot are the Access Transit buses. The tallest point on an Access Transit bus was measured to be 10.25 feet. As visible in Figure 18, the door is much taller than the Access Transit bus. If the overhead doors were lowered to only open to 11ft, the Access Transit buses could still pass through and let less cold outside air in.


*Fig. 18. An 11-foot tall Access Transit Bus by a 14-foot tall door*

From the Opera-H Installation and Instruction Manual in Appendix F-2, the setting that can be adjusted to fix this problem is the “Open Limit” function. This function adjusts how high the door will open, and can be adjusted by changing the position of a cam bracket. The method to adjust this cam bracket is shown in Appendix F-2. This manual was found online, but is suitable for the type of hoist installed in the Access Transit bus depot.

Adjusting the doors to open to 11 feet saves 4% of the overall yearly heating bill and is a 20% improvement over current conditions while the doors are opening to 14 feet.

Having the doors open higher than needed wastes time and energy. By having them open to a lower height, much energy will be saved.

## Results Discussion

There are three different ways the solutions can be compared to aid in quantifying which solution would be the best option for the Access Transit Depot. The first option is to analyze which solutions save the most amount of natural gas and choose a solution that increases the building efficiency but does not necessarily provide a payback period that can be achieved. The second option is by only being concerned with the best payback periods and financial gains. The third option is to consider solutions which are able to provide the best mixture of the first and second options.

Figure 19 will be used to quantify which solutions save the highest amount of natural gas and result in the highest increase in building efficiency. Figure 19 clearly show that air curtains installed on every single overhead door results in the highest natural gas savings. The solution that saves the highest amount of natural gas will also result in the highest increase in building efficiency. Even though changing the door times is free, they provided the second best heat savings and resulting building efficiency. It is important to mention that solutions were considered independently, so if the City of Saskatoon is considering to change the door times and install air curtains they will find that the air curtains will not perform as is being suggested.

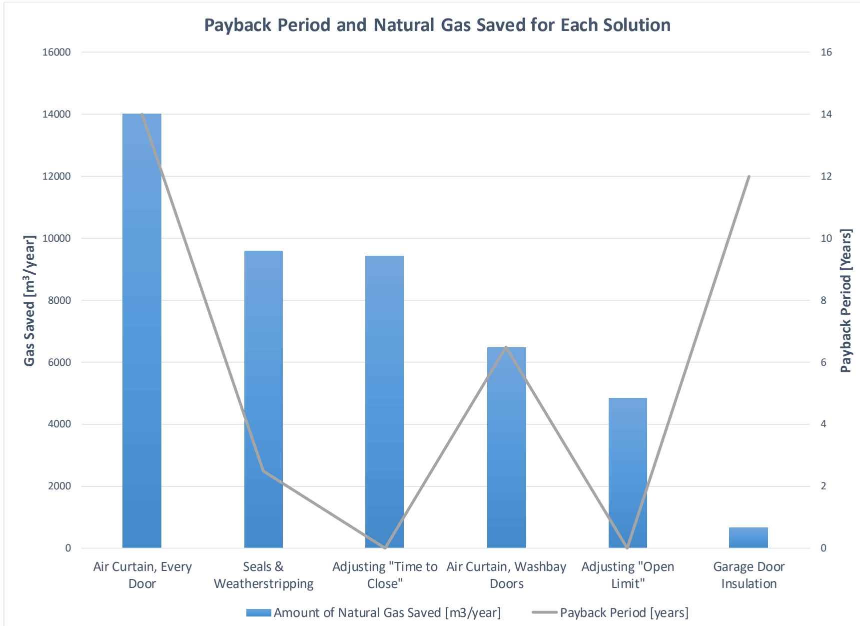



*Fig. 19. Combo Chart*

Figure 20 shows all analyzed solutions and will aid in quantifying which solution will be able to provide the highest financial gains. Figure 20 clearly shows that reducing the north door timers will provide the highest cumulative cash flow during its lifetime. This is because there are no initial costs associated and the amount of heat that is being saved is significant. The second best financial gains are associated with upgrading to the *Snirt Stopper* seals as shown in Figure 20. Even though the air curtain cash flow surpasses the *Snirt Stopper* seal cash flow, it is extremely unlikely that the air curtains will actually last 20 years without getting damaged and needing to be replaced. The *Snirt Stopper* seals have a 25 year warranty, while the air curtains only have a 5 year warranty. As mentioned before, once the north door times are lowered the air curtains are only expected to provide half the cash flow as described in Figure 20. This means that air curtains should not be considered if the main concern is the payback period.

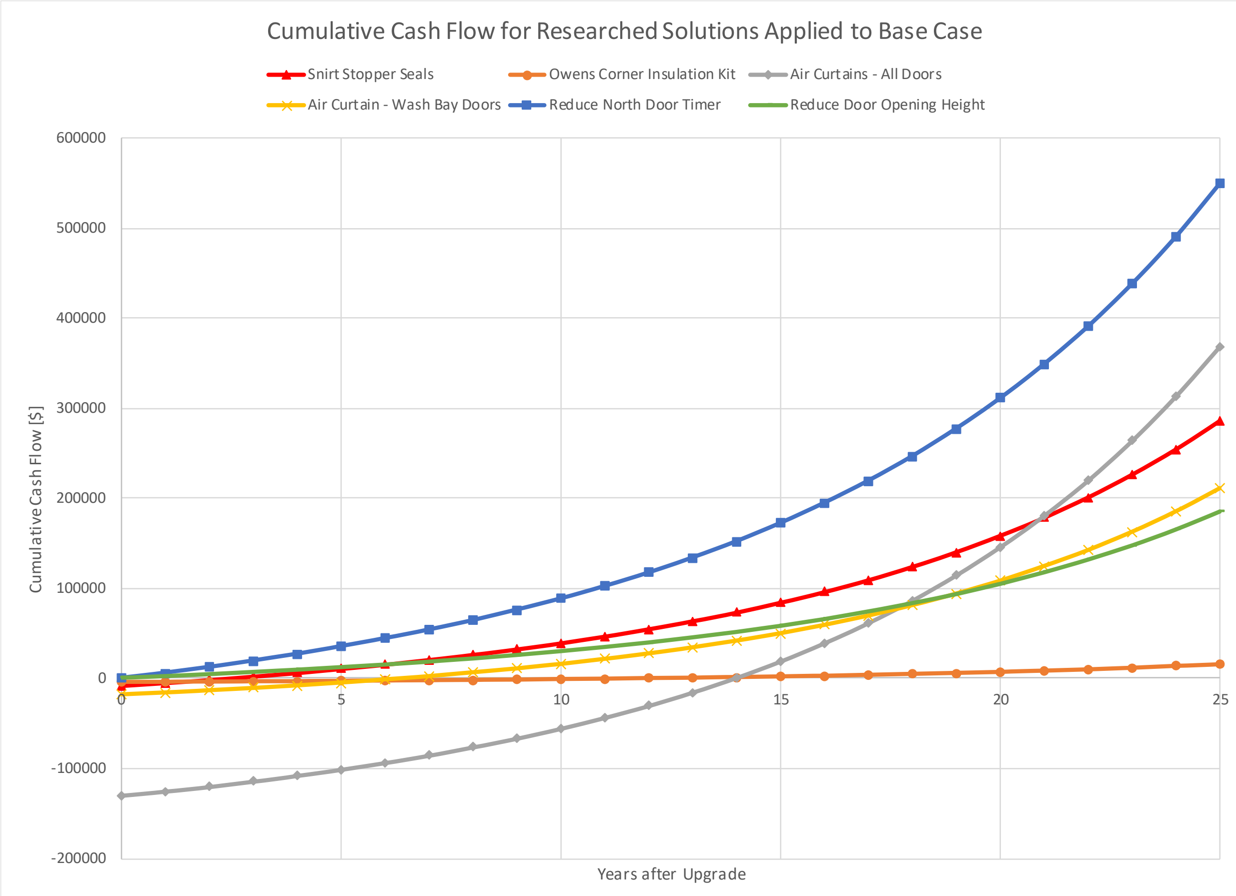



*Figure 20 - Comparing Cumulative Savings*

If both low payback period and high building efficiency are simultaneously being considered, the clear choice is adjusting the door times as they provide the best payback period and one of the highest increases in building efficiency. The second best solution that maximizes both criteria is installing *Snirt Stopper* weather stripping. These provide a low payback period of 2 years and save almost twice the amount of heat compared to adjusting the “Open Limit” setting. Adjusting the “Open Limit” setting is the next best solution that maximizes both criteria. Although air curtains have potential to save the most heat, because of their long payback period they are not able to maximize both criteria.

# Conclusion

Heat loss through overhead doors may not be able to be eliminated completely, but it can be greatly reduced. Through the analysis performed in this report, these conclusions were reached:

- Replacing seals and weather stripping on every door with higher quality materials would save 9590 $m^3$ of natural gas, have a payback period of just under 2 years, and could reduce the amount spent on average on energy by 7%.
- Of the four insulation kits analyzed, the best insulation kit found for every door would save 532 $m^3$ of natural gas, have a payback period of 11 years, and could reduce the amount spent on average on energy by 0.3%.
- Installation of air curtains bring the largest potential energy savings if installed correctly. Most manufacturers claim an effectiveness of 80%, but the actual effectiveness is closer to 60%. If installed on each door, these can save 16901 $m^3$ of natural gas with a payback of 14 years while reducing the amount spent on average on energy by 15.1%. If installed only on the frequently used wash bay doors, these can save 6477 $m^3$ of natural gas with a payback of closer to 6.5 years while reducing the amount spent on average on energy by 5.8%.
- Adjusting the timers on each door will also lead to heat gains, saving 9433 $m^3$ of natural gas with an instant payback, since it's free. Adjusting the timers also saves 12% of the average annual energy bill.
- Adjusting the height that each door opens to will also lead to heat gains, saving 5832 $m^3$ and will save 7% of the average annual energy bill with an instant payback as well.

As discussed, the City of Saskatoon has a large selection of solutions to consider, based on their specific energy savings goals. Integrating any or several of the suggested solutions will help minimize energy losses, reducing their carbon footprint and saving costs.

# Recommendations

First and foremost, adjusting the timers on the north entry doors to close sooner will lead to the largest savings with respect to money and heat. Having the doors held open for any amount of time longer than a minute on that side is a major waste of energy. The drivers are already in the buses, so once the door is open they need only to drive in. This solution requires nothing to be bought, and will instantly save money and heat. It is also highly suggested to further reduce the amount of time open by considering additional means of opening the doors, such as fobs, sensors, RFID tags in buses, or indoor pressure plates.

Another solution that has nothing to be purchased is adjusting the heights. Lowering the doors will save energy as well and since the Access Transit buses are the tallest vehicles in the building, there is no need to worry about the buses scraping the doors.

In addition to adjusting the heights and the timers, it is suggested to replace the seals and weather-stripping with *Snirt Stopper* seals and weather-stripping. Infiltration causes major heat loss while the doors are closed, and investing in higher quality seals has proven to be worth it. The 25 year warranty places *Snirt Stopper* seals above other lower quality seals.

Because the wash bay doors are the most frequently used, installing air curtains over these doors is the only feasible solution involving air curtains. Although they have potential to save large amounts of energy, special care must be taken with the installation so that they don’t make the problem worse.

It is recommended to install air curtains over the wash bay doors only after the prior solutions have been applied. This is because the air curtains have the highest initial cost and longest payback period. Because of the infrastructure of the building coupled with low usage of the non-wash bay doors, air curtains should only be installed over the wash bay doors.

However, extreme care is recommended when sizing and installing air curtains. Through testing, the *Berner High Velocity* air curtain is the product suggested for this application.

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# Appendixes

## Appendix A: Base case heat Loss through open overhead-door calculation

In order to further analyze the current situation and to see how effective potential solutions will be, the amount of heat being lost through the open doors needed to be calculated. The first step to calculating the amount of heat loss through the doors was to find the amount of outdoor air that enters the building while the doors are open which can be a factor of wind speed, wind direction, building pressure, door opening time and outdoor temperature. Table A.1 shows the inputted values that were used to find the leakage flow and heat loss, while Table A.2 shows how the leakage flow for each door was calculated. Table A.2 uses the approach from (ASHRAE 2021, Eqn 37, Pg 16.14) to calculate the leakage flow.

Table. A. 1.

| Inputs for Heat Loss Calculations While Doors are Open | | | | |
|---|---|---|---|---|
| Variable | Symbol | Value | Unit | Source |
| Avg wind velocity | $V_{avg}$ | 1.923 | m/s | Appendix I |
| Furnace Efficiency | η | 100.00% | % | From Dataplate (Model EngA,HE451) |
| Indoor Temp | $T_i$ | 18 | °C | Measured at Site |
| Air Density | ρ | 1.31 | $kg/m^3$ | Cengel A-22 (@tavg=-3.5°C) |
| Specific Heat of Air | Cp | 1.006 | kJ/kg*k | Cengel A-22 (@tavg=-3.5°C) |
| Lower Heating Value | LHV | 36.6 | $MJ/m^3$ | EngineeringToolbox.com [A.1] |
| Opening Effectivness | $C_v$ | 0.6 | x | ASHRAE 2021 Pg 16.14 |

Table. A. 2.

| Base Case Heat Loss While Overhead Doors are Open | | | | | | |
|---|---|---|---|---|---|---|
| Size | Location | Area, A | Openings Per Day, $X_{open}$ | Leakage flow, $V_{leakage}$ | Leakage flow, $m_{leakage}$ | Effective Opening Time, T |
| [ft] | x | [$m^2$] | # | [$m^3/s$] | [kg/s] | [s] |
| **11W x 14H** | North And South | 14.3 | 48 | 16.52 | 21.6 | 80 |
| **14W x 14H** | North | 18.2 | 25 | 21.01 | 27.5 | 80 |
| | South | 18.2 | 25 | 21.01 | 27.5 | 30 |
| **16W x 14H** | North | 20.8 | 2 | 24.01 | 31.5 | 80 |

Sample Calculations for Table A.2 for 11W x 14H Door:

Find Area $A_{11Wx14H}$:

$$A = W * H$$

$$A_{11Wx1} = (11ft * 0.3048\, m/ft) * (14ft * 0.3048m/ft)$$

$$\boldsymbol{A_{11Wx14H} = 14.3m^2}$$

Find number of doors $X_{door}$:

$\boldsymbol{X_{door}}$ = **Counted from Appendix L**

Find $V_{leakage}$:

$$\dot{V}_{Leakage} = C_v * A * v_{avg}$$ Eqn 37, CH16, ASHRAE 2021

$$\dot{V}_{Leakage,11Wx1} = 0.6 * 14.3m^2 * 1.923m/s$$

$$\boldsymbol{\dot{V}_{Leakage,11Wx14H} = 16.52m^3/s}$$

Find $T$:

The opening times were measured at site and it was found that all doors were on 60 second timers expect the one wash bay door on a 10 second timer. However the doors still take an additional 20 seconds to open and then another 20 seconds to close. Since the area is changing while the doors open and close, it is not adequate to add 40 seconds onto the timer value since the area used for $V_{Leakage}$ is constant. Therefor an equivalent value of 20 seconds was added onto the timer value to represent the heat lost while the doors move to open or close:

$$T = T_{Timer} + 20s$$

$$T_{11Wx14H} = 60s + 20s$$

$$\boldsymbol{T_{11Wx14H} = 80s}$$

Find $M_{Leakage}$:

$$\dot{m}_{Leakage} = \rho * V_{Leakage}$$

$$\dot{m}_{Leakage,11Wx14H} = \frac{1.31kg}{m^3} * 16.52\ m^3/s$$

$$\boldsymbol{\dot{m}_{Leakage,11Wx14H} = 21.6\ kg/s}$$

In order to ensure accuracy, average monthly temperatures from previous years were used. With the outdoor temperature and the leakage flow through each door known, the heat lost through the overhead doors can be derived from the following equation:

$$Q = \dot{m} * C_p * \Delta T$$

Table 4 uses the above equation with the historical monthly temperature data from Appendix D, to calculate the amount of heat loss per month through each size of door. A summation was performed on monthly values in order to get the final result of average heat loss through the open overhead doors per winter, this result is shown at the bottom of Table A.3. It was assumed that an annual year of heating only required the Access Transit Depot to be heated in the colder months of October through April.

*Table. A. 3. Base Case Open Door Results*

| **Historical Data** | | | **Heat Loss, $Q_{loss}$** | | | |
|---|---|---|---|---|---|---|
| **Month** | **Mean Outdoor Temp, $T_o$** | **Days, D** | **11W x 14H [80s]** | **14W x 14H [80s]** | **14W x 14H [30s]** | **16W x 14H [80s]** |
| x | [°C] | x | [MWh/month] | | | |
| Oct | 3.9 | 31 | 10.1 | 6.7 | 2.5 | 0.6 |
| Nov | -5.7 | 30 | 16.5 | 10.9 | 4.1 | 1.0 |
| Dec | -13.4 | 31 | 22.6 | 15.0 | 5.6 | 1.4 |
| Jan | -15.5 | 31 | 24.1 | 16.0 | 6.0 | 1.5 |
| Feb | -12.9 | 28 | 20.1 | 13.3 | 5.0 | 1.2 |
| Mar | -6 | 31 | 17.3 | 11.4 | 4.3 | 1.0 |
| Apr | 4 | 30 | 9.8 | 6.5 | 2.4 | 0.6 |
| **Open door heat loss per Winter , $Q_{loss,tot}$** | | | **238** | **[MWh/Winter]** | | |
| **Gas used** | | | **23363.73** | **$m^3$/Winter** | | |
| **%Gas used** | | | **20.82%** | **%/Avg Annual Heating Bill** | | |

Sample calculations for Table A.3 for an 11Wx14H door with an 80 second equivalent open time in the month of October:

Find $Q_{Loss}$ :

$$Q_{Loss} = \dot{m}_{Leakage} * C_{p\ air} * \ \Delta T * X_{open} * T_{Open/mont}$$

$$Q_{Loss,11Wx14H[80\ \ ]} = 21.64 \frac{Kg}{s} \ * \ 1.006 \frac{KJ}{Kg*K} * (18°C - 3.9°C) * \frac{80s}{opening} * \frac{48openings}{day} *$$

$$31 \frac{days}{mont} * \frac{1hr}{3600} * \frac{1Kh}{1000GWh}$$

$$\boldsymbol{Q_{Loss,11Wx14H[80s]} = 10.14\ GWh/month}$$

For the 14Wx14H door and the 16Wx14H door and there respective times, the sample calculations for $Q_{Loss}$ remain the same except that values for $X_{open}, \dot{m}_{leakage}$ and $T$ are used from the row in Table A.2 that corresponds its column in Table A.3.

Find $Q_{Loss,to}$ :

$$Q_{Loss,tot} = \sum Q_{Loss,11Wx14H[80\ \ ]} + \sum Q_{Loss,14Wx14H[80s]} + \sum Q_{Loss,14Wx14H[30\ \ ]} +$$

$$\sum Q_{Loss,16Wx14H[80\ \ ]}$$

$$\boldsymbol{Q_{Loss,tot} = 238\ MWh/Year}$$

In order to better quantify the heat loss per winter, it can be converted into meters cubed of natural gas at STP and then compared with the yearly natural gas usage that was provided by Kathryn Theede, that are also listed at STP conditions. The following equation was used to find the amount of natural gas used to replace the heat loss from the overhead doors being open.

Find $Q_{Loss,tot}$:

$$Q_{Loss,tot} = V_{loss} * LHV * \eta$$

$$237.5 \frac{Mwh}{Winter} * 3600 \frac{s}{hr} = V_{loss} * 36.6\ MJ/m3 * 1$$

$$\boldsymbol{V_{loss} = 23360\ m^3}$$

For the above calculation LHV was used instead of HHV because during a site visit it was determined that the furnace at the access transit depot is a direct fired furnace. Since a direct fired furnace doesn't vent any heat into the atmosphere it is considered to be 100% efficient, if the LHV is used [A.1]. The LHV of natural gas was used from engineeringtoolbox.com [A.2]. The furnace data plate information that was used is seen in Figure A.1.

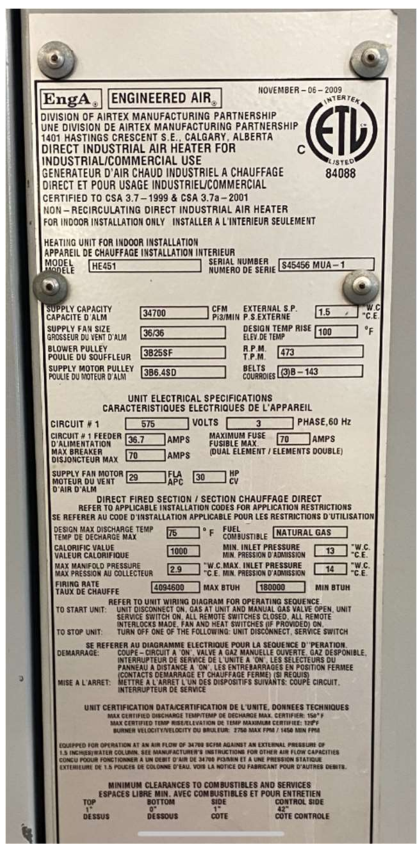



Fig. A.1. Furnace Name Plate

To accurately compare the volume of natural gas lost through the open overhead doors to the yearly heating data provided it would have to found out how much natural gas was being used to heat only the bus depot as there is a large office attached to the Access Transit depot that could skew results. Since the heating data provided predated the construction of the bus depot it could be discovered how much fuel the bus depot was using by the below equation:

$$V_{depot} = V_{total} - V_{maintance\ shop}$$

The above formula is used in Figure 4 which shows the provided data and how the average gas consumption of the bus depot was calculated. The bus depot was put into use in 2010 so the annual consumption average of 2010 and earlier can be considered $V_{maintance\ shop}$. The annual consumption average after 2010 can be considered $V_{combined}$.

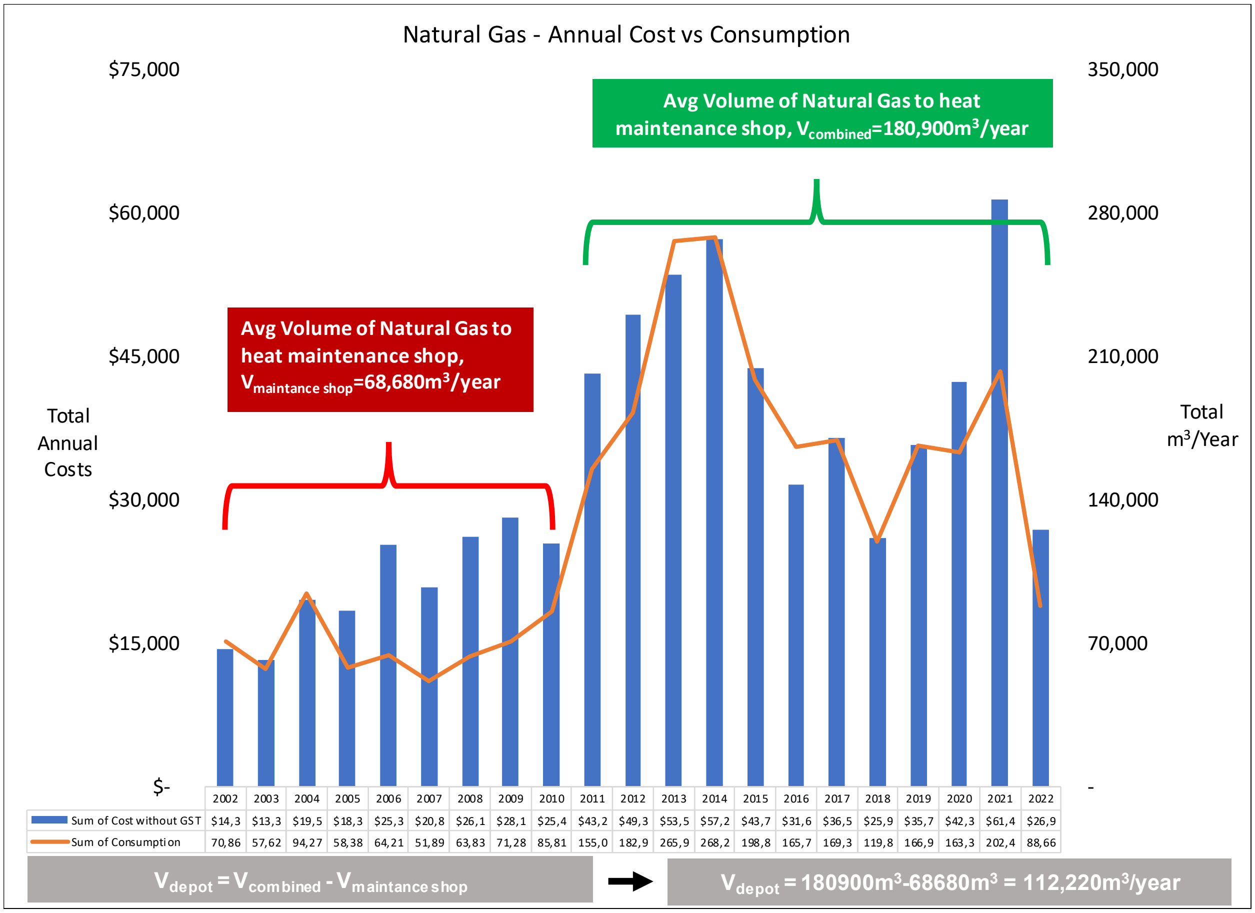



*Fig. A. 19. Natural Gas Consumption*

Now using the volume of natural gas that was lost through the overhead-doors, and the volume required to heat the Access Transit Depot, the two terms can be divided to solve for the percentage of natural gas used for the overhead doors while they are open.

Find $\%Used$:

$$\%Used = \frac{V_{lost}}{V_{depot}} * 100\%$$

$$\%Used = \frac{23360m^3}{112220m^3} * 100$$

$$\boldsymbol{\%Used = 20.8\%/Avg\ Annual\ Heating\ Bill}$$

## Appendix B: Infiltration Calculations

Table 5.8.3.2 from ASHRAE standard 90.1 discusses air fenestration rates for overhead doors. This standard dictates that when proper seals are installed on an overhead door and there is a pressure drop of 75 Pascal's from the inside to the outside, the maximum allowed amount is 0.4 cfm/ft$^2$ of door. This value of 0.4 cfm/ft$^2$ of door cannot be used because it is assumed that the pressure drop occurring across the Bus Depot doors from inside to outside to be 20 Pascal's. Because of this lower pressure, a new allowable amount must be found. The indoor and outdoor temperatures are 18 and -12 degrees Celsius, respectively. The indoor temperature has been assumed from data taken on site and outdoor air temperature has been sourced from an average of the temperature in the winter months, shown in Appendix D. All properties will be sourced at the average temperature of the inside and outside air, which is 3 degrees Celsius.

Equation 16.40 from the ASHRAE handbook gives us the relationship of:

$$V = C * \Delta P^n$$

Where V represents the infiltration, C represents the flow coefficient, ∆P represents the pressure drop, and n is a pressure exponent without units. Assume the pressure exponent "n" has a value of 0.6. Solving for the flow coefficient using equation 16.40 gives a value of:

$$0.4\ \frac{cfm}{ft^2} = C * 75\ Pa^{0.6}$$

$$\boldsymbol{C = 0.02999}$$

Now that the flow coefficient has been solved for, solving for the "new" maximum allowable volume flow rate gives a value of:

$$Vnew = 0.02999 * 20\ Pa^{0.6}$$

$$\boldsymbol{Vnew = 0.18096\ \frac{cfm}{ft^2}}$$

Using the new maximum allowable volume flow and the surface area of every door, the actual infiltration that will be from the doors can be approximated using the formula:

$$Vinfiltration = Vnew * Asurface$$

Using provided information from the floor plan in Appendix E, the total area of the doors was found to be approximately 329 $m^2$. The approximate amount of air that infiltrates through the doors when they have proper seals is:

$$Vinf. = 0.181\frac{cfm}{ft^2} * 329m^2 * 10.764\frac{ft^2}{m^2} * \frac{1\frac{m^3}{s}}{2118.88\ cfm}$$

$$\boldsymbol{Vinf. = 0.3025\ \frac{m^3}{s}}$$

When functional seals and weather-stripping are installed, 0.3025 $m^3/s$ is the allowable maximum air infiltration rate for the depot. The amount of associated heat loss through the infiltration can be calculated using a standard energy balance, which follows the basic equation of:

$$Q = m * Cp * \Delta T$$

The mass flow can be calculated using the infiltration flow rate and the density of the air. The density of the air is determined to be 1.278 $kg/m^3$, interpolated from values in Appendix A-22 (Cengel). The specific heat is also interpolated from Appendix A-22 (Cengel), and is found to be 1.006 kJ/kg K. Heat loss for when the doors have functional seals is then calculated to be:

$$Q = 0.3025\frac{m^3}{s} * 1.278\frac{kg}{m^3} * 1.006\ \frac{kJ}{kg\ K} * \left(18°C - (-12°C)\right)$$

$$\boldsymbol{Q = 11.67\ kW}$$

If all seals are replaced, then the depot will be losing a maximum amount of 11.67 kW through infiltration. The amount of air infiltration happening now with the current seals is assumed to be at least twice as ineffective, and the amount of current infiltration is assumed to be 0.7 $m^3$/s. This means the current actual heat loss is closer to:

$$Qact = 0.7\frac{m^3}{s} * 1.278\frac{kg}{m^3} * 1.006\frac{kJ}{kg\ K} * \left(18°C - (-12°C)\right)$$

$$\boldsymbol{Qact = 27.00\ kW}$$

This is equivalent to **16890 $m^3$** of natural gas! The amount of energy saved just by replacing seals and installing weather-stripping would be:

$$Qsaved = 27.00\ kW - 11.67\ kW$$

$$\boldsymbol{Qsaved = 15.33\ kW}$$

This amount of saved energy is equivalent to **7672 $m^3$** of natural gas, calculated using the same procedure as shown in Appendix A. By just replacing the seals and adding weather-stripping, the amount of heat saved is substantial.

Of the 22 doors, 19 are 11’x14’, two are 14’x14’, and one is 16’x14’. This means 253 feet of seals are needed for the bottom and 897 feet are needed for the sides and top. With the suggested brand, the seals for the bottom and the seals for the sides and top are sold in rolls of 150 feet, so buying two rolls of bottom sealer and six rolls of side and top sealer gives enough to completely replace the seals on the doors. This brings the total cost to **$7879.76.**

From the procedure shown in Appendix A, the base case percent of energy used on heat loss due to infiltration is 15.1%. Adding seals and weather-stripping has the ability to reduce this percentage down to 8.55%.

## Upgrading Seals Financials

Using the methodology from Appendix L, ROI and payback period for upgrading seals for all overhead doors is available in Table B.2 and Figure B.1. Inputs for the calculator are described in Table B.1.

*Table. B. 1.*

| Inputs for Upgrading Seals | | | |
|---|---|---|---|
| Variable | Value | Unit | Source |
| Heat Loss Saved | 7672 | $m^3$/year | Appendix B |
| Commodity Rate | 0.1674 | $/$m^3$ | SaskEnergy - Large Commericial Rates |
| Avg Cash Inflation | 3% | % | Appendix L |
| Initial Cost | 7879.76 | $ | Appednix B |

From these values, the payback period and return on investment can be calculated.

Within just 2 years the seals are able to save enough energy to pay for themselves. At the end of their 25 year warranty, they will have saved an additional $366,718.98 and at that point will be providing an immense 399% return on investment! This is definitive proof that replacing the seals is the fastest, cheapest, and most effective solution to pay for to save energy.

*Table. B. 2. Upgrading Seal Financials*

| Year | | Carbon Tax [$/m$^3$] | Predicted Delviery Charge [$/m$^3$] | Annual Savings | Total Money Saved | Cumulative Cash Flow | ROI |
|---|---|---|---|---|---|---|---|
| n | Date | | | | | | |
| 1 | 2024-01-01 | 0.153 | 0.068 | $ 3,106.94 | $ 3,106.94 | -$ 4,772.82 | -60.57% |
| 2 | 2025-01-01 | 0.181 | 0.0687 | $ 3,433.64 | $ 6,540.59 | -$ 1,339.17 | -56.42% |
| 3 | 2026-01-01 | 0.210 | 0.0694 | $ 3,777.25 | $ 10,317.83 | $ 2,438.07 | -52.06% |
| 4 | 2027-01-01 | 0.231 | 0.0702 | $ 4,072.53 | $ 14,390.36 | $ 6,510.60 | -48.32% |
| 5 | 2028-01-01 | 0.254 | 0.0709 | $ 4,400.88 | $ 18,791.24 | $ 10,911.48 | -44.15% |
| 6 | 2029-01-01 | 0.279 | 0.0716 | $ 4,766.50 | $ 23,557.74 | $ 15,677.98 | -39.51% |
| 7 | 2030-01-01 | 0.307 | 0.0724 | $ 5,174.16 | $ 28,731.91 | $ 20,852.15 | -34.34% |
| 8 | 2031-01-01 | 0.338 | 0.0731 | $ 5,629.27 | $ 34,361.18 | $ 26,481.42 | -28.56% |
| 9 | 2032-01-01 | 0.371 | 0.0738 | $ 6,137.94 | $ 40,499.11 | $ 32,619.35 | -22.11% |
| 10 | 2033-01-01 | 0.409 | 0.0746 | $ 6,707.08 | $ 47,206.19 | $ 39,326.43 | -14.88% |
| 11 | 2034-01-01 | 0.450 | 0.0753 | $ 7,344.53 | $ 54,550.72 | $ 46,670.96 | -6.79% |
| 12 | 2035-01-01 | 0.494 | 0.0760 | $ 8,059.18 | $ 62,609.90 | $ 54,730.14 | 2.28% |
| 13 | 2036-01-01 | 0.544 | 0.0768 | $ 8,861.07 | $ 71,470.97 | $ 63,591.21 | 12.45% |
| 14 | 2037-01-01 | 0.598 | 0.0775 | $ 9,761.57 | $ 81,232.54 | $ 73,352.78 | 23.88% |
| 15 | 2038-01-01 | 0.658 | 0.0782 | $ 10,773.59 | $ 92,006.13 | $ 84,126.37 | 36.72% |
| 16 | 2039-01-01 | 0.724 | 0.0789 | $ 11,911.71 | $ 103,917.84 | $ 96,038.08 | 51.17% |
| 17 | 2040-01-01 | 0.796 | 0.0797 | $ 13,192.48 | $ 117,110.32 | $ 109,230.56 | 67.42% |
| 18 | 2041-01-01 | 0.876 | 0.0804 | $ 14,634.64 | $ 131,744.96 | $ 123,865.20 | 85.72% |
| 19 | 2042-01-01 | 0.964 | 0.0811 | $ 16,259.39 | $ 148,004.35 | $ 140,124.59 | 106.34% |
| 20 | 2043-01-01 | 1.060 | 0.0819 | $ 18,090.78 | $ 166,095.13 | $ 158,215.37 | 129.59% |
| 21 | 2044-01-01 | 1.166 | 0.0826 | $ 20,156.04 | $ 186,251.17 | $ 178,371.41 | 155.80% |
| 22 | 2045-01-01 | 1.283 | 0.0833 | $ 22,486.03 | $ 208,737.20 | $ 200,857.44 | 185.36% |
| 23 | 2046-01-01 | 1.411 | 0.0841 | $ 25,115.69 | $ 233,852.89 | $ 225,973.13 | 218.74% |
| 24 | 2047-01-01 | 1.552 | 0.0848 | $ 28,084.62 | $ 261,937.50 | $ 254,057.74 | 256.41% |
| 25 | 2048-01-01 | 1.707 | 0.0855 | $ 31,437.68 | $ 293,375.18 | $ 285,495.42 | 298.97% |
| 26 | 2049-01-01 | 1.878 | 0.0862 | $ 35,225.71 | $ 328,600.90 | $ 320,721.14 | 347.04% |
| 27 | 2050-01-01 | 2.065 | 0.0870 | $ 39,506.30 | $ 368,107.20 | $ 360,227.44 | 401.36% |
| 28 | 2051-01-01 | 2.272 | 0.0877 | $ 44,344.70 | $ 412,451.90 | $ 404,572.14 | 462.77% |
| 29 | 2052-01-01 | 2.499 | 0.0884 | $ 49,814.86 | $ 462,266.76 | $ 454,387.00 | 532.19% |
| 30 | 2053-01-01 | 2.749 | 0.0892 | $ 56,000.53 | $ 518,267.29 | $ 510,387.53 | 610.69% |
| 31 | 2054-01-01 | 3.024 | 0.0899 | $ 62,996.65 | $ 581,263.93 | $ 573,384.17 | 699.47% |
| 32 | 2055-01-01 | 3.326 | 0.0906 | $ 70,910.77 | $ 652,174.70 | $ 644,294.94 | 799.91% |
| 33 | 2056-01-01 | 3.659 | 0.0914 | $ 79,864.76 | $ 732,039.47 | $ 724,159.71 | 913.54% |
| 34 | 2057-01-01 | 4.025 | 0.0921 | $ 89,996.73 | $ 822,036.20 | $ 814,156.44 | 1042.13% |
| 35 | 2058-01-01 | 4.428 | 0.0928 | $ 101,463.15 | $ 923,499.34 | $ 915,619.58 | 1187.64% |
| 36 | 2059-01-01 | 4.870 | 0.0936 | $ 114,441.33 | $ 1,037,940.67 | $ 1,030,060.91 | 1352.35% |
| 37 | 2060-01-01 | 5.357 | 0.0943 | $ 129,132.19 | $ 1,167,072.86 | $ 1,159,193.10 | 1538.78% |
| 38 | 2061-01-01 | 5.893 | 0.0950 | $ 145,763.41 | $ 1,312,836.26 | $ 1,304,956.50 | 1749.85% |
| 39 | 2062-01-01 | 6.482 | 0.0957 | $ 164,592.97 | $ 1,477,429.23 | $ 1,469,549.47 | 1988.81% |
| 40 | 2063-01-01 | 7.131 | 0.0965 | $ 185,913.22 | $ 1,663,342.45 | $ 1,655,462.69 | 2259.38% |

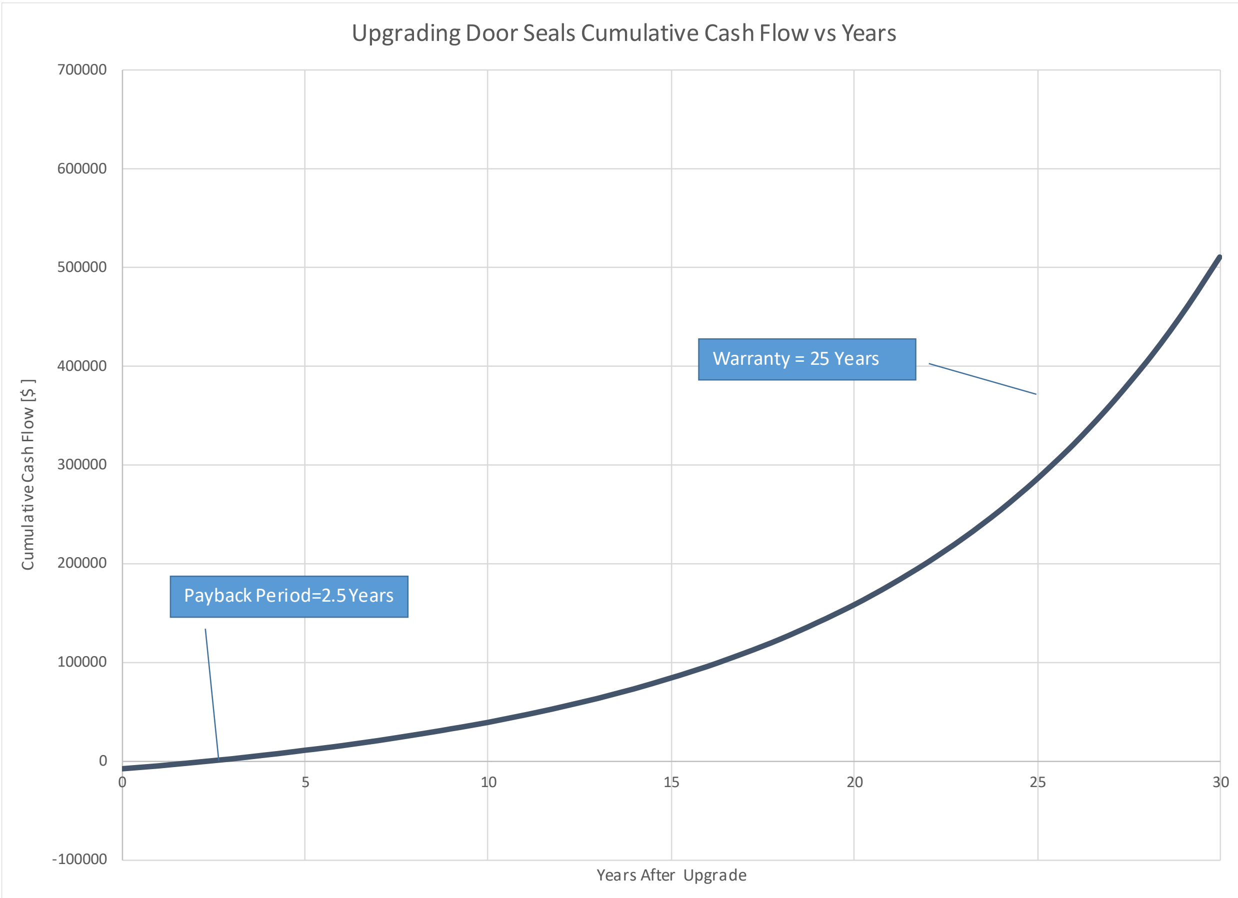



*Fig. A. 1. Cumulative Cash Flow for Upgrading Seals*

## Appendix C: Insulation Calculations

Insulation is material used to reduce the flow of thermal energy, usually from one surface to another. Increasing insulation means increasing resistance, which leads to less energy being lost. Insulation kits for garage doors are now sold, which can improve heat retention by increasing resistance.

The indoor and outdoor surface temperatures will be taken as 18°C and -12°C, respectively.

The doors that are at the Access Transit bus depot have an R-Value of R-16.04. To find the amount of energy being lost through the doors, the procedure for cooling load found in 2021 ASHRAE Handbook Fundamentals will be followed.

The surface film resistances from convection and radiation must first be found. These change based on several factors, such as direction of flow, surface emittance, and indoor or outdoor conditions. Table 10 from chapter 26 will be used.

The resistance for the inside surface is 0.12 m2*K/W based on a vertical surface with horizontal heat flow, and a non-reflective surface emittance. The resistance for the outside surface is 0.03 m2*K/W based on a wind speed for winter at 6.7 m/s, and any direction of heat flow. A wind speed of 6.7 m/s is appropriate to assume for winter in Saskatoon. Using a “series” approach for the garage door, the two resistances for the inside and outside films will be added onto the R-Value of the door, to get the total resistance. Converting the R-Value of the doors into m2*K/W then solving for total resistance gives a value of:

$$Rtot = \frac{16.04}{5.678}\frac{m^2\,K}{W} + 0.12\,\frac{m^2\,K}{W} + 0.03\,\frac{m^2\,K}{W}$$

$$\boldsymbol{Rtot = 2.975\,\frac{m^2\,K}{W}}$$

The total surface area of the doors is found to be 329 m2, from Appendix E. Since the total resistance of the door, the surface area, and the change in temperatures is known the amount of energy being conducted through all of the doors can be solved for. A standard equation for conduction is:

$$Qlost = Utot * Asurface * (Ti - To)$$

Where $Utot = \frac{1}{Rtot}$

Using this formula, the amount of energy being conducted and lost through all of the doors is:

$$Qlost = \frac{1}{2.975 \frac{m^2\ K}{W}} * 329\ m^2 * \left(18°C - (-12°C)\right)$$

$$\boldsymbol{Qlost = 3317.65\ W}$$

With no insulation, the total amount of heat lost is 3317.65 W. This is equivalent to 2075.4 m3 of natural gas, with the method for determining this found in Appendix A. Increasing the R-value of the doors will decrease the amount of heat lost.

Sample calculations will be shown for the Owens Corning Insulation Kit. Since the panels that come in the kit have an R-value of 8, this means that the new total resistance is:

$$Rowens = 2.97 \frac{m^2\ K}{W} + \frac{8}{5.678} \frac{m^2\ K}{W}$$

$$\boldsymbol{Rowens = 4.378 \frac{m^2\ K}{W}}$$

With the Owens Corning insulation installed on each door, this gives us a new heat loss of:

$$Qowens = \frac{1}{4.378 \frac{m^2\ K}{W}} * 329\ m^2 * \left(18°C - (-12°C)\right)$$

$$\boldsymbol{Qowens = 2254.45\ W}$$

This means the amount of energy being saved by adding insulation is:

$$Qsaved = 3317.65\ W - 2254.45\ W$$

$$\boldsymbol{Qsaved = 1063.2\ W}$$

Adding insulation to every door saves more than 1 kW of power. The initial costs and payback periods will now be considered.

Each kit contains 8 panels of 22 inch by 54 inch panels. This means that to cover every door the amount of packs needed will be:

$$\#req = 329\ m^2 * \frac{1\ pack}{8\ panels} * \frac{1\ panel}{22\ in * 54\ in} * 1550\ \frac{in^2}{m^2}$$

$$\boldsymbol{\#req = 54\ packs}$$

Buying 54 packs at a price of $81.57 per pack will bring the total cost to:

$$Total\ Cost = 54\ packs * \frac{\$81.57}{pack}$$

$$\boldsymbol{Total\ Cost = \$4407.78}$$

As you can see in the Table C.1 below, Owens Corning saves the most energy and therefore the most natural gas. Since the Owens Corning saved the most energy, payback period and ROI calculations were only considered for that brand.

*Table. C. 1. Summary of Insulation Upgrades*

| Insulation Type | R-Value | # Needed | Price Per Kit | Total Cost | Energy Saved [W] | NG Saved [m3] |
|---|---|---|---|---|---|---|
| Cellofoam | 3.674 | 60 | $ 61.86 | $3,711.60 | 631.20 | 315.89 |
| Plymouth | 3.815 | 60 | $ 124.24 | $7,454.40 | 730.49 | 365.58 |
| Owens | 4.378 | 54 | $ 81.57 | $4,404.78 | 1063.20 | 532.09 |
| Reflective | 3.15 | 56 | $ 55.48 | $3,106.88 | 184.32 | 92.24 |

## Upgrading to Owens Insulation Financials

Using the methodology from Appendix L, ROI and payback period for upgrading insulation for all overhead doors is available in Table C.3 and Figure C.1. Inputs for the calculator are described in Table C.2.

As you can see from the table below, the payback period is 12.5 years. This is a very long time, assuming that it doesn't need to be replaced. If it gets damaged and needs to be replaced, there is no warranty meaning that the city will need to buy more. The amount of energy insulation saves is marginal at just over one kilowatt, meaning that there are better solutions for saving energy. After 25 years (the same amount of time as the warranty on the seals) the insulation will have saved only $20000.

*Table. C. 2.*

| Inputs for Insulation Financials | | | |
|---|---|---|---|
| Variable | Value | Unit | Source |
| Heat Loss Saved | 532 | $m^3$ | Appendix C |
| Commodity Rate | 0.1674 | $\$/m^3$ | SaskEnergy - Large Commericial Rates |
| Avg Cash Inflation | 3% | % | Appendix L |
| Initial Cost | 4404.78 | $ | Appednix C |

*Table. C. 3. Results for Insulation Financials*

| Year | | Carbon Tax [$/m³] | Predicted Delviery Charge [$/m³] | Annual Savings | Total Money Saved | Cumulative Cash Flow | ROI |
|---|---|---|---|---|---|---|---|
| n | Date | | | | | | |
| 1 | 2024-01-01 | 0.153 | 0.068 | 215 | 215.44 | -4189.34 | -95.11% |
| 2 | 2025-01-01 | 0.181 | 0.0687 | 238 | 453.54 | -3951.24 | -94.59% |
| 3 | 2026-01-01 | 0.210 | 0.0694 | 262 | 715.47 | -3689.31 | -94.05% |
| 4 | 2027-01-01 | 0.231 | 0.0702 | 282 | 997.87 | -3406.91 | -93.59% |
| 5 | 2028-01-01 | 0.254 | 0.0709 | 305 | 1303.04 | -3101.74 | -93.07% |
| 6 | 2029-01-01 | 0.279 | 0.0716 | 331 | 1633.57 | -2771.21 | -92.50% |
| 7 | 2030-01-01 | 0.307 | 0.0724 | 359 | 1992.36 | -2412.42 | -91.85% |
| 8 | 2031-01-01 | 0.338 | 0.0731 | 390 | 2382.71 | -2022.07 | -91.14% |
| 9 | 2032-01-01 | 0.371 | 0.0738 | 426 | 2808.33 | -1596.45 | -90.34% |
| 10 | 2033-01-01 | 0.409 | 0.0746 | 465 | 3273.42 | -1131.36 | -89.44% |
| 11 | 2034-01-01 | 0.450 | 0.0753 | 509 | 3782.71 | -622.07 | -88.44% |
| 12 | 2035-01-01 | 0.494 | 0.0760 | 559 | 4341.56 | -63.22 | -87.31% |
| 13 | 2036-01-01 | 0.544 | 0.0768 | 614 | 4956.02 | 551.24 | -86.05% |
| 14 | 2037-01-01 | 0.598 | 0.0775 | 677 | 5632.91 | 1228.13 | -84.63% |
| 15 | 2038-01-01 | 0.658 | 0.0782 | 747 | 6379.99 | 1975.21 | -83.04% |
| 16 | 2039-01-01 | 0.724 | 0.0789 | 826 | 7205.98 | 2801.20 | -81.25% |
| 17 | 2040-01-01 | 0.796 | 0.0797 | 915 | 8120.79 | 3716.01 | -79.23% |
| 18 | 2041-01-01 | 0.876 | 0.0804 | 1015 | 9135.60 | 4730.82 | -76.96% |
| 19 | 2042-01-01 | 0.964 | 0.0811 | 1127 | 10263.08 | 5858.30 | -74.40% |
| 20 | 2043-01-01 | 1.060 | 0.0819 | 1254 | 11517.55 | 7112.77 | -71.52% |
| 21 | 2044-01-01 | 1.166 | 0.0826 | 1398 | 12915.23 | 8510.45 | -68.27% |
| 22 | 2045-01-01 | 1.283 | 0.0833 | 1559 | 14474.48 | 10069.70 | -64.60% |
| 23 | 2046-01-01 | 1.411 | 0.0841 | 1742 | 16216.08 | 11811.30 | -60.46% |
| 24 | 2047-01-01 | 1.552 | 0.0848 | 1947 | 18163.55 | 13758.77 | -55.79% |
| 25 | 2048-01-01 | 1.707 | 0.0855 | 2180 | 20343.53 | 15938.75 | -50.51% |
| 26 | 2049-01-01 | 1.878 | 0.0862 | 2443 | 22786.19 | 18381.41 | -44.55% |
| 27 | 2050-01-01 | 2.065 | 0.0870 | 2739 | 25525.68 | 21120.90 | -37.81% |
| 28 | 2051-01-01 | 2.272 | 0.0877 | 3075 | 28600.68 | 24195.90 | -30.19% |
| 29 | 2052-01-01 | 2.499 | 0.0884 | 3454 | 32054.99 | 27650.21 | -21.58% |
| 30 | 2053-01-01 | 2.749 | 0.0892 | 3883 | 35938.24 | 31533.46 | -11.84% |
| 31 | 2054-01-01 | 3.024 | 0.0899 | 4368 | 40306.62 | 35901.84 | -0.83% |
| 32 | 2055-01-01 | 3.326 | 0.0906 | 4917 | 45223.79 | 40819.01 | 11.63% |
| 33 | 2056-01-01 | 3.659 | 0.0914 | 5538 | 50761.86 | 46357.08 | 25.73% |
| 34 | 2057-01-01 | 4.025 | 0.0921 | 6241 | 57002.51 | 52597.73 | 41.68% |
| 35 | 2058-01-01 | 4.428 | 0.0928 | 7036 | 64038.28 | 59633.50 | 59.73% |
| 36 | 2059-01-01 | 4.870 | 0.0936 | 7936 | 71973.99 | 67569.21 | 80.16% |
| 37 | 2060-01-01 | 5.357 | 0.0943 | 8954 | 80928.41 | 76523.63 | 103.29% |
| 38 | 2061-01-01 | 5.893 | 0.0950 | 10108 | 91036.09 | 86631.31 | 129.47% |
| 39 | 2062-01-01 | 6.482 | 0.0957 | 11413 | 102449.47 | 98044.69 | 159.11% |
| 40 | 2063-01-01 | 7.131 | 0.0965 | 12892 | 115341.26 | 110936.48 | 192.68% |

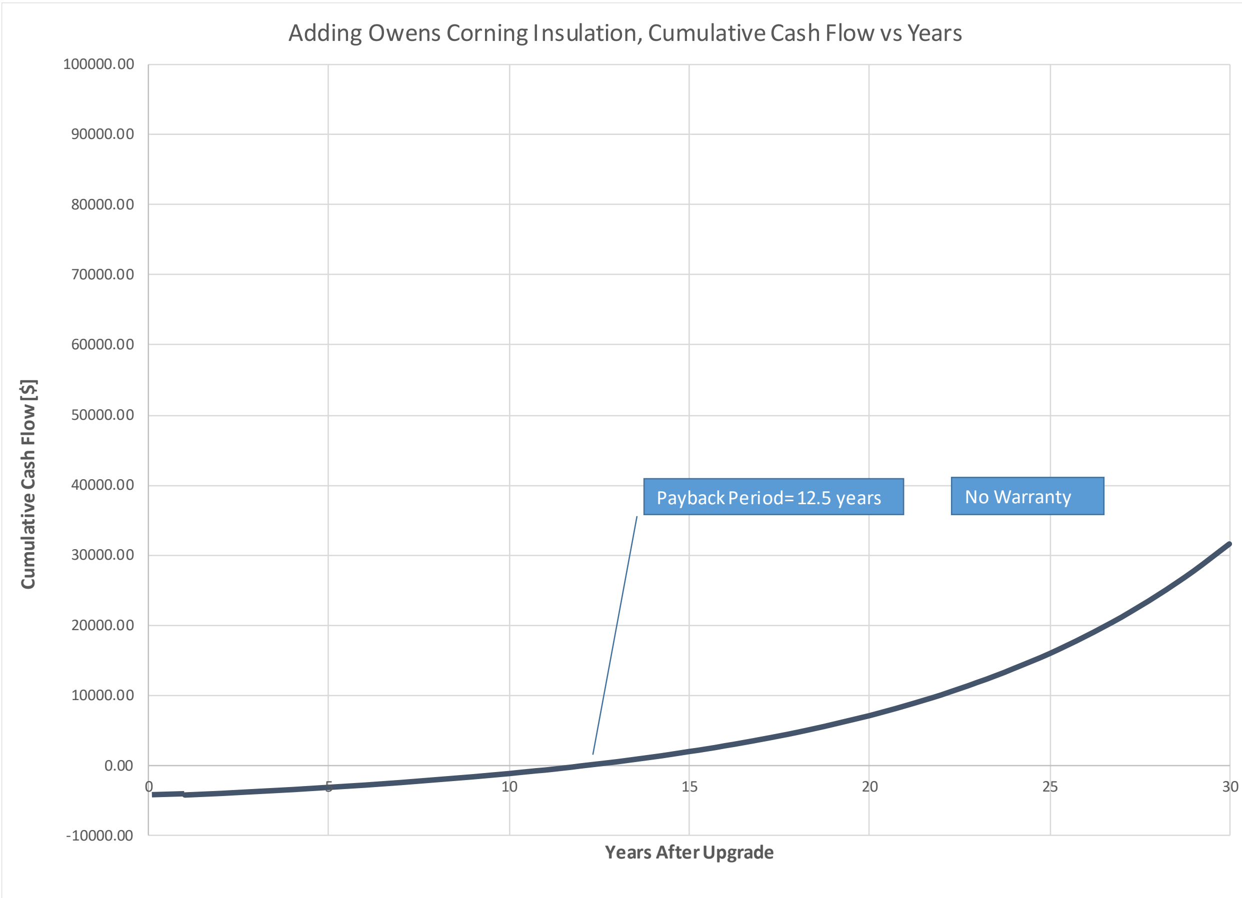

Adding Owens Corning Insulation, Cumulative Cash Flow vs Years
100000.00
90000.00
80000.00
70000.00
60000.00
50000.00
40000.00
30000.00
20000.00
10000.00
0.00
-10000.00
Cumulative Cash Flow [$]
0
5
10
15
20
25
30
Years After Upgrade
Payback Period= 12.5 years
No Warranty

*Fig. C. 1.*

# Appendix D: ASHRAE Design Table

**SASKATOON INTL, SK, Canada** — WMO#: **718660**

Lat: **52.170N** Long: **106.700W** Elev: **504** StdP: **95.41** Time Zone: **-6.00 (NAS)** Period: **90-14** WBAN: **99999**

**Annual Heating and Humidification Design Conditions**

| | Coldest Month | Heating DB | | Humidification DP/MCDB and HR | | | | | | Coldest month WS/MCDB | | | | MCWS/PCWD to 99.6% DB | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | 99.6% | | | 99% | | | 0.4% | | 1% | | | | |
| | | 99.6% | 99% | DP | HR | MCDB | DP | HR | MCDB | WS | MCDB | WS | MCDB | MCWS | PCWD | |
| | (a) | (b) | (c) | (d) | (e) | (f) | (g) | (h) | (i) | (j) | (k) | (l) | (m) | (n) | (o) | |
| (1) | 1 | -34.1 | -31.1 | -38.6 | 0.1 | -33.9 | -35.6 | 0.1 | -31.0 | 13.1 | -8.0 | 11.4 | -7.3 | 3.3 | 190 | (1) |

**Annual Cooling, Dehumidification, and Enthalpy Design Conditions**

| | Hottest Month | Hottest Month DB Range | Cooling DB/MCWB | | | | | | Evaporation WB/MCDB | | | | | | MCWS/PCWD to 0.4% DB | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 0.4% | | 1% | | 2% | | 0.4% | | 1% | | 2% | | | | |
| | | | DB | MCWB | DB | MCWB | DB | MCWB | WB | MCDB | WB | MCDB | WB | MCDB | MCWS | PCWD | |
| | (a) | (b) | (c) | (d) | (e) | (f) | (g) | (h) | (i) | (j) | (k) | (l) | (m) | (n) | (o) | (p) | |
| (2) | 7 | 12.4 | 30.2 | 18.9 | 28.2 | 18.1 | 26.4 | 17.4 | 20.7 | 27.3 | 19.5 | 25.9 | 18.4 | 24.4 | 5.1 | 180 | (2) |

| | Dehumidification DP/MCDB and HR | | | | | | | | | Enthalpy/MCDB | | | | | | Extreme Max WB | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 0.4% | | | 1% | | | 2% | | | 0.4% | | 1% | | 2% | | | |
| | DP | HR | MCDB | DP | HR | MCDB | DP | HR | MCDB | Enth | MCDB | Enth | MCDB | Enth | MCDB | | |
| | (a) | (b) | (c) | (d) | (e) | (f) | (g) | (h) | (i) | (j) | (k) | (l) | (m) | (n) | (o) | (p) | |
| (3) | 18.5 | 14.2 | 23.9 | 17.3 | 13.2 | 22.4 | 16.1 | 12.2 | 21.1 | 62.3 | 27.4 | 58.0 | 25.5 | 54.2 | 24.3 | 25.6 | (3) |

**Extreme Annual Design Conditions**

| | Extreme Annual WS | | | | Extreme Annual Temperature | | | | n-Year Return Period Values of Extreme Temperature | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Mean | | Standard Deviation | | n=5 years | | n=10 years | | n=20 years | | n=50 years | | |
| | 1% | 2.5% | 5% | | Min | Max | Min | Max | Min | Max | Min | Max | Min | Max | Min | Max | |
| | (n) | (o) | (p) | | (b) | (c) | (d) | (e) | (f) | (g) | (h) | (i) | (j) | (k) | (l) | (m) | |
| (4) | 11.1 | 9.8 | 8.7 | DB | -37.9 | 33.9 | 3.3 | 2.4 | -40.2 | 35.6 | -42.1 | 36.9 | -43.9 | 38.3 | -46.3 | 40.0 | (4) |
| (5) | | | | WB | -37.8 | 22.9 | 2.9 | 1.6 | -39.9 | 24.1 | -41.6 | 25.0 | -43.3 | 25.9 | -45.4 | 27.0 | (5) |

**Monthly Climatic Design Conditions**

| | | | | Annual | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | (d) | (e) | (f) | (g) | (h) | (i) | (j) | (k) | (l) | (m) | (n) | (o) | (p) | |
| (6) | Temperatures, Degree-Days and Degree-Hours | | DBAvg | 2.4 | -15.5 | -12.9 | -6.0 | 4.0 | 10.6 | 15.4 | 18.1 | 17.4 | 12.1 | 3.9 | -5.7 | -13.4 | (6) |
| (7) | | | DBStd | 13.56 | 8.79 | 7.71 | 7.96 | 5.67 | 4.66 | 3.70 | 3.23 | 3.85 | 4.61 | 5.41 | 6.86 | 8.37 | (7) |
| (8) | | | HDD10.0 | 3598 | 792 | 641 | 495 | 192 | 49 | 3 | 0 | 1 | 30 | 199 | 469 | 726 | (8) |
| (9) | | | HDD18.3 | 5904 | 1050 | 874 | 753 | 431 | 241 | 103 | 44 | 64 | 192 | 448 | 719 | 984 | (9) |
| (10) | | | CDD10.0 | 829 | 0 | 0 | 0 | 12 | 69 | 164 | 251 | 230 | 93 | 10 | 0 | 0 | (10) |
| (11) | | | CDD18.3 | 92 | 0 | 0 | 0 | 0 | 3 | 13 | 36 | 35 | 5 | 0 | 0 | 0 | (11) |
| (12) | | | CDH23.3 | 1298 | 0 | 0 | 0 | 6 | 67 | 189 | 427 | 473 | 131 | 4 | 0 | 0 | (12) |
| (13) | | | CDH26.7 | 361 | 0 | 0 | 0 | 1 | 13 | 44 | 112 | 156 | 34 | 0 | 0 | 0 | (13) |
| (14) | Wind | | WSAvg | 4.3 | 4.2 | 4.1 | 4.4 | 4.8 | 4.9 | 4.4 | 3.9 | 3.9 | 4.2 | 4.3 | 4.2 | 4.1 | (14) |
| (15) | Precipitation | | PrecAvg | 364 | 17 | 14 | 17 | 21 | 46 | 66 | 58 | 39 | 33 | 18 | 15 | 19 | (15) |
| (16) | | | PrecMax | 486 | 43 | 32 | 48 | 62 | 150 | 162 | 147 | 91 | 70 | 76 | 40 | 34 | (16) |
| (17) | | | PrecMin | 236 | 5 | 1 | 4 | 2 | 8 | 12 | 14 | 3 | 5 | 1 | 1 | 6 | (17) |
| (18) | | | PrecStd | 58 | 9 | 9 | 11 | 15 | 32 | 36 | 33 | 24 | 18 | 17 | 10 | 7 | (18) |
| (19) | Monthly Design Dry Bulb and Mean Coincident Wet Bulb Temperatures | 0.4% | DB | | 3.7 | 4.3 | 13.2 | 23.0 | 28.3 | 30.8 | 32.0 | 33.8 | 30.4 | 23.0 | 11.5 | 5.2 | (19) |
| (20) | | | MCWB | | 1.6 | 2.1 | 7.0 | 12.2 | 15.3 | 18.1 | 21.3 | 19.2 | 17.4 | 13.5 | 6.5 | 2.5 | (20) |
| (21) | | 2% | DB | | 1.6 | 2.1 | 8.9 | 19.8 | 25.1 | 27.6 | 29.5 | 30.5 | 27.0 | 18.5 | 7.6 | 2.5 | (21) |
| (22) | | | MCWB | | 0.0 | 0.5 | 4.9 | 10.5 | 13.9 | 17.1 | 19.9 | 18.7 | 16.2 | 11.0 | 4.1 | 0.7 | (22) |
| (23) | | 5% | DB | | -0.7 | 0.2 | 5.7 | 16.8 | 22.6 | 25.4 | 27.6 | 28.1 | 24.2 | 15.2 | 4.9 | 0.0 | (23) |
| (24) | | | MCWB | | -1.9 | -0.9 | 3.0 | 9.3 | 12.9 | 16.4 | 19.1 | 18.4 | 15.0 | 9.0 | 2.4 | -1.3 | (24) |
| (25) | | 10% | DB | | -3.2 | -1.9 | 3.4 | 13.8 | 20.2 | 23.4 | 25.7 | 25.9 | 21.3 | 12.4 | 3.0 | -2.4 | (25) |
| (26) | | | MCWB | | -4.1 | -2.8 | 1.6 | 7.5 | 11.6 | 15.5 | 18.4 | 17.5 | 13.4 | 7.5 | 1.0 | -3.4 | (26) |
| (27) | Monthly Design Wet Bulb and Mean Coincident Dry Bulb Temperatures | 0.4% | WB | | 1.7 | 2.2 | 7.8 | 13.0 | 16.8 | 21.0 | 23.4 | 21.4 | 18.6 | 14.0 | 7.0 | 2.7 | (27) |
| (28) | | | MCDB | | 3.3 | 3.9 | 12.2 | 21.7 | 24.8 | 27.2 | 29.9 | 28.8 | 27.5 | 22.6 | 10.5 | 5.0 | (28) |
| (29) | | 2% | WB | | 0.1 | 0.7 | 5.1 | 11.1 | 14.9 | 18.7 | 21.4 | 20.2 | 16.8 | 11.6 | 4.4 | 0.8 | (29) |
| (30) | | | MCDB | | 1.5 | 1.9 | 8.5 | 18.0 | 22.8 | 24.9 | 27.4 | 27.8 | 25.2 | 17.5 | 7.1 | 2.5 | (30) |
| (31) | | 5% | WB | | -1.9 | -1.0 | 3.2 | 9.7 | 13.6 | 17.5 | 20.1 | 19.0 | 15.3 | 9.6 | 2.6 | -1.2 | (31) |
| (32) | | | MCDB | | -0.7 | 0.2 | 5.6 | 16.3 | 21.2 | 23.2 | 25.9 | 26.0 | 22.7 | 14.3 | 4.6 | 0.1 | (32) |
| (33) | | 10% | WB | | -4.1 | -2.9 | 1.6 | 8.0 | 12.4 | 16.3 | 18.9 | 18.0 | 14.0 | 7.9 | 1.1 | -3.4 | (33) |
| (34) | | | MCDB | | -3.2 | -2.0 | 3.2 | 13.2 | 19.1 | 21.6 | 24.4 | 24.6 | 20.1 | 11.6 | 2.8 | -2.4 | (34) |
| (35) | Mean Daily Temperature Range | | MDBR | | 9.7 | 10.1 | 9.8 | 11.8 | 13.3 | 11.8 | 12.4 | 13.4 | 13.7 | 11.6 | 9.0 | 9.1 | (35) |
| (36) | | 5% DB | MCDBR | | 11.3 | 11.0 | 11.6 | 16.8 | 17.0 | 15.3 | 15.2 | 17.1 | 18.7 | 16.4 | 11.5 | 11.2 | (36) |
| (37) | | | MCWBR | | 10.2 | 9.7 | 8.1 | 9.4 | 8.4 | 7.2 | 7.4 | 7.4 | 9.2 | 9.8 | 8.5 | 9.5 | (37) |
| (38) | | 5% WB | MCDBR | | 11.4 | 10.5 | 11.1 | 15.8 | 15.1 | 12.8 | 13.5 | 14.7 | 17.0 | 15.5 | 11.0 | 11.0 | (38) |
| (39) | | | MCWBR | | 10.4 | 9.3 | 8.0 | 9.2 | 7.9 | 6.7 | 7.3 | 7.0 | 8.7 | 9.4 | 8.3 | 9.5 | (39) |
| (40) | Clear-Sky Solar Irradiance | | taub | | 0.251 | 0.266 | 0.296 | 0.342 | 0.357 | 0.377 | 0.376 | 0.379 | 0.324 | 0.282 | 0.253 | 0.219 | (40) |
| (41) | | | taud | | 2.285 | 2.274 | 2.347 | 2.340 | 2.347 | 2.339 | 2.343 | 2.331 | 2.470 | 2.559 | 2.473 | 2.375 | (41) |
| (42) | | | Ebn,noon | | 766 | 861 | 903 | 894 | 894 | 876 | 869 | 846 | 864 | 848 | 779 | 770 | (42) |
| (43) | | | Edh,noon | | 62 | 84 | 97 | 111 | 117 | 119 | 116 | 112 | 86 | 64 | 51 | 46 | (43) |
| (44) | All-Sky Solar Radiation | | RadAvg | | 1.24 | 2.41 | 3.99 | 4.76 | 5.67 | 5.71 | 6.20 | 5.09 | 3.76 | 2.22 | 1.18 | 0.85 | (44) |
| (45) | | | RadStd | | 0.09 | 0.10 | 0.29 | 0.55 | 0.44 | 0.38 | 0.35 | 0.41 | 0.31 | 0.25 | 0.10 | 0.11 | (45) |

Nomenclature: See separate page

## Appendix E: Base Case CFD analysis

The results from the base case CFD simulation are meant to aid in the visualization of comparing effectiveness of potential solutions and quantifying the current situation. Extreme care was taken to ensure the base case result would represent average conditions experienced by the overhead doors on the Access Transit Depot. The base case CFD solution is a very important part of this analysis since it will set up the structure that all other simulations will be performed with and provide validation for the presented results.

The initial decision was whether to use a 2D or 3D analysis, with a 3D approach initially chosen for its theoretical accuracy but abandoned due to excessive computation time and mesh quality issues. A 2D analysis was selected to reduce the number of elements. The software workflow involved using Inventor and *ANSYS Workbench* with 'Fluent' Analysis. The modeling process included creating a 2D representation of the depot, defining the bounding box for outdoor conditions, and generating a structured mesh with appropriate sizing conditions. The solver utilized a 'Density-Based' analysis with the 'Fluent' solver in the transient version, considering heat transfer and turbulent airflow using the 'SST K-omega' turbulence model. Boundary conditions were based on real-life data and assumptions, and the wind conditions were simulated using the power law. The solution was validated through convergence analysis and verifying the application of boundary conditions. The final result provides a visual representation of the temperature gradient and airflow patterns within the Access Transit Depot.

### 2D vs 3D Analysis

The first decision to make in producing this CFD result was whether a 2D or 3D analysis should be used. A 3D analysis would theoretically be slightly more realistic because it simulates the entire thermal mass of the building. Therefore a 3D approach was analyzed first.

The problem with the 3D analysis was, in order to achieve simulations that wouldn't require days of computing, a very low quality mesh would have to be used. Also scaling the 3D model down from its actual size was not a viable option as this down scaling could produce issues that would interfere with the results. Figure E.1 shows a 3D mesh with many elements over the recommended skewness value 0.95 [E.1]. In order to get an accurate mesh with low skewness, the element size needed to be reduced, which created another problem. With the element size reduced so that mesh skewness was below 0.95, the amount of elements increased to 2 million. Our Technical Advisor, Ravi Jassar recommended 1 million elements would never be exceeded as so many elements would require days of processing time. Therefore it was decided that a 2D analysis would be utilized in order to reduce the amount of elements.

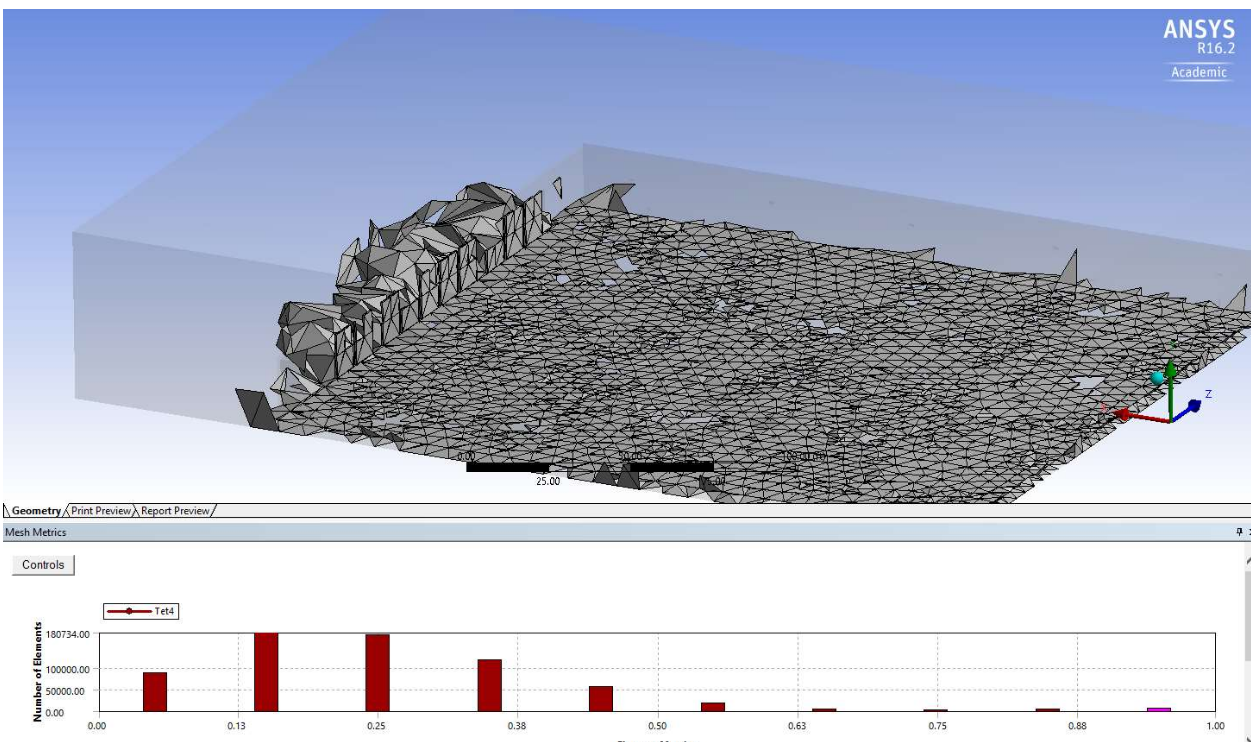



*Fig. E. 1. Mesh Matrix Showing Highly Skewed Cells*

## Software Overview

The General Process for the order of software used will remain the same for all analyses. The workflow starts in *Inventor* and is shifted to *ANSYS Workbench* where a *Fluent* Analysis is used. The workflow for the *ANSYS Fluent* Analysis is listed in Figure E.2.

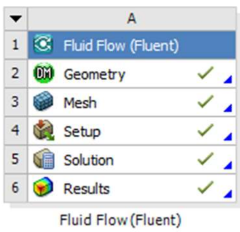



*Fig. E. 2. Workflow in ANSYS Workbench*

## Inventor Model

Appendix L was used to create a full scale 2D representation of the Access Transit Depot shown in Figure E.3, however the roof height was missing from drawing in Appendix E so it was assumed to be 6m. Appendix F was used to create supply and return air features of Figure E.3.

The area around the walls of the modeled Access Transit Depot, shown in Figure E.3 represents the volume of surrounding air, this area was modeled to be large to ensure that outdoor wind conditions could be simulated accurately. The area that represents the outdoor conditions is also commonly referred to as the “bounding box”. After doing research on recommended bounding box sizes there did not seem to be a rule that was set in stone for how big the bounding box should be, as long as it was large enough to not interfere with the desired results, the size was considered acceptable. For all simulations the bounding box was 15m higher than the roof of the building, 40 m in front of the overhead door, 10 m behind the building and 0 m under the building as there is no wind there.

The model of Figure E.3 was then exported as a .stp file format. Since the .stp format only allows solids to be exported, the area in Figure E.3 was extruded to an arbitrary thickness to allow the export to take place.

*Fig. E. 3. 2D Inventor Representation of Access Transit Building*

## Design Modeller

The first step in the *ANSYS Workbench Fluent* Analysis was to import the model in as a .stp format. Since an arbitrary thickness was given to allow the export a 'Surface from Faces' command was used on the desired faces of the model. Then the solid bodies could be suppressed leaving only the 2D surfaces remaining. Figure E.4 is the result from the *Design Modeller.* The red surface in figure E.4 can be labelled as the interior air space and green surface can be labelled as the exterior air space. Now when boundary conditions are applied, the indoor surface can be set at room temperature and the outdoor surface can be set at outdoor conditions.

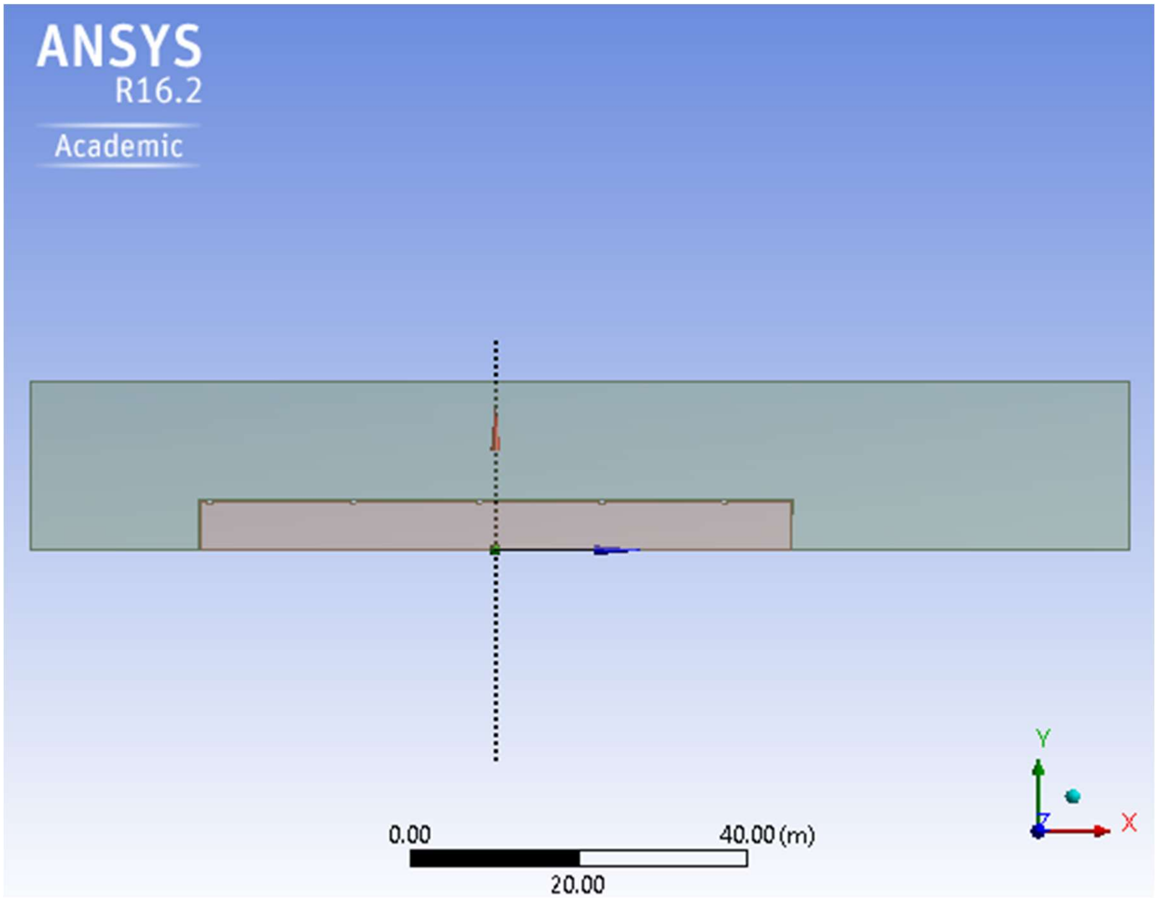



*Fig. E. 420. Design Modeller Overview*

## Mesher

The meshing strategy used was a 2D structured mesh that uses 4 node quadrilateral elements. Important features such as the overhead-door openings, supply air and return air all received edge sizing to decrease the mesh size in those areas. This decrease in mesh size at complex geometries results in a more accurate solution. Also to increase result accuracy, inside and outside floors received a mesh inflation in order to accurately predict the wind velocity as it approaches the ground. Table E.1 summarizes the previously described sizing conditions. All other elements are meshed at a size of 0.5ft with a growth rate of 105%.

*Table. E. 1*

| Object Name | *Indoor Floor Inflation* | *Supply/Return air + Overhead door Sizing* | *Outdoor Floor Inflaiton* |
|---|---|---|---|
| State | Fully Defined | | |
| **Scope** | | | |
| Scoping Method | Geometry Selection | | |
| Geometry | 1 Face | 11 Edges | 1 Face |
| **Definition** | | | |
| Suppressed | No | | |
| Boundary Scoping Method | Geometry Selection | | Geometry Selection |
| Boundary | 1 Edge | | 1 Edge |
| Inflation Option | Smooth Transition | | Smooth Transition |
| Transition Ratio | Default (0.272) | | Default (0.272) |
| Maximum Layers | 15 | | 15 |
| Growth Rate | 1.05 | Default | 1.05 |
| Inflation Algorithm | Pre | | Pre |
| Type | | Element Size | |
| Element Size | | 5.e-002 ft | |
| Behavior | | Soft | |
| Curvature Normal Angle | | Default | |
| Bias Type | | No Bias | |
| Local Min Size | | Default (5.e-002 ft) | |

Since the outdoor and indoor surfaces were modeled as separate surfaces, they had to be joined by an option called 'Mesh Connection Group'. If these surfaces were not connected then the inside and outside conditions would remain separate which would provide meaningless results. Also 'Delete Contacts' had to be performed in the mesh for indoor and outdoor environments to join.

Figure E.5 is a close up of the finalized mesh that shows the overhead door opening, floor, and supply/return air faces all with the appropriate meshing features that were discussed in the above sections.

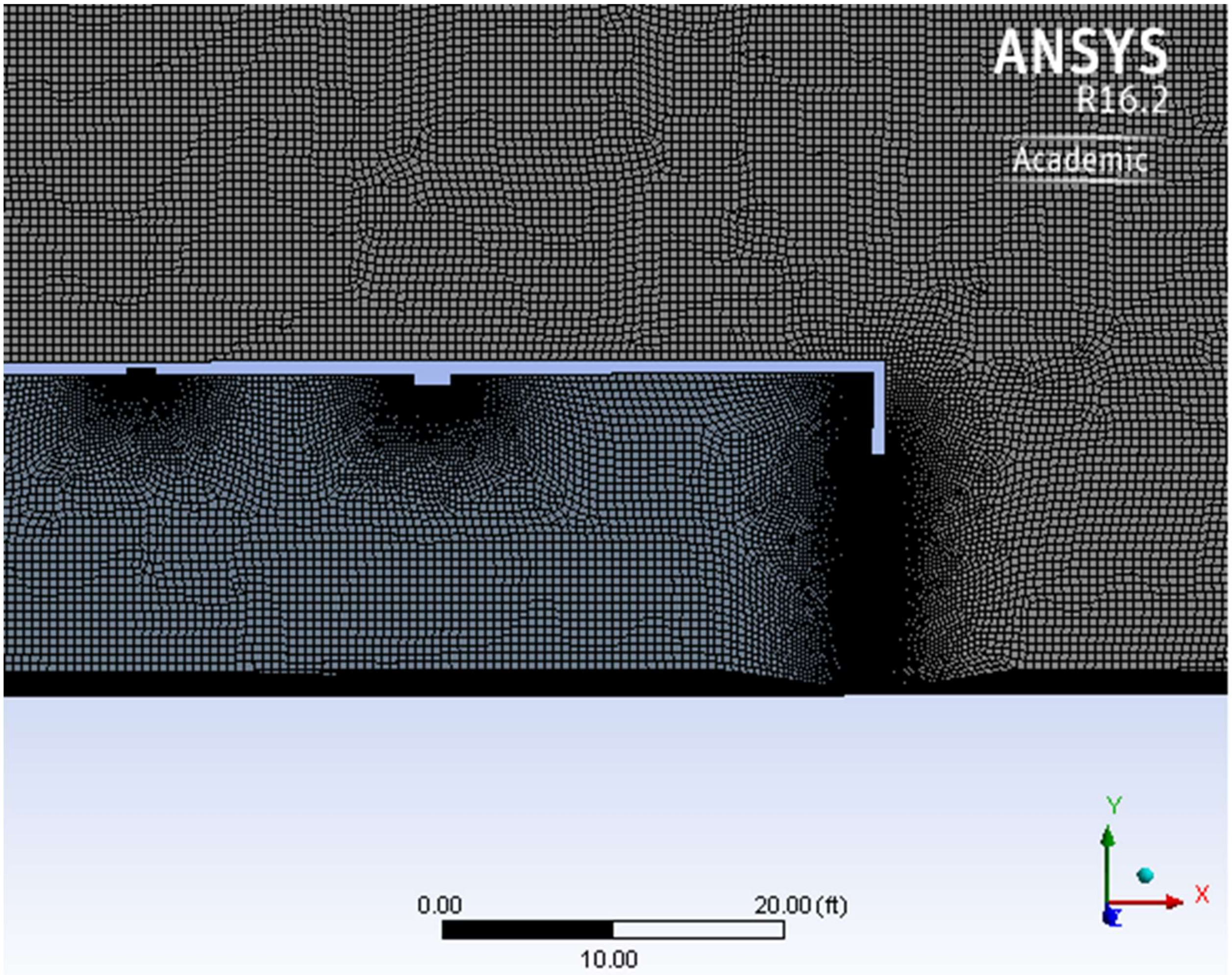



*Fig. E. 5.*

As indicated earlier, skewness was a problem with the 3D mesh, but as shown in Figure E.6, the max skewness for the 2D approach is 0.75 while most elements are at a very stable number of 0.04. This low skewness was achieved while using only around 0.1 million elements which is a significant improvement over the 3D approach.

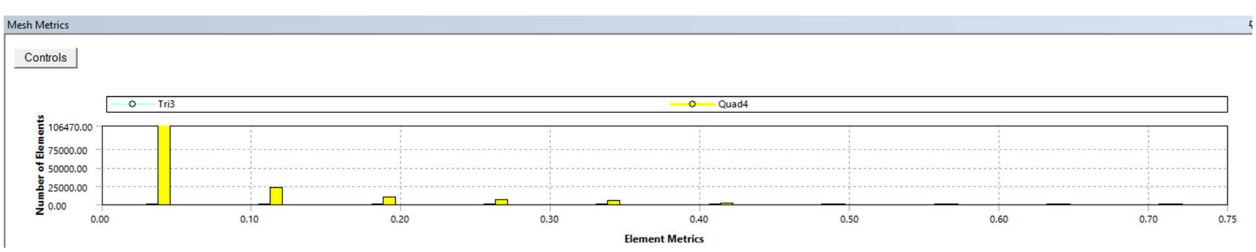



*Fig. E. 6. Mesh Metrics - Skewness*

## Solver

To take into account real life conditions a ‘Density Based’ analysis was used for all problems since the air that is being analyzed is a compressible fluid. It was also necessary to use the ‘Fluent’ solver in the ‘Transient’ version in order to properly simulate the overhead door opening for a short period of time. If ‘Steady State’ was used the solver would produce a very inaccurate result, since the Access Transit depot is never able to reach steady state conditions with the door being open for such a short period of time.  A summary of these general conditions is available in figure E.7.

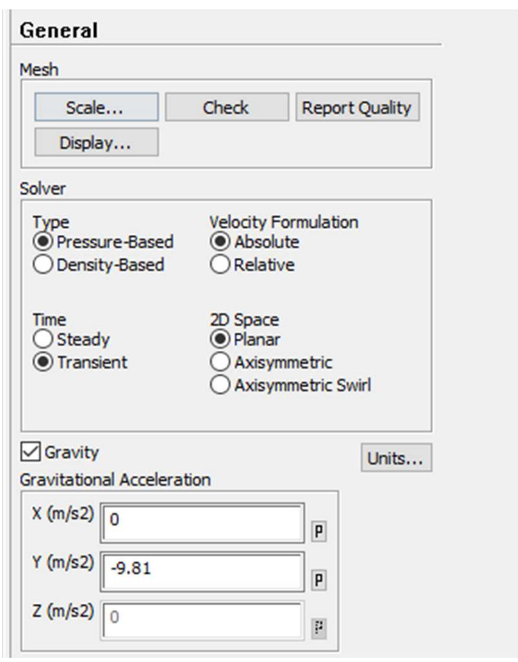



*Fig. E. 721.*

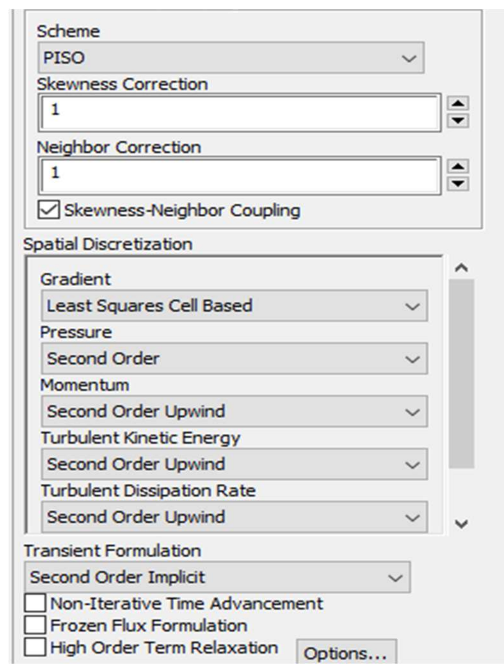



*Fig. E. 822.*

In order to analyze temperature gradients the ‘Energy Equation’ was turned on in models to allow the solver to analyze heat transfer. ‘Multiphase’ settings remain off in the models since the flow stream being analyzed was only composed of a single phase media. For the viscosity formulation, the default setting of ‘Laminar’ would not be sufficient since the velocity profile of the wind and later analyzed air curtains will include turbulent flowing airstreams. The two most popular viscosity formulations are the ‘K-omega’ and ‘K-epsilon’ equations. The turbulence model that best described the Access Transit analysis was the ‘SST k-omega’ [E.7]. The reason ‘K-omega’ was chosen over ‘K-epsilon’ is because ‘K-omega’ does a better job at predicting velocity vortices near walls, this will become especially important later on when analyzing air curtains [E.7]. However experiments were also done with the “Realizable k-epsilon" turbulence model, since it seemed to be the most versatile option with the least chance of error [E.7]. The results from these between ‘K-omega’ and ‘K-epsilon’ were similar; it was safe to use “SST K-omega”. A summary of the models is available in figure E.9 and E.10 shows the viscosity formulation in more detail.

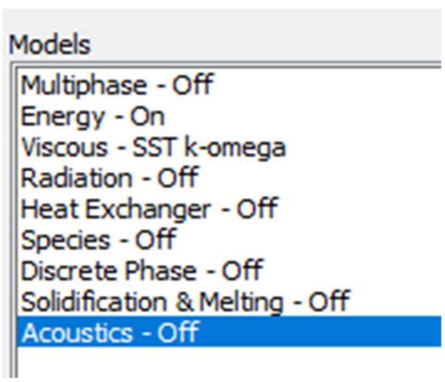



*Fig E. 9. Models Used*

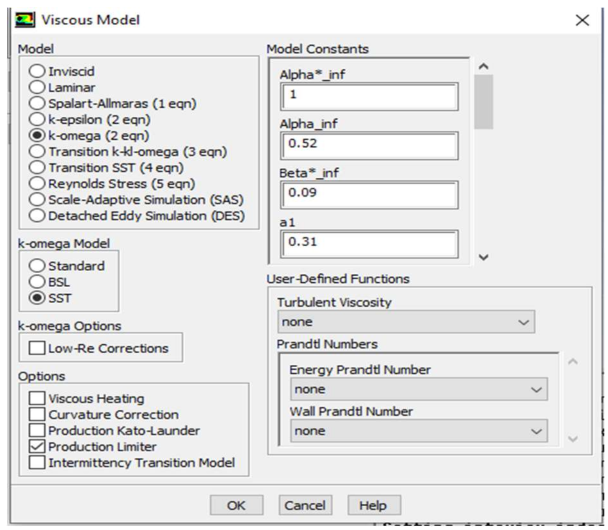



*Fig E. 10. Turbulence Model Used*

A ‘PISO’ (Pressure-Implicit with Splitting of operators) was chosen over the default ‘SIMPLE’ (Semi-Implicit Method for Pressure Linked Equations) since the ‘SIMPLE’ scheme is not recommended for use in a steady state case because it will produce unstable results [E.5]. The PISO coupling scheme is based on the ‘Naiver-Stokes’ equation which is used to solve compressible flows, like the one being described and is the most time effective coupling scheme [E.6]. Along with the PISO coupling scheme a ‘Second order Implicit Formulation’ was used for all simulations because it is well known to lead to best results since they reduce interpolation errors and false numerical diffusion [E.5]. This ‘Second order Implicit Formulation’ replaced the default ‘First order Implicit formulation’ for the transition algorithm. Figure E.8 depicts the described coupling scheme settings.

Boundary conditions were based on real life data and well informed assumptions. Effective R values for the walls were given to us by Kathryn Theede in an email [Appendix J]. R values were converted to RSI, since the units the solver wanted was w/m2*k. Slip conditions on the walls were represented according to advice from multiple sources [E.2, E.3, E.4]. The consensus of these sources was to use a roughness constant of 1 on surfaces that are not uniform, a roughness constant of 1 was used on the roof since in the actual access transit building there are lots of obstructions on the roof in the forms of ducting, piping and lights. Walls and floors received a roughness constant of 0.5 since that is the default value for uniform surfaces. The roughness heights were used from the engineering toolbox or assumed to a value that was logical.

The building pressure was not known since a manometer was not available to us. The building pressure was assumed to be a neutral 0 Pa gauge pressure. However if further CFD is performed it would be beneficial to measure the actual building pressure.

Wind Conditions were accurately simulated using the power law. If the power law had not been used, then a constant velocity would have been applied on the entire “Wind In” boundary condition, which is inaccurate since wind velocity changes depending on the elevation it is measured at. The velocity profile based on the power law was done by importing a .prof file into the parameters under the predefined “Wind In” boundary condition. Table E.2 represents the inputs used for the power law relationship. Table E.3 shows the values used in the .prof file that was applied at elevations ranging from 0 to 20m, which is the length of the “wind in” face. A sample calculation using the power law is available in Appendix I.

*Table. E. 2.*

| Inputs | | | |
|---|---|---|---|
| Variable | Value | Unit | Source |
| Roughness parameter | 0.4 | m | Howard Hemingson Notes |
| Wind velocity | 3.33 | m/s | APPEDNIX H - Windatlas |
| Measured height | 10 | m | |

*Table. E. 3.*

| velocity values in x plane [m/s] | height [m] |
|---|---|
| 0.0 | 0.0 |
| 0.0 | 0.0 |
| -0.1 | 0.1 |
| -0.1 | 0.1 |
| -0.1 | 0.1 |
| -0.2 | 0.1 |
| -0.2 | 0.2 |
| -0.3 | 0.2 |
| -0.3 | 0.2 |
| -0.4 | 0.2 |
| -0.4 | 0.3 |
| -0.5 | 0.3 |
| -0.5 | 0.4 |
| -0.6 | 0.4 |
| -0.6 | 0.4 |
| -0.7 | 0.5 |
| -0.9 | 0.7 |
| -1.0 | 0.8 |
| -1.1 | 1.0 |
| -1.2 | 1.1 |
| -1.3 | 1.3 |
| -1.4 | 1.5 |
| -1.5 | 1.6 |
| -1.5 | 1.8 |
| -1.6 | 1.9 |
| -1.7 | 2.1 |
| -1.7 | 2.2 |
| -1.8 | 2.4 |
| -1.8 | 2.5 |
| -1.9 | 2.7 |
| -1.9 | 2.8 |
| -2.0 | 3.0 |
| -2.0 | 3.1 |
| -2.0 | 3.3 |
| -2.1 | 3.4 |
| -2.1 | 3.6 |
| -2.1 | 3.7 |
| -2.2 | 3.9 |
| -2.2 | 4.0 |
| -2.2 | 4.2 |
| -2.3 | 4.4 |
| -2.3 | 4.5 |
| -2.3 | 4.7 |
| -2.4 | 4.8 |
| -2.4 | 5.0 |
| -2.4 | 5.1 |

| con't | |
|---|---|
| velocity values in x plane [m/s] | height [m] |
| -2.5 | 5.4 |
| -2.5 | 5.6 |
| -2.5 | 5.7 |
| -2.5 | 5.9 |
| -2.5 | 6.0 |
| -2.6 | 6.2 |
| -2.6 | 6.3 |
| -2.6 | 6.5 |
| -2.6 | 6.6 |
| -2.6 | 6.8 |
| -2.7 | 6.9 |
| -2.7 | 7.1 |
| -2.7 | 7.3 |
| -2.7 | 7.4 |
| -2.7 | 7.6 |
| -2.7 | 7.7 |
| -2.8 | 7.9 |
| -2.8 | 8.0 |
| -2.8 | 8.2 |
| -2.8 | 8.3 |
| -2.8 | 8.5 |
| -2.8 | 8.6 |
| -2.8 | 8.8 |
| -2.9 | 8.9 |
| -2.9 | 9.1 |
| -2.9 | 9.2 |
| -2.9 | 9.4 |
| -2.9 | 9.5 |
| -2.9 | 9.7 |
| -2.9 | 9.8 |
| -2.9 | 10.0 |
| -3.0 | 10.2 |
| -3.0 | 10.3 |
| -3.0 | 10.5 |
| -3.0 | 10.6 |
| -3.0 | 10.8 |
| -3.0 | 10.9 |
| -3.0 | 11.1 |
| -3.0 | 11.2 |
| -3.0 | 11.4 |
| -3.0 | 11.5 |
| -3.1 | 11.7 |
| -3.1 | 11.8 |
| -3.1 | 12.0 |
| -3.1 | 12.1 |
| -3.1 | 12.3 |
| -3.1 | 12.4 |
| -3.1 | 12.6 |
| -3.1 | 12.7 |
| -3.1 | 12.9 |

| con't | |
|---|---|
| velocity values in x plane [m/s] | height [m] |
| -3.2 | 13.2 |
| -3.2 | 13.4 |
| -3.2 | 13.5 |
| -3.2 | 13.7 |
| -3.2 | 13.8 |
| -3.2 | 14.0 |
| -3.2 | 14.1 |
| -3.2 | 14.3 |
| -3.2 | 14.4 |
| -3.2 | 14.6 |
| -3.2 | 14.7 |
| -3.2 | 14.9 |
| -3.2 | 15.0 |
| -3.3 | 15.2 |
| -3.3 | 15.3 |
| -3.3 | 15.5 |
| -3.3 | 15.6 |
| -3.3 | 15.8 |
| -3.3 | 16.0 |
| -3.3 | 16.1 |
| -3.3 | 16.3 |
| -3.3 | 16.4 |
| -3.3 | 16.6 |
| -3.3 | 16.7 |
| -3.3 | 16.9 |
| -3.3 | 17.0 |
| -3.3 | 17.2 |
| -3.3 | 17.3 |
| -3.4 | 17.5 |
| -3.4 | 17.6 |
| -3.4 | 17.8 |
| -3.4 | 17.9 |
| -3.4 | 18.1 |
| -3.4 | 18.2 |
| -3.4 | 18.4 |
| -3.4 | 18.5 |
| -3.4 | 18.7 |
| -3.4 | 18.9 |
| -3.4 | 19.0 |
| -3.4 | 19.2 |
| -3.4 | 19.3 |
| -3.4 | 19.5 |
| -3.4 | 19.6 |
| -3.4 | 19.8 |
| -3.4 | 19.9 |

Table E.4 summarizes the previously talked about boundary conditions. Values for turbulent Intensity and turbulent length scale were computed using an online calculator. The input and out values from the turbulence calculator are available in figure E.11 and E.12.

*Table. E. 4.*

| Boundary Conditions 'Walls' | | | | | |
|---|---|---|---|---|---|
| Location | Roughness Height [m] | Roughness Constant | Rsi [w/m2*k] | Free Stream Temp [°C] | External Rad Temp [°C] |
| Indoor Walls | No slip | | 2.27 | -20 | 18 |
| Indoor roof | 0.5 | 1 | 1.76 | -20 | 18 |
| Indoor Floor | 0.09795 | 0.5 | 0.1761 | -20 | 18 |
| Outdoor Floor | 0.09795 | 0.5 | 0 | -20 | -20 |
| Wind Tunnel Walls | No slip | | 0 | -20 | -20 |

| Boundary Conditions 'velocity inlet' | | | | | |
|---|---|---|---|---|---|
| Location | Velocity Magnitude [m/s] | Temprature [°C] | Iniital Gauge Pressure [Pa] | Turbulent Intensity [%] | Turbulent Length Scale [m] |
| Supply Air Diffuser | 0.15 | 25 | Defualt, 0 | Defualt, 5 | 0.05 |
| Wind In | 0 to 3.44 | -20 | Defualt, 0 | 2.5 | 1.4 |

| Boundary Conditions 'Pressure Outlet ' | | | | |
|---|---|---|---|---|
| Location | Gauge Pressure (pa) | Backflow Temp [°C] | Backflow Turbelent Intensity [%] | Backflow Turbulent Visocsity Ratio |
| Exhaust Air | 0 | 18 | Default- 5 | Default- 10 |
| Wind Out | 0 | -20 | Default- 5 | Default- 10 |

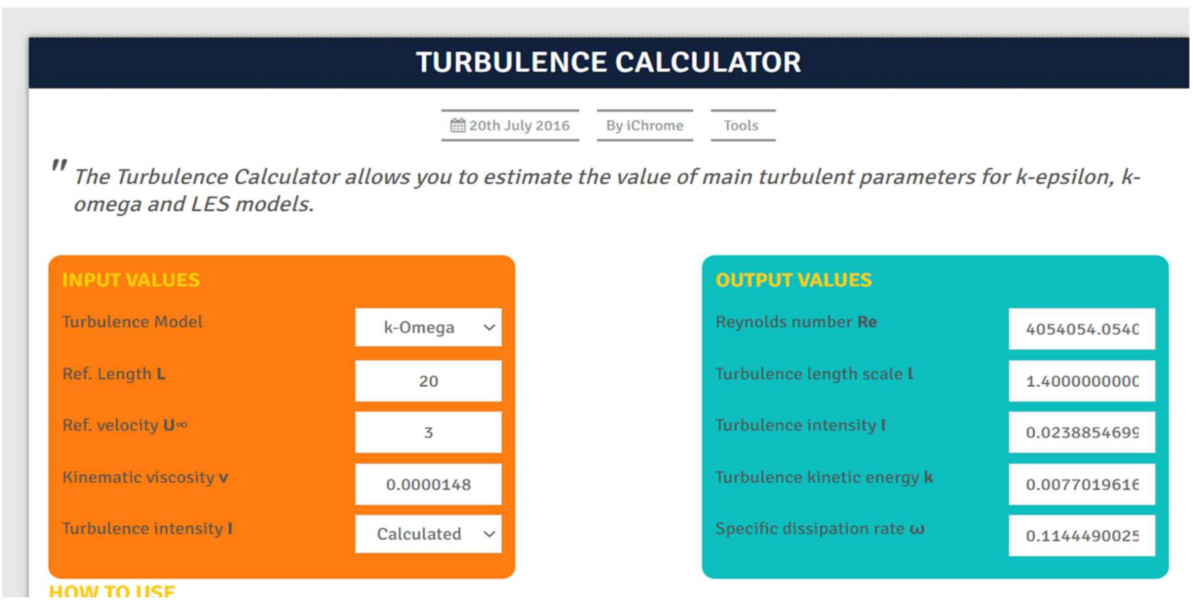



*Fig. E. 11. Initial Turbulence Values for “Wind in” BC, Adapted from [E.8]*

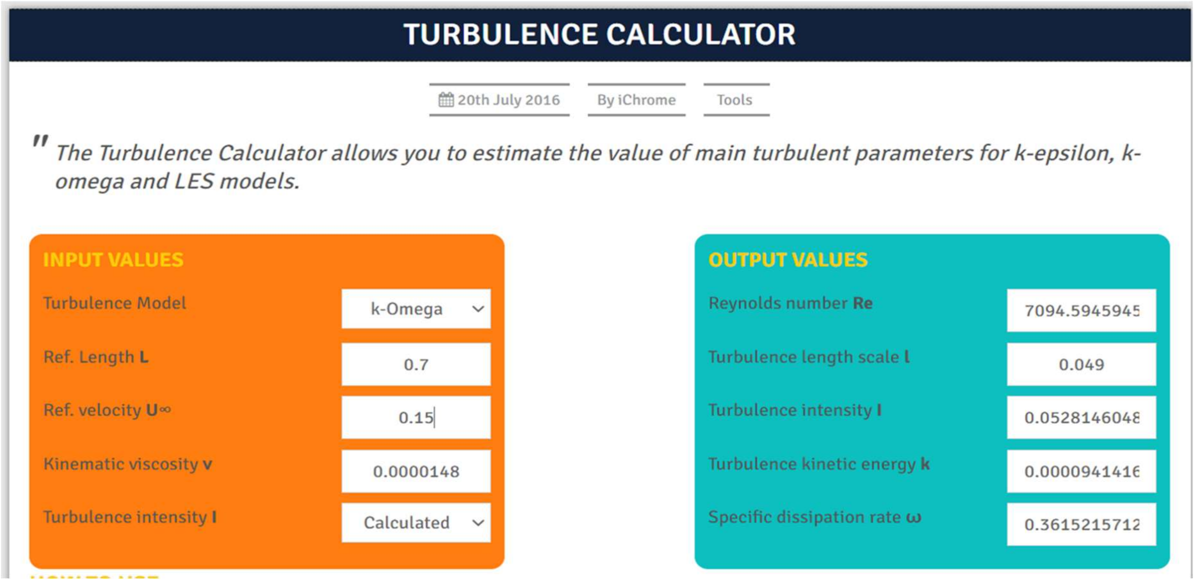



*Fig. E. 12. Initial Turbulence Values for "Supply Air" BC, Adapted from [E.8]*

Standard initialization was used for all solutions. The indoor surface was initialized at a temperature of 18°C while the outdoor surface was initialized at a temperature of -20°C.

All transient calculations were performed to provide a solution that would be representative after leaving an over head door open for 30 seconds. Since the base case did not involve any high speed profiles, a time step of 0.01 seconds was used. This time step value was determined experimentally to provide convergence in the solution while not taking longer than a couple hours to calculate. The max Iterations/Time Step was chosen to be 50 so earlier solutions had enough iterations to converge. Once the flow stream had developed, it was observed that the solver was only using about 5 iterations per time step, so that proved using 50 as a max value would not be an issue. Figure E.13 summarized the values to run the calculation.

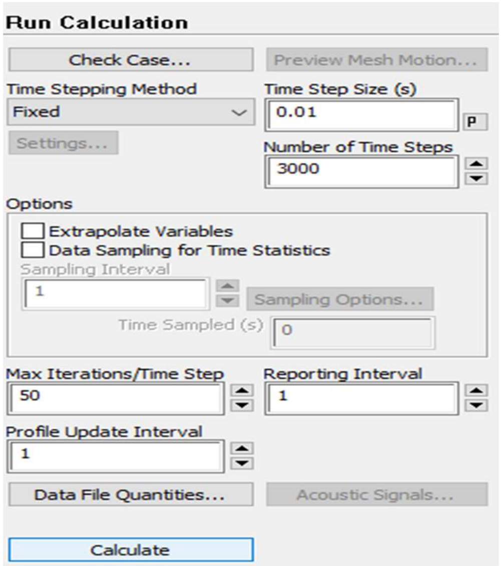



*Fig. E. 13.*

Figure E.14 shows that the base case solution was able to properly converge since there is no rapid changes from any of the residuals.

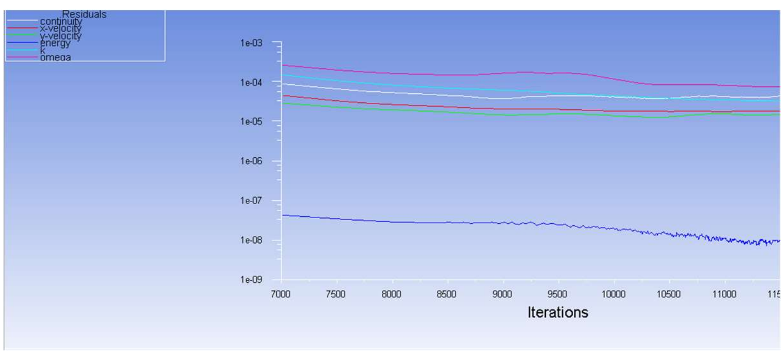



*Fig. E. 14. Residuals Plot*

## Validation

The solution was validated by analyzing the resulting velocity profiles as shown in figure E.15 to make sure that the wind velocity was applied according to the power law. The very first time step was also checked to make sure that the indoor and outdoor conditions were both applied to respective surfaces as shown in Figure E.16

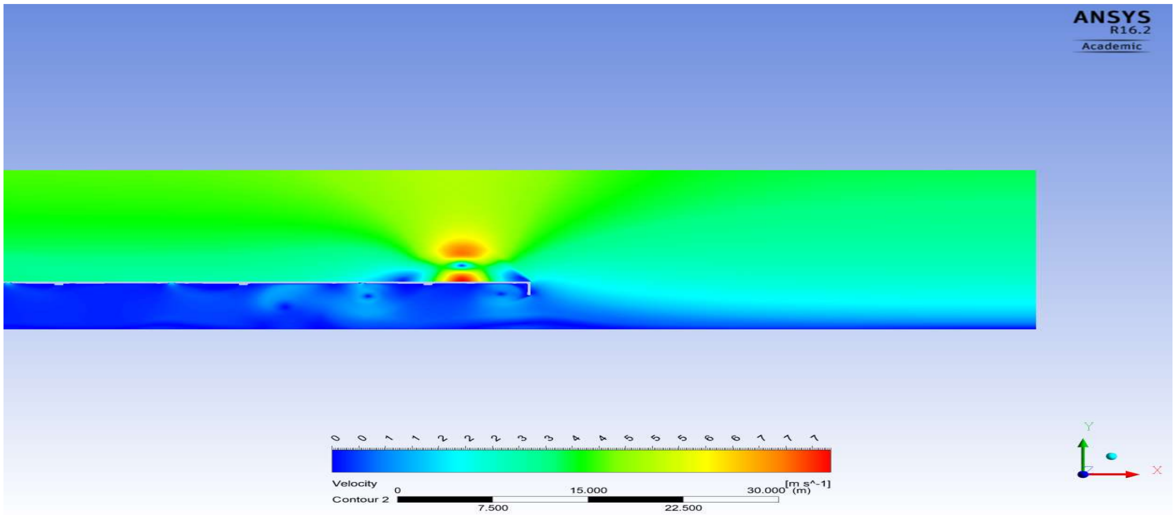



*Fig. E. 15.*

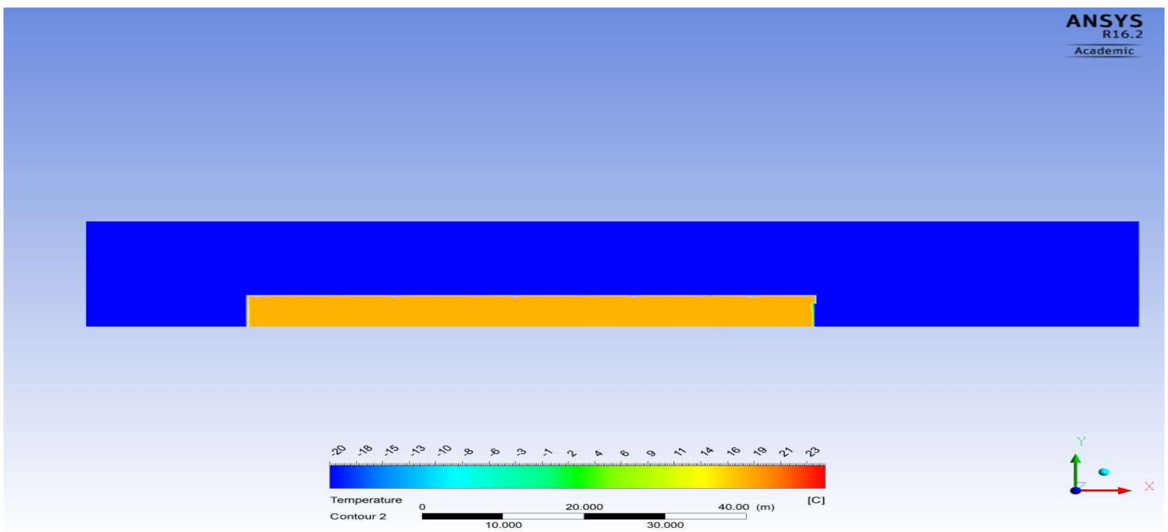
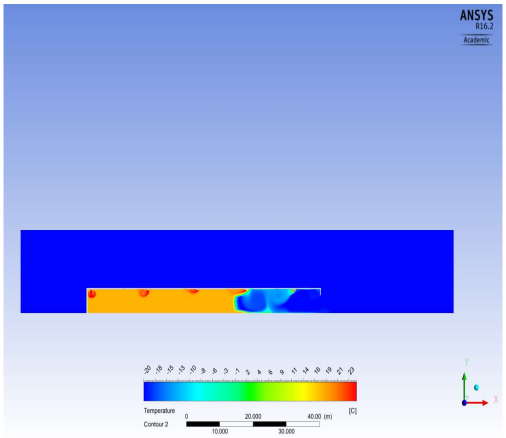



*Fig. E. 16.*

## Results

The final temperature gradient is shown in Figure E.17 which shows the entire building and bounding box and Figure E.18 which shows a zoomed in view.



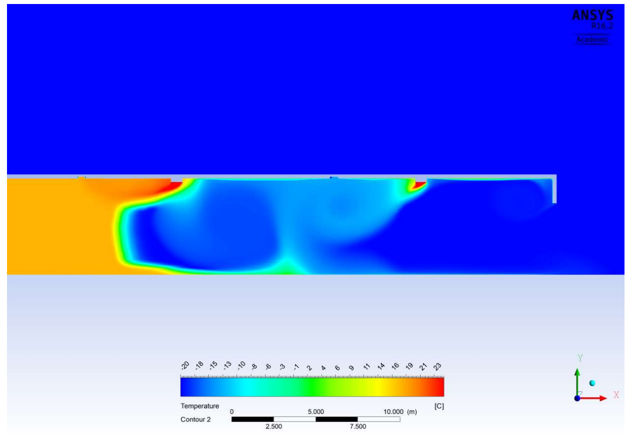




*Fig. E. 17. Temperature Plot*

*Fig. E. 18. Temperature Plot Zoom*

Another result that will be used later will be the average temperature of the inside surface. This was produced by using the ‘Function Calculator’ in the ‘ANSYS-CFD-Post’ software. The ‘Function Calculator’ was set to display average temperature in the surface the represented the interior air. The results for the average interior temperature of the base case solution are available in Figure E.19.

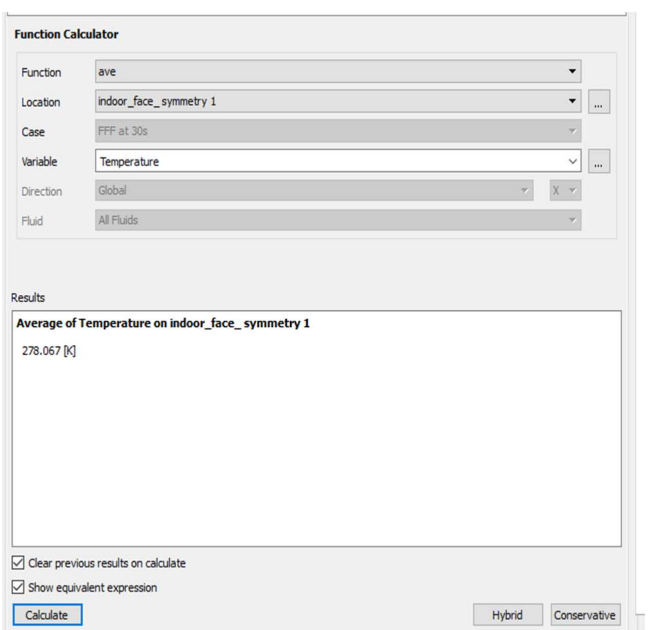
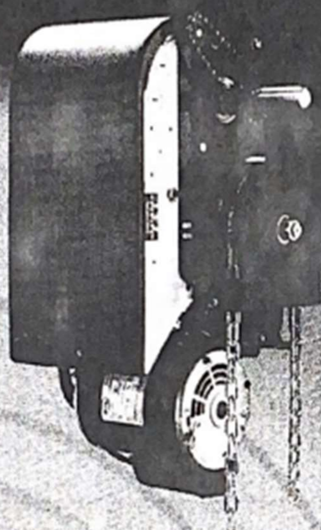



*Fig. E. 19. Average Interior Temperature Calculator*

## Appendix F-1 - Opera-H Specification Sheet

**SPECIFICATION SHEET**

# Opera™-H



- Hoist-a-matic™ self engaging chain hoist
- Hinged cover with stable opened position
- Liftable control box with retaining arm for easy access to mechanical parts
- Accu-cam™ one hand limit setting

*Opera-H, a heavy duty operator for high & vertical lift sectional doors or rolling doors and grilles. It can be wall, hood, or shelf mounted on either side of the door. It incorporates an automatic chain hoist for manual operation as well as several other innovations.*

Manaras

Somfy International

## PROGRAM AND PROGRAM SETTINGS

Programming ability and door control at electrical box are provided by Open/Close/Stop buttons and Select Switch located on the ECB.

- **Programs**

| PROGRAMS | FUNCTIONS AND DESCRIPTIONS |
|---|---|
| RUN TIMER | The Run Timer stops automatically the operator after an adjustable time delay either traveling upwards or downwards. The Run Timer is designed to protect the door and the operator by preventing the motor over running much longer than the normal time. |
| MID-STOP | Mid-Stop function will, when active, move the door from the down position to a predetermined Mid-stop position when the open button or Open/Close device is activated. Once at Mid-Stop, subsequent Open/close commands will close the door. To move the door to full open position, the open button must be pressed again. |
| TIMER TO CLOSE | Timer to Close is a function that, when active, will close the door after an adjustable time delay once the door has reached its fully open and mid-stop position. The timer to close function works only in T and TS modes. |
| TIMER TO CLOSE (from fully open position only) | Option used in conjunction with MID STOP function. When activated, Timer to Close is active from the fully open position only and not from the mid-stop position. |
| ADVANCE CLOSED TIME | This feature, when programmed, allows adjustment of the safety device disabling point and to determine the final stop point of the door once the "close limit switch" is activated. No "advance close limit switch" is needed with this feature. |

## 7.3 PROGRAM SETTING

Door should be in fully closed position while setting of these following programs.

| PROGRAM SETTING | | | |
|---|---|---|---|
| **PROGRAMS** | **ACTIVATE** | **DEACTIVATE** | **SELECT SWITCH** |
| RUN TIMER | • Check if close limit switch is activated.<br>• Set select switch on D.<br>• Press "Open" button to add 10 sec to the total time needed to open the door.<br>• Set the select switch on (0,1 or 2) | • Set select switch on D.<br>• Press "Stop" button. |  |
| MID-STOP | • Check the close limit is activated.<br>• Set select switch on "C"<br>• Press "Open" button then press "Stop" button on desired Mid-Stop position. | • Set select switch on "C"<br>• Press "Close" button. |  |
| TIMER TO CLOSE | • Set select switch on "B"<br>• Press "Open" button to add 15 sec or "Close" button to add 1 sec each time (max. 4 minutes & 30 seconds)<br>• Set the select switch on T or TS mode | • Set select switch on "B"<br>• Press "Stop" button the timer to close is reset to 0 sec but still activated.<br>• To defeat the timer to close completely set the switch on desired position (0, 1, 2 or 3) |  |
| DEFEATE TIMER TO CLOSE (from floor level) | • Then, press "Close" 3 times and then "Stop" 3 times consecutively on the push button station (Timer to close active). | • Press "Stop" 3 times and then "Close" 3 times consecutively on the push button station (No timer to close) | Not required |
| TIMER TO CLOSE (from fully open position only) | • Set select switch on "6"<br>• First press the "Close" button and then the "Stop" | • Set select switch on "6"<br>• Press "Close" button.<br>*Now the Timer to Close works from fully open and Mid-Stop position. |  |
| ADVANCE CLOSED TIME | • Set the select switch on "7"<br>• Press "Open" to add 50 milliseconds up to 500 milliseconds max.<br>• Press "Close" to deduct 50 milliseconds each time till it reaches 0/sec. | • By pressing "Stop" the default time will be set to 200 milliseconds.<br>* LED "INDICAT" comes ON only when time is increased or reduced. LED OFF when open or close button is pressed indicates "Advance Close Time" is reached Maxi or Mini. (pressing "Stop" LED ON = 200 milliseconds) |  |
| | **The "close limit switch" should be readjusted when the "advance closed time" is programmed or deactivated** | | |

# 7 Limit Switches & Limit Cams: Adjustment & Functionality

**⚠ WARNING**

To reduce risk of SEVERE INJURY or DEATH to persons:

- Do not attempt to make limit switch adjustments unless power has been electrically disconnected.

## 7.1 Limit Switch Functionality

### *Open Limit Switch and Advanced Open Limit Switch*

When activated, the Open Limit Switch will stop the operator while the door is travelling in the upward direction. Should be adjusted accordingly to stop door in fully opened position. The Advanced Open Limit Switch is used for a radio-control feature and to activate the Timer to Close feature (if used).

### *Close Limit Switch and Advanced Close Limit Switch*

When activated, the Close Limit Switch will stop the operator while the door is travelling in the downward direction. Should be adjusted accordingly to stop door in fully closed position. The Advanced Close Limit Switch is used for the operation of a reversing edge or external entrapment protection devices. With this limit switch, the floor is not considered as an obstacle, therefore the door does not reverse its movement once it reaches the floor.

## 7.2 Limit Switch Adjustments: Open and Close Cam Settings

This operator is equipped with the **ACCU-CAM®** feature, for precise and quick one-handed limit setting adjustments.

To adjust the limit cams, see Figure 17.

1. Pull the cam's retaining bracket back.
2. Turn the cams for limit adjustment: turning cams toward the center of the limit shaft increases door travel or turning the cams toward the limit switch decreases door travel.

## 7.3 Advanced Limit Switch Adjustments

The Advanced Close Limit Switch must be field adjusted in order to deactivate the reversing edge or external entrapment protection device at **a maximum of 6 in (15,2 cm) from the floor**. The adjustment can be performed by changing the position of the Advance Close Limit Switch on its slotted support bracket.

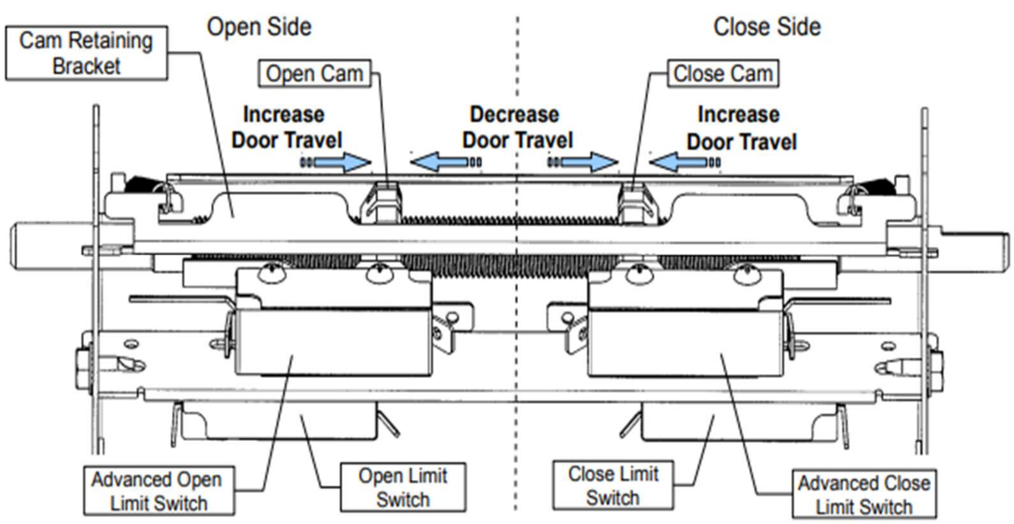



*Figure 17 - Limit Switches and Cams Adjustment*

## 7.4 Limit Switch Adjustment Using Manual Hand Chain (if applicable)

*Table 4 - Limit Switch Adjustment Procedures*

| Limit Switch | Adjustment Procedures |
|---|---|
| **Open Limit** | 1. Using the hoist, manually raise the door to a nearly opened position or desired open position.<br>2. Pull the cam-retaining bracket from the Open side, see Figure 17, and rotate the Open cam manually until it activates the Open Limit Switch sufficiently so that a "click" can be heard.<br>3. Release cam-retaining bracket and make sure that the bracket **engages** in the slots of both cams. |
| **Advanced Close Limit** | **1. Using the hoist, manually lower the door to approx. 6" above the ground.**<br>2. Pull the cam-retaining bracket from the Close side, see Figure 17, and rotate Close cam manually until it activates the Close limit switch sufficiently so that a "click" can be heard.<br>3. Release cam-retaining bracket and make sure that the bracket **engages** in the slots of both cams. |
| **Limit Switch Fine Adjustment** | 1. Limit switch fine adjustment SHOULD be done after the main power supply is connected to the operator. Refer to section Operator Start-up, Table 6, p.22.<br>Note: One (1) notch on cam is equal (=) to about ½" of the door travel. |

## 7.5 Limit Switch Adjustment Without Manual Hand Chain (if applicable)

*Table 5 - Limit Switch Adjustment Procedures (no hoist)*

| Limit Switch | Adjustment Procedures |
|---|---|
| **Open Limit** | 1. Move the open cam close to the open limit switch and proceed as per described in section Operator Start-up, Table 6, p.22.<br>2. Release cam-retaining bracket and make sure that the bracket **engages** in the slots of both cams. |
| **Advanced Close Limit** | 1. Pull the disconnect chain for manual operation.<br>**2. Manually open the door approx. 6" above the ground.**<br>3. Pull the cam-retaining bracket from the Close side, see Figure 17, and rotate Close cam manually until it activates the Close limit switch sufficiently so that a "click" can be heard.<br>4. Release cam-retaining bracket and make sure that the bracket **engages** in the slots of both cams. |
| **Limit Switch Fine Adjustment** | 1. Limit switch fine adjustment SHOULD be done after the main power supply is connected to the operator. Refer to section Operator Start-up, Table 6, p.22.<br>Note: One (1) notch on cam is equal (=) to about ½" of the door travel. |

## Appendix G - Reduced Time Calculations

As mentioned in the discussion about reducing times, every door on the north side of the depot will be reduced to remain open for only 30 seconds. The calculations in this appendix will follow the same procedure as the calculations from Appendix A. Any new calculations will have appropriate sample calculations shown to demonstrate them.

Table G.1 represents the numbers and results of calculating the leakage flow. An additional row is added to differentiate the north and south doors as there was no need to separate them in base case solution since they had the same timer time. Similarly Table G.2 has an additional column to calculate for the north doors with the changed timers.

*Table. G. 1.*

| Proposed Case With Reduced Time | | | | | | |
|---|---|---|---|---|---|---|
| Size | Location | Area, A | Openings Per Day, $X_{open}$ | Leakage flow, $V_{leakage}$ | Leakage flow, $m_{leakage}$ | Effective Opening Time, T |
| [ft] | x | [$m^2$] | # | [$m^3/s$] | [kg/s] | [s] |
| **11W x 14H** | North | 14.3 | 24 | 16.52 | 21.6 | 50 |
| | South | 14.3 | 24 | 16.52 | 21.6 | 80 |
| **14W x 14H** | North | 18.2 | 25 | 21.01 | 27.5 | 50 |
| | South | 18.2 | 25 | 21.01 | 27.5 | 30 |
| **16W x 14H** | North | 20.8 | 2 | 24.01 | 31.5 | 50 |

*Table. G. 2.*

| Historical Data | | | Heat Loss, $Q_{loss}$ | | | | |
|---|---|---|---|---|---|---|---|
| Month | Mean Outdoor Temp, $T_o$ | Days, D | **11W x 14H [50s]** | **11W x 14H [90s]** | **14W x 14H [50s]** | **14W x 14H [30s]** | **16W x 14H [60s]** |
| x | [°C] | x | [MWh/month] | | | | |
| Oct | 3.9 | 31 | 1.9 | 3.4 | 3.1 | 2.5 | 0.4 |
| Nov | -5.7 | 30 | 3.1 | 5.5 | 6.8 | 4.1 | 0.6 |
| Dec | -13.4 | 31 | 4.2 | 7.6 | 9.4 | 5.6 | 0.9 |
| Jan | -15.5 | 31 | 4.5 | 8.1 | 10.0 | 6.0 | 0.9 |
| Feb | -12.9 | 28 | 3.7 | 6.7 | 8.3 | 5.0 | 0.8 |
| Mar | -6 | 31 | 3.2 | 5.8 | 7.2 | 4.3 | 0.7 |
| Apr | 4 | 30 | 1.8 | 3.3 | 4.0 | 2.4 | 0.4 |

*Table. G. 3.*

| Results for Propsed Case With Reduced Timers | | |
| --- | --- | --- |
| Open door heat loss per Winter , $Q_{loss,tot}$ | 142 | [MWh/Year] |
| Gas used | 13931 | $m^3$/Year |
| %Gas used | 12.41% | % Used /Avg Annual Heating Bill |
| **Improvement Metrics** | | |
| %Gas Saved | 8.41% | % Saved /Avg Annual Heating Bill |
| Heat Savings | 96 | [Mwh/yr] |
| Gas Savings | 9433 | $m^3$/Year |
| % Gas Saved Vs Open Door Base Case | 40.38% | % |

Table G.3 shows the results of the reduced time with an additional four calculations versus the procedure in Appendix A. Values to calculate improvement metrics were used form Table A.3.The heat savings, gas savings and percent gas savings can all be calculated by the difference of the original value that was computed in the base case vs the proposed case with reduced timers. The % gas savings versus the base case uses a standard percent difference formula to be calculated.

Sample calculations for improvement metrics in table G.3:

Find $\%\ Gas\ Saved$:

$$\%\ Gas\ Saved\ = \%\ Gas\ Used_{\ base\ case} - \%\ Gas\ Used_{\ proposed\ case}$$

$$\%\ Gas\ Saved\ = 20.82\% - 12.41\%$$

$$\%\ \boldsymbol{Gas\ Saved}\ = \mathbf{8.41}\%$$

Find $Heat\ Savings$:

$$Heat\ Savings\ = Q_{\ loss,tot-base\ case} - Q_{\ loss,tot-propose\ \ case}$$

$$Heat\ Savings\ = 238\frac{MW}{Year} - 142\frac{MWh}{Year}$$

$$\boldsymbol{Heat\ Savings\ = 96\frac{MWh}{Year}}$$

Find $Gas\ Savings$:

$$Gas\ Savings\ = Gas\ Used\ _{base\ case}\ - Gas\ Used\ _{proposed\ case}$$

$$Gas\ Savings\ = 23363m^3 - 13931m^3$$

$$\boldsymbol{Gas\ Savings\ =\ 9433m^3}$$

Find % $Gas\ Saved\ Vs\ Base\ Case$:

$$\%\ Gas\ Saved\ Vs\ Base\ Case = \frac{Gas\ Savings}{Gas\ Used_{base\ case}} * 100$$

$$\%\ Gas\ Saved\ Vs\ Base\ Case = \frac{9433m^3}{23363m^3} * 100$$

$$\%\ \boldsymbol{Gas\ Saved\ Vs\ Base\ Case = 40.4}\%$$

## Appendix H - Lower Door Heights Calculations

All overhead doors at the Access Transit Depot are 14ft tall. Drivers at site said that the tallest vehicle that enters and exits the Transit depot are the Access Transit busses. The tallest point on an Access Transit bus was measured by us to be 10.25 ft. Therefore if the overhead doors were lowered to only open to 11ft they could still pass through. To find the heat savings and potential improvements, methodologies from Appendix A and G were used in there respective areas.

The following tables represent the results of reducing the opening height of the overhead doors down to 11ft.

*Table. H. 1.*

| Proposed Case With Reduced Height | | | | | | |
|---|---|---|---|---|---|---|
| Size | Location | Area, A | Openings Per Day, $X_{open}$ | Leakage flow, $V_{leakage}$ | Leakage flow, $m_{leakage}$ | Effective Opening Time, T |
| [ft] | x | [$m^2$] | # | [$m^3/s$] | [kg/s] | [s] |
| **11W x 11H** | North And South | 11.2 | 48 | 12.97 | 17.0 | 80 |
| **14W x 11H** | North | 14.3 | 25 | 16.51 | 21.6 | 80 |
| | South | 14.3 | 25 | 16.51 | 21.6 | 30 |
| **16W x 11H** | North | 21.2 | 2 | 24.49 | 32.1 | 80 |

*Table. H. 2.*

| Historical Data | | | Heat Loss, $Q_{loss}$ | | | |
|---|---|---|---|---|---|---|
| Month | Mean Outdoor Temp, $T_o$ | Days, D | **11W x 14H [90s]** | **14W x 14H [90s]** | **14W x 14H [30s]** | **16W x 14H [90s]** |
| x | [°C] | x | [MWh/month] | | | |
| Oct | 3.9 | 31 | 8.0 | 5.3 | 2.0 | 0.6 |
| Nov | -5.7 | 30 | 13.0 | 8.6 | 3.2 | 1.0 |
| Dec | -13.4 | 31 | 17.8 | 11.8 | 4.4 | 1.4 |
| Jan | -15.5 | 31 | 18.9 | 12.6 | 4.7 | 1.5 |
| Feb | -12.9 | 28 | 15.8 | 10.5 | 3.9 | 1.2 |
| Mar | -6 | 31 | 13.6 | 9.0 | 3.4 | 1.1 |
| Apr | 4 | 30 | 7.7 | 5.1 | 1.9 | 0.6 |

*Table. H. 3.*

| Results for Propsed Case With Reduced Height | | |
|---|---|---|
| Open door heat loss per Winter , $Q_{loss,tot}$ | 188 | [MWh/Year] |
| gas used | 18524 | $m^3$/Year |
| %gas used | 16.5% | % Used /Avg Annual Heating Bill |
| **Improvement Metrics** | | |
| %Gas Saved | 4.31% | % Saved /Avg Annual Heating Bill |
| Heat Savings | 49 | [Mwh/yr] |
| Gas Savings | 4840 | $m^3$/Year |
| % Gas Saved Vs Open Door Base Case | 20.7% | % |

## Appendix I: Average Wind Velocity

The effective wind velocity is a value that will be used to represent the yearly average wind speed at the mean height of the overhead doors at the Access Transit Depot.

The effective wind velocity for the overhead doors was computed by using historical wind data from Global Wind Atlas [I.1]. This is more accurate than using design tables like the one in Appendix D, since Global Wind Atlas is able to account for the impact that large buildings in a city have on the average wind speed. Figure I.1 shows a contour plot of wind velocities and how much they differ when measured outside the city. Global Wind Atlas is also more accurate since it gives the height that the wind velocity is measured at, which can then be used to reliably predict the velocity at a different height with the equations like the power law.

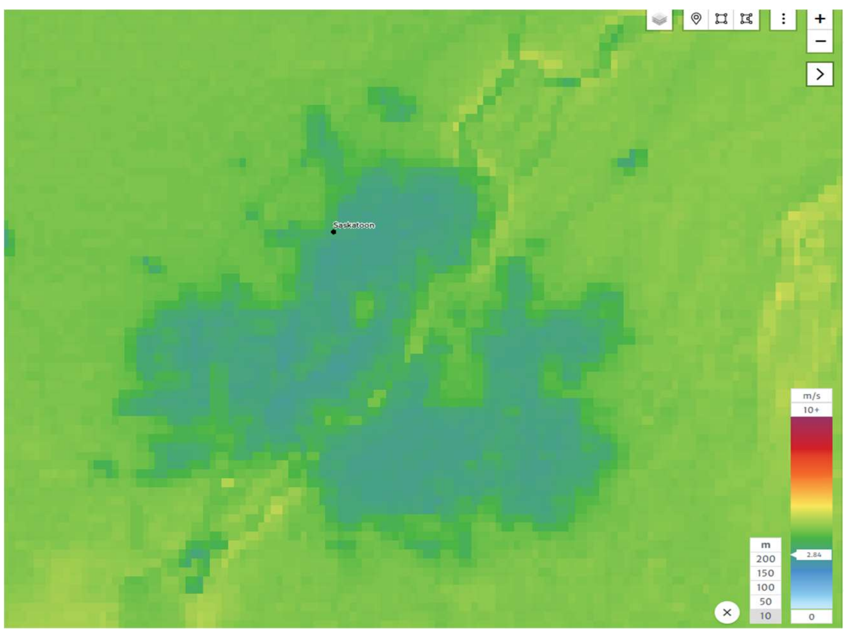



*Fig. I. 1 Wind Speed Plot around Saskatoon*

Figure I.2 shows the area that the wind velocity was measured at. The Access Transit building is near the center of this area, and all buildings in the area have the same profile as the access transit building. The results show an average wind speed of 3.33 m/s at a height of 10m.

However the overhead doors at the Access Transit building have a height of 4.3m so the effective wind velocity would be at half the door height of 2.15m.

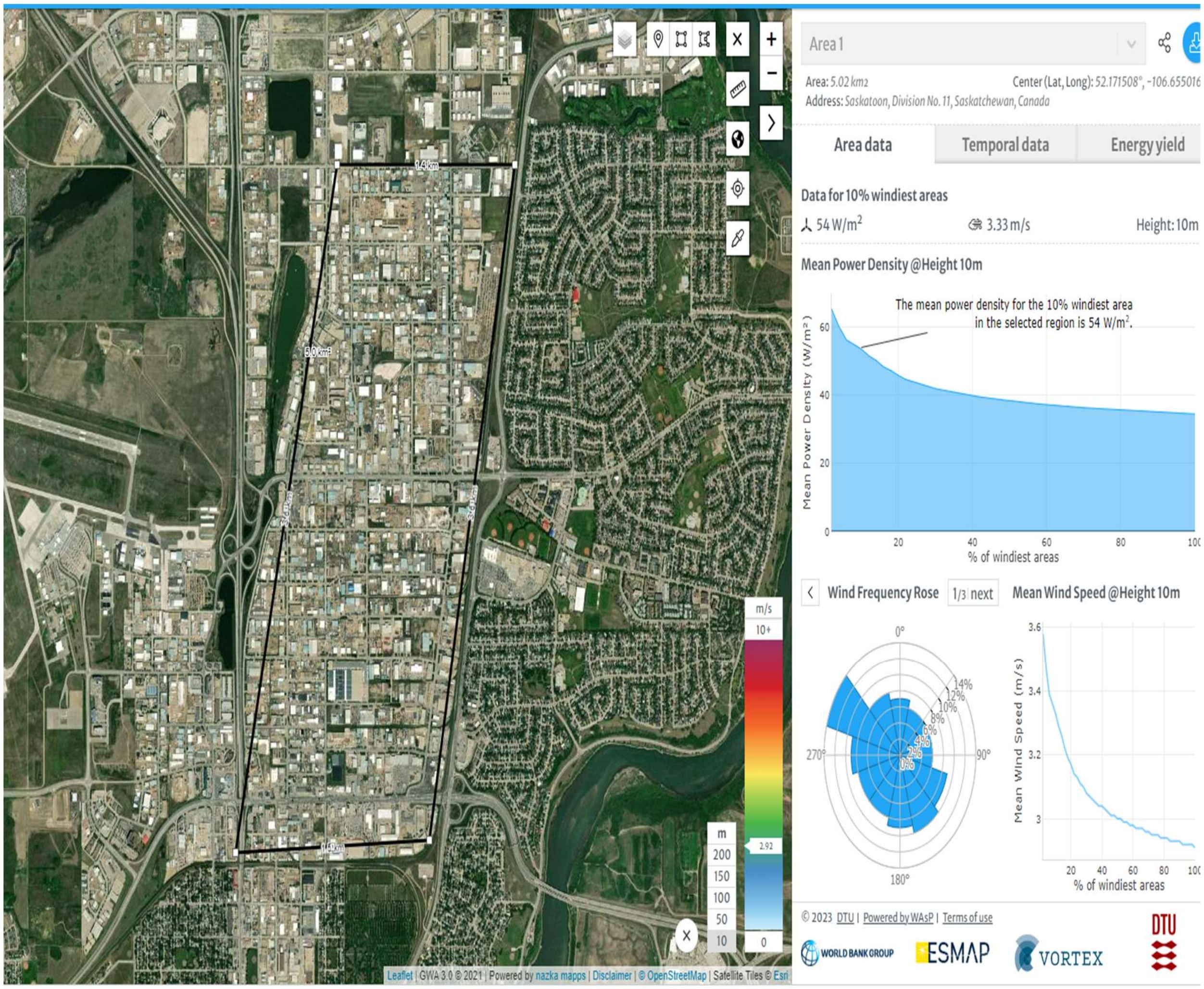



*Fig. I. 2. Wind Data From, Adapted from [I.1]*

To convert the measured wind velocity at 10m to 2.15m the power law was used:

$$v_z = v_{zr} * (\frac{Z}{Z_r})^{\alpha}$$

Where: $\alpha - wind\ shear\ exponent$

$Z_r - refrence\ (measured) elevation\ [m]$

$z - elevation\ of\ interest\ [m]$

To solve for $\alpha$, the following formula was used:

$$\alpha = \frac{1}{2} * (\frac{z_o}{z})^{0.2}$$

Where: $z_o = roughness\ parameter$

For the final calculation of the effective wind velocity a roughness parameter of 0.4m was used. The source of the roughness parameter is from a THER202 class notes that was taught by Howard Hemingson. In the notes the recommended roughness parameter for urban areas is 3-0.4m. 0.4m was used because it produced a slightly larger average wind velocity. Therefore alpha can be solved and then substituted into the velocity equation.

Find alpha:

$$\alpha = \frac{1}{2} * (\frac{z_o}{z})^{0.2}$$

$$\alpha = \frac{1}{2} * (\frac{0.4m}{2.15m})^{0.2}$$

$$\boldsymbol{\alpha = 0.3571}$$

Find effective wind velocity:

$$v_z = v_{zr} * (\frac{z}{z_r})^{\alpha}$$

$$v_z = 3.33m/s * (\frac{2.15m}{10m})^{0.3571}$$

$$\boldsymbol{v_z = v_{equivalnt} = 1.923m/s}$$

# Appendix J: Emails from Kathryn Theede

This sender Kathryn.Theede@Saskatoon.ca is from outside your organization. Block sender

TK **Theede, Kathryn** <Kathryn.Theede@Saskatoon.ca>
To: Peppard, Austin; Mourre, Peter

Tue 2/21/2023 2:31 PM

Access Transit.xlsx
174 KB

Peter,

Have you been able to arrange meeting Muhammad onsite on Wednesday?

I've included the following information:

1. Floor Plan – see link Drawings for SKPolyTech
2. HVAC layout – see attached link above
3. R-Values of Walls/Roof – (I will have these by the end of the week)
4. Bus Schedule –
   How often are the overhead doors open on each side (east and west North and South))? More specifically how many busses are coming and leaving each day and how long is a door open to receive the bus on each side. (Or just estimate % of time open)
   a. East Side?
   b. West Side? This will vary, but on an average day, we will have 25 buses leave the South doors, and re-enter the North doors. So 50 times total/day, just leaving and re-entering the garage. The doors remain open for 60 seconds before closing.

   Do you know how many buses you wash a day and when the washing occurs? It is every day or only when needed? Every bus that goes out gets washed. On Average, 25 buses/day get washed. This includes an exit out the north door and a re-enter on the north door in our wash bay/utility area. Once the bus is washed, we can usually turn the bus around in the garage and park it, however, we may have to exit the South door and re-enter in the south door, to park it in the garage. These exits and enters are in addition to questions #1, therefore this puts us at 100 or garage openings/closings. The bus does gets refueled every day and the fuel tank is located outside. Sometimes the bus will remain outside and drive around to refuel, sometimes it will get washed, leave the south doors, refuel and re-enter the south doors to park
5. Energy Bills – see attached. The east side garage was built and occupied by the city on February 25th, 2010. Prior to that date was only the west side maintenance shop.

Let me know if you have any questions.


**Kathryn Theede** P.Eng, CEM, CMVP | tel 306.986.1681
Energy & Sustainability Engineering Manager
City of Saskatoon | 222 3rd Avenue North | Saskatoon, SK S7K 0J5
*Treaty 6 Territory and Homeland of the Métis*
kathryn.theede@saskatoon.ca
www.saskatoon.ca
Pronouns: she/her/hers




TK **Theede, Kathryn** <Kathryn.Theede@Saskatoon.ca>
To: Peppard, Austin
Cc: Mourre, Peter

Heat Retention for Overhead...
270 KB

Austin,

Here is the signed file.

I also have the Roof and Wall R-Values:
The *effective* Rvalues are as follows:

Wall R-12.9
Roof R-10

Regards,
Kathryn


**Kathryn Theede** P.Eng, CEM, CMVP | tel 306.986.1681
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## Appendix K- Air Curtain CFD Analysis

This CFD analysis is meant to analyze the effects of installing a *BERNER, model IDC14-3132AQ-G*, High Velocity air curtain on an access transit bus depot door. This appendix will not provide reasoning to why certain settings were used since they have already been discussed in more detail from the base case analysis in Appendix E. This appendix will only provide a general summary of the settings used in each software. However if any new conditions or methodologies are adapted because of the air curtains they will be discussed.

## Inventor

A copy of the base case Inventor model was made and using the BERNER, IDC14-3132AQ-G High Velocity Air Curtain data sheet, the air curtain was modeled. The 2D model used is available in Figure K.1. The dimensions from the data sheet used to model the air curtain box are available in figure K.2. The air curtain was modeled at a 0° tilt for this simulation. The door was also extended down two feet to cover the air curtain box as recommended by air curtain manufacturers.

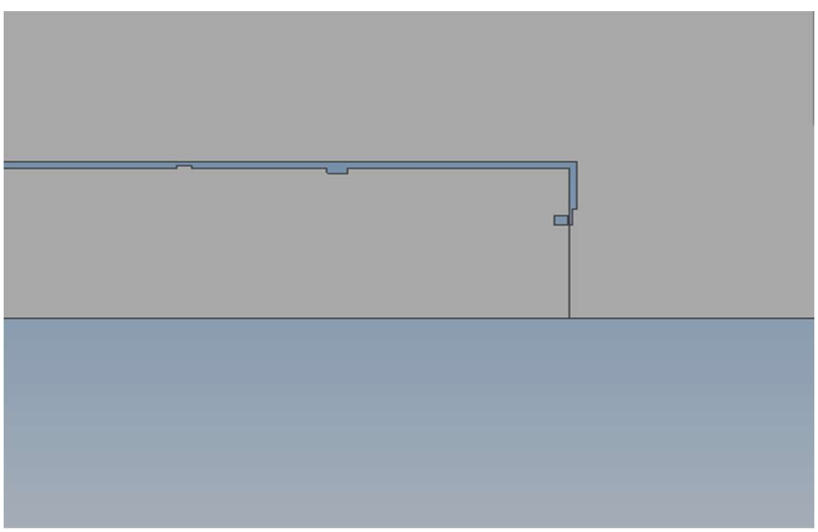


*Fig. K. 1. 2D Model of Access Transit Depot with Air Curtain*

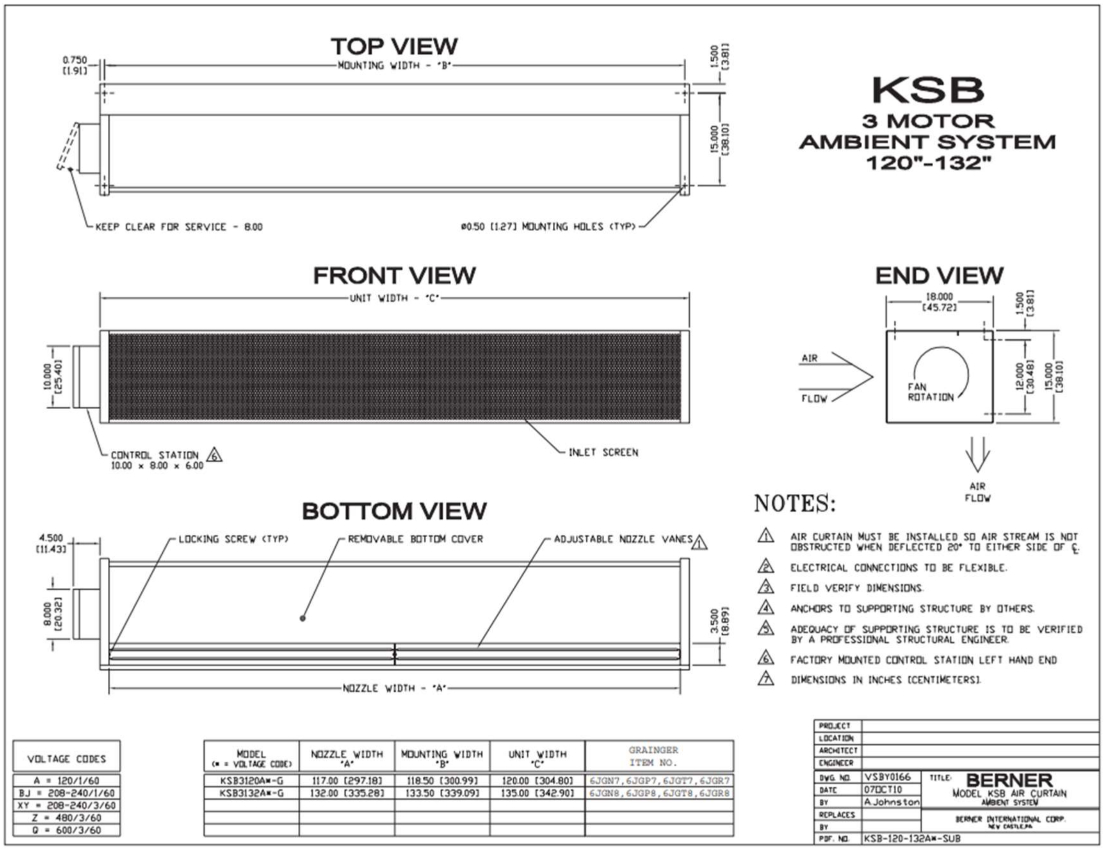



*Fig. K. 2. Drawing For BERNER model IDC14-3132AQ-G, Adapted From [M.1]*

## Mesher

Figure K.3 provides a summary of the mesh and its skewness that was generated for the air curtain analysis with the sizing conditions summarized in Table K.1.

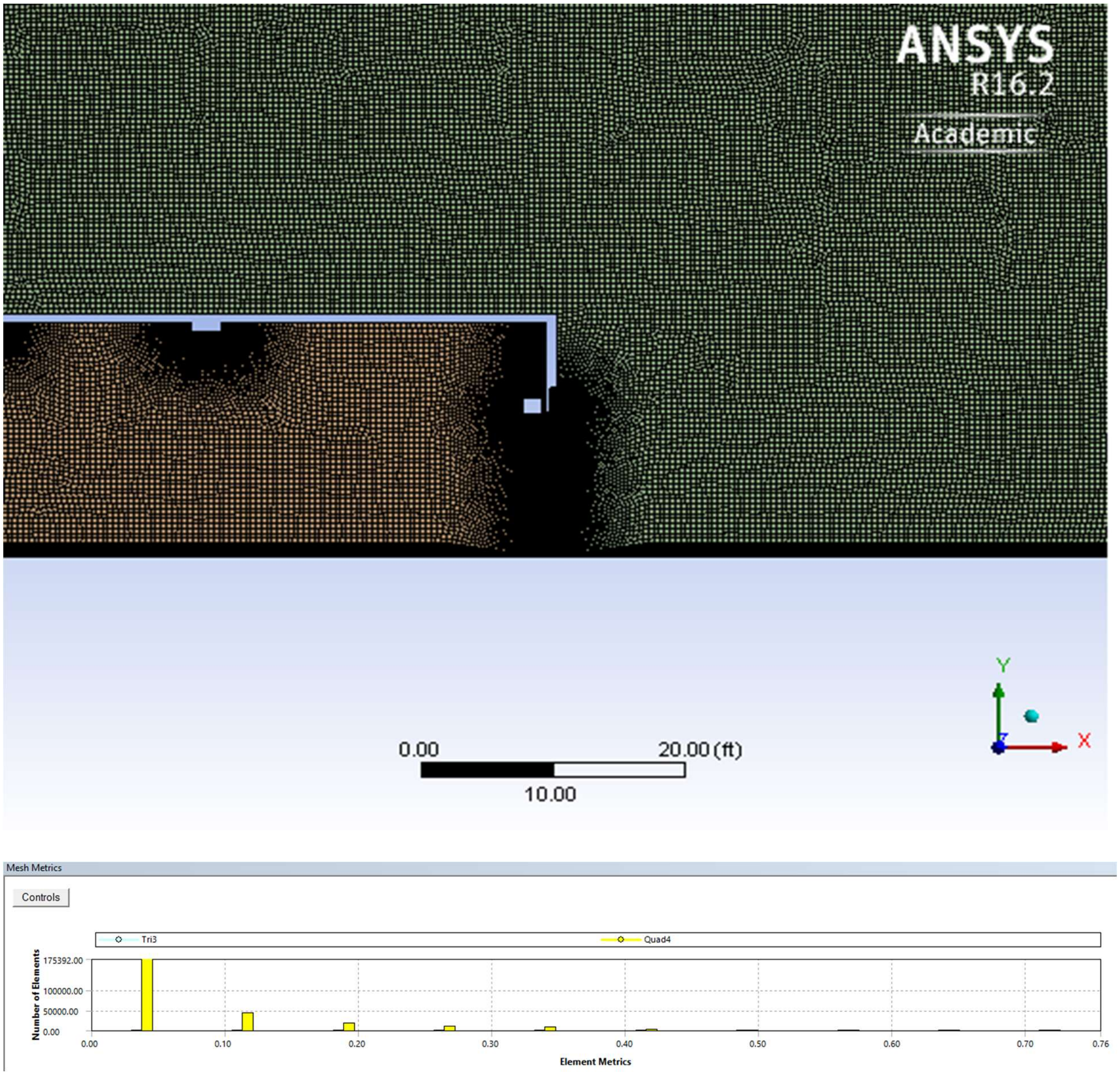



*Fig. K. 3. Mesh Used and Skewness Mesh Metrics*

*Table K. 1. Mesh Sizing Summary*

| Object Name | *Indoor Floor Inflation* | *Outdoor Floor Inflation* | *Air Curtain, Supply/Return Air Sizing* |
|---|---|---|---|
| State | Fully Defined | | |
| **Scope** | | | |
| Scoping Method | Geometry Selection | | |
| Geometry | 1 Face | | 15 Edges |
| **Definition** | | | |
| Suppressed | No | | |
| Boundary Scoping Method | Geometry Selection | | |
| Boundary | 1 Edge | | |
| Inflation Option | Smooth Transition | | |
| Transition Ratio | Default (0.272) | | |
| Maximum Layers | 15 | | |
| Growth Rate | 1.05 | | 1.050 |
| Inflation Algorithm | Pre | | |
| Type | | | Element Size |
| Element Size | | | 2.e-002 ft |
| Behavior | | | Soft |
| Curvature Normal Angle | | | 5.0 ° |
| Bias Type | | | No Bias |
| Local Min Size | | | Default (2.e-002 ft) |

# SOLVER

The following boundary conditions in table K.2, were used for the air curtain analysis. All conditions remained the same for the air curtains, except the addition of a face that the air curtain velocity was modeled from. The air curtain velocity of 25.4 m/s was taken from its corresponding datasheet [M.1]. The inputs and outputs for the initial turbulence boundary condition values for the air curtain supply are available in Figure K.4.

*Table K. 2. Boundary Conditions*

| Boundary Conditions 'Walls' | | | | | |
|---|---|---|---|---|---|
| Location | Roughness Height [m] | Roughness Constant | Rsi [w/m2*k] | Free Stream Temp [°C] | External Rad Temp [°C] |
| Indoor Walls | slip | | 2.27 | -20 | 18 |
| Indoor roof | 0.5 | 1 | 1.76 | -20 | 18 |
| Indoor Floor | 0.09795 | 0.5 | 0.1761 | -20 | 18 |
| Outdoor Floor | 0.09795 | 0.5 | 0 | -20 | -20 |
| Wind Tunnel Walls | slip | | 0 | -20 | -20 |

| Boundary Conditions 'velocity inlet' | | | | | |
|---|---|---|---|---|---|
| Location | Velocity Magnitude [m/s] | Temprature [°C] | Inital Gauge Pressure [Pa] | Turbulent Intensity [%] | Turbulent Length Scale [m] |
| Supply Air Diffuser | 0.15 | 25 | Defualt, 0 | 5 | 0.05 |
| Wind In | 0 to 3.44 | -20 | Defualt, 0 | 2.5 | 1.4 |
| Air Curtain Supply | 25.4 | 18 | Defualt, 0 | 3.5 | 0.00623 |

| Boundary Conditions 'Pressure Outlet ' | | | | |
|---|---|---|---|---|
| Location | Gauge Pressure (pa) | Backflow Temp [°C] | Backflow Turbelent Intensity [%] | Backflow Turbulent Visocsity Ratio |
| Exhaust Air | 0 | 18 | Default- 5 | Default- 10 |
| Wind Out | 0 | -20 | Default- 5 | Default- 10 |

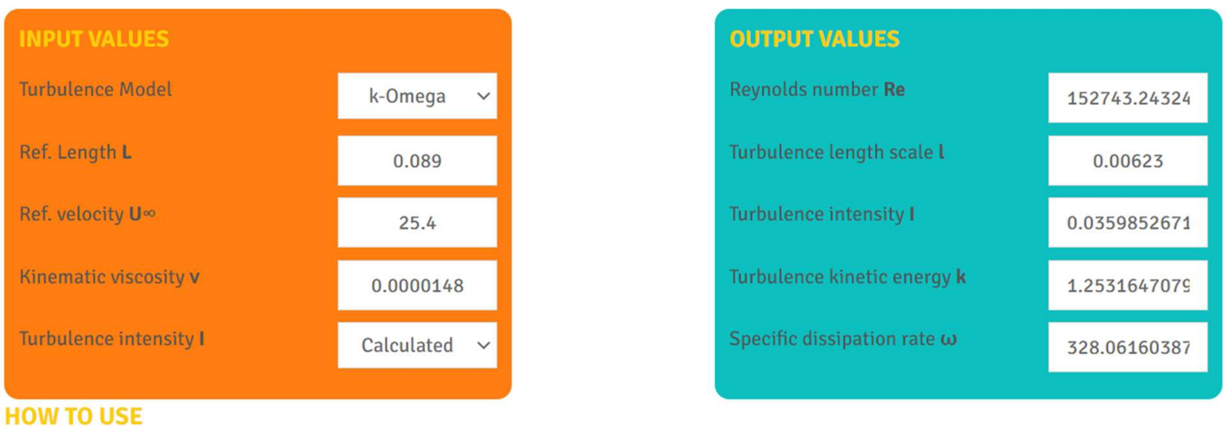



*Fig. K. 4. Initial Turbulence Values for "Air Curtain Supply" BC, Adapted from [E.8]*

Solution initialization was done in the same manner as for the base case. The overall time the solution represented was still 30 seconds with the time step settings shown in Figure K.5 being used.

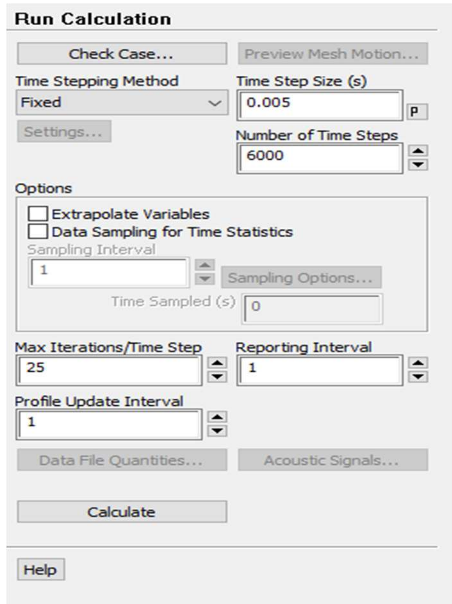



*Fig. K. 5. Transient Settings*

## Validation

The air curtain simulation was validated by analyzing the velocity profile it produces. This velocity profile is shown in Figure K.6 and is correct since it is able the reach the ground and split. The wind profile is also correct because the velocity decreases as it approaches the ground.

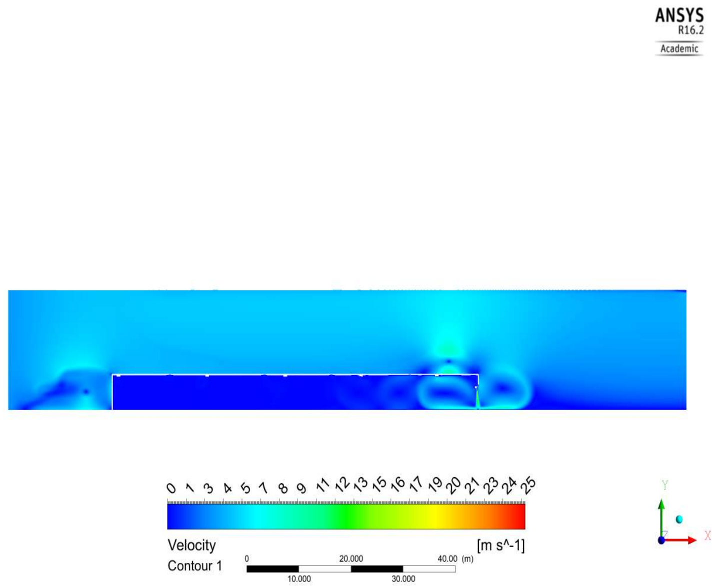



*Fig. K. 6. Velocity Profile Validation for Air Curtain*

## Results

Figure K.6 shows the result of this air curtain simulation and Figure K.7 shows the same result but zoomed out. Figure K.8 shows average air temperature of the interior air space.

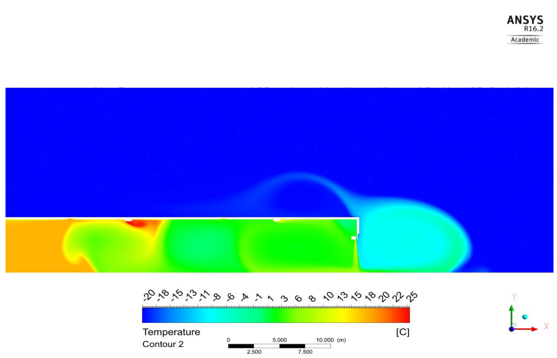



*Fig. K. 6. Temperature Gradient Zoom*

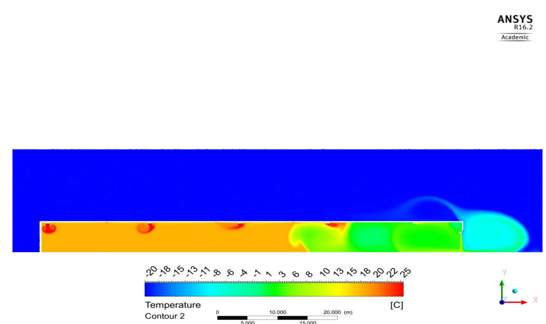



*Fig. K. 7.  Temperature Gradient*

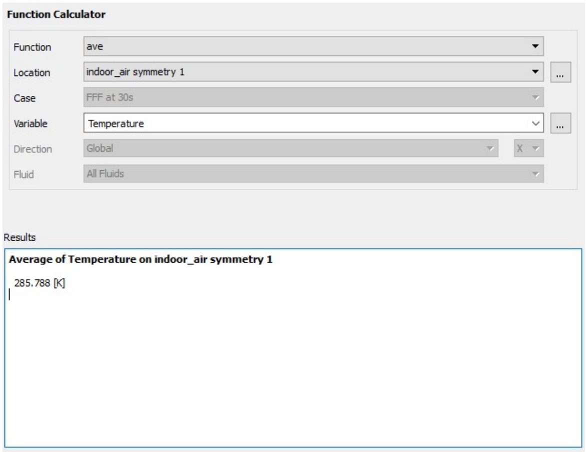
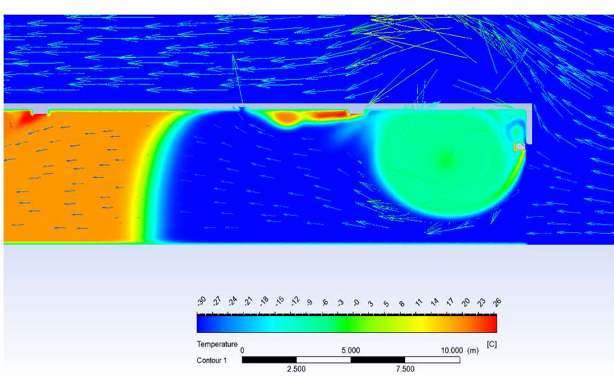



*Fig. K. 8. Average Interior Temperature Calculation*

## Other Results

Similar air curtain simulations were done to produce other results. The result in Figure K.9 was produced by changing the air curtain angle from 0° to 10° outwards. The result in figure k.10 was done by using a lower velocity of 15m/s which is common for lower velocity air curtains.



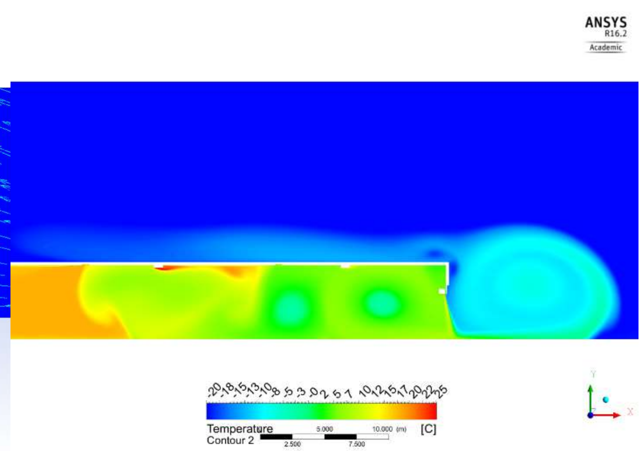




*Fig. K.9. Low Velocity Air Curtain*

*Fig. K.9. Berner Air Curtain adjusted 10° out*

## Appendix L: Financial Calculator

This financial calculator is based on an input of how much natural gas was saved by a solution in $m^3$. A dollar amount in CAD is entered for how much the solution will cost and then using the cost of natural gas it computes payback period, ROI and cumulative cash flow. The cost of natural gas is made up of three costs: commodity rate, delivery charge and carbon tax. Since all three costs change at a different rate, it was necessary to analyze the cash flow annually with all three costs separated so they can accurately be predicted. To predict the carbon tax, *SaskEnergy* supplied a table with predicted costs for the next 3 years and after that they recommended a compounding rate of 10%. For the delivery charge and commodity rate, historical data from *SaskEnergy* was used to extrapolate values into the future. All costs used from *SaskEnergy* were from the "Large Commercial" section, since the average usage calculated from Appendix A was in between 100000 and 600000 $m^3$. Inflation was also accounted for using an average value from Stats Canada.

### Equations

The following equation were developed to solve for the amount of money saved annually for a potential solution:

$$\boldsymbol{Annual\ Savings} = (\boldsymbol{V_{saved}} * \left(\boldsymbol{C_{rate}} + \boldsymbol{D_{charge}} + \boldsymbol{C_{tax}}\right) * ((\mathbf{1} + \boldsymbol{Avg\ Inflation})^{\boldsymbol{n}})$$

Where: $V_{saved} - Gas\ saved\ by\ potential\ solution\ [m^3]$

$C_{rate} - Commodity\ rate\ [\$/m^3]$

$D_{charge} - Delivery\ charge\ rate\ [\$/m^3]$

$C_{tax} - Carbon\ tax\ [\$/m^3]$

$I_{avg} - Average\ annual\ cash\ inflation$ [%]

$n - Number\ of\ years\ after\ solution\ was\ employed\ [x]$

The following equation was used to find the total amount of money saved by the investment at each year:

$$\boldsymbol{Total\ Money\ Saved = \sum A_{savings,n}}$$

Where: $A_{savings,n} - Annual\ Savings\ at\ n\ number\ of\ years$ [$]

The following equation was used to find the cumulative cash flow of the investment at each year:

$$\boldsymbol{Cumilative\ Cash\ Flow = T_{saved,n} - I_{cost}}$$

Where: $T_{saved,n} - Totall\ money\ saved\ at\ n\ number\ of\ years$ [$]

$I_{cost} - Inital\ cost\ of\ solution$ [$]

The following equation was used to calculate the ROI for a potential solution at $n$ number of years:

$$\boldsymbol{ROI = \frac{(A_{savings,n} - I_{cost})}{I_{cost}} * 100}$$

## Commodity Rate

Table L.1 was used to determine the commodity rate. The current value of 0.1674 $\$/m^3$ was used for the commodity rate for all years since all historical data does not follow a linear relationship. Figure L.1 shows the historical commodity rate graph vs time with a BFSL displayed to show its slope. What can be observed from figure L.1 is that the commodity rate does not follow any specific trend since the plotted line fluctuates largely over the years. This means that even though the commodity rate is currently on an upwards trend, the BFSL will extrapolate the future cost to decrease it. Therefore it would be impossible to accurately predict the commodity rate over the following years using extrapolation; using today's value will result in a much more realistic answer.

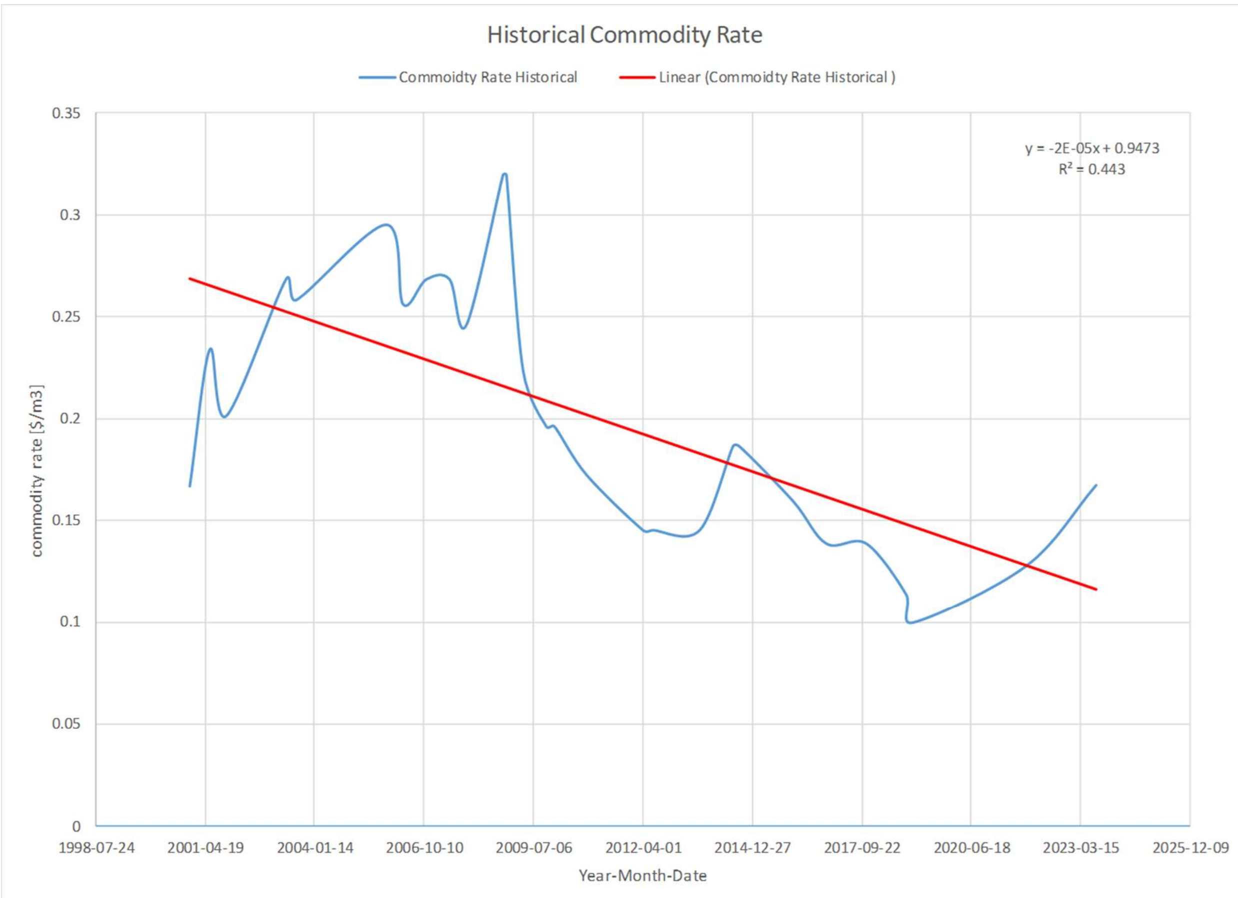



*Fig. L. 1.*

*Table. L. 1. Large Commercial Rates, Adapted from [L.1]*

Large Commercial Rates from 2000-2022

| Effective Date | Commodity Rate ($/m$^3$) | Commodity Rate ($/GJ) | Basic Monthly Charge ($/month) | Delivery Charge ($/m$^3$) |
|---|---|---|---|---|
| 2022, August 1 | 0.1674 | 4.20 | 159.50 | 0.0732 |
| 2021, November 1 | 0.1278 | 3.20 | 137.40 | 0.0684 |
| 2019, April 1 | 0.0998 | 2.575 | 137.40 | 0.0684 |
| 2018, November 1 | 0.1136 | 2.95 | 137.40 | 0.0673 |
| 2017, November 1 | 0.1387 | 3.65 | 137.40 | 0.0673 |
| 2016, November 1 | 0.1387 | 3.65 | 137.40 | 0.0647 |
| 2016, January 1 | 0.1596 | 4.30 | 133.40 | 0.0597 |
| 2014, September 1 | 0.1863 | 4.84 | 133.40 | 0.0567 |
| 2014, July 1 | 0.1863 | 4.84 | 133.40 | 0.0556 |
| 2013, September 1 | 0.1453 | 3.82 | 133.40 | 0.0556 |
| 2012, July 1 | 0.1453 | 3.82 | 133.40 | 0.0551 |
| 2012, April 1 | 0.1453 | 3.82 | 77.40 | 0.0551 |
| 2010, November 1 | 0.1725 | 4.55 | 77.40 | 0.0551 |
| 2010, January 14 | 0.1961 | 5.21 | 77.40 | 0.0551 |
| 2009, November 1 | 0.1961 | 5.21 | 64.10 | 0.0551 |
| 2009, April 1 | 0.2238 | 5.96 | 64.10 | 0.0551 |
| 2008, November 1 | 0.3195 | 8.51 | 64.10 | 0.0551 |
| 2008, October 1 | 0.3195 | 8.51 | 43.50 | 0.0551 |
| 2007, November 1 | 0.2459 | 6.57 | 43.50 | 0.0551 |
| 2007, June 1 | 0.2683 | 7.17 | 43.50 | 0.0551 |
| 2006, November 1 | 0.2683 | 7.17 | 37.25 | 0.0551 |
| 2006, April 1 | 0.2562 | 6.80 | 37.25 | 0.0551 |
| 2005, November 1 | 0.2951 | 7.95 | 37.25 | 0.0551 |
| 2003, August 1 | 0.2582 | 6.97 | 37.25 | 0.0551 |
| 2003, May 1 | 0.2685 | 7.25 | 37.25 | 0.0551 |
| 2001, November 1 | 0.2014 | 5.44 | 37.25 | 0.0551 |
| 2001, June 1 | 0.2338 | 8.30 | 37.25 | 0.0551 |
| 2000, December 1 | 0.1669 | 7.52 | 37.25 | 0.0551 |

## Delivery Charge

The delivery charge was able to be extrapolated for each year since its cost followed a linear shape. Figure L.2 was made with information from table L.1. The following equation from Table L.2 was used to predict the delivery charge for each year:

$$Predicted\ Delivery\ Charge = 2 * 10^{-6} * x - 0.0226$$

Where: $x - Date\ converted\ to\ excel\ numerical\ format$ *[Year-Month-Date]*

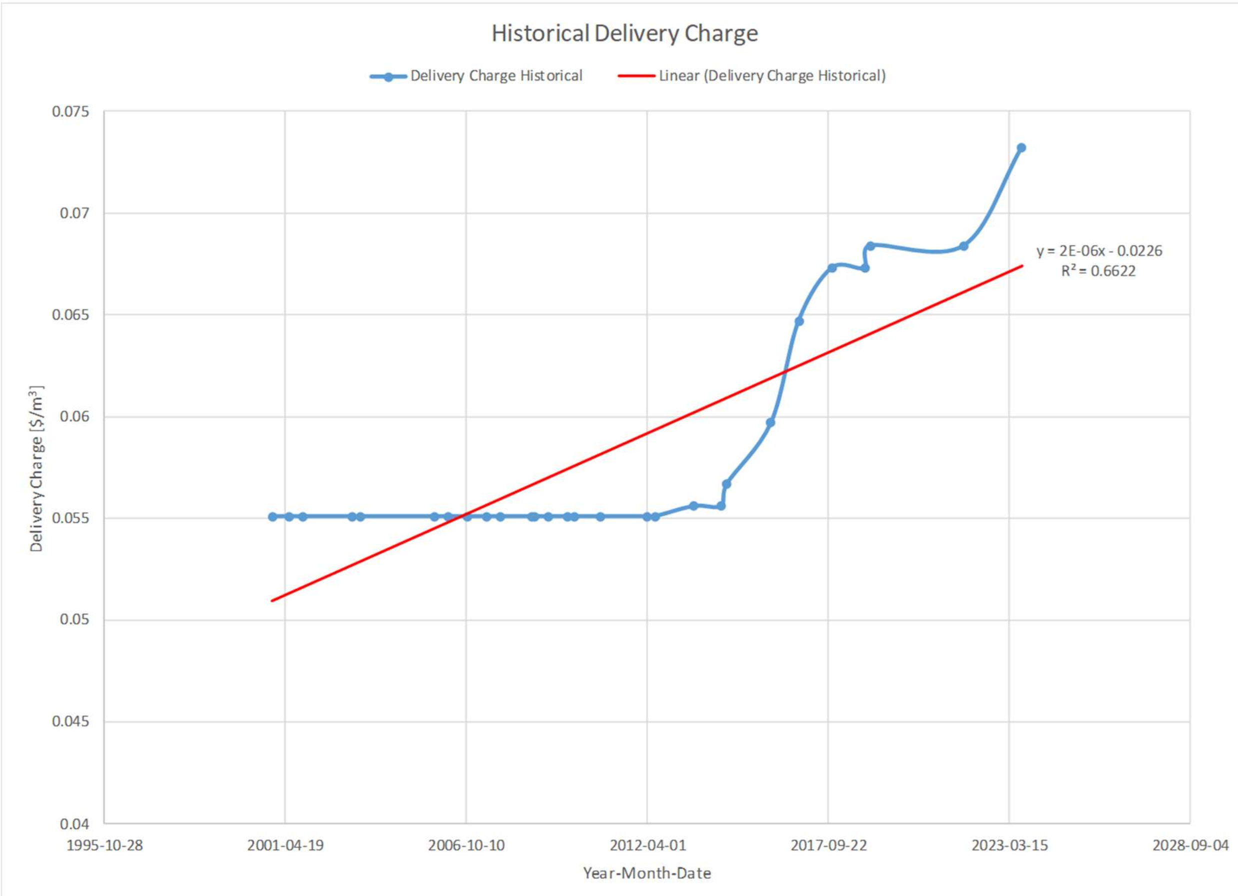



*Fig. L. 2.*

## Carbon Tax

The Carbon tax is predicted by using values from SaskEnergy as shown in Figure L.4 Prices for the carbon tax are listed until 2026 and then a compounding value of 10% was used for each year following 2026 as this is what SaskEnergy predicts in the bottom of figure H.4. These prices were inputted into every year of an excel sheet. The *Government of Canadas* predicted carbon tax values match the ones supplied by *SaskEnergy*, however after 2030 the *Government of Canada* does not provide any values on the carbon tax. It was chosen to keep the 10% compounding rate after 2030 because the way the current government is handling the carbon tax it is a reasonable guess to assume that this value stays the same.

- April 2019 → $20 per tonne ($0.0391 per cubic metre)
- April 2020 → $30 per tonne ($0.0587 per cubic metre)
- April 2021 → $40 per tonne ($0.0783 per cubic metre)
- April 2022 → $50 per tonne ($0.0979 per cubic metre)
- April 2023 → $65 per tonne ($0.1239 per cubic metre)
- April 2024 → $80 per tonne ($0.1525 per cubic metre)
- April 2025 → $95 per tonne ($0.1811 per cubic metre)
- April 2026 → $110 per tonne ($0.2097 per cubic metre)

- GST applies to the tax amount. PST is not applicable.
- The average residential customer can expect an annual increase of about $67 (or 7%) in 2023 and $74 (or 7%) each year after that.
- Commercial customers can expect an annual increase of 10%.

*Fig. L. 3. Carbon Tax Prices, Adapted from [L.1]*

## Inflation

A monetary Inflation value was required to make the solution more accurate because the payback periods would be long enough that inflation could have a significant impact. Using the consumer price index the average cash inflation value will be 3% [L.3].

## Appendix M-1 - Air Curtains on All Doors

This appendix will detail the methodology's used calculate payback period for installing air curtains on all of the overhead doors.

## Air Curtain Effectiveness

To find the thermal effectiveness of the installed BERNER High Velocity Air Curtain, the base case temperature gradient of the Transit Depot was compared to a temperature gradient of the Transit Depot with the BERNER air curtain installed. A zero 0% effective air curtain would mean that the temperature gradient remained the same as the base case, while a 100% effective air curtain would mean that the indoor environment remained at room temperature. The areas in Figure M.1 and M.2 can be compared by using ANSYS Fluent to specify the average temperature of the indoor area as shown in figure M.3 and M.4. This can be done because both analysis represent the same conditions, the only variable that changes being the air curtain. The following equation can then be used to find the effectiveness of an air curtain:

$$\eta_{air\ curtain} = \frac{(T_{Avg,air\ curtain} - T_{Avg,base\ case})}{(T_{ambient} - T_{Avg,base\ case})} * 100$$

Where: $T_{Avg,air\ curtain}$ $- Average\ interior\ temprature\ with\ air\ curtian\ installed\ [K]$

$T_{Avg,base\ case}$ $- Average\ interior\ temprature\ overhead\ door\ open\ [K]$

$T_{ambient}$ $- Ambient\ air\ temprature\ of\ interior\ air\ space\ [K]$

Find $\eta_{air\ curtain}$:

$$\eta_{air\ curtain} = \frac{(T_{Avg,air\ curtain} - T_{Avg,base\ case})}{(T_{ambient} - T_{Avg,base\ case})} * 100$$

$$\eta_{air\ curtain} = \frac{(285.788K - 278.076K)}{((18° + 273K) - 278.076K)} * 100$$

$$\boldsymbol{\eta_{air\ curtain} = 59.7\%}$$

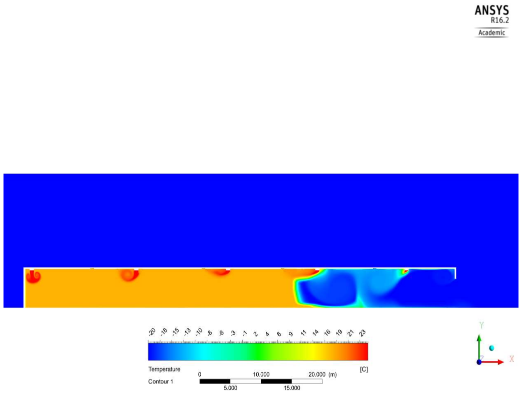



*Fig. M.1. Base Case CFD, Adapted from Appendix E*

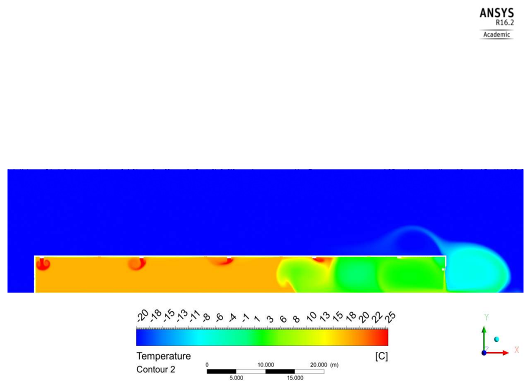



*Fig. M.2. Air Curtain CFD, Adapted from Appendix K*


*Fig. M.3. Base Case, Adapted from Appendix E*

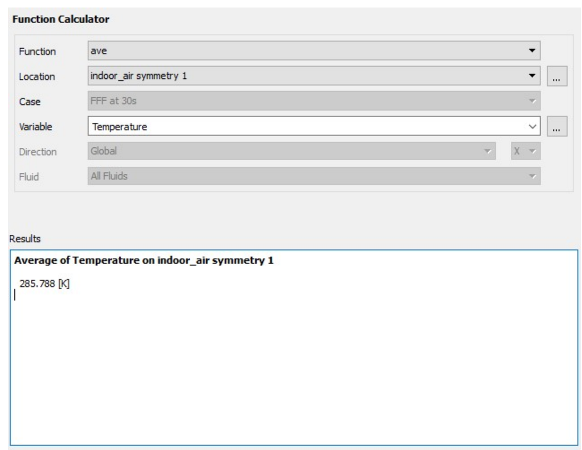



*Fig. M.4. Air Curtain, Adapted from Appendix K*

## Initial Costs

Table M.1 represents the initial costs of installing air curtains on all 22 of the overhead doors. These values were taken from Grainger [M.1].

*Table M.1*

| Air Curtain Unit Pricing | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Size | Area, A | Qty, $X_{door}$ | Type | Part Number | Velocity | Cost Per Unit | Cost Per Unit | Totall Cost |
| [ft] | [$m^2$] | # | | | [FPM] | [$ US] | [$ CAD] | [$ CAD] |
| **11W x 14H** | 14.3 | 19 | Berner High Velcity Air Curtain | IDC14-3132AQ-G | 5000.00 | $ 3,969 | $ 5,397 | $ 102,552 |
| **14W x 14H** | 18.2 | 2 | | IDC14-4168AZ-G | 7040.00 | $ 6,562 | $ 8,925 | $ 17,850 |
| **16W x 14H** | 20.8 | 1 | | IDC14-5192AXY-G | 7175.00 | $ 6,985 | $ 9,499 | $ 9,499 |
| | | | | | | | Total Cost in CAD | $ 129,901 |

## Electrical Consumption

Electrical consumption was calculated by finding the total amount of electrical energy the fan motors consumed each year for the air curtains. None of the air curtains had air heaters so the fans would be the main power draw. It was also assumed that the air curtains would only be on for 212 days per year, since the air curtains should be shut off in the summer. The electrical cost was used from the *City of Saskatoon* cite as shown in figure M.5. The following equations were used with data from each air curtain to calculate the total electrical power consumed per year as shown in table M.2:

$$P_x = V * A * T_0 * O * D$$

Where: $P_x - Power\ of\ x\ size\ door\ consued\ per\ year\ [Kwh/year]$

$V\ - Fan\ motor\ voltage\ [V]$

$A\ - Fan\ motor\ amprage\ [A]$

$T_o - Overhead\ door\ open\ to\ close\ time\ [S/opening]$

$O\ - Overhead\ door\ openings\ per\ day\ [Openings/Day]$

$D\ - Operational\ days\ per\ year\ [Days/Year]$

$$Totall\ Electrical\ Cost = \sum P_x$$

| Commercial Loads Greater Than 75 But Not Exceeding 3,000 kVA - Utility Owned Transformer | |
|---|---|
| Service Charge ($) | $80.30 |
| Energy charge (¢/kWh) | |
| First 16,750 kWh | 12.67¢/kWh |
| **Balance** | **7.94¢/kWh** |
| Carbon Tax Charge (¢/kWh) | 1.11¢/kWh |
| Demand ($/kVA) | |
| First 50 kVA | no charge |
| **Balance** | **$22.90/kVA** |

*Fig. M. 5. Electrical Cost, Adapted from [M.2]*

*Table. M. 2.*

| Air Curtain Power Table | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Size | Location | Openings Per Day, $X_{open}$ | Opening Time [s] | Part Number | Specified Motor Voltage [v] | Specified Motor Amprage [a] | Number of Motors | Power Consumed [Kwh/Year] |
| **11W x 14H** | North And South | 48 | 80 | IDC14-3132AQ-G | 600.00 | 7.80 | 3.00 | 3174.91 |
| **14W x 14H** | North | 25 | 80 | IDC14-4168AZ-G | 480.00 | 12.80 | 4.00 | 2894.51 |
| | South | 25 | 30 | | | | | 1085.44 |
| **16W x 14H** | North | 2 | 80 | IDC14-5192AXY-G | 480.00 | 32.50 | 5.00 | 734.93 |
| | | | | | **Total electrical used per winter [Kwh/Year]** | | | 7890 |
| | | | | | **Cost of electrical per winter** | | | $999.64 |

## Air Curtain Financials

Using the previously calculated power cost and initial cost the methodology from Appendix L was used with some slight modifications. The thermal efficiency of the air curtain can be used to find heat loss saved since the amount of natural gas used directly correlates with the thermal efficiency. In table M.3 the heat lost saved became the following equation:

$$V_{Saved} = V_{base,case} * \eta_{ther,air\ curtain}$$

Where: $V_{Saved}$ $- Amount\ of\ heat\ save\ by\ installing\ air\ curtain\ [m^3/year]$

$V_{base,case} - Amount\ of\ heat\ save\ by\ installing\ air\ curtain\ [m^3/year]$

Find $Q_{Saved,all\ aircurtains}$:

$$V_{Saved} = V_{base,case} * \eta_{ther,air\ curtain}$$

$$V_{Saved} = 28169.7m^3 * \eta_{ther,air\ curtain}$$

$$V_{Saved} = 23364m3\ *\ 0.597$$

$$V_{Saved} = 14018m^3$$

The other modification made to the Appendix L methodologies was the Annual savings had the electrical cost used by the air curtains subtracted for each year. The yearly results for the financials are shown in table M.4, Figure M.6 and the inputs are in Table M.3.

*Table. M. 3.*

| Input for Air Curtains on all Doors | | | |
|---|---|---|---|
| Variable | Value | Unit | Source |
| Heat Loss Saved | 14018.4 | $m^3$/year | Appendix M.1 |
| Commodity Rate | 0.1674 | \$/$m^3$ | SaskEnergy - Large Commericial Rates |
| Avg Cash Inflation | 3% | % | Appendix L |
| Initial Cost | 129901 | $ | Appednix M.1 |
| Electrical | 999.64 | $ per year | Appendix M.1 |

*Table. M. 4. Air Curtains On all Doors Financials*

| Year/Winter # | Year/Winter Date | Carbon Tax [\$/$m^3$] | Predicted Delviery Charge [\$/$m^3$] | Annual Savings [$] | Totall Money Saved [$] | Cumulative Cash Flow [$] | ROI |
|---|---|---|---|---|---|---|---|
| 1 | 2024-01-01 | 0.153 | 0.068 | 4572 | 4571.90 | -125329.10 | -96.48% |
| 2 | 2025-01-01 | 0.181 | 0.0687 | 5135 | 9707.37 | -120193.63 | -96.05% |
| 3 | 2026-01-01 | 0.210 | 0.0694 | 5729 | 15436.30 | -114464.70 | -95.59% |
| 4 | 2027-01-01 | 0.231 | 0.0702 | 6233 | 21669.36 | -108231.64 | -95.20% |
| 5 | 2028-01-01 | 0.254 | 0.0709 | 6797 | 28465.88 | -101435.12 | -94.77% |
| 6 | 2029-01-01 | 0.279 | 0.0716 | 7427 | 35892.88 | -94008.12 | -94.28% |
| 7 | 2030-01-01 | 0.307 | 0.0724 | 8133 | 44026.04 | -85874.96 | -93.74% |
| 8 | 2031-01-01 | 0.338 | 0.0731 | 8925 | 52950.88 | -76950.12 | -93.13% |
| 9 | 2032-01-01 | 0.371 | 0.0738 | 9813 | 62764.05 | -67136.95 | -92.45% |
| 10 | 2033-01-01 | 0.409 | 0.0746 | 10811 | 73574.83 | -56326.17 | -91.68% |
| 11 | 2034-01-01 | 0.450 | 0.0753 | 11932 | 85506.76 | -44394.24 | -90.81% |
| 12 | 2035-01-01 | 0.494 | 0.0760 | 13193 | 98699.55 | -31201.45 | -89.84% |
| 13 | 2036-01-01 | 0.544 | 0.0768 | 14612 | 113311.26 | -16589.74 | -88.75% |
| 14 | 2037-01-01 | 0.598 | 0.0775 | 16209 | 129520.70 | -380.30 | -87.52% |
| 15 | 2038-01-01 | 0.658 | 0.0782 | 18009 | 147530.16 | 17629.16 | -86.14% |
| 16 | 2039-01-01 | 0.724 | 0.0789 | 20038 | 167568.61 | 37667.61 | -84.57% |
| 17 | 2040-01-01 | 0.796 | 0.0797 | 22327 | 189895.16 | 59994.16 | -82.81% |
| 18 | 2041-01-01 | 0.876 | 0.0804 | 24908 | 214803.10 | 84902.10 | -80.83% |
| 19 | 2042-01-01 | 0.964 | 0.0811 | 27821 | 242624.47 | 112723.47 | -78.58% |
| 20 | 2043-01-01 | 1.060 | 0.0819 | 31111 | 273735.18 | 143834.18 | -76.05% |
| 21 | 2044-01-01 | 1.166 | 0.0826 | 34826 | 308560.82 | 178659.82 | -73.19% |
| 22 | 2045-01-01 | 1.283 | 0.0833 | 39023 | 347583.33 | 217682.33 | -69.96% |
| 23 | 2046-01-01 | 1.411 | 0.0841 | 43765 | 391348.45 | 261447.45 | -66.31% |
| 24 | 2047-01-01 | 1.552 | 0.0848 | 49126 | 440474.21 | 310573.21 | -62.18% |
| 25 | 2048-01-01 | 1.707 | 0.0855 | 55186 | 495660.59 | 365759.59 | -57.52% |
| 26 | 2049-01-01 | 1.878 | 0.0862 | 62040 | 557700.36 | 427799.36 | -52.24% |
| 27 | 2050-01-01 | 2.065 | 0.0870 | 69791 | 627491.46 | 497590.46 | -46.27% |
| 28 | 2051-01-01 | 2.272 | 0.0877 | 78560 | 706051.03 | 576150.03 | -39.52% |
| 29 | 2052-01-01 | 2.499 | 0.0884 | 88480 | 794531.22 | 664630.22 | -31.89% |
| 30 | 2053-01-01 | 2.749 | 0.0892 | 99706 | 894237.20 | 764336.20 | -23.24% |
| 31 | 2054-01-01 | 3.024 | 0.0899 | 112410 | 1006647.49 | 876746.49 | -13.46% |
| 32 | 2055-01-01 | 3.326 | 0.0906 | 126790 | 1133437.11 | 1003536.11 | -2.40% |
| 33 | 2056-01-01 | 3.659 | 0.0914 | 143067 | 1276503.66 | 1146602.66 | 10.14% |
| 34 | 2057-01-01 | 4.025 | 0.0921 | 161493 | 1437997.03 | 1308096.03 | 24.32% |
| 35 | 2058-01-01 | 4.428 | 0.0928 | 182356 | 1620352.91 | 1490451.91 | 40.38% |
| 36 | 2059-01-01 | 4.870 | 0.0936 | 205978 | 1826330.96 | 1696429.96 | 58.57% |
| 37 | 2060-01-01 | 5.357 | 0.0943 | 232727 | 2059057.82 | 1929156.82 | 79.16% |
| 38 | 2061-01-01 | 5.893 | 0.0950 | 263018 | 2322076.09 | 2192175.09 | 102.48% |
| 39 | 2062-01-01 | 6.482 | 0.0957 | 297324 | 2619399.69 | 2489498.69 | 128.88% |
| 40 | 2063-01-01 | 7.131 | 0.0965 | 336177 | 2955576.60 | 2825675.60 | 158.79% |

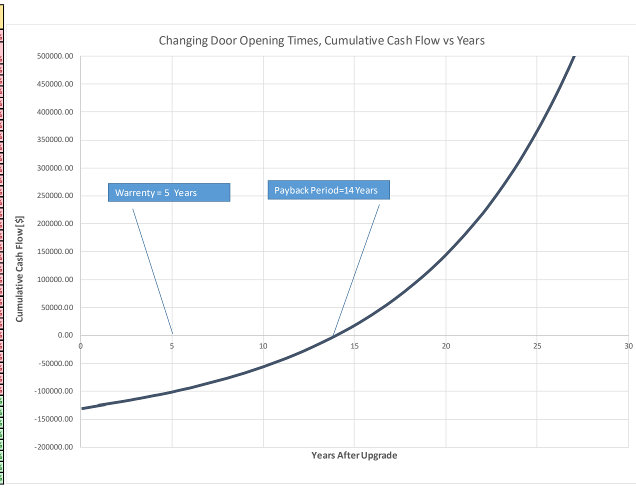



*Fig. M. 6. Results Plotted*

## Appendix M-2 - Air Curtains on Wash Bay Doors

This appendix will describe how pay pack period was calculated for installing air curtains over the two wash bay doors. The methodology described in Appendix M.1 will be used here.

## Fuel Saved by Wash Bay Air Curtains

The only extra procedure for the air curtains will be to find out how much natural gas is being lost out the wash bay doors in order to properly determine how much the air curtains will save. Results from Table 3 use the following procedure to find out the amount of heat lost through the wash bay doors:

Find $Q_{L,washbay}$ :

$$Q_{L,washbay} = \sum Q_{L,14Wx14H\,[80]} + \sum Q_{L,14Wx14H[30]}$$

$$Q_{L,washbay} = 79.8\frac{MWh}{Year} + 29.9\frac{MWh}{Year}$$

$$\boldsymbol{Q_{L,washbay} = 109.8\frac{MWh}{Year}}$$

Find $V_{loss,washbay}$:

$$Q_{L,washbay} = V_{loss} * LHV * \eta$$

$$109.8\frac{Mwh}{year} * 3600\frac{s}{hr} = V_{loss} * 36.6\ MJ/m3 * 1$$

$$\boldsymbol{V_{loss,washbay} = 10800\ m^3}$$

Find $V_{Saved,washbay-aircurtains}$:

$$V_{Saved,washbay-aircurtains} = V_{loss,washba} * \eta_{ther,air\ curtain}$$

$$Q_{Saved} = 10800m^3 * \eta_{ther,air\ curtain}$$

$$Q_{Saved} = 10800m^3 * 0.597$$

$$\boldsymbol{Q_{Saved} = 6447.6m^3}$$

## Initial Cost

Table M.5 outlines the results for the initial cost calculation for the two wash bay air curtains. The methodology is the same as outlined in Appendix M.1.

*Table. M. 5.*

| Air Curtain Unit Pricing -Wash Bay | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Size [ft] | Area, A [$m^2$] | Qty, $X_{door}$ # | Type | Part Number | Velocity [FPM] | Cost Per Unit [$ US] | Cost Per Unit [$ CAD] | Totall Cost [$ CAD] |
| **14W x 14H** | 18.2 | 2 | Berner High Velcity Air | IDC14-4168AZ-G | 7040.00 | $ 6,562 | $ 8,925 | $ 17,850 |
| | | | | | | | Total Cost in CAD | $ 17,850 |

## Electrical Consumption

Table M.6 outlines the results for the amount of electrical the two wash bay air curtains will consume per year. The methodology is the same as outlined in Appendix M.1.

*Table. M. 6.*

| **Air Curtain Power Table - Wash Bay Doors** | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Size | Location | Openings Per Day, $X_{open}$ | Opening Time [s] | Part Number | Specified Motor Voltage [V] | Specified Motor Amprage [A] | Number of Motors | Power Consumed [Kwh/Year] |
| **14W x 14H** | North | 25 | 80 | IDC14-4168AZ-G | 480.00 | 12.80 | 4.00 | 2894.51 |
| | South | 25 | 30 | | | | | 1085.44 |
| | | | | | **Total electrical used per year [Kwh/Year]** | | | 3980 |
| | | | | | **Cost of electrical per year** | | | $504.26 |

## Air Curtain Financials

Using the financial calculator from Appendix L and the inputs calculated in this Appendix, the financials are able to be quantified. The yearly results for the financials are shown in Table M.8, Figure M.5 and the Inputs are In Table M.7.

*Table. M. 7.*

| Inputs for Air Curtains on both Washbay Doors | | | |
|---|---|---|---|
| Variable | Value | Unit | Source |
| Heat Loss Saved | 6477 | $m^3$/year | Appendix M-2 |
| Commodity Rate | 0.1674 | $/$m^3$ | SaskEnergy - Large Commericial Rates |
| Avg Cash Inflation | 3% | % | Appendix L |
| Initial Cost | 17850 | $ | Appednix M-2 |
| Electrical | 504.26 | $ per year | Appendix M-2 |

*Table. M. 8. Financial Results for Installing Air Curtains on Wash bay Doors*

| Year/Winter | | Carbon Tax [$/m$^3$] | Predicted Delviery Charge [$/m$^3$] | Annual Savings [$] | Totall Money Saved [$] | Cumulative Cash Flow [$] | ROI |
|---|---|---|---|---|---|---|---|
| # | Date | | | | | | |
| 1 | 2024-01-01 | 0.153 | 0.068 | 2069 | 2068.71 | -15781.29 | -88.41% |
| 2 | 2025-01-01 | 0.181 | 0.0687 | 2328 | 4396.49 | -13453.51 | -86.96% |
| 3 | 2026-01-01 | 0.210 | 0.0694 | 2601 | 6997.11 | -10852.89 | -85.43% |
| 4 | 2027-01-01 | 0.231 | 0.0702 | 2832 | 9829.26 | -8020.74 | -84.13% |
| 5 | 2028-01-01 | 0.254 | 0.0709 | 3091 | 12920.30 | -4929.70 | -82.68% |
| 6 | 2029-01-01 | 0.279 | 0.0716 | 3381 | 16301.17 | -1548.83 | -81.06% |
| 7 | 2030-01-01 | 0.307 | 0.0724 | 3706 | 20006.77 | 2156.77 | -79.24% |
| 8 | 2031-01-01 | 0.338 | 0.0731 | 4070 | 24076.58 | 6226.58 | -77.20% |
| 9 | 2032-01-01 | 0.371 | 0.0738 | 4479 | 28555.21 | 10705.21 | -74.91% |
| 10 | 2033-01-01 | 0.409 | 0.0746 | 4938 | 33493.09 | 15643.09 | -72.34% |
| 11 | 2034-01-01 | 0.450 | 0.0753 | 5454 | 38947.26 | 21097.26 | -69.44% |
| 12 | 2035-01-01 | 0.494 | 0.0760 | 6035 | 44982.22 | 27132.22 | -66.19% |
| 13 | 2036-01-01 | 0.544 | 0.0768 | 6689 | 51670.95 | 33820.95 | -62.53% |
| 14 | 2037-01-01 | 0.598 | 0.0775 | 7425 | 59095.99 | 41245.99 | -58.40% |
| 15 | 2038-01-01 | 0.658 | 0.0782 | 8255 | 67350.77 | 49500.77 | -53.75% |
| 16 | 2039-01-01 | 0.724 | 0.0789 | 9190 | 76541.01 | 58691.01 | -48.51% |
| 17 | 2040-01-01 | 0.796 | 0.0797 | 10245 | 86786.37 | 68936.37 | -42.60% |
| 18 | 2041-01-01 | 0.876 | 0.0804 | 11436 | 98222.30 | 80372.30 | -35.93% |
| 19 | 2042-01-01 | 0.964 | 0.0811 | 12780 | 111002.16 | 93152.16 | -28.40% |
| 20 | 2043-01-01 | 1.060 | 0.0819 | 14297 | 125299.55 | 107449.55 | -19.90% |
| 21 | 2044-01-01 | 1.166 | 0.0826 | 16012 | 141311.06 | 123461.06 | -10.30% |
| 22 | 2045-01-01 | 1.283 | 0.0833 | 17948 | 159259.28 | 141409.28 | 0.55% |
| 23 | 2046-01-01 | 1.411 | 0.0841 | 20137 | 179396.28 | 161546.28 | 12.81% |
| 24 | 2047-01-01 | 1.552 | 0.0848 | 22611 | 202007.56 | 184157.56 | 26.67% |
| 25 | 2048-01-01 | 1.707 | 0.0855 | 25409 | 227416.45 | 209566.45 | 42.35% |
| 26 | 2049-01-01 | 1.878 | 0.0862 | 28573 | 255989.15 | 238139.15 | 60.07% |
| 27 | 2050-01-01 | 2.065 | 0.0870 | 32151 | 288140.47 | 270290.47 | 80.12% |
| 28 | 2051-01-01 | 2.272 | 0.0877 | 36200 | 324340.27 | 306490.27 | 102.80% |
| 29 | 2052-01-01 | 2.499 | 0.0884 | 40781 | 365120.81 | 347270.81 | 128.46% |
| 30 | 2053-01-01 | 2.749 | 0.0892 | 45964 | 411085.02 | 393235.02 | 157.50% |
| 31 | 2054-01-01 | 3.024 | 0.0899 | 51831 | 462915.96 | 445065.96 | 190.37% |
| 32 | 2055-01-01 | 3.326 | 0.0906 | 58471 | 521387.44 | 503537.44 | 227.57% |
| 33 | 2056-01-01 | 3.659 | 0.0914 | 65989 | 587376.13 | 569526.13 | 269.68% |
| 34 | 2057-01-01 | 4.025 | 0.0921 | 74499 | 661875.24 | 644025.24 | 317.36% |
| 35 | 2058-01-01 | 4.428 | 0.0928 | 84135 | 746010.05 | 728160.05 | 371.34% |
| 36 | 2059-01-01 | 4.870 | 0.0936 | 95045 | 841055.52 | 823205.52 | 432.47% |
| 37 | 2060-01-01 | 5.357 | 0.0943 | 107401 | 948456.16 | 930606.16 | 501.68% |
| 38 | 2061-01-01 | 5.893 | 0.0950 | 121393 | 1069848.66 | 1051998.66 | 580.07% |
| 39 | 2062-01-01 | 6.482 | 0.0957 | 137239 | 1207087.48 | 1189237.48 | 668.84% |
| 40 | 2063-01-01 | 7.131 | 0.0965 | 155186 | 1362273.83 | 1344423.83 | 769.39% |

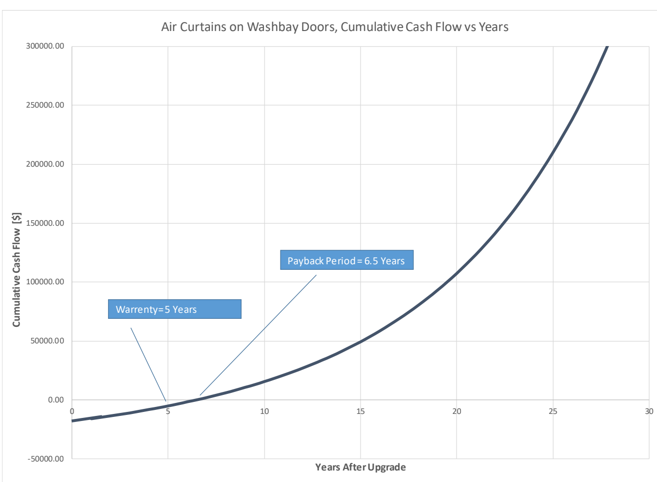



*Fig. M. 5.*

## Appendix N - Seals Conditions

This data is recorded from a visit to the Access Transit Bus Depot. From visual inspection and measuring the amount of infiltration at each door using the Fluke IR Sensor, the seals were able to be ranked. The ranking system goes from 1-4, with 1 being the worst condition of a seal, and 4 being the best condition. Under comments, specific issues were recorded.

**Overhead Door Condition Measurments**

| Door Number | Avg Sill Temp | Sill Seal cond (Ranked 1-4) | Avg Door Jamb Temp | Jamb Seal cond (Ranked 1-4) | Comments |
|---|---|---|---|---|---|
| 11 | -1 | 3 | -15 | 2 | slight gap |
| 12 | -2 | 3 | -15 | 2 | sill gap |
| 13 | -5 | 2 | -15 | 1 | big gaps |
| 14 | -15 | 1 | -30 | 1 | colder around it and frost buildup,worst door |
| 15 | -1 | 3 | -15 | 2 | |
| 16 | -1 | 3 | -15 | 2 | |
| 17 | -10 | 3 | -15 | 2 | wind gaps, frost, dirt |
| 18 | -10 | 2 | -15 | 1 | big gaps, frost, wind |
| 19 | 1 | 3 | -15 | 2 | sill varies |
| 20 | 1 | 3 | -15 | 2 | north washdown bay door |
| 21 | 6 | 4 | 7 | 4 | south washdown bay door |
| 22 | 8 | 4 | -5 | 3 | |
| 23 | 0.5 | 3 | 0.7 | 2 | frost |
| 24 | 5 | 3 | 0.5 | 3 | |
| 25 | 8 | 3 | 0.1 | 2 | tiny gap/frost |
| 26 | 1 | 3 | 0.5 | 2 | slim gap |
| 27 | 2 | 4 | -3 | 3 | slim gap |
| 28 | 6.8 | 4 | -0.5 | 4 | |
| 29 | 5 | 4 | 2 | 1 | big gaps, frost, wind |
| 30 | 5 | 4 | 2 | 4 | bottom air gap |
| 31 | 13 | 3 | 2.5 | 2 | |
| 32 | 0.7 | 3 | 6 | 4 | |

## Appendix O: Combined Financial Graph

All previously talked about financial results produced in this report were plotted on the same graph to produce the result in Figure O.1.

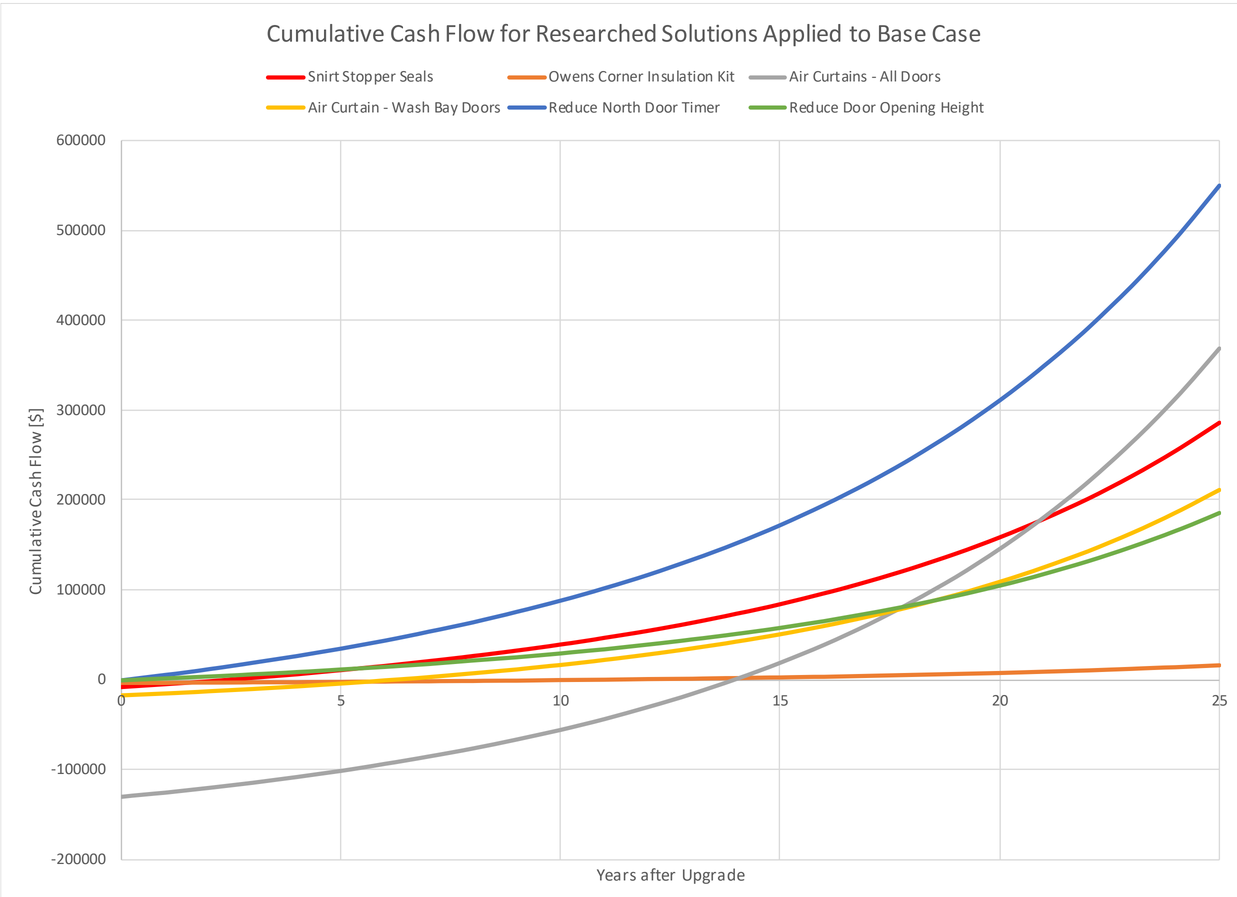
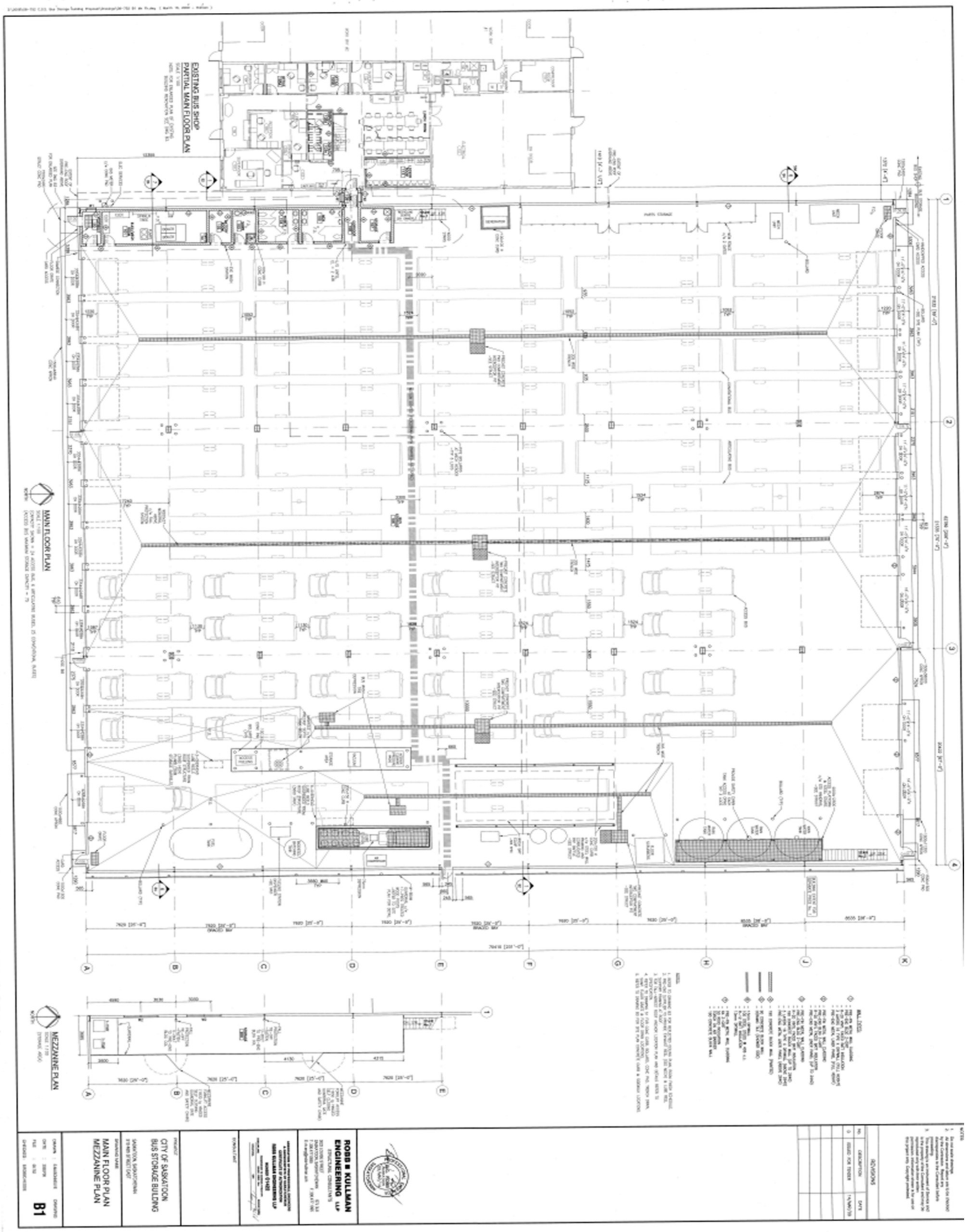
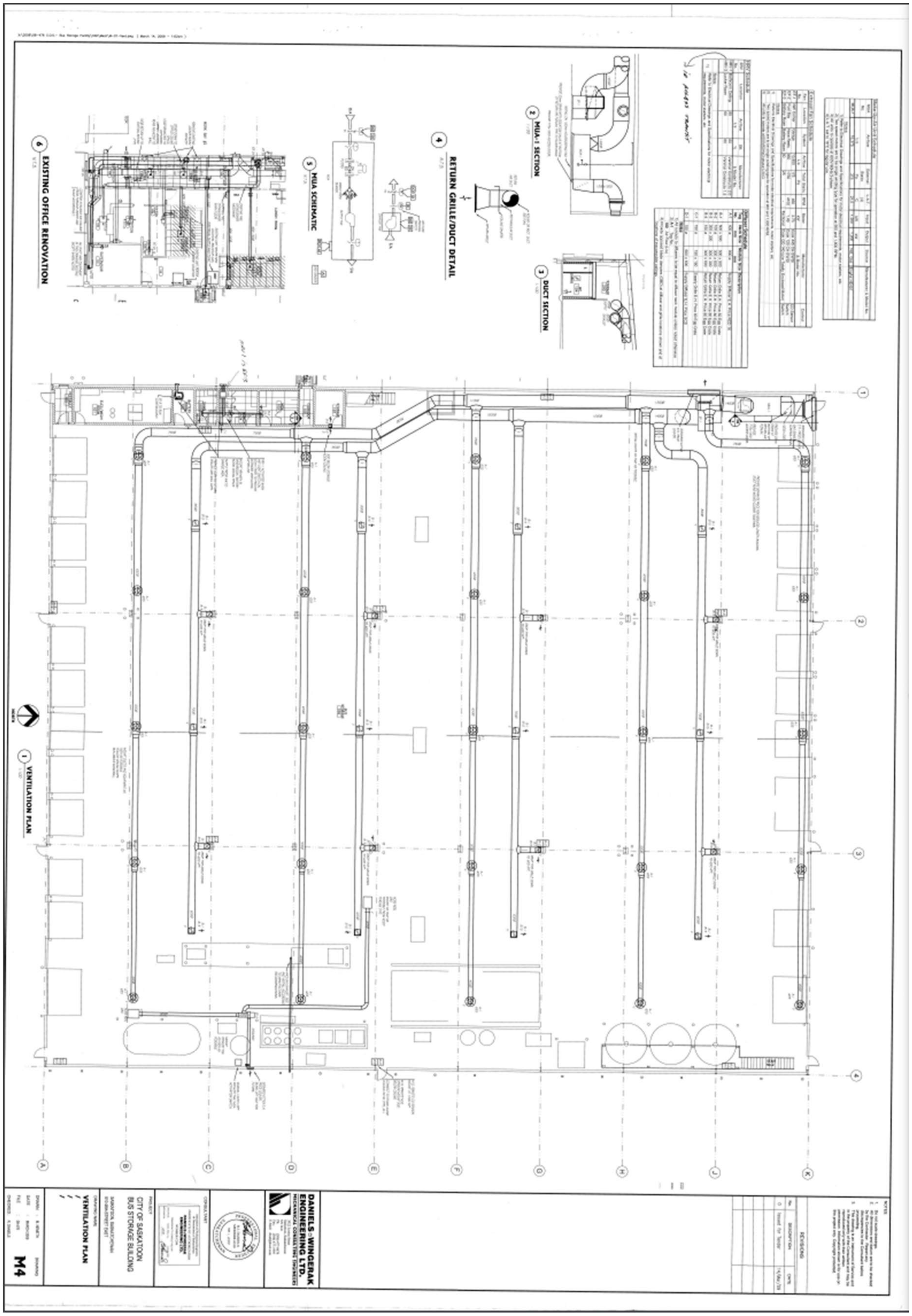



*Fig. O. 1.*

# Appendix P: Floor Plan and Ducting Layout





EXISTING OFFICE RENOVATION
MUA SCHEMATIC
RETURN GRILLE/DUCT DETAIL
MUA-1 SECTION
DUCT SECTION
VENTILATION PLAN
NOTES
REVISIONS
Issued for Tender
DANIELS WINGERAK ENGINEERING LTD.
MECHANICAL CONSULTING ENGINEERS
CITY OF SASKATOON
BUS STORAGE BUILDING
VENTILATION PLAN
M4

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