Bus Envelope Optomization
by
Gabriel Kafka-Gibbons
A Major Qulifying Project
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Abstract

Individuals have been converting vehicles into livable spaces for generations and such practices are becoming common and increasingly socially acceptable. The project was developed to optimize a 1987 school bus into a space conducive of comfortable human life. The following areas were researched to understand the existing vehicle and develop tools for future renovation. The development of an accurate three-dimensional model of the frame, industry standard insulation research, and air and moisture leakage testing.

Acknowledgments

All thanks to Professor Aaron Sakulich who enabled this solo major qualifying project. I have had Professor Sakulich for multiple formative civil engineering classes and his relaxed, encouraging style has been incredibly beneficial for my studies.

Another hugely supportive entity was Simpson Gumpertz and Heger (SGH). Specifically, Jason Der Ananian, Kimberly Lazar, and Zachary Svec who spent significant time and energy organizing, supplying materials, and teaching that blower door tests were possible. For context, I interned for the Oakland SGH office during the summer of 2021. The immediate willingness to support a local student is testament to the beautiful intertwined culture at SGH. Additionally, it is certain the efficiency and quality of results were significantly improved due to our new friends' involvement!

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Executive Summary-5 page maximum summary jist of the whole project. 2 page for my micro report

The Bus envelope optimization project was motivated by a widespread migration to vanlife. Troves of individuals are converting vehicles into nomadic homes. The project focused on a 1987 Ford E350 20 foot school bus. The vehicle had been modified to increase the interior height by attaching an aluminum boat to the top of the roof and cutting out the center of the roof under the boat section.

The projected use case for the vehicle was in temperatures as low as 0° F. A focus on on envelope was necessary to create a vehicle suitable for extreme cold temperatures. The envelope is the partition that seperates the interior of the bus from the outside world. The envelope is being optimized to overcome external thermal and moisture environmental challenges.

In order to develop the envelope of the bus a methodology was developed. The four categories of optimization were developed through, drafting a 3D modecl of the current vehicle, researching industry standard insulation, performing blower door testing, and researching water infiltration. The modeling aspect of the project was completed by accurated measuring elements of the vehicle and designing them in the computerized drawing software, Rhino7. The insulation study was completed by researching other successful van conversion projects and focusing on the insulator materials used. A set of important factors for the insulation were developed then collected. The blower door testing was performed to gain a metric for the air leakage performance of the envelope and inform the water leakage study. Quantitative data is collected in positive and negative pressure tests to illustrate overall performance in regards to air entering and exiting the envelope. Then a positive pressure blower door test pumps air and fog into the envelope creating a positive pressure and forcing the foggy air out of the cracks and gaps in the envelope of the bus. This allows for a visual of areas that will likely allow for water infiltration as well as air infiltration.

The resulting product of the 3D model is an accurate model of the structural and functional elements of the rear of the bus. The metal sheet that encapsulates the bus is omitted because it is uniform and obstructs the other details of the bus frame. The resulting bus frame will be used to expedite renovations and all projects on the vehicle. Instead of having to physically measure the vehical one can quickly measure the computer model. Additionally, the prototyping process can take place on a computer instead of having to physically build a first draft of a design.

The thermal aspect of the project resulted in a table that took into account fiberglass, wool, and foam insulations. Of the different materials there were multiple forms with varied performances. After the materials were researched, the most thermally insulatory, affordable material chosen was foam EPS board insulation for flat surfaces. For the more complex curved areas and the more moisture prone areas, the more expensive wool insulation was chosen. These two materials in conjunction will be used the insulate te entire envelope of the bus.

The air infiltration blower door testing resulted in quantitative baseline data for the air leakage of the envelope. The average between positive and negative air leakage blower door tests at a difference of 75 Pascals between the interior and exterior of the bus has a result of 2.24CFM. This result is significantly worse than a typical New England home which would likely receive a result of between .5 and 1CFM. This was explained by the leaky double-hung windows and drilled holes in the floor of the vehicle.

The water infiltration is illustrated by the positive pressure blower door fog testing. The areas where significant quantities of fog visably leak from the envelope are the areas where moisture will leak into the vehicle.

The project developed an understanding of how the envelope of this bus must be adapted to address thermal and moisture necessities. The project identified the areas that must be addressed and will provide an understanding of problem areas to future designers of similar vehicles and this specific vehicle.

Background:

The subject of this project is a 1987 Ford E350 short school bus. Typically, the chassis of school buses are manufactured by automotive companies and the envelopes are developed by fabrication companies that specialize in school buses and vans. This vehicle has a Ford drivetrain and chassis, and a Thomas Built Buses envelope.

The Ford E350 is the most popular van in America and in this case the chassis is taken from that van and distributed to school bus manufacturing companies. The Collins Dictionary defines a chassis as "… the framework that a vehicle is built on." (1) Also pictured is the drivetrain exhaust and suspension.

Figure 1, Ford commercial chassis similar to the buses older chassis

The envelope of the bus is the focus of the project. The structure that encloses the vehicle is the envelope. The structural elements of the envelope are comprised of 1.5-inch cubic steel members. These members create a frame covered with 1/16" sheet metal for the roof, typical bus windows hung up both sides, and a sheet metal floor with indents for the wheel wells. Shown in figure 2 is the steel frame.

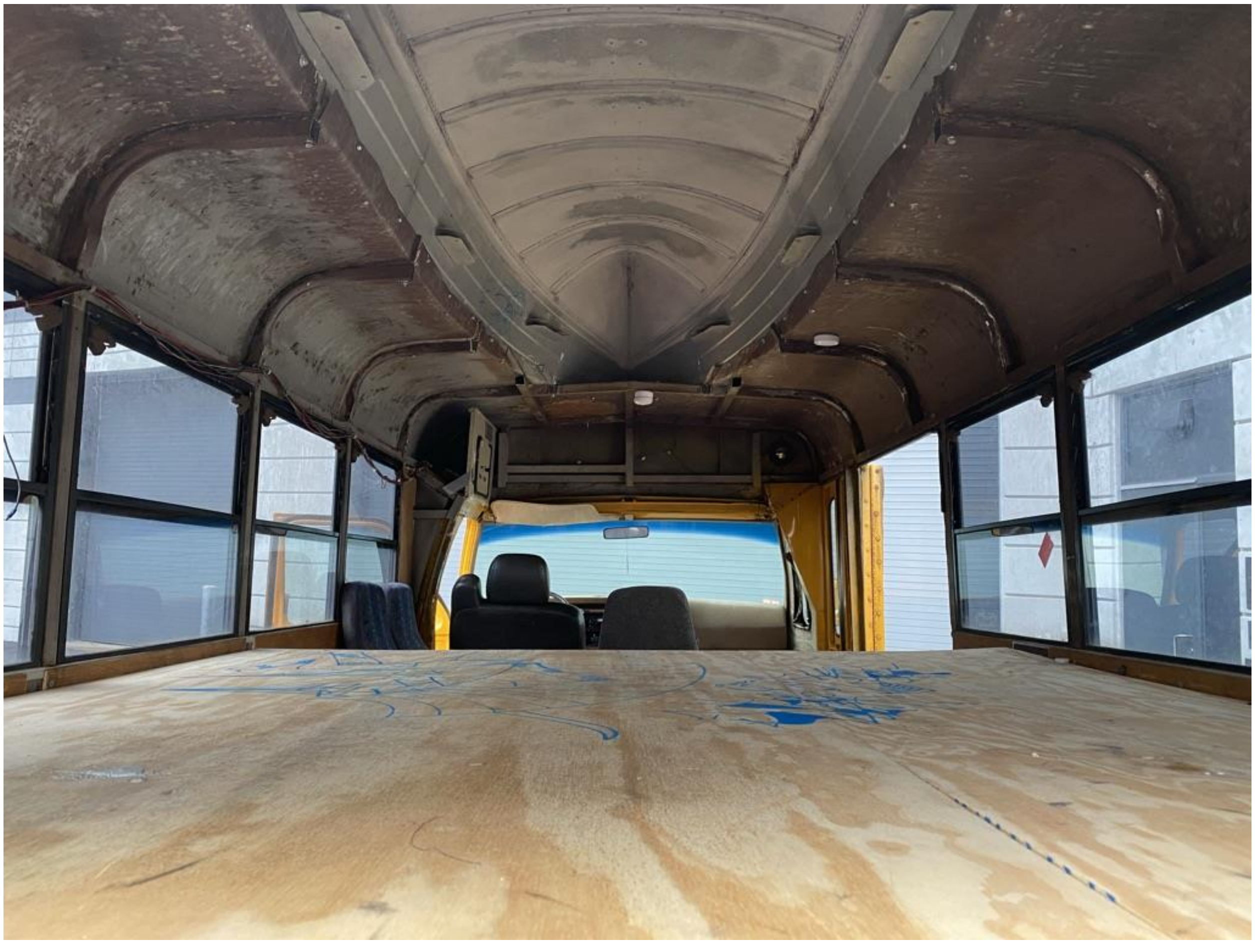


Figure 2, bus 1.5” cubic steel frame and aluminum roof raise

Additionally, a 12-foot aluminum boat has been secured to the frame of the roof and the area of the roof within the boat has been cut out to add extra headroom. This boat extension will be referred to as the “roof raise”. This will be a major consideration in the paper because although it created important head space in the living area, it also allowed for thermal and moisture weak points in the envelope. The roof raise is illustrated in figure 3.

Figure 3, aluminum boat roof extension

This vehicle is being prepared to minimize moisture and thermal conductivity as well as possible because its use case is as a recreational vehicle or tiny home. The van life movement has been a migration of people living in typical apartments and houses to move into vehicles like vans or buses. There are many factors that have driven this movement, some of them being the overwhelming cost of living, inability to live nomadically, and lack of access to nature.

The cost of living in a typical rented residence is incredible in the United States. Rent is very dependent on location. In the major coastal centers rent is often over 40% of one's annual income. (2) This staggering figure is one of the core causes for the van life migration.

Additionally, leases are typically for full year cycles and bind renters to their contracted apartment. With the recent Covid-19 pandemic "roughly 70%" of the US population was working remotely as of May 2020. (3) This remote work is allowing employees to take on nomadic lifestyles that physically going to the office doesn't allow. This has enabled remote workers to take up van life.

A final common theme among van lifers is a desire for more nature. Urban cityscapes are devoid of nature apart from sparse trees and suburbs with sprawling non-indigenous grass fields. In contrast, van life allows remote workers to continue work anywhere they can access the internet.

The alterations in a van build vary widely but a typical final project would often account for temperature control, food access, bathroom access, water access, electricity, sleeping space, recreation space, and workspace. These requirements are met to differing degrees in the wide range of van builds. In this short bus project, climate control will be incredibly important when the van is exposed to temperatures below freezing. The space will be designed to accommodate the Dickinson Newport P12000, a propane nautical heater. The short bus will have a small two cubic foot refrigerator, two cubic foot pantry, and a double burner stove. There will be a small sink with a gravity-fed hose coming from a 20-gallon tank. Electricity will run off a 200V solar panel connected to a 1500W inverter and charge controller. The alternator will send excess energy while driving to the batteries. This system will be able to power most appliances. The sleeping area will be a single bed that can be pulled out into a queen size bed. Apart from thermal control, these elements are not central to the scope of this project but provide the context for the narrower scope of the project.

This vehicle is being designed for use in conditions suitable for skiing. The vehicle must be able to maintain an internal 60° F at an external 0° F. This means the van must be insulated. The propane heater will produce heat, but for the space to maintain its heated temperature it must be thermally insulated. The way resistance to heat transfer is measured is with R-values. Oxford Libraries defines R-value as “the capacity of an insulating material to resist heat flow. The higher the R-value, the greater the insulating power.”

The van will also be designed to withstand heavy rains and consistent snow melting on the roof as well as two humans living in the vehicle. For a typical home, the focus of full waterproofing happens below grade. Grade is the height of soil surrounding the structure. For this reason, the full structure of the bus is going to be above grade. Generally, above grade structures have a vapor barrier to ensure humidity isn’t being trapped within the walls of the structure and depending on the use are sometimes waterproofed. The bus will be different from a typical structure in this regard because it must be waterproof while stationary and while driving on the highway. For that reason, it’s important to waterproof all angles of the vehicle. Additionally, a human’s moisture output while breathing is significant, especially in such a low volume space. In the winter windows will have frozen layers of moisture in vans depending on their heating systems. Typically, humid propane heaters add moisture to the environment and will create an environment where surfaces, blankets, and windows are all damp. If one uses a miniature wood stove or a diesel heater it acts as a dehumidifier and the moisture problem is eliminated. For that reason, a diesel heater was chosen.

The bus will be tested for air leakage to support both thermal insulation and waterproofing. Air leakage will be tested with a blower door test. More significant air leakage indicates worse thermal insulation and greater likelihood for water infiltration. It is less efficient to insulate a space with thick non thermally conductive foam but leave a window open. Effectively one is allowing for direct flow atmosphere through whatever area is allowing the pressurized air in the system to escape. The reasoning for blower door tests in homes is to test the rate of air leakage in a home. In a static house, the reason for testing is almost exclusively thermal optimization. In the bus project, the blower door test will identify both thermal and liquid areas of weakness. This is because the van must be waterproof from every angle as it is often driven in the rain.

Methodology

The four components of this MQP project were CAD design, thermal insulation, air leakage testing, and moisture mitigation. The existing frame was modeled in Rhino based on measurements taken from the bus. Building from that physical CAD model, industry standard insulations were researched and documented. Blower door teting was conducted to research air leakage and points of likely moisture intrusion.

The focus on computerized design and modeling (CAD) was in order to create a more efficient version of the bus to access while developing the testing methodologies for the thermal and moisture components of the project. For this segment of the project, the program Rhino 7 was used. Rhino 7 is the leading industry standard for three dimensional computerized design projects. The modeling began with measuring and replicating the simple geometry of the back of the bus. The bus is constructed of 1.5 inch square cross section steel members, so the seperation of these members were measured. Then a singular "rib" was modeled. The rib being referred to is a fabricated length of 1.5 inch square cross section steel that makes two 90 degree, one-foot filleted angles. This rib creates the shape of the bus looking at it from the front or the rear. The singular rib was copied and pasted at the measured intervals to create a to scale model of the back cabin of the bus. The side windows were added to the model. Then the ribbed floor was modeled and inserted. The hinging handicap door was added to the model and finally the boat roof raise was measured and modeled. Once the boat was modeled and attached to the model, the areas of the ribs that were inside the bounds of the boat roof raise were trimmed out of the model as they were trimmed out in the physical bus. This CAD model then represented the existing bus. With that model, future square footage estimations will be made and other design decisions where the physical bus would've otherwise needed to be measured.

The blower door testing was conducted with Simpson Gumpertz and Heger guidance. The testing consisted of negative pressure blower door testing, positive pressure blower door testing, and positive smoke machine blower door testing.

The blower door was installed in the handicap side door. For all three tests brackets were installed in the door frame to ensure the blower wouldn't pop out during positive pressure tests.

Figure 4, blower door bracket

The frame was then sized and inserted with the red canvas material sealing the entry. As shown in figure 5, the frame was sized using sliding aluminum brackets. Figure 6 shows the frame fully installed, and the fan was inserted for the negative pressure test blowing out.

Figure 5, blower door canvas

Figure 6, blower door frame

Figure 7, blower door installed for negative test

Once the blower door was fully installed as seen in figure 7, one of the DG700 pressure sensors was connected to the fan with reference to internal atmospheric pressure. The other DG700 was connected to the outside atmospheric pressure with reference to inside atmospheric pressure. All tubes end outside of the path of the blower.

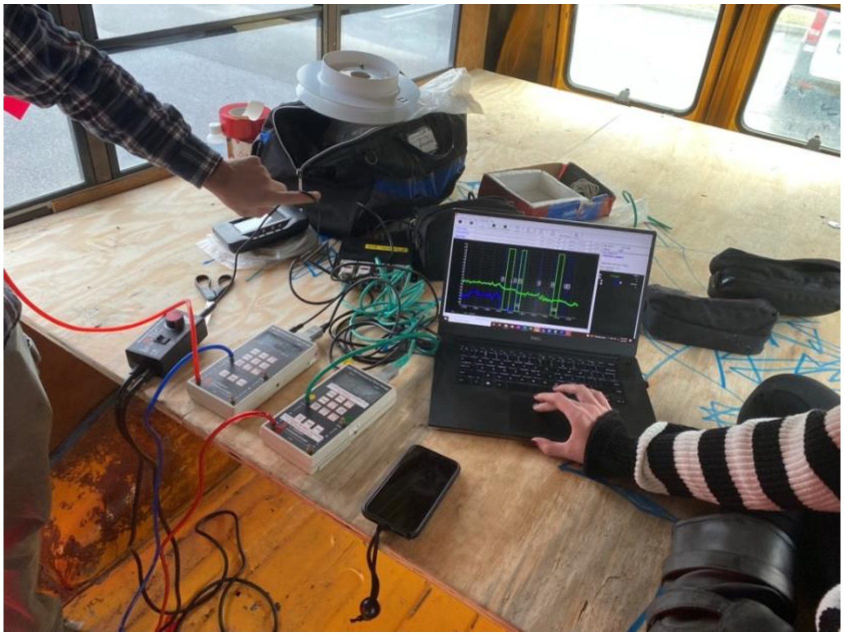


Figure 8, DG700 and TecLog4 system

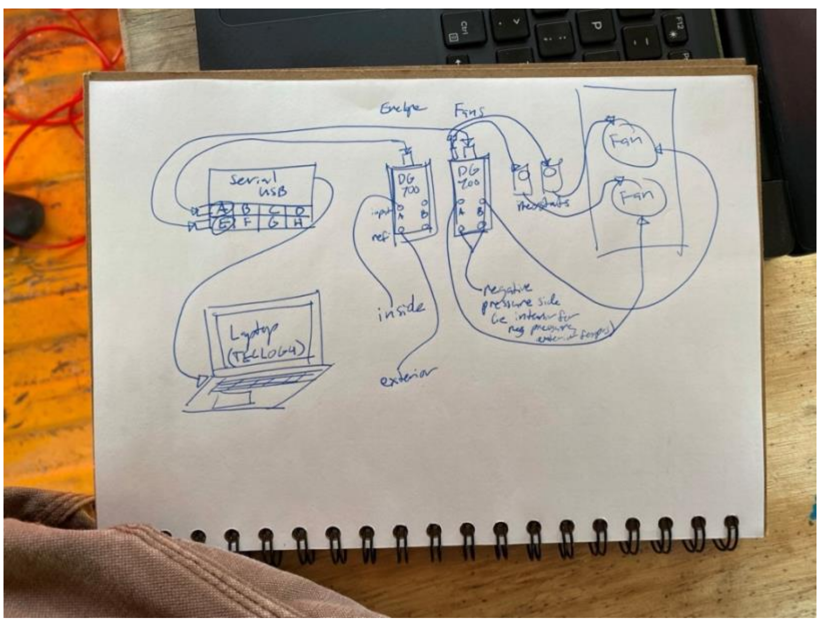


Figure 9, DG700 and blower door system diagram by Kimberly Lazar

As seen in figure 9, SGH employee Kimberly Lazar's diagram of the DG700 Teclog setup illustrated in figure 10. The test is performed by increasing the pressure over the fan in 10 Pascal increments. It was decided to conduct a 75 Pascal test where the test was started with a baseline at a 0 pascal difference through the fan then collected about atleast 30 seconds of clean data at 10, 20, 30, 40, 50, 60, 70, and 75 Pascals. The difference in pressure was then scaled back down starting from 75 then 65, 55, 45, 35, 25, 15. The periods of time with the most consistent data at these points were selected. The fan was on “autopilot” where the fan adjusts to meet the set value pressure difference across the fan at the aforementioned points. Throught the test, the plastic “rings” were removed to allow for designated fan pressures. To begin, all of the rings were installed and the fan was sealed for the baseline test. The test began with ring B installed. When the fan couldn’t produce the pressure necessary rings were removed. After the test was conducted with the fan blowing out it was untaped and turned around for the positive test. The process was then repeated for the positive pressure test.

During the positive pressure test, it was noted that external wind was affecting the external pressure readings so a shielded pressure gauge was used to mitigate the problem.

The third test was a positive pressure visual test using a fog machine. The fan was set up to blow into the bus and a power cord was routed throught the fan elastic section to power a fog machine. The fog machine was then started and filled the bus with fog with all elements sealed, then the blower was turned on and forced fog out of the vehicle to give a visual of the areas of greatest leakage.

Figure 10, Fog machine test

Figure 11, Fog positive pressure testing. The fog appears faint but was clear in person.

The determining factor for insulation choice was based off internet research and expert consultation. There are many factors in choosing a thermal insulation for a van build. The first step was researching the common insulation materials for bus conversions. Then categories were developed for important factors for each of the chosen insulation materials. These categories included R value per inch, price per cubic inch, moisture entrapment, and material rigidity/construction consideration. After these categories were identified, database searches were conducted on Google and accessible building material wholesellers like Home Depot were used to determine price and R-value. The moisture entrapment data was gathered from typical building practices for homes and sheds as well as material rigidity.

Regarding moisture content, research was conducted through both online research and expert consultations. The research was gathered from other van life builds that completed roof raises regarding water leakage. The expert consultation for roof raises and direct water leakage was through Parker Gregory who completed an aluminum frame sheathed in plywood roof raise on his 2003 Ford E350 van. The boat design was based on Parker's successes adding head height to his van with an aluminum frame. On the topic of moisture entrapment from breathing, internet research was the main source. In this case the Google search was "how to manage breath condensation in van builds" because it is a common problem where vans become damp internally because of the occupants breath.

Results

The computerized drawing section of the project was realtively straightforward and the results mirror the plan laid out in the methodology. The resulting product was a 3D Rhino 7 model. The model included the structural components of the vehicle and general form. The tools used to create the relatively complex curves of the frame and boat used the “sweep1” extrusion tool and other manuevering, sketching, copying and pasting. The resulting elements are a Rhino model that can be used to mock up floor plans in the future and an expanded knowledge of the Rhino 7 software.

Figure 12, Still of CAD model

The resulting industry research revolving around van conversion insulation yielded a table of factors central to insulations effectiveness. The metrics used were R-value per inch, price, moisture performance, and construction factors. The different insulations were chosen because of their common use in van life projects.

Insulation Type	R-Value Per Inch	Price Per cubic inch	Moisture	Material Rigidity/Construction Considerations
Unfaced Fiberglass Insulation	2.9 – 3.8	.004$	Mold is possible and gets trapped by facing	Flexible
Roxul Rockwhool 1.5"	3.3 – 4.2	.008$	Mold is possible but the material will shed water better than fiberglass	Semi rigid sheets
Havelock Wool Batt insulation		.75$	Mold is unlikely and the wool will shed water better than Rockwool	
R-tech Rigid Foam Insulation (Extruded Polystyrene)	5		Mold is near impossible within the foam	
Formular Foam Board (expanded polystyrene)	5.78		Mold is near impossible within the foam	
Spray foam(Open Cell)	3.6-3.9		Mold is near impossible within the foam	

Table 1: R values from https://todayshomeowner.com/insulation-r-value/

The moisture testing and air leakage testing became intertwined in the testing and investigation of the bus. This is because the areas of air leakage coincide directly witht the areas of moisture intrusion. The blower door testing therefore yielded results for both moisture and air leakage. The resulting weak points were identified through blower door testing.

The first two tests preformed were positive and negative pressure blower door tests. These tests produce a quantitative value to gauge the air tightness of an enclosure. The first test was a 75 Pascal positive pressure blower door test, followed by a 75 Pascal negative pressure blower door test.

The blower door air leakage testing was done in three tests. The first two tests were typical blower door tests that would be done on a typical home to gauge the overall air tightness of an enclosure. The third test was a visual fog test to illustrate the areas of greatest leakage. The resulting data produce a quantitative metric for the airtightness of a home. The units for this test are in cubic feet per minute, abbreviated to CFM.

As illustrated in the methodology, the test is done by changing the pressure difference between the inside and outside of the envelope and recording how much air has escaped or entered the vehicle. As the delta pressure is increased the amount of air escaping increases. These data are taken over time. The resulting graph is illustrated in figures 13 and 14. The green line illustrates the pressure difference on the inside and outside of the vehicle. The blue line represents fan speed. The blower door setup automatically changes the speed of the fan to reach the pressure difference dictated by the program user. Figure 13 illustrates the negative pressure test where the fan was blowing airnout of the bus creating a negative pressure in the vehicle. On the left side of the image the failed test can be seen. As the delta pressure was ramped up, the fan was unable to create delta pressure above 45 Pascals. We did not notice the data had plateaued and completed the test. The delta pressure was unable to reach the necessary delta pressure because the rings that are taken off to increase air flow were not removed as needed. The program typically alerts the tester when a ring needs to be removed to reach a delta pressure but in this case the program did not alert the tester. For the second test seen on the right side of the image, the ring was removed when the testers manually observed the platue. The resulting test offered usable data that could be processed to produce figure 14. In Figure 14 one can see the data points extracted from the test in figure 13. The horizontal green lines on the right side of figure 13 show the areas of clean data selected to create the data points for different delta pressure levels. Notice the "envelope pressure" on the x-axis are at roughly 5Pa intervals. The resulting graph is the final metric for how airtight the envelope is. The negative pressure test yields a result of 2.176 CFM.

The overall result of negative pressure blower door testing is 2.176 CFM. This result means 2.176 cubic feet of air per minute enters the envelope when the internal pressure is 75Pa less than external atmospheric pressure.

The positive pressure blower door testing was parallel to the negative pressure testing apart from the failure apparent in the early data of the negative test. The positive test went smoothly and the resulting data is in figure 16. The resulting cubic feet per minute for the positive pressure test is 2.304 CFM.

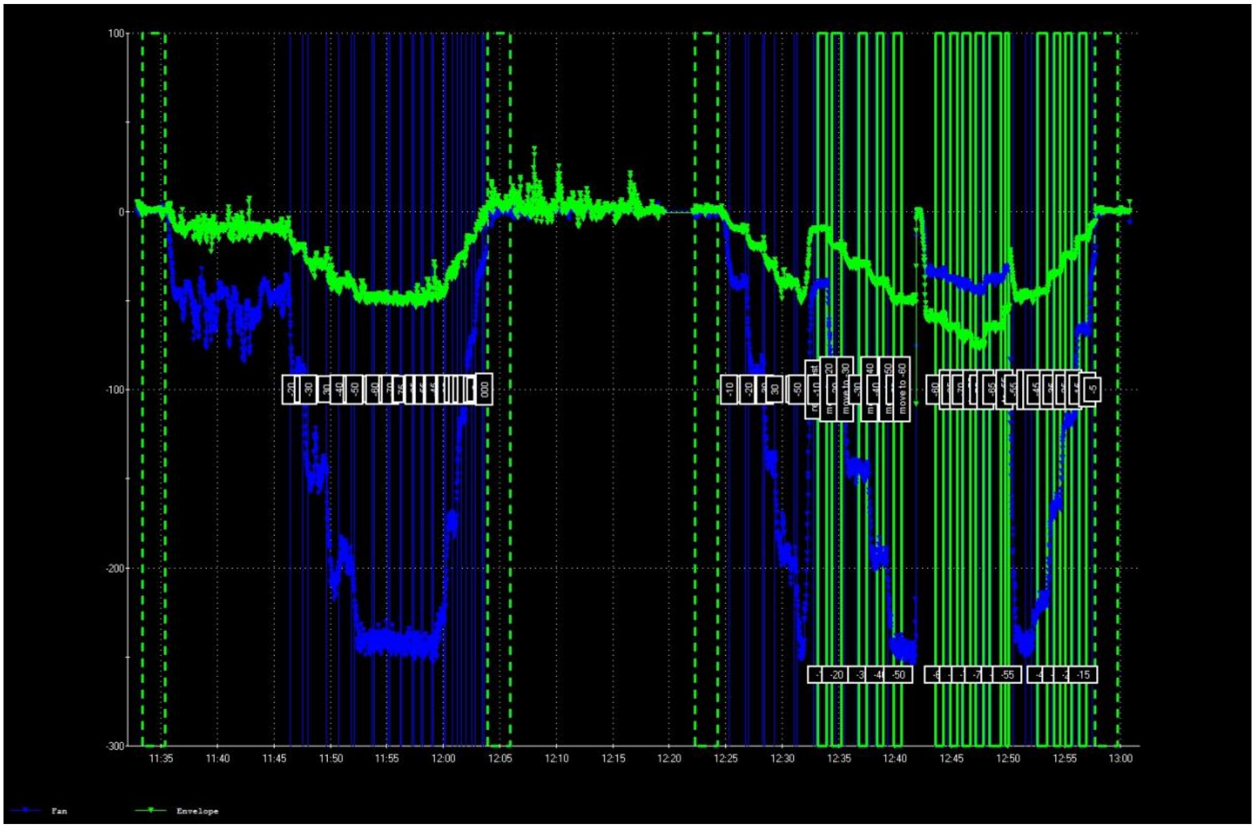


Figure 13, negative pressure blower door results

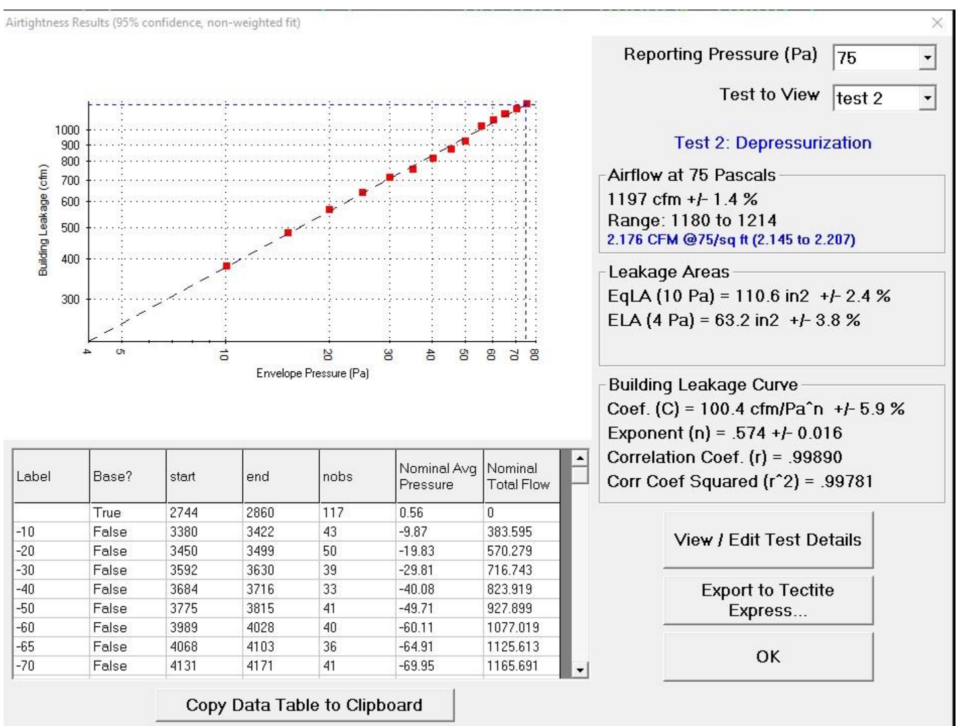


Figure 14, negative pressure blower door results

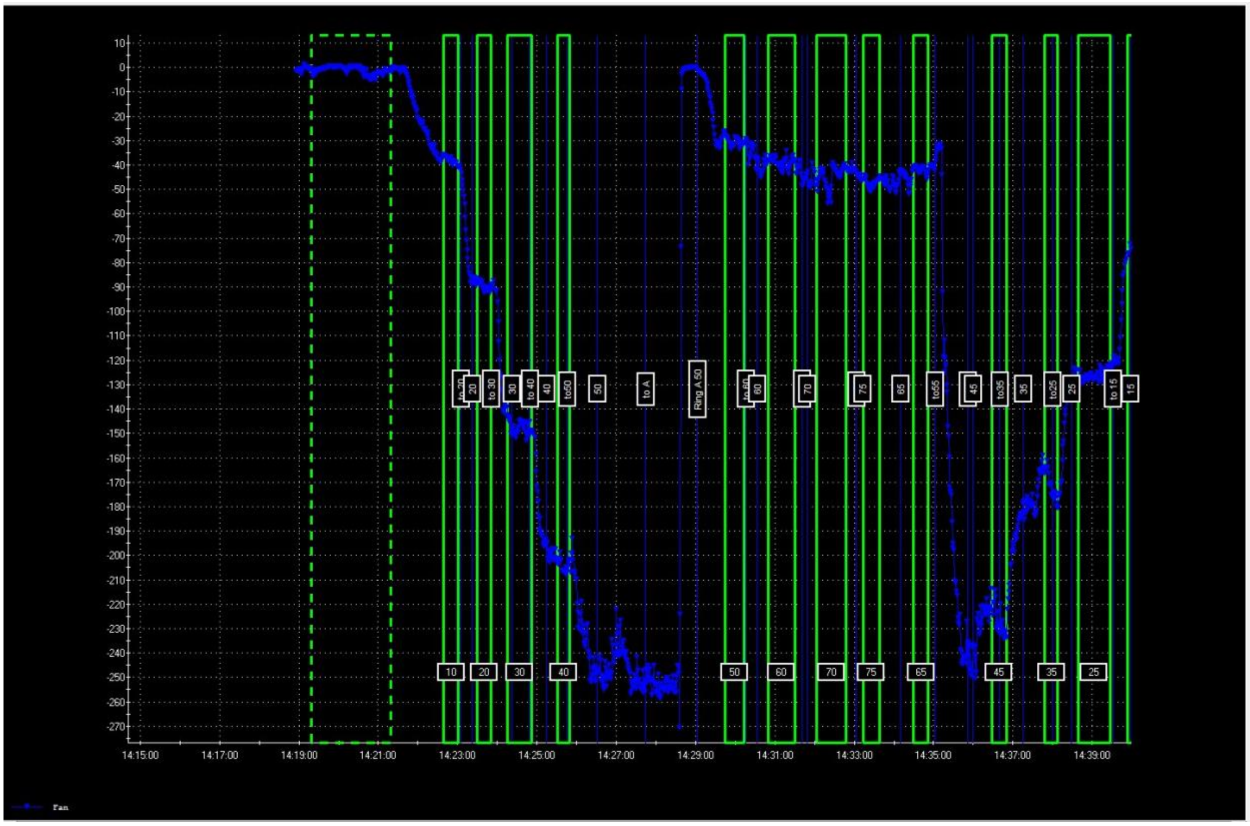
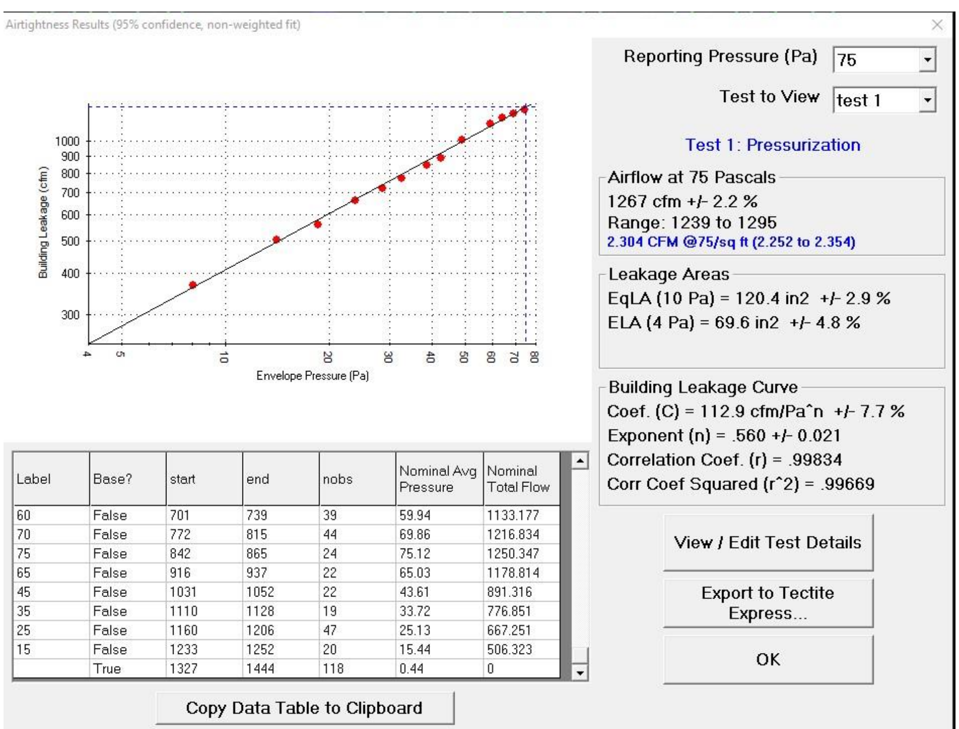


Figure 15, negative pressure blower door results



Label	Base?	start	end	nobs	Nominal Avg Pressure	Nominal Total Flow
60	False	701	739	39	59.94	1133.177
70	False	772	815	44	69.86	1216.834
75	False	842	865	24	75.12	1250.347
65	False	916	937	22	65.03	1178.814
45	False	1031	1052	22	43.61	891.316
35	False	1110	1128	19	33.72	776.851
25	False	1160	1206	47	25.13	667.251
15	False	1233	1252	20	15.44	506.323
	True	1327	1444	118	0.44	0

Figure 16, positive pressure blower door results

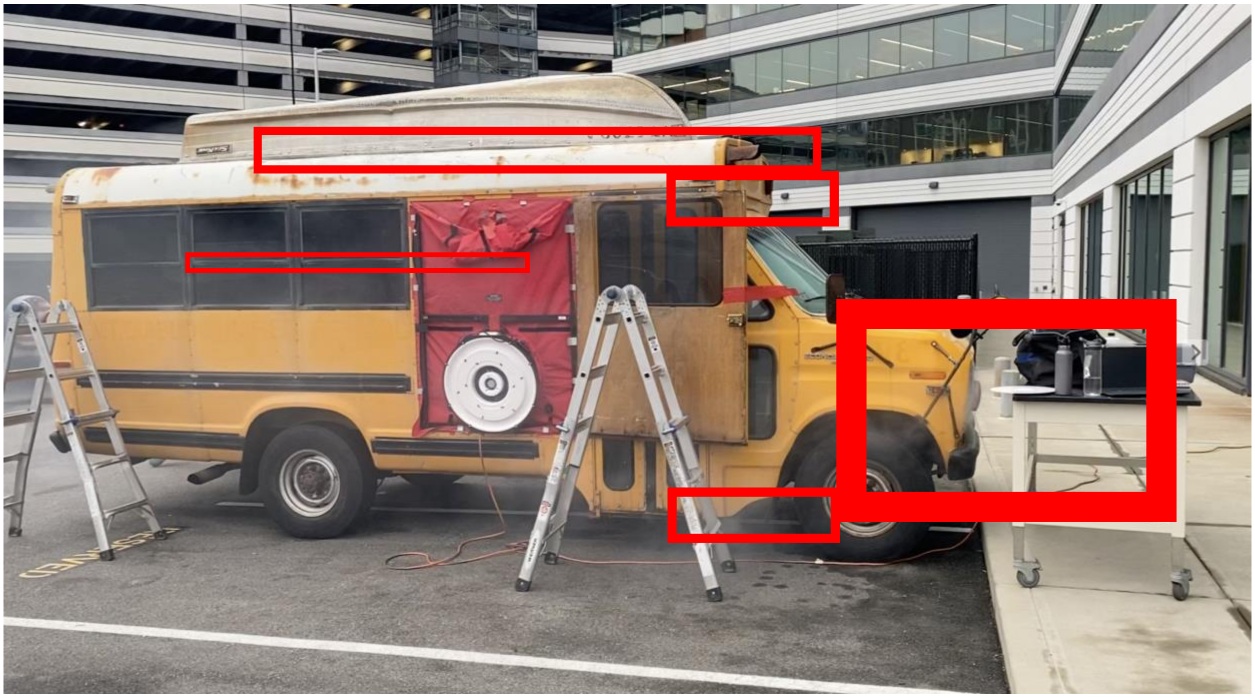


Figure 15, points of air leakage

Figure 16, detailed photos of air leakage

The fog machine positive pressure test was preformed last to identify the areas of greatest air leakage. It was discovered the holes in the floor of the bus initially drilled for the seats in the school bus were a major cause of leakage. All of the windows were quite leaky at the seam between the doube hung windows. The lights were all relatively leaky. All entrances illustrated significant leakage. The point of attachment of the boat was a point of air loss. The front cabin demonstrated significant air leakage.

With these common causes identified the necessities for the bus build can be investigated.

Conclusions

The Computer Aided Drawing model developed throughout this project will serve as a guide for future renovations of the bus. Accurate measurements were referenced and mirrored resulting in a model that is exactly to scale. This will be helpful when anyone that plans to make alterations to the vehicle can return to the model to take measurments instead of having to physically measure the bus. Additionally in an instance where the bus were being converted into a tiny home, items such as a bed and cabinets will have to be added. Having a computerized model to develop the furniture will expedite the process. The model can affectively help one prototype without the user having to physically create prototypes. Additionally items can be hidden to allow for better view of other elements of the vehicle. For instance the boat that has been added to the top of the vehicle could be temporarily hidden to allow one to explore a different roof alteration or for instance the addition of a skylight. Generally the CAD model will increase efficiency in future additions to the bus.

The insulation portion of this project resulted in an understanding of industry standard insulation materials. Using these results we can decide which areas to prioritize. In this instance R-value per foot is the most important factor, followed by moisture, followed by price. With these priorities taken into account we can conclude that a mixture of foam EPS insulation will be the best insulating material for flat areas such as the floor and the walls. The roof is a curved area that is likely to get wet so the more expensive wool insulation option will be employed.

The two branches of testing were the blower door air leakage testing, which provided a metric for air tightness and the fog positive pressure test which demonstrated areas of greatest leakage. In regard to blower door testing we were able to take away a quantitative understanding of the air tightness of the enclosure. In the future when the envelope is optimized, testing can be repeated to allow for an understanding of the envelope improvement. The fog testing is linearly helpful in the sense that the areas that demonstrated fog leakage must be prioritized when sealing the envelope.

These two conclussions will work well in conjuction to mitigate air leakage and if blower door tests are redone after optimization, the level of improvement will be able to be quatitatively understood. For instance the average leakage between positive and negative tests will be comparted to the average leakage between positive and negative tests post optimization. The average leakage prior was 2.24CFM. This result will allow us a baseline metric to gauge how well the optimization of the envelope has gone after construction.

It is noteable that positive and negative pressure tests yielded slightly different results. There is no significant conclusion because the differences between the tests were minor. If the results had been significantly different, that would be explained by a flap that is opening with positive pressure and closing with negative pressure or something of the sort. In this case the results were uniform. A typical building in Masachusettes would have a blower door result between .5 and 1CFM. Therefore, the bus is quite leaky in comparison to a typical building. This can be explained by the vehicles age, the leakiness of the doors and windows, and the holes present in the floor of the vehicle.

Design and Licensure Statement

The ability to design engineering systems is central to the WPI experience and education. Throughout the first couple years of undergraduate study, students gain general knowledge in the field of civil engineering with calculus, physics, and chemistry classes. These classes evolve into more specialized courses for each of these disciplines within Civil Engineering. For instance, physics evolved into multiple statics courses specific to structural and civil engineering. These are the fundamental 2000-level Civil Engineering courses required for all undergraduate Civil engineers. As the only student in this project group, Gabriel Kafka-Gibbons began to gain knowledge in a variety of specialized fields, design and execution of theoretical skills became incredibly important.

The design challenge for this MQP was to optimize an enclosure with less than ideal thermal and moisture conditions for living. This ties directly into the work Gabriel Kafka-Gibbons has done with SGH during his internship. SGH was additionally brought in as a sponsor in this project. They donated the time of their workers and the testing material that allowed for the team to complete blower door tests on the envelope. This testing was central to the analysis element of the design process. Most of the project was focused on research and design with minor elements of synthesis. The physical intervention was fabricating blockages with epoxy, rubberized caulk, and fiberglass. The analysis led to discoveries of areas that were not airtight in the envelope and once they were located, they were sealed.

It is important that projects like these and especially projects on a larger scale are backed by a licensure procedure because it holds engineers accountable for the work they produce. It is a necessity that the Sika-flex was used to seal the cracks in the bus has testing to back the manufacturer's claims regarding material properties. Additionally, Civil Engineering licensure is even more important. A clear example of the necessity for licensure is for structural civil engineers. There is a clear process to becoming a structural engineer wherein a student must attend an ABET accredited college then pass their more general FE Civil engineering exam, complete four years of structural engineering under a licensed structural engineer who effectively acts as a mentor, then pass their specialized PE structural engineering exam. This allows the structural engineer to get the ability to give the final pass and stamp projects. This ensures we have specialists making sure our buildings are safe. Furthermore, the system feeds back into itself because it holds universities to a high standard to meet the ABET accreditation process.

Bibliography

1 big bag 200 sqft. Havelock Wool. (n.d.). Retrieved December 21, 2021, from https://shop.havelockwool.com/products/wool-batt-2?variant=17431525523507¤cy=USD&utm_medium=ppc&utm_source=adwords&utm_content=sag_organic&utm_campaign=Shopping&utm_term=&hsa_src=u&hsa_kw=&hsa_mt=&hsa_cam=8259444373&hsa_grp=82479894382&hsa_net=adwords&hsa_ad=399725416929&hsa_ver=3&hsa_tgt=pla-1216162338852&hsa_acc=3434447461&gclid=CjwKCAiA1aiMBhAUEiwACw25MT2HxQYkrad2fHPcPTLh8so3diXXZyN45T_OiUuP43DO6yt9jtWHqxoCkEMQAvD_BwE

1 1/2 in x 48 in x 24 in mineral wool high temperature insulation, density 8#, green. Grainger. (n.d.). Retrieved December 21, 2021, from https://www.grainger.com/product/19NE77?ef_id=CjwKCAiA1aiMBhAUEiwACw25MYpwGNNJYYF2NfILBFZrjPBola1cTvhoJRR9U_z5OvSP46b4ef88wBoC3HsQAvD_BwE%3AG%3As&s_kwcid=AL%212966%213%21281698275777%21%21%21g%21471093561309%21&gucid=N%3AN%3APS%3APaid%3AGGL%3ACSM-2295%3A4P7A1P%3A20501231&gclid=CjwKCAiA1aiMBhAUEiwACw25MYpwGNNJYYF2NfILBFZrjPBola1cTvhoJRR9U_z5OvSP46b4ef88wBoC3HsQAvD_BwE&gclsrc=aw.ds

2022 FORD® E-350 Stripped Chassis: Model Details & Specs. Ford Motor Company. (n.d.). Retrieved December 21, 2021, from https://www.ford.com/commercial-trucks/e-series-stripped-chassis/models/e350-drw/

HarperCollins Publishers Ltd. (n.d.). *Chassis definition and meaning: Collins english dictionary*. Chassis definition and meaning | Collins English Dictionary. Retrieved December 21, 2021, from https://www.collinsdictionary.com/us/dictionary/english/chassis

Owens Corning foamular 150 1-1/2 in. x 4 ft. X 8 ft. R-7.5 scored squared edge rigid foam board insulation sheathing-88wd. The Home Depot. (n.d.). Retrieved December 21, 2021, from https://www.homedepot.com/p/Owens-Corning-FOAMULAR-150-1-1-2-in-x-4-ft-x-8-ft-R-7-5-Scored-Squared-Edge-Rigid-Foam-Board-Insulation-Sheathing-88WD/202085958

Owens Corning R-6.7 ecotouch pink multi-purpose, small project unfaced fiberglasss insulation roll 16 in. X 48 in.-a85p. The Home Depot. (n.d.). Retrieved December 21, 2021, from https://www.homedepot.com/p/Owens-Corning-R-6-7-EcoTouch-PINK-Multi-Purpose-Small-Project-Unfaced-Fiberglasss-Insulation-Roll-16-in-x-48-in-A85P/100320315

R-tech 1-1/2 in. x 4 ft. X 8 ft. R-5.78 rigid foam insulation-320817. The Home Depot. (n.d.). Retrieved December 21, 2021, from https://www.homedepot.com/p/R-Tech-1-1-2-in-x-4-ft-x-8-ft-R-5-78-Rigid-Foam-Insulation-320817/202532855

Ringler, A. (2020, January 8). *What is the R-value of spray foam insulation?* RetroFoam of Michigan. Retrieved December 21, 2021, from https://www.retrofoamofmichigan.com/blog/r-value-of-spray-foam-insulation#:~:text=The%20R%2DValue%20for%20spray%20foam%20insulation%20can%20vary%20depending,to%20R%2D7%20per%20inch. https://www.google.com/search?q=r+value+definition&rlz=1C5CHFA_enUS974US975&oq=R+value+definition&aqs=chrome.0.0i512l2j0i20i263i512j0i22i30l7.4364j0j4&sourceid=chrome&ie=UTF-8

Sarah O'Brien, J. W. S. (2019, March 7). *Here's the share of income that goes to rent in cities across the country*. CNBC. Retrieved December 21, 2021, from https://www.cnbc.com/2019/03/07/heres-the-share-of-income-that-goes-to-rent-in-cities-across-the-us.html