UBC Social Ecological Economic Development Studies (SEEDS) Student Report

An Investigation into Energy-Generating Revolving Doors

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An Investigation into Energy-Generating Revolving Doors

APSC 261: Technology and Society I

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ABSTRACT

This report analyzes the possibility of implementing energy-generating revolving doors in the new Student Union Building (SUB) at the University of British Columbia by making a triple-bottom-line assessment. This is done by investigating the impact on the economy, society and environment. The economic impact results in a net savings in the operational costs of the building. Although the initial cost of the revolving door is significantly higher than the normal swinging or sliding doors—approximately $17,000 to $42,000 more—the long term savings from reduced energy consumption accounts for the initial cost in less than one year. Furthermore, because revolving doors limit air leakage, they prevent the fluctuation of building temperature that occurs with the use of swinging or sliding doors. Therefore, less energy is consumed by the air conditioning units and heating units, which respectively cool and heat the building to maintain an optimal room temperature. By using less energy, the new SUB would be producing less greenhouse gases. In addition, an energy-generating revolving door may also serve as an icon of the sustainability movement at UBC. Unlike other renewable energy sources, a revolving door involves an interaction between the users and the door itself, thereby allowing the users to feel like they are personally contributing towards sustainability. The report also recommends the number of revolving doors that should be installed, taking into consideration the need for a good balance of triple-bottom-line aspects. Ultimately, this report shows that the energy-generating revolving door is a favorable renewable energy source for the new SUB. Each door saves over 75% of the energy consumption from building heating and cooling, as compared to traditional doors. They generate nearly 4600 kWh of energy while reducing ten tonnes of greenhouse gas emissions per year, and they inspire people to think of how and why practicing sustainability is paramount in the building of a strong future.

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Glossary

Embodied Energy	The amount of energy that is used to make a product, bring it to market, and dispose of it.
Greenhouse Gases	A gas in the atmosphere that absorbs and emits radiation.
LEED Platinum	The highest level of certification in designing sustainable buildings.
Maxwell's Law	Four differential equations relating electric and magnetic fields.
Rectifier	A device that converts alternating current (AC) to direct current (DC).

1.0 Introduction

Sustainability, specifically energy regeneration and the reduction of greenhouse gas emission, has become the rising environmental concern in the world. With an open mind to create a sustainable campus, the University of British Columbia (UBC) has become one of the leading universities in the sustainability movement. The new Student Union Building (SUB) is designed to achieve LEED Platinum rating. One of the requirements for this rating is to have 20% of the building's energy come from renewable energy sources. As one of the most used facilities on campus, the current SUB consumes huge amounts of energy from air conditioning and heating units, which produce tonnes of greenhouse gases each year.

This report investigates the employment of energy-generating revolving doors at the main entrances of the new SUB as a means of reducing UBC's environmental footprint and developing a new renewable energy source that capitalizes on human activity. Compared with traditional swinging and sliding doors, the revolving door not only reduces the heating and cooling costs for large buildings, but also provides an opportunity to transform human kinetic energy into electrical power [1]. As seen in Appendix A, an energy-generating revolving door consists of a revolving door panel, a fixed wire coil wheel, a rotating magnetic wheel, a gear assembly, a rectifier, and a set of batteries. Pushing the door panel spins the rotating magnetic wheel, which changes the magnetic field density through each sub-coil of the fixed wire wheel. By Maxwell's law, this generates an alternating current (AC) in the coil. The rectifier, which is connected to all the coils, converts the AC into a direct current (DC) and stores the generated energy into a set of batteries for future use. Following a triple-bottom-line assessment, this report analyzes the economic, social and environmental impact of using energy-generating revolving doors.

2.0 Economic Impact

In this section, an economic analysis is performed in four parts. First, the initial cost of building an energy-generating revolving door is examined. This is followed by an analysis of the door's maintenance costs. Then the cost savings from using an energy-generating revolving door is investigated. Lastly, the amount of energy generated from a revolving door is calculated.

2.1 Initial Cost

After contacting several companies, two companies, Horton Automatics and Crane Revolving Doors, provided an estimate for a revolving door with a diameter of seven feet and a height of seven feet. Both Horton Automatics and Crane Revolving Doors estimated the cost to be in a range of $25,000 to $50,000. The specification of the door from Horton Automatics can be seen in Appendix B. This included the cost of installation and the cost of materials. The generator, on the other hand, would have to be obtained separately. This was estimated at a cost of around $500 to $1,000.

The price of a normal sliding door, seven feet in height and twelve feet in width, is in the range of $8000 to $9000. This estimate was also obtained from Horton Automatics. In comparing the two types of doors, it is obvious that the revolving door has a significantly larger initial cost. This large difference in initial cost is due to the fact that the revolving door requires a greater amount of materials. In addition, the labor costs to install the revolving door also increases the initial cost due to the complexity in assembling all of the components of the door. In the end, the construction of an energy-generating revolving door costs roughly $17,000 to $42,000 more than a normal sliding door.

2.2 Maintenance

The maintenance costs for revolving doors are mainly from replacing broken seals. Replacing these seals can be easily done by a maintenance team and costs approximately $12 per meter. Zmeureanu describes the importance of maintaining a proper seal on revolving doors in his study on the effects of air leakage from revolving doors [2]. If the broken seals are not replaced, they will allow air to leak in and out of the building. Consequently, the energy costs will significantly increase due to the increase in heating and cooling costs.

These additional energy costs incurred by the broken seals can be seen when we calculate the pressure difference between the inside and outside of the building. The National Building Code of Canada states that in order to limit the physical force needed to open a door, the force exerted on the door cannot be greater than 90 N. This equates to a maximum pressure difference of 20 Pa between the outside and inside of a building. If, hypothetically, the pressure difference is 10 Pa and the seal on the revolving door is broken, then the additional costs of heating and cooling the air from the leakage is approximately $47 to $124 per meter of broken seal per year. If, on the other hand, the pressure difference is 20 Pa, which is the maximum allowed by the National Building Code of Canada, then the cost of heating and cooling the air from leakage rises to $75 to $204 per meter of broken seal per year. Therefore, the maintenance of a revolving door, especially the replacement of broken seals, is essential to reducing the energy costs of a building.

2.3 Cost Savings

Using a revolving door can improve the air conditioning and heating efficiency of the building by reducing air leakage, which will result in a net saving in air conditioning and heating costs. The average amount of energy saved is around 4600 kWh per year, when compared to a normal sliding door [3]. Such an amount could power 5.1 houses for an entire year. Furthermore, using a revolving door can save up to $7,500 from the cost of the natural gas which is used to heat up the building. This in turn affects the environment in a positive way by reducing the CO_2 emissions by fifteen tonnes.

The Massachusetts Institute of Technology (MIT) conducted a study on the effects of having revolving doors on campus and showed the relationship between the frequency of revolving door usage and the amount of energy saved [4]. As the usage of the revolving door increases, the amount of annual energy savings dramatically increases as well. If revolving doors are used exclusively for a building, there is a 74% savings in energy consumption. If the revolving doors are used only half the time and normal sliding doors are used the other half of the time, the savings in energy consumption drops radically to 14.5%. These figures are shown in Table 1 below.

Table 1. Energy savings comparison

Revolving Door Usage	50%	75%	100%
Saving of annual Energy consumption	14.5%	38.7%	74.0%
# of houses the saved energy can heat in one year	1.0	2.7	5.1
# of years the saved energy can light a 100W bulb	5.8	15.3	29.0

Note. Adapted from "Modifying habits towards sustainability: a study of revolving door usage on the MIT campus" by B.A. Cullum, O. Lee, S. Sukkasi, and D. Wesolokski, Massachusetts Institute of Technology, 2006.

Furthermore, according to the MIT study, the energy savings rate varies throughout the year depending on the temperature. This is due to a variation in the amount of air leakage from the building. Air leakage is most significant in the winter months when the temperature is cold. Compared to a sliding door, a revolving door can save more than eight times the amount of air leakage created by the pressure difference and door usage. Figure 1 below, also from MIT, shows the fluctuation of the amount of air leakage throughout the year.

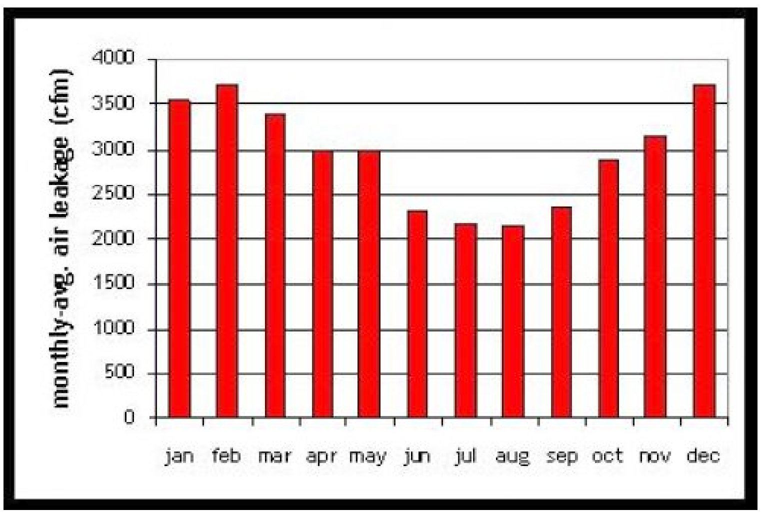

Figure 1. Air leakage frequency

Note. Adapted from "Modifying habits towards sustainability: a study of revolving door usage on the MIT campus," by B.A. Cullum, O. Lee, S. Sukkasi, and D. Wesolokski, Massachusetts Institute of Technology, 2006.

The average daily cost of energy in the winter is dependent on the frequency of usage of the revolving door. When revolving doors are used half the time and normal sliding doors are used the other half of the time, the average daily cost of energy is roughly $11. On the other hand, when the revolving doors are used exclusively, the average daily cost of energy drops to approximately $2.50. In Figure 2 below, as constructed by MIT, the average daily cost of energy in the winter is displayed as a function of revolving door usage.

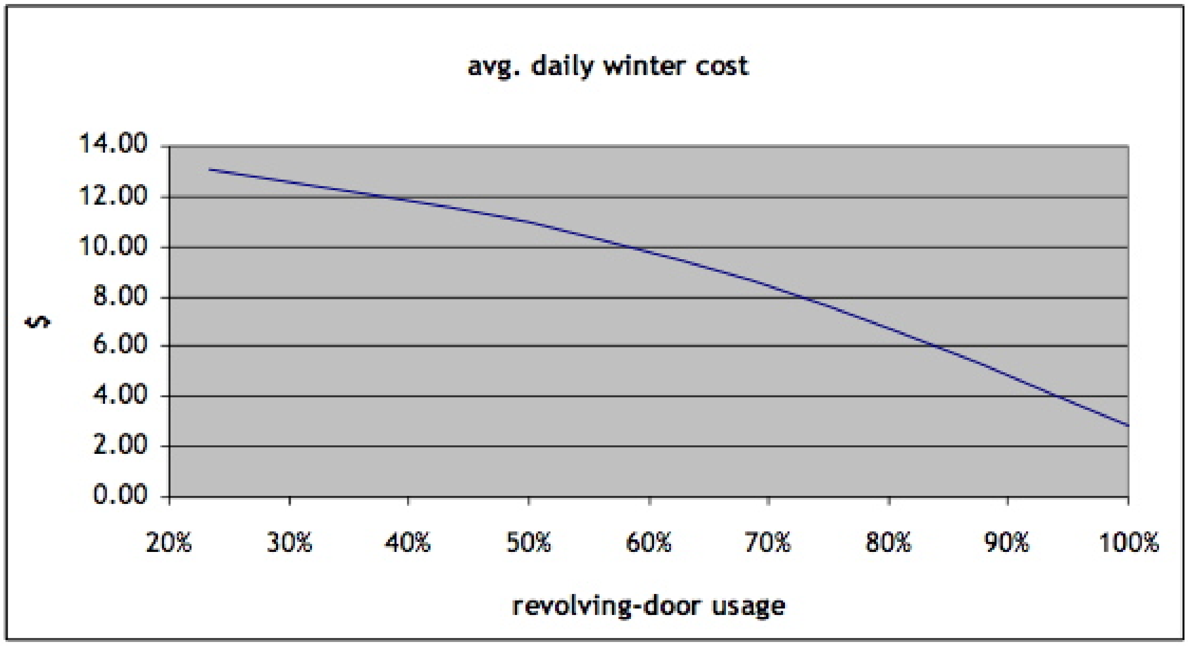

Figure 2. Average daily winter cost of energy as a function of revolving door usage

Note. Adapted from "Modifying habits towards sustainability: a study of revolving door usage on the MIT campus," by B.A. Cullum, O. Lee, S. Sukkasi, and D. Wesolokski, Massachusetts Institute of Technology, 2006.

Using an energy savings calculator from Horton Automatics, as seen in Appendix C, the expected payback period will be around seven months when comparing a $50,000 revolving door to a $8,000 sliding door. This is calculated by estimating the average temperature in the building to be 75 degrees Fahrenheit with 50% humidity, with approximately 8,000 people entering and leaving during the ten hours of operation each day. This number of 8,000 people entering and leaving per day is a conservative estimate, and takes into account the new SUB Project Coordinator Andreanna Doyon's estimation of approximately 5,000 people entering and leaving the SUB during the peak time at noon.

2.4 Energy Generation

The revolving door energy generator is the innovation that combines three major components: people, technology, and architecture. This revolving door generator combines the architecture of a revolving door with the technology of an electric generator to capture the unused energy created when people enter and leave a building. This idea, introduced by Fluxxlab, is similar to the idea of a hydroelectric dam or a wind turbine [5].

The door is equipped with a special generator, gears, and battery. First, when a person passes through the door, the gear that connects to the core of the door will turn the smaller gear that connects to the power generator, as seen in Figure 3 below.

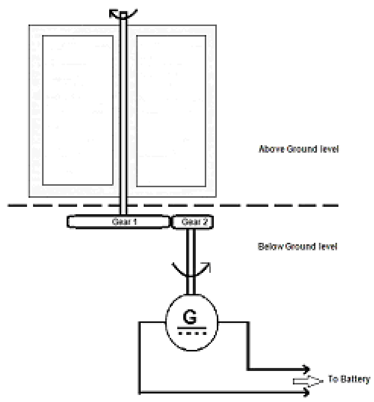

Figure 3. Generator circuit diagram

Note. Adapted from "Power generation from revolving doors," by G. Rajasekar, and A. Meenakshi, IEEE, 2010.

This power generator consists of a special DC magnetic motor. This gear system uses a technique called piezoelectricity, which converts the kinetic energy into electric energy [6]. The gear system is limited by the speed of the power generator, which is set at 4500 rpm in order to ensure the safety of users. With this speed, the revolving door is able to generate a power of 0.8-0.9 volts with 200mA to be collected in the battery. The estimated calculation shows that this revolving door can power a 150W light bulb for 100 hours if the door runs continuously for one day. Thus, the revolving door can potentially save approximately $1.52 per day in electricity costs. Another factor that affects the amount of energy that can be generated is the weight of the revolving door. With a heavier revolving door, more power is generated through the generator because more kinetic energy is required to operate the door. However, a heavier revolving door might deter people from using it.

3.0 Social Impact

Energy-generating revolving doors have a significant social impact, both positive and negative. These will be discussed in further detail in the following sections.

3.1 Positive Aspects

Revolving doors that generate power have many social positive influences. By having doors that generate energy each time a student comes in and out of the Student Union Building, the students will be individually contributing towards sustainability. This awareness can be reinforced by notices and posters that are put up near or on the doors, which will remind students of their own personal roles in achieving sustainability. Such awareness may allow students a sense of self-fulfillment, as they can say that they are consciously contributing towards sustainability. Furthermore, through the knowledge that every other person who comes in or out of the SUB will also be helping sustainability, these energy-generating revolving doors have the potential to increase the students' sense of connectedness to the rest of the UBC community. Thus, students can feel as though they are each doing their part in helping UBC as a whole attain its goals of sustainability.

In addition to posters, these revolving doors will have images and slogans printed on the glass of the door to promote sustainability. For example, images and slogans were employed for the first revolving doors in the Netherlands, in order to bring awareness to the public [7]. These Dutch revolving doors also included a meter to show how much energy each person is producing as they enter and leave the building. Such a tool would further people's awareness of their own contribution, giving them a concrete, quantitative indicator to show the results of their actions. The importance of educating people about sustainability is undeniable, especially when these people are the students who are the future of this world. After all, if we as a society continue living the way we are currently, we will not be able to sustain our lifestyles indefinitely [8]. Promoting sustainability at the center of the campus, where most students come and go everyday, is the first step towards bringing sustainability awareness to the students. If we are able to get the students educated on this matter, they will be able to spread their knowledge to others, disseminating this knowledge and positive attitude to the general public as well.

Of course, while energy-generating revolving doors may bring about many positive consequences, we must also consider the negative aspects of using this strategy to promote sustainability. After all, only in recognizing and understanding both the positive and the negative aspects of such a project can we then properly assess its value and its potential for execution.

3.2 Negative Aspects

Although the positive social impacts outweigh the negatives, the negative aspects still exist and must be discussed. Firstly, due to the fact that revolving doors cost a lot more to construct than normal doors, the overall cost of operating the SUB would increase. When we consider the multiple revolving doors that would be required in order to effectively allow a continual, steady flow of people in and out of the building without lineups, the initial cost to install these doors increases dramatically. This increase in cost must be covered by someone. Most likely, the students would ultimately be required to cover the extra cost by paying higher SUB fees. As 46% of students already oppose the rise in such SUB fees in recent years [9], a further increase might enrage them. This is especially of concern given that many students work hard in order to be able to afford postsecondary education at UBC while also supporting themselves; increases in fees or tuition always affects them financially, physically, and mentally. Ross, Cleland, and Macleod argue, for example, that as high as 82% of students suffer from money-related stress [10]. If students are required to pay higher school fees, this additional burden to financially sustain themselves will increase their stress, potentially leading to health consequences.

There are also many problems that would affect some students who go to the SUB. After all, not everyone can use these revolving doors. People in wheelchairs or people with children in strollers would have a difficult time using the revolving doors; therefore, there would have to be normal swinging doors for them. This would further increase the cost of the SUB, which would then increase the fees to the students. In addition, normal swinging doors must also be installed because they are needed as fire exits, as revolving doors do not allow people to evacuate quickly out of a building.

4.0 Environmental Impact

The technology of the revolving door, even without an electromechanical generator, would be very beneficial for any new building as a result of the savings incurred from lowered heating and cooling costs. While there are some problematic issues, such as a need for more materials to store and distribute the electricity, the environmental and energy saving benefits far outweigh the problems that arise. By retrofitting an already sustainable system, the revolving door, with an electromechanical generator, the positive environmental impact is increased, thus making this technology an ideal replacement for at least some of the entrances in the new SUB. The generator of the revolving door will not create an abundance of energy in a stand-alone system. However, with the use of one or more revolving doors, this technology will greatly reduce total energy usage at the SUB, which will help UBC attain the 20% renewable energy resources goal and achieve the LEED Platinum certification.

4.1 Energy Savings

The use of a revolving door as an electromechanical energy generator is a unique idea in that it harnesses current technology to provide another benefit. As already stated in our report, the use of a revolving door can save up to 4600 kWh per year in reduced air heating and cooling costs. This 4600 kWh translates into an equivalent reduced emission of greenhouse gases, which is depicted in Table 2 below [11].

Table 2. Reduction of greenhouse gas emissions based on a 4600 kWh energy savings

Gaseous Emission	**Reduction (kg)**
Carbon Dioxide	2801.82
Methane	23209.09
Nitrous Oxides	40145.45

Note. Adapted from “Calculators,” by A. Joseph, 2000.

By reducing heating costs, there would be a smaller need for the use of natural gas to heat the building. This would further reduce the greenhouse gas emissions created by the new SUB. Of course, this 4600 kWh figure does not include the amount of energy generated by the door, which would be used to offset the external energy source from the UBC power grid. The generated electricity would help meet the 20% renewable energy goal in two ways: Firstly, by reducing the overall energy used by the SUB, and secondly, by providing a renewable energy resource.

4.2 Construction

The construction of a revolving door is not too different from a regular door so the additional environmental impacts are minimal [12]. There are no known harmful chemicals used in the manufacturing process of the door. For a typical revolving door, the materials used are glass, aluminum, steel and sometimes wood, most of which are recyclable, hence making disposal of these doors environmentally friendly. The most common materials used by manufacturers is an aluminum frame with some form of coating and glass panes [13] [14]. However, creating a door made out of wood would further lower the environmental impact and the embodied energy required in the construction of the materials before it is used to manufacture the door. Another alternative is to use recycled aluminum and steel, on the assumption that the suppliers of these materials can provide metal of a high enough quality to be of acceptable use for a revolving door.

Embodied energy is the amount of energy that is consumed in the entire cycle of a product from the harvesting of raw materials, to the manufacturing, and to the transportation. Table 3 below only depicts the embodied energy calculated for the possible materials used for a revolving door, and do not include assembly and transportation of the final product to the construction site [15].

Table 3. Embodied energy of revolving door materials

Material	**Embodied Energy**	
	MJ/kg	**MJ/m^3**
Lumber	2.5	1380
Plywood	10.4	5720
Glass	15.9	37 550
Steel	32.0	251 2s00
Steel (Recycled)	8.9	37 210
Aluminum	227	515 700
Aluminum (Recycled)	8.1	21 870

Note. Adapted from "Embodied Energy," by Unknown Author, Canadian Architect, 2000.

The amount of material used for each door varies from supplier to supplier. One recurring issue is that all revolving door models use more raw materials than what is used to make a normal sliding or swinging door. Nonetheless, over the lifetime of the revolving door, the yearly energy savings achieved from by using a revolving door will still offset the additional energy used in construction.

4.3 Negative Impact

Unfortunately, there are some negative environmental impacts that arise from the use of a revolving door generator. Firstly, the electricity created from the generator will need to be stored on batteries, which contain a lot of environmentally hazardous products such as lead. In addition batteries are very volatile substances, and need to be handled, stored and maintained with care so as to limit the possibility of an accident resulting in an explosion, especially of concern given that the revolving door generator would employ large lead cell batteries. Special care should be taken to reduce any movement that could cause these batteries to shift and to eliminate the possibility of the terminals shorting together which would make the batteries susceptible to combustion.

Another added building material would be the wiring and electrical circuitry required to allow the generated electricity to be plugged into the normal power grid for the new SUB and to be distributed throughout the building. Any power created would need to be stored and accessed at a later date. To do this, the system would have to be connected to the main SUB power grid, which would increase the amount of wiring needed. By increasing the wiring in the building, we would also increase the amount of raw materials that are required, consequently increasing the total embodied energy of the materials of the revolving door.

5.0 Conclusion

After analyzing both positive and negative impacts, this report concludes that the energy-generating revolving door is a great source of renewable energy. We recommend that the new SUB should implement three revolving doors at the main entrance and at least one at each of the other entrances in order to balance the traffic flow and the initial costs. As detailed in our report, the use of revolving doors in the new SUB has certain benefits and drawbacks for the economy, the environment, and society. Financially, the revolving door saves over three quarters of the annual energy consumption on heating and cooling. Although the costs of materials and installation for revolving doors are higher than for traditional doors, there is an expected payback period of less than one year. Environmentally, the revolving door reduces over ten tonnes of carbon dioxide, methane and nitrous oxides emissions every year from the SUB. Although we must consider the issue of battery recycling, the overall performance of revolving doors is more sustainable than swinging or sliding doors. Socially, an energy-generating revolving door inspires people to be aware of sustainability and to implement sustainable strategies in other avenues of their lives. Ultimately, the energy-generating revolving doors have the potential to be a great icon of the sustainability movement at UBC and to contribute to the new SUB's goal of achieving the LEED Platinum rating.

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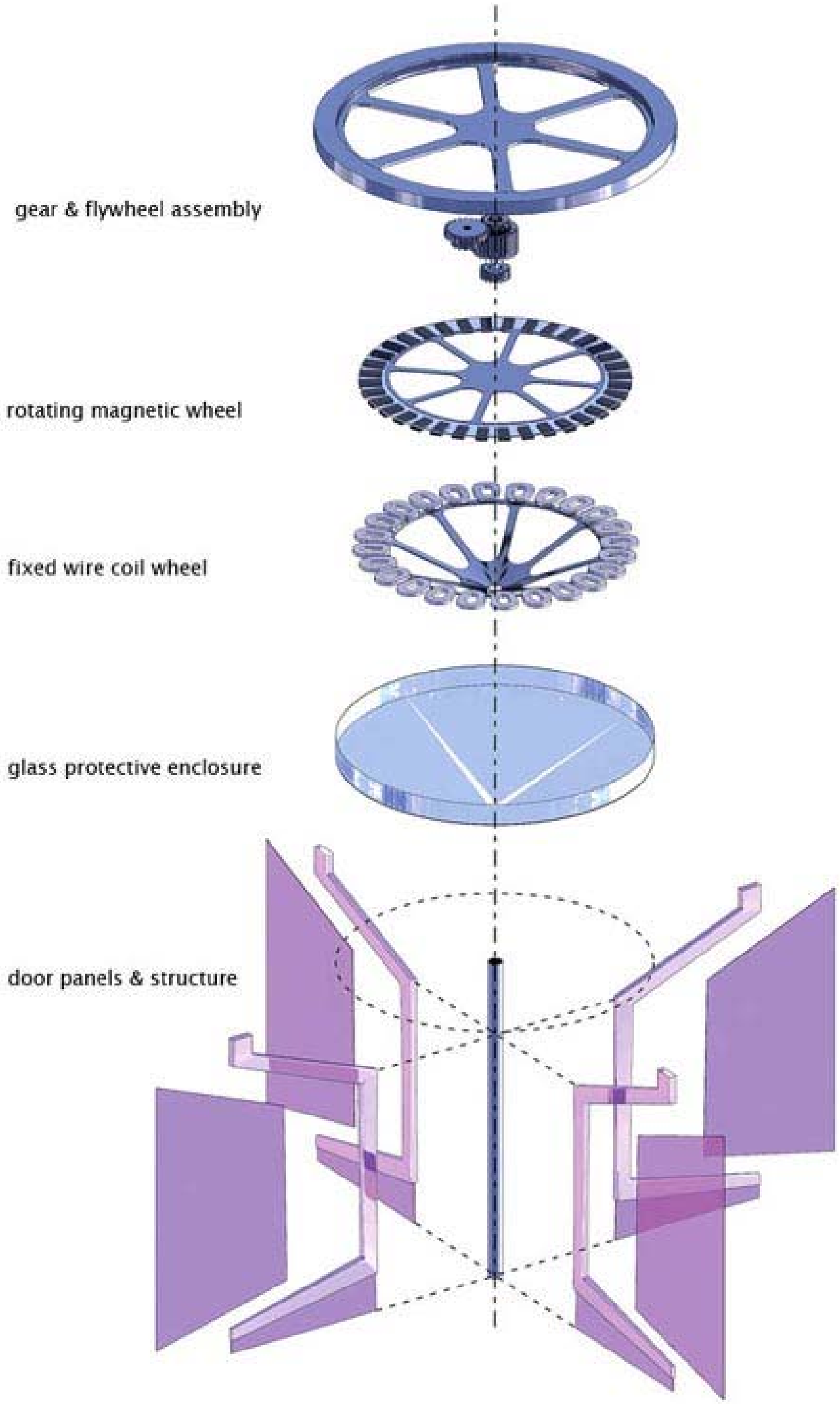
APPENDICES

Appendix A: Diagram of Revolving Door with Generator



Note. Adapted from "*Generate Energy with Fluxxlab's 'Revolution' Revolving Door*" by *K. Yergaliyev*, 2008.

Appendix B: Specification of Revolving Door

Horton Automatics
© 4242 Baldwin Boulevard
Corpus Christi, Texas
USA 78405-3399
Tel: 800-531-3111, 361-888-5591
Fax: 800-531-3108, 361-888-6510
www.hortondoors.com
The Automatic Choice

ARCHITECTURAL DETAILS

REVOLVING DOORS

EasyFlow® Manual Series 9530 — F2.4

Type: 3-Wing with Round Drum, Narrow Stile — Jan 08

Standard Packages

Nominal Inside Diameter	Outside Diameter	Entry	Rough Opening Width	Rough Opening Height
6'-6" (1981)	6'-9 1/2" (2070)	3'-0 1/8" (918)	6'-10" (2083)	Overall Unit Height + 1/4"
7'-0" (2134)	7'-3 1/2" (2223)	3'-3 1/8" (994)	7'- 4" (2235)	
Ceiling Height: 7'- 0" (2134), **Canopy Height:** 4" (102) or 6" (152) **Glazing:** Standard wing prep'd for 1/4" (6) glass. Glass provided by others. Standard drum provided with 7/16" clear laminated curved glass.				**Anodized Finish:** Clear or Dark Bronze

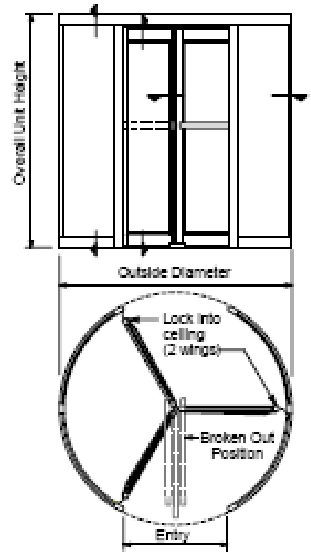
Options

- Custom diameters between 6'-6" & 8'-0".
- Custom ceiling height up to 9'-0".
- Extended or cropped canopy.
- Round push bars or muntin bars
- Aluminum roof.
- Ceiling lights or partial glass ceiling.
- Prep up to 1" glazing in wings & 9/16" in drum.
- Custom anodized, clad or paint finish.

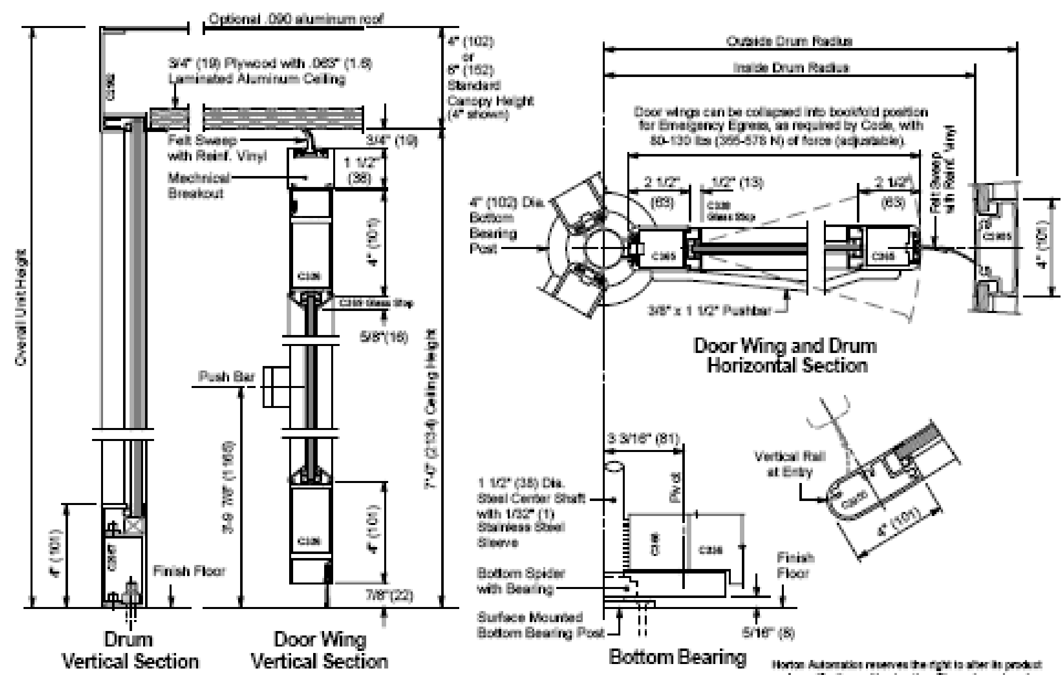
For further standard and optional equipment see Architectural Specifications starting on p. F4.0 and Specification Details on p. F3.0.

Installation and Operation

- Door unit is surface mounted to finish floor (floor not to exceed 1/4" out of level). Unit is free-standing with no additional support required.
- Drum enclosure can be center connected to adjacent construction or 'throat connected' (at entry vertical rails). Allow for 1/4" shim space each side and at canopy. Adjacent construction not to bear down on revolving door.
- Standard overhead mechanical speed control allows up to 12 RPM (ANSI 156.27) and provides smooth braking action. Optional electronic speed control allows for resistance-free rotation up to 12 RPM. Optional Return-to-QuarterPoint feature also available.
- Electrical (for optional lighting and/or electronic speed control) : Provide 120 VAC , 60 cycle, single phase, 15 amp service (in conduit) on a dedicated 20 amp circuit breaker routed into canopy.



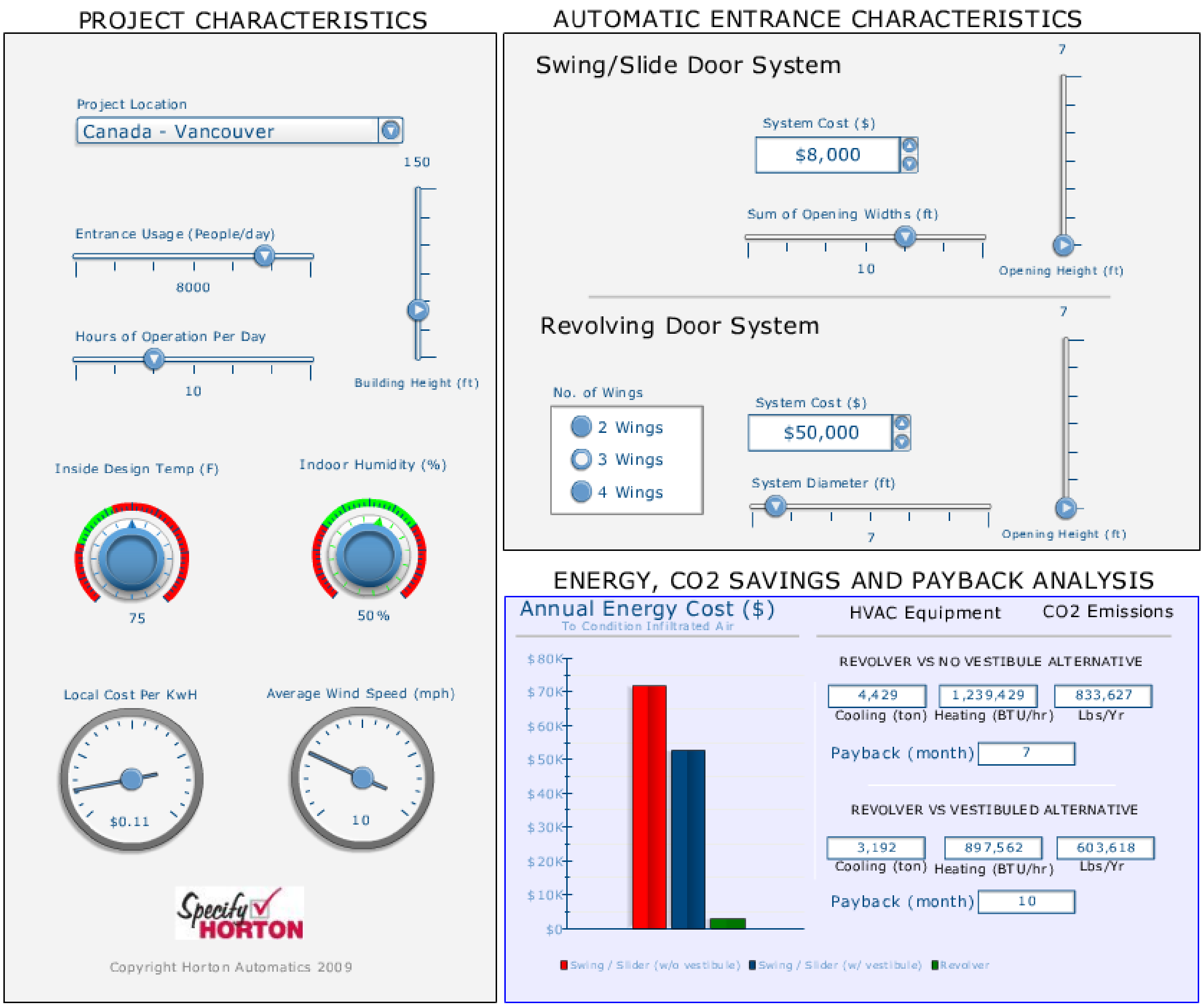
Floor Plan and Exterior Elevation



Horton Automatics reserves the right to alter its product and specifications without notice. Dimensions given in U.S. inches followed by millimeters in parenthesis.

Note. Adapted from "*EasyFlow™ Manual Revolving Door*" by Horton Automatics, 2008.

Appendix C: Energy Saving Calculator



Note. Adapted from "*Energy Saving Calculator*" by Horton Automatics, 2003.