APPLICATION OF REVOLVING DOOR TECHNOLOGY IN REDUCING ENERGY LOSS IN ANCHORAGE, ALASKA

By

Raymond A.C. Ballard, B.S.

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APPROVED:

Hannelle Zubeck, Ph.D., Committee Chair
Robert J. Lang, Ph.D., Committee Member
Zhaohui Yang, Ph.D., Committee Member
Hannelle Zubeck, Ph.D., Chair
Arctic Engineering Program
Fred Barlow, Dean
College of Engineering

ABSTRACT

Arctic entryways (vestibules) are an important building feature in Alaska for energy savings. Vestibules and revolving doors are often designed to reduce air infiltration rates and ultimately reduce building energy costs. In Anchorage, most buildings utilize vestibule technology for building entrances but revolving door technology is also a viable option to consider. In Anchorage, Alaska, reduction of energy consumption is necessary for long-term sustainability of most buildings and businesses.

The project included a review of relevant literature publications to select methods to predict air infiltration rate due to vestibules versus revolving doors; calculations for energy usage of various Anchorage public buildings with existing doorways versus with revolving doors; and an analysis of the energy savings. The case study selected six Anchorage public buildings for evaluation based on differences in building size, utility, and availability of energy data.

The study found that while revolving door technology can technically save some energy costs, the additional cost was not justifiable in most of the buildings selected for study due to lack the occupancy throughput, building height, and quantity of wind. One exception was East High School (East entrance) where a vestibule or revolving door should be added. It was observed that sufficient space exists for most Anchorage public buildings to install vestibules, and that in existing revolving door locations the adjacent sliding doors are often preferred by users. A case study for restaurants and strip malls in Alaska would be beneficial as these building types may be more energy efficient with revolving doors due to higher user throughput.

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ACKNOWLEDGMENTS

To my wife for her loving support in everything we achieve. Thank you for being my strongest champion and guiding my ambitions.

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INTRODUCTION

Arctic entryways (vestibules) are an important building feature in Alaska for energy savings and practicality. Vestibules and revolving doors are often designed to reduce air infiltration rates and ultimately reduce building energy costs. In Anchorage, few buildings utilize alternative technologies to the vestibule for building entrances. The revolving door is common in several cities in cold regions, and generally considered eight times more energy efficient for large buildings than normal doorways (Augustine, B., Campos E. of Horton Automatics, 2012). For example, in the Canadian province British Columbia where building designers are required to meet American Society of Heating, Refrigeration, and Air-Conditioning Engineers (ASHRAE) Standards 90.1 (ASHRAE, 2004) (ASHRAE, 2007) stipulating that for most multi-unit residential buildings in various climate zones (e.g. the city of Vancouver), require a vestibule or revolving door for entrances doors (Homeowner Protection Office, Branch of BC Housing, 2010). Codes do not distinguish which technology (vestibule or revolving door) is the optimum technology for both energy loss and potential cost savings. In Anchorage, Alaska, reduction of energy consumption is necessary for long-term sustainability of most buildings and businesses. Utilization of revolving doors should be reviewed and considered.

This project determined the potential application of revolving door technology in Anchorage, Alaska by comparing use of revolving doors against current door technologies utilized through extensive literature review, modeling calculations, and observation. There are no known works of literature to this author on the utility of revolving door technology in reducing large building thermal loss in Alaska. Government and journal publications on the subject mostly refer to guidelines provided by ASHRAE that stipulate either a vestibule or revolving door be used (Cho, Gowri, & Liu, 2010). If a revolving door was more energy efficient than a vestibule, cost savings for several building examples in Anchorage were quantified.

The project included a review of relevant literature; calculation of air infiltration rates of various Anchorage public building main entrances with their existing doors versus theoretical revolving doors; and an analysis of the energy savings.

LITERATURE REVIEW

A review was conducted of pertinent literature in which calculations or empirical methods are provided to predict air infiltration rate due to manual standard swing doors, vestibules, and revolving door technology. Several works state improved efficiency of revolving doors over standard vestibules. However, most fail to cite published sources. Most reliable published works are available from the American Society of Heating, Refrigeration, and Air-Conditioning Engineers (ASHRAE).

Methods used for a similar study in Boston by students at the Massachusetts Institute of Technology (MIT) were also considered for reference (Cullum, Lee, Sukkaski, & Wesolowski, 2006). It was observed that many private industry publications, such as the article entitled "Revolving Doors 101" written by Horton Automatics and featured in Construction Canada (Augustine, B., Campos E. of Horton Automatics, 2012), cite the MIT paper out-of-context and exaggerate the benefits of revolving doors compared to vestibules. The MIT paper was intended to study existing swing doors versus revolving doors, and the energy savings found by encouraging greater utilization of the revolving doors. The MIT study does not cover construction costs of adding new revolving doors, or contrast the energy savings of vestibules against revolving doors.

ASHRAE standards 90.1 recommend vestibules or revolving door technologies based on climate zones of the location considered. From 1971 to 2000, Anchorage averaged 10470 mean annual heating degree days (HDD) above 65°F (Alaska Climate Research Center). Climate Zone 7 is described as "very cold" and defined in Table 1.

Table 1: International Climate Zone Definitions (ASHRAE, 2007)

Zone Number	Zone Name	Thermal Criteria (I-P Units)	Thermal Criteria (SI Units)
1A and 1B	Very Hot –Humid (1A) Dry (1B)	9000 < CDD50°F	5000 < CDD10°C
2A and 2B	Hot-Humid (2A) Dry (2B)	6300 < CDD50°F ≤ 9000	3500 < CDD10°C ≤ 5000
3A and 3B	Warm – Humid (3A) Dry (3B)	4500 < CDD50°F ≤ 6300	2500 < CDD10°C < 3500
3C	Warm – Marine (3C)	CDD50°F ≤ 4500 AND HDD65°F ≤ 3600	CDD10°C ≤ 2500 AND HDD18°C ≤ 2000
4A and 4B	Mixed-Humid (4A) Dry (4B)	CDD50°F ≤ 4500 AND 3600 < HDD65°F ≤ 5400	CDD10°C ≤ 2500 AND HDD18°C ≤ 3000
4C	Mixed – Marine (4C)	3600 < HDD65°F ≤ 5400	2000 < HDD18°C ≤ 3000
5A, 5B, and 5C	Cool-Humid (5A) Dry (5B) Marine (5C)	5400 < HDD65°F ≤ 7200	3000 < HDD18°C ≤ 4000
6A and 6B	Cold – Humid (6A) Dry (6B)	7200 < HDD65°F ≤ 9000	4000 < HDD18°C ≤ 5000
7	Very Cold	9000 < HDD65°F ≤ 12600	5000 < HDD18°C ≤ 7000
8	Subarctic	12600 < HDD65°F	7000 < HDD18°C

Based on climate data and the definitions in Table 1, a map of climate zones in North America was developed. The Municipality of Anchorage is located in Climate Zone 7 as shown in Figure 1.

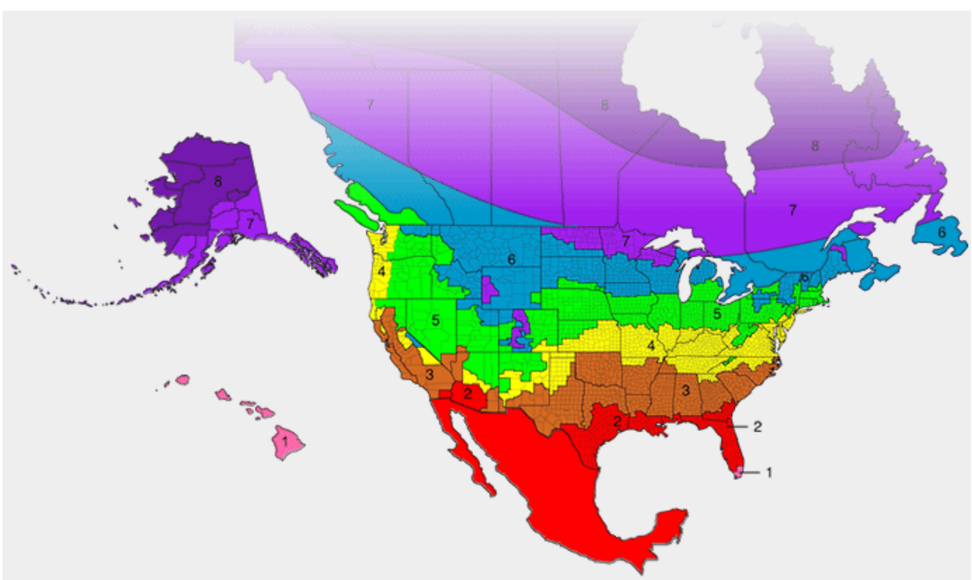

Figure 1: ASHRAE Climate Zones in North America (Atlas Roofing, 2010)

In 2010, the Northwest Pacific Laboratory modeled the air infiltration through door openings in order to evaluating the energy savings impact of the ASHRAE 90.1 Vestibule requirements (Cho, Gowri, & Liu, 2010). Table 2 presents their findings; most buildings see energy savings from use of vestibule or revolving door technology.

Table 2: National Weighted-Average Savings for Each Building Prototype. (Cho, Gowri, & Liu, 2010)

Building Type	Savings (%)	Building Type	Savings (%)
Small Office	0.63	Secondary School	0.06
Medium Office	0.23	Quick Service Restaurant	4.16
Warehouse	0.36	Sit-down Restaurant	1.89
Stand-alone Retail	2.38	Outpatient Health Care	0.03
Strip Mall	5.61	Small Hotel	0.57
Primary School	0.29	Mid-rise Apartment	0.30

Buildings in Climate Zone 7 greater with more than 3000 ft² should utilize a vestibule or revolving door for the main entrance. Buildings considered for this project met this requirement to avoid consideration of other alternatives. Revolving doors are generally considered more expensive than manual swing doors or vestibules, but if operating/maintenance costs are reduced, there may be satisfactory return on investment (ROI) and payback period to warrant investment in other Anchorage buildings of similar construction.

Since neither the Pacific Northwest National Laboratory study nor ASHRAE identified a simple method for differentiating vestibules vs revolving doors, this project focused primarily on that aspect and had to make many assumptions.

Although many sources are cited in this study, the most often cited sources are:

- 2013 ASHRAE Handbook – Fundamentals (ASHRAE, 2013)
- Schutrum et. al. 1961. Air Infiltration through Revolving Doors. ASHRAE 68th Annual Meeting in Denver, Colo. (Schutrum et. al., 1961)

- Min, T. C. "Winter infiltration through swinging-door entrances in multi-story buildings." Heating, Piping and Air Conditioning 30.2 (1958): 121-128. (Min, 1958)

Together, these sources provide the means to determine air-leakage through a standard swing door, vestibule, or revolving door using similar building design data or figures.

The primary assumption made in this study is that all doors are manual, not automatic. There were other sources and figures found during literature review that covered differences in automatic doors, such as Yuill's RP-763 (Yuill, 1996) in Figure 2 which combined the discharge coefficients of automatic doors as they open and close with the fraction of time that doors are open at a particular level of use (i.e. for varying levels of the vestibule), and presents the overall airflow coefficient as a function of usage rate (persons per hour). Since this study focuses on automated sliding doors, it was not used in this study but is included here for future reference.

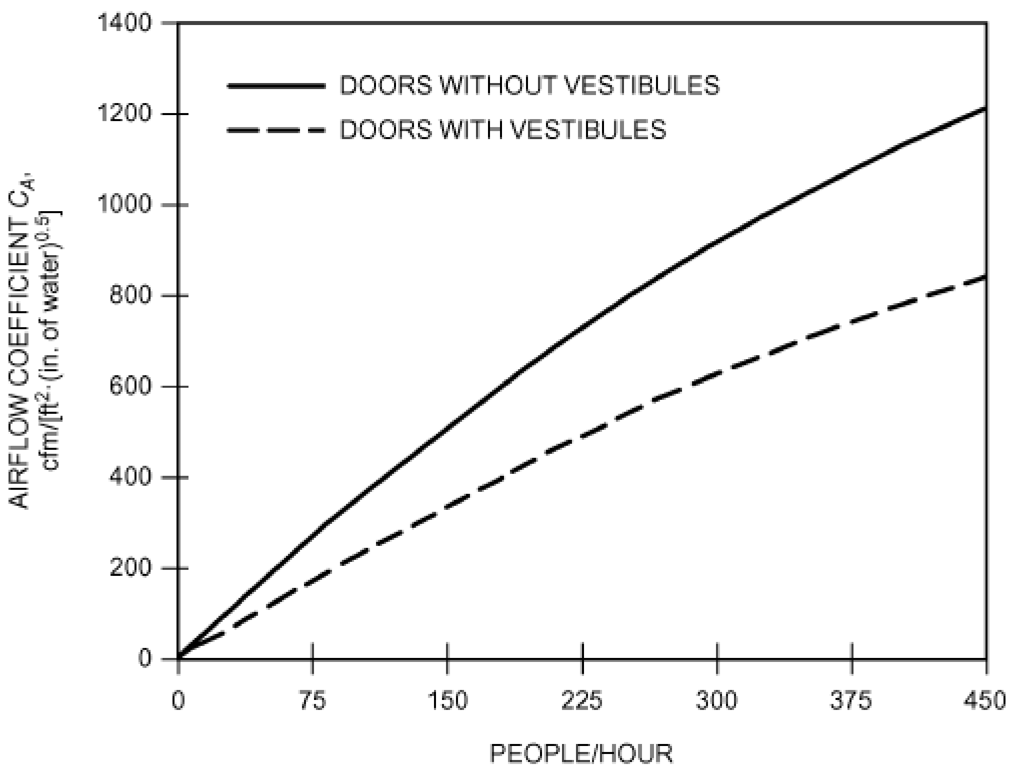

Figure 2: Airflow coefficient for Automatic Doors (Not Utilized) (Yuill, 1996)

With no studies that determine differences in air leakage rates (seal infiltration and crack infiltration) for manual swing doors vs vestibules vs revolving doors, it was assumed that a swing door is equivalent to a 2-wing revolving door and that a vestibule is equivalent to a 4-wing revolving door (in which all 4-wings are in the closed position. This allowed use of T.C. Min's study (Min, 1958) regarding revolving door air leakage for all manual door technologies.

The remainder of the literature considered for this study is cited throughout the paper.

METHODOLOGY

In November 2012, the Alaska Housing Finance Corporation (AHFC) published a white paper authored by Dick Armstrong presenting the results of over 1200 benchmarks and 327 investment grade audits using American Recovery and Reinvestment Act (ARRA) funds (Armstrong, 2012). Anchorage public buildings of different types were selected from this project due to the availability of sufficient data for this study.

The selection of six Anchorage public buildings for evaluation of revolving door technology was based on differences in building size, utility, and availability as provided by the Alaska Housing Finance Corporation following the *AkWarm Commercial*™ simulation modeling of the building envelopes during the statewide public building energy audits performed using American Recovery and Reinvestment Act (ARRA) funds. The buildings selected include:

a. Anchorage Police Department Headquarters
   4501 Elmore Road
   Anchorage, AK 99517
b. East Anchorage High School
   4025 East Northern Lights Boulevard
   Anchorage, AK 99508
c. Loussac Library
   3600 Denali Street
   Anchorage, AK 99516
d. Martin Luther King Career Center
   2650 E Northern Lights Blvd
   Anchorage, AK 99508

e. Sullivan Sports Arena

   1600 Gambell St

   Anchorage, AK 99501

f. Transit Administrative Building

   3600 Dr. Martin Luther King Jr. Ave

   Anchorage, AK 99507

Ideally, private buildings of other building types (e.g. restaurants, high-rise hotels and office buildings) would also be considered but private building data may not exist, let alone be available publicly. A more in-depth case studies of restaurants, strip malls, etc. in Alaska would be beneficial as these building types were already previously identified by ASHRAE as more energy efficient with revolving doors due to high user throughput (Cho, Gowri, & Liu, 2010).

Next, differences in the air infiltration rates were calculated using revolving door technology for the main entrance of each building as compared to the current door design. Key measurements and assumptions such as the frequency of high occupancy usage, building envelope, overall air change rates, average building heights, etc. have already been evaluated during the audits managed by the Alaska Housing Finance Corporation. Other assumptions such as the door usage traffic, timing of door opening, automatic versus manual doors, etc. were evaluated during this study. Table 3 below summarizes the building conditions including space type, floor area, hours of operation, and number of occupants. Table 5 includes a more detailed breakdown of the usage rates based on building type.

Table 3: Buildings Considered for Revolving Door Study

Building	Space Type	Floor Area (sq ft)	Hours of Operation*	# Occupants
APD Headquarters	Office	11,246	24/7	94
		51,804	7:30AM-5:30PM M-F	74
East High School	Education	361,698	Varies	2500
Loussac Library	Library	135,671	9AM-6PM M-Su	1200
MLK Career Center	Education	127,116	7:30AM-6:00PM M-F	1251
Sullivan Arena	Arena	151,470	Varies	1827
Transit Admin Bld.	Office	19,022	7:30AM-5:30PM M-F	25

*Hours considered are the primary hours of operation. A full list of high use operating periods are considered in the audit simulation files.

Using AkWarm-C simulation models provided by the Alaska Housing Finance Corporation (AHFC) energy audits of Alaska public and commercial facilities, air infiltration rates were considered based on theoretical infiltration rates for swing doors, vestibules, and revolving doors.

Finally, average annual energy savings (if any) were evaluated. Payback period for average assumed cost of revolving door installation for current buildings was calculated.

BUILDINGS CONSIDERED

Figures 3 through 41 identify the door entrances considered during this study for the Anchorage public buildings considered.

Figure 3: Anchorage Police Department Public (South) Entrance

Note that the main door entrance evaluated in this study was the East employee entrance which is assumed as a vestibule. This is due to the lack of public access to this building entrance. The main public (south) entrance has fewer users.

Figure 4: Anchorage Police Department Aerial View

Figure 5: East High School main entrance (West)

Figure 6: East High School southwest doors (south and west-facing)

Figure 7: East High School southwest corridor doors (south and west-facing)

Figure 8: East High School main entrance (South)

Figure 9: East High School School-Within-A-School (SWS) section southwest south facing doors

Figure 10: East High School School-Within-A-School (SWS) section southeast south-facing doors

Figure 11: East High School south hallway south-facing doors

Figure 12: East High School science wing southwest south-facing doors

Figure 13: East High School science wing southeast south-facing doors

Figure 14: East High School main entrance (East)

Figure 15: East High School northeast section

Figure 16: East High School northeast hallway north-facing door

Figure 17: East High School northeast section east-facing entrance

Figure 18: East High School northeast section “art wing” northeast west-facing doors

Figure 19: East High School northeast section "art wing" northwest east-facing doors

Figure 20: East High School main entrance (North) and other entrances into central courtyard

Figure 21: East High School gym/pool southern doors into central courtyard

Figure 22: East High School gym west-facing emergency exit doors

Figure 23: East High School gym north-facing emergency exit doors

Figure 24: East High School gym/pool main entrance (North)

Figure 25: East High School pool doors (north and west-facing)

Figure 26: East High School northwest hallway west-facing doors

Figure 27: East High School Aerial View

Figure 28: King Career Center Main (Northeast) Entrance

Figure 29: King Career Center (East Entrance)

Figure 30: King Career Center South Facing Garage Doors (Southeast Portion)

Figure 31: King Career Center South Facing Garage Doors (Southwest Portion)

Figure 32: King Career Center West Entrance

Figure 33: King Career Center Aerial View

Figure 34: Loussac Public Library Aerial View

Figure 35: Sullivan Arena main entrance (Northwest)

Figure 36: Sullivan Arena entrance (Northeast)

Figure 37: Sullivan Arena entrance (Southeast)

Figure 38: Sullivan Arena entrance (Southwest)

Figure 39: Sullivan Arena

Figure 40: Municipality of Anchorage Transit Building Main Entrance

Figure 41: Municipality of Anchorage Transit Building Aerial View

DISCUSSION OF RESULTS

Air infiltration through doors should be considered in two separate categories; air leakage when the door is closed (i.e. stationary air leakage through cracks and seals) and air flow when the door is open or revolving (air change rate). This results in Equation 1 below.

Equation 1: Air Infiltration Rate (ASHRAE, 2013)

$$Q = C_A A \sqrt{\Delta p}$$

where

$Q = \text{airflow rate, cfm}$

$C_A = \text{airflow coefficient,} \frac{\text{cfm}}{[\text{ft}^2 * (\text{in. of water})^{0.5}]}$

$A = \text{area of the door opening, ft}^2$

$\Delta p = \text{pressure difference across door, in. of water}$

For all types of doors, calculation of the differential pressure is first required before proceeding to calculate air infiltration.

DIFFERENTIAL PRESSURE (STACK EFFECT AND WIND)

The building air leakage (Equation 2 below) caused by pressure differential is driven principally by the stack effect, and somewhat by the wind pressure differential.

Equation 2: Combined Differential Pressure (ASHRAE, 2013)

$$\Delta p = p_w - \Delta p_s$$

where

$p_w = \text{wind-induced surface pressure relative to static pressure, in. of water}$

$\Delta p_s = \text{pressure differential due to stack effect, in. of water}$

Stack effect (buoyancy) is caused by the hydrostatic pressure differential caused by the weight difference of a column of air located inside and outside a building as a direct result of the differences in air temperature. The hydrostatic pressure of an air column depends on density and the height of interest above a reference point (ASHRAE, 2013). The formula for calculation of the Stack Effect is noted as Equation 3 below.

Equation 3: Differential Pressure (Stack Effect) (ASHRAE, 2013)

$$\Delta p_s = 0.00598(\rho_o - \rho_i)g(H_{NPL} - H)$$
$$= 0.00598 p_o \left(\frac{T_i - T_o}{T_i}\right) g(H_{NPL} - H)$$

where

T_o = outdoor temperature, °R

T_i = indoor temperature, °R

ρ_o = outdoor air density, $\frac{\text{lb}}{\text{ft}^3}$

ρ_i = indoor air density, $\frac{\text{lb}}{\text{ft}^3}$

H_{NPL} = height of neutral pressure level above reference plane without any other driving forces, ft

Average weather conditions for Anchorage, Alaska are provided in Table 4 below. Historical monthly weather data was utilized from an average of a 30-year period from 1981 to 2010 at Ted Stevens International Airport from the Alaska Climate Research Center.

Table 4: Average Anchorage Weather Conditions (Alaska Climate Research Center)

Month	Avg. Temp (°F)	Avg. Wind Speed
Jan	17.1	4
Feb	20.2	4
Mar	26.6	3
Apr	36.8	3
May	47.8	2
Jun	55.2	2
Jul	58.8	2
Aug	56.7	2
Sep	48.6	3
Oct	34.8	3
Nov	22.2	3
Dec	19	4

The building envelope was provided in the AkWarm files provided by AHFC which included data such as the ground surface area of the building and the average ceiling height of the building. In general, it may be assumed the neutral pressure level (H_{NPL}) is half of the average ceiling height of the building but this is not always the case. For example, the AHFC white paper defined the neutral pressure level of the Sullivan Arena as 12.5 ft. For the purpose of this study, the same building information was utilized as in the AHFC white paper. Other building information included in the AkWarm files included the surveyed hours of operation of the building, number of occupants, etc. and is provided in Table 5 below.

Table 5: Building Information for this Study (Armstrong, AkWarm Software Files, 2012)

Building	Space Type	Floor Area (ft²)	Hours of Use	# Users /day	# Passages /day	Hrs/ day of use	Days used/ Week	#/hr of use
APD Headquarter	Public Safety	11,246	24/7	94	188	24	7	7.8
		51,804	7:30AM-5:30PM M-F	74	148	10	5	14.8
MLK Career Center	Education	127,116	7:30AM-6:00PM M-F	1251	2502	10.5	5	238.3
East High School	Education	293,868	6AM-4:30PM M-F	2300	4600	10.5	5	438.1
	Gym	48,700	7AM-7PM M-F	180	360	12	5	30.0
	Pool	19,130	7AM-7PM M-F	20	40	12	5	3.3
Loussac Library	Public Assembly	135,671	9AM-6PM M-Su	1200	2160	9	7	240.0
	Public Assembly	135,671	9AM-6PM M-Su		240	2	7	120.0
Sullivan Arena	Public Assembly	151,470	Varies	1827	3654	4	5	913.5
Transit Admin Bld.	Office < 20k ft²	19,022	7:30AM-5:30PM M-F	25	50	10	5	5.0

Assuming a normal indoor temperature of 70°F and using the data provided by AkWarm files, the differential pressure caused by stack effect was calculated for each month of the year and then averaged. An example of the calculation used is provided for the King Career Center in Table 6 below with an assumed year-round indoor temperature of 70°F (21.1°C or 529.7°R).

Table 6: Example Stack Effect Calculation for the King Career Center

MLK Career Center	Outdoor Temp								Stack Pressure
Month	**To oF**	**To oC**	**To oR**	**C1 factor**	**po, lb/ft³**	**g, ft/s²**	**Hnpl, ft**	**H, ft**	**dPs (inH2O)**
Jan	17.1	-8.3	476.8	0.00598	0.083	32.2	13.5	4	-0.015
Feb	20.2	-6.6	479.9	0.00598	0.083	32.2	13.5	4	-0.014
Mar	26.6	-3.0	486.3	0.00598	0.082	32.2	13.5	4	-0.012
Apr	36.8	2.7	496.5	0.00598	0.080	32.2	13.5	4	-0.009
May	47.8	8.8	507.5	0.00598	0.078	32.2	13.5	4	-0.006
Jun	55.2	12.9	514.9	0.00598	0.077	32.2	13.5	4	-0.004
Jul	58.8	14.9	518.5	0.00598	0.077	32.2	13.5	4	-0.003
Aug	56.7	13.7	516.4	0.00598	0.077	32.2	13.5	4	-0.004
Sep	48.6	9.2	508.3	0.00598	0.078	32.2	13.5	4	-0.006
Oct	34.8	1.6	494.5	0.00598	0.080	32.2	13.5	4	-0.010
Nov	22.2	-5.4	481.9	0.00598	0.082	32.2	13.5	4	-0.014
Dec	19	-7.2	478.7	0.00598	0.083	32.2	13.5	4	-0.015
Avg	**36.9**	**2.8**	**496.7**	**0.00598**	**0.080**	**32.2**	**13.5**	**4**	**-0.009**

The pressure differential in each building as a result of stack effect was calculated using the data provided by the Alaska Housing Finance Corporation audit simulation models. The calculated stack effect differential pressure for each building is noted in Table 7 below. Also for reference and included in this table is the estimated air leakage rate of the entire building envelope as was included in the AkWarm simulation models.

Table 7: Calculated Differential Pressure Due to Stack Effect (Thermal Buoyancy)

Building	Avg. Ceiling Height (ft)	Estimated Air Leakage, ft^3/min (CFM)	Primary Door	Stack Effect (in. H2O)
APD Headquarters	8	16,950*	East (employees)	0.000
MLK Career Center	27	1,695**	Northeast	-0.009
East High School	20	7,234**	West	-0.006
	20		South	-0.006
	20		East	-0.006
	20		North (Gym/Pool)	-0.006
Loussac Library	70	306**	South (west-facing)	-0.011
	70	306**	South (downstairs)	-0.030
Sullivan Arena	25	8,000*	Northwest	-0.008
Transit Admin Bld.	9	6,900*	East	0.000

*Estimated Total CFM at 50/75 Pa
** Estimated CFM at 75 Pa per ft2 of Above-Grade Shell Area

Differential pressure resulting from wind is a result of the redistribution of stack pressures on the building's exterior surface. Wind driven air leakage is inward (positive) on the windward side and outward (negative) on all other sides when there is no stack effect or fan pressurization at work, although sides can also be positive depending on building shape and surrounding obstructions (ASHRAE, 2013). Wind pressure depends on wind direction, wind speed, air density, surface orientation, and surrounding conditions. The formula for calculation of the Wind Effect is noted as Equation 4 below.

Equation 4: Differential Pressure (Wind Effect) (ASHRAE, 2013)

$$p_w = 0.0129 C_p \rho \frac{U^2}{2}$$

where

p_w = wind surfacepressure relative to outdoor static pressure in undisturbed flow, in. of water

ρ = outdoor air density, $\frac{\mathrm{lb_m}}{\mathrm{ft^3}}$ (about 0.075 at or near sea level)

U = wind speed, mph

C_p = wind surface pressure coefficient, dimensionless

0.0129 = unit conversion factor, in. ofwater $* \mathrm{ft^3/lb_m} * \mathrm{mph^2}$

Research studies have shown that wind is not the dominant force driving air leakage, but can account for up to 25 percent of the air change rate on a seasonal basis (Quirouette & Arch, Revised November 2004). Utilization of city average wind speed data may also be an overestimation; the British Standards governing the principles which should be observed when designing natural ventilation of buildings for occupation estimates that a wind speed reduction should be accounted for depending on the terrain surrounding the buildings (British Standards Institute, 1991). Alaska simulation program AKWarm uses a similar assumption for calculations by asking users to select the wind shielding as "shielded, average, or exposed." Despite the impact of wind direction, amount of nearby obstructions, etc., Anchorage has a relatively low average wind speed (<5 mph) in most locations such that the impact on overall pressure differential is relatively small compared to any potential stack effect. In cases where stack effect is also minor, air leakage through cracks and seals may also be minor in contrast to the overall air flow resulting from opening and closing of doors. In other areas of Alaska, wind speed and nearby landscaping may be a more important factor to consider when estimating the infiltration rate.

Wind pressure effects were considered in the calculations and varied significantly depending on building orientation versus wind direction. This study concluded that the general assumption that wind accounts for no more than approximately 25% of the entire infiltration differential pressure is generally true for this study. The high contribution of even small wind velocity in this study is in part due to the low stack effect differential pressure observed on these low-rise buildings considered relative to high-rise buildings. Per ASHRAE, for high-rise buildings, height is more than three times the width (ASHRAE, 2013). Due to the low average speed as well as unpredictable wind direction, wind could probably be ignored in the Anchorage, particularly if there is any wind protection (trees, etc.). The wind is most often out of the north (15% of the time) and northwest (10% of the time) while least often out of the southeast (3% of the time) as shown in Figure 42 below (Weatherspark.com, 2016). This spread in wind direction makes determination of the wind coefficient unreliable. As an assumption, this study assumed the average wind direction was from the North. With more time, the study could shift the wind coefficient factor depending on time of year, but it is unlikely that the conclusions of this study would change.

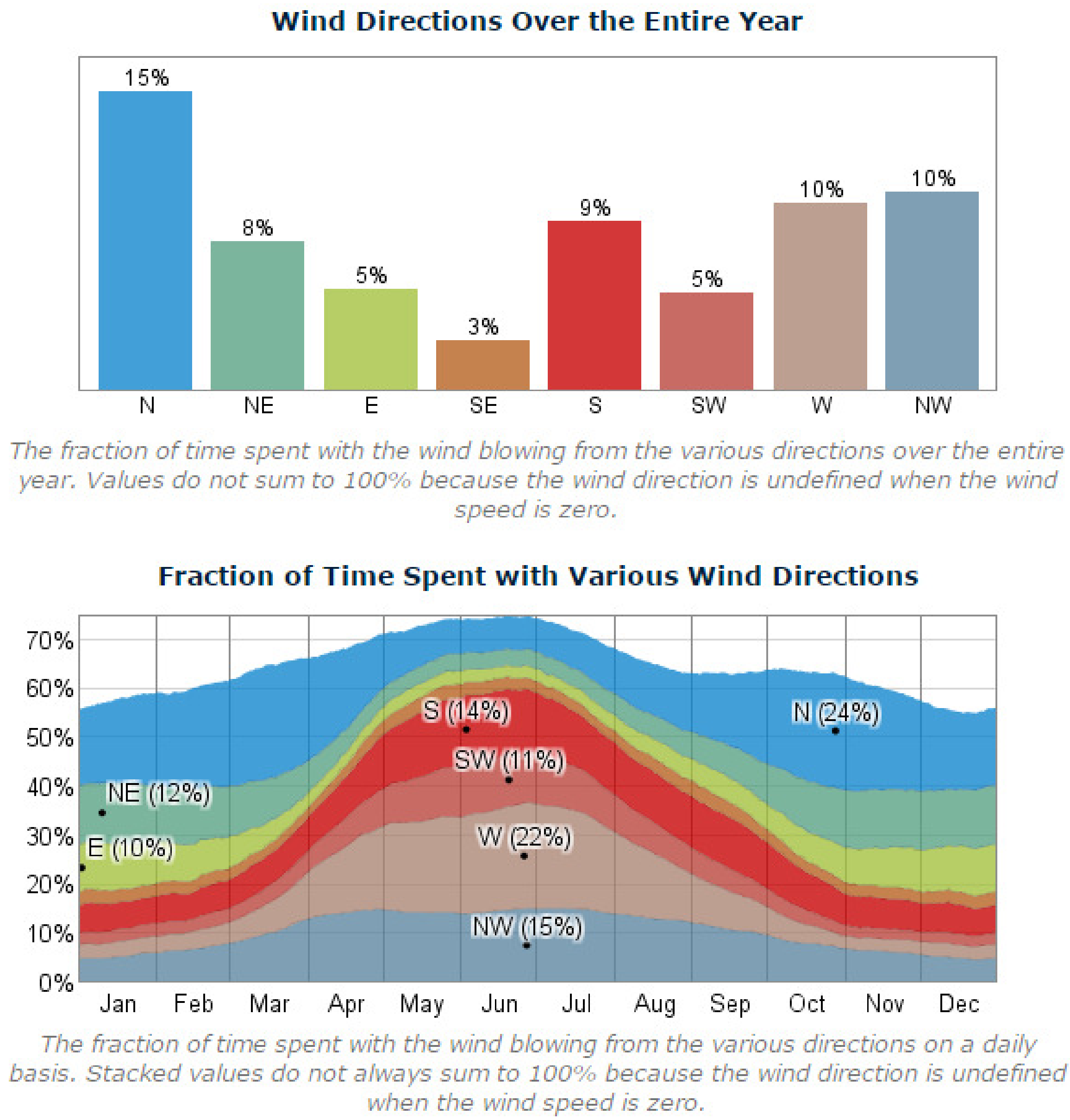

Figure 42: Average Anchorage Wind Direction (Weatherspark.com, 2016)

Since the angle of the wind has a significant impact on the wind differential of a particular building door, it is necessary to select a wall pressure coefficient. Studies vary significantly on the value of wall coefficients. For example, according to the ASHRAE 2013 Fundamentals Handbook (ASHRAE, 2013), Chapter 16, studies by Akins et al. (Akins, Peterka,

& Cermak, 1979) and Wiren (Wiren, 1984) show the typical values for the pressure coefficients as $C_p(0°) = 0.6$, $C_p(180°) = -0.3$, and $C_p(90°, 270°) = -0.65$ for low-rise buildings in which the longest wall is less than three times the length of the shortest wall. In Chapter 24 however, this statement is contradicted by ASHRAE's reference to Figure 43 below from the Akins et al. (1979) study as applying to tall buildings.

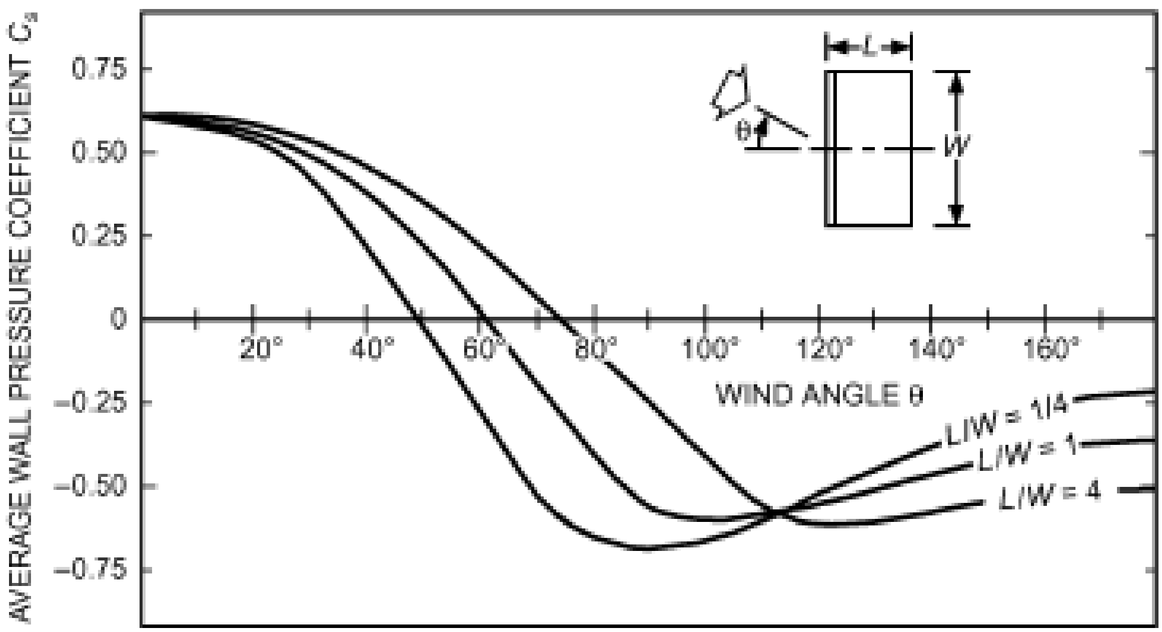

Figure 43: Surface-Averaged Wall Pressure Coefficients for Tall Buildings (Akins, Peterka, & Cermak, 1979)

Since this study focuses on low-rise buildings, coefficients provided by Swami and Chandra (Swami & Chandra, 1987) for surface pressure coefficients averaged over a complete wall of a low-rise building are used and are found below in Figures 44 and 45.

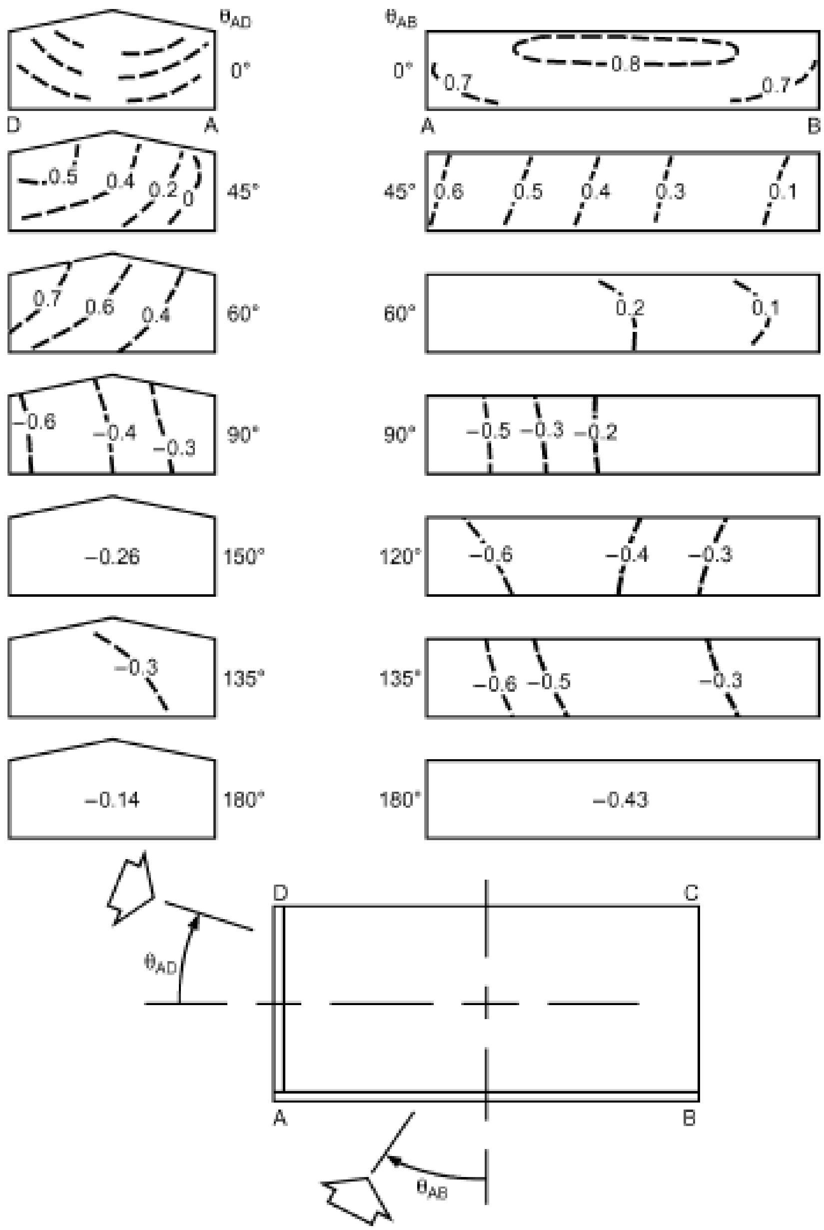

Figure 44: Local Pressure Coefficients for Walls of Low-Rise Building with Varying Wind Direction (Swami & Chandra, 1987)

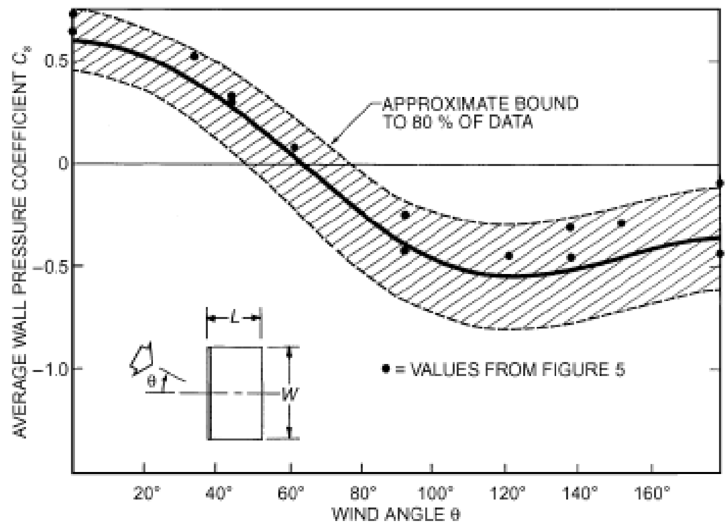

Figure 45: Variation of Surface-Averaged Wall Pressure Coefficients for Low-Rise Buildings (Swami & Chandra, 1987)

For this study, only the primary building doors for user passage were considered to maximize the impact of any potential change in door type. Once primary doors were identified, the surface-averaged wall pressure coefficients from Swami and Chandra (Swami & Chandra, 1987) were determined depending on the door's angle relative to North. An example wind pressure calculation for the King Career Center is shown in Table 8 below.

Table 8: Example Wind Effect Calculation for the King Career Center

Month	C2 factor (inH2O)*ft3/(lb*mph^2)	Cp	p, lb/ft3	U, mph	Wind Pressure Pw (in H2O)
Jan	0.0129	0.4	0.083	4	0.003
Feb	0.0129	0.4	0.083	4	0.003
Mar	0.0129	0.4	0.082	3	0.002
Apr	0.0129	0.4	0.080	3	0.002
May	0.0129	0.4	0.078	2	0.001
Jun	0.0129	0.4	0.077	2	0.001
Jul	0.0129	0.4	0.077	2	0.001
Aug	0.0129	0.4	0.077	2	0.001
Sep	0.0129	0.4	0.078	3	0.002
Oct	0.0129	0.4	0.080	3	0.002
Nov	0.0129	0.4	0.082	3	0.002
Dec	0.0129	0.4	0.083	4	0.003
Average	**0.0129**	**0.4**	**0.080**	**3**	**0.002**

Average values for wind coefficients selected are noted in Table 9 below, as well as the calculated wind effect differential pressure for each building considered in this study.

Table 9: Calculated Differential Pressure Due to Wind Effect

Building	Primary Door	Primary Door Type	Primary Door Area (ft2)	Wind ° Relative to Door	Wind Coeff.	Wind dP (in. H2O)
APD	East	Vestibule*	40	90	-0.4	-0.002
MLK Career Center	Northeast	Vestibule	40	45	0.4	0.002
East High School	West	Vestibule	40	270	-0.4	-0.002
	South	Vestibule	40	180	-0.4	-0.002
	East	Single 2-Doors	40	90	-0.4	-0.002
	North (Gym/Pool)	Single 2-Doors	40	0	0.6	0.003
Loussac Library	South (west-facing)	Vestibule	40	180 (door faces 270)	-0.4	-0.002
	South (downstairs)	Vestibule	40	180	-0.4	-0.002
Sullivan Arena	Northwest	Vestibule	40	305	0.4	0.002
Transit Admin Bld.	East	Vestibule	40	90	-0.4	-0.002

*Assumed due to lack of public access

Finally, the combined differential pressure can be calculated per Equation 2 aforementioned and is established in Table 10 below.

Table 10: Combined Differential Pressure for Buildings Studied

Building	Primary Door	Primary Door Type	Stack Effect (in. H2O)	Wind dP (in. H2O)	Total dP (in. H2O)	Total dP (Pa)
APD Headquarters	East (employees)	Vestibule*	0.000	-0.002	0.001	10
MLK Career Center	Northeast	Vestibule	-0.009	0.002	0.011	77
East High School	West	Vestibule	-0.006	-0.002	0.004	27
	South	Vestibule	-0.006	-0.002	0.004	27
	East	Single 2-Doors	-0.006	-0.002	0.004	27
	North (Gym/Pool)	Single 2-Doors	-0.006	0.003	0.009	60
Loussac Library	South (west-facing)	Vestibule	-0.011	-0.002	0.009	61
	South (downstairs)	Vestibule	-0.030	-0.002	0.028	195
Sullivan Arena	Northwest	Vestibule	-0.008	0.002	0.010	70
Transit Admin Bld.	East	Vestibule	0.000	-0.002	0.001	10

*Assumed due to lack of public access

AIR LEAKAGE (SEALS AND CRACKS)

Recall Equation 1; air infiltration through doors should be considered in two separate categories; air leakage when the door is closed (i.e. stationary air leakage through cracks and seals) and air flow when the door is open or revolving (air change rate). This study first examines when the door is closed.

Air leakage depends primarily on the pressure differential between indoor and outdoor air conditions, the door usage rate, and the type of door. Air leakage (or lack of tightness) rate (in cubic feet per minute) in all closed doors is a result of cracks and gaps in the door seal and the pressure differential across the door as a result of differences in air density. For residences and small buildings where doors are used infrequently, air exchange associated with a door can be estimated based on air leakage through cracks between door and frame. Vestibules or revolving doors should always be considered for high-frequency applications (ASHRAE, 2013). Both door systems (considering a standard 4-wing revolving door) essentially utilize two set of doors to minimize air leakage.

Door seals wear over time and vary significantly in quality depending on many conditions (age, wear, usage rate, etc.). Air leakage monitoring in buildings is important to check when considering heating and cooling losses. In one study, the air infiltration through gaps and cracks in seals of revolving doors accounts for about 30% of the total infiltration in the case of old doors, and for about 10% of the total infiltration in the case of a new door while correspondingly the remaining 70% (old door) and 90% (new door) are due to the door movement (Schijndel, Zmeureanu, & Stathopoulos, 2003). However, air leakage also exists through places such as windows, garage doors, combustion air supply, exhaust fans, ventilation ducting leaks, etc. Air leakage of the entire building can be measured using the Blower Door Test, or can be estimated qualitatively by an auditor, but identifying the specific causes of leakage in a particular building requires detailed inspection.

Air leakage rate estimates of the entire building envelopes studied are included previously as found in the AkWarm simulation models provided by AHFC. AkWarm uses a qualitative method shown in Table 11 below on a 0 – 3 scale to estimate the air leakage rate based on the size of the building audited. The breakdown guidance is similar to that given by ASHRAE.

Table 11: AkWarm (and AHFC) Method for Estimating Envelope Air Leakage Rate (Armstrong, AkWarm Software Files, 2012)

Building Component	BEST	AVERAGE	WORST	TOTAL
WINDOWS & DOORS (15%)	All window and door frames caulked. Window and door sashes well-fitting and weather-stripped, or storm windows and doors with good fit.	Window and door frames caulked. Window and door sashes poorly weather-stripped, or poorly fitting storm doors and windows.	No caulking on window and door frames. No weather-stripping. No storm doors or storm windows	
	0	0.53	1.05	
WALLS (27%)	Ceiling and floor joints and corners well sealed, electrical outlets with gaskets, no holes around plumbing penetrations.	Some cracks in ceiling and floor joints and corners. No gaskets on electrical outlets. Two or fewer plumbing penetrations with visible holes around them	Many cracks in ceiling and floor joints and corners. No gaskets on electrical outlets. Three or more plumbing penetrations with holes around them.	
	0	0.94	1.89	
CEILING (18%)	No cracks in ceiling. No air gaps around flues. No gaps around ducts, pipes or wiring penetrating attic floor. No recessed light fixtures. No trap door or weather-stripped trap door to attic.	Some cracks in ceiling. No air gaps around flues. Some gaps around ducts, pipes or wiring penetrating attic floor. Two or fewer recessed light fixtures. Unweather-stripped trap door to attic.	Many cracks in ceiling. Air gaps around flues. Many gaps around ducts, pipes or wiring penetrating attic floor. Three or more recessed light fixtures. Uncovered attic access.	
	0	0.63	1.26	
FLOOR OVER CRAWLSPACE (5%)	No crawl space or floor penetrations.	Few (2 or less) floor penetrations.	Many floor penetrations and/or poorly sealed.	
	0	0.17	0.35	

HEATING/ WATER HEATING SYSTEMS	Both furnace and water heater electric, or if fossil fuel fired, sealed-combustion. No ductwork or all ductwork in conditioned space.	No more than one fossil fuel-fired unit in living space with vent damper. Others in unconditioned space. Ductwork not sealed.	More than one fossil fuel-fired unit in living space without vent damper. Ductwork in unconditioned space. Ductwork noticeably leaky	
	0	0.63	1.26	
FIREPLACE OR WOOD STOVE (12%)	No wood heat, or sealed combustion wood stove.	Gasketed wood stove or fireplace with well fitting damper and glass doors.	Poorly sealed wood stove and any fireplace, or a fireplace with poorly fitting damper or no glass doors.	
	0	0.42	0.84	
VENTS IN LIVING SPACE (5%)	No undampered vents and two or fewer dampered vents.	Two or fewer undampered vents or three or more dampered vents.	Three or more undampered vents.	
	0	0.18	0.35	
Baseline Air Change				3

Once the baseline air change is determined by the auditor, the air changes are converted back to cubic feet per minute by Equation 5 below.

Equation 5: Conversion of baseline Air Change per Hour to Cubic Feet per Minute (Armstrong, AkWarm Software Files, 2012)

$$\mathrm{CFM} = \mathrm{ACH} * \mathrm{Volume}/60$$

Evaluating the differences in air leakage rates between standard swing doors and revolving doors is theoretically possible by using empirical data provided by studies, but doesn't necessarily consider a wide variety of factors, including the size differences between the selected doors, as well as the number of revolving door segments or wings (two vs. three vs. four). Additionally, the air leakage of a revolving door changes depending on the number of wings (i.e. two, three, or four) that are touching the building. Figure 46 below exemplifies this difference.

For a four wing revolving door, the air leakage is approximately 50% higher when only two wings are touching the housing than when four wings are touching the housing. Although a three wing door is not shown, it the infiltration rate due to leakage would fall between the two wing and four wing models. Ideally, automatic revolving doors would stop perfectly such that minimal leakage occurs (maximum wings connected to the housing during stoppage time). This would not increase the number of revolutions (and consequently air flow rate) since shifting the door further to the closed position does not constitute an additional quarter revolution. On the other hand, manual revolving doors are cheaper to install and maintain but almost always stop such that only two wings are connected to the housing (for common three wing and four wing arrangements). Therefore, it can be generally stated that based on these studies an automatic 4-wing revolving door (automated to close with four wings touching the housing) would reduce the air leakage rate through door cracks by up to 33% compared to a manual revolving door. By inference, it can then be generally stated that automatic 4-wing revolving door (automated to close with four wings touching the housing) would reduce total infiltration by 10% in the case of old doors and for more than 3% of a new door compared to a similarly-aged automatic 2-wing revolving door or manual 4-wing revolving door. Vestibules would seemingly have a great advantage over manual revolving doors in this regard, since the two sets of doors would have a similar air leakage as an automatic 4-wing revolving door (automated to close with four wings touching the housing). We can infer from these studies that the air leakage of a vestibule (with similar age cracks and surface area) has up to 33% less air leakage rate through door cracks than a manual 4-wing revolving door due to its inability to seal on all four wings.

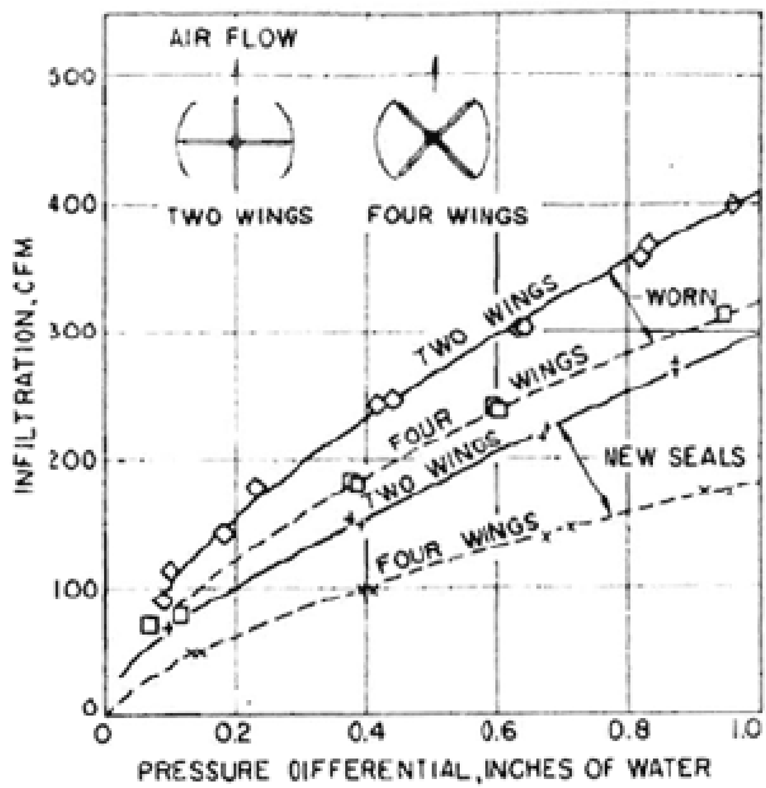

Figure 46: Air infiltration rates through new and worn door seals (two vs. four wing) when stopped. (Schutrum et. al., 1961)

An evaluation of a vestibule versus 4-wing automatic revolving door for air leakage differences in seals may or may not show the differences to be relatively negligible compared to the quality of the seals themselves. It may depend heavily on the design of the vestibule spacing, and how often both sets of doors are open at the same time. A specific study comparing vestibules versus revolving doors was not identifiable during the literature review, and should be studied further to verify this difference.

Due to the low usage frequency in lower density areas such as Anchorage, it is assumed that all potential revolving doors to be installed would be manually operated due to the lower installation and operating costs. From general online searches, the non-install cost of a revolving door can range from $2,500 to $30,000+ depending on the size, style, and automation of the door. For this study, it was assumed that a 4-wing manual revolving door at a $10,000 installed cost would be utilized. It is possible that this is underestimating the retrofitting costs required to install a revolving door where a swing door or vestibule currently exists.

Most existing doors also have cracks in the sealing surface that increase the air infiltration rate. This rate can be calculated if the size of the crack is known using Figure 47 below. For the purposes of this study, it was assumed that each existing door has a 1/4" crack that is 12 inches in linear length. A similar assumption was made in a similar study by a group of students at MIT (Cullum, Lee, Sukkaski, & Wesolowski, 2006).

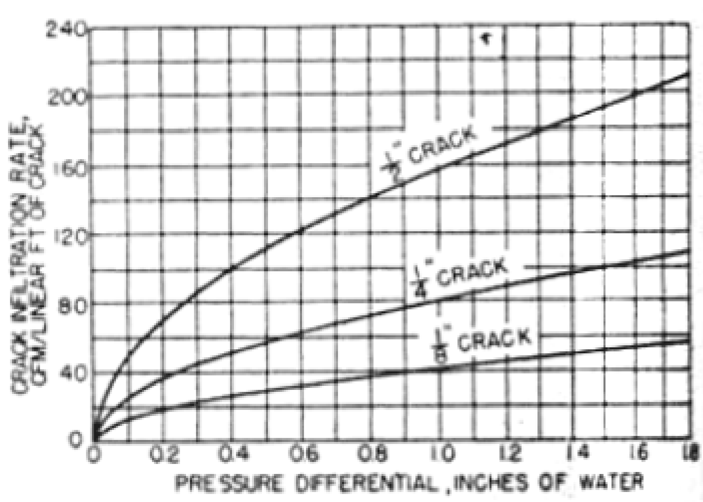

Figure 47: Air infiltration through cracks when doors are not moving (Min, 1958)

Using Figures 46 and 47, the seal infiltration rates and crack infiltration rates (CFM) for the primary doors of the buildings studied were estimated in Table 12 below. All existing vestibules assume a seal infiltration similar to a 4-wing automatic revolving door with worn seals. All existing single set of 2-doors (swing doors) assume a 2-wing revolving door with worn seals. As expected, the infiltration rate for East High School's East main entrance is relatively higher than the South and West entrances due to the lack of a vestibule.

Table 12: Estimated Primary Door Seal and Crack Infiltration Rates (CFM)

Building	Primary Door	Primary Door Type	Primary Door Area (ft2)	Total dP (in. H2O)	Seal Infiltration (CFM)	Crack Infiltration (CFM)
APD Headquarters	East (employees)	Vestibule*	40	0.001	1.30	0.35
MLK Career Center	Northeast	Vestibule	40	0.011	10.09	2.66
East High School	West	Vestibule	40	0.004	3.62	0.96
	South	Vestibule	40	0.004	3.62	0.96
	East	Single 2-Doors	40	0.004	4.70	0.96
	North (Gym/Pool)	Single 2-Doors	40	0.009	10.28	2.09
Loussac Library	South (west-facing)	Vestibule	40	0.009	8.01	2.12
	South (downstairs)	Vestibule	40	0.028	24.75	6.49
Sullivan Arena	Northwest	Vestibule	40	0.010	9.23	2.44
Transit Admin Bld.	East	Vestibule	40	0.001	1.30	0.35

*Assumed due to lack of public access

AIR INFILTRATION IN STANDARD SWING DOORS AND VESTIBULES

Infiltration through the existing manual standard swing doors and vestibules was then calculated using established figures by T.C. Min (Min, 1958). Figure 48 provides entrance coefficients for the existing single standard swing-doors of the primary doors in this study. Figure 49 provides the same entrance coefficients but for vestibules. Figure 50 correlates the entrance coefficients to the actual air infiltration rates in cubic feet per min. A crucial assumption is the traffic rate (number of persons / hr / door). Each door in this study received different assumptions. The APD building East entrance (for 24/7 employee entrance) utilized only the 24hrs/day occupancy provided by AHFC. The King Career Center assumed 80% of entrants utilize the Northeast main door, which is likely an exaggeration. East High School assumed that the traffic is evenly split between the West, South, and East entrances. There are dozens of entrances at East High School and a longer study would be needed to observe traffic patterns to better identify occupancy. It could also be said that for schools such as East and King Career Center, occupants likely enter and exit the building more than once per day which is also not considered in this study. The East High pool/gym entrance also assumes only one set of doors is used, and that only pool/gym users utilize this door. That is not the case, but more complicated assumptions would require a significantly longer study beyond the basis of this examination. For the Loussac Library, the assumption is that 90% of the users traffic through the main upper floor South entrance (which faces West), while the remaining 10% use the lower door. The Sullivan Arena assumption is that 80% of traffic is through the Northwest entrance which is the main ticket entrance, but people exiting main events are likely to utilize alternative routes. The Transit Admin Building assumed 80% of users are through the East entrance.

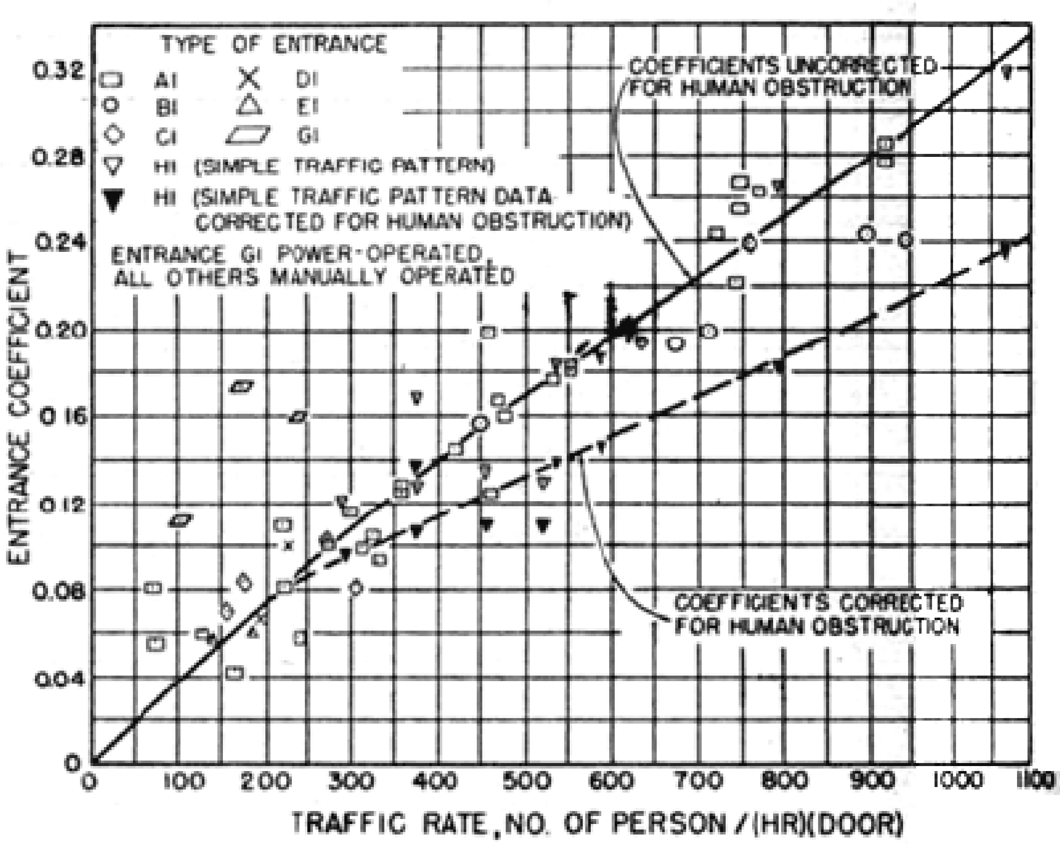

Figure 48: Entrance coefficients for single-door entrances. (Min, 1958)

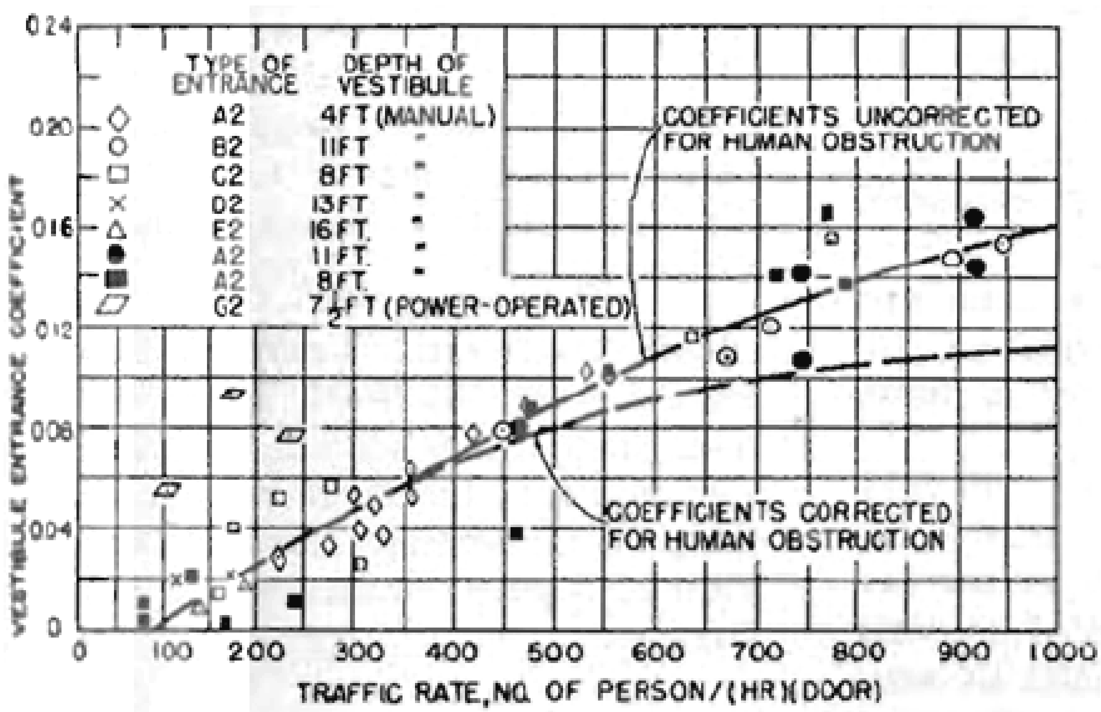

Figure 49: Entrance coefficients for vestibule entrances. (Min, 1958)

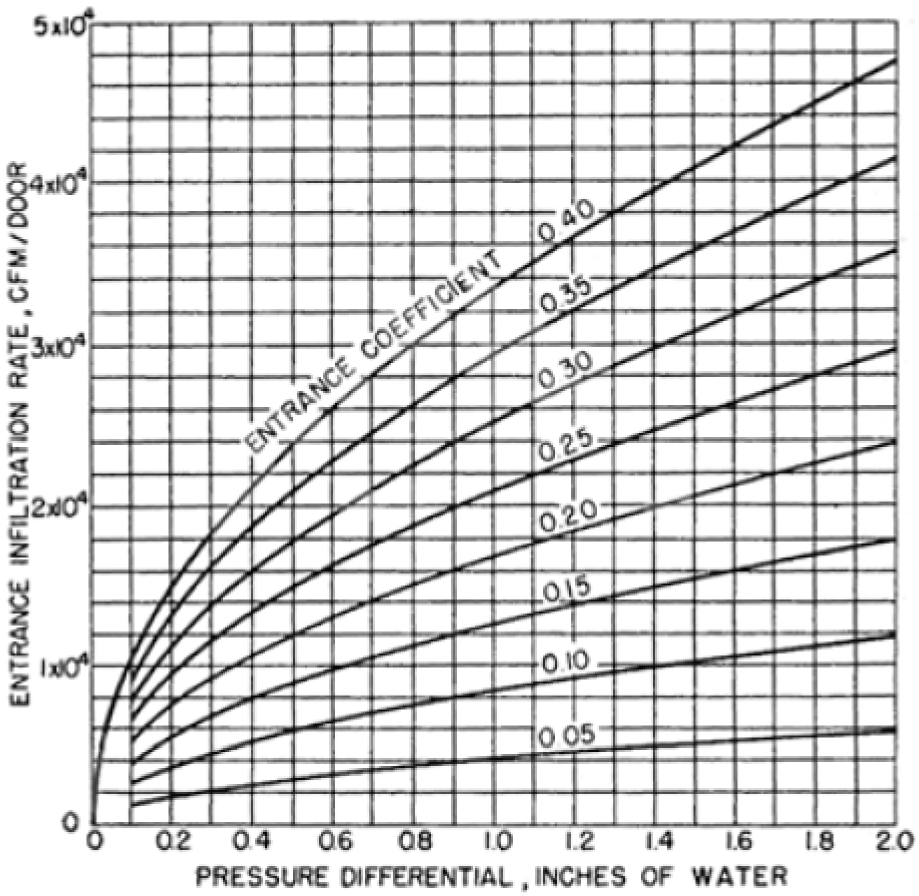

Figure 50: Entrance infiltration rates for swing doors at various pressure differentials and traffic rates. (Min, 1958)

The estimated traffic rate, entrance coefficients, and air infiltration rates during traffic periods for the existing doors of the buildings studied are included in Table 13 below.

Table 13: Estimated Traffic Rate, Entrance Coefficient, and Infiltration for Open Existing Doors

Building	Primary Door	Primary Door Type	Traffic Rate, # passages/hr	Entrance Coeff.	Open Infiltration Rate (CFM)
APD Headquarter	South (employees)	Vestibule*	8	0.00	0
MLK Career Center	Northeast	Vestibule	238	0.04	352
East High School	West	Vestibule	146	0.02	144
	South	Vestibule	146	0.02	144
	East	Single 2-Doors	146	0.06	924
	North (Gym/Pool)	Single 2-Doors	33	0.02	88
Loussac Library	South (west-facing)	Vestibule	240	0.04	355
	South (downstairs)	Vestibule	120	0.02	85
Sullivan Arena	Northwest	Vestibule	731	0.07	1137
Transit Admin Bld.	East	Vestibule	4	0.00	0

*Assumed due to lack of public access

With seal and crack infiltration estimated for closed doors, and air infiltration estimated for periods when doors are open, the total air infiltration rate was compiled in Table 14 below.

Table 14: Calculated Total Air Leakage Rate of Existing Primary Doors

Building	Primary Door	Primary Door Type	Seal Infiltration Rate (CFM)	Crack Infiltration Rate (CFM)	Open Infiltration Rate (CFM)	Total Rate (CFM)
APD Headquarters	East (employees)	Vestibule*	1.30	0.35	0	2
MLK Career Center	Northeast	Vestibule	10.09	2.66	352	365
East High School	West	Vestibule	3.62	0.96	144	149
	South	Vestibule	3.62	0.96	144	149
	East	Single 2-Doors	4.70	0.96	924	929
	North (Gym/Pool)	Single 2-Doors	10.28	2.09	88	101
Loussac Library	South (west-facing)	Vestibule	8.01	2.12	355	366
	South (downstairs)	Vestibule	24.75	6.49	85	116
Sullivan Arena	Northwest	Vestibule	9.23	2.44	1137	1148
Transit Admin Bld.	East	Vestibule	1.30	0.35	0	2

*Assumed due to lack of public access

AIR INFILTRATION IN REVOLVING DOORS

Air infiltration for open or revolving doors differs significantly between standard swing doors and revolving doors. The main parameters impacting the flow through the open swing door is the building pressure differential, the surface area of the door, and the frequency of opening. Several studies have shown that the revolving of the door is practically independent of the pressure differential (ASHRAE, 2013). Therefore, the main parameter impacting the flow through the revolving door is the rate and volume of the displaced air during the rotation.

Using the same methods as previously outlined, seal infiltration and crack infiltration rates were estimated for new manual 4-wing revolving doors. It was assumed that the seal infiltration rate for the new doors was equivalent to a 2-wing automatic door with new seals. The crack infiltration rate was assumed zero due to the new installation.

The infiltration rate for manual revolving doors is approximated based on the traffic rate using Figure 51 by Schutrum (Schutrum et. al., 1961) with air leakage past seals deducted and an indoor air movement of 35 fpm.

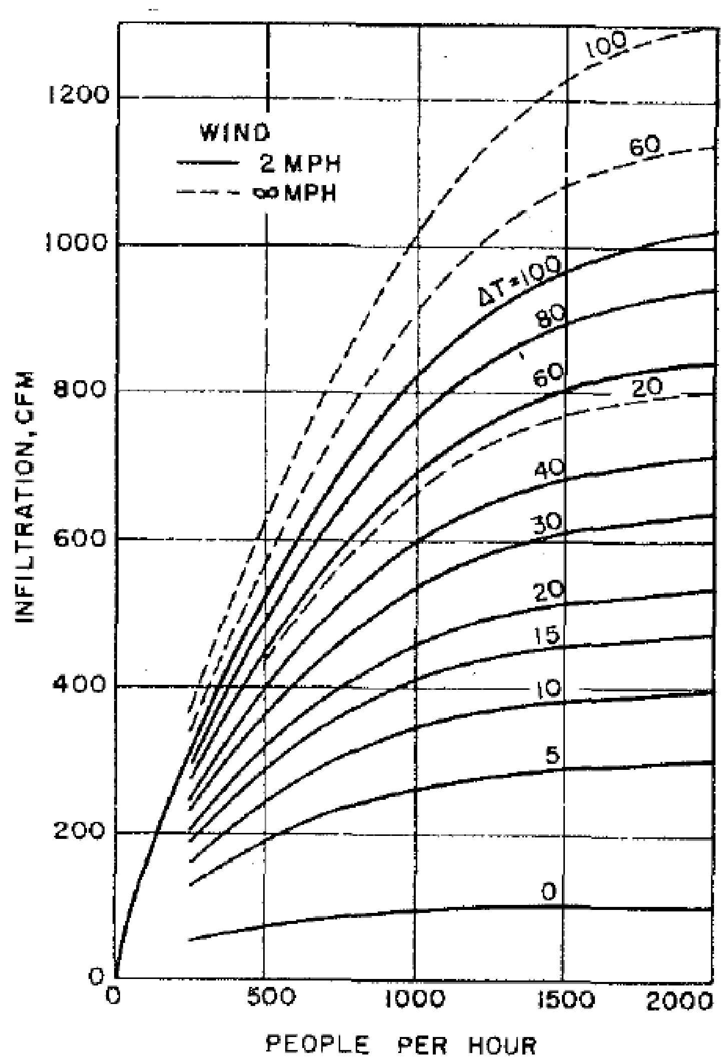

Figure 51: Infiltration through Manually Operated Revolving Doors (Schutrum et. al., 1961)

Using the aforementioned methods, the total air change rate of the new revolving doors was calculated in Table 15 below. One critical assumption made at this stage was that the surface area of the new revolving doors was equivalent to the existing doors. It was also assumed that if the traffic during usage periods was less than eighty per hour, the revolving door air infiltration rate due to door revolving was negligible. This is due to the limitations of estimating air infiltration rates for low occupancy doors with the methods available.

Table 15: Calculated Total Air Leakage Rate of Revolving Doors at Primary Locations

Building	**Primary Door**	**Primary Door Type**	**Seal Infiltration (CFM)**	**Crack Infiltration (CFM)**	**Open Infiltration Rate (CFM)**	**Total Rate (CFM)**
APD Headquarter	East (employees)	Revolving	1.41	0.00	15	16
MLK Career Center	Northeast	Revolving	10.84	0.00	219	229
East High School	West	Revolving	3.90	0.00	144	148
	South	Revolving	3.90	0.00	144	148
	East	Revolving	3.90	0.00	144	148
	North (Gym/Pool)	Revolving	8.50	0.00	41	49
Loussac Library	South (west-facing)	Revolving	8.61	0.00	220	228
	South (downstairs)	Revolving	26.28	0.00	122	148
Sullivan Arena	Northwest	Revolving	9.91	0.00	475	485
Transit Admin Bld.	East	Revolving	1.41	0.00	11	13

ENERGY SAVINGS OF REVOLVING DOORS

With the calculated total air infiltration rate, the total volume of air heated for existing doors and theoretical revolving doors during the calendar year was tabulated in Table 16 below. It was assumed that all users paid $0.10/kWh for energy (Armstrong, AkWarm Software Files, 2012). In Table 17, the total cost of each door was identified, theoretical savings calculated, and payback period identified if feasible that the revolving door would impact energy savings.

Table 16: Estimated Annual Energy Cost of Existing Primary Doors

Building	Primary Door	Primary Door Type	Annual Volume (ft3)	Current Door Energy Use (kWh)	Annual Cost $
APD Headquarters	East (employees)	Vestibule*	864,008	274	-$27
MLK Career Center	Northeast	Vestibule	59,707,893	18,942	-$1,894
East High School	West	Vestibule	24,350,964	7,725	-$773
	South	Vestibule	24,350,964	7,725	-$773
	East	Single 2-Doors	173,957,989	55,187	-$5,519
	North (Gym/Pool)	Single 2-Doors	18,859,034	5,983	-$598
Loussac Library	South (west-facing)	Vestibule	35,927,251	11,398	-$1,140
	South (downstairs)	Vestibule	5,086,379	1,614	-$161
Sullivan Arena	Northwest	Vestibule	71,658,363	22,733	-$2,273
Transit Admin Bld.	East	Vestibule	257,145	82	-$8

*Assumed due to lack of public access

Table 17: Estimated Annual Energy Cost of Revolving Doors and Potential Payback Period

Building	Primary Door	Annual Volume (ft3)	Revolving Door Energy Use (kWh)	Annual Cost $	Annual Savings ($)	Payback Period (yrs)
APD	East (employees)	8,602,466	2,729	-$273	$0	
MLK Career Center	Northeast	37,567,846	11,918	-$1,192	$702	14
East High School	West	24,258,515	7,696	-$770	$3	
	South	24,258,515	7,696	-$770	$3	
	East	27,724,017	8,795	-$880	$4,639	2
	North (Gym/Pool)	9,175,280	2,911	-$291	$307	33
Loussac Library	South (west-facing)	22,449,523	7,122	-$712	$428	23
	South (downstairs)	6,456,274	2,048	-$205	$0	
Sullivan	Northwest	30,233,548	9,591	-$959	$1,314	8
Transit Admin Bld.	East	1,951,607	1	$0	$8	

OBSERVATIONS ABOUT VESTIBULES VS. REVOLVING DOORS

It is necessary to consider the building type and door utilization needs carefully when considering revolving door technology. It was visually observed that even in Anchorage high-rise buildings where revolving doors are used (Atwood Building, Hilton Hotel) customers frequently utilize the adjacent swing doors due to user preference. At one hotel, it was observed that the manual swing doors were left wide open in order to welcome guests more easily and avoid the restriction caused by a revolving door.

If there is building space available to construct a vestibule rather than revolving door, it is theorized that Anchorage users would strongly prefer a vestibule system over a revolving door, but this should be studied further via survey and documented observation of existing Anchorage buildings.

For example, there is apparently space available at the East High School eastern entrance to implement a vestibule (which may have even existed previously). At Sullivan Arena, the traffic rate is so high during events that a revolving door may actually be an hindrance to traffic flow and result in people bypassing the revolving door in favor of the simpler vestibule. Of course, due to the high traffic this would imply the vestibule is kept practically wide open during high-use periods. At large event complexes in Chicago (United Center, All State Arena), it was observed that only vestibule systems are used.

In addition, the Loussac Library began extensive renovations during mid-way through the study that render the analysis of the pre-existing entrances useful only for general knowledge of this problem pre-renovation. Any further analysis of the building would require reviewing the AkWarm files for potential updates, as well as the construction of new entrances.

CONCLUSION

Air infiltration of selected public buildings was thoroughly studied following an extensive literature review for appropriate methodology to compare standard swing doors to vestibules and revolving doors. The study found that simple methods do not exist for evaluating vestibules versus revolving doors, and many studies assert benefits of revolving door technology without considering whether vestibules are more efficient or suitable for the building type.

From this study, a clear opportunity was identified to modify the East High School eastern entrance to either a revolving door or a vestibule. The usage of the existing door may be overestimated in this study due to the usage assumptions, but it is a primary entrance for the eastern parking lot and could provide an energy savings with minimal payback period. Determination of vestibule versus revolving door will depend primarily on the style preferred. Since no revolving doors are currently in place at East High, it is assumed that a vestibule would preferably be implemented to simplify user education and maintenance costs.

The Sullivan Arena northwest entrance is also worth further investigation to implement a revolving door over the existing vestibule due to the high traffic rate during usage periods. However, it was noted that entertainment arenas do not typically utilize revolving doors due to the extremely high throughput during peak use periods.

The study concluded that although some entrances could be improved by utilizing a vestibule or revolving door, there was only a small differential between vestibules and revolving doors. This is mostly due to the building types selected, which were all generally low-rise buildings with low usage even during periods (the exception being Sullivan Arena). Revolving door technology is more likely to apply to high-rise buildings and high-occupancy low-rise buildings such as restaurants and strip malls.

RECOMMENDATIONS

Air infiltration through doors should be strongly considered at the East High School eastern main entrance where a single set of swing doors currently exist. The Sullivan Arena may also warrant additional review.

The results of this study will be provided to the Alaska Housing Finance Corporation for review and consideration in their future audit work.

Additional study with clear methodology for comparing revolving doors to vestibules would be highly useful nationwide and should be considered by ASHRAE in their Fundamentals Handbook.

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