Energy Savings Impacts of Airtightness in U.S. Commercial Buildings

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ABSTRACT

Air leakage in commercial buildings in the U.S. accounts for about one quad of energy annually. As the thermal resistance of commercial building envelopes continues to improve, the relative contribution of air leakage to heating and cooling loads is increasing. Several manufacturers have developed advance air barrier technologies and construction practices to reduce the air leakage in buildings. To help in the market penetration of these advance technologies, advances in easy to use tools for determining the impact of air leakage are needed. Oak Ridge National Laboratory (ORNL), the Air Barrier Association of America, the National Institute of Standards and Technology, and the US-China Clean Energy Research Center for Building Energy Efficiency partnered to develop an online calculator that estimates the potential energy and cost savings in major US, Canadian, and Chinese cities from improvements in airtightness. The calculator estimates the energy and cost savings potential based on the pre and post retrofit air leakage rates for prototype commercial buildings. This report explores extending these savings to determine the national level energy savings potential based on the weightage of commercial building type in different ASHRAE climate zone locations. The base infiltration rate of 1.07 CFM/ft^2 (5.43 L/s/m^2) at 0.3 in. water column (75 Pa) was assumed for these calculations and the savings were calculated for three different air infiltration target rates of 0.4, 0.25 and 0.06 CFM/ft^2 (2.03, 1.27 and 0.3 L/s/m^2).. The national source energy savings of 238, 283, and 313 TBtu (251, 299 and 330 PJ) respectively were estimated for these target air infiltration rates.

INTRODUCTION

Commercial buildings in the United States (U.S.) consume about 19 Quads of energy per year. Air leakage through the envelope of these buildings is responsible for ~6% of their energy use [US DOE 2014], which is approximately one quad of primary energy use annually. The air leakage in commercial buildings mainly affects the heating energy consumption. U.S Energy Information Agency's (EIA) Commercial Building Energy Consumption Survey (CBECS) indicates U.S. commercial buildings consume 1,740 TBtu (1,835 PJ) for space heating [US EIA 2012]. Previous studies show that infiltration is responsible for an average of 33% of the heating load and 3.3% of cooling loads in U.S. [Emmerich et al. 2005].

Oak Ridge National Laboratory (ORNL), the Air Barrier Association of America, the National Institute of

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Standards and Technology, and the US-China Clean Energy Research Center for Building Energy Efficiency are collaborating to develop an online airtightness savings calculator (henceforth referred to as the calculator) for commercial buildings [Shrestha et al. 2016]. The calculator (https://airleakage-calc.ornl.gov/#/) uses the U.S. Department of Energy (DOE) prototype building models, given that these represent 80% of U.S. commercial building floor area [Deru et al 2010]. These prototypes were developed by DOE as a standardized baseline for energy savings calculations. The envelope assembly and HVAC unit for each of the prototypes varies based on geographical location and the building code that the building complies with. The features of the building models and a detailed description of their development are provided by Goel et al. [2014]. In particular, the calculator uses the prototype buildings that comply ASHRAE Standard 90.1-2013 [ASHRAE 2013]. The calculator also utilizes DOE's whole-building energy simulation software EnergyPlus [DOE 2016] to calculate energy consumption at different building envelope airtightness levels. What differentiates this tool is its use of hourly air leakage rates calculated with CONTAM [Dols and polidoro 2015], a multizone airflow and contaminant transport analysis software that considers variables such as weather conditions, envelope airtightness, stack effect, and operation of the HVAC system to calculate air leakage rates throughout the building enclosure. The calculator uses these leakage values as inputs in EnergyPlus. To calculate the annual energy savings impact of airtightness, the simulations for 16 climate zones were performed using the prototype models that use the detailed hourly leakage rates. Construction area weights by building prototype and climate zones [Zhang et al. 2013 and Jarnagin and Bandyopadhyay, 2010] were used to determine the potential nationwide energy savings.

METHODOLOGY

The calculator methodology was used for estimating the electricity and gas consumption of 7 prototype buildings: Standalone Retail, Mid-Rise Apartment, Medium Office, High-Rise Apartment, Large Hotel, Secondary School, Small Hotel. Applying a set of infiltration rates in different climate zones, the methodology included the following steps:

1. Create the hourly air infiltrating rates for each prototype building and climate zone; a) Base- 1.07 CFM/ft2 (5.43 L/s/m2) ; b) Case 1-0.4 CFM/ft2 (2.03 L/s/m2) ; b) Case 2-0.25 CFM/ft2 (1.27 L/s./2) ; c) Case 3-0.06 CFM/ft2 (0.3 L/s/m2). All the rates are assumed at 0.3 in. of water (75 Pa) pressure differential. The air infiltration rates at 75 Pascal were converted to air infiltration rates at building operating pressures (X Pa) using this formule: $Q_{X\ Pa} = Q_{75\ Pa}/(75^{0.65}) * X^{0.65}$ – this assumes pressure exponent = 0.65.
2. Using the air infiltration rates created in step 1, prepare the EnergyPlus models
3. Using the models created step 2, simulate the buildings with a set of airtightness values set by codes for 16 ASHRAE climates zones
4. Apply the weightage of buildings, using Zhang et al. 2013 and Jarnagin and Bandyopadhyay, 2010, in a building category and estimate the potential savings in each of the 16 climate zones
5. Estimate the national savings potential.

Building Types and Locations

As a starting point for DOE commercial buildings research, Commercial Reference Building Models were developed for the most common commercial buildings [Deru et al. 2011]. The current suite of Commercial Prototype Building Models covers 16 common building types— Standalone Retail, Mid-Rise Apartment, Medium Office, High-Rise Apartment, Hospital, Large Hotel, Secondary School, Small Hotel, Large Office, Small Office, Outpatient

Healthcare, Restaurant Fast Food, Restaurant Sit Down, Strip mall, Primary School and Warehouse. The models are developed for different vintages and for all the 16 ASHRAE climate zones [ASHRAE-2013]. The current 16 prototype building covers 80% of the US commercial building floorspace [US EIA 2012]. A few new prototype models such as Courthouse and Supermarket are under the development process. **Figure 1** shows the prototype buildings as a percentage of total US commercial building floorspace.

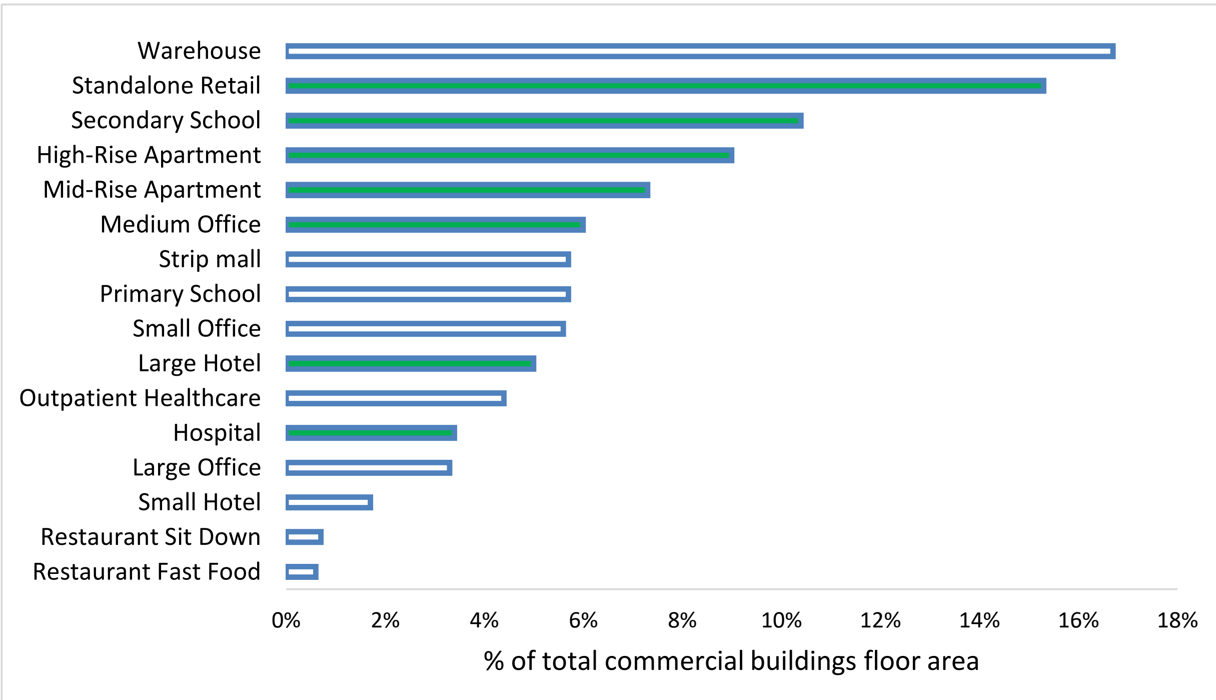

Figure 1: Prototype buildings as a percentage of total US commercial building floorspace

The prototype buildings use simplified algorithms for air leakage and specifically assume that the infiltration is 0 or a fraction (generally 0.25 or 0.5) of input air infiltration rates when the building HVAC system is operating. This hypothesis is based on the fact that since buildings are pressurized during the HVAC operation, the air leakage, therefore, will not take place. Several studies show that this assumption is not valid and a 0 or a fraction infiltration rate would produce inaccurate results. The calculator uses the detailed CONTAM and EnergyPlus pre-run simulations. Hourly CONTAM results for each building were calculated at 52 locations. These simulations utilize the energy analysis hourly air leakage rates that are estimated by considering key variables such as weather conditions, envelope airtightness, and HVAC system operation.

These detailed hourly air leakage rates are, however, very time and resource consuming. As a result, only 7 prototype buildings, Standalone Retail, Mid-Rise Apartment, Medium Office, High-Rise Apartment, Large Hotel, Secondary School, Small Hotel, were added in the first phase of the study. These 7 selected prototype buildings, highlighted in green in **Figure 1**, are reasonably diverse and represent over 55 percent of US commercial building floorspace.

For the study, fifty-two locations, as shown in **Figure 2**, were applied in the calculator. However, as the weighted areas of buildings are available only for 16 representative climate locations (**Table 1**), the national savings potential calculations are based on the simulation results of just these 16 locations.

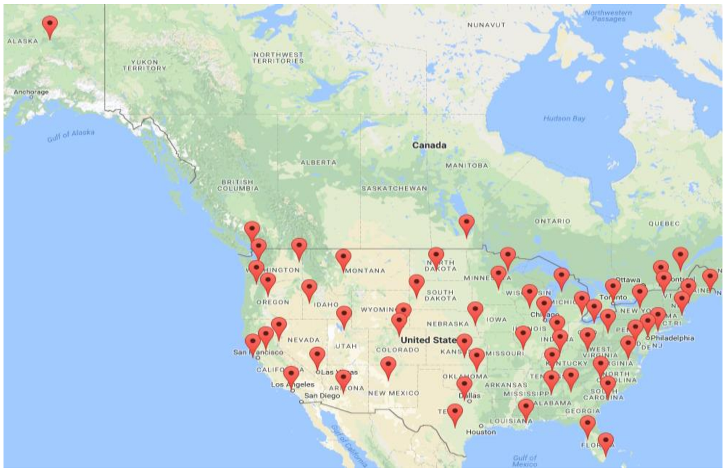

Figure 2: Locations used for airtightness calculations

Table 1: Climate zones and representative locations used for the savings potential estimation.

Location	Climate Zone	Climate Zone Name and Type
Miami	1	Very Hot
Houston	2A	Hot-Humid
Phoenix	2B	Hot-Dry
Memphis	3A	Warm-Humid
El_Paso	3B	Warm-Dry
San Francisco	3C	Warm-Marine
Baltimore	4A	Mixed-Humid
Albuquerque	4B	Mixed-Dry
Salem	4C	Mixed-Marine
Chicago	5A	Cool-Humid
Boise	5B	Cool-Dry
Burlington	6A	Cool-Humid
Helena	6B	Cool-Dry
Duluth	7	Very Cold
Fairbanks	8	Subarctic

Note: A, B, C represent, Moist, Dry and Marine respectively

Airtightness Considered

For the savings calculation, a baseline air infiltration rate of 1.07 cfm/ft^2 (5.43 L/s/m^2) at 0.3 in. of water (75 Pa), which is the average value that Emmerich and Persily (2014) reported for 387 buildings that were built from 1950 to 2010 was assumed. The calculated estimated savings for air leakage reduction of 0.4 (optional in most building codes – Case 1), and 0.25 (as mandated by USACE-Case 2) at 0.3 in. of water (75 Pa) were applied. The data from the blower tests conducted in two commercial buildings before and after retrofits, show that it is possible to reduce the air leakage to 0.06 cfm/ft^2 (0.3 L/s/m^2) (Case 3) at 0.3 in. of water (75 Pa). This air change rate for estimating the highest potential for airtightness was used, since using a zero-infiltration rate would be unrealistic.

RESULTS

The calculated savings from improvements in airtightness for the 7 prototype buildings selected indicates Standalone Retail prototype buildings to have the largest potential energy savings from reduced air infiltration across the 3 tested levels. Amongst the climate zones, climate zone 5A also shows the highest potential energy savings. The baseline of 1.07 CFM/ft^2 (5.4 L/s/ms/m^2) at 0.3 in. of water (75 Pa), which is the average value that Emmerich and Persily (2014) reported for 387 buildings that were built from 1950 to 2010, indicates a justified case for retrofitting the existing buildings. The savings after decreasing air leakage from 1.07 to 0.6, 0.4 (optional in most building codes), 0.25 (USACE) and 0.06 CFM/ft^2 (5.43, 3.05, 2.03,1.27 and 0.3 L/s/m^2) at 0.3 in. of water (75 Pa) also indicates potential energy savings.

Table 2 and **Table 3** show the cumulative site and source energy savings for the 7 selected prototype buildings and different climate zones respectively for the air infiltration rate reduction of 0.4 cfm/ft^2 (2.03 L/s/m^2) as compared to the base case of 1.07 cfm/ft^2 (5.43 L/s/m^2)The savings for an individual building in a particular climate zone were multiplied by the prototype building construction area weights in that climate zone. The savings for all the climate zones were added to get the cumulative nationswide savings for the building type. Similarly, the savings for a particlur climate zones weer calculated fro all the building types. The reduction in airtightness from 1.07 cfm/ft^2 (5.43 L/s/m^2) to 0.4 cfm/ft^2 (2.03 L/s/m^2) results in the estimated potential savings of 238 TBtu (251 PJ). Standalone Retail, with an energy savings potential of 112 TBtu (118 PJ) shows the greatest opportunity amongst the building types and climate zone 5A shows the highest potential with 87 TBtu (92 PJ).

Table 2: Cumulative site and source energy savings for different building types for the air infiltration rate reduction of 0.4 cfm/ft^2 (2.03 L/s/m^2) as compared to the base case of 1.07 cfm/ft^2 (5.43 L/s/m^2)

Building type	Site				Source					
	Gas		Electricity		Gas		Electricity		Total	
	Tbtu	PJ	TBtu	PJ	Tbtu	PJ	TBtu	PJ	TBtu	PJ
Medium office	3.39	3.58	0.19	0.20	3.90	4.11	0.56	0.59	4.46	4.71
Standalone retail	80.22	84.64	6.63	6.99	92.25	97.33	19.82	20.91	112.07	118.24
Secondary school	36.51	38.52	4.34	4.58	41.98	44.29	12.98	13.69	54.96	57.98
Hospital	4.99	5.26	0.18	0.19	5.74	6.05	0.54	0.57	6.28	6.62
Large hotel	6.86	7.24	0.53	0.56	7.89	8.32	1.58	1.67	9.47	9.99
High-rise apartment	23.02	24.28	4.07	4.30	26.47	27.92	12.17	12.84	38.64	40.77
Mid-rise apartment	9.33	9.84	0.50	0.53	10.73	11.32	1.51	1.59	12.23	12.91
Total	**164.3**	**173.4**	**16.4**	**17.3**	**189.0**	**199.4**	**49.2**	**51.9**	**238.1**	**251.2**

Table 3: Cumulative site and source energy savings for different climate zones for all the 7 building types for the air infiltration rate reduction of 0.4 cfm/ft² (2.03 L/s/m²) as compared to the base case of 1.07 cfm/ft² (5.43 L/s/m²)

Climate zone	Site				Source					
	Gas		Electricity		Gas		Electricity		Total	
	Tbtu	PJ	TBtu	PJ	Tbtu	PJ	TBtu	PJ	TBtu	PJ
1	0.08	0.08	1.34	1.41	0.09	0.09	4.00	4.22	4.09	4.32
2A	7.05	7.44	2.45	2.58	8.11	8.56	7.32	7.72	15.43	16.28
2B	0.45	0.47	0.44	0.46	0.51	0.54	1.30	1.37	1.81	1.91
3A	15.31	16.15	1.61	1.70	17.60	18.57	4.82	5.09	22.42	23.65
3B	7.89	8.32	1.97	2.08	9.07	9.57	5.90	6.22	14.97	15.79
3C	0.98	1.03	0.00	0.00	1.13	1.19	0.00	0.00	1.13	1.19
4A	37.37	39.43	1.60	1.69	42.98	45.35	4.77	5.03	47.75	50.38
4B	0.53	0.56	0.00	0.00	0.61	0.64	0.01	0.01	0.62	0.65
4C	4.59	4.84	-0.10	-0.11	5.28	5.57	-0.31	-0.33	4.97	5.24
5A	61.28	64.65	5.68	5.99	70.47	74.35	16.98	17.91	87.45	92.26
5B	6.90	7.28	0.03	0.03	7.93	8.37	0.08	0.08	8.01	8.45
6A	17.19	18.14	1.25	1.32	19.77	20.86	3.75	3.96	23.52	24.81
6B	1.20	1.27	-0.01	-0.01	1.38	1.46	-0.03	-0.03	1.35	1.42
7	3.04	3.21	0.15	0.16	3.50	3.69	0.45	0.47	3.95	4.17
8	0.47	0.50	0.04	0.04	0.54	0.57	0.11	0.12	0.65	0.69
Total	**164.3**	**173.4**	**16.5**	**17.4**	**189.0**	**199.4**	**49.2**	**51.9**	**238.1**	**251.2**

Similarly, the site and source energy savings for the air infiltration rate reduction of 0.25 cfm/ft² (1.27 L/s/m²) and 0.06 cfm/ft² (0.3 L/s/m²) as compared to the base case of 1.07 cfm/ft² (5.43 L/s/m²) were calculated and tabulated. The savings results are presented in

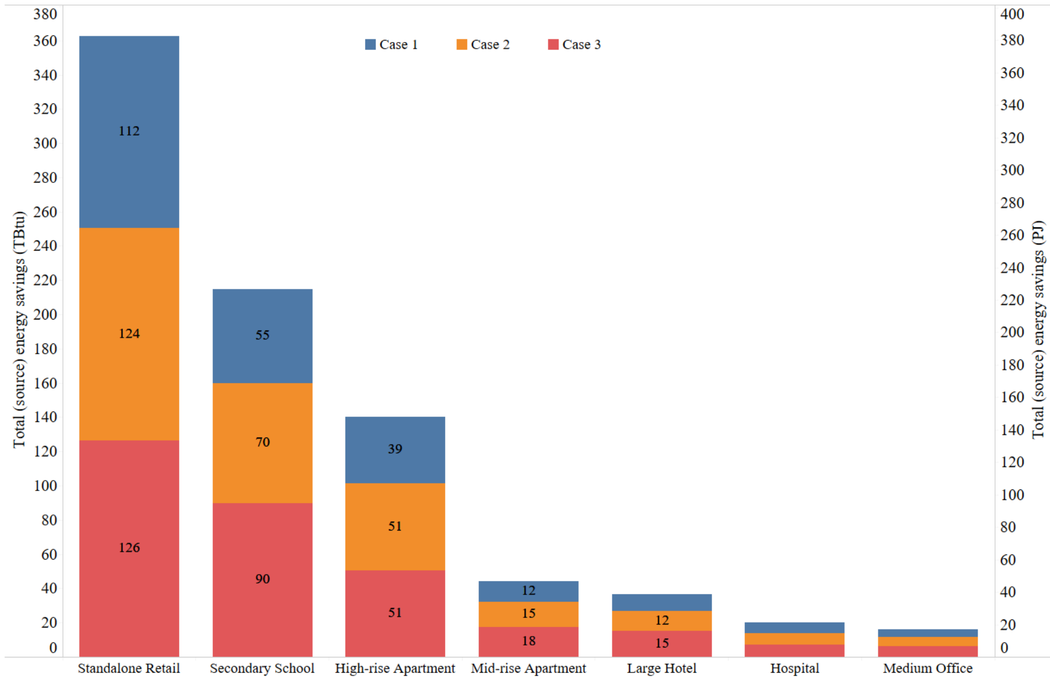

Figure 3 and Figure 4 for different building types and different climate zones respectively. The reduction in airtightness from 1.07 cfm/ft² (5.43 L/s/m²) to 0.25 cfm/ft² (1.27 L/s/m²) results in the estimated potential savings of 283 TBtu (251 PJ). Standalone Retail, with an energy savings potential of 124 TBtu (131 PJ) shows the greatest opportunity amongst the building types and climate zone 5A shows the highest potential with 105 TBtu (111 PJ). The reduction in airtightness from 1.07 cfm/ft² (5.43 L/s/m²) to 0.06 cfm/ft² (0.3 L/s/m²) results in the estimated potential savings of 313 TBtu (330 PJ). Standalone Retail, with an energy savings potential of 126 TBtu (133 PJ) shows the greatest opportunity amongst the building types and climate zone 5A shows the highest potential with 115 TBtu (121 PJ).

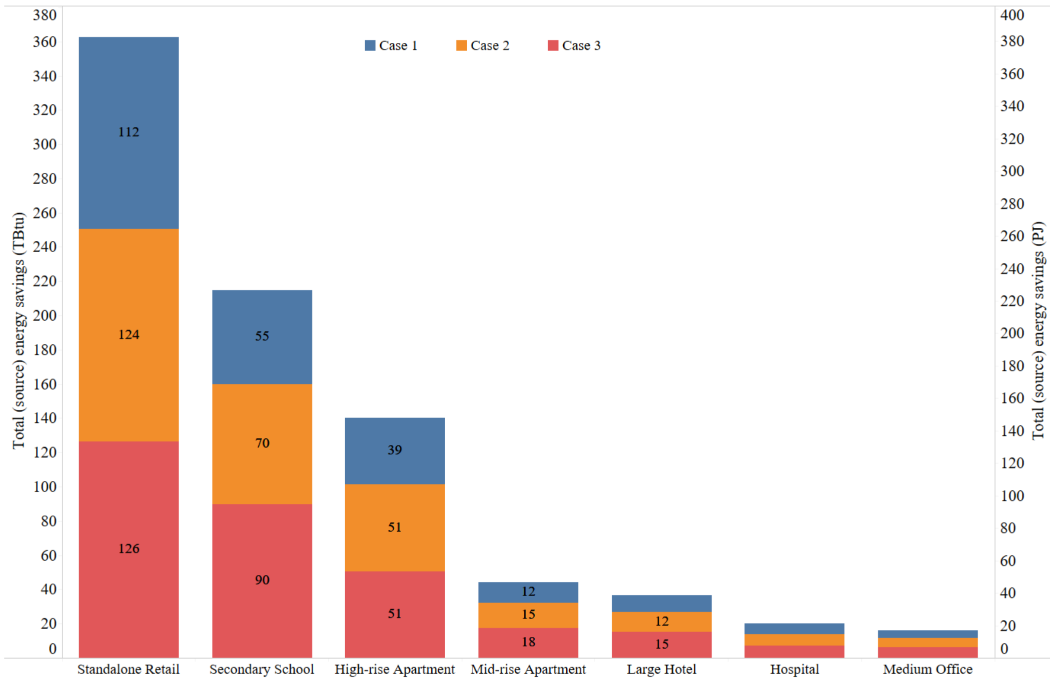

Figure 3: Cumulative site and source energy savings for different building types for the air infiltration rate reduction of 0.40 cfm/ft^2 (2.03 L/s/m^2) (Case 1) , 0.25 cfm/ft^2 (1.27 L/s/m^2) (Case 2) and 0.06 cfm/ft^2 (0.3 L/s/m^2) (Case 3) as compared to the base case of 1.07 cfm/ft^2 (5.43 L/s/m^2)

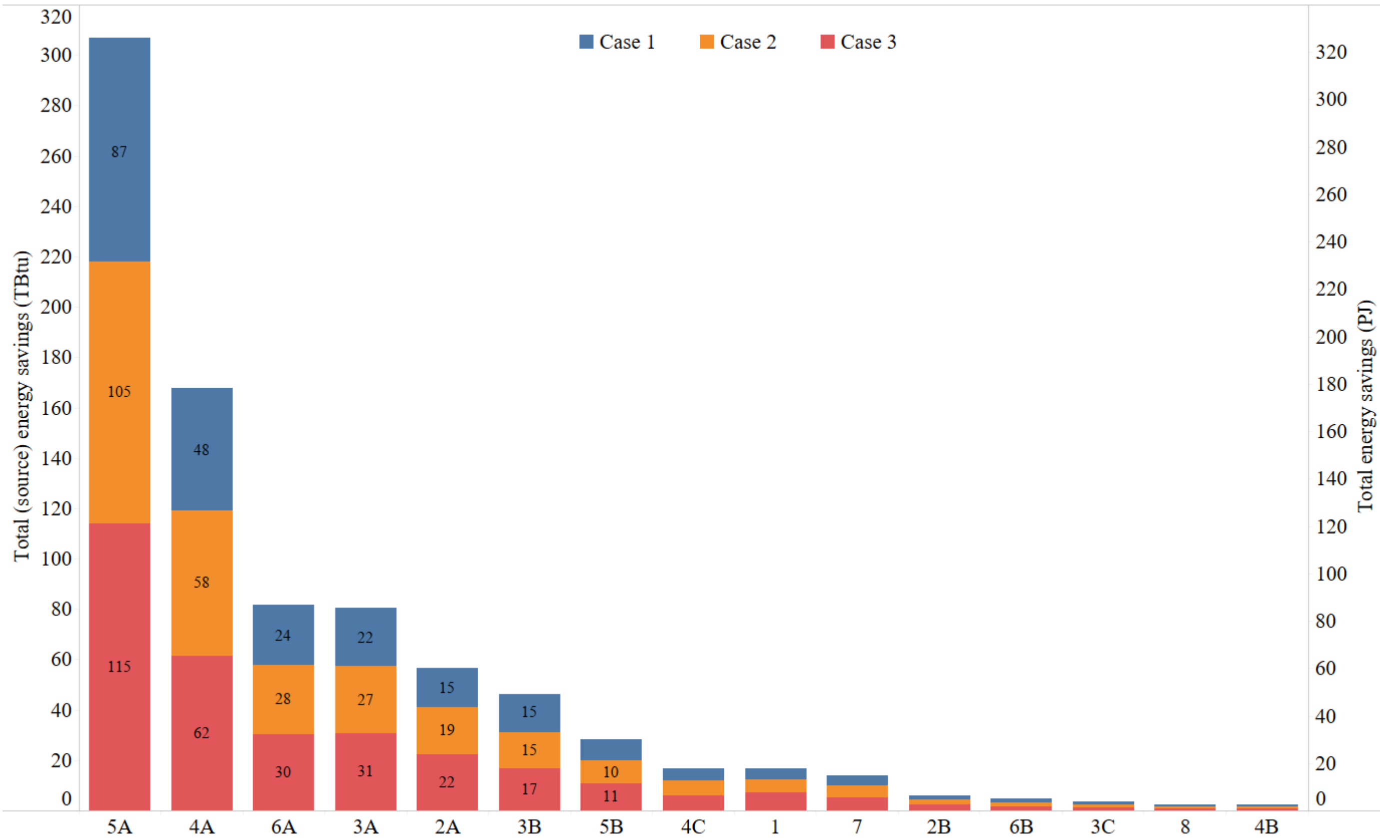

Figure 4: Cumulative site and source energy savings for different climate zones for all the 7 building types for the air infiltration rate reduction 0.40 cfm/ft² (2.03 L/s/m²) (Case 1) , 0.25 cfm/ft² (1.27 L/s/m²) (Case 2) and 0.06 cfm/ft² (0.3 L/s/m²) (Case 3) as compared to the base case of 1.07 cfm/ft² (5.43 L/s/m²)

SUMMARY

The calculator estimated energy savings were extended to determine the national level energy savings potential by using the weightage of the type of commercial building in different ASHRAE climate zone locations. Amongst the 7 prototype buildings used in this study, Standalone Retail shows the highest energy savings potential. Additionally, climate zone 5A shows the overall highest potential for energy savings from reduced air leakage. The base infiltration rates of 1.07 CFM/ft² (5.43 L/s/m²) was assumed for these calculations and the savings were calculated for three different air infiltration target rates of 0.4 CFM/ft² (2.03 L/s/m²), 0.25 CFM/ft² (1.27 L/s/m²) and 0.06 CFM/ft² (0.3 L/s/m²). The national source energy savings of 238, 283 and 313 TBtu (251, 299 and 330 PJ) respectively were estimated for these target air infiltration rates.

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