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Investigation of the Impact of Commercial Building Envelope Airtightness on HVAC Energy Use

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Results

The annual gas use, electrical use and average infiltration predicted for the office building is presented in Table 5. The annual average infiltration rate with the baseline air leakage ranges from 0.17 h^{-1} to 0.26 h^{-1} depending on the climate. Reducing the air leakage rate to the target level results in annual average infiltration rates ranging from 0.02 h^{-1} to 0.05 h^{-1} for an average reduction in infiltration of 83 %. Further tightening of the building envelope to the best achievable level essentially eliminates infiltration for the office building. There were no differences in average infiltration between the frame and masonry buildings, and only small differences between the masonry and frame buildings for gas and electricity use for heating and cooling. Table 6 summarizes the annual energy cost savings for the office building at the target air leakage level relative to the baseline level. The annual cost savings are largest in the heating dominated climates with potential gas savings of greater than 40 % and electrical savings of greater than 25 %.

Table 6 Energy cost savings for office building

City	Gas Savings		Electrical Savings		Total Savings
Bismarck	$1,854	42%	$1,340	26%	$3,195
Minneapolis	$1,872	43%	$1,811	33%	$3,683
St. Louis	$1,460	57%	$1,555	28%	$3,016
Phoenix	$124	77%	$620	9%	$745
Miami	$0	0%	$769	10%	$769

Retail building

Table 7 presents the annual gas use, electrical use and average infiltration predicted for the retail building. The annual average infiltration for the retail building with the baseline air leakage ranges from 0.13 h^{-1} to 0.24 h^{-1}. Reducing the air leakage rate to the target level almost eliminates infiltration, with all climates having an average rate of less than 0.02 h^{-1}. Further tightening of the building envelope to the best achievable level completely eliminates infiltration for the retail building. Again, there were very few differences between the frame and masonry buildings in either average infiltration or energy. Table 8 summarizes the annual energy cost savings for the retail building at the target air leakage level relative to the baseline level. Unlike the office building, the predicted cost savings for the retail building are fairly independent of climate. The electrical savings in the hot climates are about as large as the gas savings in the cold climates in absolute terms.

Table 8 Energy cost savings for retail building

City	Gas Savings		Electrical Savings		Total Savings
Bismarck	$1,835	26%	$33	2%	$1,869
Minneapolis	$1,908	28%	$364	18%	$2,272
St. Louis	$1,450	38%	$298	9%	$1,748
Phoenix	$176	64%	$992	14%	$1,169
Miami	$6	98%	$1,224	14%	$1,231

Residential building

Table 9 presents the annual gas use, electrical use and average infiltration predicted for the apartment building. The annual average infiltration rate for the apartment building with the baseline air leakage ranges is slightly higher than the other buildings and ranges from 0.19 h^{-1} to 0.26 h^{-1}. Reducing the air leakage to the target level results in an average reduction in infiltration of 64 %. Further tightening of the building envelope to the best achievable level further reduces the infiltration by an average of 33 %. The infiltration remains higher in the tighter apartment buildings relative to the other buildings due to the lack of a mechanical system pressurization effect. The clapboard siding and masonry veneer buildings were quite similar with the masonry building resulting in slightly lower gas use.

Table 10 summarizes the annual energy cost savings for the apartment building at the target air leakage level relative to the baseline level. Similar to the office building, the predicted cost savings for the apartment building are largest in the cold climates with gas savings of 40 % or more.

Table 10 Energy cost savings for apartment building

City	Gas Savings		Electrical Savings		Total Savings
Bismarck	$2,187	40%	-$116	-9%	$2,071
Minneapolis	$2,421	43%	-$165	-14%	$2,256
St. Louis	$1,794	57%	-$232	-12%	$1,562
Phoenix	$133	65%	$0	0%	$133
Miami	$31	63%	$380	9%	$411

Unlike the retail and office buildings, tightening the residential building envelope in the cooler climates resulted in a predicted electrical cost penalty of up to 14 %. In all of the building types, there are some hours where the reduction of infiltration eliminates a 'free cooling' effect during which time the cool outdoor air offsets the internal heat gain of the building. However, in the apartment building for these cooler climates, this impact summed over the course of the year more than offsets the impact of lower infiltration during hot hours when it adds to the cooling load. There are key differences between the building types that produce this effect. First, the apartment building lacks both an economizer to purposefully take advantage of free cooling effect. In fact, the apartment also lacks continuous ventilation to coincidentally take advantage of the free cooling effect. Second, the apartment building cooling setpoints are higher during the day and lower at night, which results in smaller cooling loads during the hottest hours and larger cooling hours during the cooler hours. However, it is likely that some of the predicted electrical use for cooling in the residential building would not occur in the real world because part of the free cooling effect happens during winter or shoulder seasons when residents may not operate their air-conditioning and would open windows for the free cooling. Figure 12 demonstrates this effect for the apartment building in Phoenix. The tighter target air leakage level results in predicted increases in cooling energy use from October through April but reduces cooling energy in the hottest months of June through September. The average savings during these hot months is 10 %.

Cost Effectiveness
As described earlier, a cost effectiveness analysis of the air barrier energy savings was conducted using the scalar ratio methodology employed by SSPC 90.1. This cost analysis was performed to put the calculated energy savings in context using estimated values of the costs associated with the air barrier measures. As seen in Table 12, the majority of cases with one exception (the office building with masonry backup in climate zones 1 and 2) have a Scalar Ratio less than 8 for the Target case. Based on this criterion, the residential building can use either of the airtightening options outlined in climate zones 3 and higher, but Option 2 is more cost effective in climate zones 1 and 2.

Office building: The masonry building expenditure on the continuous air barrier is cost-effective in climate zoned 3 and higher. The energy savings in climate zones 1 and 2, although significant, is not enough to offset the expenditure for the air barrier within the accepted guidelines of 90.1; in other words, with a Scalar of 16.2 or higher, it does not meet the maximum Scalar Ratio limit of 8. This would imply that an exception for masonry buildings in climate zones 1 and 2 is suggested by the study. The frame building air barrier is cost effective with both airtightening strategies in all climates.

Retail building: The Scalar Ratio calculated for all the climate zones for both the masonry and frame building types indicate that all air barrier strategies are cost-effective.

Multi-Unit Apartment Building: Based on the Scalar Ratio, the air barrier strategy option 1 is not cost-effective in climate zones 1 and 2, but the air barrier strategy option 2 is cost-effective in all climates. There is no significant difference between the building with clapboard siding and masonry veneer.

Discussion

This simulation study included a small number of building types with a specific set of energy-related parameters (i.e., envelope construction types, internal loads, ventilation rates, etc.) in a limited set of climates. Predicted potential annual heating and energy cost savings for these buildings ranged from 2 % to 36 % with the largest savings occurring in the heating-dominated climates of Minneapolis and Bismarck and the smallest savings occurring in the cooling-dominated climates of Phoenix and Miami. The cost effectiveness analysis utilized costs for certain specific materials but other materials may be used to achieve the whole building airtightness target level used in the study.

Only a few other reports of the energy impacts of infiltration in commercial buildings and the potential savings due to tightening could be found for comparison. For the most part, these other studies are not as detailed as the current effort and may employ building configuration, airtightness, and other parameters that vary significantly from this study but they do provide some reference for comparison.

Potter et al. (1995) estimated the heating load due to infiltration for two U.K. office buildings of approximately equal size. They found that a 63 % reduction in air leakage could result in a reduction in annual heating energy loss due to infiltration of about 300 MW/m^2. Since whole building energy analysis was not performed, this is not directly equivalent to the heating energy savings predicted in this study but it does concur with the potential large impact of building airtightness on heating energy use.

Edwards (1999) reported a modeling study of the ventilation and infiltration energy impacts in a 10-story apartment building in a range of Canadian climates. This study employed the CONTAM multizone airflow model to create a model of an actual tested building and estimated that infiltration would be responsible for 31 % to 46 % of the average peak heating load (based on measurements in four Toronto apartment buildings reported by Scanada 1991). While the potential savings due to envelope tightening of 40 % to 43 % calculated for Bismarck and Minneapolis predicted in the current study are not directly comparable, the impact of infiltration on heating loads are of a similar magnitude. The Scanada report estimated that infiltration contributed an average of 32 % of the annual heating load in those buildings.

Building Sciences LTD presents an estimate of potential annual heating savings for an industrial building in London of 60 MJ/m^2 due to a reduction in envelope leakiness of 75 % (http://www.air-leakage.co.uk/why.htm). The gas savings for the target level relative to the baseline level in St. Louis (the closest climate) estimated in this study ranged from 56 MJ/m^2 to 130 MJ/m^2 depending on the building type. Again, these estimates are for different buildings with different assumptions but the magnitude of savings falls within the same overall range.

Parekh (1992) described measured airtightness and monitored energy before and after sealing efforts in two existing high-rise residential buildings in Canada. The air leakage of the buildings was reduced by an average of 35 %, which resulted in an average heating energy consumption reduction of 9 %. While the energy saving is smaller than predicted in this study, the difference is readily explained by the modest reduction in air leakage achieved for this retrofit study.

Similarly, Shaw and Reardon (1995) reported an 11 % reduction in monitored heating energy consumption after a 43 % improvement in measured airtightness of a 20-story office building in Ottawa. Again, the measured energy savings is smaller than the estimates in this study but the differences are easily explained by the different building type and the more modest reduction in air leakage achieved in this retrofit study.

As mentioned above, this study included a limited set of building-climate combinations and this work could be extended in a variety of ways. Specific recommendations for future work include:

- Continue study to develop more refined (i.e., climate-specific) airtightness targets,
- Extend study to other building categories,
- Perform factorial analysis to examine the potential interaction between airtightness and other building parameters,

- Test airtightness of buildings built to a tightness standard (possibly in MA) to evaluate whether tightness targets are being met in practice,
- Analyze the costs and potential energy savings from tightening of existing buildings and develop recommendations for the existing building stock,
- And, develop diagnostic protocols and tools for failures of building envelopes that deteriorate IAQ and energy efficiency.

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