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Technical Report:

Energy Study in Support of the Proposed Revision of the International Energy Conservation Code (IECC), Skylight Portion of Table 502.3 – Part 1: Daylighting Controls

Report prepared for: Skylight Collaborative

February 23, 2006

Executive Summary

In order to provide basis for proposing updated prescriptive criteria for skylights in IECC Table 502.3 (Table 802.2(2) in IECC 2003), comprehensive energy study has been carried out for a set of actual skylights (glass and plastic) under the 8 climate zone conditions and for three typical commercial buildings. The three building types studied were:

- 1) Big Box Retail Building
- 2) Grocery
- 3) Warehouse

This study included 2 step photo or daylighting controls (ON/50%/OFF) and the recommendation for updated prescriptive criteria will be based on the use of such controls as a minimum. 3 step and continuous daylighting controls will certainly provide even better energy performance and so the recommendation will be based on the two step controls as a minimum.

Based on the results from this study, two major changes to the table 502.3 (Table 802.2(2) in IECC 2003) are proposed:

- 1) Increase of maximum skylight area from 3% to 6% SRR
- 2) Change maximum U-factors and SHGC values to better correspond with the availability of the products in the market and with the results of energy study.

The proposed performance values for the IECC 2007 Code Supplement for skylights portion of the Table 802.2(2) is shown in the table below. The values for glass and plastic skylights are combined into the single set of values.

Table 1. Proposed Skylights Portion of Table 502.3 (former 802.2(2)) with minimum of 2 step daylighting controls (6% maximum)

| Climate Zone | 1 | 2 | 3 | 4 except Marine | 5 and Marine 4 | 6 | 7 | 8 |
|-------------------------------|------|------|------|-----------------------|----------------------|------|------|------|
| Skylights (6% maximum) | | | | | | | | |
| U-Factor | 1.35 | 0.95 | 0.90 | 0.90 | 0.90 | 0.90 | 0.90 | 0.60 |
| SHGC | 0.35 | 0.50 | 0.55 | 0.55 | 0.55 | 0.60 | NR | NR |

This report is complimentary to the report and spreadsheets produced by HMG (2005), which did original energy simulations. The HMG (2005) report contains details about energy study assumptions, including buildings, constructions, schedules, etc.

Introduction

To cover the range of commercial buildings, three building types: big box retail, grocery and warehouse commercial buildings have been analyzed for 21 cities across all 8 climate zones. 25 real skylight products both in glass and plastic skylights categories were considered in this study. The details of methodology and building assumptions are given in HMG (2005). Table 1 gives the description of 25 skylights considered in the study. The indices for existing code skylights are given in table 2.

Table 2. Description of Real Skylights Used in Study and Corresponding Performance Indices

| ID # | Frame | No. of Layers | Glazing Description | Glazing Indices | | | |
|----------------|--------------|---------------|---------------------------|------------------------------------|------|------|------|
| | | | | U | SHGC | VT | |
| Glass | | | | | | | |
| 301 | Aluminum | Single | mWHTNfla | G Med.Wht Interlayer | 1.29 | 0.67 | 0.61 |
| 302 | Aluminum | Single | mCLRNfla+PRM | G Clear - Prismatic | 0.80 | 0.71 | 0.79 |
| 303 | Aluminum | Single | mEVGNfla+PRM | G Evergreen - Prismatic | 0.80 | 0.41 | 0.59 |
| 304 | T/B Aluminum | Double | bCLRNairWHTNfla | G Clear - Air - Med.Wht | 0.69 | 0.62 | 0.54 |
| 305 | T/B Aluminum | Double | bCLRNairCLRNfla+PRM | G Clear - Air - Clear - Prismatic | 0.52 | 0.61 | 0.70 |
| 306 | T/B Aluminum | Double | bEVGNairWHTNfla | G Evergreen - Air - Med.Wht | 0.69 | 0.37 | 0.41 |
| 307 | T/B Aluminum | Double | bCLRLairWHTNfla | G ClearL - Air - Med.Wht | 0.52 | 0.35 | 0.47 |
| 308 | T/B Aluminum | Double | bCLRLairCLRNfla+PRM | G ClearL - Air - Clear - Prismatic | 0.43 | 0.35 | 0.61 |
| 309 | T/B Aluminum | Double | bEVGLairWHTNfla | G EvergreenL - Air - Med.Wht | 0.52 | 0.27 | 0.37 |
| 310 | T/B Aluminum | Double | bCLRLargWHTNfla | G ClearL - Arg - Med.Wht | 0.47 | 0.35 | 0.47 |
| 311 | T/B Aluminum | Double | bCLRLargCLRNfla+PRM | G ClearL - Arg - Clear - Prismatic | 0.40 | 0.35 | 0.61 |
| 312 | T/B Aluminum | Double | bEVGLargWHTNfla | G EvergreenL - Arg - Med.Wht | 0.47 | 0.26 | 0.37 |
| 313 | T/B Aluminum | Double | bCLRLairCLRNfla | G ClearL - Air - Clear | 0.53 | 0.38 | 0.66 |
| Plastic | | | | | | | |
| 401 | Aluminum | Single | mPRMdom | P Prismatic | 1.33 | 0.80 | 0.83 |
| 402 | Aluminum | Double | mWHTdom | P Medium white | 1.33 | 0.59 | 0.62 |
| 403 | T/B Aluminum | Double | bCLRairMWHTdom | P Clear - Med.Wht | 0.71 | 0.58 | 0.55 |
| 404 | T/B Aluminum | Double | bLWHTairCLRdom | P Low.Wht - Clear | 0.71 | 0.35 | 0.29 |
| 405 | T/B Aluminum | Double | bCLRairHWHTdom | P Clear - High.Wht | 0.71 | 0.58 | 0.62 |
| 406 | T/B Aluminum | Double | bPRMairPRMdom | P Prismatic - Prismatic | 0.71 | 0.69 | 0.72 |
| 407 | T/B Aluminum | Triple | bCLRairCLRairMWHTdom | P Clear - Clear - Med.Wht | 0.67 | 0.56 | 0.41 |
| 408 | T/B Aluminum | Triple | bLWHTairCLRairCLRdom | P Low.Wht - Clear - Clear | 0.67 | 0.31 | 0.27 |
| 409 | T/B Aluminum | Triple | bCLRairCLRairHWHTdom | P Clear - Clear - High.Wht | 0.67 | 0.56 | 0.69 |
| 410 | T/B Aluminum | Triple | bPRMairPRMairPRMdom | Triple Prismatic | 0.67 | 0.61 | 0.63 |
| 411 | T/B Aluminum | Quadruple | bCLRairCLRairCLRairCLRdom | Quadruple Clear | 0.60 | 0.65 | 0.71 |

Table 3. Existing Code Skylight Performance Indices for Different Climate Zones

| Climate Zone | 1 | 2 | 3 | 4 except Marine | 5 and Marine 4 | 6 | 7 | 8 |
|----------------|------|------|------|-----------------|----------------|------|------|------|
| Glass | | | | | | | | |
| U-Factor | 1.60 | 1.05 | 0.90 | 0.60 | 0.60 | 0.60 | 0.60 | 0.60 |
| SHGC | 0.40 | 0.40 | 0.40 | 0.40 | 0.40 | 0.40 | NR | NR |
| Plastic | | | | | | | | |
| U-Factor | 1.90 | 1.90 | 1.30 | 1.30 | 1.30 | 0.90 | 0.90 | 0.60 |
| SHGC | 0.35 | 0.35 | 0.35 | 0.62 | 0.62 | 0.62 | NR | NR |

NR = No Requirement

Table 3 lists the climate zones and representative cities for each zone that were used in the study. Depending on the zone, from 2 to 4 cities were modeled per zone. This was varied based on variations within the zone and population weighting per zone.

Table 4. Representative cities and climate zones considered in the study

| Zone# | City, State |
|---------|-------------------|
| 1A | Honolulu, HI |
| 1A | Miami, FL |
| 2A | Houston, TX |
| 2B | Phoenix, AZ |
| 3A | Memphis, TN |
| 3B | El Paso, TX |
| 3C CA-3 | Los Angeles, CA |
| 3C | San Francisco, CA |
| 4A | Baltimore, MD |
| 4A NE-4 | New York City, NY |
| 4B | Albuquerque, NM |
| 4C | Portland, OR |
| 4C | Salem, OR |
| 4C | Seattle, WA |
| 5A NE-5 | Boston, MA |
| 5A | Chicago, IL |
| 5B | Boise, ID |
| 6A | Burlington, VT |
| 6B | Helena, MT |
| 7 | Duluth, MN |
| 8 | Fairbanks, AK |

The complete set of assumptions and details about energy modeling are contained in HMG (2005).

Further inspection of values reported in HMG study, reveals that the values are more representative of residential construction and of vertical orientation, which was used in NFRC procedure previously. The first time NFRC has used sloped orientation, which increases the U-factor by an estimated 20%, was in 2001, but the old values will be completely phased out by 2008. Therefore, the values from Table 2 are increased by 20% in order to better represent typical products that would be rated today. Table 5 shows indices of performance corrected for sloped orientation. These U-factors were increased on average by 20% from the U-factors in Table 2.

Table 5. Corrected Performance Indices for Sloped Orientation

| ID # | Frame | No. of Layers | Code | Glazing Description | Glazing Indices | | |
|----------------|--------------|---------------|---------------------------|------------------------------------|-----------------|------|------|
| | | | | | U | SHGC | VT |
| Glass | | | | | | | |
| 301 | Aluminum | Single | mWHTNfla | G Med.Wht Interlayer | 1.54 | 0.67 | 0.61 |
| 302 | Aluminum | Single | mCLRNfla+PRM | G Clear - Prismatic | 0.96 | 0.71 | 0.79 |
| 303 | Aluminum | Single | mEVGNfla+PRM | G Evergreen - Prismatic | 0.96 | 0.41 | 0.59 |
| 304 | T/B Aluminum | Double | bCLRNairWHTNfla | G Clear - Air - Med.Wht | 0.83 | 0.62 | 0.54 |
| 305 | T/B Aluminum | Double | bCLRNairCLRNfla+PRM | G Clear - Air - Clear - Prismatic | 0.63 | 0.61 | 0.70 |
| 306 | T/B Aluminum | Double | bEVGNairWHTNfla | G Evergreen - Air - Med.Wht | 0.83 | 0.37 | 0.41 |
| 307 | T/B Aluminum | Double | bCLRLairWHTNfla | G ClearL - Air - Med.Wht | 0.62 | 0.35 | 0.47 |
| 308 | T/B Aluminum | Double | bCLRLairCLRNfla+PRM | G ClearL - Air - Clear - Prismatic | 0.52 | 0.35 | 0.61 |
| 309 | T/B Aluminum | Double | bEVGLairWHTNfla | G EvergreenL - Air - Med.Wht | 0.62 | 0.27 | 0.37 |
| 310 | T/B Aluminum | Double | bCLRLargWHTNfla | G ClearL - Arg - Med.Wht | 0.56 | 0.35 | 0.47 |
| 311 | T/B Aluminum | Double | bCLRLargCLRNfla+PRM | G ClearL - Arg - Clear - Prismatic | 0.48 | 0.35 | 0.61 |
| 312 | T/B Aluminum | Double | bEVGLargWHTNfla | G EvergreenL - Arg - Med.Wht | 0.56 | 0.26 | 0.37 |
| 313 | T/B Aluminum | Double | bCLRLairCLRNfla | G ClearL - Air - Clear | 0.64 | 0.38 | 0.66 |
| Plastic | | | | | | | |
| 401 | Aluminum | Single | mPRMdom | Prismatic | 1.60 | 0.80 | 0.83 |
| 402 | Aluminum | Double | mWHTdom | Medium White | 1.60 | 0.59 | 0.62 |
| 403 | T/B Aluminum | Double | bCLRairMWHTdom | Clear - Medium White | 0.85 | 0.58 | 0.55 |
| 404 | T/B Aluminum | Double | bLWHTairCLRdom | Low White - Clear | 0.85 | 0.35 | 0.29 |
| 405 | T/B Aluminum | Double | bCLRairHWHTdom | Clear - High White | 0.85 | 0.58 | 0.62 |
| 406 | T/B Aluminum | Double | bPRMairPRMdom | Prismatic - Prismatic | 0.85 | 0.69 | 0.72 |
| 407 | T/B Aluminum | Triple | bCLRairCLRairMWHTdom | Clear - Clear - Medium White | 0.80 | 0.56 | 0.41 |
| 408 | T/B Aluminum | Triple | bLWHTairCLRairCLRdom | Low White - Clear - Clear | 0.80 | 0.31 | 0.27 |
| 409 | T/B Aluminum | Triple | bCLRairCLRairHWHTdom | Clear - Clear - High White | 0.80 | 0.56 | 0.69 |
| 410 | T/B Aluminum | Triple | bPRMairPRMairPRMdom | Triple Prismatic | 0.80 | 0.61 | 0.63 |
| 411 | T/B Aluminum | Quadruple | bCLRairCLRairCLRairCLRdom | Quadruple Clear | 0.72 | 0.65 | 0.71 |

Figure 1 and Figure 2 show comparison of U-factors and SHGC for the set of real glass and plastic skylights at 20° slope vs. IECC 2006 Code Performance levels. Figure 3 shows the same set of real glass and plastic skylights compared to the proposed IECC 2007 Supplement code proposal values.

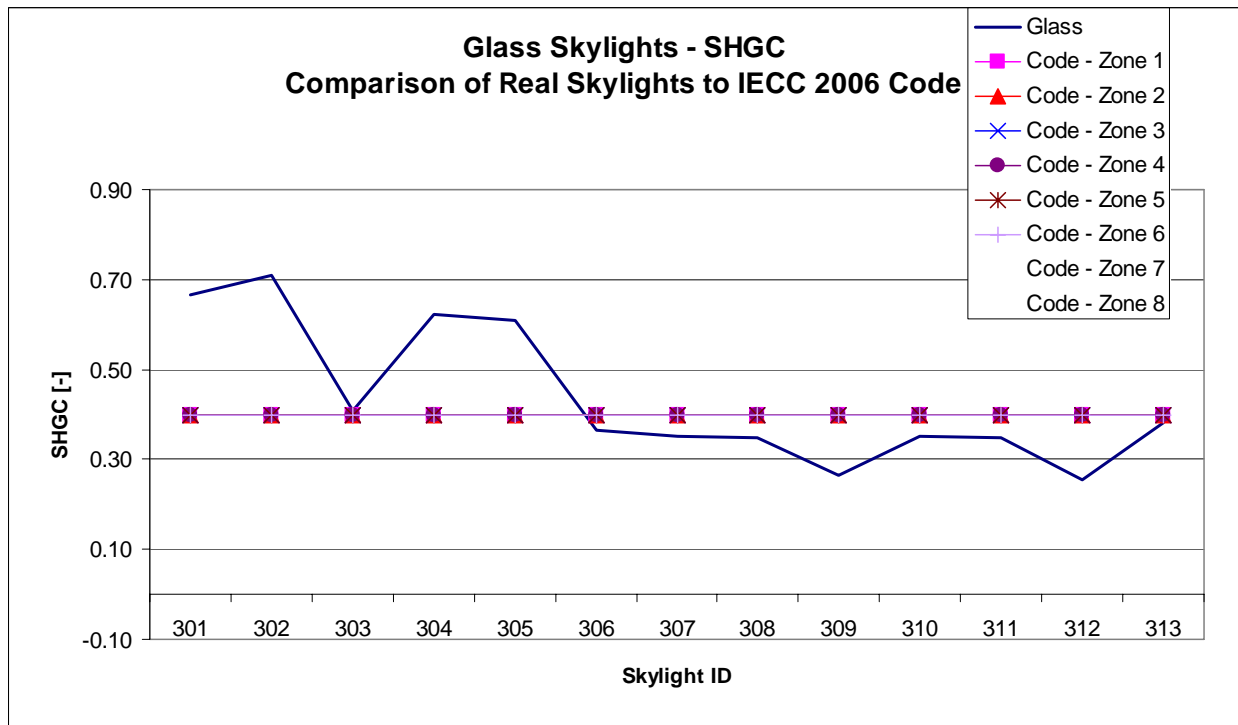
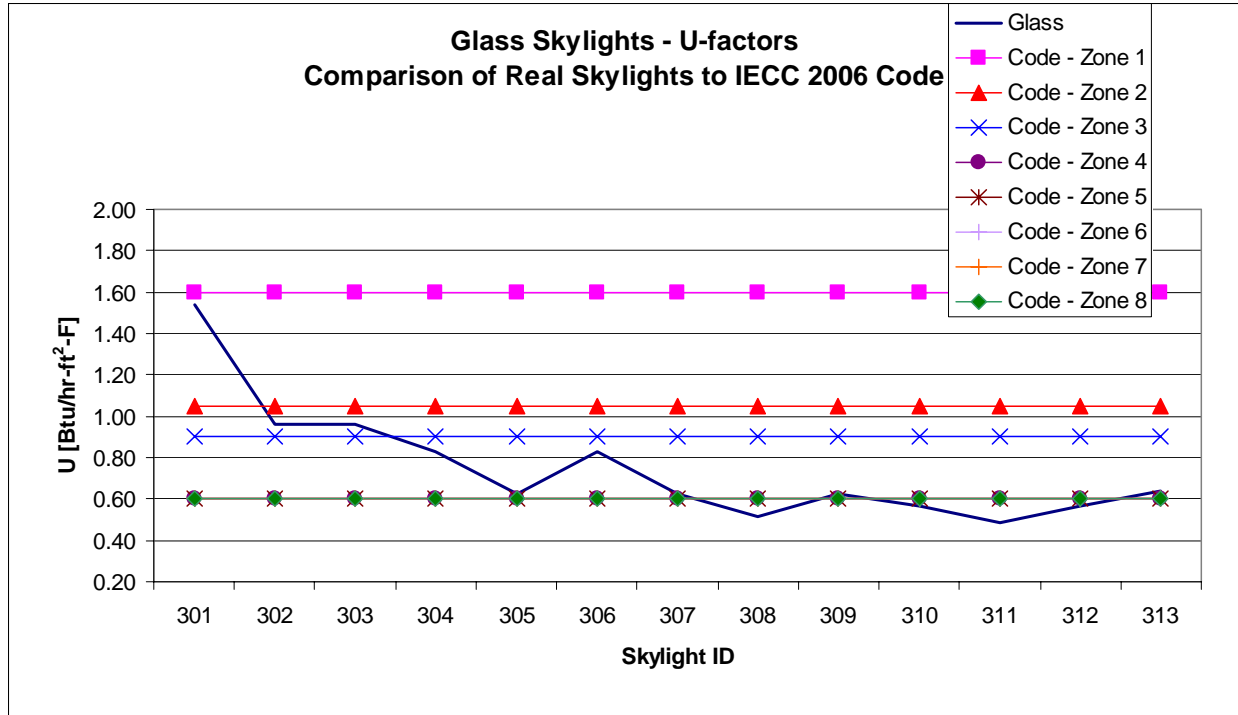


Figure 1. Comparison of the Performance of Real Glass Skylights to the IECC2006 Code Values

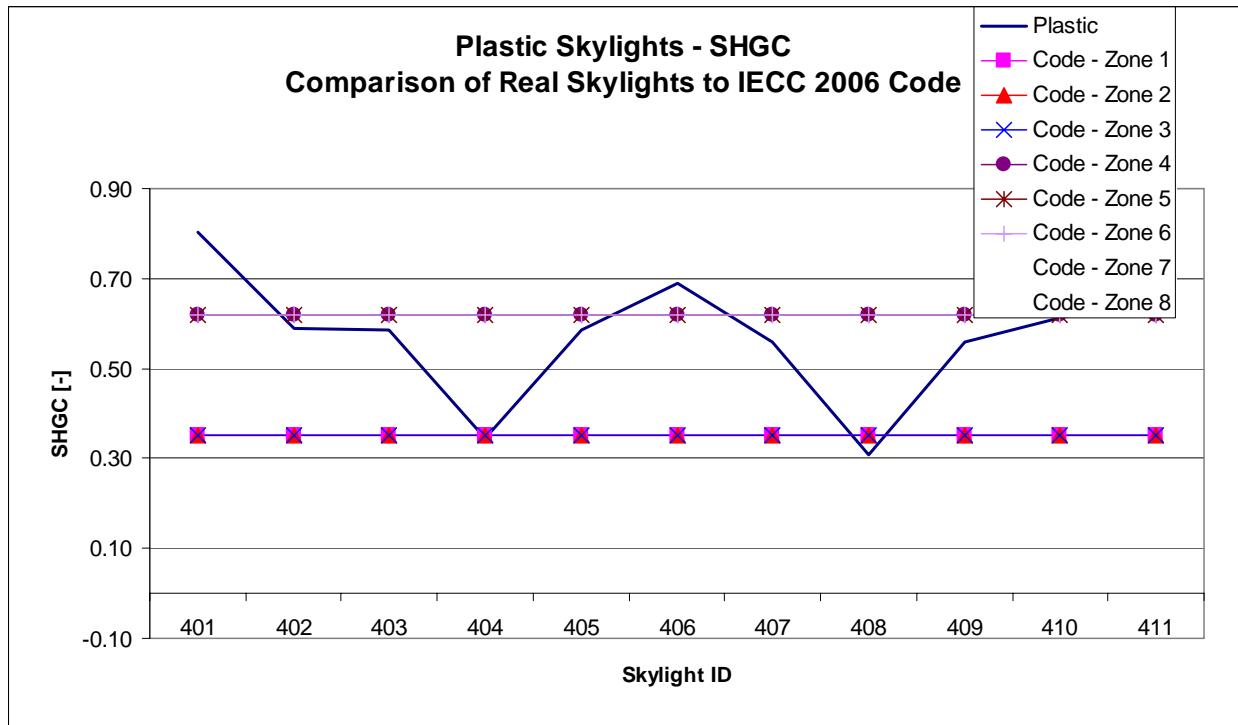
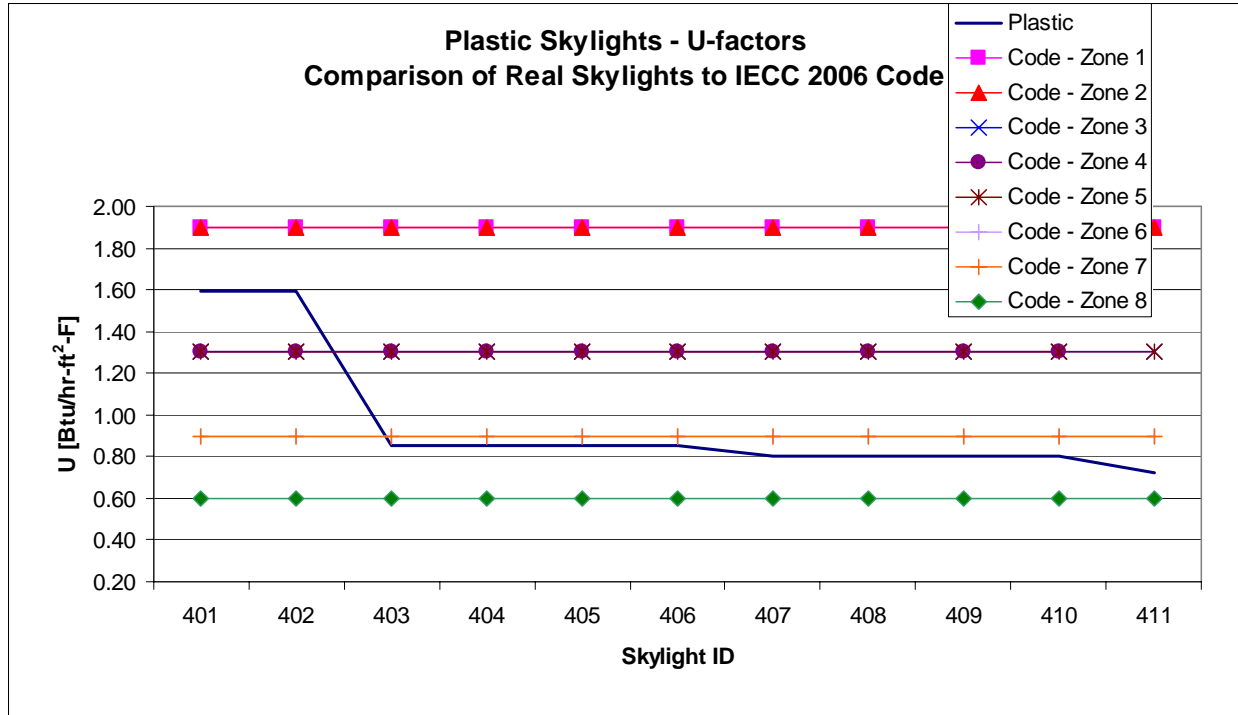


Figure 2. Comparison of the Performance of Real Plastic Skylights to the IECC2006 Code Values

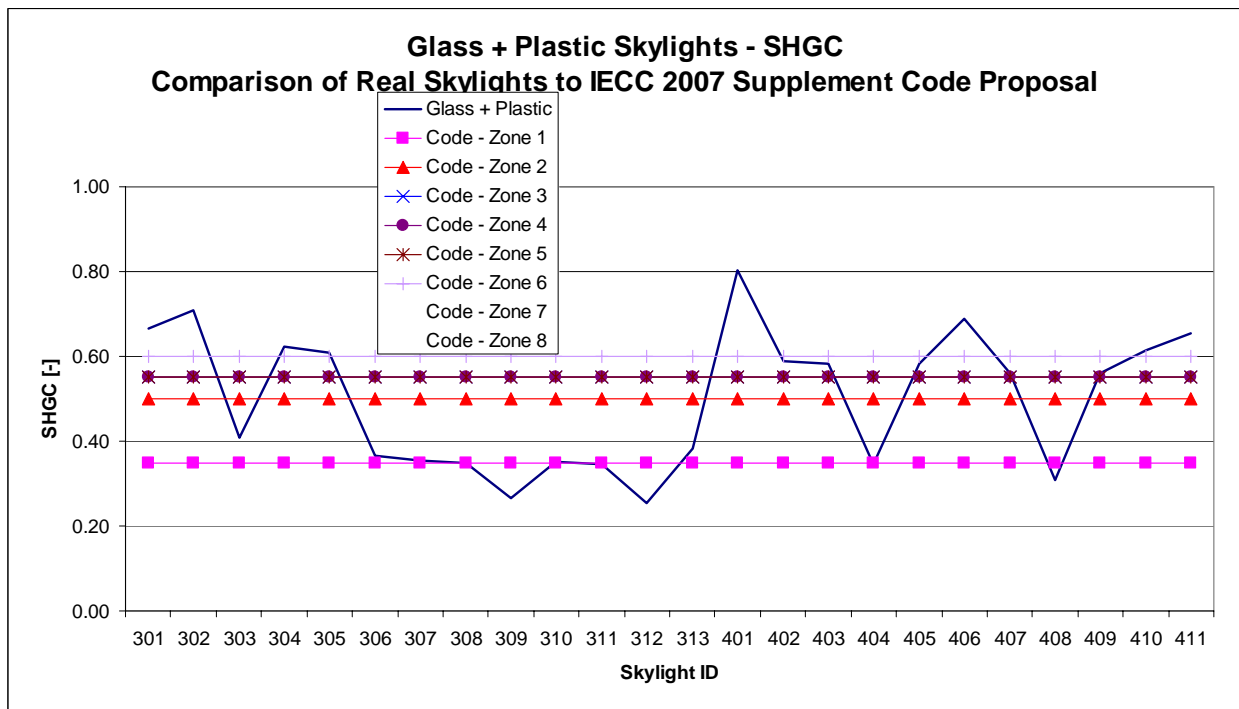
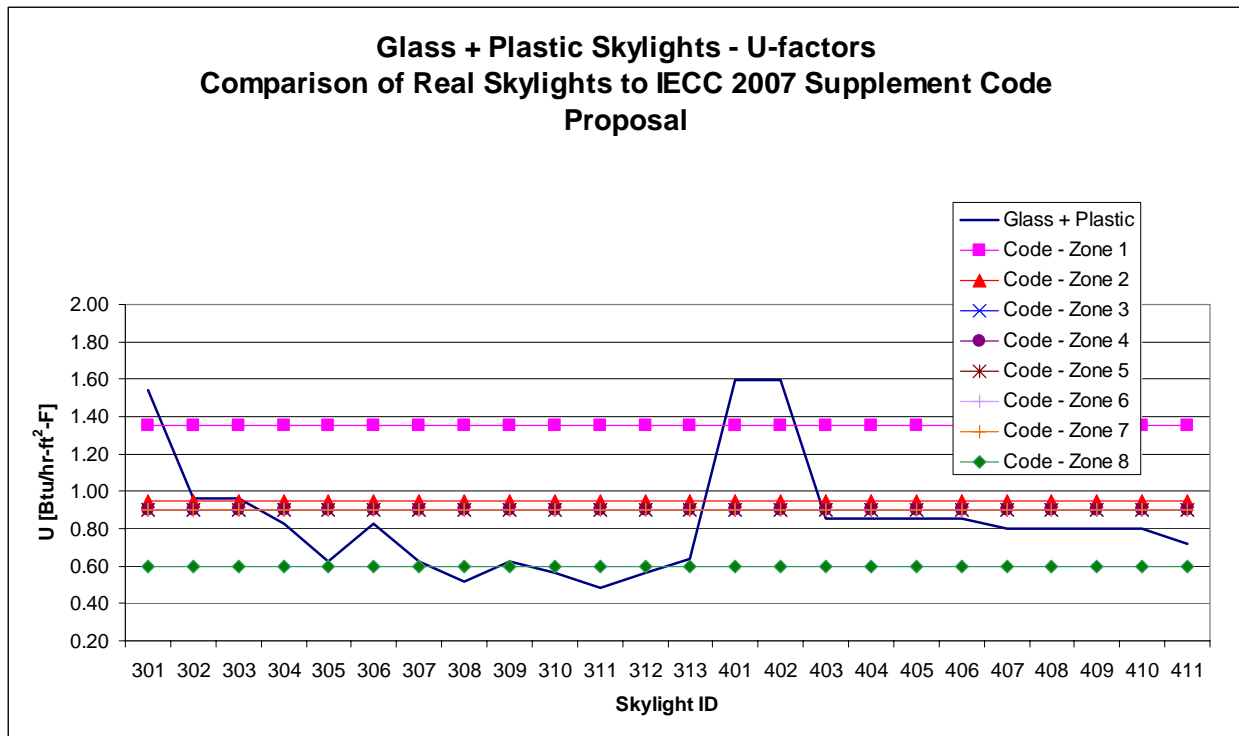


Figure 3. Comparison of the Performance of Real Glass and Plastic Skylights to the IECC2007 Supplement Code Proposal Values

Results and Discussion

Energy Analysis was performed for the three building types for a range of skylight to Roof Ratios (SRR) from 1% to 12%. The graphs showing energy savings for the 21 skylights vs. SRR are plotted for 3 building types, and 8 climate zones and shown in Figures A1.1. to A3.8. This analysis was done with two step daylighting controls (ON/50%/OFF) and this type of daylighting control is proposed as a minimum for code compliance. Three-step and continuous control is also acceptable, since it will provide even greater savings. More details on assumption used in the analysis are given in HMG (2005).

The inspection of Figures A1.1 to A3.8, show that 6% approximately represents optimal skylight to roof ratio, where maximum energy and cost savings are achieved. For this reason, the 6% maximum skylight to roof ratio percentage was selected as representative. In addition to the increased percentage, new prescriptive criteria (U and SHGC) is proposed to better correspond with the availability of the products in the market and with the results of energy study (See Table 2 and Figures 1 to 3).

The proposed performance values for the IECC 2007 Code Supplement for skylights portion of the Table 502.3 (formerly 802.2(2)) is shown in the table below. The values for glass and plastic skylights are combined into the single set of values.

Table 6. Proposed Skylights Portion of Table 502.3 (former 802.2(2)) [with minimum of 2 step daylighting controls \(6% maximum\)](#)

| Climate Zone | 1 | 2 | 3 | 4 except Marine | 5 and Marine 4 | 6 | 7 | 8 |
|-------------------------------|------|------|------|-----------------------|----------------------|------|------|------|
| Skylights (6% maximum) | | | | | | | | |
| U-Factor | 1.35 | 0.95 | 0.90 | 0.90 | 0.90 | 0.90 | 0.90 | 0.60 |
| SHGC | 0.35 | 0.50 | 0.55 | 0.55 | 0.55 | 0.60 | NR | NR |

Figure 4 to Figure 27 show energy usage results and comparison of real skylights from Table 2 to the IECC 2006 code level skylight for proposed 6% SRR. Skylights that are equal or better than the proposed values from Table 6, are represented in Figure 4 to Figure 27 with patterned coloring, while the skylights that are worse than the proposed values in Table 6 are represented with solid colors. The results for additional representative cities are given in Tables 3-5 for completeness.

It is evident from these results that the each and every skylight from Table 2, incorporated into any of the three buildings with two step daylighting controls and with 6% SRR will save energy in each of the climate zones and are cost effective in comparison to current 3% SRR code skylights. It is also evident that both, skylights that are better and skylights that are worse then proposed code values, when used with daylighting controls, are better than the present code value skylight without daylighting controls.

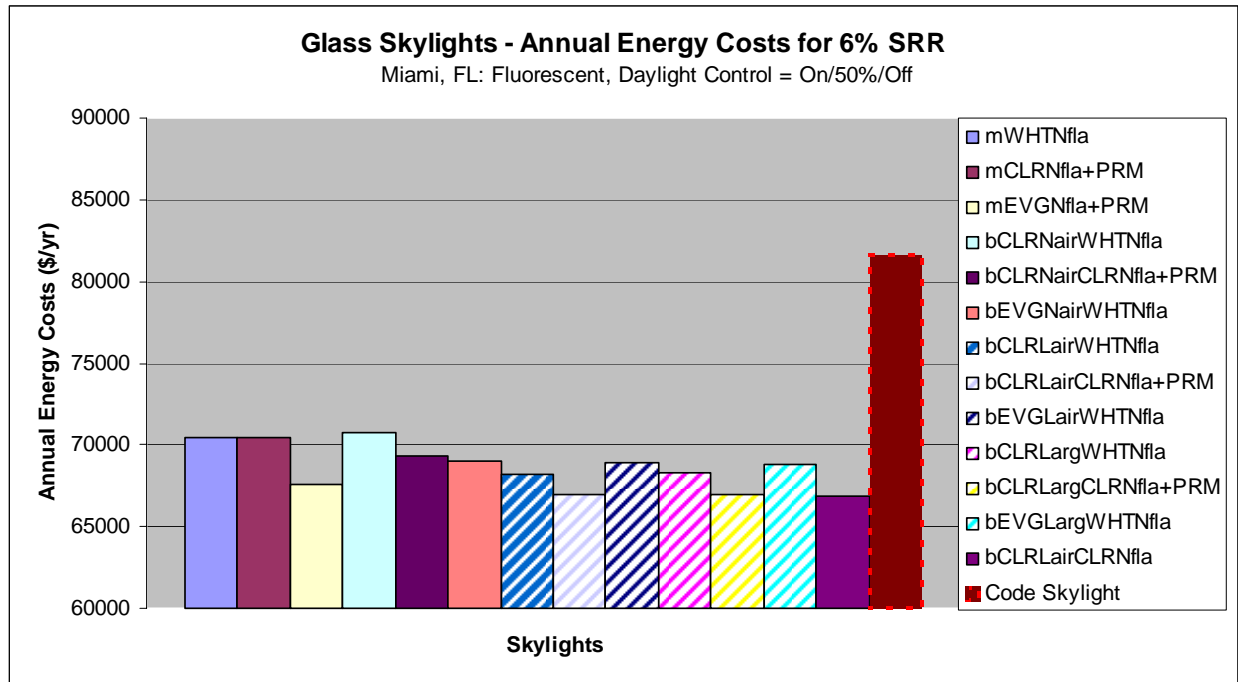
Table 7 shows how do analyzed skylights compare to the proposed 2007 IECC supplement values. For each climate zone, the skylight checked with X meets or exceeds to proposed code values.

Table 7. Compliance of Analyzed Skylights with the Proposed 2007 IECC Supplement Values.

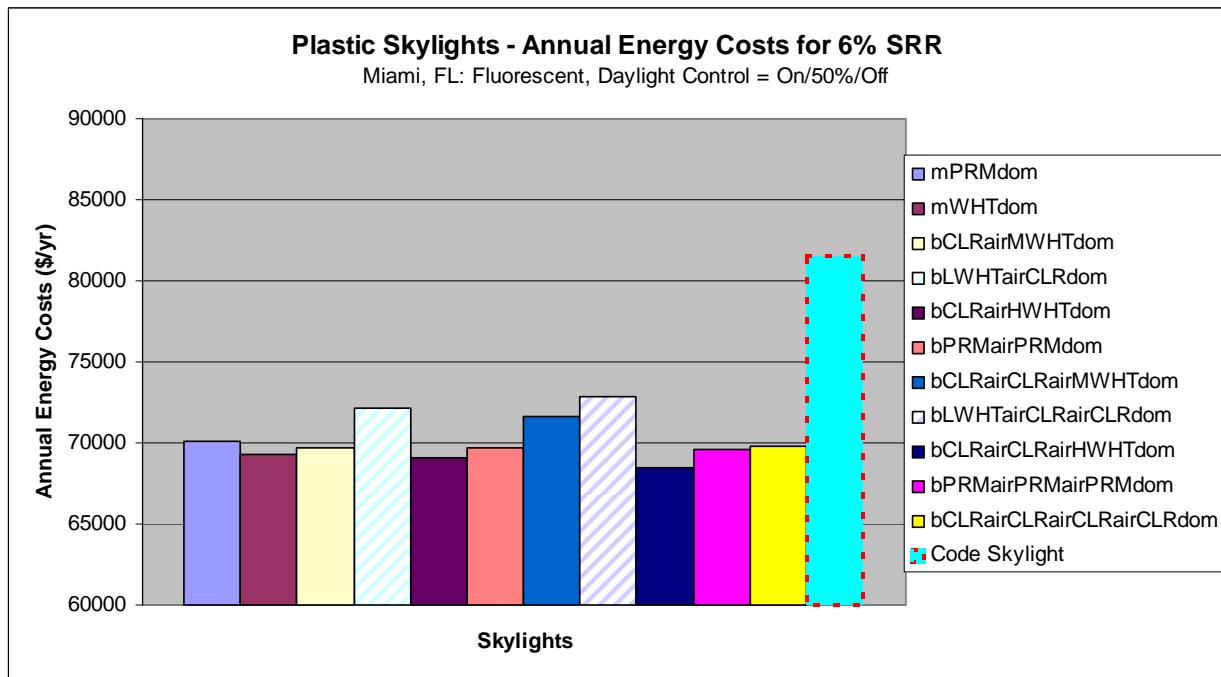
| ID # | Code | Glazing Description | Glazing Indices | | | Climate Zone* | | | | | | | |
|----------------|---------------------------|------------------------------------|-----------------|------|------|---------------|---|---|---|---|---|---|---|
| | | | U | SHGC | VT | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
| Glass | | | | | | | | | | | | | |
| 301 | mWHTNfla | G Med.Wht Interlayer | 1.29 | 0.67 | 0.61 | | | | | | | | |
| 302 | mCLRNfla+PRM | G Clear - Prismatic | 0.80 | 0.71 | 0.79 | | | | | | | X | |
| 303 | mEVGNfla+PRM | G Evergreen - Prismatic | 0.80 | 0.41 | 0.59 | | X | X | X | X | X | X | |
| 304 | bCLRNairWHTNfla | G Clear - Air - Med.Wht | 0.69 | 0.62 | 0.54 | | | | | | | X | |
| 305 | bCLRNairCLRNfla+PRM | G Clear - Air - Clear - Prismatic | 0.52 | 0.61 | 0.70 | | | | | | X | X | X |
| 306 | bEVGNairWHTNfla | G Evergreen - Air - Med.Wht | 0.69 | 0.37 | 0.41 | | X | X | X | X | X | X | |
| 307 | bCLRLairWHTNfla | G ClearL - Air - Med.Wht | 0.52 | 0.35 | 0.47 | X | X | X | X | X | X | X | X |
| 308 | bCLRLairCLRNfla+PRM | G ClearL - Air - Clear - Prismatic | 0.43 | 0.35 | 0.61 | X | X | X | X | X | X | X | X |
| 309 | bEVGLairWHTNfla | G EvergreenL - Air - Med.Wht | 0.52 | 0.27 | 0.37 | X | X | X | X | X | X | X | X |
| 310 | bCLRLargWHTNfla | G ClearL - Arg - Med.Wht | 0.47 | 0.35 | 0.47 | X | X | X | X | X | X | X | X |
| 311 | bCLRLargCLRNfla+PRM | G ClearL - Arg - Clear - Prismatic | 0.40 | 0.35 | 0.61 | X | X | X | X | X | X | X | X |
| 312 | bEVGLargWHTNfla | G EvergreenL - Arg - Med.Wht | 0.47 | 0.26 | 0.37 | X | X | X | X | X | X | X | X |
| 313 | bCLRLairCLRNfla | G ClearL - Air - Clear | 0.53 | 0.38 | 0.66 | | X | X | X | X | X | X | X |
| Plastic | | | | | | | | | | | | | |
| 401 | mPRMdom | P Prismatic | 1.33 | 0.80 | 0.83 | | | | | | | | |
| 402 | mWHTdom | P Medium white | 1.33 | 0.59 | 0.62 | | | | | | | | |
| 403 | bCLRairMWHTdom | P Clear - Med.Wht | 0.71 | 0.58 | 0.55 | | | | | | | X | X |
| 404 | bLWHTairCLRdom | P Low.Wht - Clear | 0.71 | 0.35 | 0.29 | X | X | X | X | X | X | X | X |
| 405 | bCLRairHWHTdom | P Clear - High.Wht | 0.71 | 0.58 | 0.62 | | | | | | | X | X |
| 406 | bPRMairPRMdom | P Prismatic - Prismatic | 0.71 | 0.69 | 0.72 | | | | | | | | |
| 407 | bCLRairCLRairMWHTdom | P Clear - Clear - Med.Wht | 0.67 | 0.56 | 0.41 | | | X | X | X | X | X | |
| 408 | bLWHTairCLRairCLRdom | P Low.Wht - Clear - Clear | 0.67 | 0.31 | 0.27 | X | X | X | X | X | X | X | X |
| 409 | bCLRairCLRairHWHTdom | P Clear - Clear - High.Wht | 0.67 | 0.56 | 0.69 | | | X | X | X | X | X | X |
| 410 | bPRMairPRMairPRMdom | Triple Prismatic | 0.67 | 0.61 | 0.63 | | | | | | | X | X |
| 411 | bCLRairCLRairCLRairCLRdom | Quadruple Clear | 0.60 | 0.65 | 0.71 | | | | | | | X | X |

Notes: * checked skylights are equal or better than the proposed 2007 supplement code skylight

1. Retail Building



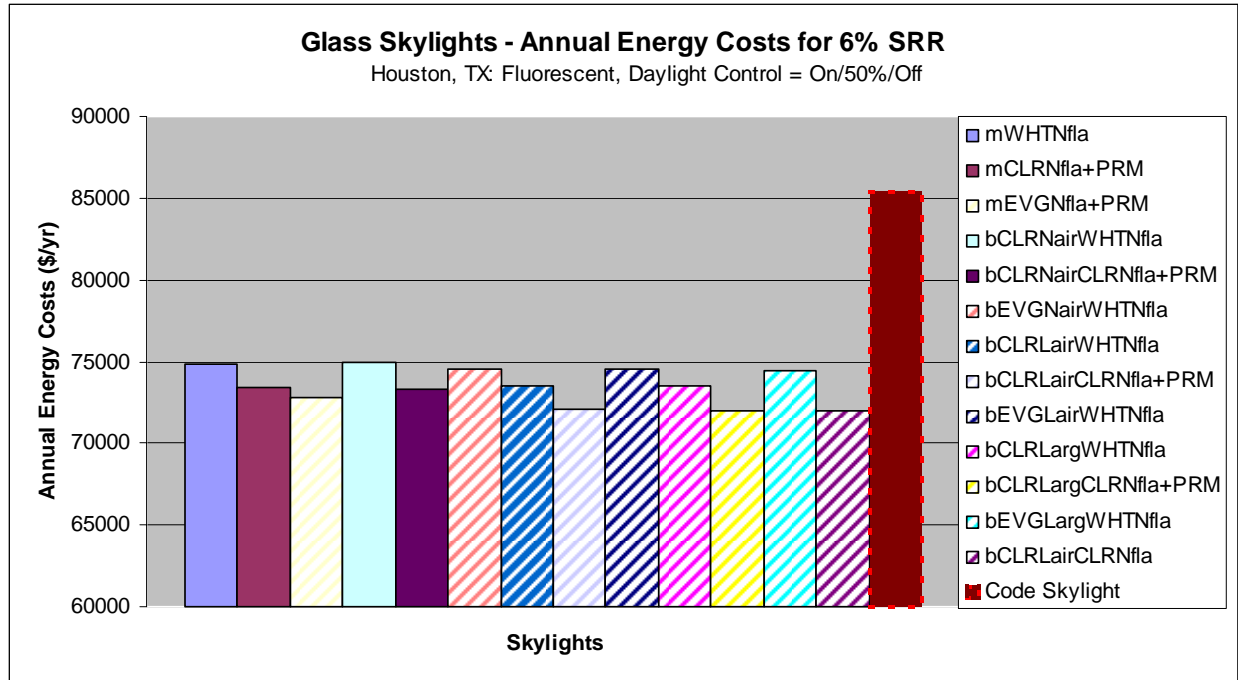
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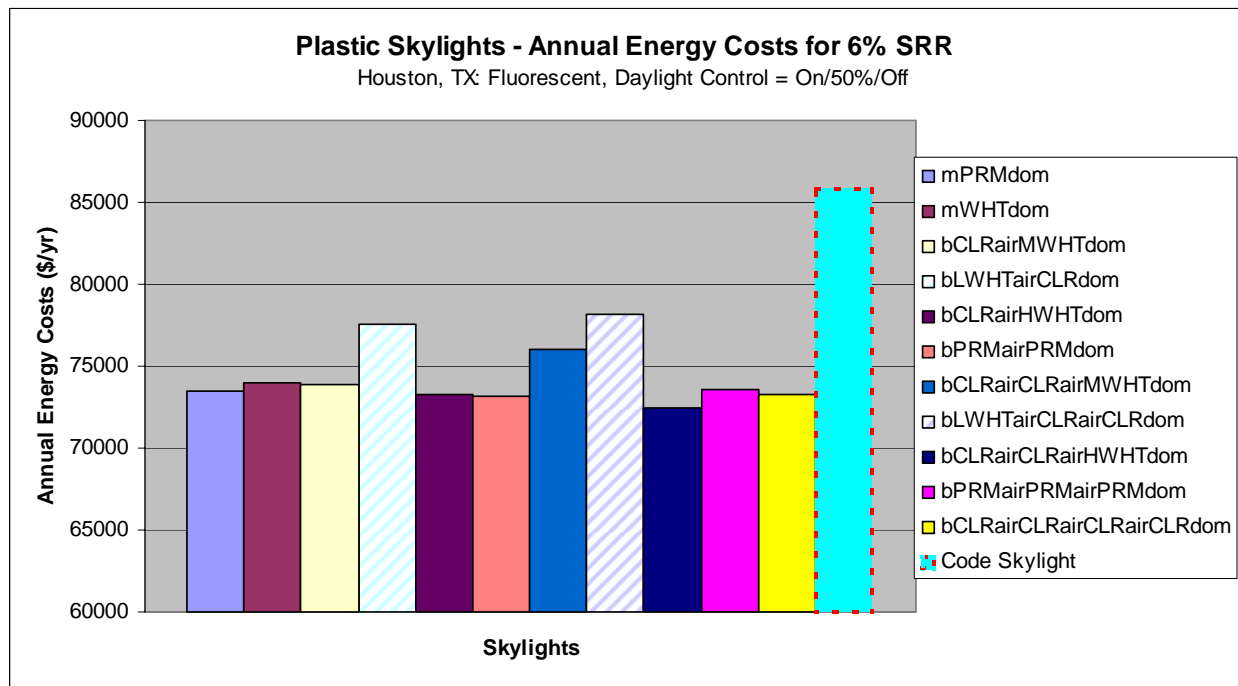
(b)

Figure 4. Annual Energy Costs for Big Box Retail Building with 6% SRR Skylights and Code Skylight in Miami, FL (Zone 1) – (a) Glass skylights, (b) Plastic skylights

Note: The skylights that meet the proposed code values (from Table 6) are represented by patterned colors and those that do not are represented by solid colors.



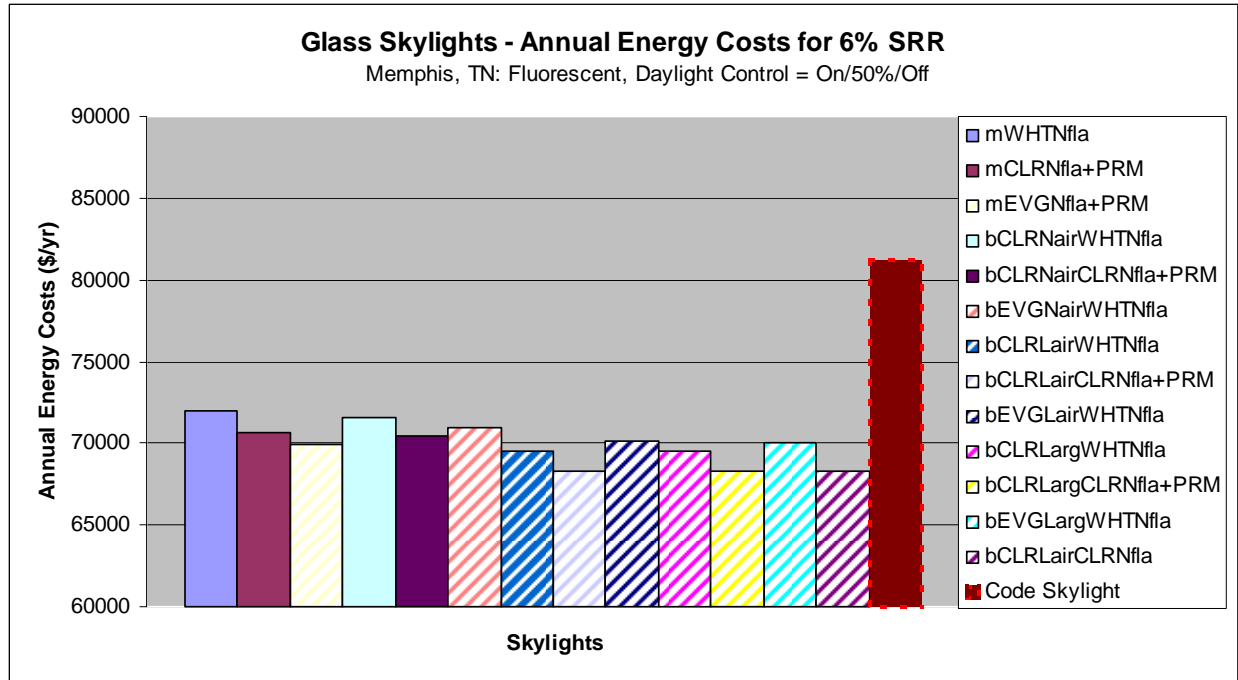
(a)



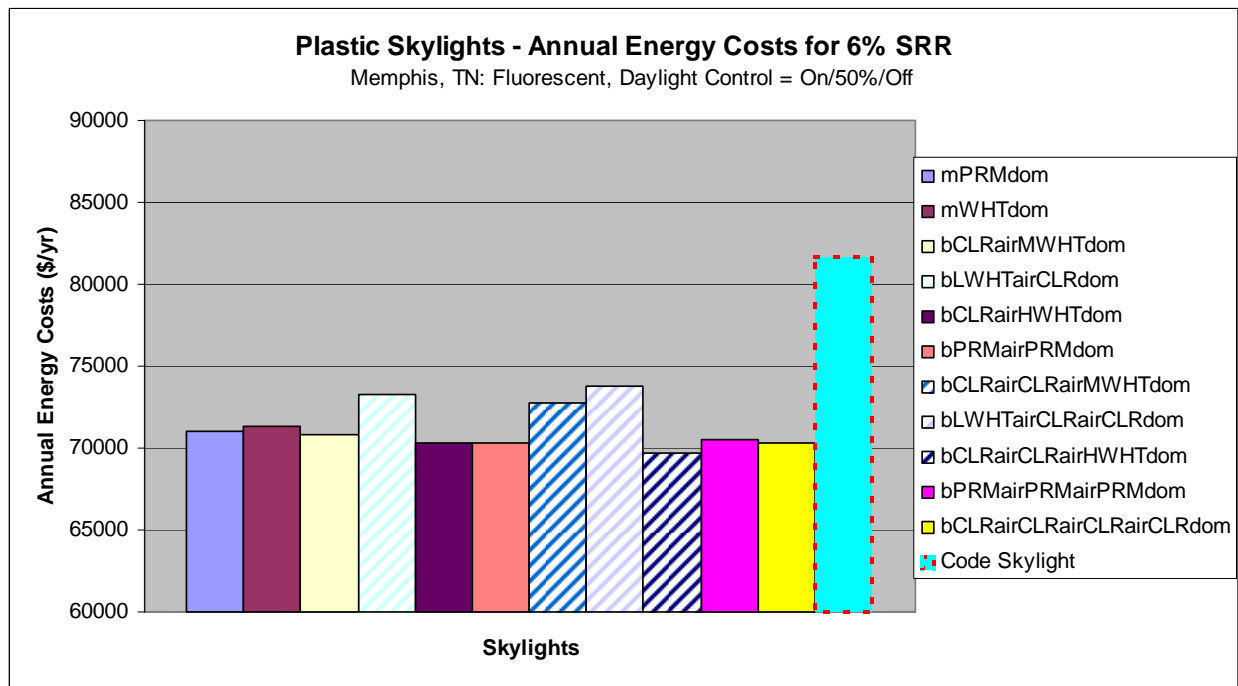
(b)

Figure 5. Annual Energy Costs for Big Box Retail Building with 6% SRR Skylights and Code Skylight in Houston, TX (Zone 2) – (a) Glass skylights, (b) Plastic skylights

Note: The skylights that meet the proposed code values (from Table 6) are represented by patterned colors and those that do not are represented by solid colors.



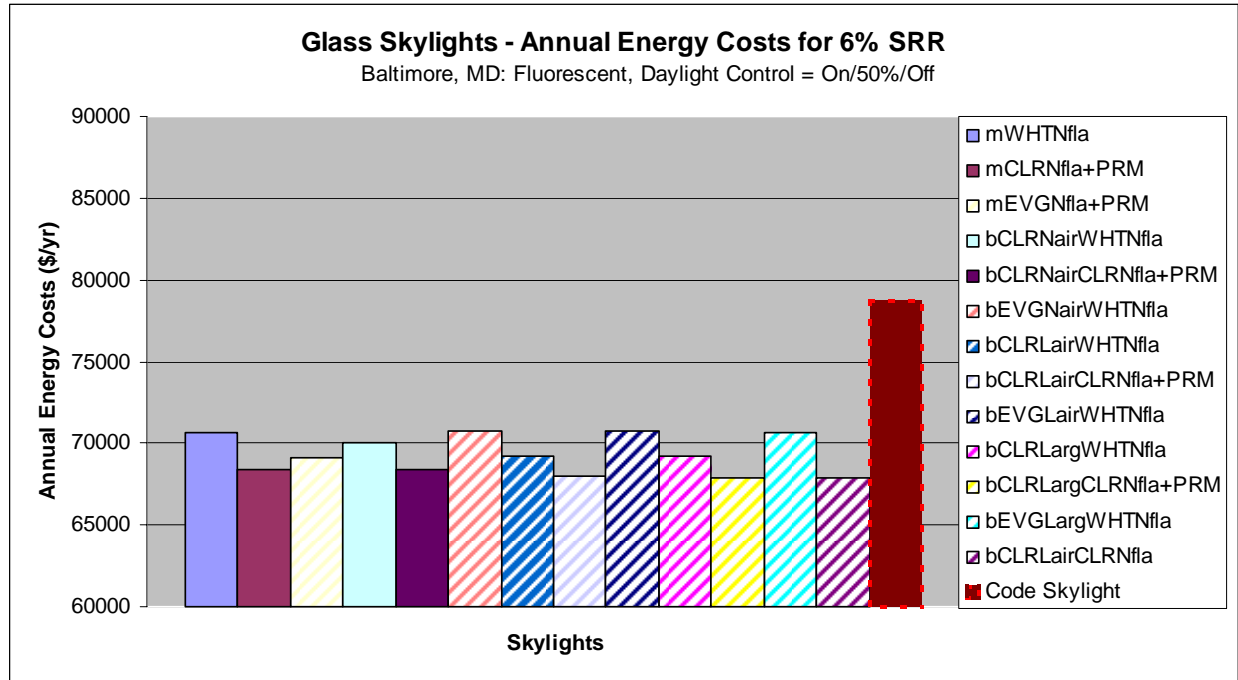
(a)



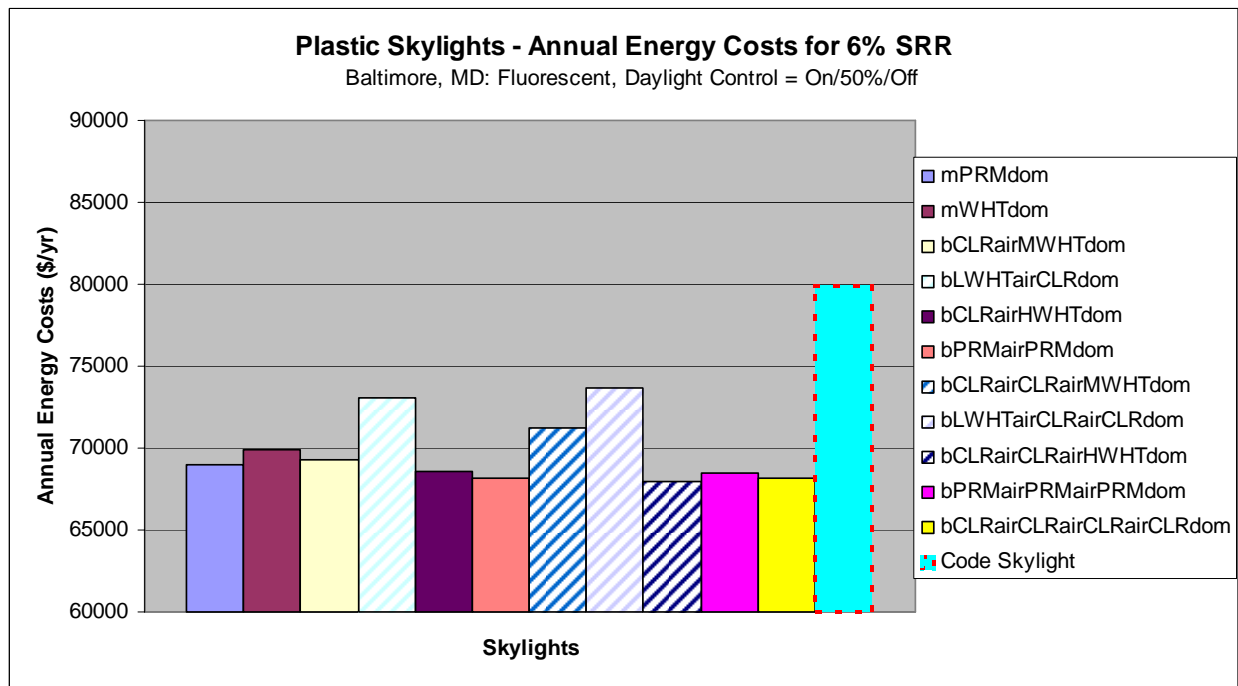
(b)

Figure 6. Annual Energy Costs for Big Box Retail Building with 6% SRR Skylights and Code Skylight in Memphis, TN (Zone 3) – (a) Glass skylights, (b) Plastic skylights

Note: The skylights that meet the proposed code values (from Table 6) are represented by patterned colors and those that do not are represented by solid colors.



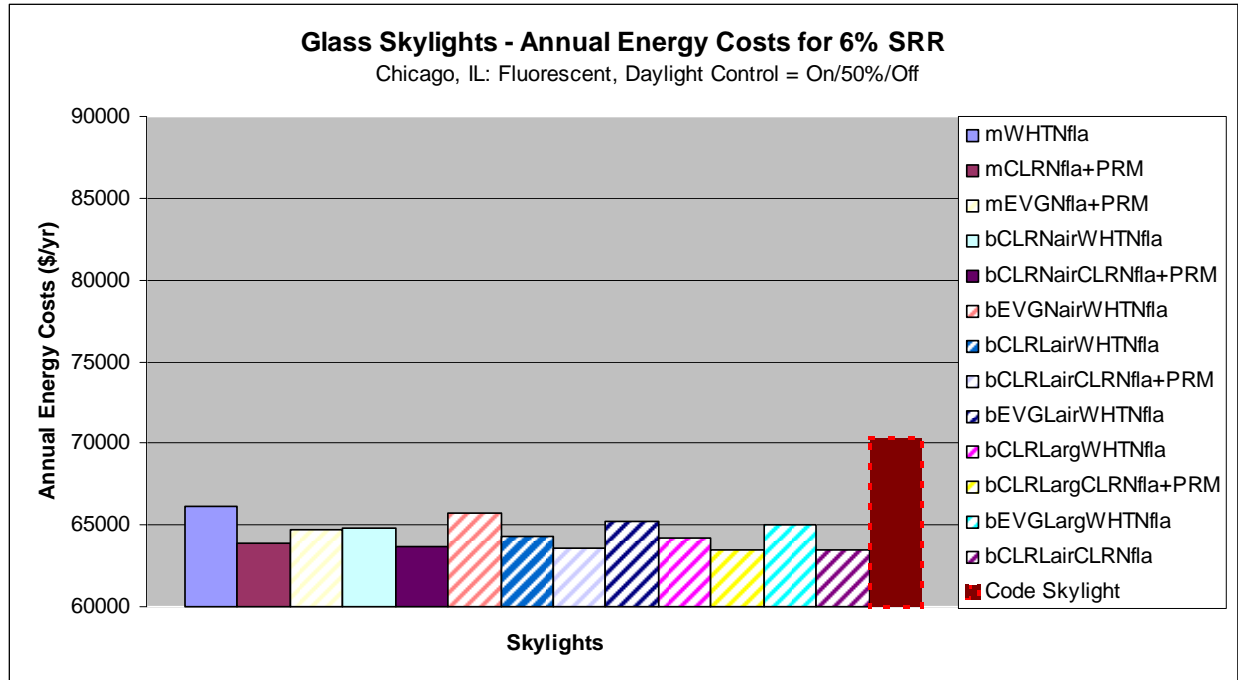
(a)



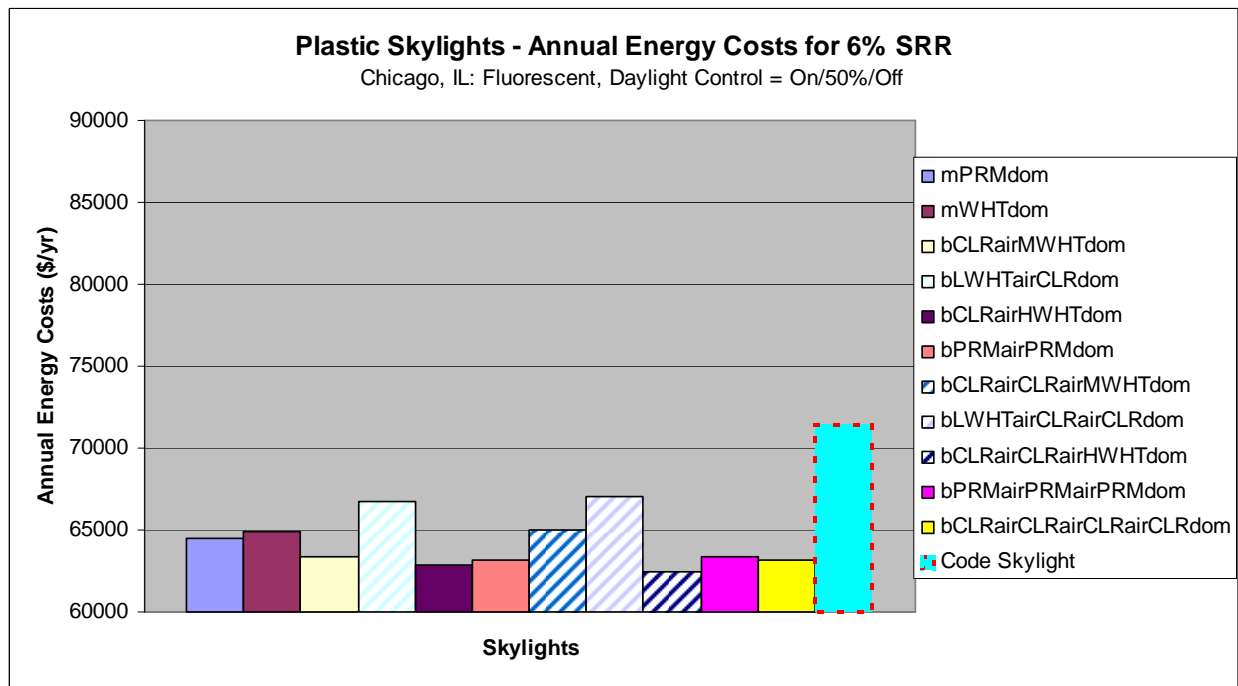
(b)

Figure 7. Annual Energy Costs for Big Box Retail Building with 6% SRR Skylights and Code Skylight in Baltimore, MD (Zone 4) – (a) Glass skylights, (b) Plastic skylights

Note: The skylights that meet the proposed code values (from Table 6) are represented by patterned colors and those that do not are represented by solid colors.



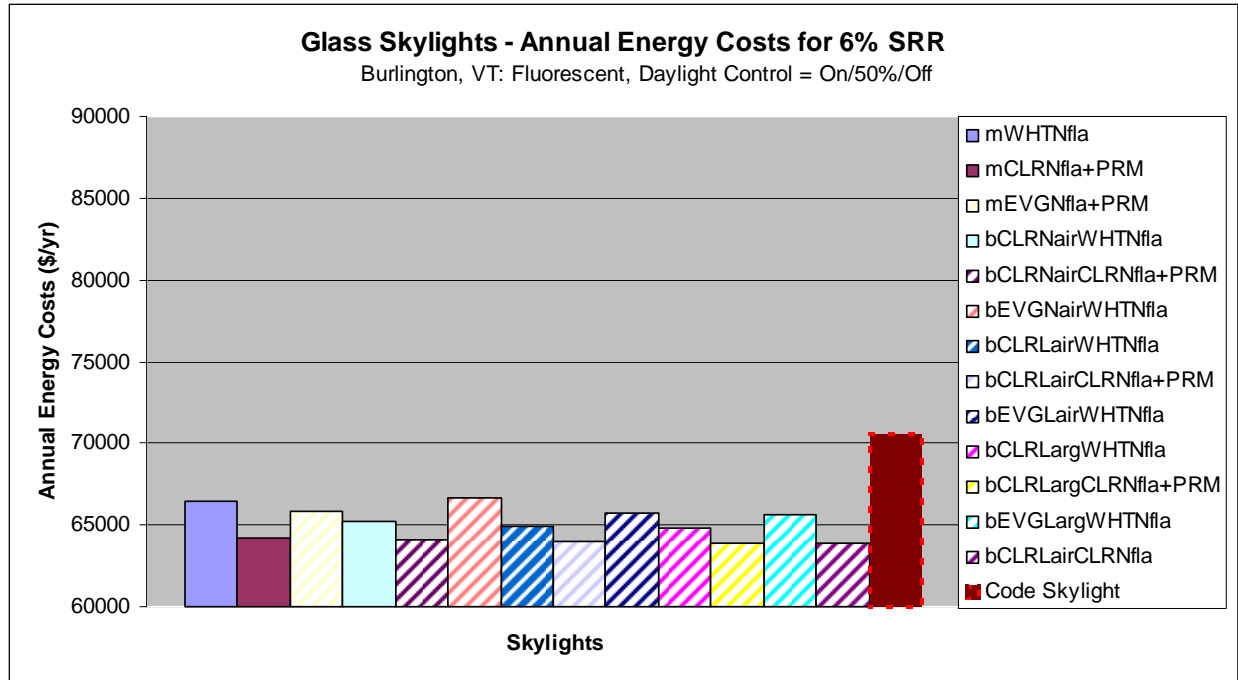
(a)



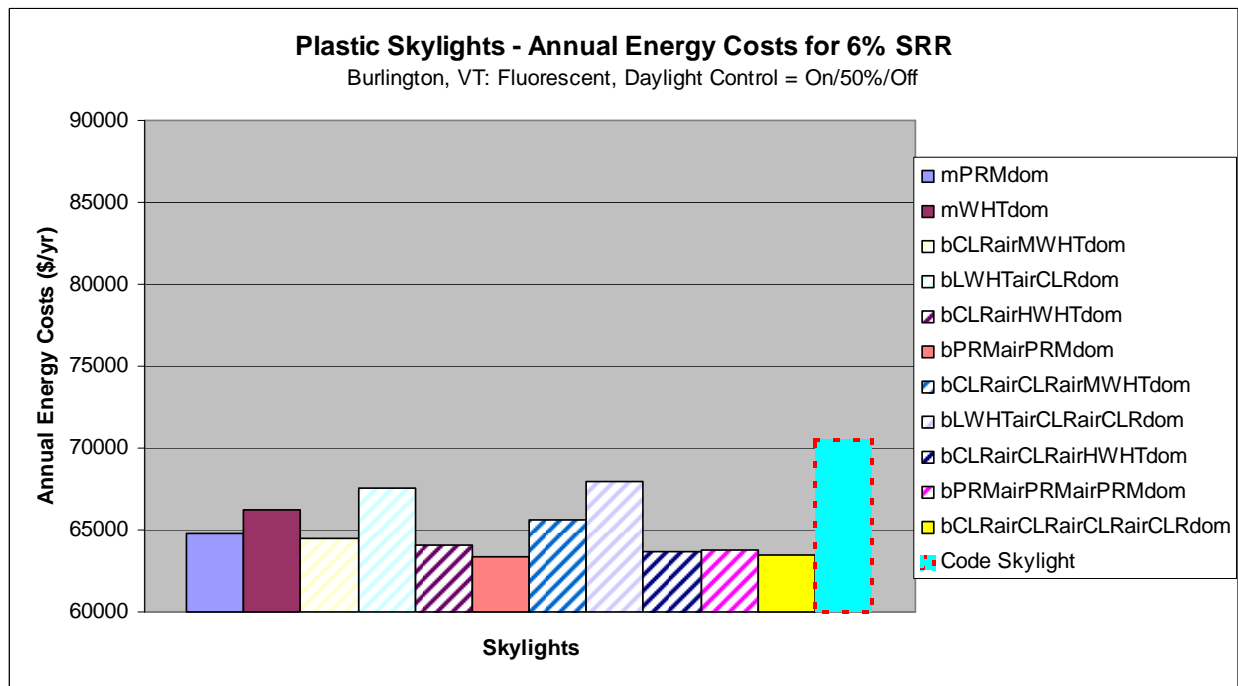
(b)

Figure 8. Annual Energy Costs for Big Box Retail Building with 6% SRR Skylights and Code Skylight in Chicago, IL (Zone 5) – (a) Glass skylights, (b) Plastic skylights

Note: The skylights that meet the proposed code values (from Table 6) are represented by patterned colors and those that do not are represented by solid colors.



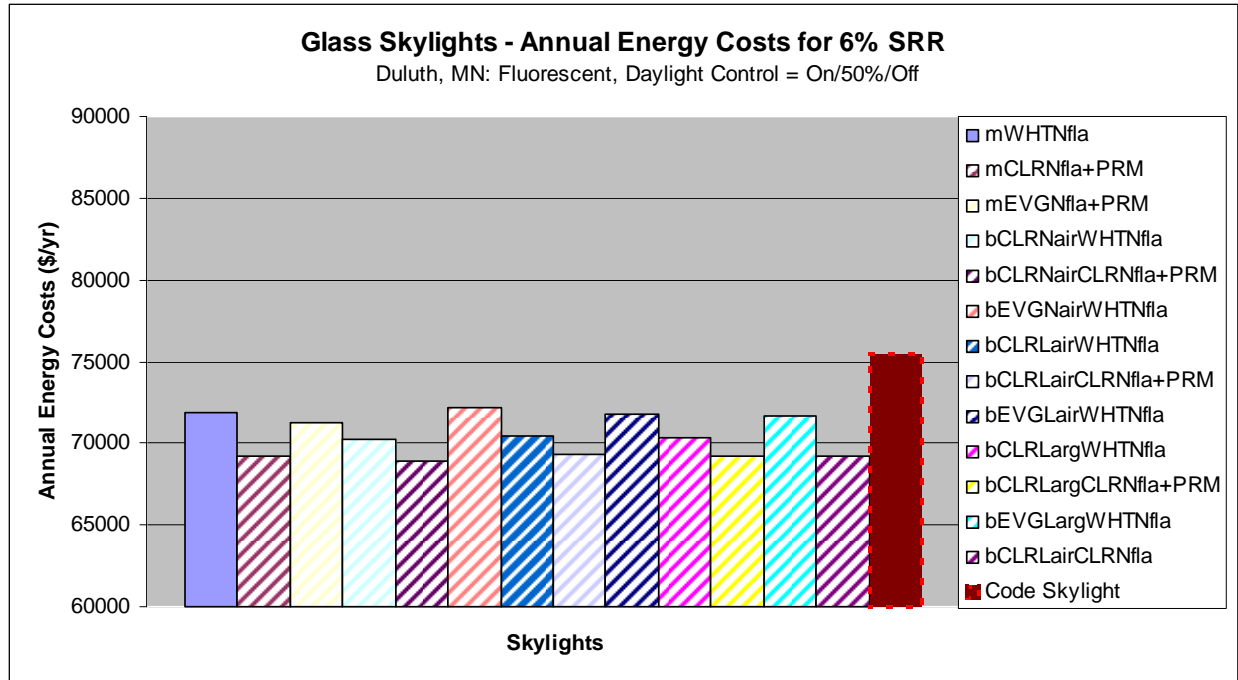
(a)



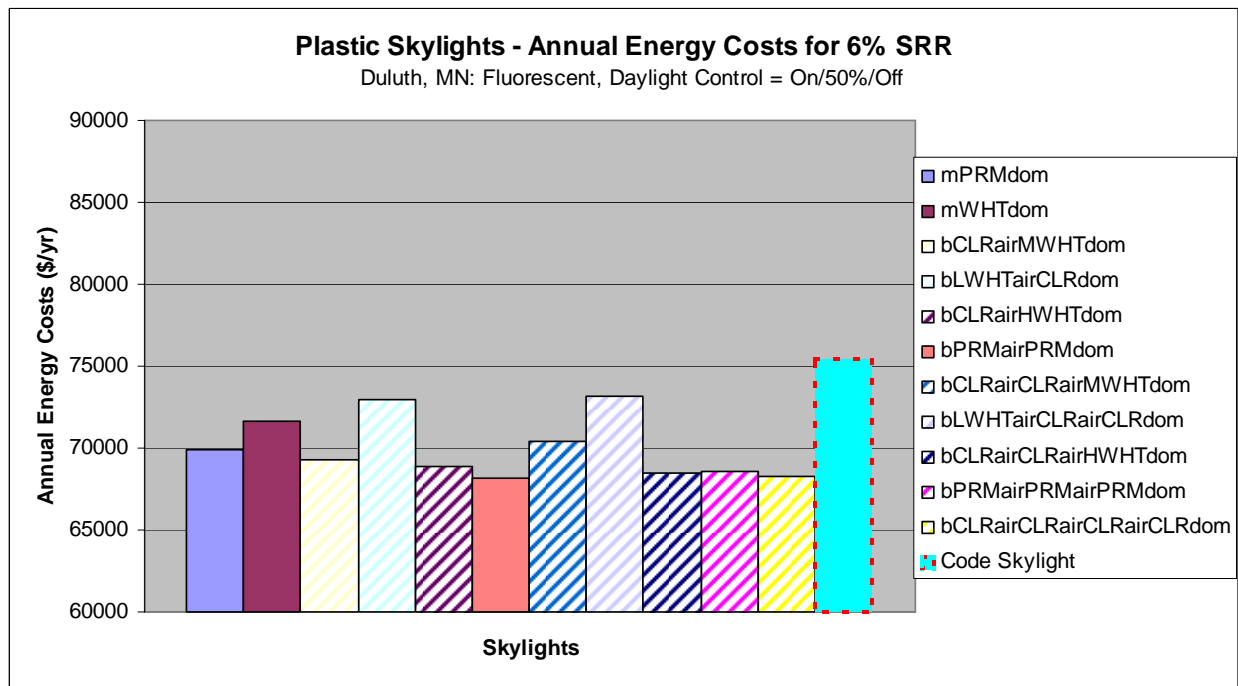
(b)

Figure 9. Annual Energy Costs for Big Box Retail Building with 6% SRR Skylights and Code Skylight in Burlington, VT (Zone 6) – (a) Glass skylights, (b) Plastic skylights

Note: The skylights that meet the proposed code values (from Table 6) are represented by patterned colors and those that do not are represented by solid colors.



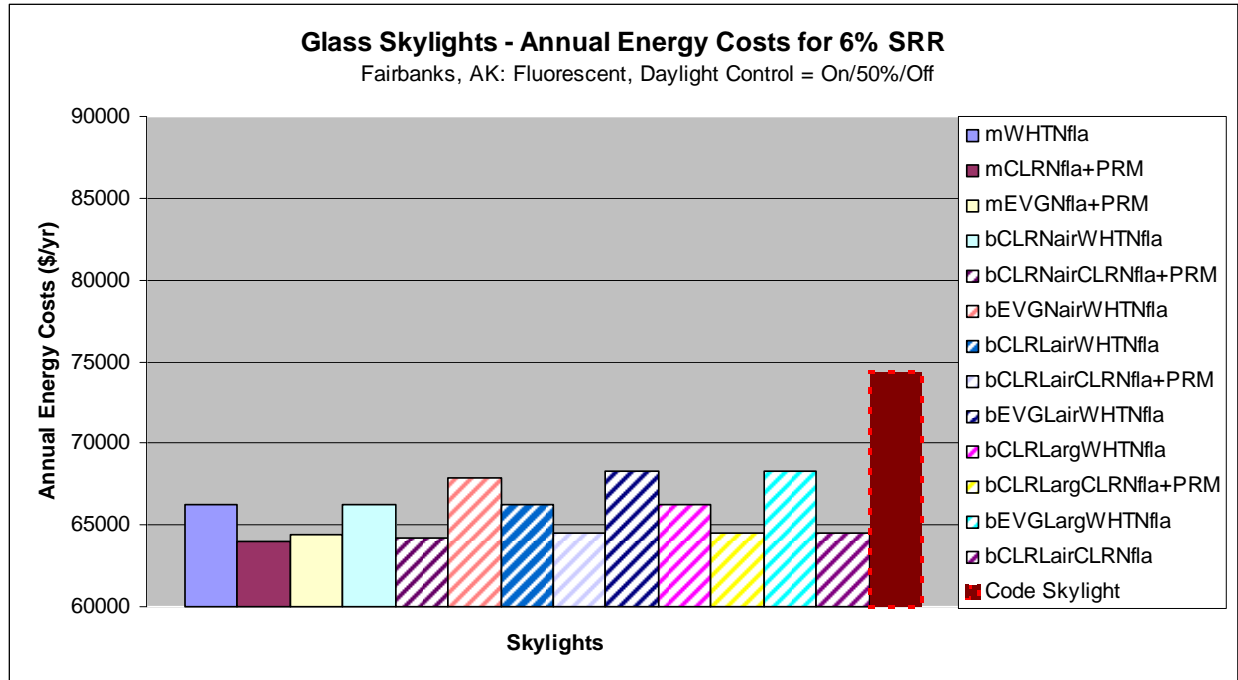
(a)



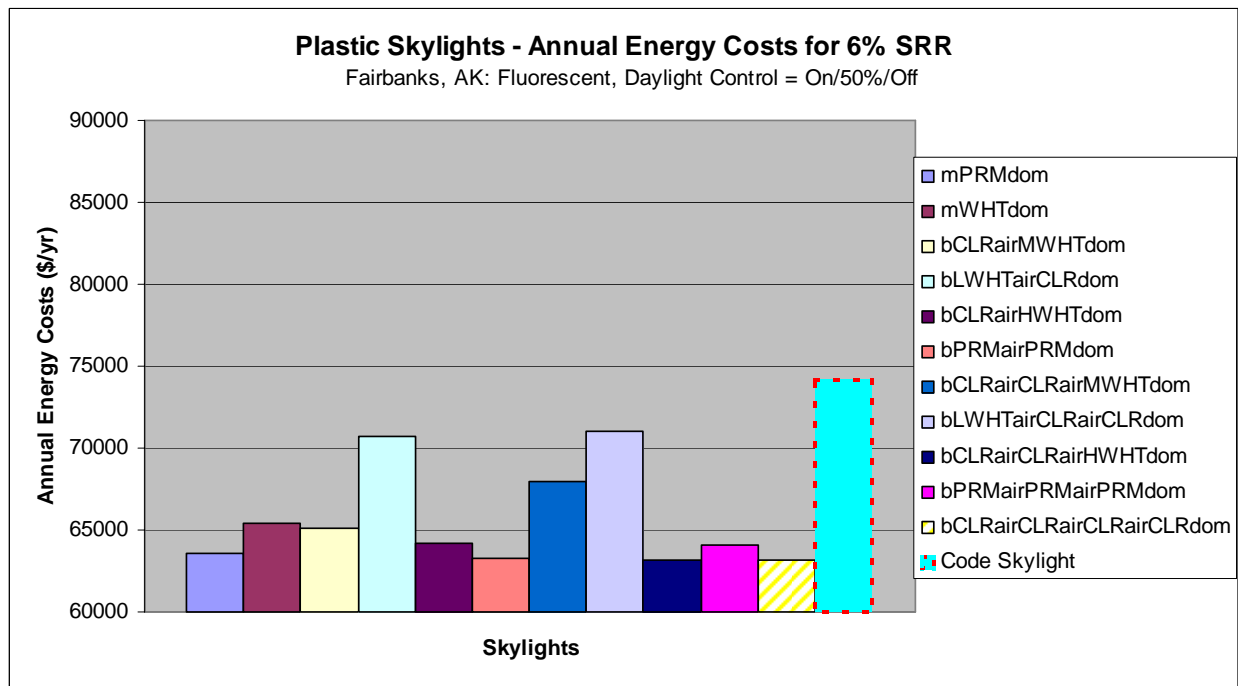
(b)

Figure 10. Annual Energy Costs for Big Box Retail Building with 6% SRR Skylights and Code Skylight in Duluth, MN (Zone 7) – (a) Glass skylights, (b) Plastic skylights

Note: The skylights that meet the proposed code values (from Table 6) are represented by patterned colors and those that do not are represented by solid colors.



(a)



(b)

Figure 11. Annual Energy Costs for Big Box Retail Building with 6% SRR Skylights and Code Skylight in Fairbanks, AK (Zone 8) – (a) Glass skylights, (b) Plastic skylights

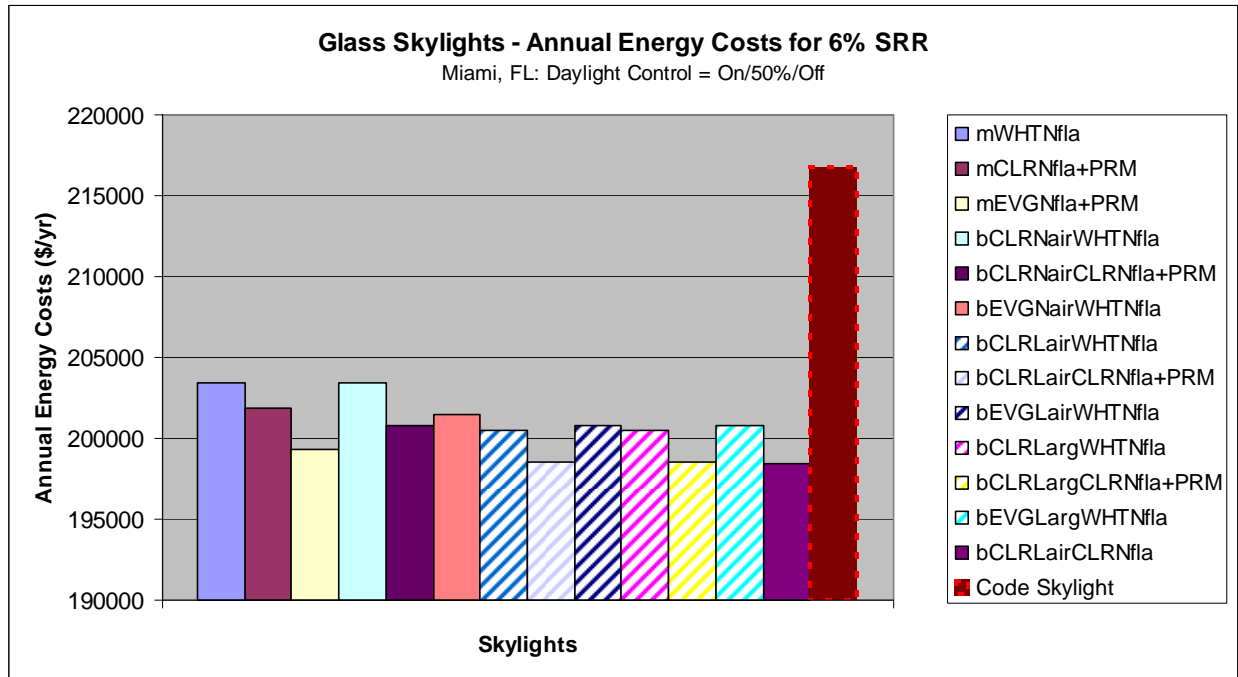
Note: The skylights that meet the proposed code values (from Table 6) are represented by patterned colors and those that do not are represented by solid colors.

The annual cost data for the big box retail building for rest of the cities considered in the analysis are summarized in Table 8.

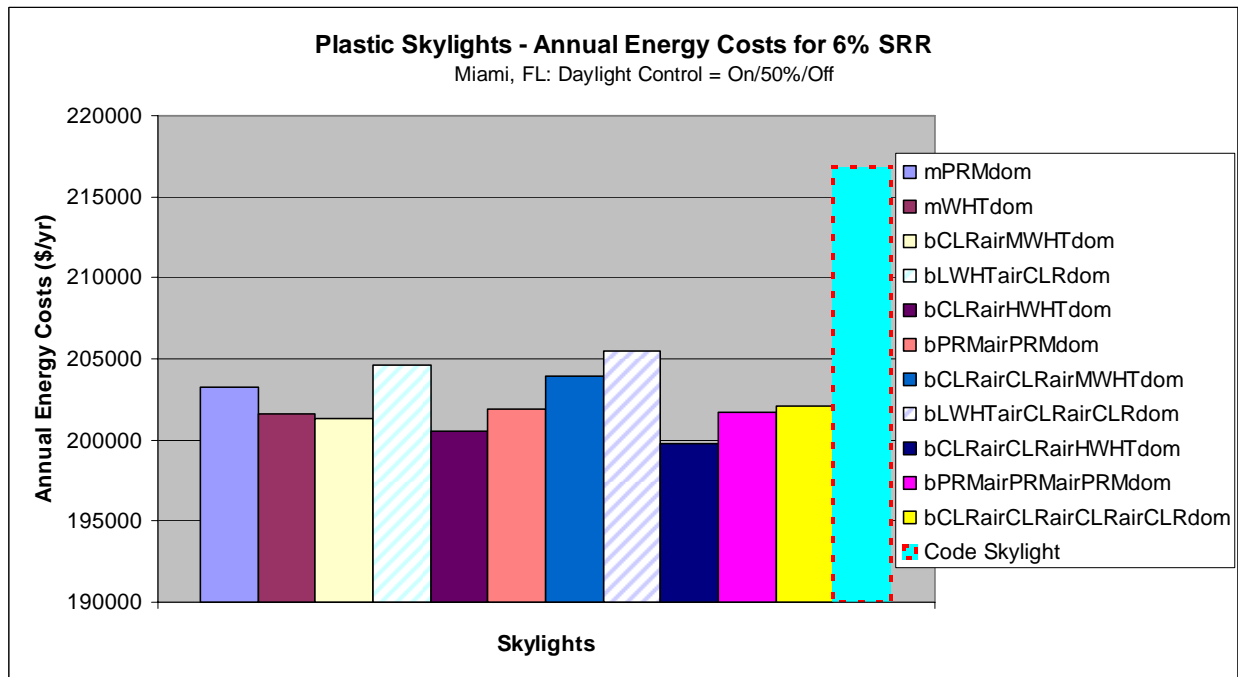
Table 8. Annual Energy Costs for Big Box Retail Building with 6% SRR Skylights and Code Skylight in Various Cities Across 6 Climate Zones

| Skylights | Zones/Cities | | | | | | | | | | | | |
|---------------------------|---------------|--------------|--------------|-----------------|------------------|-------------------|-----------------|--------------|--------------|--------------|--------------|--------------|--------------|
| | 1 | 2 | 3 | | | 4 | | | | 5 | 6 | | |
| Glass | Honolulu, HI | Phoenix, AZ | El Paso, TX | Los Angeles, CA | San Fransico, CA | New York City, NY | Albuquerque, NM | Portland, OR | Salem, OR | Seattle, WA | Boston, MA | Boise, ID | Helena, MT |
| Code Skylight | 160392 | 78531 | 60780 | 67264 | 70537 | 105989 | 59409 | 57164 | 59214 | 55996 | 96314 | 67649 | 64230 |
| 1 mWHTNfla | 135499 | 68043 | 51148 | 51061 | 54962 | 94067 | 51719 | 52699 | 54115 | 52314 | 88053 | 60997 | 59464 |
| 2 mCLRNfla+PRM | 134453 | 67369 | 50173 | 49998 | 52973 | 91207 | 50105 | 51243 | 52538 | 50551 | 85496 | 58978 | 57420 |
| 3 mEVGNfla+PRM | 126885 | 65895 | 50200 | 49182 | 56237 | 92109 | 51392 | 51658 | 53985 | 52237 | 85412 | 59462 | 58816 |
| 4 bCLRNairWHTNfla | 135532 | 67374 | 50617 | 51314 | 55115 | 93150 | 50732 | 51910 | 53406 | 51367 | 86440 | 59797 | 58189 |
| 5 bCLRNairCLRNfla+PRM | 132513 | 66390 | 49962 | 50217 | 53642 | 91144 | 49957 | 50833 | 52418 | 50453 | 84719 | 58645 | 57112 |
| 6 bEVGNairWHTNfla | 130011 | 66449 | 51049 | 51269 | 57631 | 94501 | 52057 | 52530 | 54692 | 52742 | 87457 | 60658 | 59863 |
| 7 bCLRLairWHTNfla | 128525 | 65668 | 49353 | 49853 | 56096 | 92160 | 50803 | 51400 | 53498 | 51560 | 85218 | 58629 | 58298 |
| 8 bCLRLairCLRNfla+PRM | 125418 | 63393 | 48818 | 48252 | 55055 | 90112 | 50350 | 50597 | 52963 | 51097 | 83580 | 57628 | 56980 |
| 9 bEVGLairWHTNfla | 128579 | 65943 | 50522 | 50861 | 57830 | 94109 | 51732 | 52103 | 54400 | 52338 | 87615 | 60391 | 59240 |
| 10 bCLRLargWHTNfla | 128715 | 65662 | 49319 | 49877 | 55993 | 92092 | 50711 | 51328 | 53396 | 51461 | 85114 | 58538 | 58203 |
| 11 bCLRLargCLRNfla+PRM | 125457 | 63366 | 48776 | 48234 | 54971 | 90014 | 50268 | 50521 | 52884 | 51009 | 83471 | 57539 | 56854 |
| 12 bEVGLargWHTNfla | 128452 | 65875 | 50394 | 50758 | 57738 | 93965 | 51653 | 52022 | 54302 | 52253 | 87486 | 59644 | 59143 |
| 13 bCLRLairCLRNfla | 125297 | 63339 | 48767 | 48205 | 54988 | 89976 | 50278 | 50520 | 52881 | 51012 | 83454 | 57531 | 56877 |
| Plastic | | | | | | | | | | | | | |
| Code Skylight | 151276 | 79062 | 61074 | 67276 | 70930 | 107551 | 60250 | 58192 | 59748 | 56472 | 98661 | 69098 | 64501 |
| 14 mPRMdom | 136203 | 68003 | 51087 | 49941 | 53200 | 92014 | 51366 | 51361 | 52736 | 50742 | 86686 | 59454 | 57899 |
| 15 mWHTdom | 131647 | 66837 | 50733 | 50666 | 55498 | 93123 | 51954 | 51911 | 53935 | 52107 | 86947 | 60087 | 59210 |
| 16 bCLRairMWHTdom | 132564 | 66594 | 50294 | 50980 | 54863 | 92203 | 50622 | 50851 | 52684 | 50704 | 85400 | 58748 | 57538 |
| 17 bLWHTairCLRdom | 136784 | 69064 | 52783 | 54405 | 60805 | 98161 | 53592 | 53871 | 55767 | 53471 | 90280 | 62712 | 61141 |
| 18 bCLRairHWHTdom | 131234 | 66185 | 49860 | 50249 | 54232 | 91117 | 50316 | 50448 | 52366 | 50414 | 84623 | 58205 | 57112 |
| 19 bPRMairPRMdom | 134006 | 66622 | 49941 | 49850 | 52989 | 90894 | 49973 | 50248 | 51712 | 49665 | 84569 | 58060 | 56588 |
| 20 bCLRairCLRairMWHTdom | 137176 | 68029 | 51492 | 53239 | 56829 | 94885 | 51563 | 51980 | 53604 | 51384 | 87456 | 59832 | 58670 |
| 21 bLWHTairCLRairCLRdom | 138352 | 69597 | 53525 | 55250 | 61869 | 99416 | 54329 | 54165 | 56016 | 53673 | 90861 | 63299 | 61334 |
| 22 bCLRairCLRairHWHTdom | 130402 | 65821 | 49473 | 49515 | 53600 | 90135 | 49952 | 50083 | 51986 | 50058 | 83752 | 57698 | 56564 |
| 23 bPRMairPRMairPRMdom | 132866 | 66628 | 50007 | 50263 | 53655 | 91295 | 50147 | 50417 | 52142 | 50041 | 84791 | 58237 | 56897 |
| 24 bCLRairCLRairCLRairCLR | 134207 | 66820 | 50007 | 49745 | 52953 | 90779 | 50039 | 50299 | 51743 | 49772 | 84645 | 58144 | 56654 |

2. Grocery



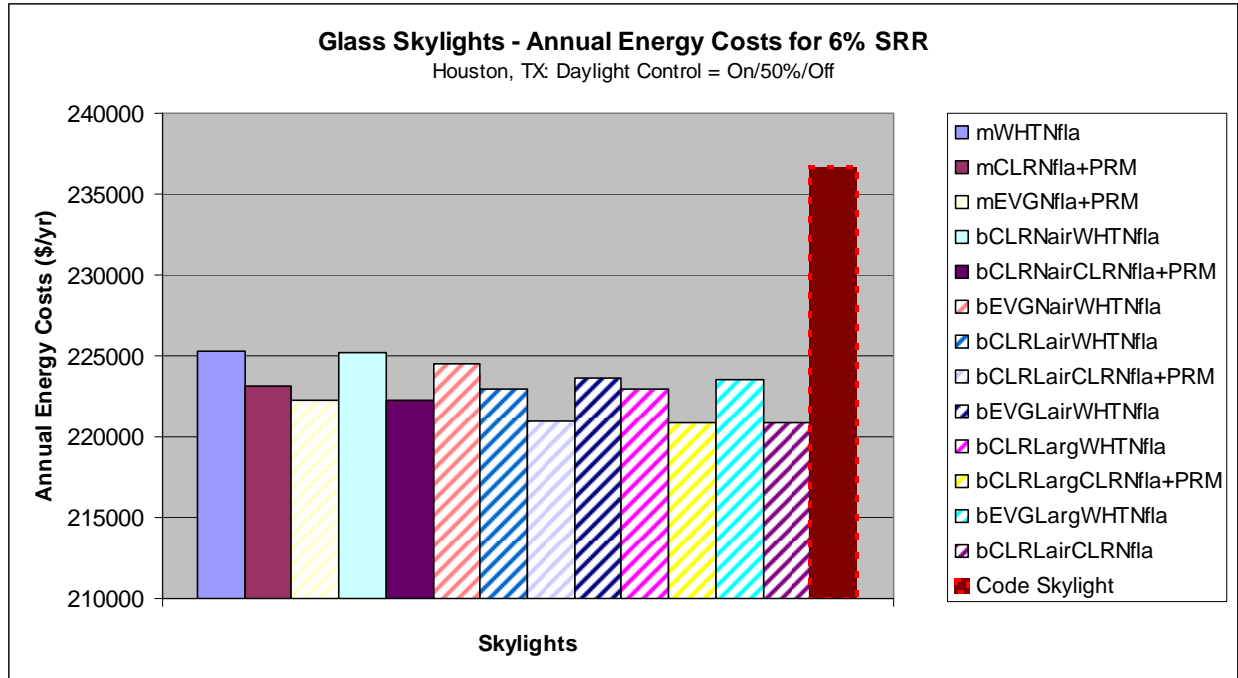
(a)



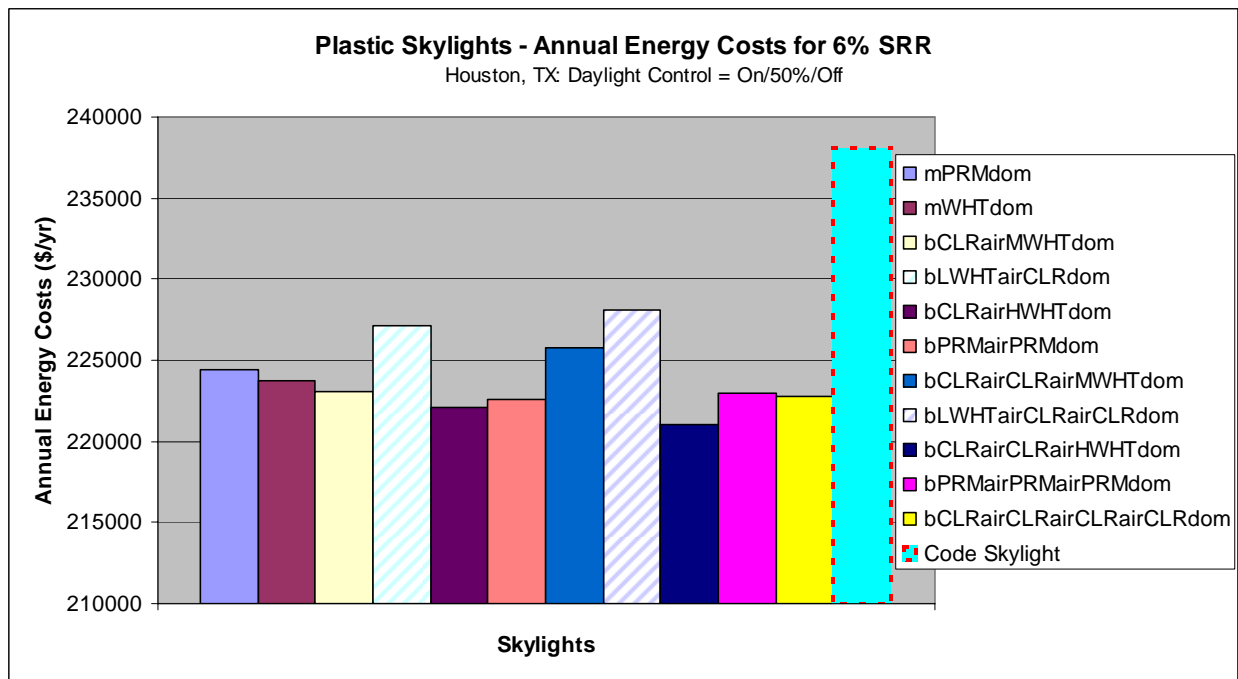
(b)

Figure 12. Annual Energy Costs for Grocery Building with 6% SRR Skylights and Code Skylight in Miami, FL (Zone 1) – (a) Glass skylights, (b) Plastic skylights

Note: The skylights that meet the proposed code values (from Table 6) are represented by patterned colors and those that do not are represented by solid colors.



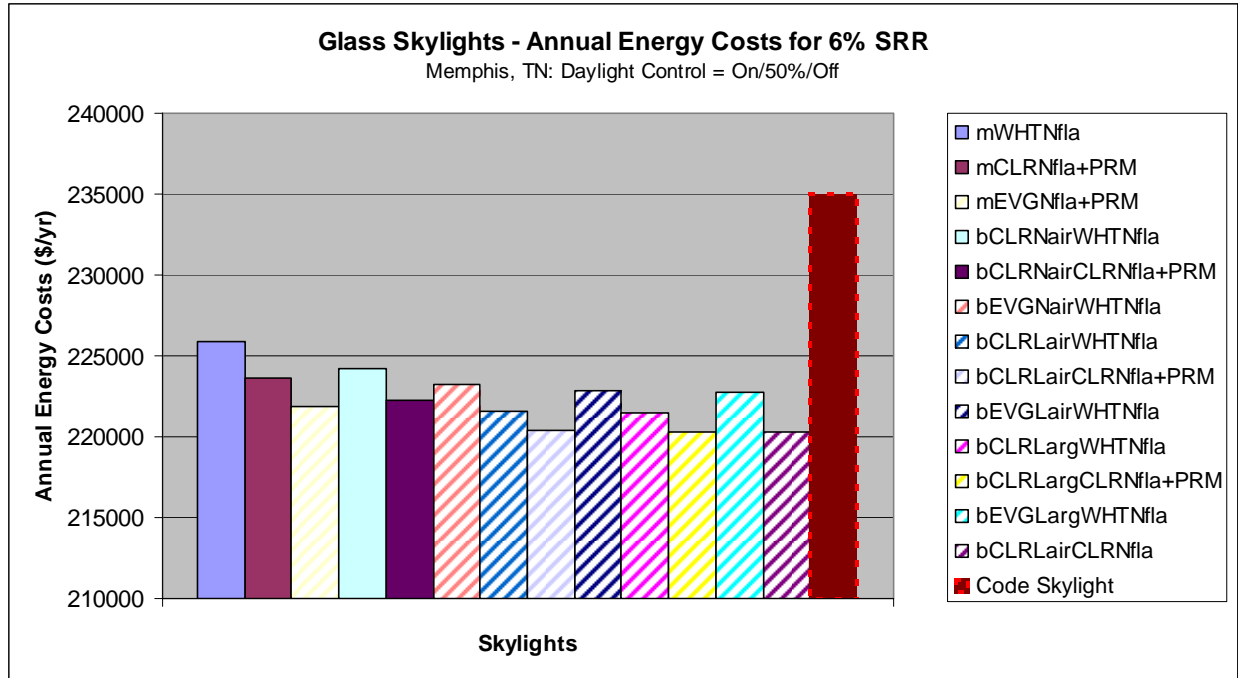
(a)



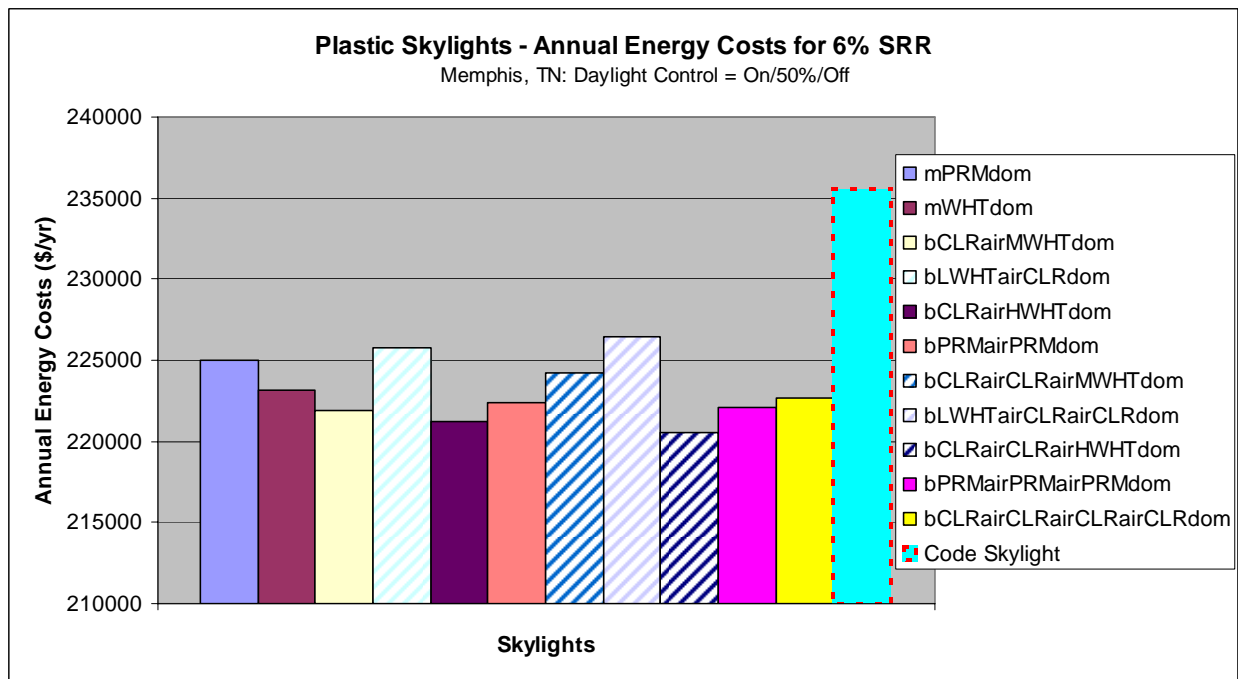
(b)

Figure 13. Annual Energy Costs for Grocery Building with 6% SRR Skylights and Code Skylight in Houston, TX (Zone 2) – (a) Glass skylights, (b) Plastic skylights

Note: The skylights that meet the proposed code values (from Table 6) are represented by patterned colors and those that do not are represented by solid colors.



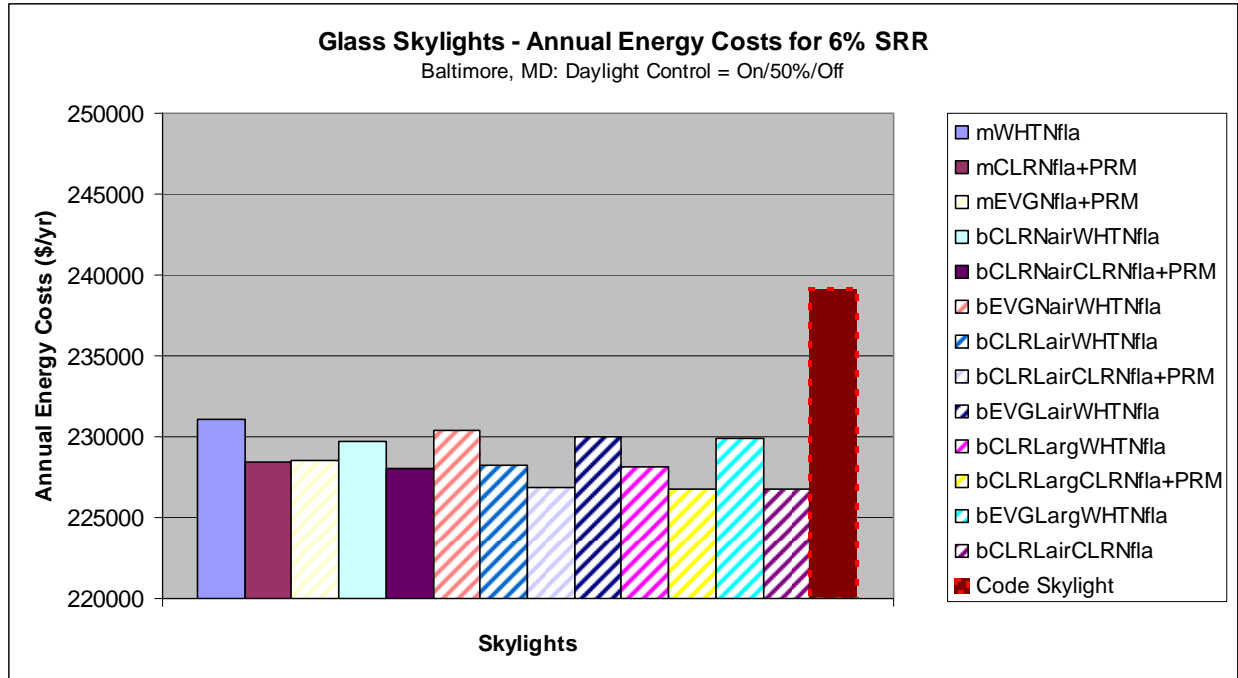
(a)



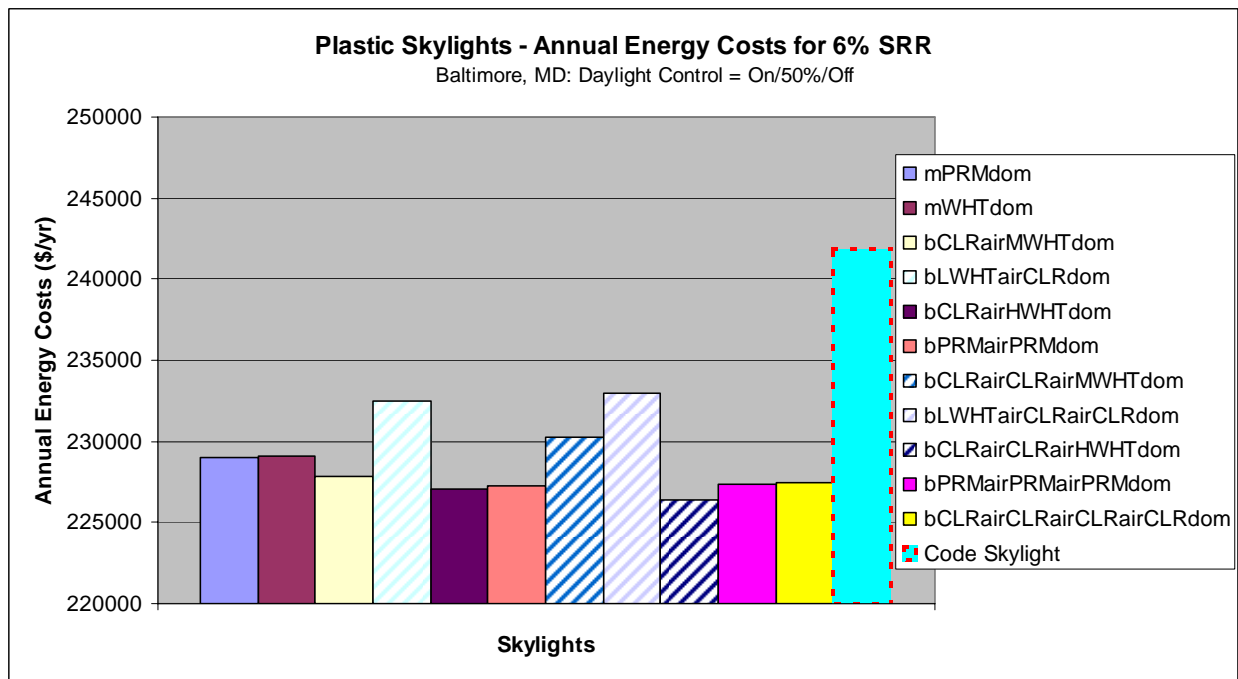
(b)

Figure 14. Annual Energy Costs for Grocery Building with 6% SRR Skylights and Code Skylight in Memphis, TN (Zone 3) – (a) Glass skylights, (b) Plastic skylights

Note: The skylights that meet the proposed code values (from Table 6) are represented by patterned colors and those that do not are represented by solid colors.



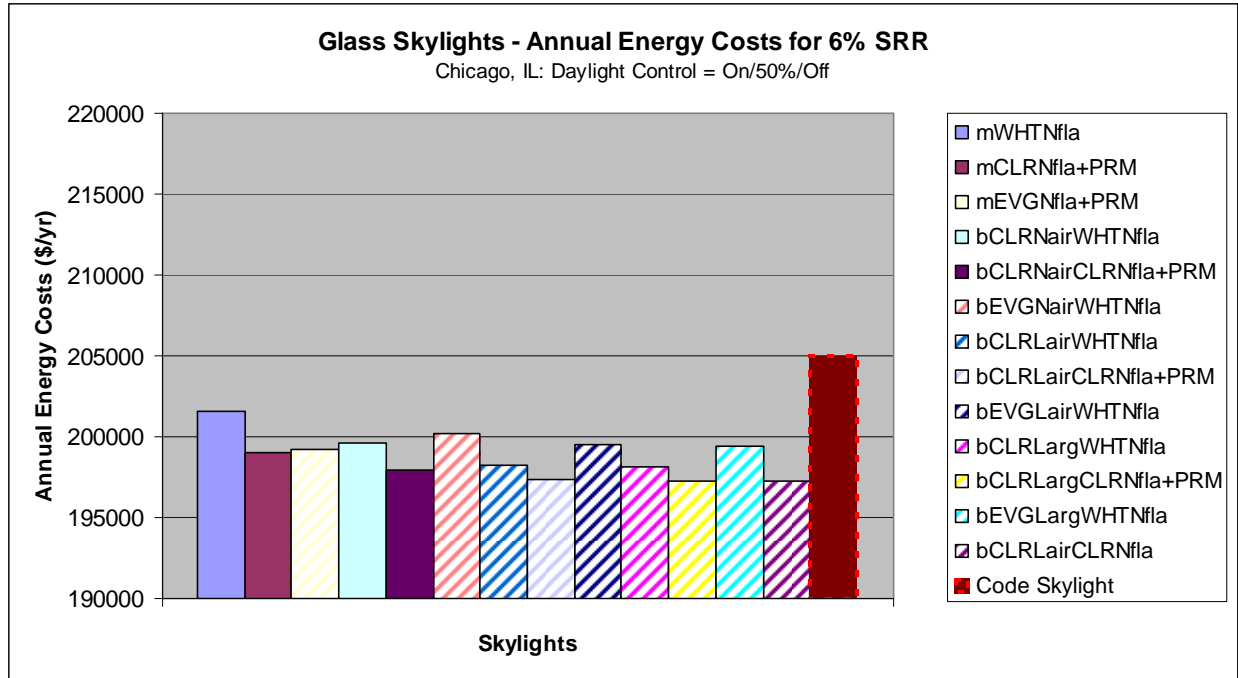
(a)



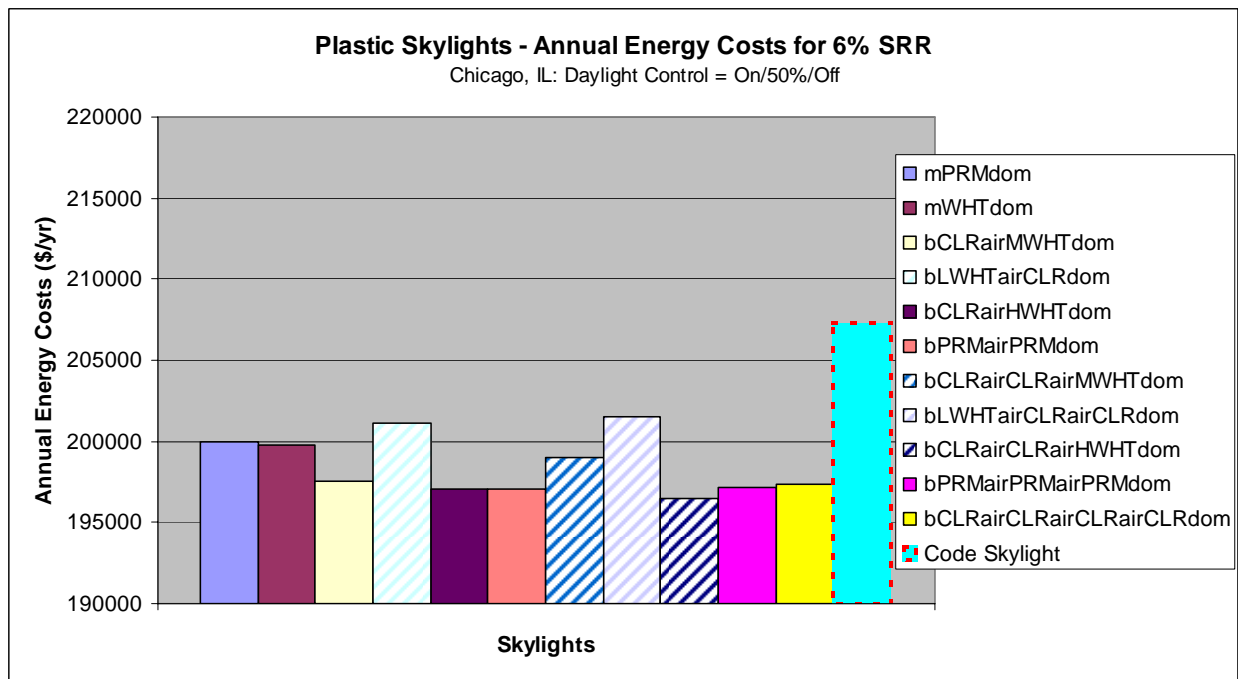
(b)

Figure 15. Annual Energy Costs for Grocery Building with 6% SRR skylights and Code Skylight in Baltimore, MD (Zone 4) – (a) Glass skylights, (b) Plastic skylights

Note: The skylights that meet the proposed code values (from Table 6) are represented by patterned colors and those that do not are represented by solid colors.



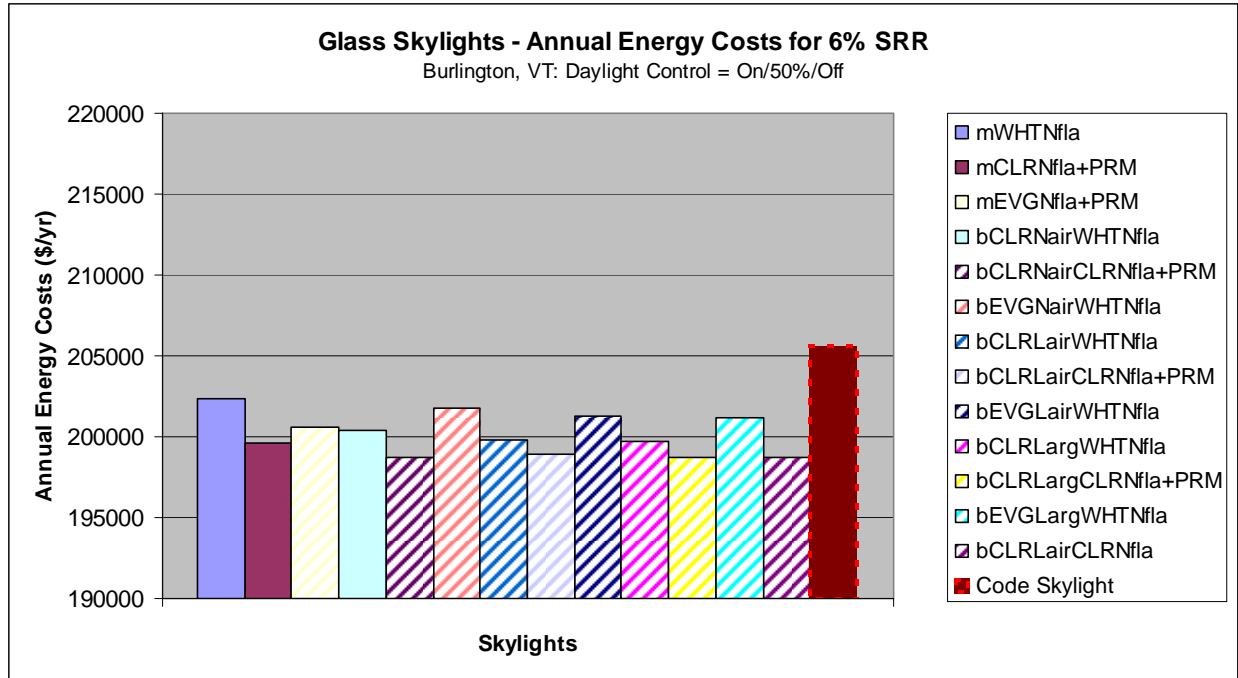
(a)



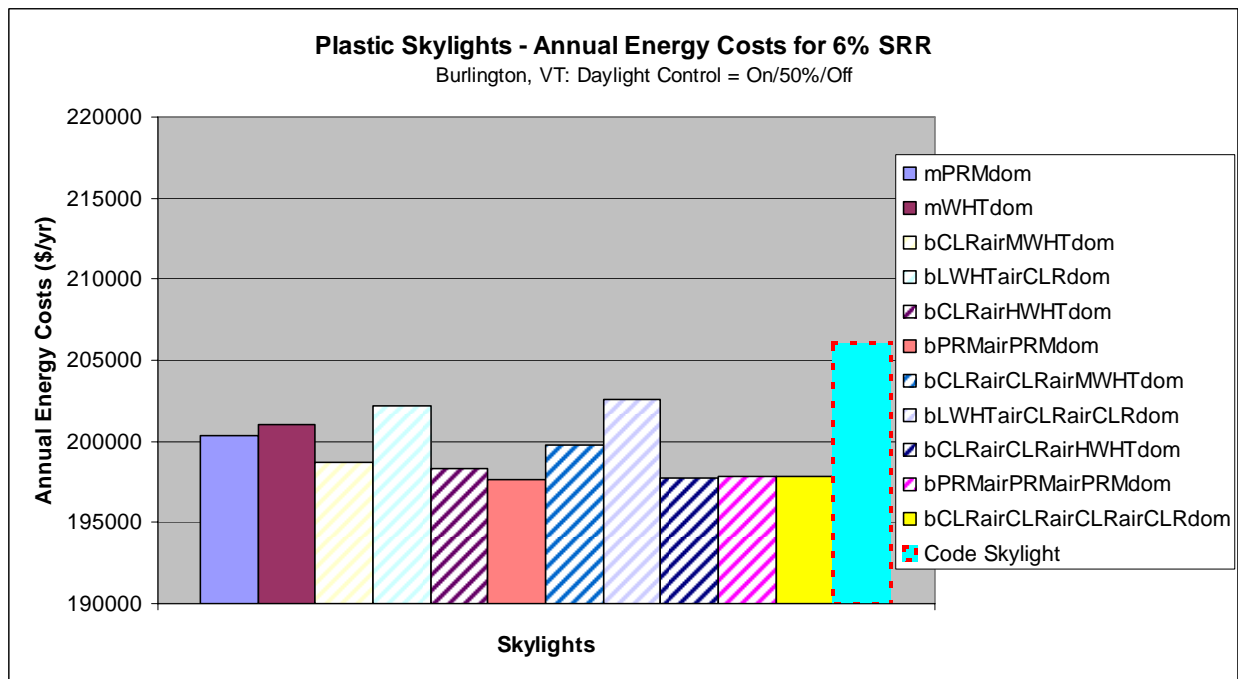
(b)

Figure 16. Annual Energy costs for Grocery Building with 6% SRR Skylights and Code Skylight in Chicago, IL (Zone 5) – (a) Glass skylights, (b) Plastic skylights

Note: The skylights that meet the proposed code values (from Table 6) are represented by patterned colors and those that do not are represented by solid colors.



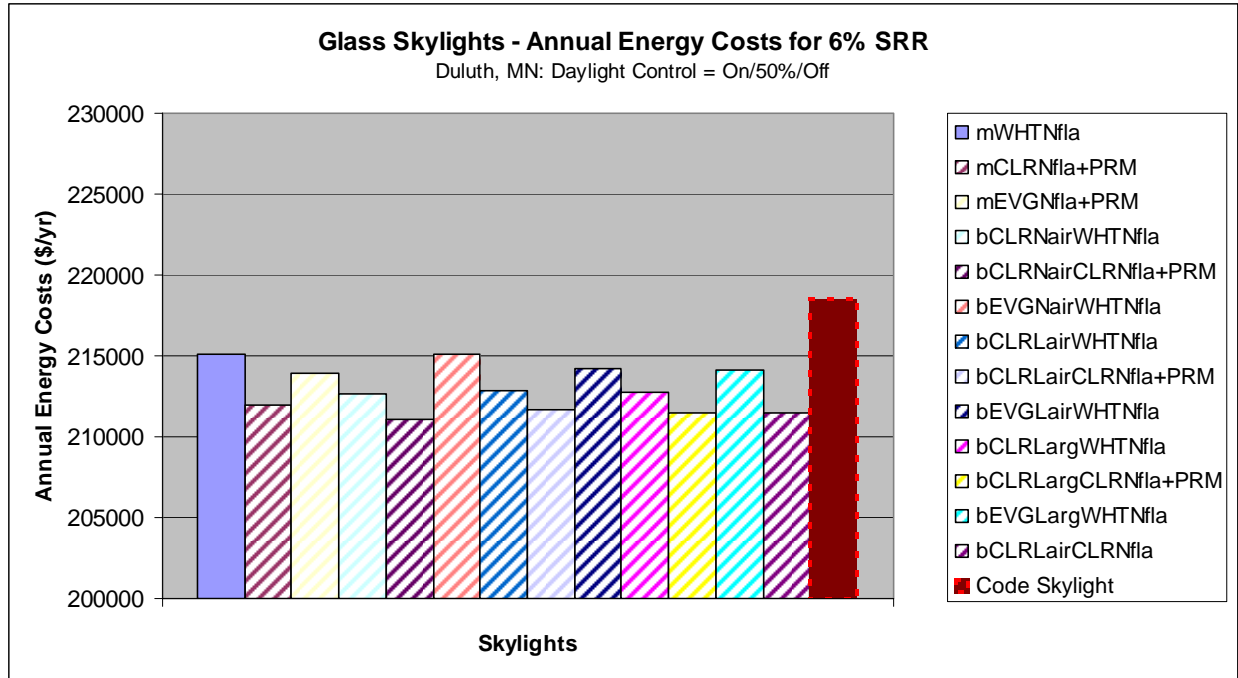
(a)



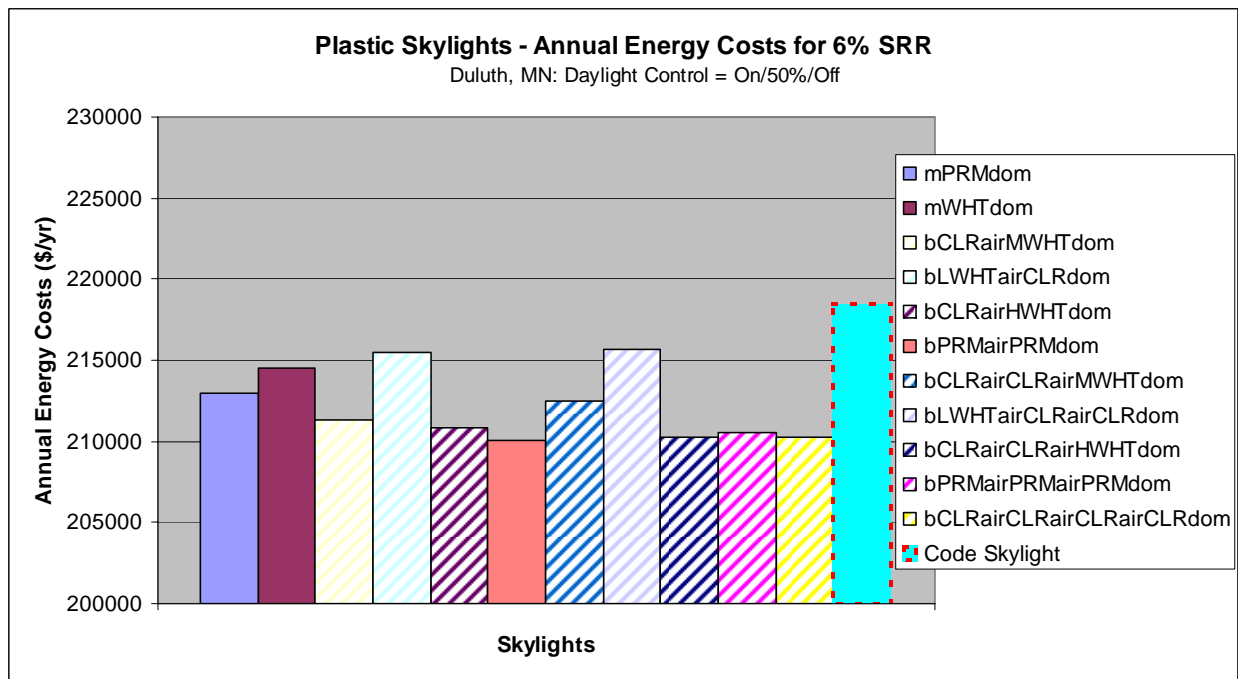
(b)

Figure 17. Annual Energy costs for Grocery Building with 6% SRR Skylights and Code Skylight in Burlington, VT (Zone 6) – (a) Glass skylights, (b) Plastic skylights

Note: The skylights that meet the proposed code values (from Table 6) are represented by patterned colors and those that do not are represented by solid colors.



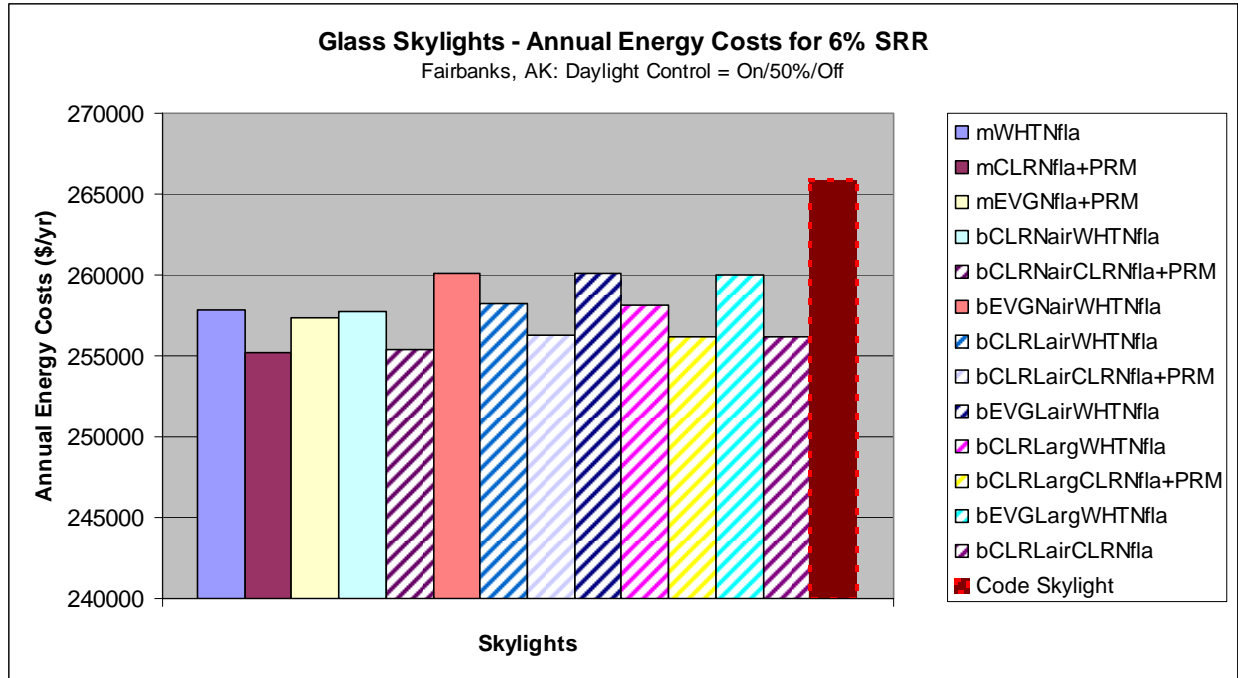
(a)



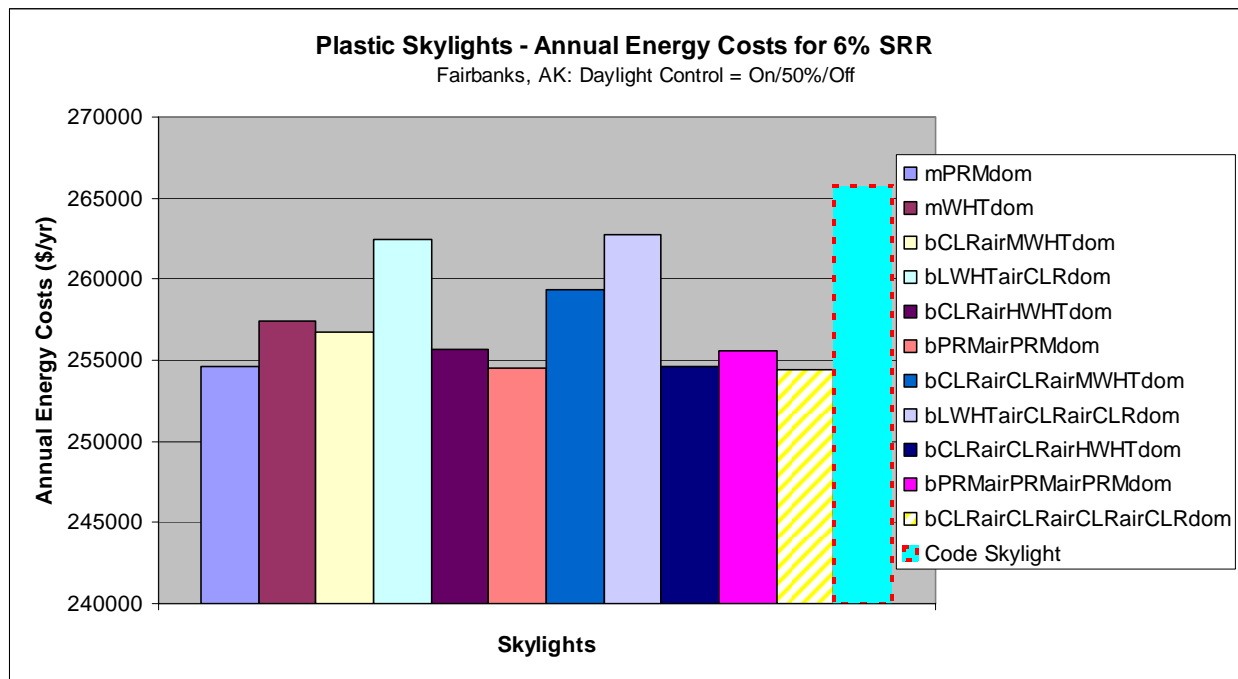
(b)

Figure 18. Annual Energy costs for Grocery Building with 6% SRR Skylights and Code Skylight in Duluth, MN(Zone 7) – (a) Glass skylights, (b) Plastic skylights

Note: The skylights that meet the proposed code values (from Table 6) are represented by patterned colors and those that do not are represented by solid colors.



(a)

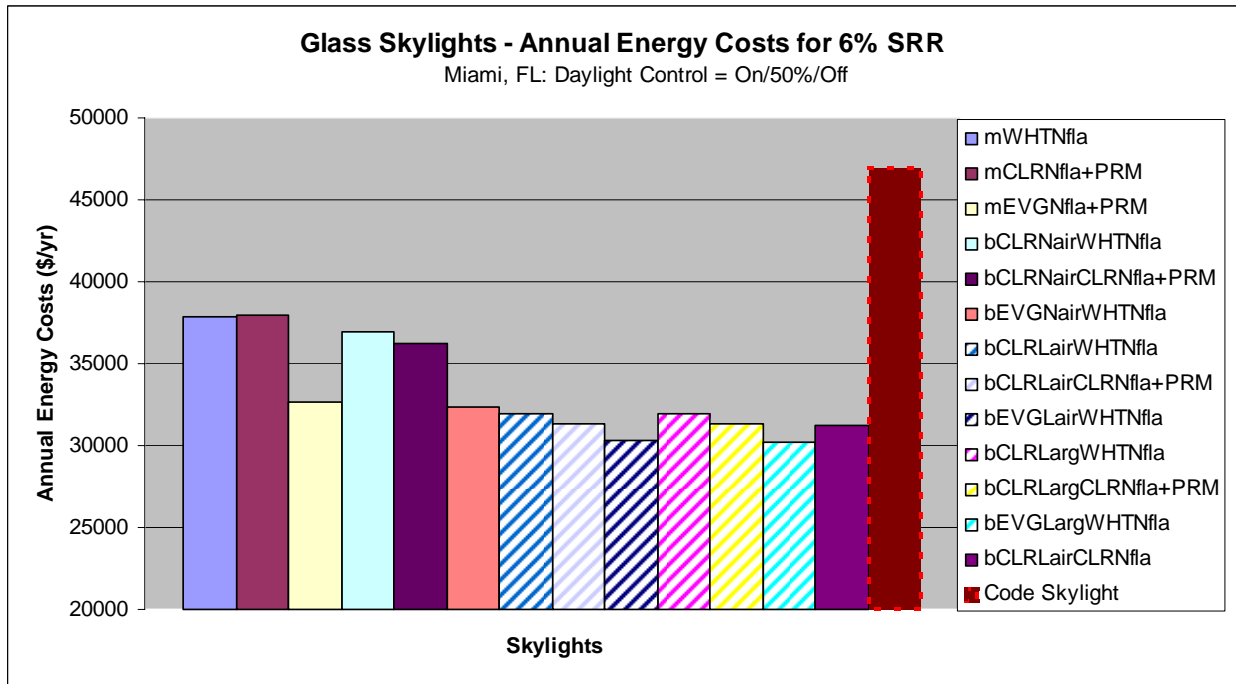


(b)

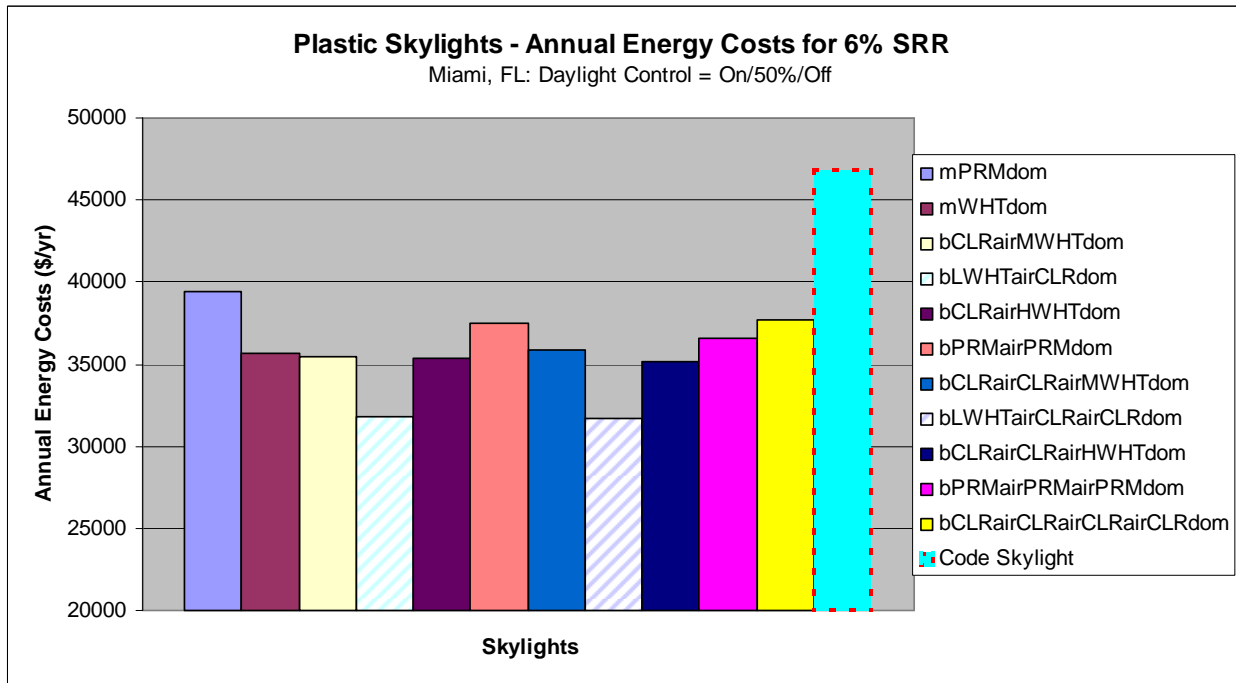
Figure 19. Annual Energy costs for Grocery Building with 6% SRR Skylights and Code Skylight in Fairbanks, AK (Zone 8) – (a) Glass skylights, (b) Plastic skylights

Note: The skylights that meet the proposed code values (from Table 6) are represented by patterned colors and those that do not are represented by solid colors.

3. WAREHOUSE



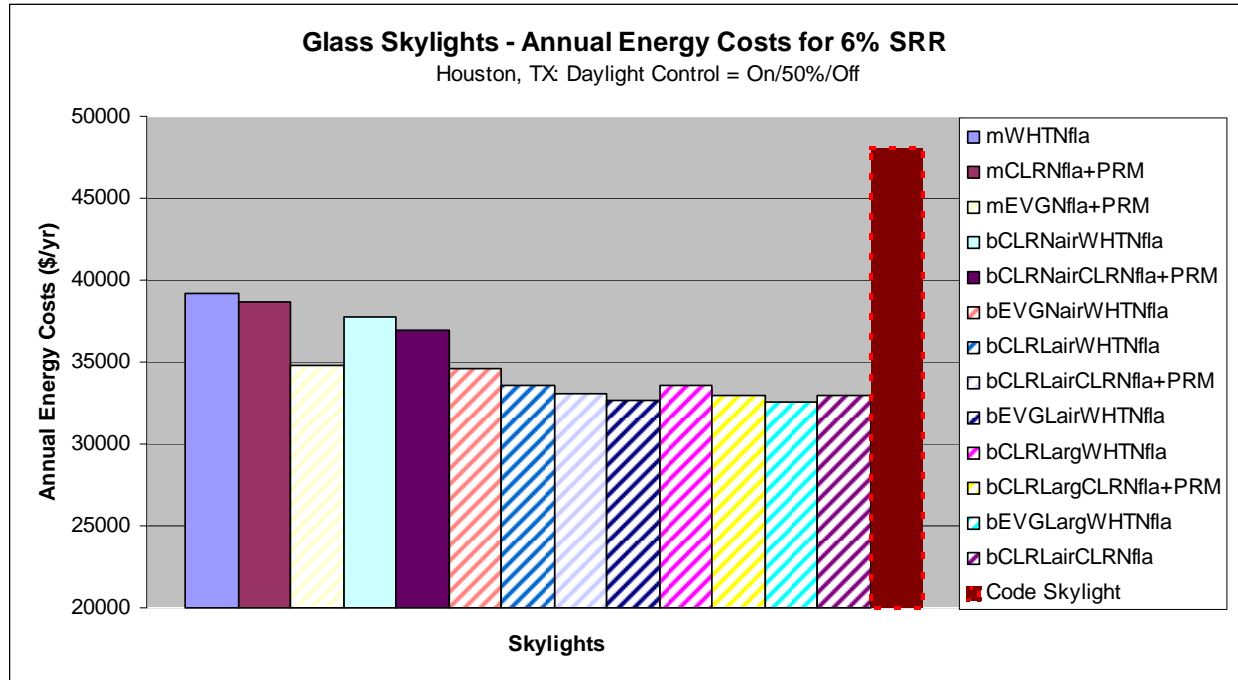
(a)



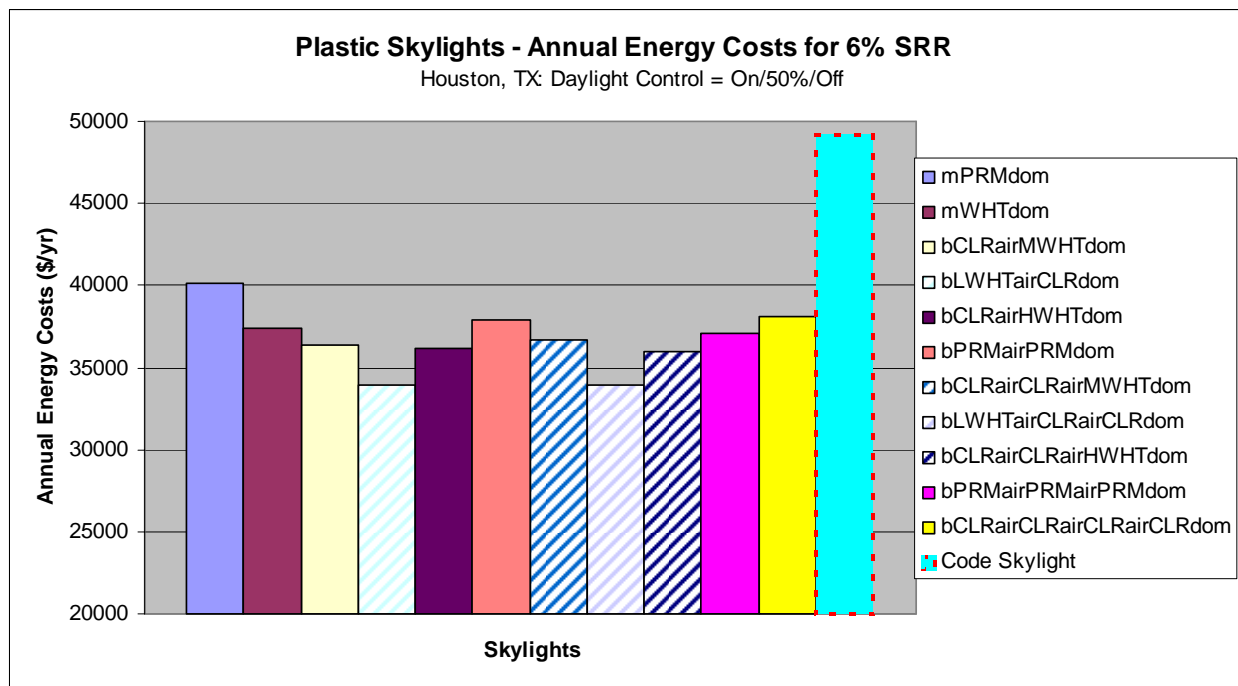
(b)

Figure 20. Annual Energy costs for Warehouse building with 6% SRR skylights and code skylight in Miami, FL (Zone1) – (a) Glass skylights, (b) Plastic skylights

Note: The skylights that meet the proposed code values (from Table 6) are represented by patterned colors and those that do not are represented by solid colors.



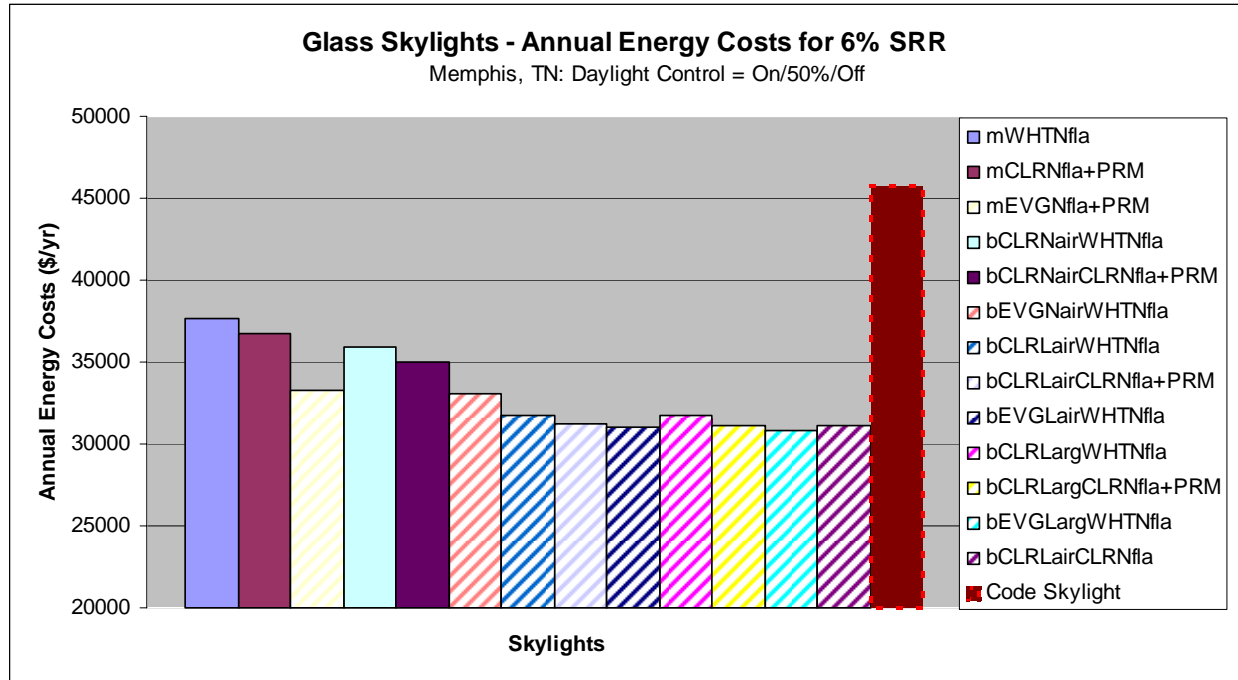
(a)



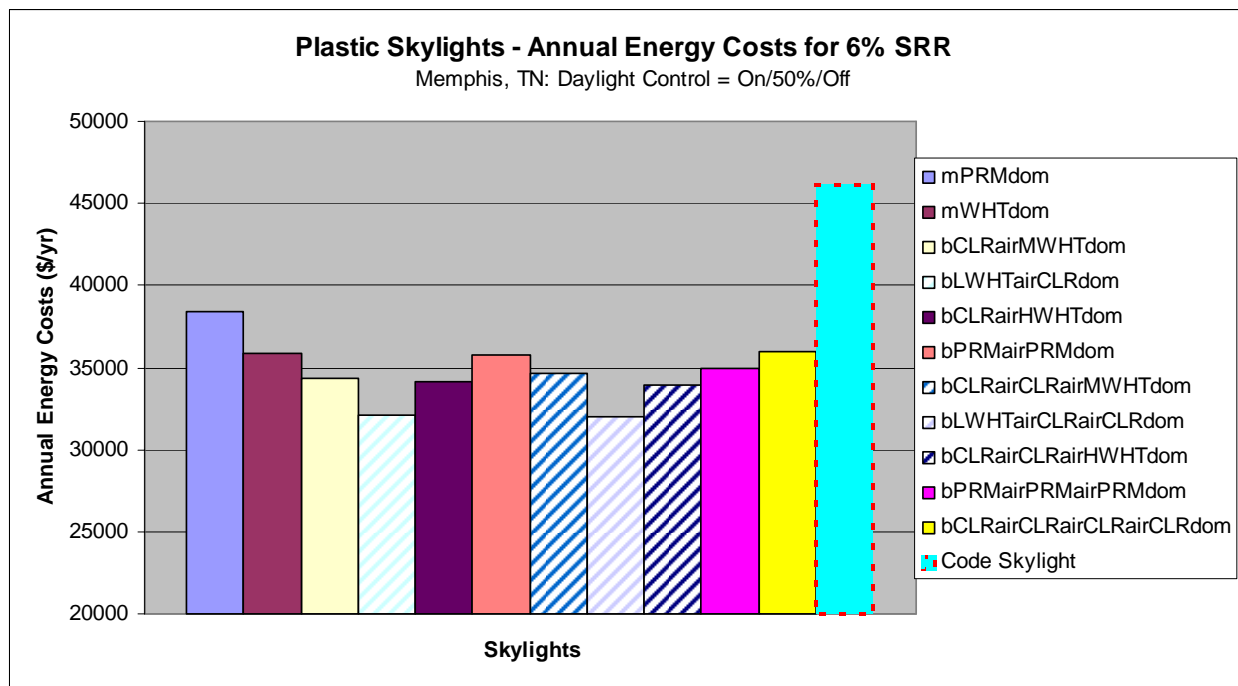
(b)

Figure 21. Annual Energy costs for Warehouse building with 6% SRR skylights and code skylight in Houston, TX (Zone2) – (a) Glass skylights, (b) Plastic skylights

Note: The skylights that meet the proposed code values (from Table 6) are represented by patterned colors and those that do not are represented by solid colors.



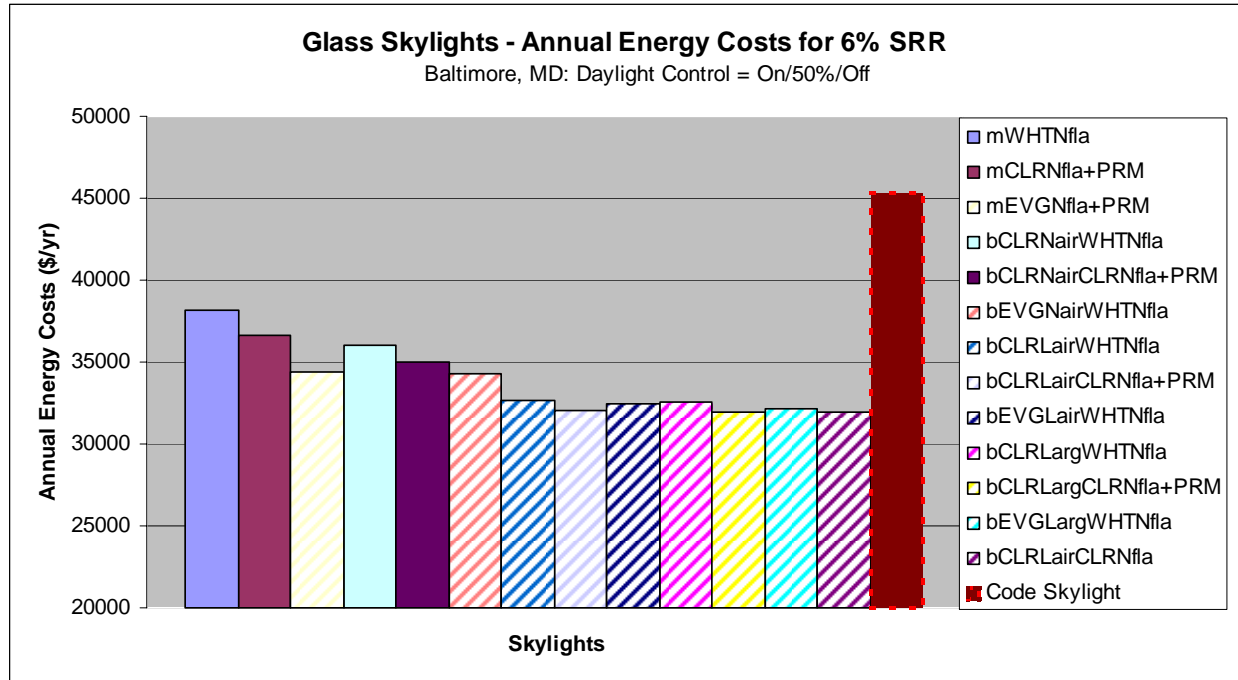
(a)



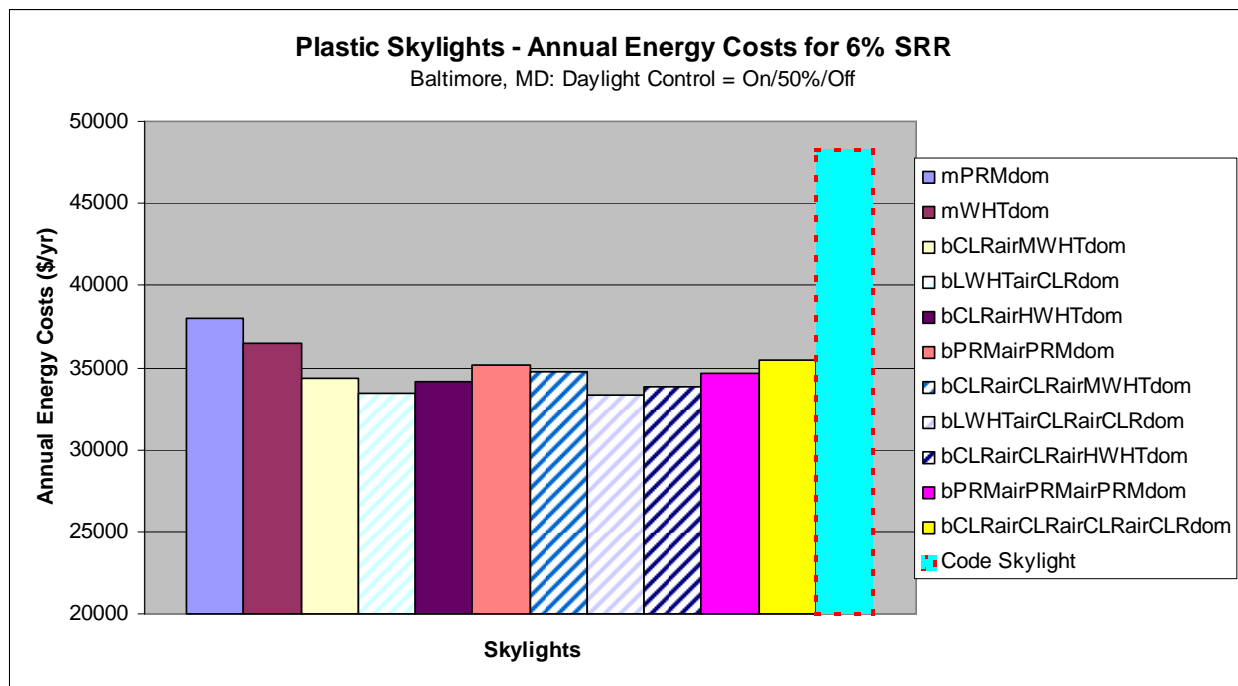
(b)

Figure 22. Annual Energy costs for Warehouse building with 6% SRR skylights and code skylight in Memphis, TN (Zone3) – (a) Glass skylights, (b) Plastic skylights

Note: The skylights that meet the proposed code values (from Table 6) are represented by patterned colors and those that do not are represented by solid colors.



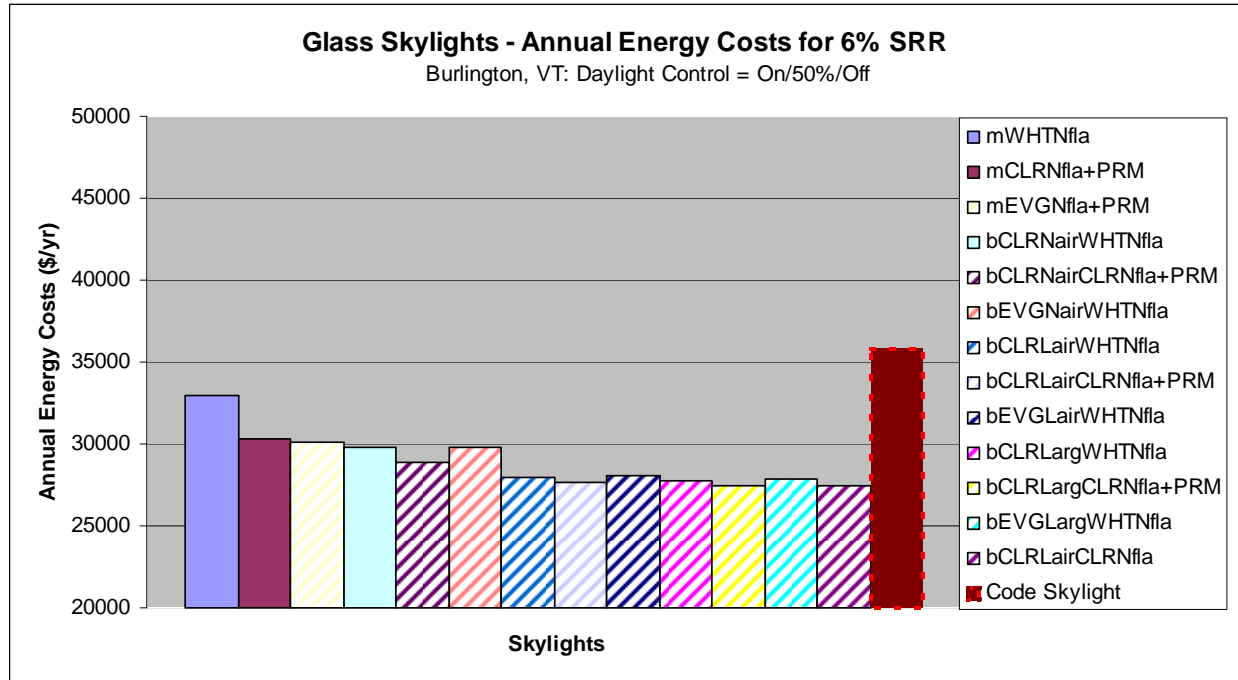
(a)



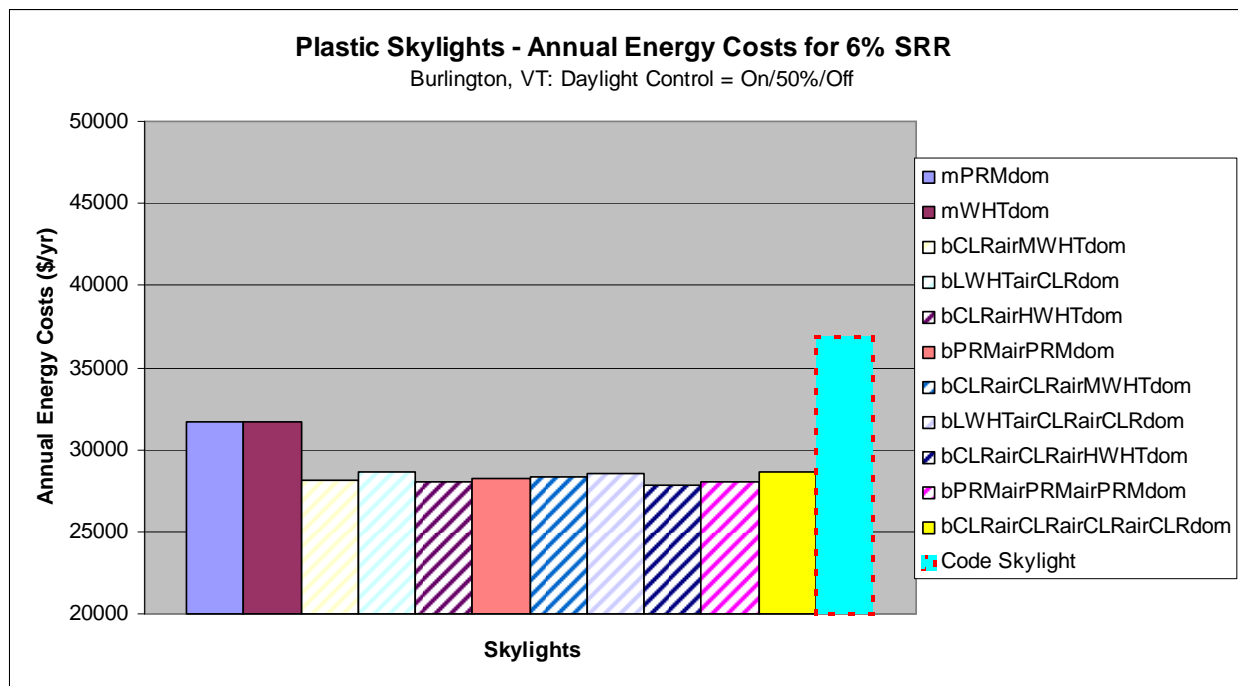
(b)

Figure 23. Annual Energy costs for Warehouse building with 6% SRR skylights and code skylight in Baltimore, MD (Zone 4) – (a) Glass skylights, (b) Plastic skylights

Note: The skylights that meet the proposed code values (from Table 6) are represented by patterned colors and those that do not are represented by solid colors.



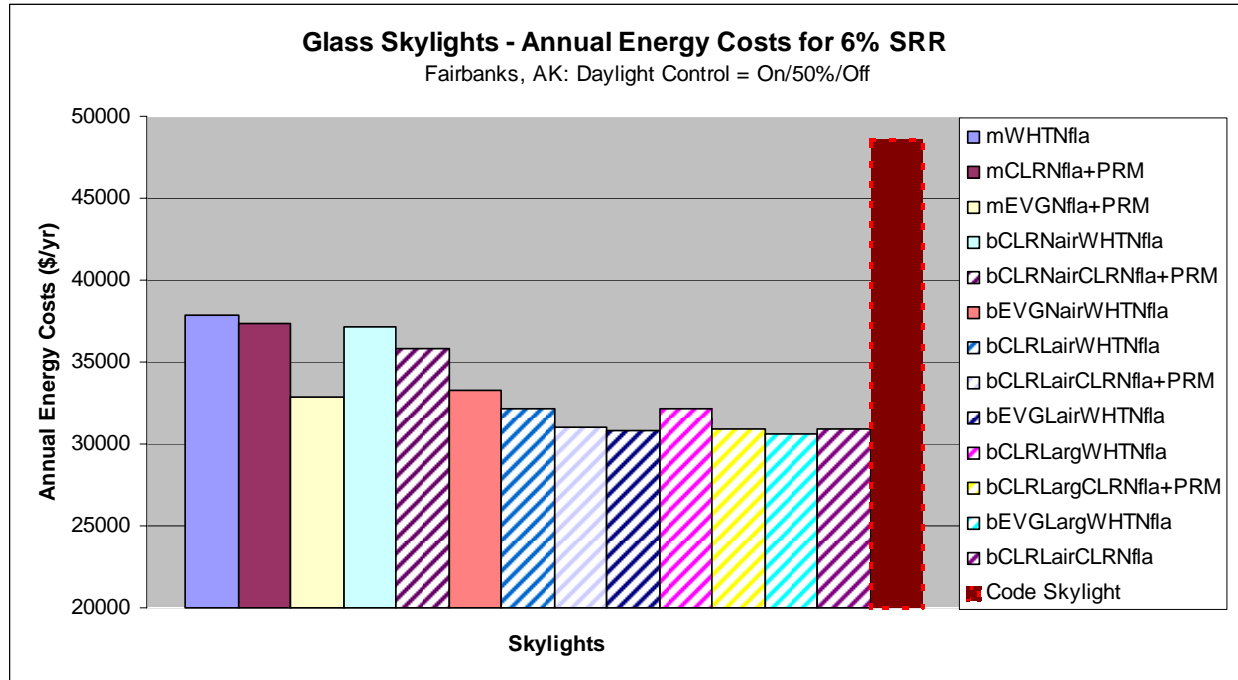
(a)



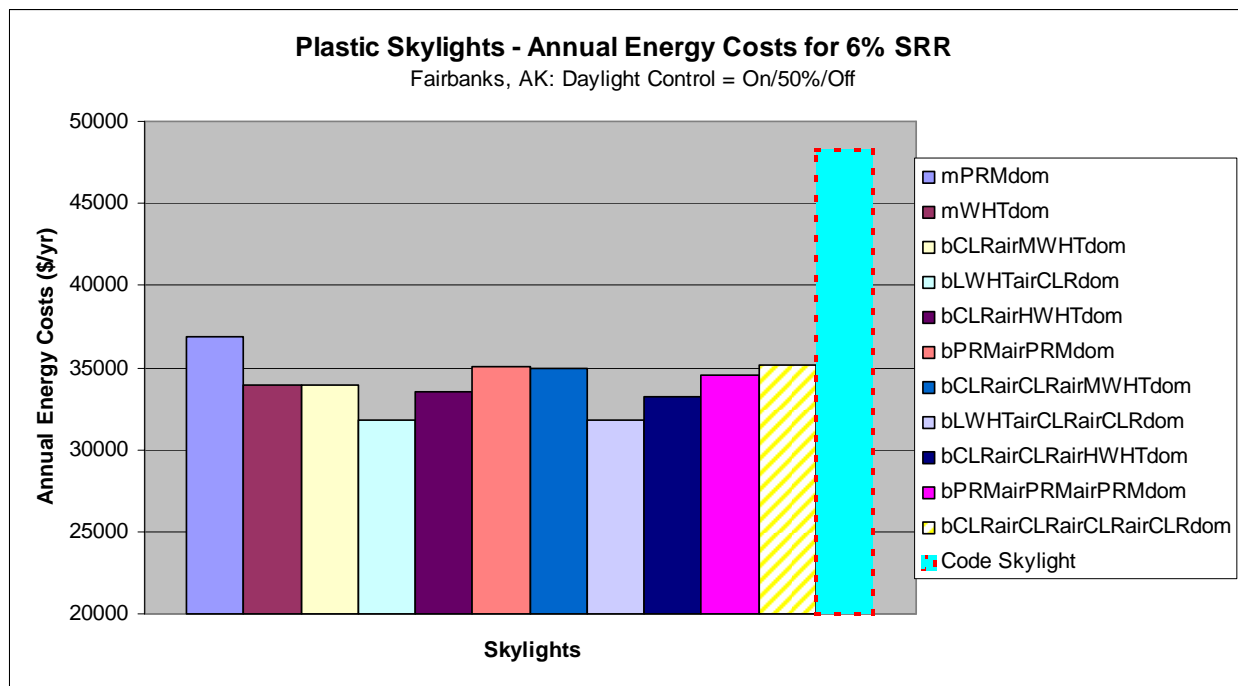
(b)

Figure 25. Annual Energy costs for Warehouse building with 6% SRR skylights and code skylight in Burlington, VT (Zone 6) – (a) Glass skylights, (b) Plastic skylights

Note: The skylights that meet the proposed code values (from Table 6) are represented by patterned colors and those that do not are represented by solid colors.



(a)



(b)

Figure 27. Annual Energy costs for Warehouse building with 6% SRR skylights and code skylight in Fairbanks, AK (Zone 8) – (a) Glass skylights, (b) Plastic skylights

Note: The skylights that meet the proposed code values (from Table 6) are represented by patterned colors and those that do not are represented by solid colors.

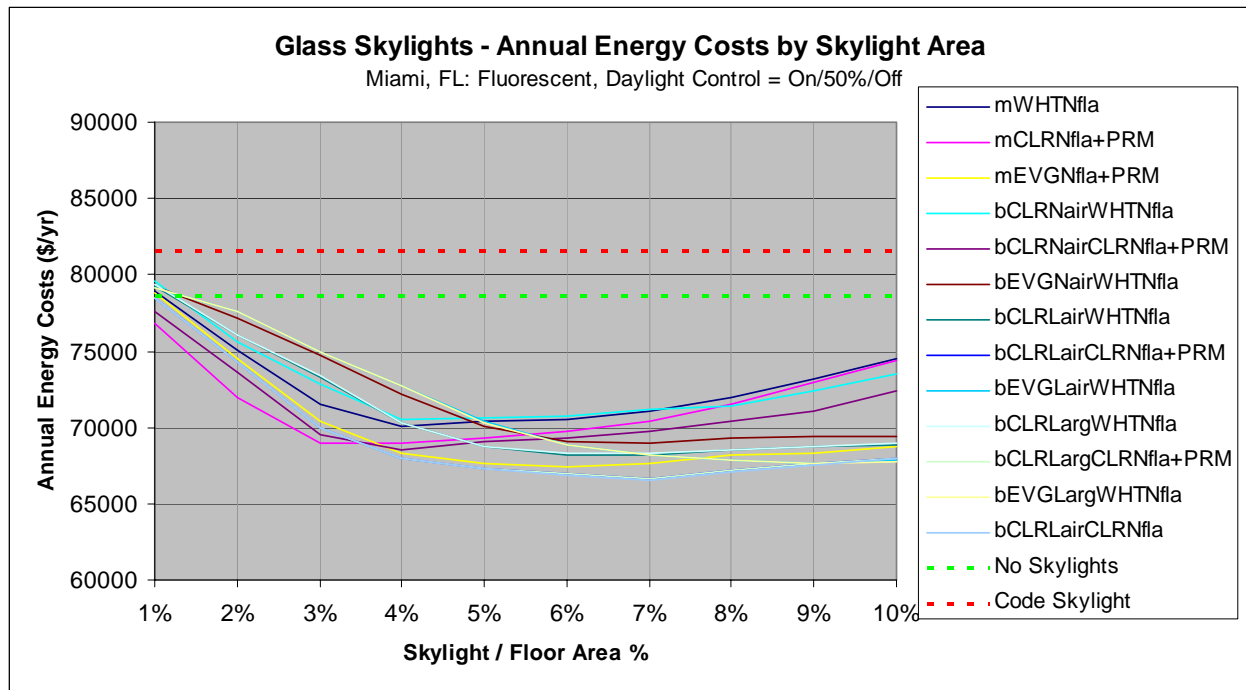
The annual cost data for the Warehouse building for rest of the cities considered in the analysis are given in Table 5.

Table 10. Annual Energy Costs for Warehouse Building with 6% SRR Skylights and Code Skylight in Various Cities Across 6 Climate Zones

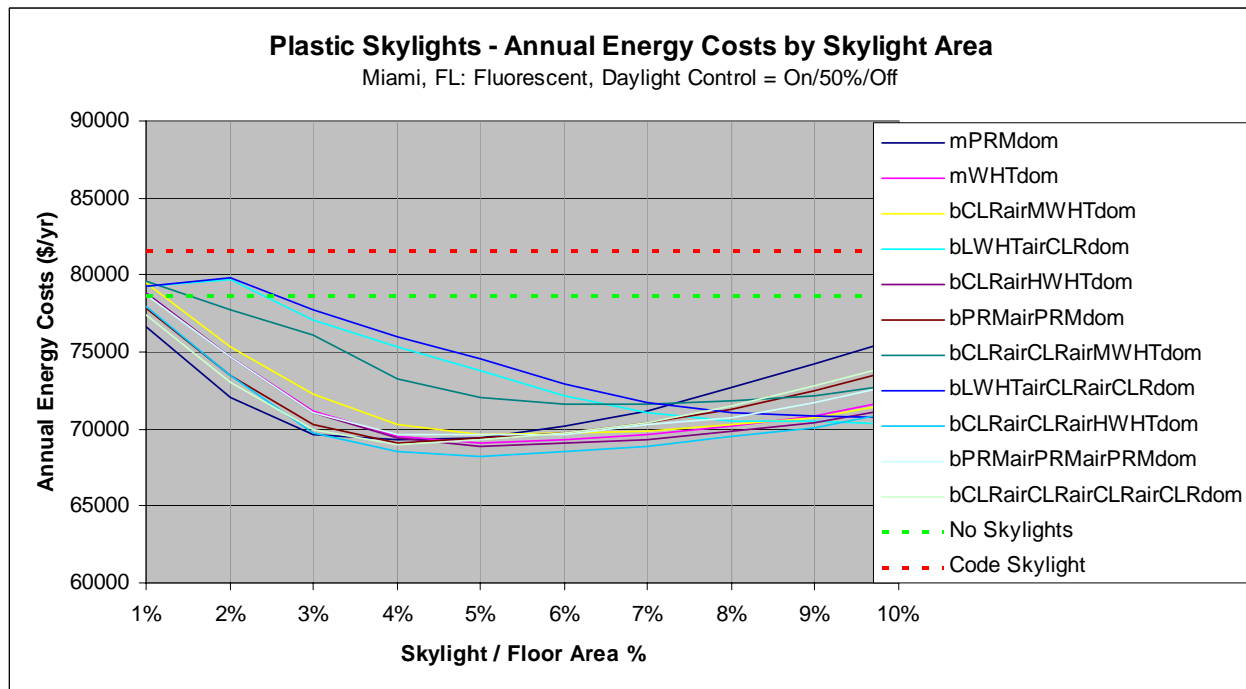
| Skylights | Zones/Cities | | | | | | | | | | | | | |
|--------------------------|--------------|--------------|--------------|-----------------|-------------------|-------------------|-----------------|--------------|--------------|--------------|--------------|--------------|--------------|--|
| | 1 | 2 | 3 | | | 4 | | | | 5 | | 6 | | |
| | Honolulu, HI | Phoenix, AZ | El Paso, TX | Los Angeles, CA | San Francisco, CA | New York City, NY | Albuquerque, NM | Portland, OR | Salem, OR | Seattle, WA | Boston, MA | Boise, ID | Helena, MT | |
| Glass | | | | | | | | | | | | | | |
| Code Skylight | 90385 | 53529 | 42875 | 48173 | 49250 | 64143 | 39110 | 28353 | 34730 | 26884 | 56274 | 40695 | 37850 | |
| 1 mWHTNfla | 81209 | 47142 | 36738 | 36071 | 33959 | 53260 | 33474 | 30287 | 30702 | 30253 | 48278 | 36123 | 35031 | |
| 2 mCLRNfla+PRM | 82084 | 46737 | 36114 | 36752 | 33114 | 51072 | 32096 | 28480 | 28842 | 28149 | 45174 | 34087 | 32599 | |
| 3 mEVGNfla+PRM | 68894 | 41493 | 32077 | 30817 | 31248 | 47541 | 30432 | 27985 | 28503 | 28171 | 42907 | 32695 | 31999 | |
| 4 bCLRNairWHTNfla | 79356 | 45227 | 35022 | 36150 | 33035 | 50177 | 31377 | 28231 | 28521 | 27983 | 44279 | 33285 | 31989 | |
| 5 bCLRNairCLRNfla+PRM | 77919 | 44443 | 34162 | 35130 | 32017 | 48740 | 30574 | 27328 | 27650 | 27073 | 42763 | 32362 | 31011 | |
| 6 bEVGNairWHTNfla | 67939 | 40822 | 31492 | 30895 | 31554 | 47417 | 29881 | 27892 | 28357 | 28119 | 42624 | 32280 | 31599 | |
| 7 bCLRLairWHTNfla | 67604 | 39641 | 30296 | 30457 | 30301 | 45337 | 28889 | 26351 | 26728 | 26449 | 39956 | 30454 | 29636 | |
| 8 bCLRLairCLRNfla+PRM | 66500 | 39218 | 29850 | 29547 | 29553 | 44442 | 28999 | 25908 | 26313 | 25992 | 39103 | 30062 | 29258 | |
| 9 bEVGLairWHTNfla | 63681 | 38240 | 29142 | 29071 | 30242 | 44774 | 29096 | 26492 | 26914 | 26738 | 39743 | 30324 | 29647 | |
| 10 bCLRLargWHTNfla | 67769 | 39609 | 30232 | 30542 | 30214 | 45210 | 28804 | 26216 | 26579 | 26294 | 39753 | 30296 | 29475 | |
| 11 bCLRLargCLRNfla+PRM | 66510 | 39149 | 29750 | 29565 | 29452 | 44281 | 28907 | 25771 | 26166 | 25843 | 38880 | 29898 | 29038 | |
| 12 bEVGLargWHTNfla | 63424 | 38014 | 28918 | 28913 | 30076 | 44496 | 29001 | 26314 | 26725 | 26556 | 39694 | 30100 | 29434 | |
| 13 bCLRLairCLRNfla | 66347 | 39082 | 29724 | 29505 | 29459 | 44254 | 28885 | 25777 | 26175 | 25855 | 38874 | 29891 | 29074 | |
| Plastic | | | | | | | | | | | | | | |
| Code Skylight | 90152 | 54930 | 43412 | 47844 | 49629 | 68304 | 41805 | 30224 | 36574 | 28660 | 60013 | 43386 | 39046 | |
| 14 mPRMdom | 85649 | 47986 | 38009 | 38490 | 34135 | 53261 | 34385 | 29103 | 29485 | 28812 | 47465 | 35387 | 33872 | |
| 15 mWHTdom | 76426 | 44348 | 35005 | 34057 | 32837 | 50789 | 33219 | 28878 | 29349 | 28998 | 45865 | 34378 | 33538 | |
| 16 bCLRairMWHTdom | 76341 | 43043 | 33415 | 34672 | 31634 | 47798 | 30481 | 26534 | 26843 | 26333 | 41739 | 31352 | 30021 | |
| 17 bLWHTairCLRdom | 66785 | 39433 | 30388 | 30450 | 31008 | 46247 | 30099 | 26848 | 27227 | 27040 | 41334 | 30893 | 30165 | |
| 18 bCLRairHWHTdom | 76086 | 42916 | 33328 | 34452 | 31429 | 47584 | 30394 | 26376 | 26717 | 26197 | 41479 | 31213 | 29900 | |
| 19 bPRMairPRMdom | 81464 | 45158 | 35221 | 36825 | 32265 | 49234 | 31467 | 26631 | 26928 | 26232 | 42577 | 31966 | 30271 | |
| 20 bCLRairCLRairMWHTdor | 77018 | 43400 | 33567 | 35252 | 32108 | 48392 | 30709 | 26909 | 27146 | 26672 | 42252 | 31636 | 30217 | |
| 21 bLWHTairCLRairCLRdor | 66491 | 39250 | 30153 | 30264 | 30922 | 46158 | 29976 | 26833 | 27178 | 27000 | 41413 | 30784 | 30064 | |
| 22 bCLRairCLRairHWHTdor | 75697 | 42762 | 33129 | 34106 | 31042 | 47148 | 30082 | 26143 | 26499 | 25928 | 40986 | 30969 | 29619 | |
| 23 bPRMairPRMairPRMdor | 79074 | 44232 | 34246 | 35669 | 31770 | 48377 | 30896 | 26432 | 26732 | 26127 | 41873 | 31512 | 29952 | |
| 24 bCLRairCLRairCLRairCL | 81739 | 45589 | 35493 | 36715 | 32285 | 49542 | 31746 | 26908 | 27223 | 26517 | 43005 | 32309 | 30622 | |

APPENDIX A: Annual energy cost vs. skylight area variation

RETAIL BUILDING – ZONE 1



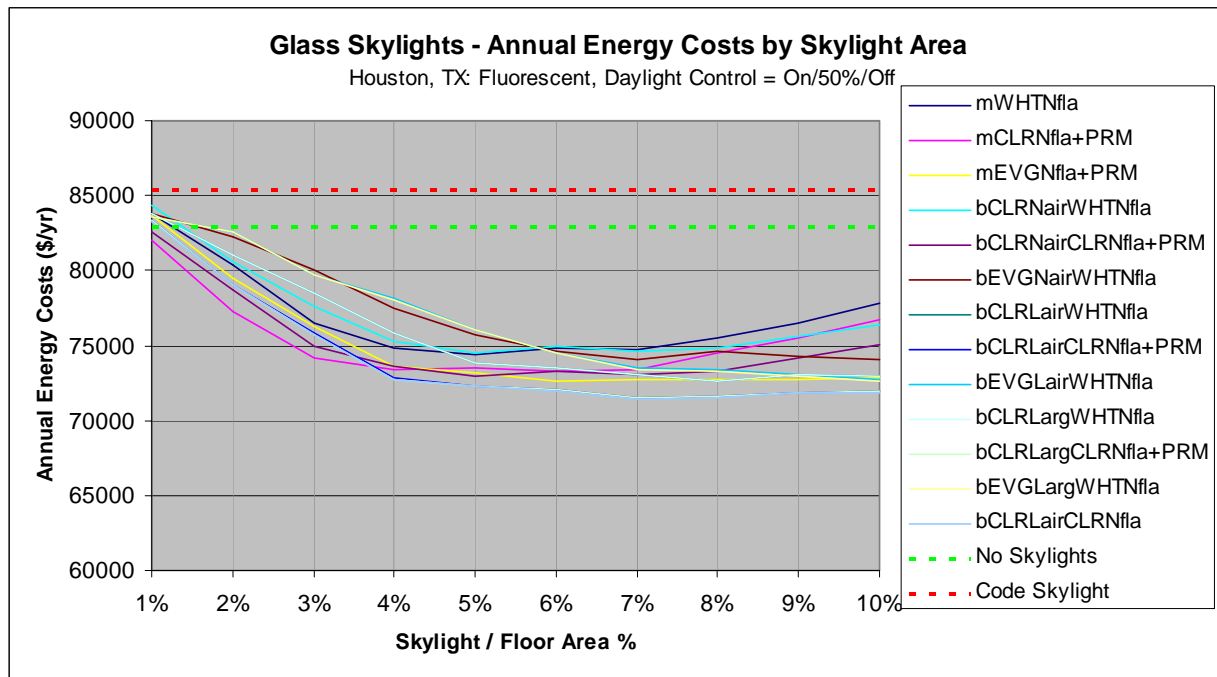
(a)



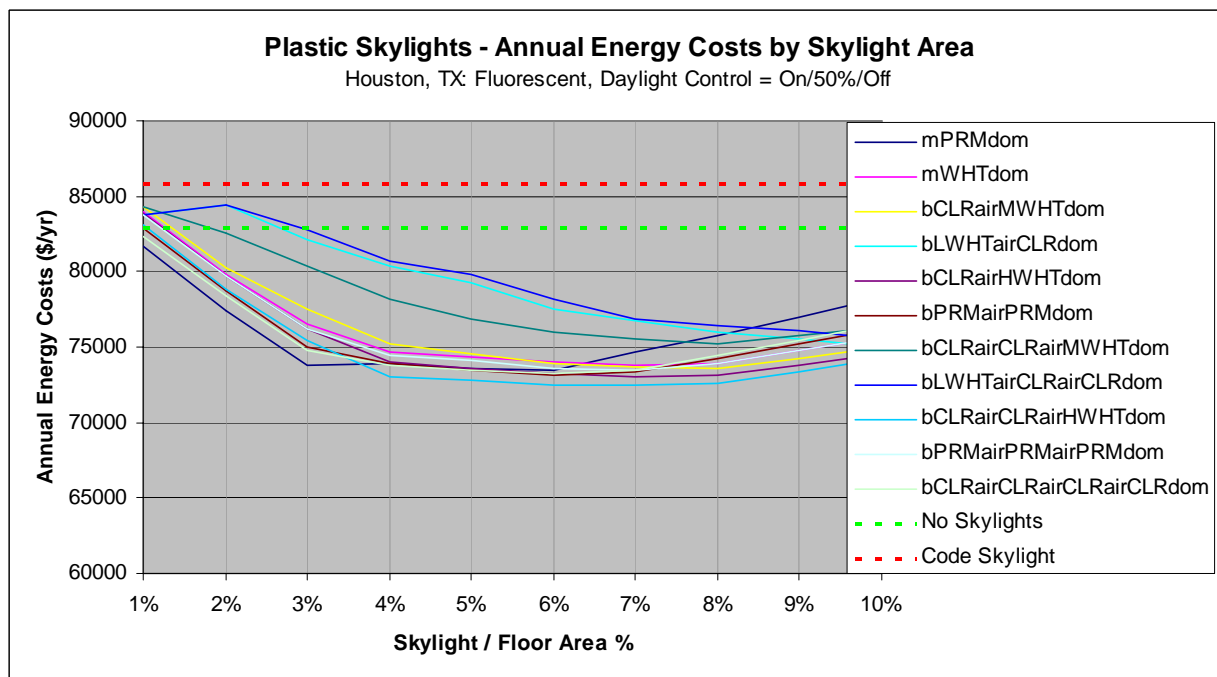
(b)

Figure A1.1: Energy cost savings from skylights across increasing SRR for Retail building in Miami, FL (Zone 1) – (a) Glass skylights, (b) Plastic skylights

RETAIL BUILDING – Zone 2



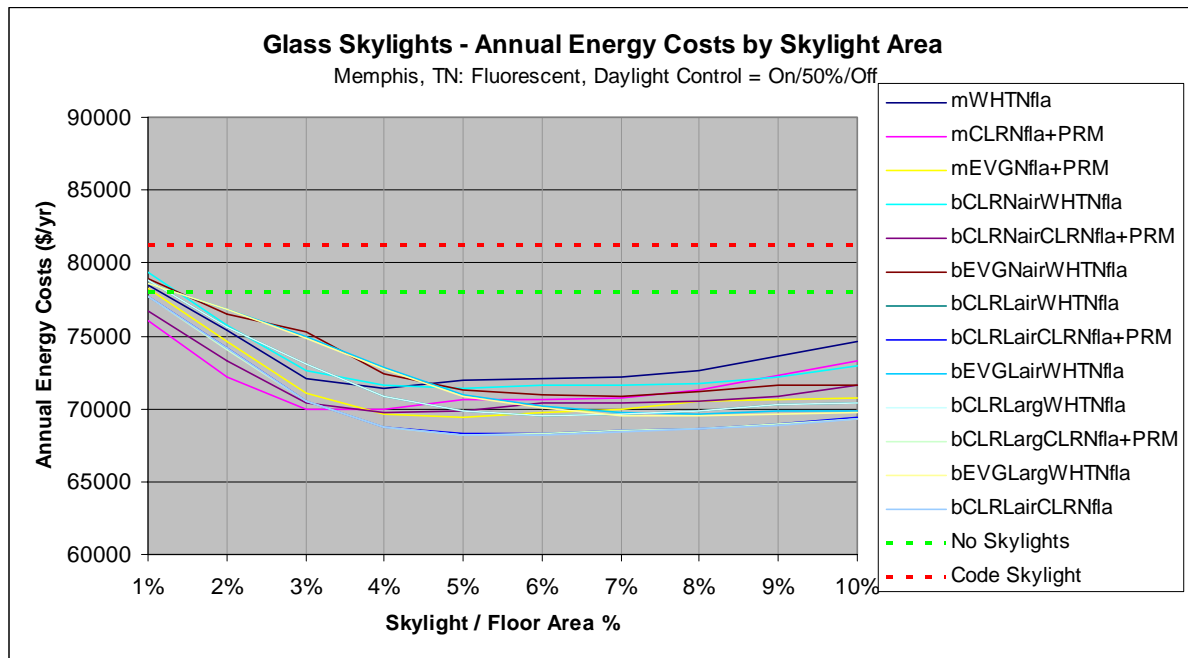
(a)



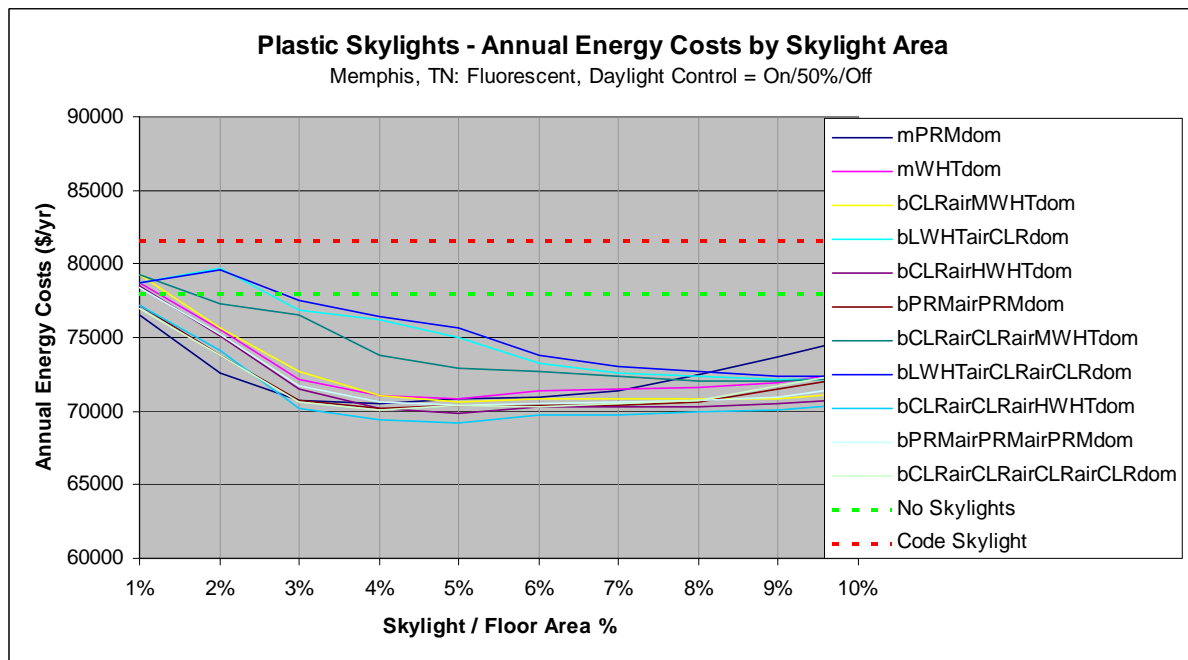
(b)

Figure A1.2. Energy cost savings from skylights across increasing SRR for Retail building in Houston, TX (Zone 2) – (a) Glass skylights, (b) Plastic skylights

RETAIL BUILDING – Zone 3



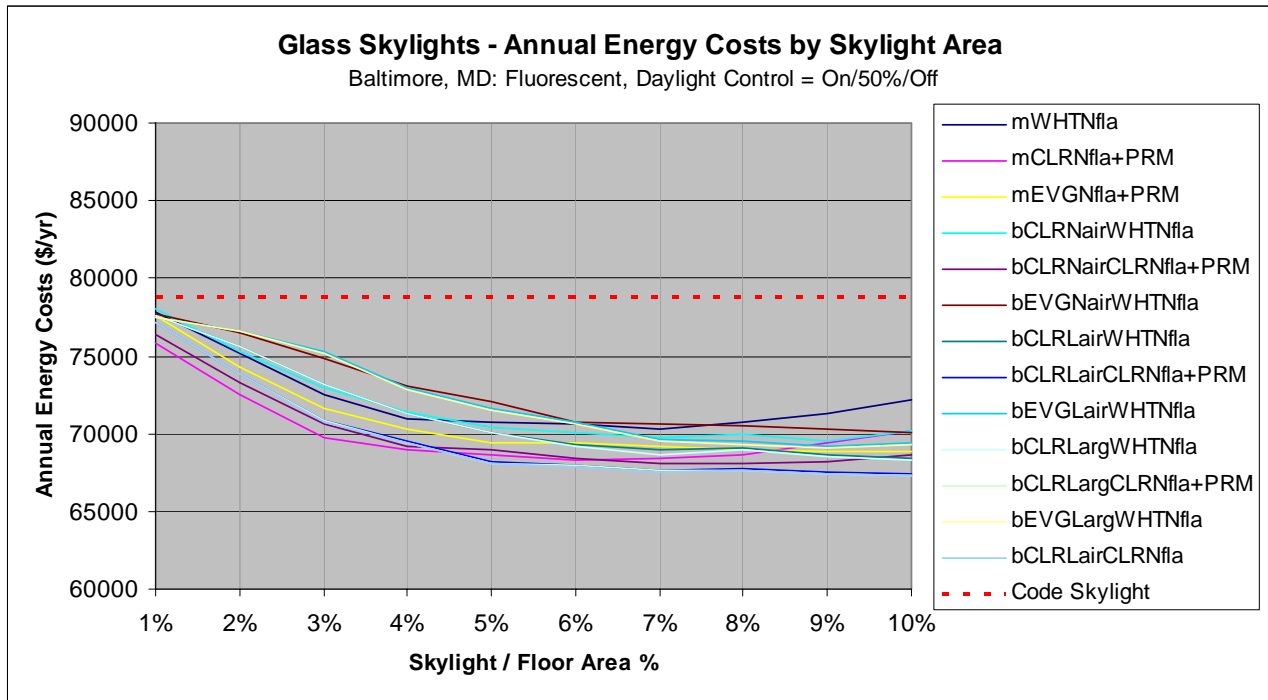
(a)



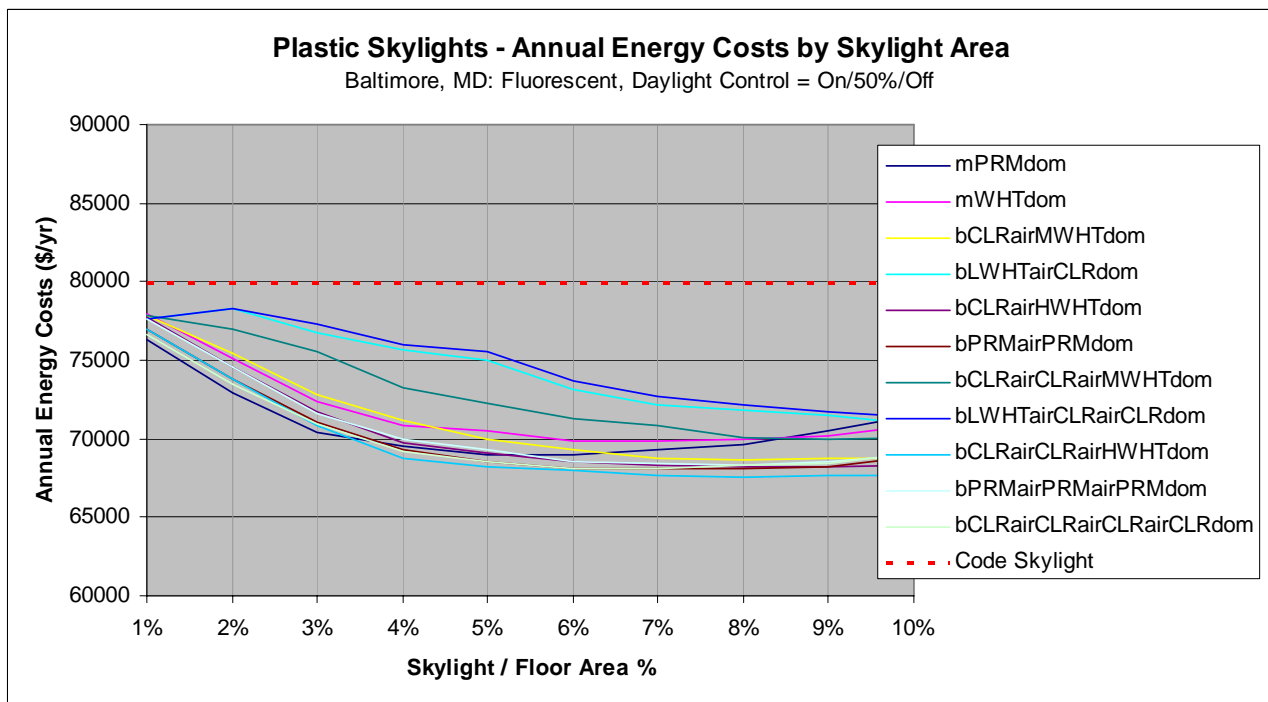
(b)

Figure A1.3. Energy cost savings from skylights across increasing SRR for Retail building in Memphis, TN (Zone 3) – (a) Glass skylights, (b) Plastic skylights

RETAIL BUILDING – Zone 4



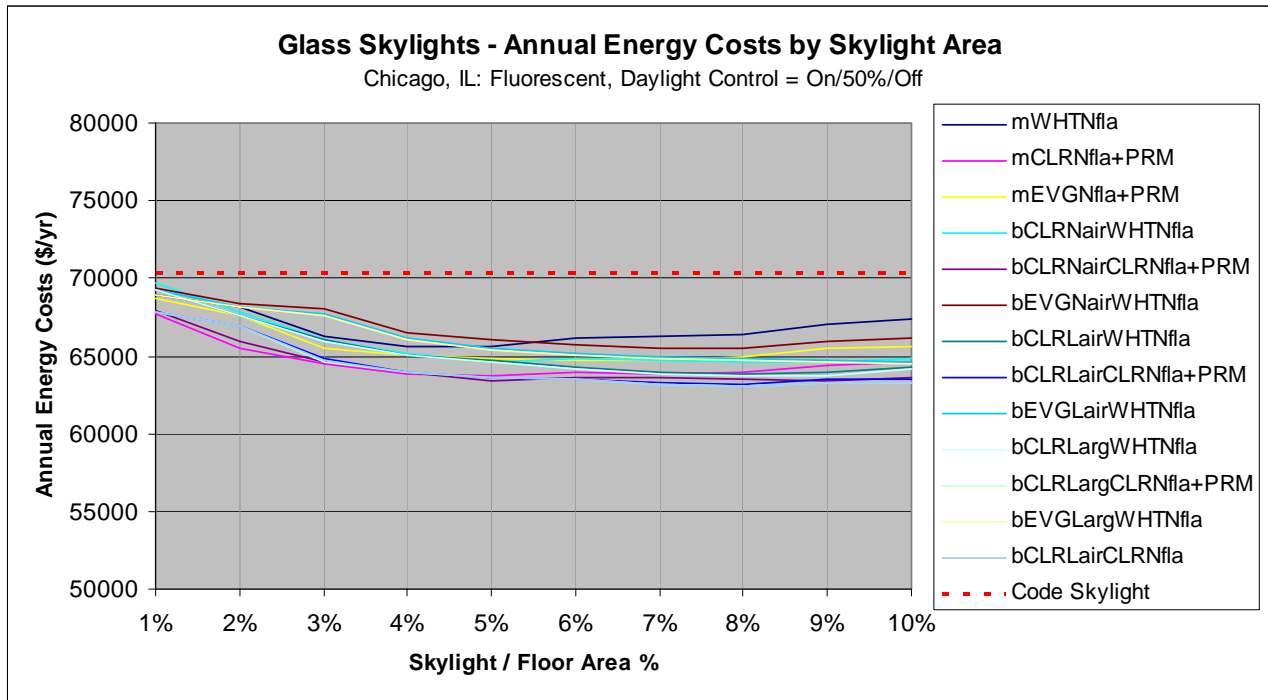
(a)



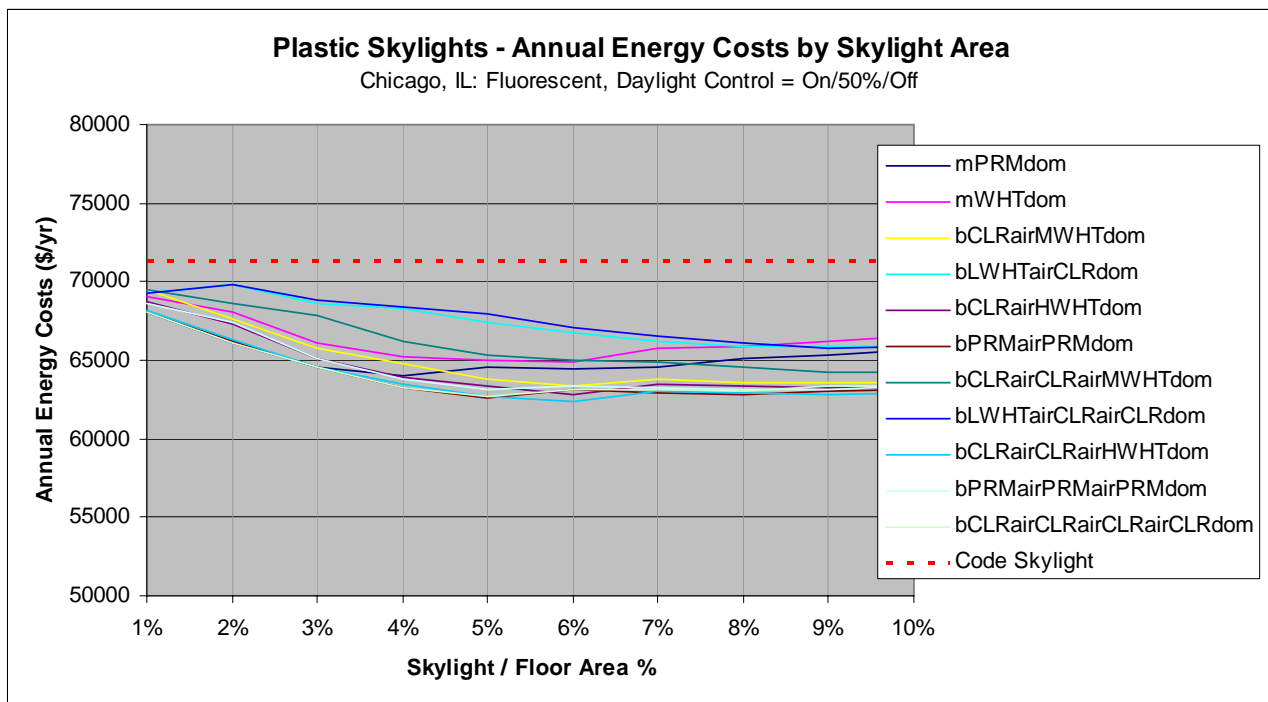
(b)

Figure A1.4. Energy cost savings from skylights across increasing SRR for Retail building in Baltimore, MD (Zone 4) – (a) Glass skylights, (b) Plastic skylights

RETAIL BUILDING – Zone 5



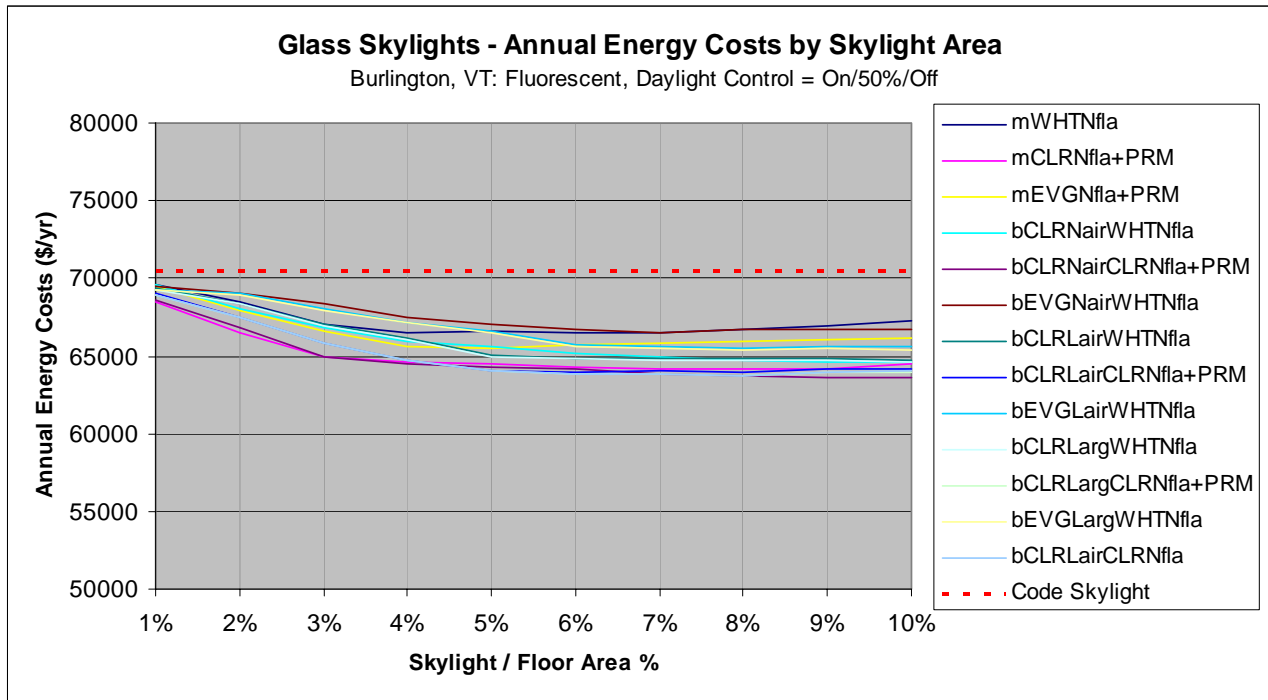
(a)



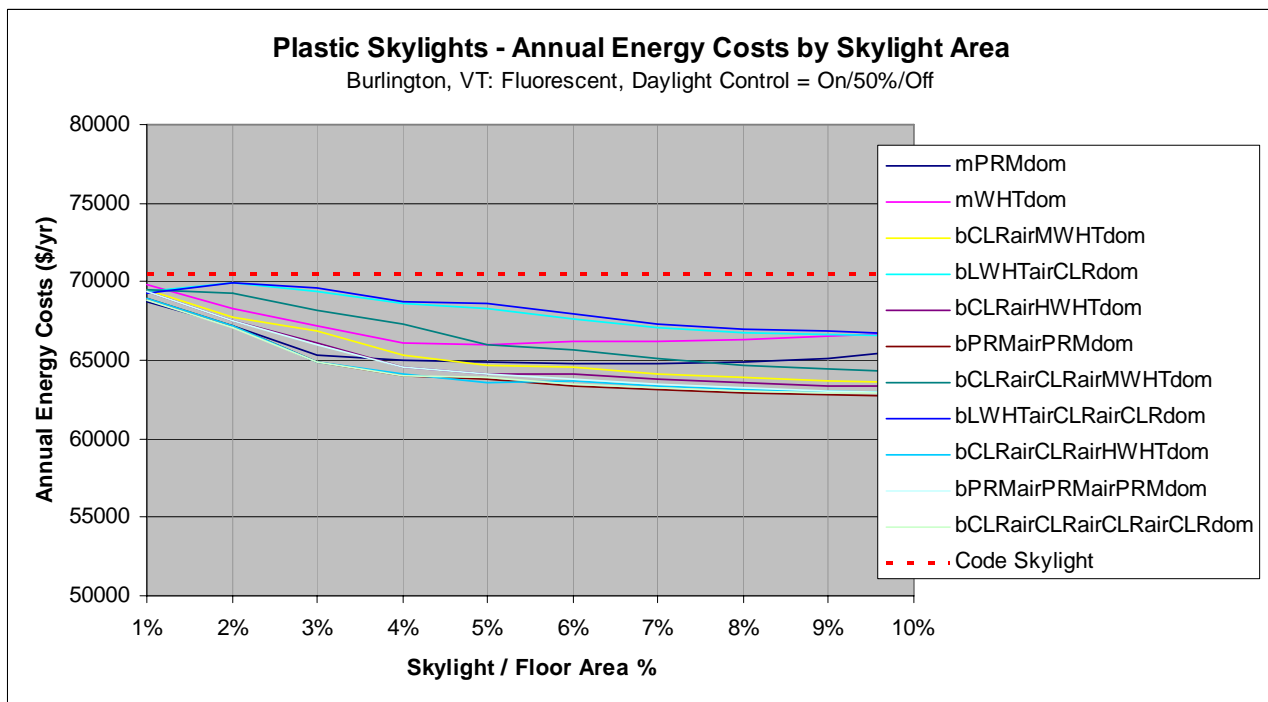
(b)

Figure A1.5. Energy cost savings from skylights across increasing SRR for Retail building in Chicago, IL (Zone 5) – (a) Glass skylights, (b) Plastic skylights

RETAIL BUILDING – Zone 6



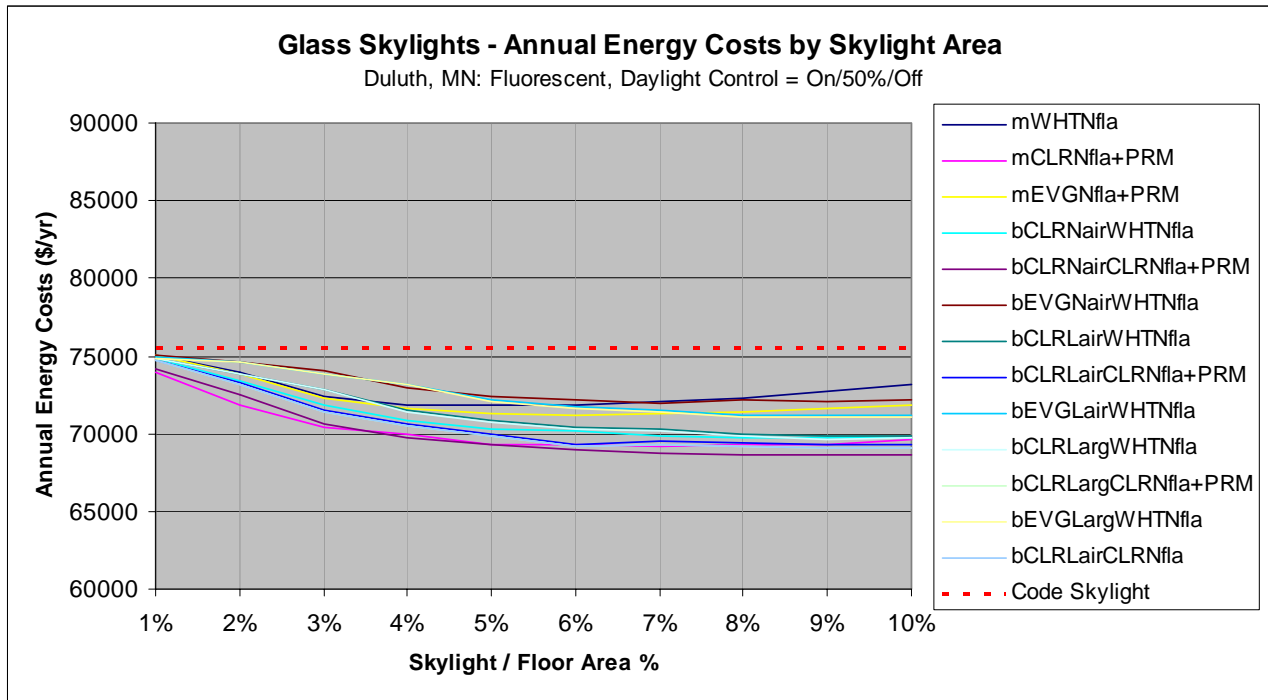
(a)



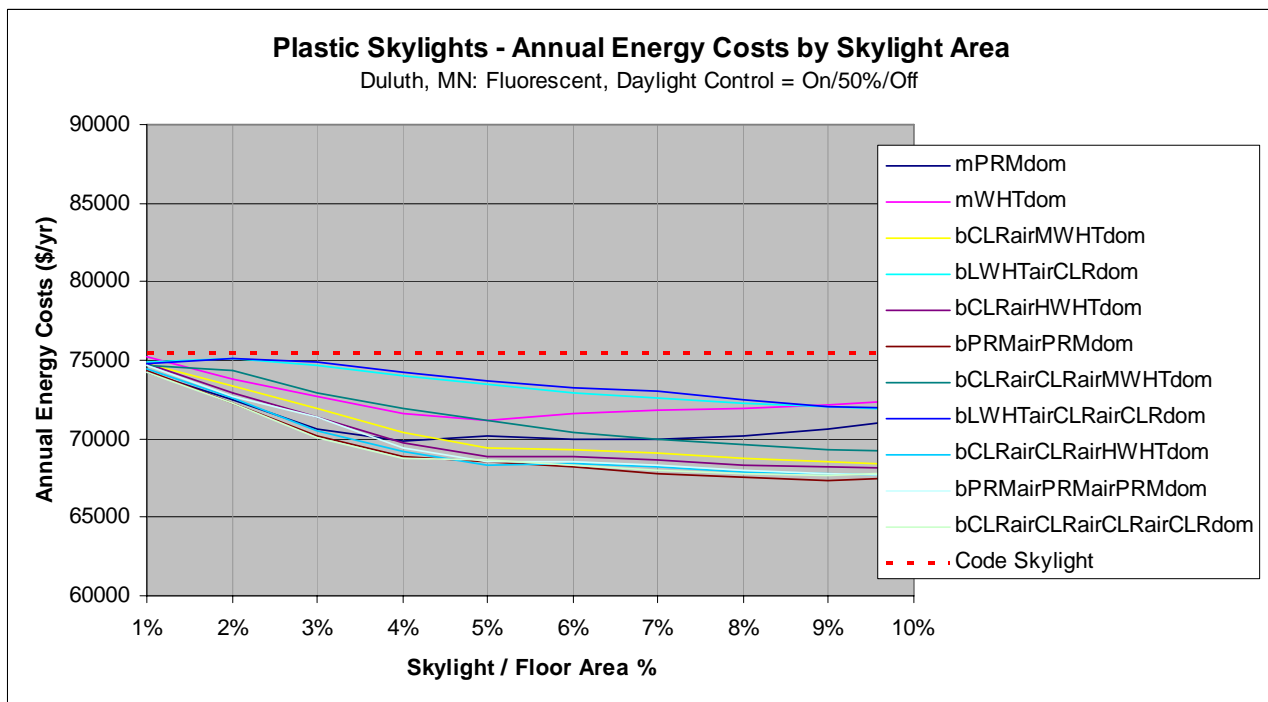
(b)

Figure A1.6. Energy cost savings from skylights across increasing SRR for Retail building in Burlington, VT (Zone 6) – (a) Glass skylights, (b) Plastic skylights

RETAIL BUILDING – Zone 7



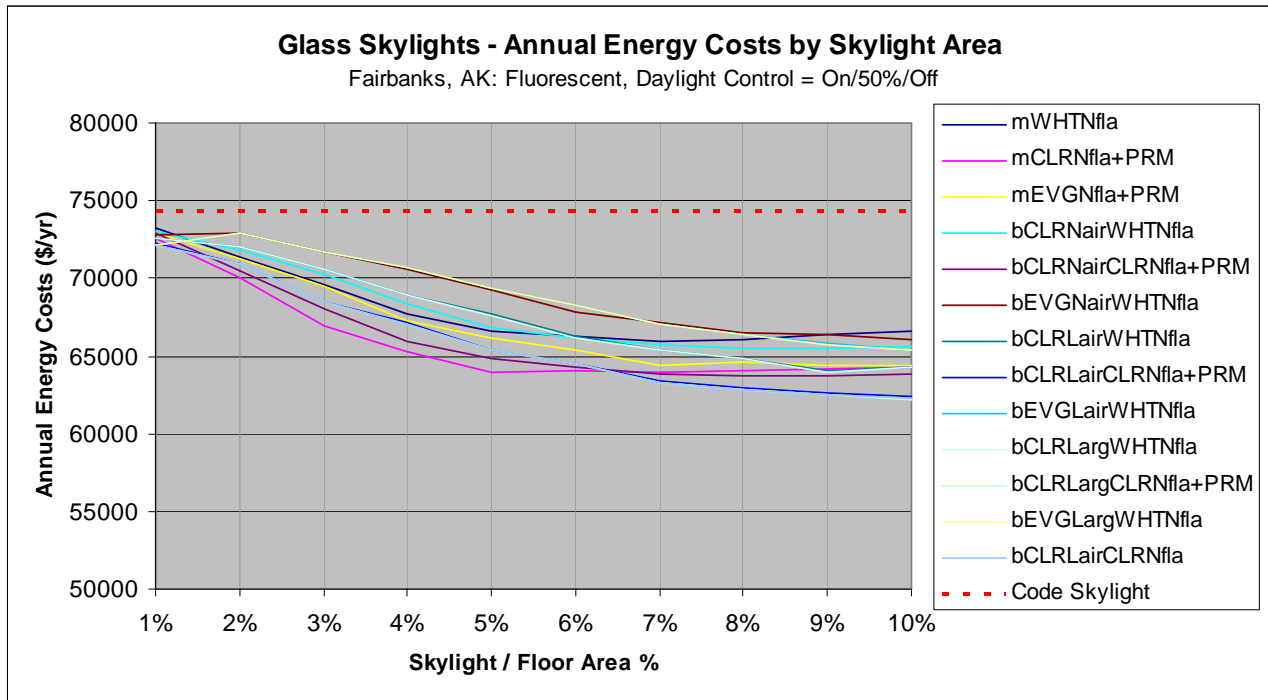
(a)



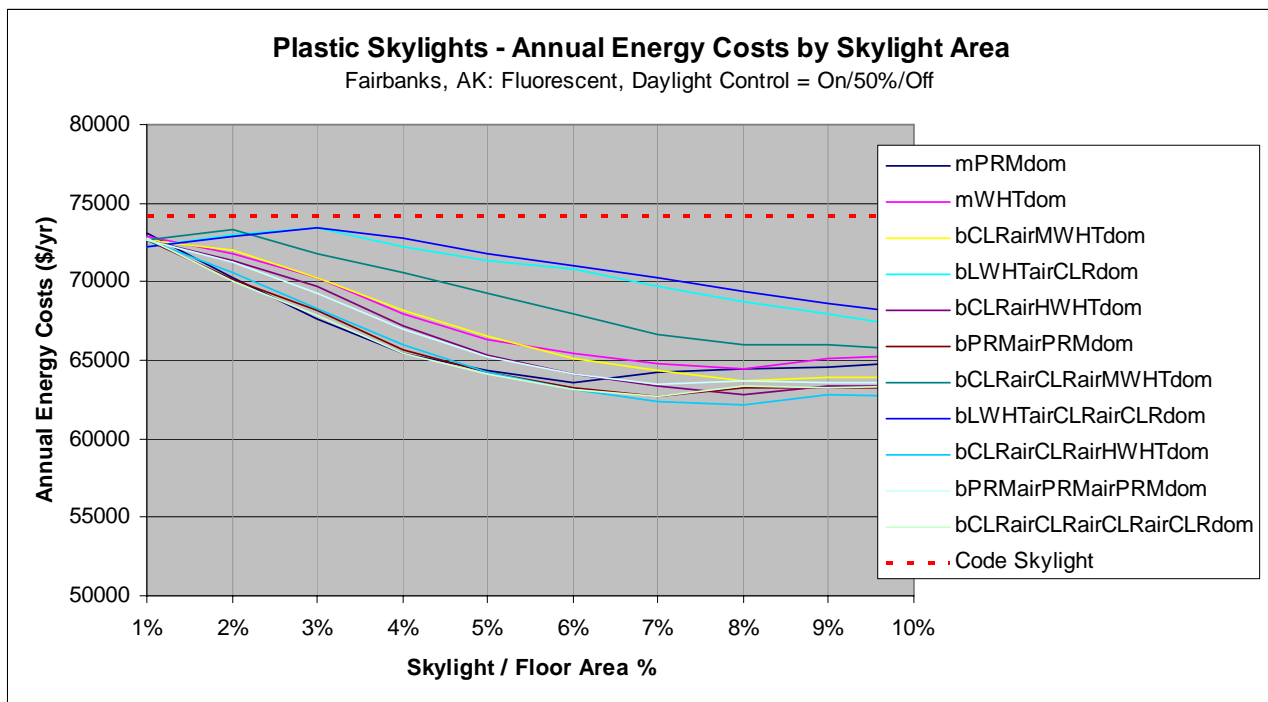
(b)

Figure A1.7. Energy cost savings from skylights across increasing SRR for Retail building in Duluth, MN (Zone 7) – (a) Glass skylights, (b) Plastic skylights

RETAIL BUILDING – Zone 8



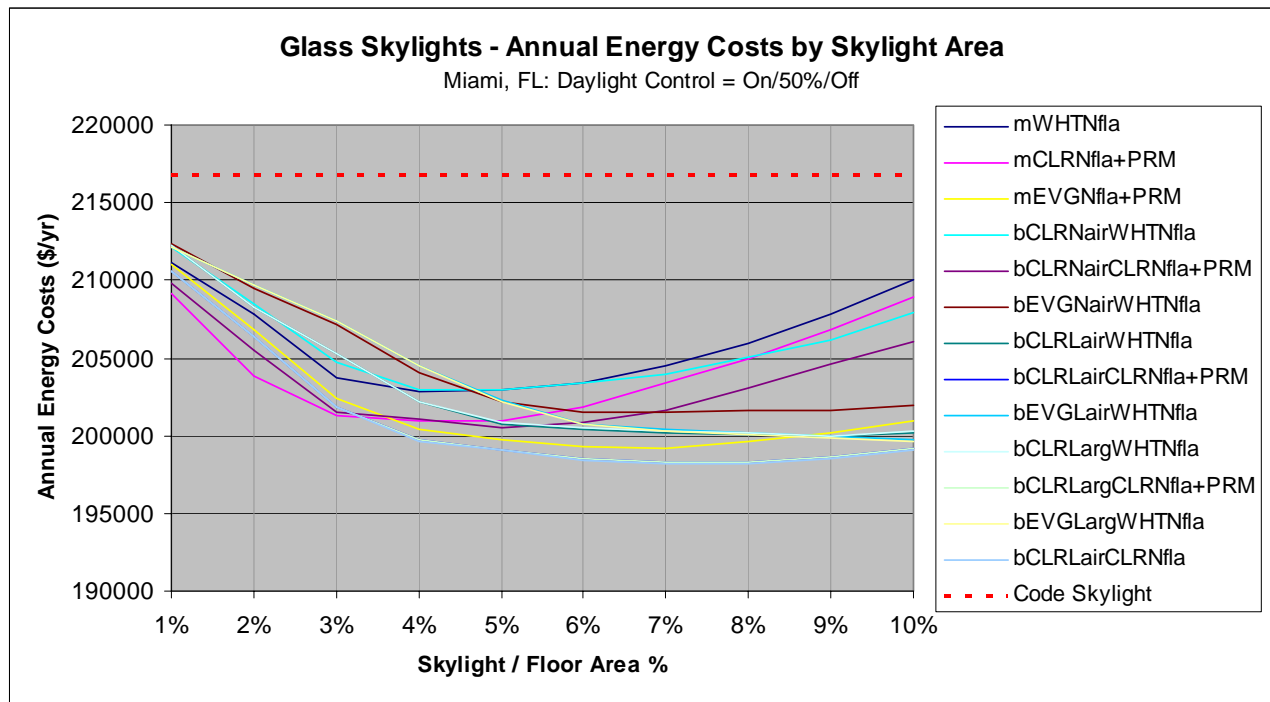
(a)



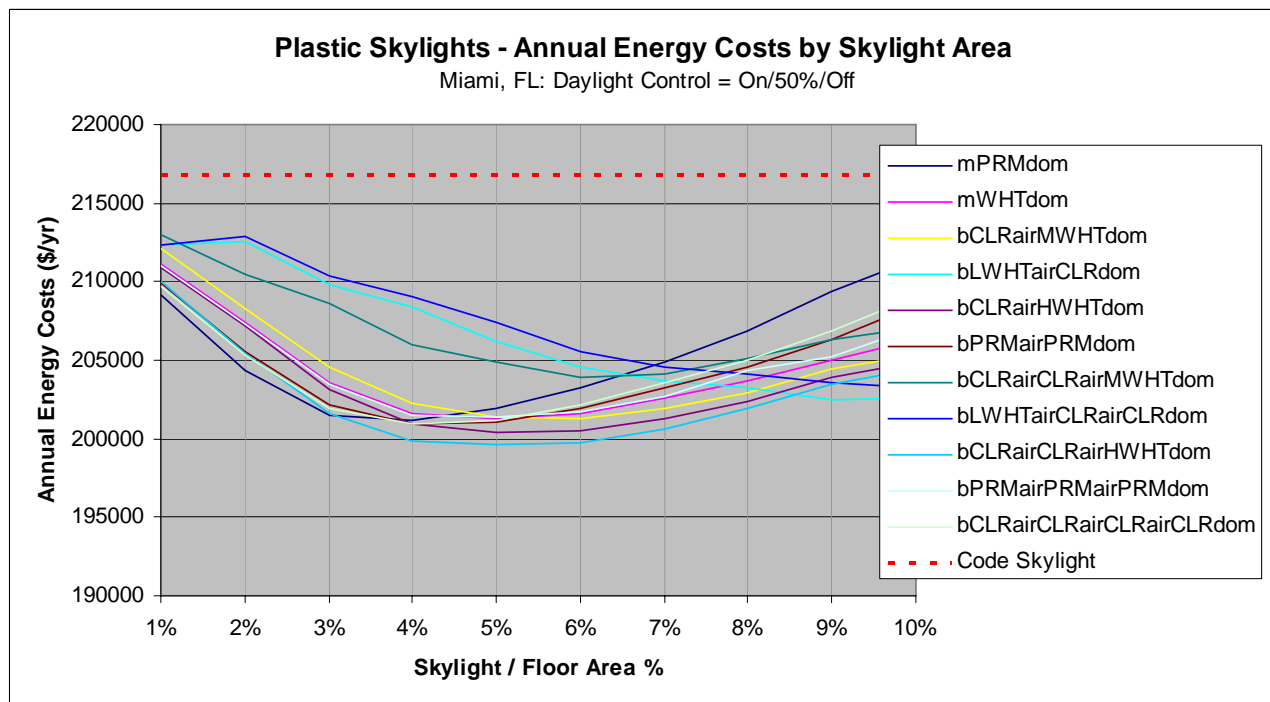
(b)

Figure A1.8. Energy cost savings from skylights across increasing SRR for Retail building in Fairbanks, AK (Zone 8) – (a) Glass skylights, (b) Plastic skylights

GROCERY STORE – ZONE 1:



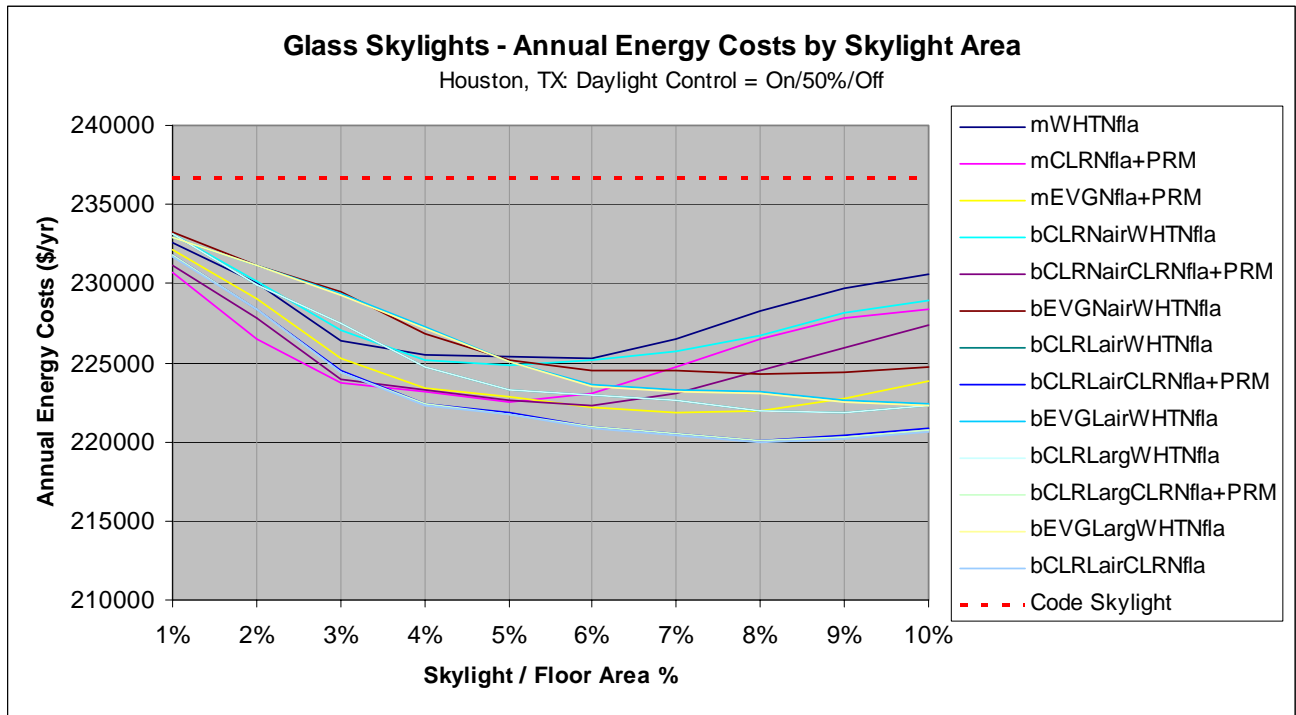
(a)



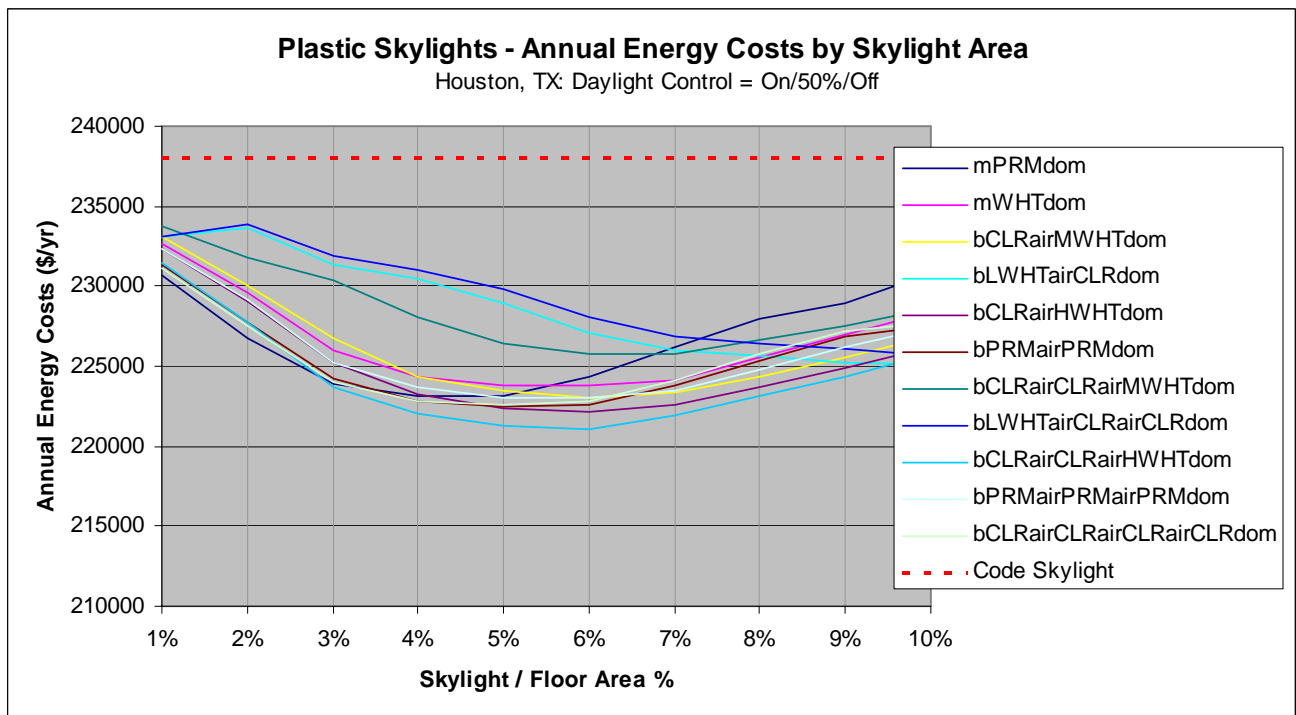
(b)

Figure A2.1. Energy cost savings from skylights across increasing SRR for Grocery-BB building in Miami, FL (Zone 1) – (a) Glass skylights, (b) Plastic skylights

GROCERY STORE – ZONE 2:



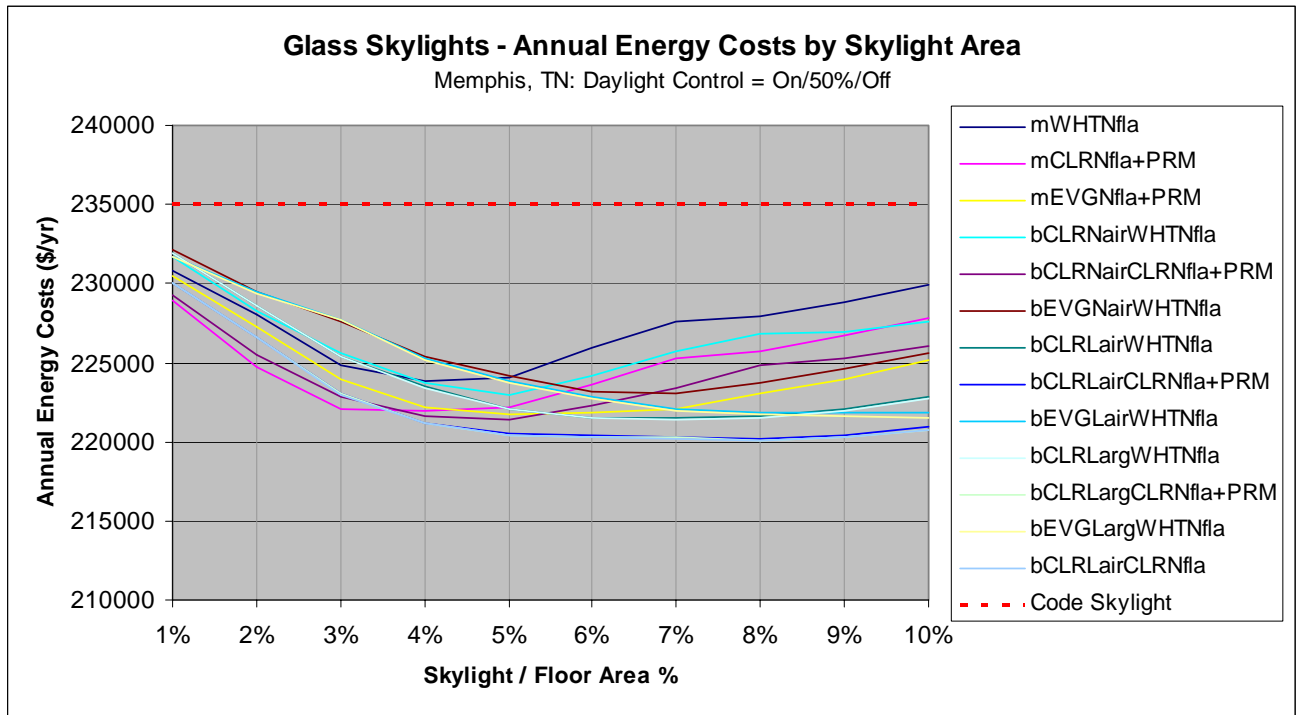
(a)



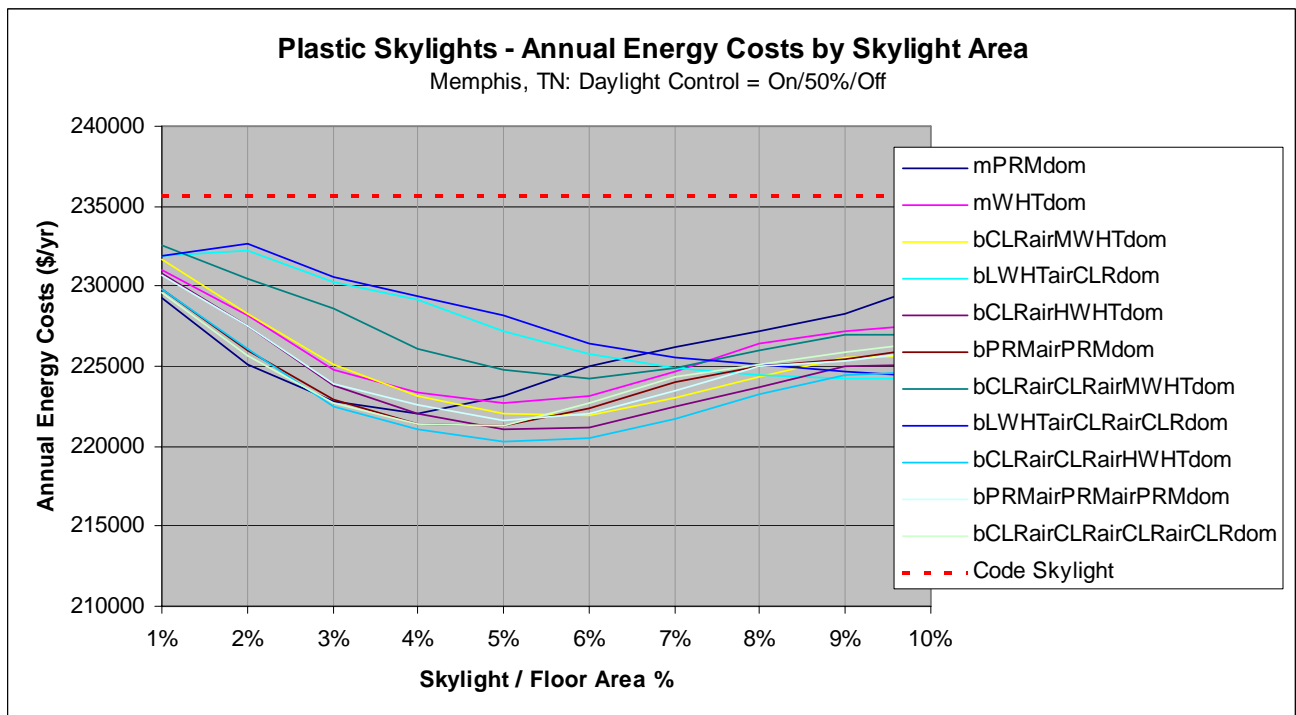
(b)

Figure A2.2. Energy cost savings from skylights across increasing SRR for Grocery-BB building in Houston, TX (Zone 2) – (a) Glass skylights, (b) Plastic skylights

GROCERY STORE – ZONE 3:



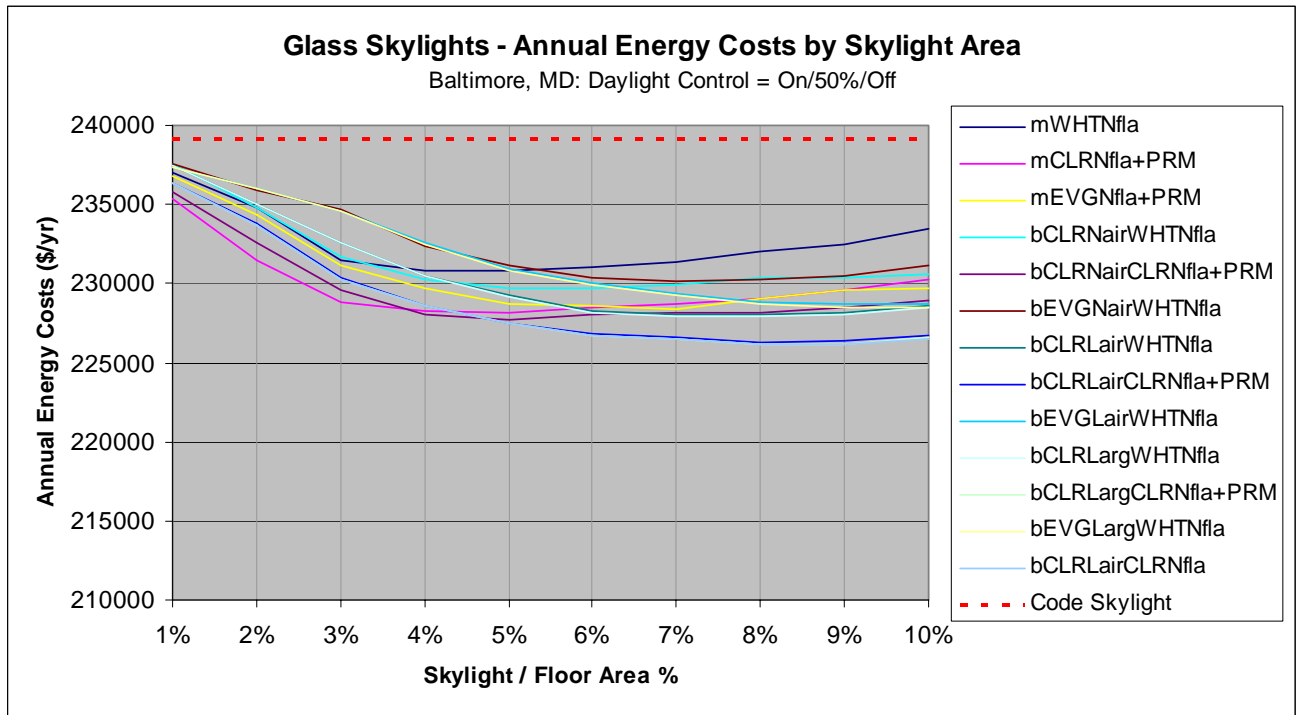
(a)



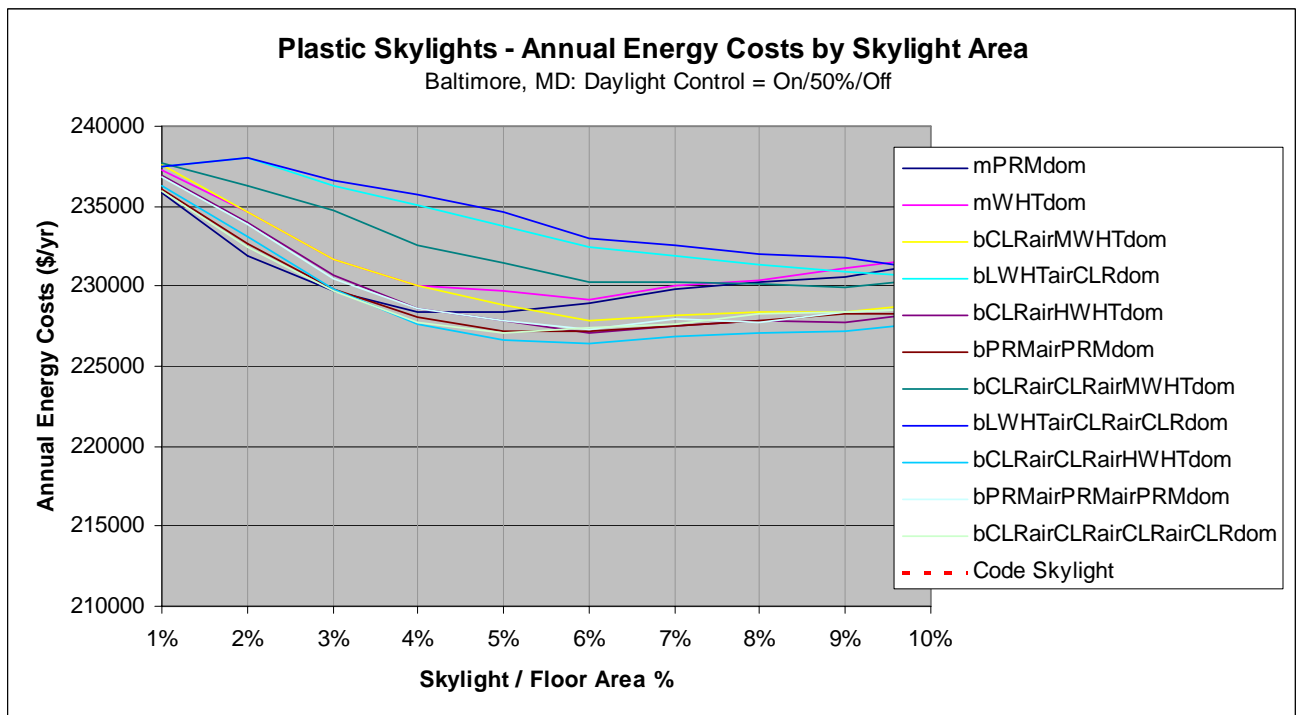
(b)

Figure A2.3. Energy cost savings from skylights across increasing SRR for Grocery-BB building in Memphis, TN (Zone 3) – (a) Glass skylights, (b) Plastic skylights

GROCERY STORE – ZONE 4:



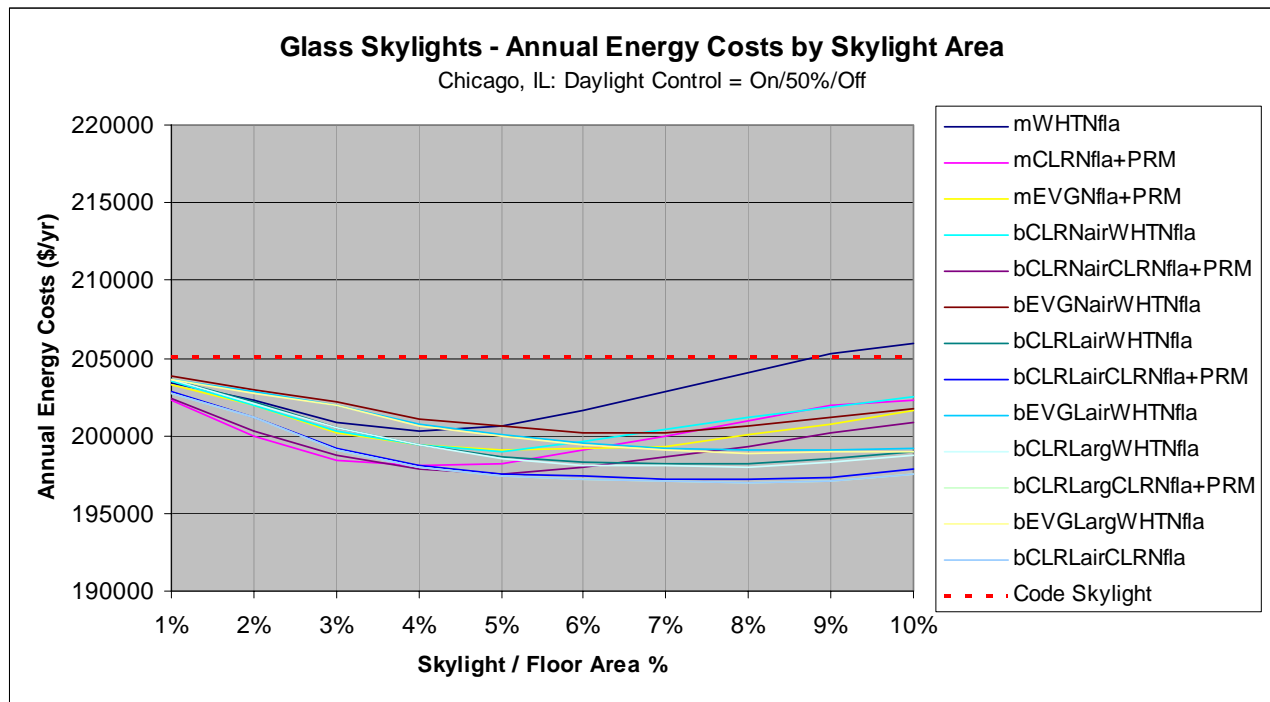
(a)



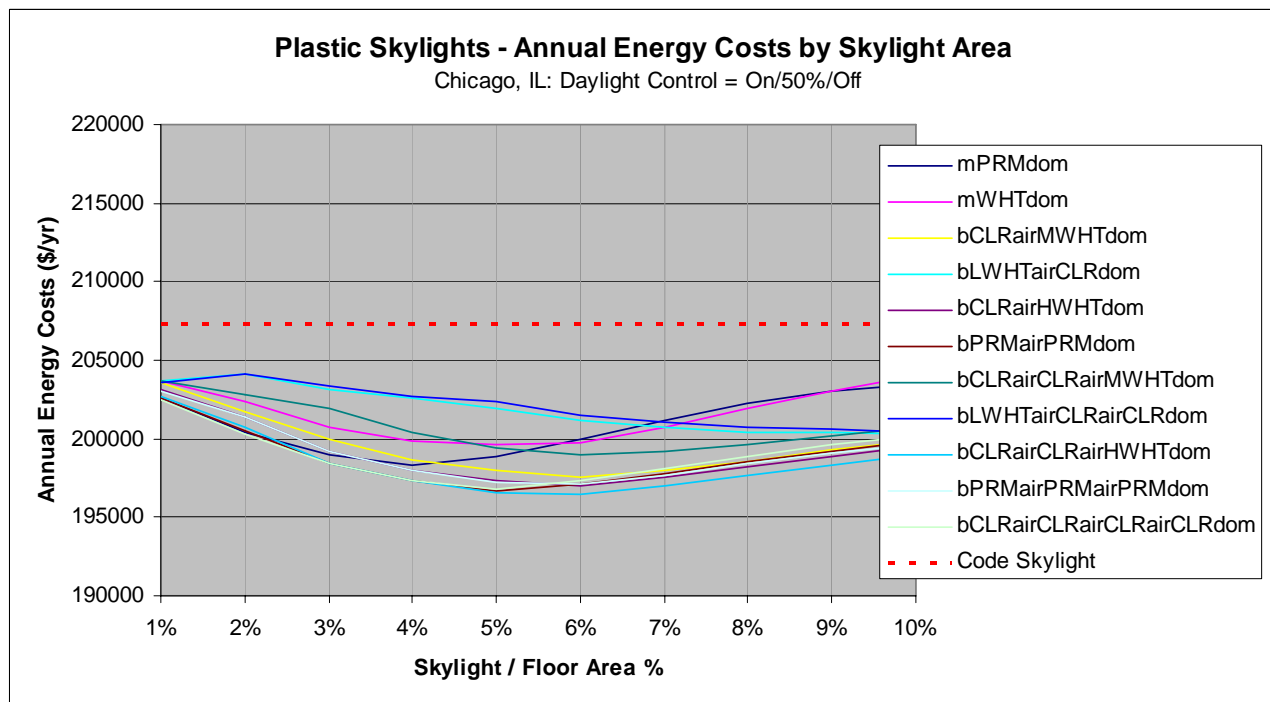
(b)

Figure A2.4. Energy cost savings from skylights across increasing SRR for Grocery-BB building in Baltimore, MD (Zone 4) – (a) Glass skylights, (b) Plastic skylights

GROCERY STORE – ZONE 5:



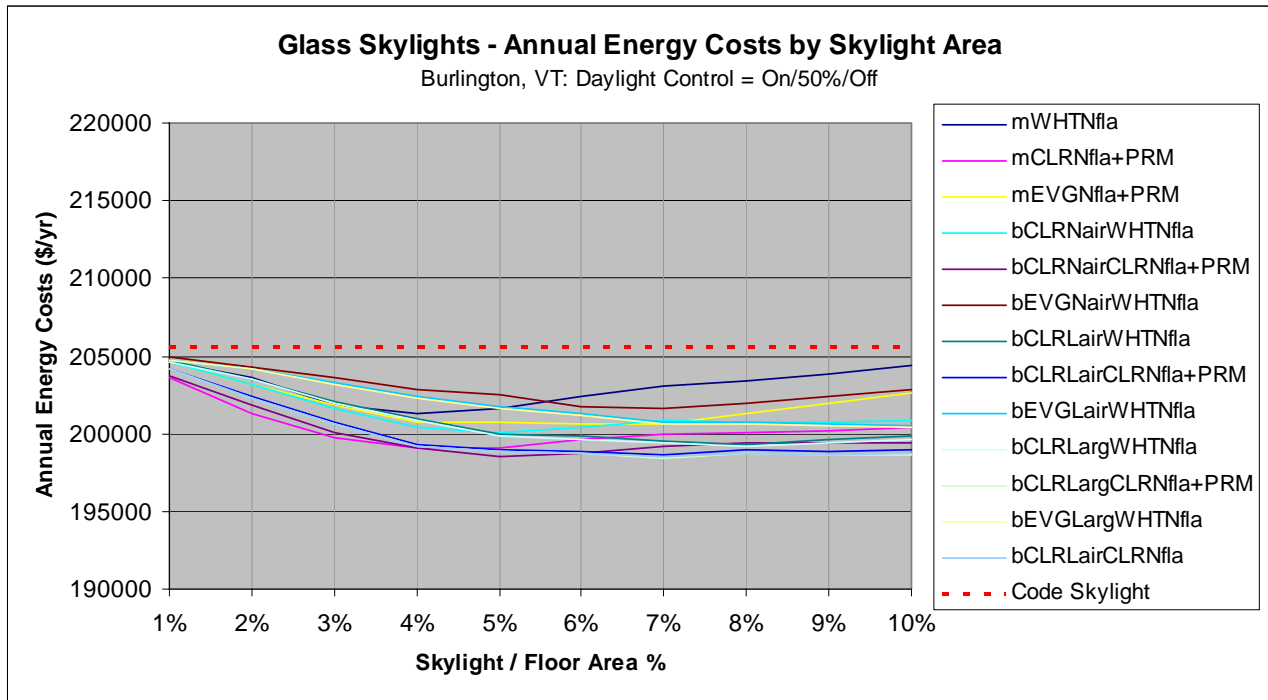
(a)



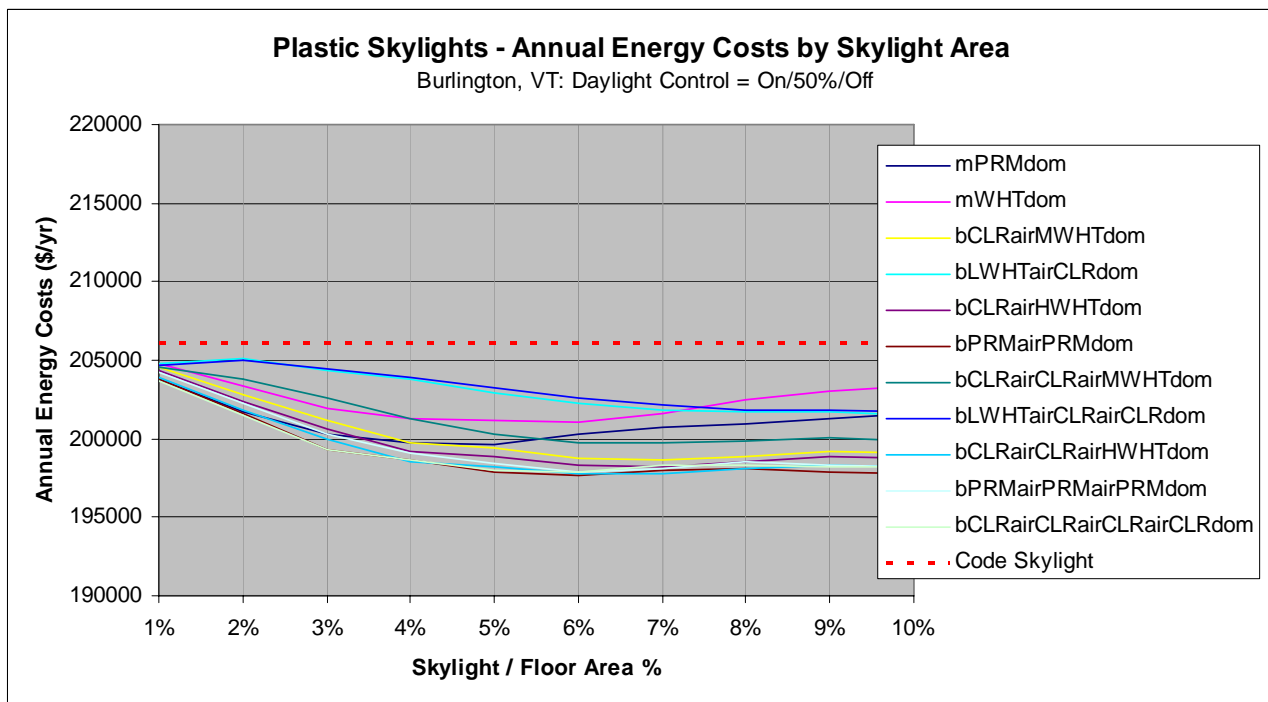
(b)

Figure A2.5. Energy cost savings from skylights across increasing SRR for Grocery-BB building in Chicago, IL (Zone 5) – (a) Glass skylights, (b) Plastic skylights

GROCERY STORE – ZONE 6:



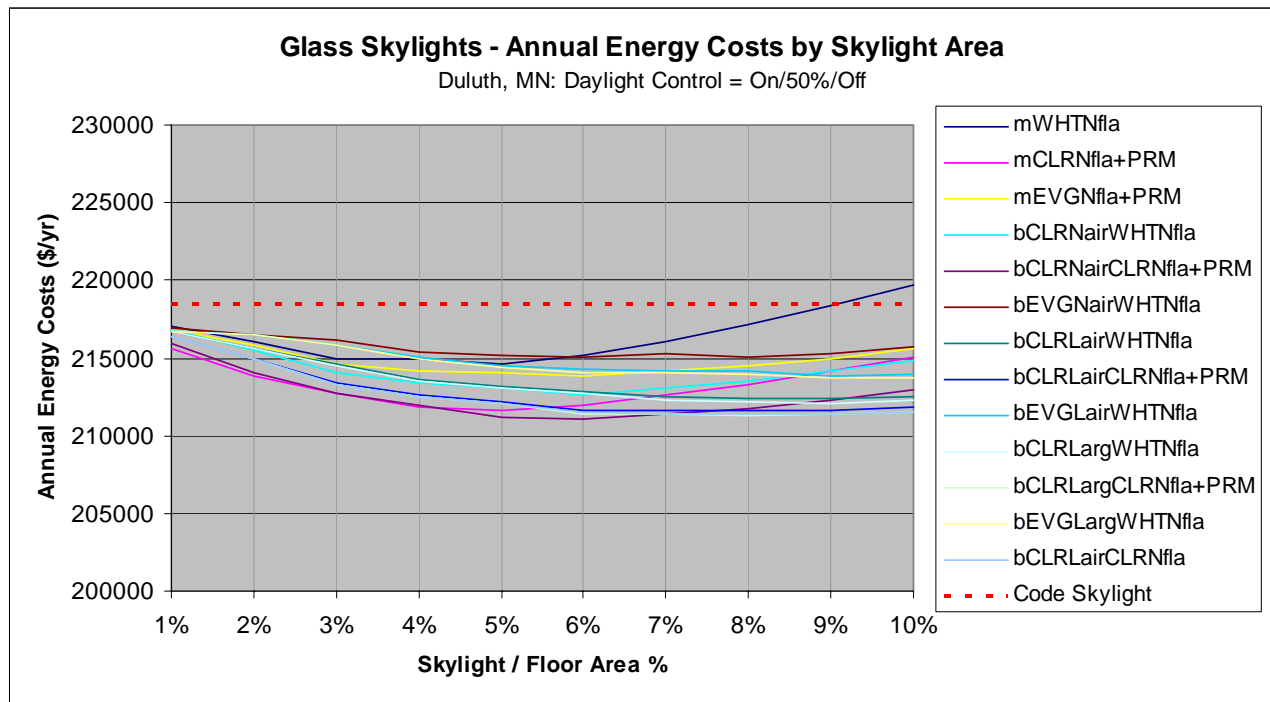
(a)



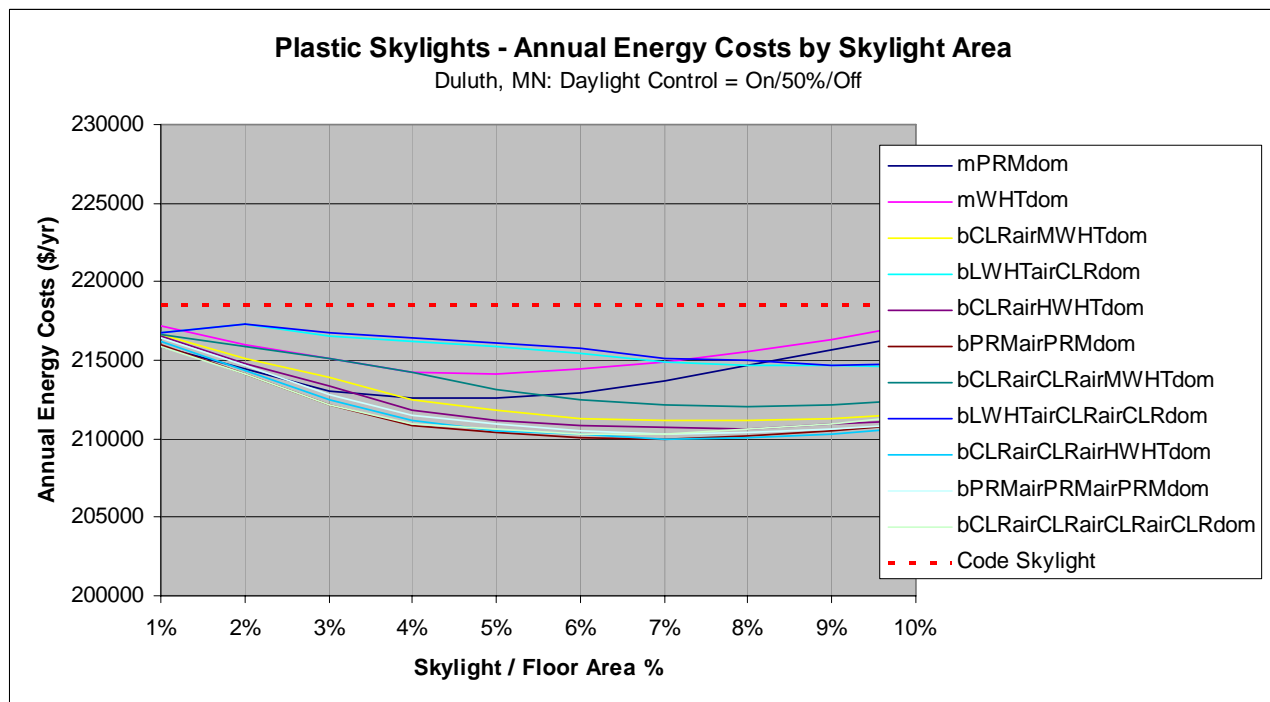
(b)

Figure A2.6. Energy cost savings from skylights across increasing SRR for Grocery-BB building in Burlington, VT (Zone 6) – (a) Glass skylights, (b) Plastic skylights

GROCERY STORE – ZONE 7:



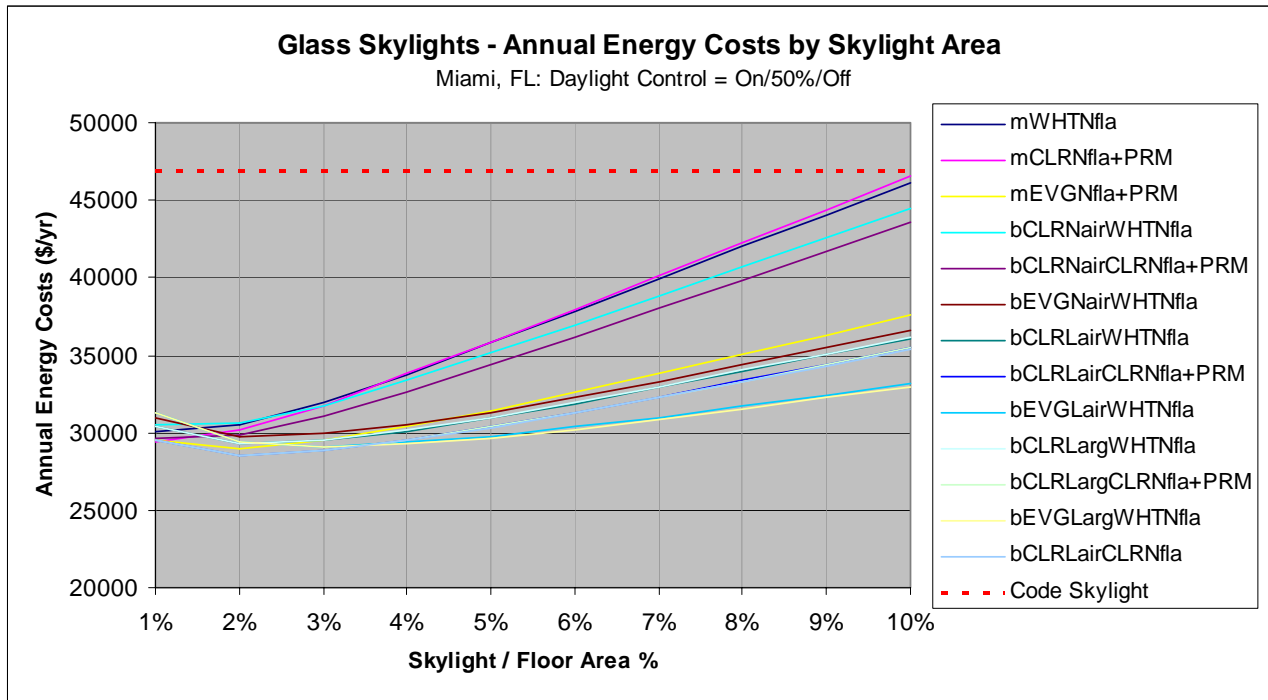
(a)



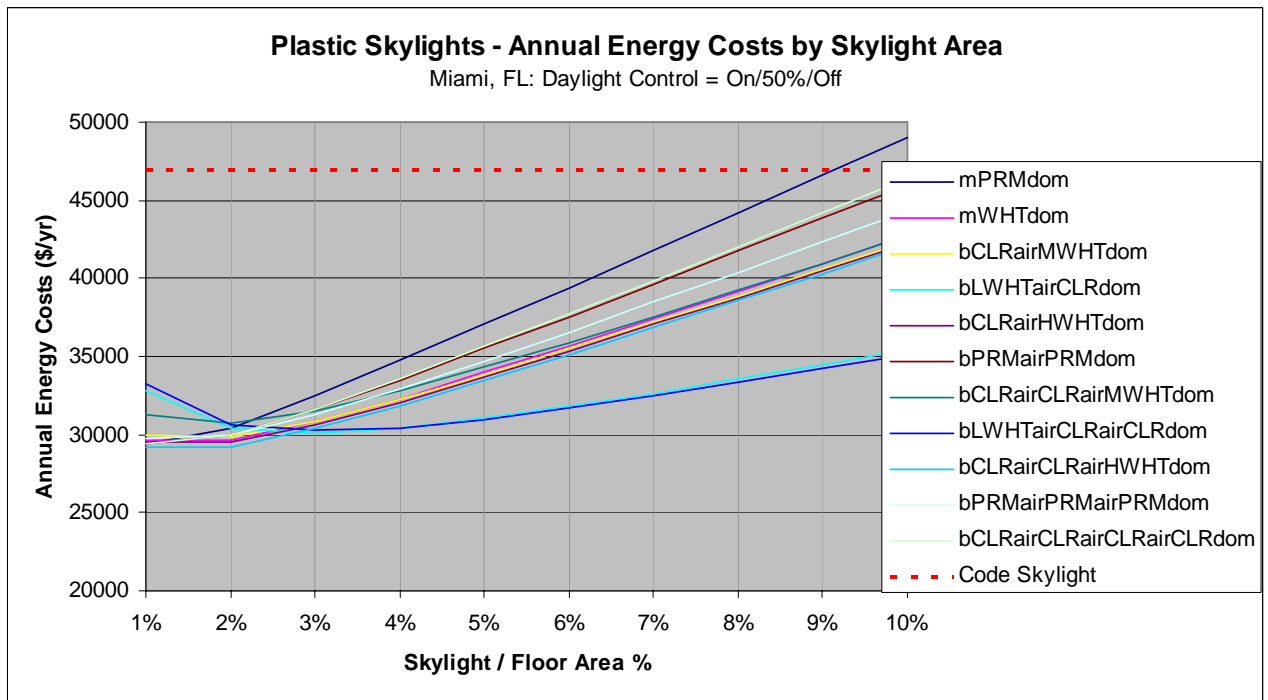
(b)

Figure A2.7. Energy cost savings from skylights across increasing SRR for Grocery-BB building in Duluth, MN (Zone 7) – (a) Glass skylights, (b) Plastic skylights

WAREHOUSE BUILDING – ZONE 1



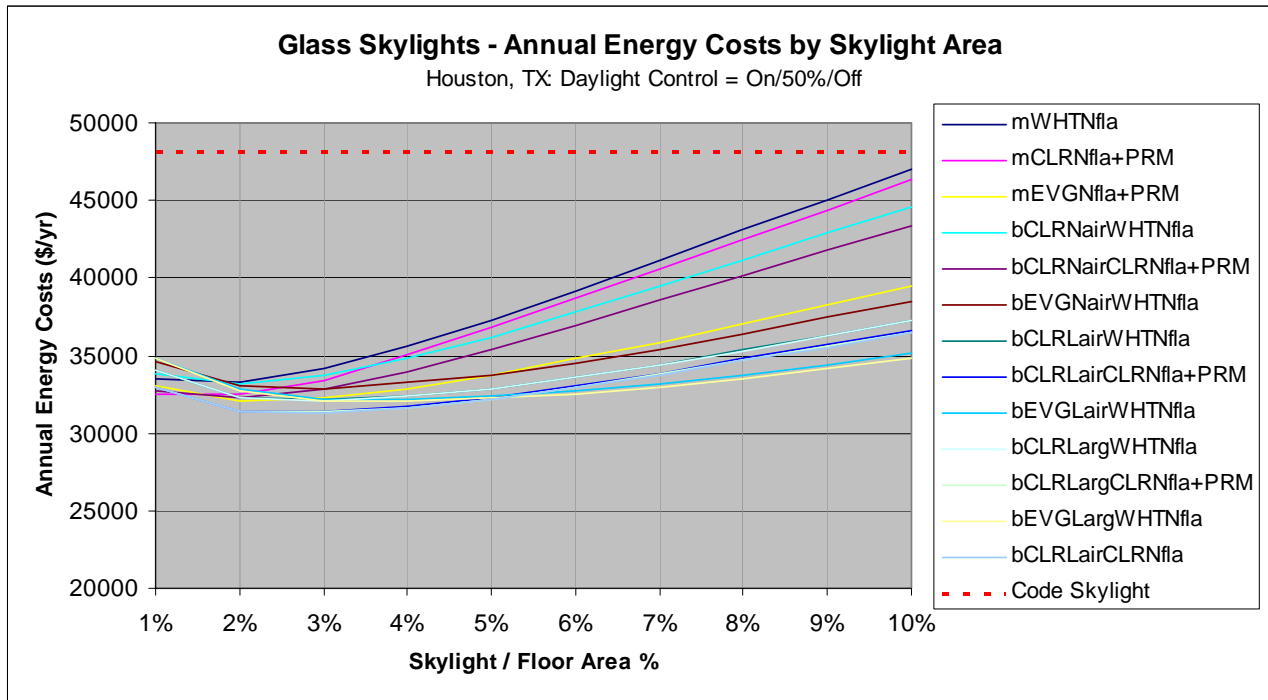
(a)



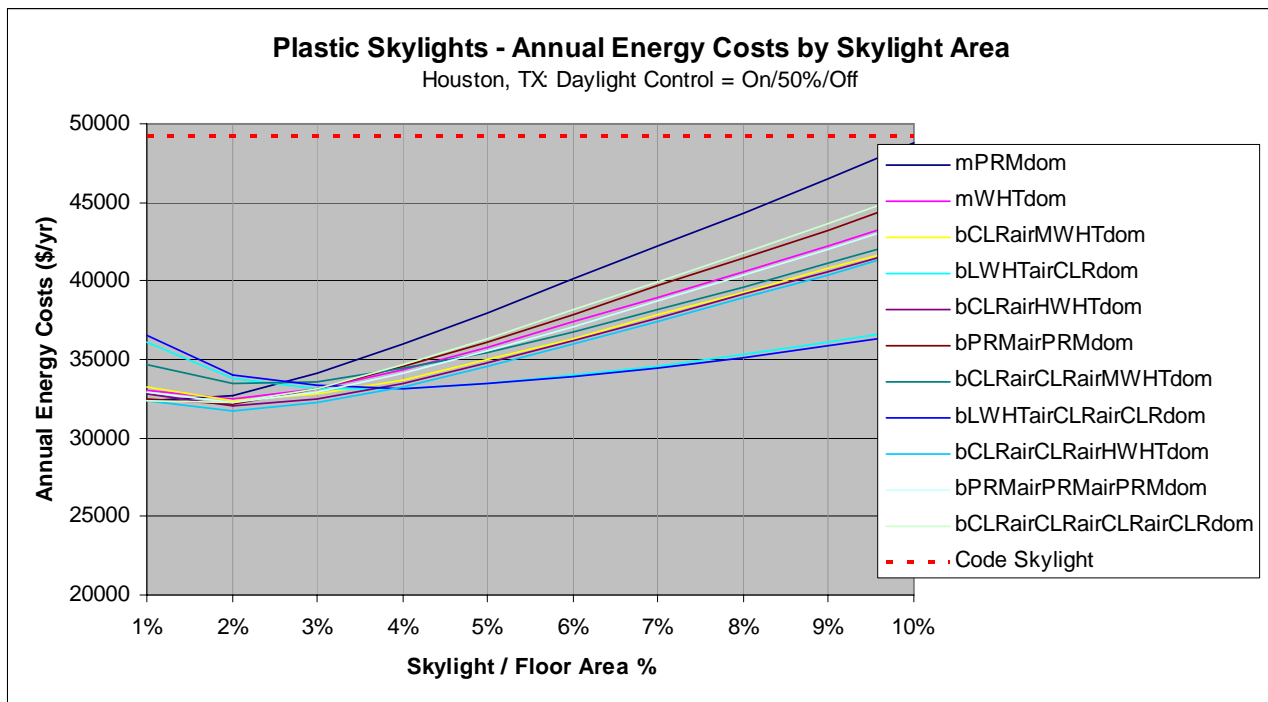
(b)

Figure A3.1. Energy cost savings from skylights across increasing SRR for Warehouse building in Miami, FL (Zone 1) – (a) Glass skylights, (b) Plastic skylights

WAREHOUSE BUILDING – ZONE 2



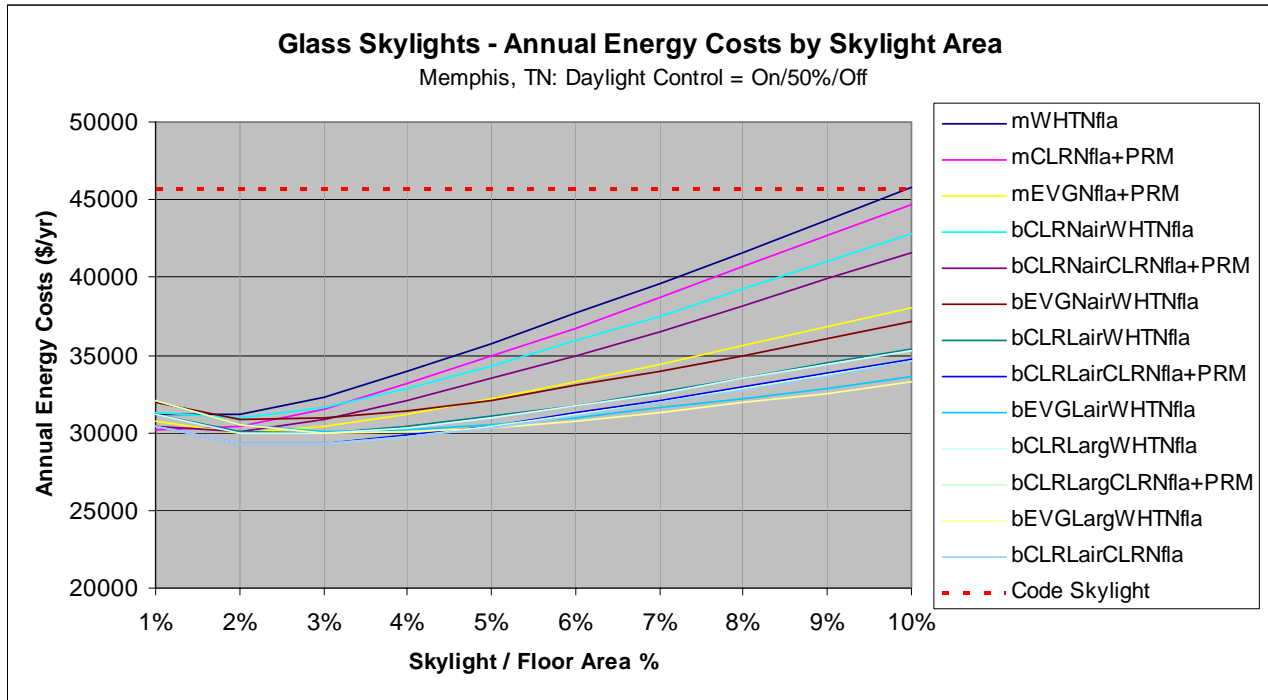
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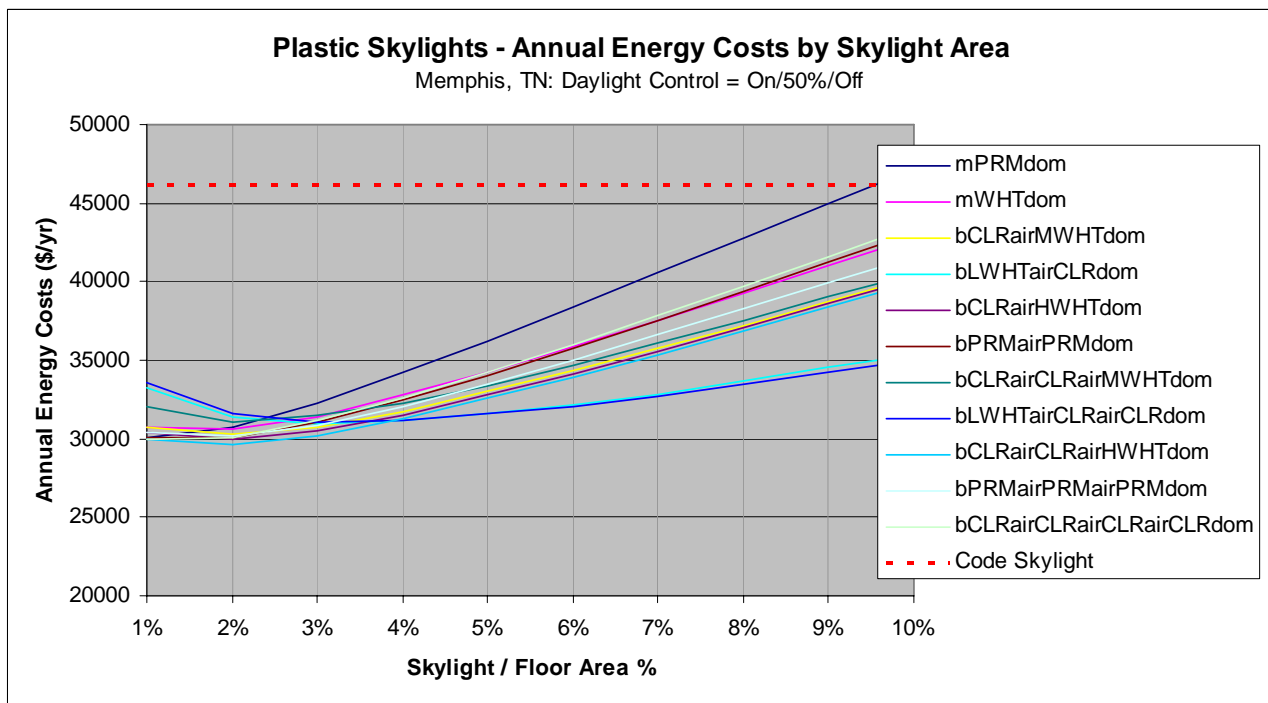
(b)

Figure A3.2. Energy cost savings from skylights across increasing SRR for Warehouse building in Houston, TX (Zone 2) – (a) Glass skylights, (b) Plastic skylights

WAREHOUSE BUILDING – ZONE 3



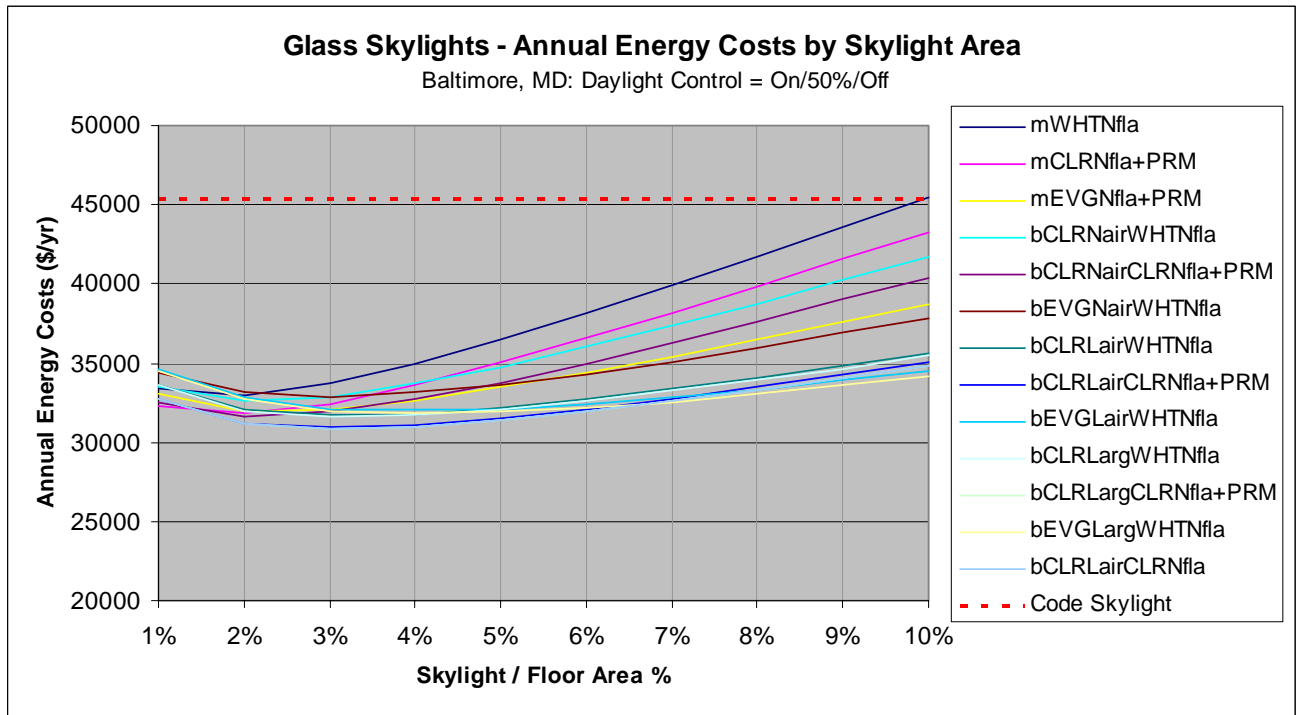
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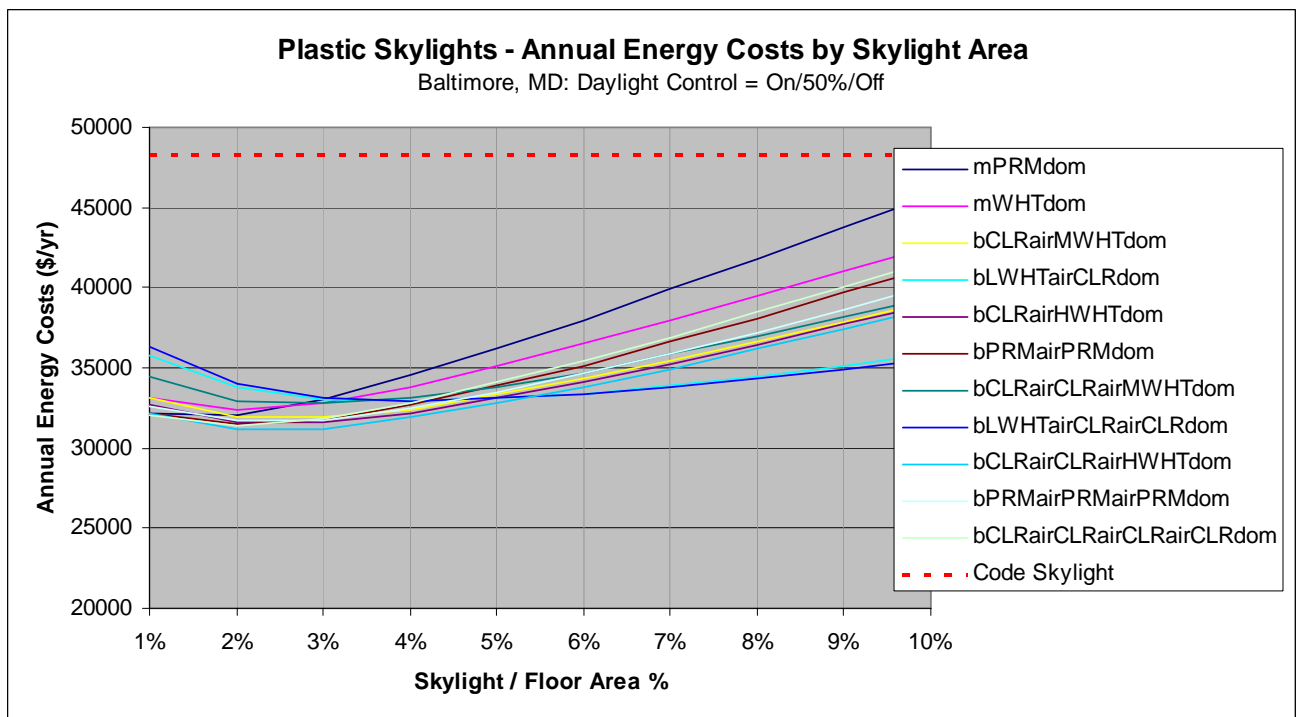
(b)

Figure A3.3. Energy cost savings from skylights across increasing SRR for Warehouse building in Memphis, TN (Zone 3) – (a) Glass skylights, (b) Plastic skylights

WAREHOUSE BUILDING – ZONE 4



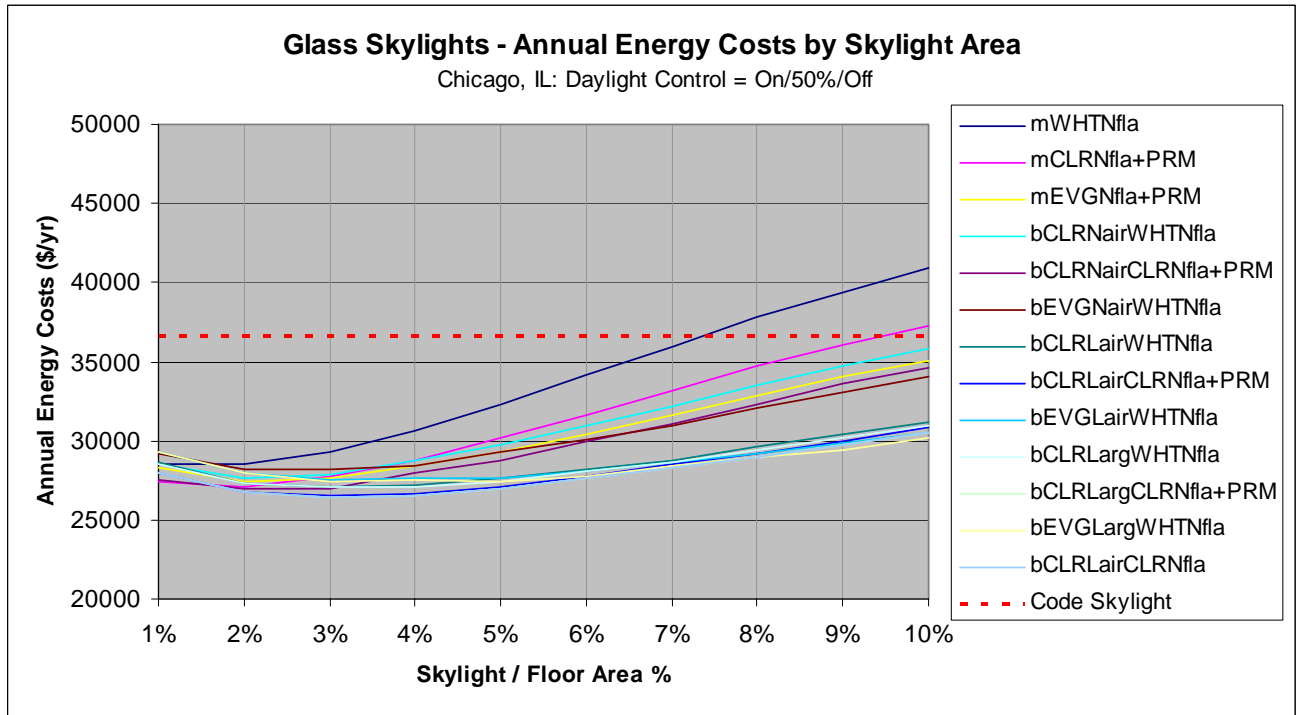
(a)



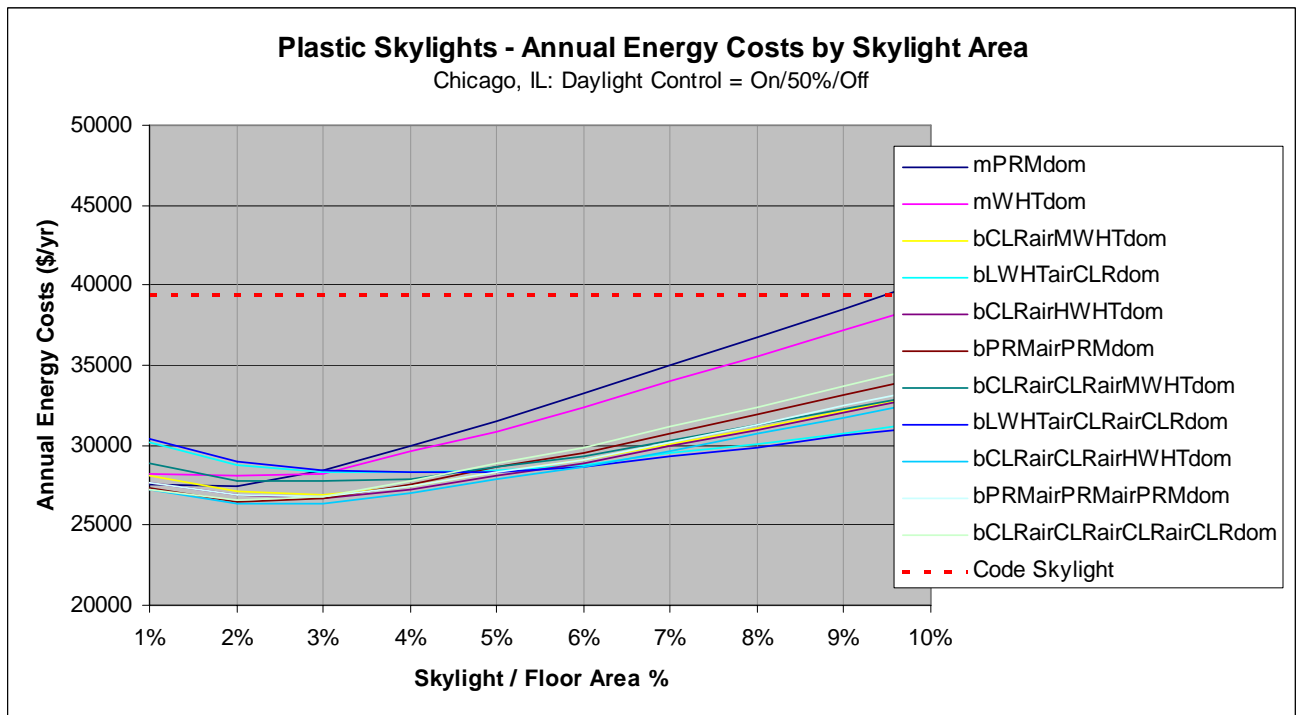
(b)

Figure A3.4. Energy cost savings from skylights across increasing SRR for Warehouse building in Baltimore, MD (Zone 4) – (a) Glass skylights, (b) Plastic skylights

WAREHOUSE BUILDING – ZONE 5



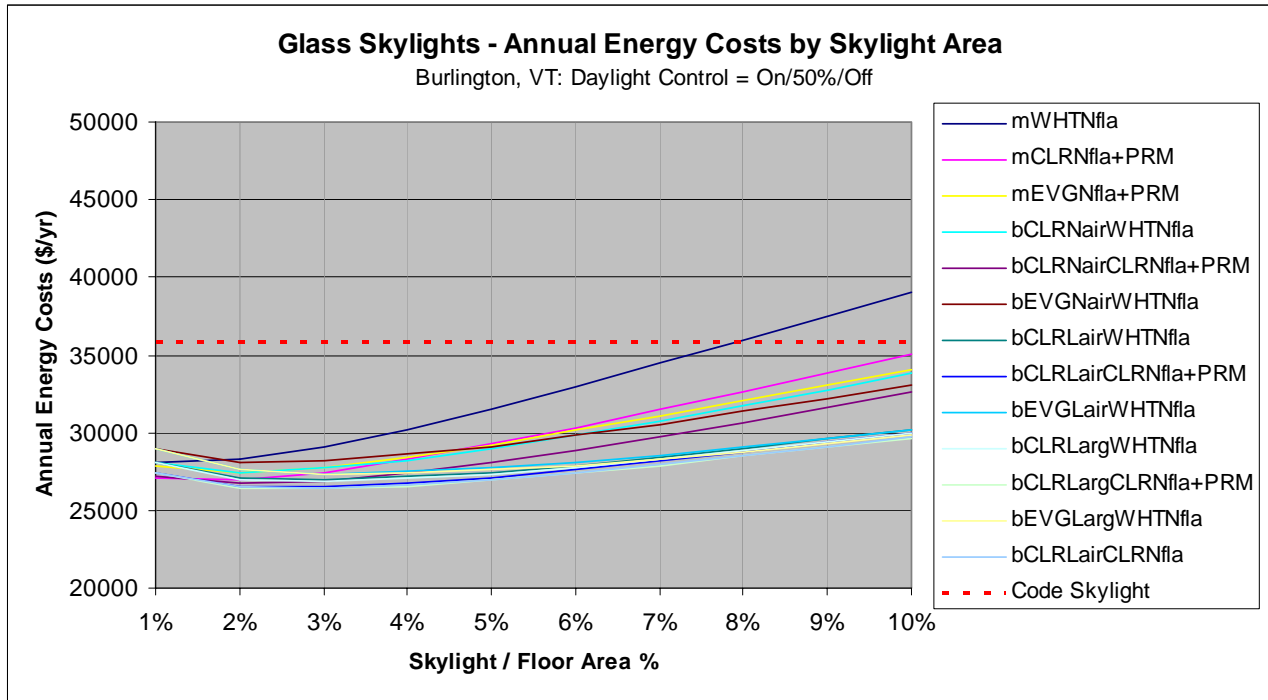
(a)



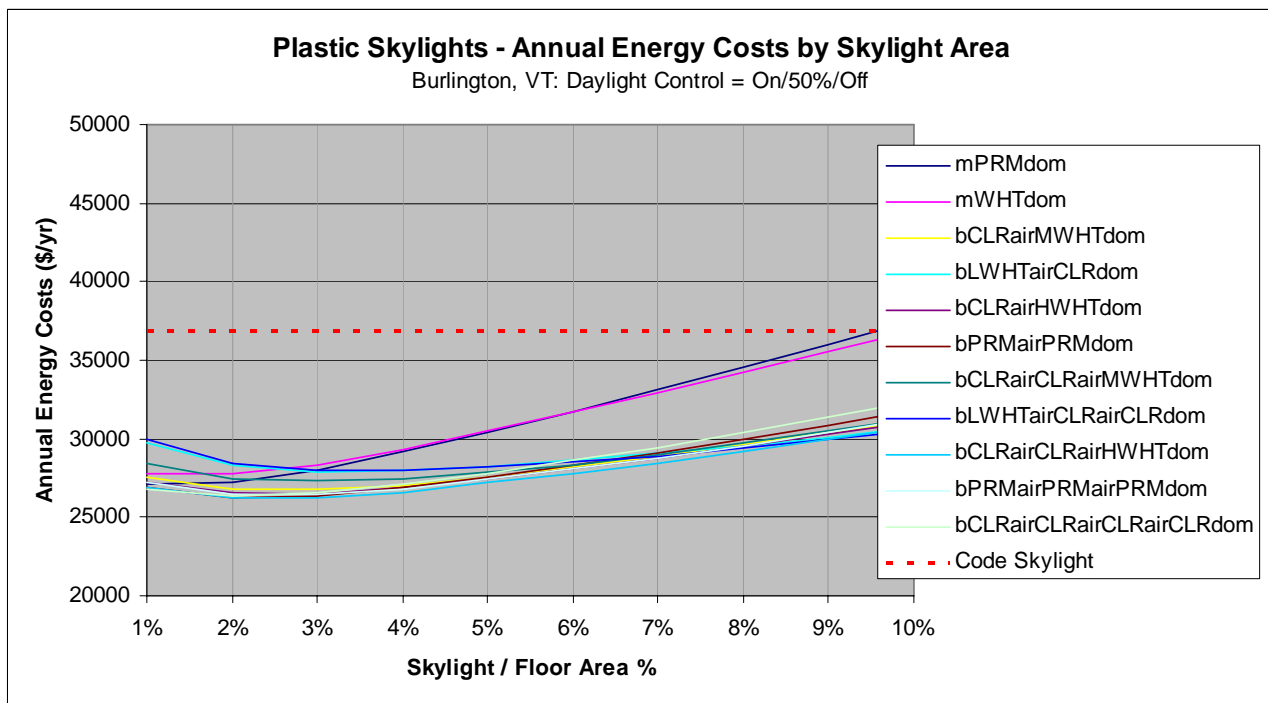
(b)

Figure A3.5. Energy cost savings from skylights across increasing SRR for Warehouse building in Chicago, IL (Zone 5) – (a) Glass skylights, (b) Plastic skylights

WAREHOUSE BUILDING – ZONE 6



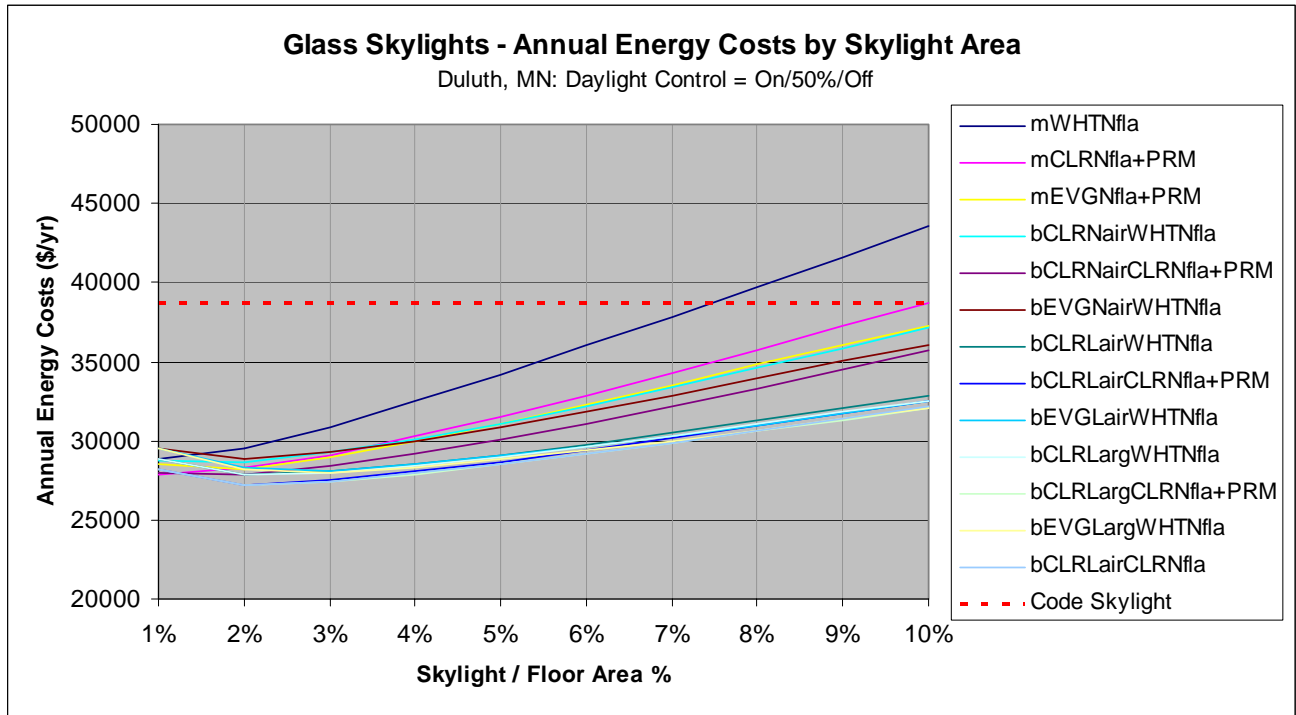
(a)



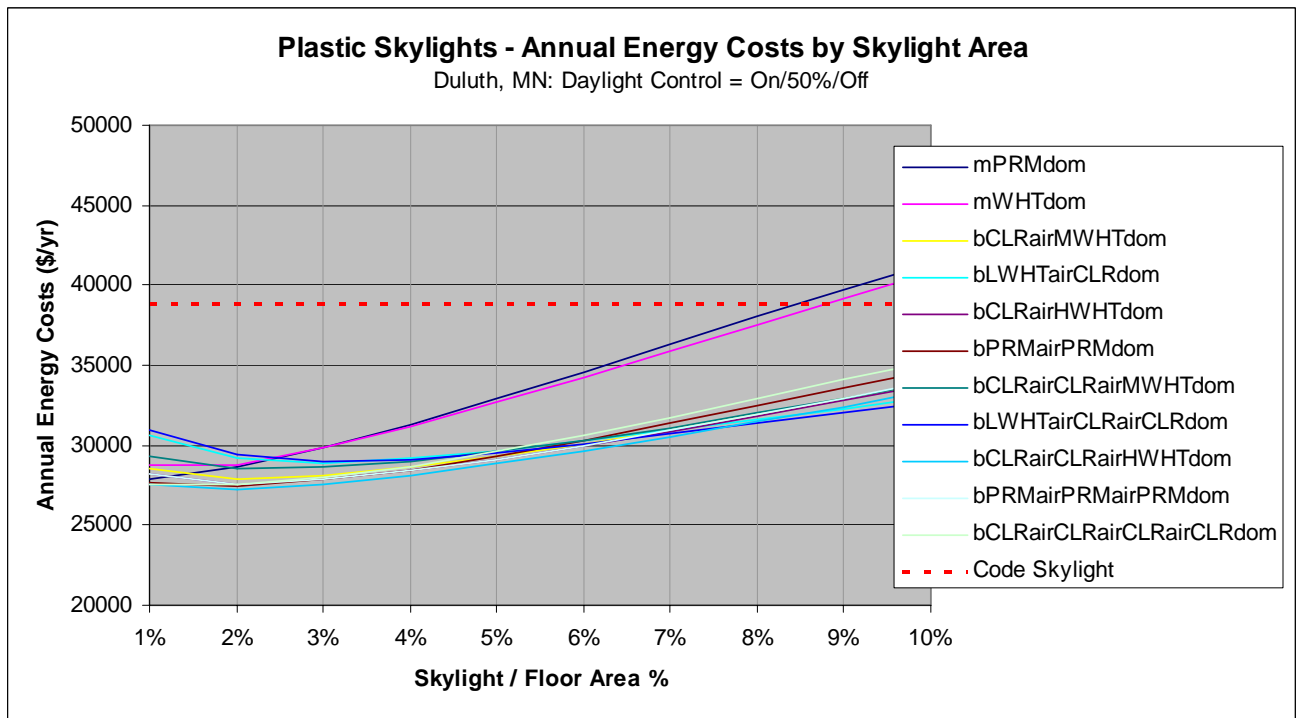
(b)

Figure A3.6. Energy cost savings from skylights across increasing SRR for Warehouse building in Burlington, VT (Zone 6) – (a) Glass skylights, (b) Plastic skylights

WAREHOUSE BUILDING – ZONE 7



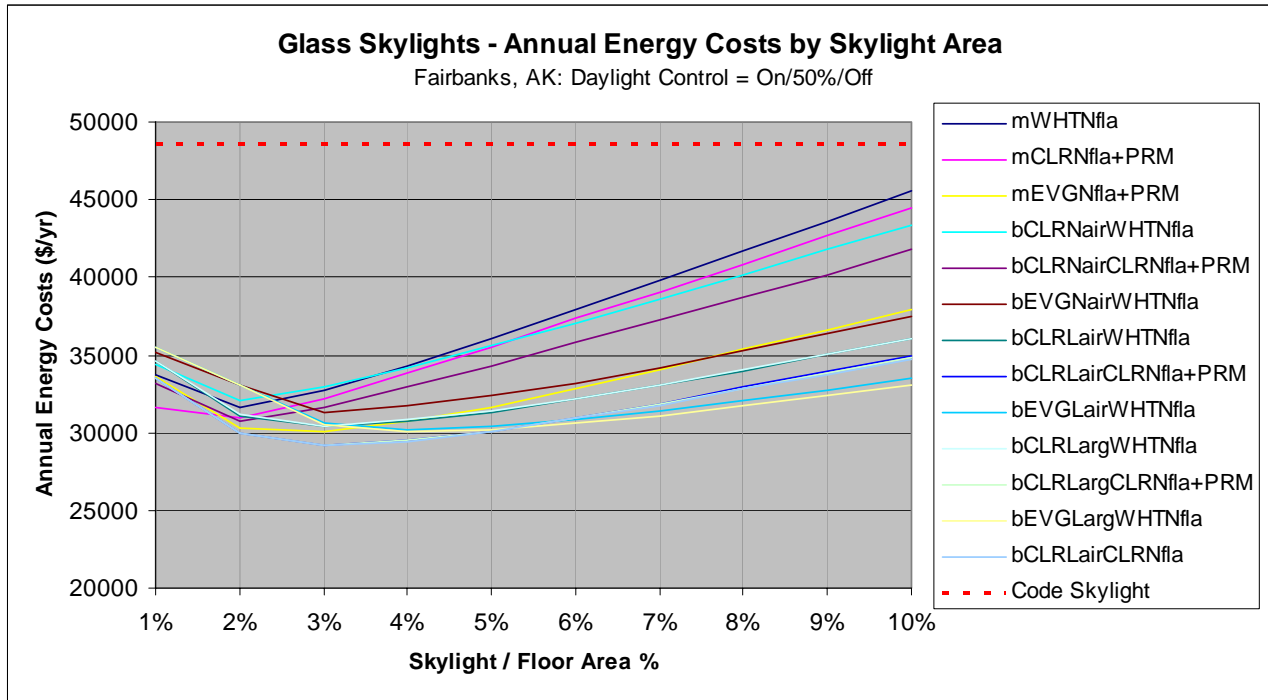
(a)



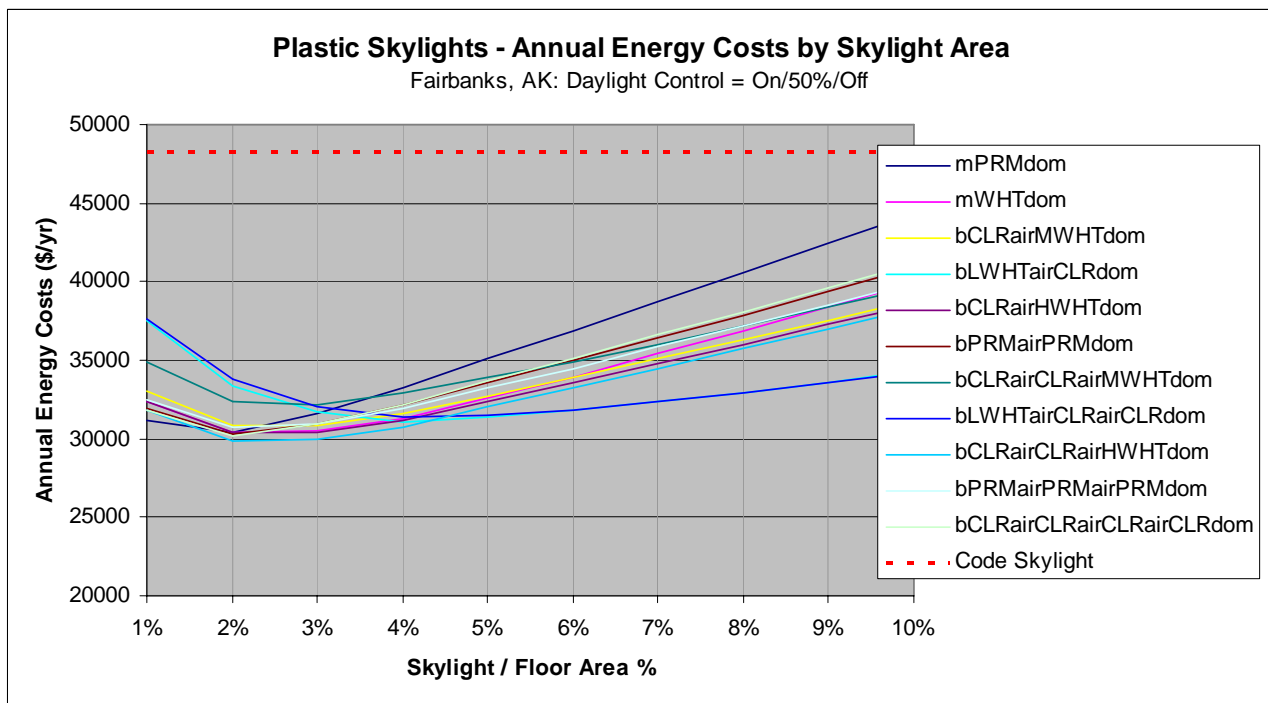
(b)

Figure A3.7. Energy cost savings from skylights across increasing SRR for Warehouse building in Duluth, MN (Zone 7) – (a) Glass skylights, (b) Plastic skylights

WAREHOUSE BUILDING – ZONE 8



(a)



(b)

Figure A3.8. Energy cost savings from skylights across increasing SRR for Warehouse building in Fairbanks, AK (Zone 8) – (a) Glass skylights, (b) Plastic skylights