DAYLIGHTING *initiative*

Design tools and information from The Pacific Gas and Electric Company

Skylighting and Retail Sales

An Investigation into the Relationship Between Daylighting and Human Performance

Detailed Report

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Submitted to:

George Loisos
Pacific Gas and Electric Company
on behalf of the
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Submitted by:

HESCHONG MAHONE GROUP
11626 Fair Oaks Blvd. #302
Fair Oaks, CA 95628

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1. EXECUTIVE SUMMARY

This study looks at the effect of daylighting on human performance. It specifically focuses on skylighting as a way to isolate daylight as an illumination source, and avoid all of the other qualities associated with daylighting from windows. In this project, we established a statistically compelling connection between skylighting and retail sales, and between daylighting and student performance. This report focuses on the retail analysis.

We analyzed data on the sales performance of a chain retailer that operates a set of nearly identical stores. The analysis included 108 stores, where two thirds of the stores have skylighting and one third do not. The design and operation of all the store sites is remarkably uniform, with the exception of the presence of skylights in some. The electric lighting was primarily fluorescent. Daylight from the skylights often provided more than two to three times the target illumination levels. Photo-sensor controls turned off some of the fluorescent lights when daylight levels exceeded target illumination.

The monthly gross sales per store were averaged over an 18-month period running from February 1 of one year to August 31 of the next. This average sales figure was transformed into a “sales index” that we could manipulate statistically, but that did not reveal actual dollar performance. Stores in the sample were located within a limited geographic region that had similar climatic conditions. Buildings in the study fell within constrained ranges of size and age. The geographic region has a relatively sunny climate. All of the stores in the data set are one story.

The multivariate regression analysis allowed us to control for the influence of other variables which might influence sales. Other variables considered included the size and age of the store, hours of operation, and economic characteristics associated with the zip code location.

Skylights were found to be positively and significantly correlated to higher sales. All other things being equal, an average non-skylit store in the chain would likely have 40% higher sales with the addition of skylights, with a probable range between 31% and 49%. This was found with 99% statistical certainty. After the number of hours open per week, the presence of skylights was the best predictor of the sales per store of all the variables that we considered. Thus, if a typical non-skylit store were averaging sales of $2/sf, then its sales might be expected to increase to between $2.61 and $2.98 with the addition of a skylighting system.

The skylights are seen to have a major impact on the overall operation of the chain. Were the chain to add the skylighting system to the remaining 33% of its stores, yearly gross sales are predicted to increase by 11%. The difference between having none of their stores skylit and all their stores skylit is an increase of up to a 40% in gross sales for the retail chain.

2. INTRODUCTION

The purpose of this study was to see if we could demonstrate a clear relationship between the presence of daylight and human performance in buildings. We postulated that by focusing on buildings with skylights rather than daylighting from windows, we could isolate the effect of daylight.

In this study, we used multivariate regression analysis on performance data from four organizations: one retailer and three school districts. This analysis allowed us to estimate the effect of each of the known variables and to determine which variables have no significant effect. Using this method, we established a statistically compelling connection between skylighting and retail sales, and between daylighting and student performance. This report focuses on the retail analysis.

We have included as much information in this report as we can, given the limitation of our confidentiality agreement with the participating retailer. While more information could be very informative to the reader, many of the details about skylighting will have to be filled in by others. We have also prepared a "condensed version" of this report for those less interested in the details of the statistical analysis and methodology.

2.1 Background

Skylights provide a simple illumination function, whereas windows may have a far more complex effect on people. Windows typically offer a view, which may provide relaxation, inspiration or distraction. They are often operable, which may add ventilation, air quality, and thermal comfort issues. Daylight illumination levels from windows are highly variable within a space, and may include components of unacceptable contrast and glare. User control of blinds or curtains also adds another variable that may be hard to account for. Windows are also connected with personal status, and may have psychological implications beyond their mere physical attributes. Skylights would not seem to be as imbued with cultural meaning and don't tend to have as much variability in their function.

Skylighting was a widely used method of providing light to industrial and warehouse buildings before the widespread use of fluorescent lighting. Most single-story industrial buildings built before the 1950's had rows of north-facing roof monitors which allowed ample light into the interior of these large buildings. With the advent of inexpensive fluorescent lighting and air conditioning, daylighting techniques were abandoned in favor of electric lighting.

Recent analysis has shown that skylighting has enormous potential to provide energy savings in single-story commercial buildings. An appropriately sized skylighting system, combined with photosensor controls to turn off unneeded electric lights, will produce net whole building energy savings in almost all parts

of the country.[1] Nationally, 40 percent of all commercial buildings are single-story, and 60% of commercial square footage is directly under a roof.[2] In California, those numbers are even higher, where it is estimated that 90 percent of new construction is single-story.[3] Thus, the potential energy impacts of increased use of skylighting systems is enormous.

Retail buildings tend to be a fairly straightforward application for skylighting. The trend towards large, single-story retail centers, with open expanses of shelving is well adapted to a skylighting approach. Skylighting in these buildings can save significant amounts of money. For example, a skylighting system in a typical grocery store in Los Angeles saves about $10,000 per year[4]. A number of retailers have adopted skylighting as a standard design feature of their stores in order to take advantage of these savings.

With the advent of these skylit stores, anecdotal stories began to surface that stores with skylighting had higher sales. One retailer reported that clothing returns decreased dramatically after installing skylights. Another retailer was rumored to have discovered that merchandise placed under a skylight had much faster turnover.

In November of 1995, an article appeared on the front page of the Wall Street Journal business section describing Wal-Mart's experience with adding skylights to their experimental "Eco-Mart" in Lawrence, Kansas[5]. Although no numbers were offered, this article considerably raised the interest level in skylighting for retail applications. It reported that, as a last minute cost saving measure, Wal-Mart had installed skylights in only half of store.

> *Wal-Mart claims energy savings from drawing natural light through the skylights. But 'something else has gotten the corporation's attention,' says the [Rocky Mountain] Institute. In every Wal-Mart store, each cash register is connected in real time back to headquarters in Bentonville, Ark. According to Tom Scay, who was then the company's vice president for real estate, sales were 'significantly higher' in those departments in the daylit half of the store, and they were also higher there than in the same departments at other stores. Employees in the half*

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[1] Analysis with *SkyCalc*, a simulation program, available by downloading from www.energydesignresources.com

[2] Derived from the US Energy Information Agency publication, *Commercial Building Energy Consumption* (CBECs) 1995

[3] Personal communications from PG&E and SDG&E staff.

[4] Per monitoring by PG&E for daylighting case study series, which showed savings of 2kWh/yr per sf for a 50,000sf store paying $0.10/kWh.

[5] "Letting the Sun Shine is Good for Business," John Pierson, *The Wall Street Journal*, November 20, 1995, page B1.

> *without daylighting continue to try to have their departments move to the daylit side."*

Such anecdotal studies have been intriguing, but have not offered a measure of how large such a positive effect might be. It has been clear for awhile that the value of such productivity impacts are potentially much greater than energy savings, not only for retailers, but for any business. A building that promises 1% higher productivity is likely to be far more interesting to an owner than a building that is guaranteed to use 10% less energy. Thus, we set out to see if a daylighting effect on performance could be demonstrated and quantified using rigorous statistical techniques.

While it turned out that one of our study participants was a chain retailer, the implications for daylighting extend beyond the retail sector. Considered with the companion study showing improved student performance in daylit classrooms, the two studies suggest that the beneficial effects of daylight are not confined to just schools or retail establishments, but that human activity in general is likely to benefit from exposure to daylighting.

3. METHODOLOGY

Our study methodology compared the performance of people in similar buildings with and without skylights. To do this, we sought organizations that had pre-existing productivity measurements that could be compared between buildings with and without skylights (or daylight). We began by casting a wide net looking for the ideal organizations that could provide us with data sets amenable to our analysis.

3.1 Data Set Criteria

Our criteria for selection included organizations which:

- Operated at least 60 sites, about ½ with and ½ without skylighting (Or had a scalable range of daylighting conditions)
- Where all building sites had nearly identical operations, and similar climate conditions
- Where human performance measures, that could be identified by building site, were consistently tracked in an electronic database
- And, of course, where the organization was interested in participating in the study.

The human performance data would then be statistically analyzed to see if there was a strong correlation between the presence of daylighting and improved performance. We would attempt to control for as many other variables as possible using multivariate regression analysis. We realized that our ability to control for other influences on human performance would be limited by:

- The size of the data set
- The availability of information about other influences
- The time period of the performance measurements

Thus, our goal was to find data sets as large as possible that measured human performance over a long time period, and allowed us the opportunity to control for other potential influences on performance.

3.2 Selection of Sites

We began our search for data sets by identifying target building types, and then conducted an extensive phone search to identify organizations that might meet the criteria above. We focused on:

- Chain store retailers

- Manufacturers with multiple locations, or the potential for "before and after" measurements
- Distributors with multiple locations
- Elementary school districts
- Office buildings with identical operations at multiple sites

After identifying potential sites all over the country, we began a multi-level screening process. We interviewed potential candidates and attempted to negotiate cooperative agreements with the best candidates. For the commercial sites, confidentiality and interference in operations were significant concerns. A promising manufacturer with excellent data on employee productivity was eliminated as a study participant when the upper management ruled the study to be an unnecessary distraction to their production schedule.

- After over 125 interviews with candidate organizations, we selected two types of organizations—elementary schools and a chain retailer—and pursued a parallel analysis of both groups. This report details the analysis and findings from the retailer data. A companion report details the work with the school districts.

3.3 The Retailer

We were lucky to find a retailer that met all of these conditions, and was willing to participate in the study. This retailer provided us with basic descriptive information about its stores and a "sales index" for each location. The sales index became the measure of productivity. The retailer, which wishes to remain anonymous, operates a set of nearly identical chain stores that sell a variety of consumer merchandise.

This retailer has had a policy of building its new stores with skylights for a number of years. However, it also has a considerable number of stores built during the same period that do not have skylights. About 2/3 of the stores in the data set have skylights and 1/3 do not. Most of these non-skylit stores were acquired during mergers with other chains. The merged sites were then remodeled to match the design image and layout of the primary chain; however, skylights were not added.

About ¼ of the non-skylit stores were originally built by the chain itself. Apparently some new managers acquired during the merger did not agree with the skylighting policy, and so those new store sites where they had the greatest influence were built without skylights. Thus, there does not seem to have been a systematic decision made about which sites should have skylights and which should not. Rather, the location of skylit stores seems more of a historical accident based on internal corporate politics.

Energy savings has always been a major motivation in the use of skylights by the chain. The retailer believes that they are seeing significant operational savings by

turning off the electric lights under the skylights. However, we did not attempt to confirm these claims in any way. Our interest was in the impacts on sales.

3.3.1 Data from the Retailer

The chain store retailer, who sells a variety of consumer merchandise, and who wishes to remain anonymous, was able to provide us with sales performance data for 108 stores that included 2/3 with skylights and 1/3 without skylights. The monthly gross sales per store were averaged over an 18-month period that went from February 1 of one year to August 31 of the following year. Before it was given to us, this average was transformed into a unit-less "sales index" that we could manipulate statistically, but that did not reveal actual dollar performance. As shown in Figure 1 this index ranged from 1.73 to 12.61, with an average of 4.89.

Dependent Variable:	low	high	range	mean	std. Dev.
SALES INDEX	1.73	12.61	10.88	4.89	2.06

Figure 1: Sales Index Variable Descriptive Statistics

Stores in the sample were selected to operate within a limited geographic region that had similar climatic conditions, and to have constrained ranges of size and age. The geographic region has a relatively sunny climate. All of the stores in the data set are one story.

The retailer was also able to provide us with additional data about each store, which included:

- Square footage of store
- Hours of operation
- Location (zip code)
- Date of original construction
- Date of most recent major renovation
- Historical "type" of store, which influenced basic construction and architecture. (Any location which was not built by the chain as new construction, was extensively renovated to conform to the company's design norm)

3.3.2 Census Data

In addition, we wanted to control for potential demographic effects of each store location. The retailer did not provide us with demographic information about the store locations, so we used census data tied to the zip code location of each store. To do this, we added two fields of data derived from the U.S. 1990 Census: population and average household income per zip code.

This demographic information is only a proxy for the influence of store location. We would have preferred a population density measure in stead of raw population per zip code, but that information was not easily available. We do not know how representative the zip code location is of the population actually served by the store. The store could be located on the edge of a zip code boundary and more predominately serve other neighboring zip codes. We don't know how large each store's territory is. In some cases sales may be reduced by other members of the chain that are close by, reducing the effective population served by each store. We also don't know how many competing companies are within the territories for each store. Presumably some locations have more competition than others do.

A more sophisticated analysis would have also included a measure of the number of competitors within a given range, more information about the demographic characteristics of the population served by the store, and perhaps also information about a store's relation to various traffic corridors. Internal analysis might also have included information about the experience of individual store managers, or other measures of how well the sales staff might be expected to perform. However, this information was not available to us, and therefore we cannot account for the influence of these variables.

3.3.3 On-site Observations

The design and operation of all the stores is remarkably uniform, with the exception of the presence of skylights in some, and the raised ceiling and lighting controls associated with the skylights. The electric lighting was primarily fluorescent, designed to provide a target illumination of 50 horizontal footcandles throughout the store, with some supplemental highlighting provided by occasional incandescent and/or HID lamps.

The skylights often provided far more illumination, often ranging from 100 to 250 footcandles horizontally in the aisles. Photo-sensor controls turned off some of the fluorescent lights when daylight levels exceeded target illumination. At night, all stores, skylit and non, have similar levels of illumination. The skylights are all diffusing, meaning that no image can be seen through the skylights, and any beam of sunlight is widely scattered.

We visited one dozen of the stores to confirm the information in the data set, and perform some on-site observations. All site visits were performed during the day; we also never visited a site during inclement weather. On-site observations involved walking around the public areas of the store, observing and interviewing customers and staff. The dozen stores visited included three of the highest ranked stores, three of the lowest ranked stores, and the remainder in the middle range. We also visited three stores that were not included in the data set (because they were outside of the size or age constraints).

The focus of these site visits was to see if there was any other obvious influence on sales that we should explore further, or if there was any obvious correlation

between skylighting and some other aspect of store configuration or operation that we should try to test for. We also used the site visits as an opportunity to probe how the skylights might potentially have an effect on sales. Figure 2 below tabulates these site visits.

Site Visits:	Skylit	Non Skylit	Total
In Data Set	9	3	12
Not in Data Set	1	3	4
Total	10	6	16

Figure 2: Retailer Site Visits

One store listed in the data set as not having skylights, actually did. One store listed as a certain type, was of a different type. So we made those two corrections to the data. There were no other discrepancies observed with the data set. Based on this sub-sample finding an error rate of 8% for two fields, and our correction for these two fields, there could potentially be a remaining error rate in the data set of about 7%. However, other than two on-site discrepancies, we found the data set to be very clean and reliable. There were no missing fields, or values out of range or with suspiciously repeating values. This is consistent with the observation that since the retailer uses this data for their own analysis, one would expect any errors to have been uncovered and corrected in earlier usage.

Thus, we believe the data set to be highly reliable.

Retailer Observations:

Other than the presence of skylights, the skylit stores have two other features that differentiate them from the non-skylit stores: higher ceilings and photosensor control of the lights under the skylights. No other systematic difference between skylit and non-skylit stores was observed.

The store design of the retailer in this study would best be described as an exemplary skylighting application. The skylights diffuse any sunlight so that there is even illumination below. The design provides high illumination levels during peak daylighting conditions. The electric lighting design throughout the stores is carefully thought out in relation to the skylighting and consistently applied. Strategic display lighting and highlighting are used in both the skylit and non-skylit stores. Quality lighting design is very clearly considered part of the merchandising strategy for the chain.

A sampling of stores, both with and without skylights, found seemingly equal attention to other design elements such as building façade, signage presence on the street, and parking lot size and accessibility. All of the stores were laid out in nearly identical fashion, so that similar items were located in similar places.

Stores of the same vintage had similar signage and decoration within the stores. The individual stores are managed at the corporate level, so management and advertising is extremely similar between sites.

Interviews

Informal interviews with shoppers repeatedly confirmed that the vast majority of shoppers were not aware of the skylights. The questioner would approach a shopper and ask: "May I ask you a question?" The response was universally affirmative. The questioner then asked, "What do you think of the skylights in this store?" The typical response was to look up, look puzzled, and then say, "That's funny. I never noticed them before." Out of 42 interviews in 10 skylit stores, only three shoppers could be found who were already aware of the skylights. Two of those volunteered that they had only noticed the skylights because their small child had pointed them out on an earlier trip, while looking up at a balloon or other bright object.

The questioner then asked, "Does this store feel any different to you than other stores like this?" By far the most common response (80%) was, "This store feels cleaner." The second most common response (65%) was, "It feels more spacious, more open." About one third of the respondents also mentioned that it was brighter. Three middle-aged respondents volunteered that they specifically came to this store instead of another closer to their home because they liked how it felt—cleaner, more open. Three elderly respondents commented on how important the brightness and the light quality were for them (although none had been aware of the skylights). Two middle-aged respondents talked about how important natural light was. Two older men commented that the energy savings must be considerable. Not one respondent objected to the skylights or had any negative comments about them.

Five store managers were interviewed about the skylights. All were positive about them, and reported they thought their customers liked them. Two mentioned the importance of energy savings. One commented on the "inviting feeling" the skylights created. Six store clerks were also interviewed: three were generally indifferent to the skylights; one claimed they were irrelevant, stating, "They make no difference."; two were very positive, one saying, "I love them."

3.4 The Analysis Process

The data from the retailer, the census, and the site visits were entered in the statistical analysis software program SPSS to run multivariate linear regression models.

After all the variables of interest were entered into the model, the residuals were calculated for each store record. The residual for a record is the actual value of the dependent variable for that record, minus the value predicted by the regression equation. The store sites with the greatest absolute value for their residuals were considered to be the outliers. Once an outlier was identified, an

indicator for that site was entered into the model in order to represent the influence of the outlier on the model. A judgement was made by the analyst on the number of outliers to be entered into the model, according to the distribution of the residuals.

The full regression equation was run again in SPSS, this time including the newly identified outlier indicator variables. The same process was performed to identify any additional outliers that may have become more influential due to the addition of the first set of outliers, until a final model was settled on that identified all the extreme cases.

The next step in the process was to use the backward elimination method to select the subset of independent variables that were most significant in the model. The backward elimination method removes the least significant predictor at each step. The skylighting variable had to achieve a significance of 0.05 for inclusion in the model (95% statistical certainty). Other variables were dropped if their statistical significance was less than 0.10 (90% certainty of an effect). We used a lower standard of significance for the non-skylighting variables as a conservative method to include all potential influences, which might reduce the impact of skylighting.

As the last step in the analysis, a step-wise regression was performed to determine the explanatory power of each variable included in the final models. The step-wise regression calculates the R^2 for each additional variable added to the model, in order of influence. This is termed the “explanatory power” of each independent variable, as it is a function of both the magnitude and the certainty of the observed effect. The R^2 for each variable reflects its ability to effectively explain the variation of the data found in the data set. The most powerful explanatory variables enter the step-size regression first, and the least power, but still significant, enter last.

4. FINDINGS

The regression model calculates a B-coefficient for each independent variable, along with a standard error. The B-coefficient reports the magnitude of the effect on the dependent variable of a one-unit change in the independent variable. The standard error reports on the spread of the findings for that variable, and is used to calculate a number of statistical tests to predict the certainty of the observed effect.

4.1.1 The Regression Equation

The results of the retailer regression are graphed in Figure 3 below. This graph clearly shows the magnitude of the B-coefficient for skylighting compared to the other significant variables. We discuss each variable in turn.

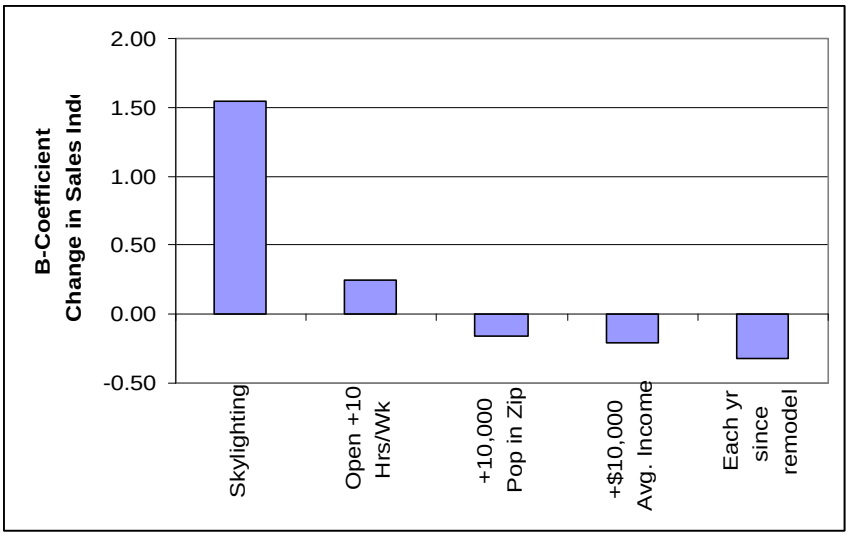

Figure 3: Change in Sales Index per Variable

Skylighting: Skylighting in this study is a simple yes-no variable, so there is no multiplier here. A store with skylights is observed to have a sales index higher than an equivalent store without skylights. This is clearly the largest effect of any of the variables considered, at B=+1.55. It is possible that there may be other reasons that the skylit stores are performing so well as a group. In our site visits, we made every effort to try to identify other characteristics of the skylit stores that might contribute to higher sales, but we did not find any obvious candidates. However, that possibility should always be kept in mind when examining these results.

Population and Income: The negative effects shown here might seem to be counter intuitive. One might expect that having more people in the zip code where the store is located, and especially having a higher average income would

instead produce a positive effect on sales. However, the negative effect may occur since more densely populated and higher income areas may attract more competition, both from within the chain and from outside competitors. Indeed, on our site visits we noted that the stores in the chain did seem to be more closely spaced together in higher income areas. This was not confirmed in any formal fashion.

Hours per Week: Opening more hours per week is seen to have a weak positive effect on store sales. Ten additional hours of operation per week shows a sales index increase of 0.2. The small effect here may be a function of the compressed range of hours possible for the stores in this chain, or the likely possibility that the optimum hours of operation for each store location have already been determined and implemented.

Years Since Remodel: The number of years since the last full remodel of the store is a highly significant variable. Each year since the last remodel shows a negative effect. A store which was last remodeled five years ago, has lost about as many sale index points as a skylit store gains. Thus, according to this equation, if the chain remodeled all of their stores at least every five years the effect would be of the same magnitude as adding skylights to all of the stores.

Figure 4 below presents the results of the regression equation in tabular form. The variables are ordered by their B-coefficients. Other columns list the standard error, the student's t-test statistic, and the significance of the variable. Later we will also discuss the order of entry and the change in R^2.

SIGNIFICANT VARIABLES:	B	Std. Error	t	Sig.	**Order of Entry**	**Change in R^2**
(Model Constant)	2.47	1.52	1.63	0.106		
Skylights	**1.55**	**0.36**	**4.35**	**0.000**	**5**	**0.04**
Hours open per week	0.02	0.01	2.65	0.009	1	0.16
Population (per 10,000)	-0.16	0.08	-1.99	0.049	9	0.02
Average income ($10,000s)	-0.20	0.10	-2.03	0.045	8	0.01
Years since last retrofit	-0.32	0.06	-5.12	0.000	3	0.09
Outlier 97	6.91	1.41	4.90	0.000	2	0.12
Outlier 57	4.98	1.44	3.47	0.001	7	0.05
Outlier 94	4.23	1.43	2.97	0.004	4	0.05
Outlier 15	5.82	1.57	3.70	0.000	6	0.04
					Model R^2	**0.58**
NON SIGNIFICANT VARIABLES:		Store types				
		Gross square feet				
		Years since original opening				

Figure 4: Retailer Regression Findings

The table shows that the skylighting variable has the strongest positive effect on sales of all variables considered. Skylighting has a B-coefficient of 1.55, with a significance of 0.000. The B-coefficient tells us that the presence of skylighting will raise the sales index for a given store by 1.55 points. The significance value tells us that there is 0.000 probability that this finding could be a null effect. The

inverse of this is stated more intuitively, that there is a 99.9% certainty that this is a true effect associated with skylighting.

The R2 value for a model is usually interpreted to be its explanatory power. The R2 for this model is 0.58. In other words, 58% of the variation found in the data is explained by the variables included in the model.

The order of entry is an important indicator of the explanatory power for each independent variable. In a stepwise regression, the variables that have the most power to explain the variation in the data enter the model first. Figure 4 shows that the skylight variable enters the model as the 5th most powerful variable, after two outliers and the hours of operation and years since remodeling. When the skylighting variable is added, it comes with a delta R2 of 0.04. This tells us that the skylighting variable is responsible for explaining an additional 4% of the variation found in the data set.

While our results are based on a linear multivariate regression analysis, it is possible that the effect of skylighting on sales is not a linear function. We did not investigate the potential for non-linear relationships in the data set.

4.1.2 Other Variables

In examining the model it is also interesting to note which variables have dropped out. In this case, the historical type of store (4 types) and, perhaps surprisingly, the square footage of the stores, have dropped out as insignificant. The scatter plot of the store sales vs. square footage in Figure 5 makes it visually clear that there is not a linear relationship between the size of the store and sales. It should be remembered that the size of the stores within the sample was constrained so that the stores considered were all about ±20% of the sample mean.

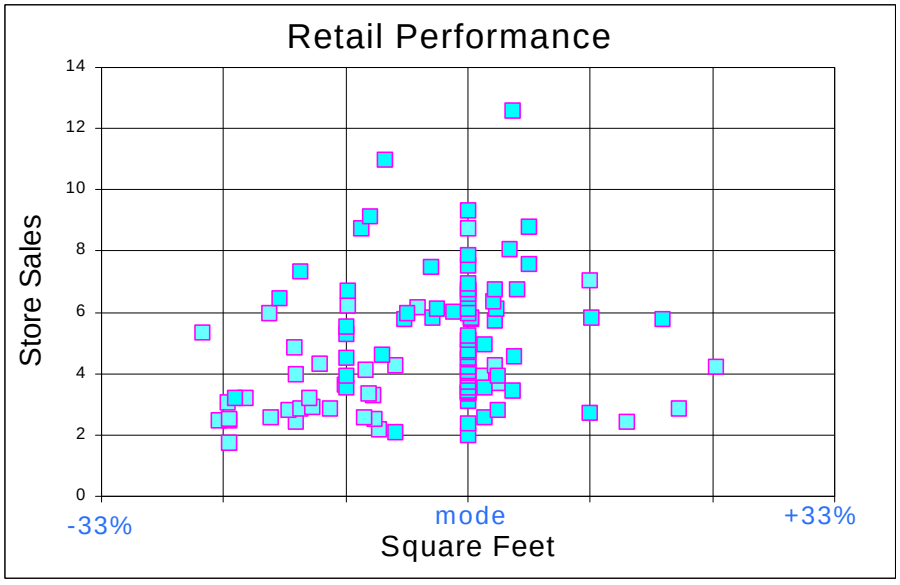

Figure 5: Scatter Plot of Store Sales vs. Square Footage

This scatter plot suggests that while there may not be a linear relationship between the size of the store and the gross sales, there appears to be a non-linear function, with optimum performance tending towards the mode of the store size. The retailer has clearly picked this mode as their standard store size. We also tested for a nonlinear relationship to square footage in the regression equation, and found it not significant (p-value=.71).

An examination of the data set shows that skylit stores do have different average characteristics than non-skylit stores. Skylit stores tend to be slightly larger and less frequently remodeled than non-skylit stores. They also tend to be operated for more hours per week. The following graphs in figures 6-8 show the relationship of the characteristics of the skylit stores to the non-skylit stores. Figure 6 graphs the average size of skylit, non-skylit, and all the stores, along with the standard deviation of the size, Figure 7 similarly graphs the months since most recent remodel for the stores, and Figure 8 the hours of operation per week.

The vertical scales have been removed to avoid breaching confidentiality. They do not cross the X-axis at zero.

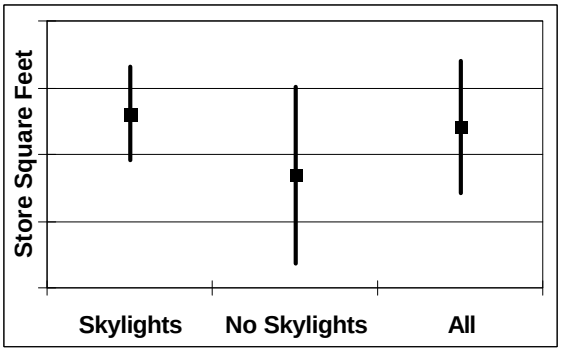

Figure 6: Size Range of Stores

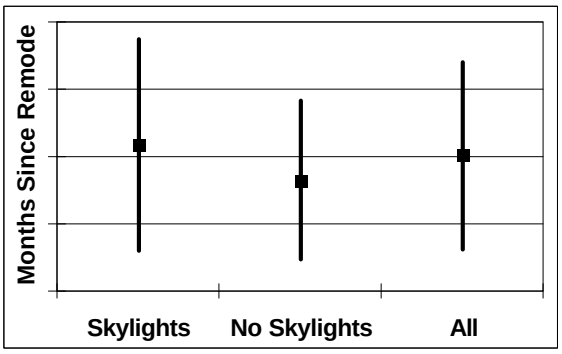

Figure 7: Age Range of Stores

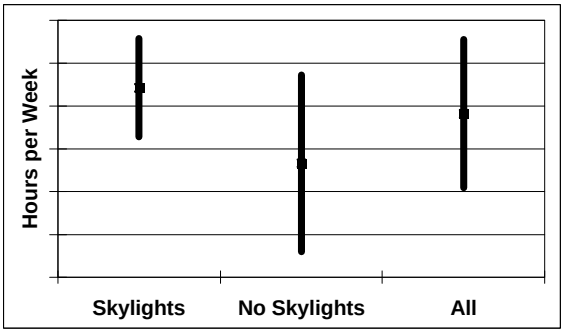

Figure 8: Hours per Week

From these graphs we can see that while the skylit stores tend to be slightly larger (by 9%), less recently remodeled, and open longer hours, there is sufficient variation and overlap within the data for both categories of stores to allow competent analysis of these variables.

We examined correlations between skylighting and all other variables, and found only two to be statistically significant: square feet (correlation 0.4) and years since original opening (–0.5). However, neither were statistically significant when included in the regression model (p-value of .87 and .54 respectively), and the B-coefficient of the skylighting variable remained essentially unchanged and highly significant with their inclusion (p-value=0.001). Therefore we concluded that the correlations with these variables did not compromise the validity of our model.

5. DISCUSSION AND CONCLUSIONS

It is useful to try to translate the results of the model into terms that can be applied to other situations. In this analysis, we were not able to describe the absolute dollar value of the skylighting variable. Therefore we will try to describe the relative effect of the presence of skylighting on sales in other ways.

5.1 Interpreting the Retailer Results

One way to look at the results is: how might adding skylighting impact the average store currently without skylights? The results of the regression equation predict that adding skylighting to the average non-skylit store within the chain would be likely to improve its performance by 40%, with a probable range between 31% and 49% (± the standard error). Thus, if this non-skylit store were averaging sales of $2/SF, then its sales might be expected to increase to between $2.61 and $2.98 with the addition of a skylighting system.

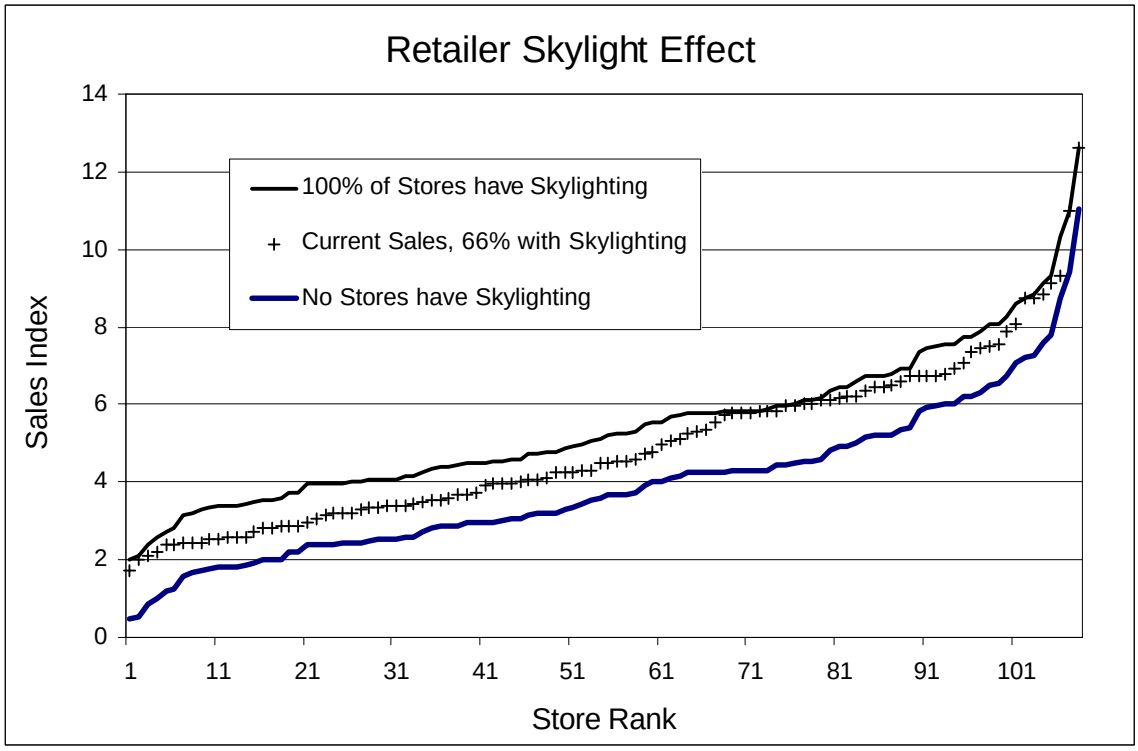

Figure 9: Chain-wide Sales Index with and without Skylighting

An alternative way to think about the impact of the skylighting is to ask how skylighting affects the overall gross sales for the chain as a whole. Currently 66% of the chain's stores have skylighting. If the chain added skylights to the rest of its locations, what effect would that have on gross sales? Because the linear

regression equation gives us one value for all skylit stores, adding skylighting to a high performing store will have relatively less impact than adding it to a low performing store. Figure 9 shows the distribution of the sales index across all stores in the data set, and the relative magnitude of the skylighting effect for the chain.

Figure 9 also shows both the effect of adding skylighting to all stores in the chain, and the effect of removing the skylighting from all stores. The difference is dramatic. If this particular chain were to add skylighting to the remaining 34% of its stores, their chain-wide sales could increase by 11%.[1] The difference between no skylighting in any of the stores and skylighting in all of the stores is a likely 40% increase in chain-wide gross sales.[2]

It should be remembered that there were many other variables not considered in our analysis, such as the number of competitors within a store's territory. Also, in spite of the apparent uniformity of the stores, there may be operational differences between skylit and non-skylit stores that were not visible to the observer. For example, the air temperatures might be slightly different, or they may tend to use different music play-lists that somehow affect sales. If such additional variables could be properly identified and found significant in the analysis, then magnitude of the skylighting effect would probably be reduced somewhat.

There is no way to know how these results would translate to another retail chain. A different chain would have a different distribution of sales per store, which would change the percentage effect. It is, of course, also unknown how skylighting of a different design would affect a store with different operations. The results of the regression equation are specific only for this data set. However, we can say that there clearly seems to be a positive effect to skylighting, and it is quite significant.

Mechanisms

With this analysis, we have shown a clear relationship between skylighting and increased sales, and quantified the effect for this particular chain. The next question that arises is why does this happen? What is causing the increased sales?

Unfortunately, this kind of analysis cannot prove that skylighting causes increased sales. It can only demonstrate that there is a strong correlation between the presence of skylighting and increased sales. The reason for the

[1] The chain wide gross sales for 100% skylighting is calculated by adding the B-coefficient for skylighting, 1.55, to the existing sales index for each store in the chain which currently does not have skylighting.

[2] The chain wide gross sales for no skylighting is calculated by subtracting the B-coefficient for skylighting from the current sales index for all the stores in the chain that currently do have skylighting. The chain wide gross sales for 100% skylighting is then divided by that for no skylighting to produce the percentage effect.

effect is left to hypothesis at this point. Below we discuss a number of possible mechanisms for such an effect.

Customer Loyalty: In our interviews, it was clear that customers were not consciously aware of the skylights. But a number of them did express loyalty to a skylit store, because it seemed cleaner, or had better lighting. A few mentioned that they did routinely travel a little farther to shop at a skylit store over another option closer to their home. This informal survey suggests that there may a customer loyalty effect to skylights. This would translate into a competitive advantage in attracting and keeping more customers.

More Relaxed Customers: It may be that once a customer is in the store the skylights somehow relax them, in a manner similar to piped-in music that has been found so effective at relaxing customers and encouraging them to spend more time in a store shopping. We do know from interviews that customers seem to have positive feelings about the skylit stores and identify those stores with an airy, clean feeling.

Better Visibility: The high daytime illumination levels along with improved lighting quality from the daylight may make it easier or more comfortable for customers to select products. Especially for elderly customers with declining eyesight, labels are likely to be more legible during the peak daylight hours. It may be easier to find products and/or discriminate between alternatives with daylight illumination.

More Attractive Products: The skylights may make products seem more attractive, inducing customers to buy more expensive products, or simply more products than they otherwise would. It is possible that the visual quality provided by daylighting, with high color rendition and three-dimensional modeling, may make products look more appealing.

Employee Morale: It could be that employees have higher morale, and as a result provide better service. We did not have any way to measure employee productivity. Ultimately, in a retail environment, employee productivity would be measured by sales per employee hour. Logically, if there are higher sales per store, and no increase in the staffing level, there will also be higher sales per employee hour.

Any one of these mechanisms, or all of them, may be responsible for the increased sales. The actual mechanism may not be as important as determining the design characteristics of a high performing skylighting system. In order to apply these findings to other retailers, and other organizations, it would be useful to understand which qualities of skylighting are the most influential. At this point in time, that information may best be obtained from a knowledgeable designer with substantial daylighting experience, rather than a scientific study.

Applying the Results outside of Retail

Another important question to consider is whether these results translate outside of the retail sector. If skylighting is associated with higher sales, does that mean it will increase productivity in a manufacturing building, or improve morale in an office building or reduce absenteeism at a postal facility. If so, by how much? The answer is, of course, that we don't know.

However, in the companion study, we have shown that daylighting is strongly associated with better performance in elementary school students. Considered as a whole, the two studies suggest that there is a general principle at work whereby daylight affects human beings in a positive way. Furthermore, these studies indicate that when this effect can be quantified, the impact can be quite significant.