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# LIFE CYCLE COSTS FOR LOW-RISE CONCRETE AND STEEL FRAMED OFFICE AND RETAIL BUILDINGS

by John Gajda, Peter Taylor, and Martha VanGeem

## KEYWORDS

Buildings, Concrete, Cost, Energy, Life cycle, Modeling, Steel

## ABSTRACT

Building material and construction decisions are often made solely to minimize the initial cost of construction. Although the construction cost represents a significant portion of the total costs associated with the life of a building, energy costs for heating and cooling and maintenance costs are considerable over the life of a building and must also be considered. A building constructed of inexpensive materials may have total life cost that greatly exceeds that of an identical building constructed with more expensive materials.

A life cycle cost analysis is a powerful tool used to make economically sound decisions for selection of materials. Currently, no single software package can perform a robust life cycle cost analysis of buildings. Individual software packages are available for gathering initial costs, maintenance costs, modeling of the energy costs, and assembling costs as life cycle costs. This report describes a method for determining energy consumption using one software program and using that as an input for life cycle costing software. Two prototypical low-rise buildings with construction material variations were modeled using this approach.

The two buildings, one retail and one office, were modeled in three climatic zones of the U.S. The retail building consisted of a one-story square building; typical of stand-alone retail or convenience stores located in suburban or rural locations. The office building consisted of a typical suburban two-story square building. Each was modeled using a steel or concrete construction alternative to compare the life cycle costs for the two construction types over a twenty-year period. Initial capital, energy, and total life cycle costs were found similar for the concrete and steel alternatives for both building types in all three climates.

## REFERENCE

Gajda, John, Taylor, Peter, and VanGeem, Martha, *Life Cycle Costs for Concrete and Steel Framed Office and Retail Buildings*, R&D Serial No. 2410, Portland Cement Association, 2000, 44 pages.

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John Gajda, Peter Taylor, and Martha VanGeem*

## INTRODUCTION

A life cycle cost analysis is a powerful tool used to make economically sound decisions for selection of materials. Life cycle cost analysis is the practice of accounting for all expenditures incurred over the lifetime of a particular structure. Costs at any given time are discounted back to a fixed date, based on assumed rates of inflation and the time-value of money. Using this widely accepted method, it is possible to compare, in a fair way, the economics of alternatives which may have different cash flow factors but which provide a similar standard of service. The result is financial information for decision making, which can be used to balance capital costs and future repair or maintenance costs.

For bridges and pavements, the bulk of the costs are in construction, maintenance, and repairs. Software for such structures tends to emphasize these aspects. For buildings, the bulk of the costs are for construction, and heating and cooling energy, with little maintenance costs. However, energy costs are usually not considered and building decisions are often made solely on the basis of the initial or construction cost.

Currently, no single software package can perform a robust life cycle cost analysis of buildings. Two building-related life-cycle-cost software packages available require energy consumption as an input. These software packages do not assist in determining the required energy input values. Because of this, energy consumption needs to be determined using energy usage software and then used as an input for the life cycle cost software. This report describes the methodology and software used in performing life-cycle cost modeling of two standard buildings in three different climatic zones.

Two *prototypical* low-rise buildings, one retail and one office, were modeled. Their configuration was based on prototypical buildings used in the development of ASHRAE Standard 90.1-1999[1]. The retail building consisted of a one-story square building with windows on one facade. The total building area was approximately 12,000 square feet. The building is typical of stand-alone retail or convenience stores located in suburban or

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rural locations. The office building consisted of a typical two-story square building. The total building area was approximately 22,000 square feet. Windows were equally distributed on all four exterior walls. The office building was typical of suburban office buildings.

The buildings were assumed to be constructed of typical steel or concrete construction materials. The steel framed building consisted of a steel deck roof, steel stud exterior walls with portland cement stucco on the exterior, insulation, and interior gypsum wallboard, and a 6-in. concrete slab-on-grade floor. The concrete building consisted of a 4-in. precast roof deck, 8-in. concrete masonry walls with interior insulation and gypsum board, and a 6-in concrete slab-on-grade floor. Insulation was selected to meet the minimum standards prescribed in ASHRAE Standard 90.1-1999 depending on the climate assumed and wall construction material. Windows were selected to meet the minimum standard prescribed in ASHRAE Standard 90.1-1999 depending on the climate assumed and did not vary with building construction.

The buildings were modeled in three climates; Detroit, Michigan as the cold climate; Tampa, Florida as the hot and humid climate, and Phoenix, Arizona as the hot and dry climate. The analyses used 30-year historical average weather data.

Life cycle costing of building energy consumption can be compared using any of several energy usage models. The model used for this analysis was Visual DOE 2.6[2].

Life cycle costing for building construction and maintenance were carried out using the National Institute of Standards and Technology "Building Life-Cycle Cost" version 4.51 (BLCC) software[3] and the University of Illinois WinLLCID software[4] (WinLCC) for comparison. Energy consumption data derived from the Visual DOE 2.6 analyses were used as input to these programs.

## THE COMPUTER MODELS

This section provides brief descriptions of the different computer models used in this project. Details of their use are given in Appendices A through C for those who may desire to model other buildings.

## Visual DOE2

Visual DOE 2.6 is a Windows™ based program that allows users to model the energy use of buildings. The software allows the user to model buildings, alternative buildings, building components, and building systems to evaluate strategies for energy savings. The software uses the DOE2.1-E hourly simulation tool as the calculation engine so that hourly energy usage and peak demand are accurately simulated and evaluated.

Within the software, the building is graphically constructed. Separate HVAC zones, and building systems are literally dragged and dropped into place. The software has the ability to model many buildings from simple to complex. The software allows the user to customize the usage of a building. This feature allows for accurate prediction of the energy use from extended hours, equipment upgrades, or modification of building usage.

## BLCC 4.5

The Building Life-Cycle Cost software from the National Institute of Standards and Technology (NIST) provides economic analysis of capital investments, energy, and operating costs of buildings, systems or components. The software includes the means to evaluate costs and benefits of energy conservation. It complies with ASTM standards related to building economics[5] and Federal Energy Management Program requirements.

The software is DOS™ based and can be launched from the Windows™ operating system. The software operates as a batch system in which data input is handled using a "Quick Input" program. The output is a text file that can be read by spreadsheet or word-processing software.

## WinLCCID 98

The WinLCCID 98 software from the University of Illinois is similar to BLCC except that it is written for the Windows™ operating system. Input parameters are similar except the program is designed to use energy costs from the U.S. Department of Energy BLAST™ software, one of a suite of life cycle assessment programs maintained by the University of Illinois.

For this report, energy requirements from Visual DOE 2.6 were used as input in BLCC and WinLCC.

# BUILDING DESCRIPTIONS

This section describes the two buildings that were modeled, including the construction materials, dimensions, and other assumptions.

## General

Both buildings were square in plan to reduce the influence of solar effects due to orientation. Windows were selected to meet the minimum energy efficiency standards prescribed by ASHRAE Standard 90.1-1999, as presented in Table 1. Windows were assumed to be non-operable. Both buildings were assumed to be of new construction. Neither building contained interior partition walls in order to facilitate simpler modeling.

Hot water delivered to bathrooms was provided by natural gas fired hot water heaters. Efficiencies of HVAC systems were assumed to be identical for both buildings and construction variations. Sizing of the HVAC equipment was performed automatically by the analysis program. Daylight control of the office building was by interior manually operated blinds. The retail building did not have daylight control.

The lighting and equipment power densities of the buildings were set to the default values provided in the analysis software. For the office building, the default equipment power density was 0.75 watts/ft$^2$ and the lighting power density was 1.50 watts/ft$^2$. For the retail building, the default equipment power density was 0.25 watts/ft$^2$ and the lighting power density was 2.60 watts/ft$^2$. The electricity required for exterior lighting (independent of the lighting power density) of the office and retail buildings was 9,378 kWh and 40,150 kWh, respectively. Exterior lighting was based on ASHRAE 90.1 NEM4-1995[6].

**Table 1 - Window Requirements and Assumptions**

| Location | Type | Minimum Requirements | | Selected Windows | | | |
|---|---|---|---|---|---|---|---|
| | | Maximum U-factor* | Maximum SHGC** | Visual DOE Window ID | U-factor* | SHGC† | VLT†† |
| Detroit | Office | 0.57 | 0.39 | Double Tint Pyr. | 0.479 | 0.294 | 0.228 |
| | Retail | | | Double Clear Pyr. | 0.479 | 0.347 | 0.307 |
| Tampa | Office | 1.22 | 0.25 | Single Clear LR13 | 0.879 | 0.229 | 0.130 |
| | Retail | | | Double Tint Low E Argon | 0.232 | 0.232 | 0.407 |
| Phoenix | Office | 1.22 | 0.25 | Single Clear LR13 | 0.879 | 0.229 | 0.130 |
| | Retail | | | Double Tint Low E Argon | 0.232 | 0.232 | 0.407 |

* U-factor in units of Btu/hr·ft$^2$·°F

** Solar heat gain coefficient in a non-north orientation.

† Solar heat gain coefficient at a 60° angle of incidence.

†† Visible light transmission.

Hours of operation of the office building were 2,966.8 hours per year. This corresponds to approximately 11¾ hours of operation per day, Monday through Friday, excluding holidays. Hours of operation of the retail building were 3,889.75 hours per year. This corresponds to approximately 10¾ hours of operation per day, every day except holidays. The operating hours of the retail and office buildings were based on ASHRAE 90.1 NEM4-1995.

All roofs were constructed of a medium colored built-up asphalt roofing material with a coefficient of solar absorption of 70 percent. This value is commonly used as the default value for most computer simulation programs. No exterior shading was assumed around the buildings. This assumption is typical for new construction in rural and suburban locations.

Air infiltration rates of the buildings were based on ASHRAE Standard 62-1989[7]. The air infiltration rate for the office building was 0.82 air changes per hour (ACH). The air infiltration rate for the retail building was 1.42 ACH. The occupant densities of the office and retail buildings were 7 and 15 people per 1000 $ft^2$, respectively. Occupant densities were based on ASHRAE 90.1 NEM4-1995.

## Office Building

The office building was a two-story building with plan dimensions of 105 x 105 ft and total floor area of 22,050 $ft^2$. The height of the building was 20½ ft. The resulting gross wall area including windows was 8,610 $ft^2$. The window-to-wall ratio (WWR) was 20 percent. This is typical of office buildings across the U.S., and was used by others in the development of ASHRAE 90.1 NEM4-1995. All facades were identical. On each facade, there were 20 identical windows measuring 5½ ft wide by 4 ft high. Windows were flush mounted (non-recessed) and were equally spaced. Figure 1 presents the assumed office facade.

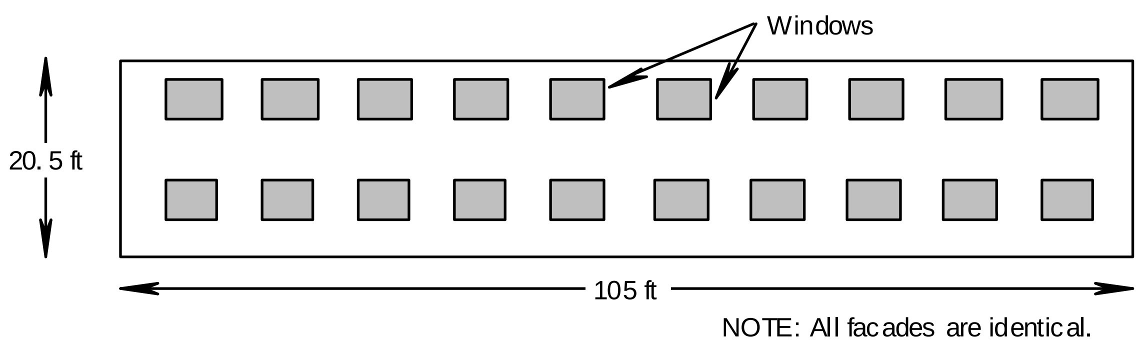


**Figure 1 - Office Building Facade**

## Retail Building

The retail building was a single-story building with plan dimensions of 110 x 110 ft and total floor area of 12,100 $ft^2$. The height of the building was 10¼ ft. The resulting gross wall area including windows was 4,510 $ft^2$. The WWR was 15 percent. This is typical of small retail buildings across the U.S., and was used by others in the development of the ASHRAE 90.1 NEM4-1995. The building had all windows placed on one facade. This is representative of the majority of the retail buildings in the U.S. Figure 2 presents the assumed retail building facade with windows. Since HVAC loads and lighting levels are dependent on the window orientation, an analysis was performed with the windows oriented in each of the four cardinal orientations.   Results for the four orientations were averaged to provide an average result free of orientation bias.

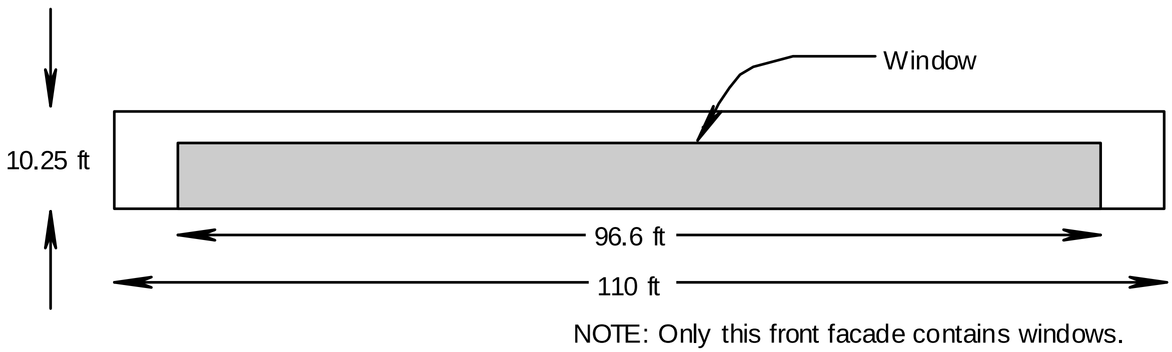


**Figure 2 - Retail Building Front Facade**

## Concrete Construction

The concrete building variation consisted of a concrete slab-on-grade floor, reinforced concrete masonry walls, precast concrete intermediate floors (if applicable), and a precast concrete roof.  Specifically, the walls consisted of medium-weight concrete masonry units (CMU) with interior steel studs.  Steel studs were required for attachment of ½-in. painted interior gypsum board and insulation.  The level of insulation was the minimum required by ASHRAE Standard 90.1-1999 for the locations analyzed, as presented in Table 2.  In locations where insulation was not required, drywall was attached to wood furring strips fastened to the CMU wall.

The roof consisted of a 4-in. thick precast concrete deck.  For all locations, R-15 board insulation was placed on the deck, as required by ASHRAE Standard 90.1-1999.  A built-up asphalt roofing material was applied to the insulation.  A spray-on textured finish material was applied directly to the bottom side of the deck.  The interior floor of the office building consisted of a 4-in. thick precast concrete slab with a 1-in. thick concrete topping slab.  The top side was carpeted.  A spray-on textured finish material was applied directly to the bottom side of the floor slab.  The ground-level floor slab was a carpeted 6-in. thick cast-in-place concrete slab-on-grade.

**Table 2 – Required Insulation Levels for Concrete Framed Buildings***

| Location | Component | Required Max. U-factor** | Actual U-factor*** | Insulation Utilized |
|---|---|---|---|---|
| Detroit | Roof | 0.063 | 0.062 | R-15 board |
| | Walls | 0.123 | 0.097 | R-11 batts |
| | Floor Slab | 0.730 | 0.216 | None |
| Tampa | Roof | 0.063 | 0.062 | R-15 board |
| | Walls | 0.580 | 0.190 | None |
| | Floor Slab | 0.730 | 0.216 | None |
| Phoenix | Roof | 0.063 | 0.062 | R-15 board |
| | Walls | 0.580 | 0.190 | None |
| | Floor Slab | 0.730 | 0.216 | None |

* Applies to both the office and retail buildings.
** The maximum U-factor. is the inverse of the minimum R-value. U-factor in units of Btu/hr·ft$^2$·°F.
*** The actual "clear wall" U-factor of the entire wall assembly. U-factor in units of Btu/hr·ft$^2$·°F.

## Steel Framed Construction

The steel frame alternative consisted of a concrete slab-on-grade floor, steel-stud walls, a steel-framed intermediate floor, and a steel-framed roof. Specifically, the walls were steel studs with the minimum level of insulation required by ASHRAE Standard 90.1-1999, as presented in Table 3. The interior consisted of ⅝-in. painted gypsum wallboard. The exterior consisted of ½-in. portland cement stucco over ½-in. backer board.

The roof was steel framed with a ribbed steel deck, ⅝-in. siliconized gypsum wallboard, R-15 board insulation, and a built-up asphalt roofing material. Siliconized gypsum board is required by a large number of insurers to prevent liquid asphalt from dripping through joints in the steel deck during a fire. Ceiling tiles were attached directly to the bottom side of the framing. The interior floor consisted of steel framing with a ribbed steel deck and a 3-in. concrete topping slab. The top side was carpeted. Ceiling tiles were attached directly to the bottom side of the floor framing. The ground-level floor slab consisted of a carpeted 6-in. thick cast-in-place concrete slab-on-grade.

The assumption of ceiling tiles applied directly to the bottom side of interior floors and the roof assembly was made primarily to simplify the analyses. Energy simulation models currently do not reliably model the space between a suspended ceiling and interior floor or roof.

**Table 3 – Required Insulation Levels for Steel Framed Buildings***

| Location | Component | Required Max. U-factor** | Actual U-factor*** | Insulation Utilized |
|---|---|---|---|---|
| Detroit | Roof | 0.063 | 0.062 | R-15 board |
| | Walls | 0.084 | 0.082 | R-11 batts and R-3 board |
| | Floor Slab† | 0.730 | 0.216 | None |
| Tampa | Roof | 0.063 | 0.062 | R-15 board |
| | Walls | 0.124 | 0.110 | R-11 batts |
| | Floor Slab† | 0.730 | 0.216 | None |
| Phoenix | Roof | 0.063 | 0.062 | R-15 board |
| | Walls | 0.124 | 0.110 | R-11 batts |
| | Floor Slab† | 0.730 | 0.216 | None |

* Applies to both the office and retail buildings.
** The maximum U-factor is the inverse of the minimum R-value. U-factor in units of Btu/hr·ft$^2$·°F.
*** The actual "clear wall" U-factor of the entire wall assembly.
† The ground floor slab is a concrete slab on grade. Intermediate floors do not have a required insulation value.

## Climates

The office and retail buildings were modeled in three climate locations. These climates were selected to represent a range of conditions from cold to arid to hot and humid. Detroit, Michigan represented the cold climate; Phoenix, Arizona represented the arid (hot and dry) climate; and Tampa, Florida represented the hot and humid climate. The locations selected are those typically used by others when modeling national energy use in buildings.

Analyses utilized Typical Mean Year, Data Set No. 2 (TMY2) weather data for all cities. These weather data consist of the average surface hourly weather for particular locations, compiled from 1961 to 1990.

## Construction and Maintenance Costs

Construction and materials costs were taken from Reference 8. Appendix D contains summaries of how the total costs for each building in each city were derived, including cross references to materials costs given in the reference. Factors for regional price differences and seismic requirements have been applied, as indicated in the reference.

Annual maintenance and consumable (excluding energy) costs were taken from Reference 9 for the three cities, as tabulated in Appendix E. There were no differences in maintenance costs for concrete or steel framed buildings.

## Other Assumptions

The life cycle comparison of the buildings was set at 20 years. At this time, it was assumed that the buildings would be extensively renovated to update current styling, use and building code compliance.

For ease of analysis and to generalize buildings across the United States, the buildings were assumed to be free of taxes. Discounting was assumed to be applied at the end of each year and the buildings were assumed to have a residual value of 80% of the present value dollar amount at the end of 20 years. Escalation rates for periodic capital purchases, such as replacement HVAC systems, were assumed to be 4% while the overall discount rate was assumed to be 8%. These are customary assumptions when performing life cycle cost analyses.

The computer models applied inflation rates to the energy consumables based on tables published by the Department of Energy. The input to the life cycle cost program was the fuel requirement for each building (in kWh or therms), a unit price for each at current rates and the assumed escalation rate (4%).

## RESULTS

The energy requirements of the steel and concrete buildings for each climate were found to not vary significantly depending on building type. This is not surprising because the buildings were similar in size and allocated similar insulating properties. A summary of the annual energy requirements for all the alternatives in this project is given in Table 4. Electricity use for the concrete buildings ranged from 2 to 6% less than the steel buildings. This is most likely due to the thermal mass effects of concrete during the cooling season. The concrete buildings in Detroit used more natural gas because they had less insulation than the steel alternatives and thermal mass is less effective in cold winter conditions.

Table 5 presents life cycle costs and energy based on the analysis conducted using the BLCC software. The differences in life-cycle costs of the various buildings are dependent on the initial capital costs. Capital costs were strongly dependent on the assumptions made regarding initial costs, especially unit costs of construction materials. This means the precision and accuracy of construction material costs can greatly affect the results of a life cycle comparison between buildings constructed of different materials. Good practice would be to perform the analysis with a range of material costs and other assumptions in order to gauge sensitivity.

In this case it was found that the difference in life cycle costs between using steel or concrete for the frame was less than 3%, which is considered to be less than the error in the assumptions used.

**Table 4 - Annual Energy Values Determined Using Visual DOE**

| Location | Building Type | Concrete | | Steel | | Difference, % | |
|---|---|---|---|---|---|---|---|
| | | Electricity, kWh | Gas, therms | Electricity, KWh | Gas, therms | Electricity | Gas |
| Detroit | Office | 230,000 | 8,268 | 242,000 | 7,423 | 5.2 | -10.2 |
| | Retail | 240,000 | 8,593 | 245,000 | 7,639 | 2.1 | -11.1 |
| Tampa | Office | 304,000 | 1,189 | 318,000 | 1,211 | 4.6 | 1.9 |
| | Retail | 298,000 | 1,793 | 315,000 | 1,650 | 5.7 | -8.0 |
| Phoenix | Office | 325,000 | 1,331 | 337,000 | 1,359 | 3.7 | 2.1 |
| | Retail | 320,000 | 1,793 | 327,000 | 1,891 | 2.2 | 5.5 |

Notes: Negative sign indicates steel used less energy.
Concrete values as base for percentage calculations.

**Table 5 – Twenty-Year Life Cycle Cost Data from BLCC**

| Comparison | | Detroit | | Tampa | | Phoenix | |
|---|---|---|---|---|---|---|---|
| | | Office | Retail | Office | Retail | Office | Retail |
| Concrete | Total LCC, $ | 2,523,000 | 1,462,000 | 2,110,000 | 1,243,000 | 2,239,000 | 1,322,000 |
| | Capital, $ | 1,208,000 | 582,000 | 1,049,000 | 512,000 | 1,147,000 | 560,000 |
| | Energy, $ | 301,000 | 313,000 | 327,000 | 324,000 | 350,000 | 349,000 |
| Steel | Total LCC, $ | 2,580,000 | 1,455,000 | 2,172,000 | 1,257,000 | 2,304,000 | 1,325,000 |
| | Capital, $ | 1,291,000 | 573,000 | 1,124,000 | 505,000 | 1,229,000 | 552,000 |
| | Energy, $ | 307,000 | 312,000 | 343,000 | 343,000 | 364,000 | 357,000 |
| Differences | LCC, $ | 57,000 | -7,000 | 62,000 | 14,000 | 65,000 | 3,000 |
| | LCC, % | 2.3 | -0.5 | 2.9 | 1.1 | 2.9 | 0.2 |
| | Capital, % | 6.9 | -1.5 | 7.1 | -1.4 | 7.1 | -1.4 |
| | Energy, % | 2 | -0.3 | 4.9 | 5.9 | 4 | 2.3 |

Notes: A negative sign indicates steel is less expensive.
Concrete values are the base for percentage calculations.

The BLCC program allowed an assumed general rate of inflation of 4% to be imposed over the escalation tables built into the software, however the WinLCC program did not permit this input parameter to be applied. This was the source of the only significant difference between the output from the two programs. The differences are illustrated in Table 6; where the output from WinLCC is shown along with two sets of outputs from BLCC, one with the inflation rate imposed and another with no inflation imposed. The data is for the steel office building in Detroit. When inflation is assumed to be 0%, both programs give similar results.

**Table 6 – Typical Life Cycle Cost Results from BLCC and WinLCC with Different Inflation Rates Imposed on Energy Cost Tables for One of the Structures***

| Costs, $ | BLCC | | WinLCC |
|---|---|---|---|
| | 4% | 0% | 0% |
| Initial | 1,291,000 | 1,291,000 | 1,291,000 |
| Annually occurring OM&R | 1,315,000 | 1,315,000 | 1,315,000 |
| Energy | 307,000 | 220,000 | 217,000 |
| Replacement | 152,000 | 152,000 | 152,000 |
| Residual | 485,000 | 485,000 | 488,000 |
| Total life cycle | 2,580,000 | 2,493,000 | 2,487,000 |

* Steel office building in Detroit.

## SUMMARY AND CONCLUSIONS

Currently, no single software package can perform a robust life cycle cost analysis of buildings. This report describes a method for determining energy consumption using the Visual DOE 2.6 software program and using that as input in BLCC and WinLLCID life cycle costing software. Two low-rise buildings, one retail and one office, were modeled. Each was modeled using a steel or concrete construction alternative to compare the life cycle costs for the two construction types over a twenty-year period. The retail building consisted of a one-story square building with windows on one façade and a total building area of approximately 12,000 square feet. This building is typical of stand-alone retail or convenience stores located in suburban or rural locations. The office building consisted of a typical two-story suburban office building with windows equally distributed on all four sides and a total area of approximately 22,000 square feet. The buildings were modeled in three climates regions; Detroit, Michigan as the cold climate; Tampa, Florida as the hot and humid climate; and Phoenix, Arizona as the hot and dry climate.

Initial capital, energy, and total life cycle costs were similar for the concrete and steel alternatives for both building types in all three climates.

## ACKNOWLEDGEMENT

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# APPENDIX A - VISUAL DOE 2.6

This appendix is intended to help those who may desire to model other buildings using Visual DOE 2.6. Information provided in this appendix is intended to cover the basics of the software. For specifics, please consult the on-line help or users manual.

Visual DOE 2.6 is relatively straightforward to use, although not all features or capabilities are user-friendly. Figure A1 shows the initial screen.

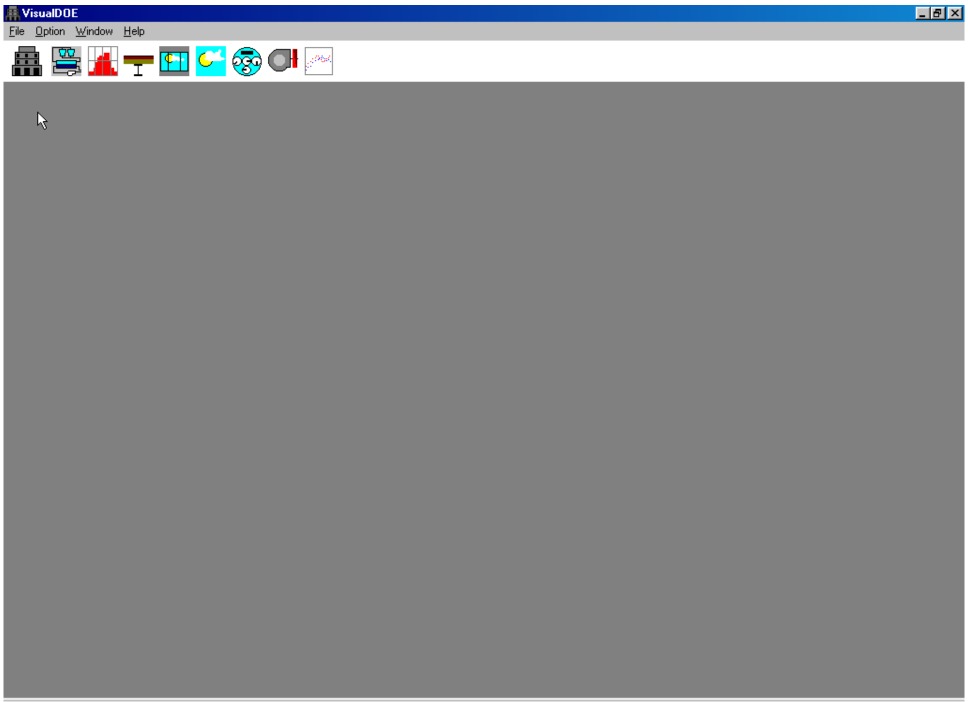


**Figure A1 – Visual DOE 2.6 initial screen**

Clicking on the building icon (above the cursor) in Fig. A1 brings up the graphic editor as shown in Fig. A2.

## Graphic Editor

The graphic editor is the section of the program in which all aspects of the building are defined. Figure A2 shows the basic information for the analyzed office building in Tampa. The six "tabs" (project, blocks, zones, facades, systems, and zone air), shown in Fig. A2, are used to define the building. The data required in each is described below.

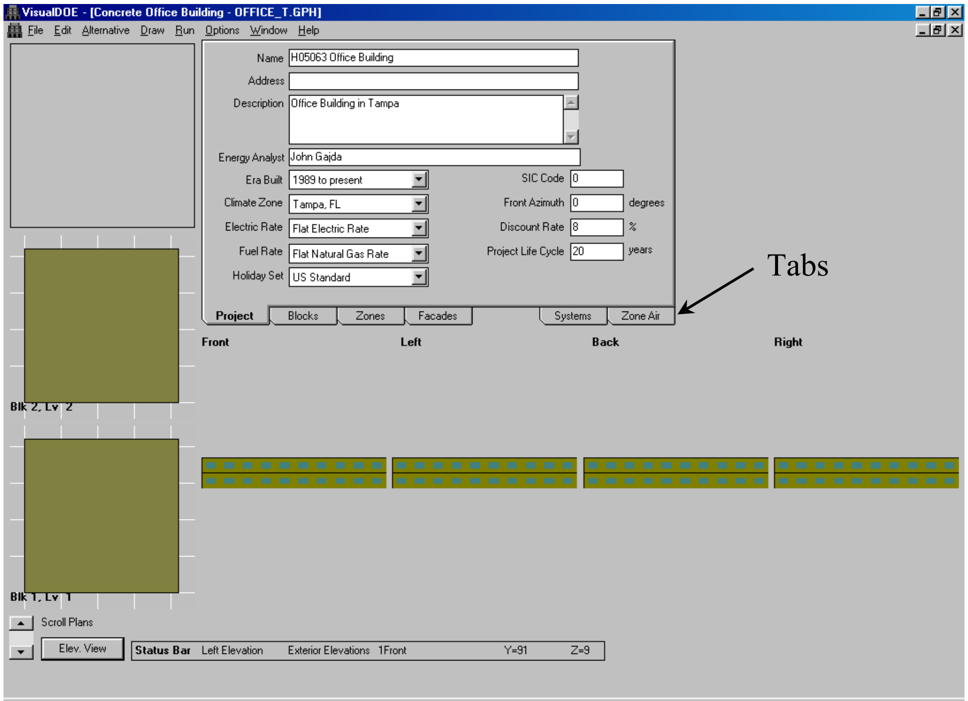


**Figure A2 - The graphic editor**

## Project Tab

The *Project* tab is used to define basic information regarding the project. This tab is shown in Fig. A2. The information entered in this tab is used for the base-case building as well any building alternatives. Therefore, it is not possible, in one analysis, to model the same building in different locations or with different life cycles. It is possible to model, in one analysis, the same building with different windows, exterior finishes, interior finishes, HVAC systems, or roof materials. The analyses presented in this report were run for each building type (office or retail) in the three locations (Detroit, Phoenix, and Tampa).

Specific information entered in this tab includes: building location, era of construction, standard fuel and electric rates, holiday occupancy and use schedules, building orientation, the discount rate, and the building life cycle. The azimuth indicates the orientation of the front of the building.

## Blocks Tab

The *Blocks* tab is used to define the geometry and construction materials of the building. This tab is shown in Fig. A3. Block shapes (shown at the top left corner of the tab) are literally dragged and dropped into place to define the geometry of the building. Blocks are sized and positioned through the data boxes titled, “width”, “depth”, “X”, and “Y”. Figure A3 shows two blocks that are 105 ft square, representing the two levels of the office building.

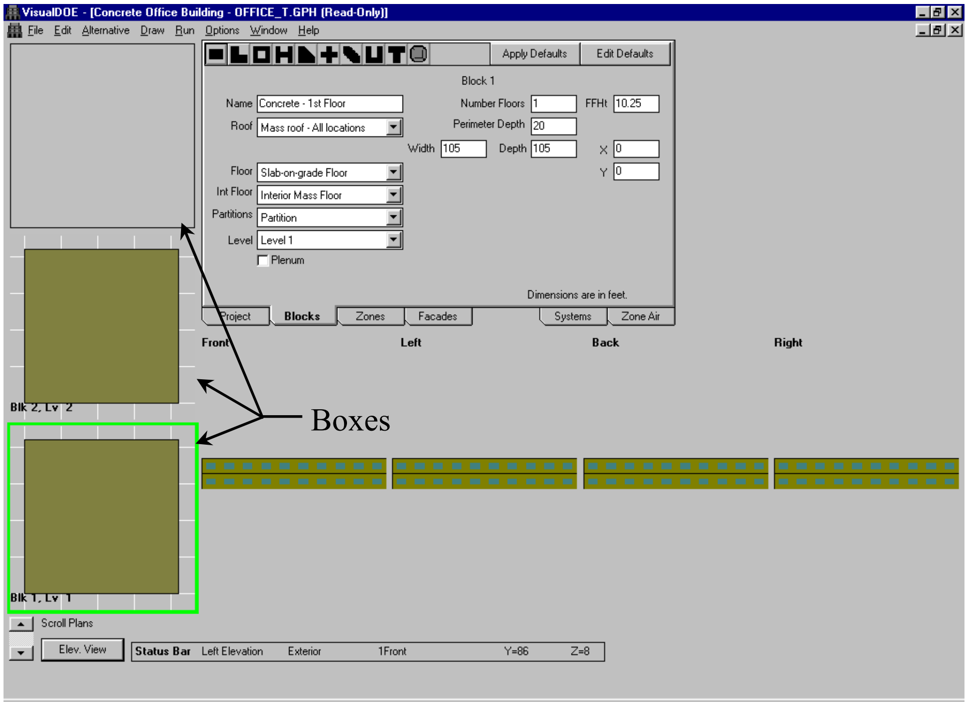


**Figure A3 – The blocks tab showing stacked blocks to create a two-story building**

The numbers of floors, distance between floors (FFHt), and perimeter depth (a zone with separate HVAC controls, if zone heating/cooling is selected on the *zone* tab) are also defined in the data boxes. A check box titled "plenum" is provided to indicate whether an airspace exists above a suspended ceiling.

Construction of the building on this tab directly affects the heat and cooling system and interior partitions. HVAC zones are discussed in a later section titled "Zones Tab". A multiple story building can have a single heating and cooling zone by using one block and using the "Number Floors" data box. If a separate HVAC system or zone is desired on each floor, additional blocks must be used. Additional blocks should be placed in the box directly above the previous box. Note the "boxes" are denoted by an arrow in Fig. A3. If interior partitions are desired, multiple blocks must be dragged onto one another, and then sized and positioned using the "width", "depth", "X", and "Y" data boxes.

Roof, floor, interior floor (if applicable) and partitions (if applicable) assemblies are selected with list boxes. Creation of new and modification existing assemblies is discussed in the section titled "Constructions Editor".

## Zones Tab

The *zones* tab is used to define the interior heat loads and HVAC zones. This tab is shown in Fig. A4. HVAC zones are separately controlled areas for heating and cooling.

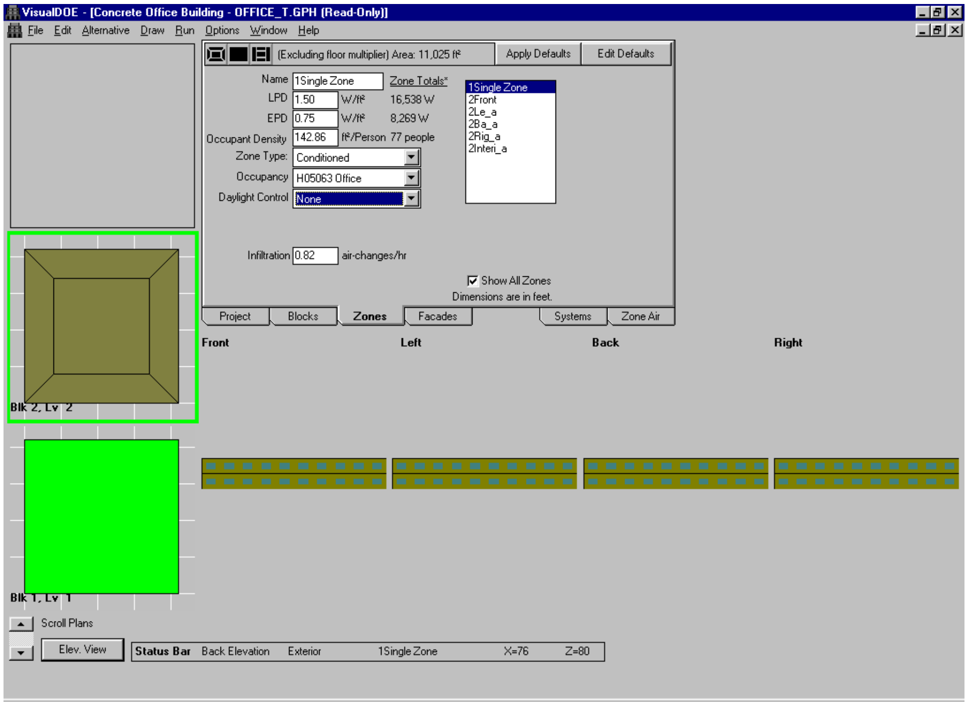

**Figure A4 – The zones tab showing a two-story building with different zones**

Data boxes are provided for equipment power densities (EPD), interior lighting power densities (LPD), the amount of floor space per person, the type of conditioned space, the occupancy schedule (defined in the “Schedule Maker”, but not discussed in this report), the daylight control (autodimming of interior lights during sunny days), and the rate of exterior air infiltration.

Zones, either multiple or single, are created by dragging the appropriate shape (located at the top left corner of the tab) on to the individual blocks. Figure A4 shows a two-story building with a single zone on the first floor and five zones (perimeter zones with a core zone) on the second floor. Each zone can have its own unique set of heat loads and operating conditions as defined in the list boxes.

## Facades Tab

The *facades* tab is used to define exterior wall construction and windows. This tab is shown in Fig. A5. Walls can be modified individually or as groups. Figure A5 shows exterior walls named “1Front” and “2Front” being modified as a group.

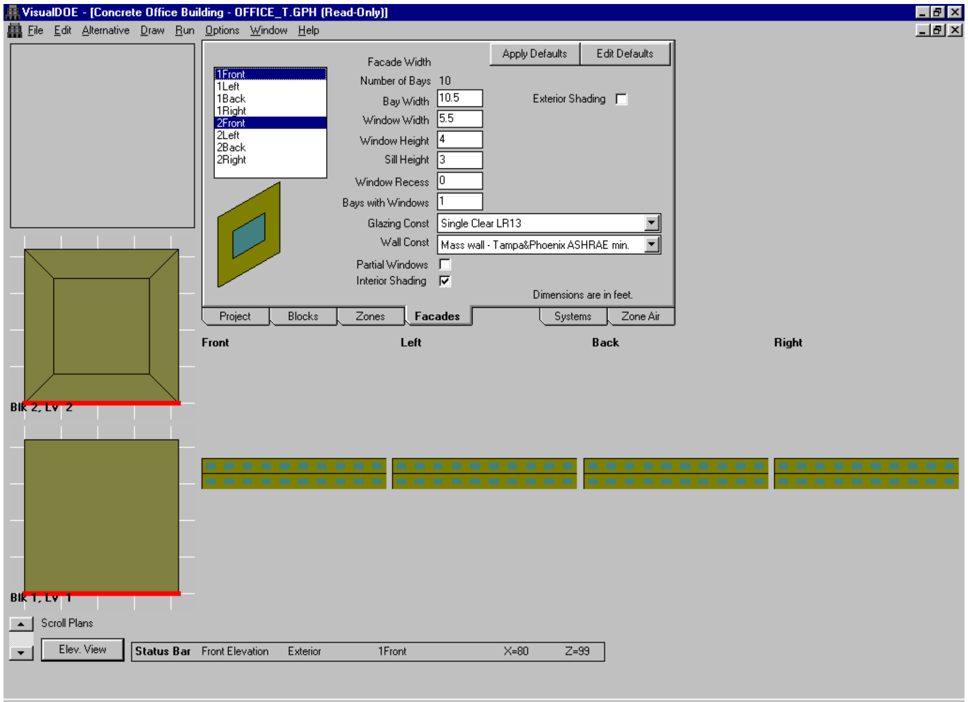


**Figure A5 – The facade tab showing modification of the front facade**

Each wall is defined in terms of a number of window bays, Each "bay" contains one window and a defined amount of opaque wall area surrounding the window. In Fig. A5, the building is 105 ft wide and has 10.5-ft bays, resulting in 10 windows on each floor of the front facade. Data boxes are also provided to indicate the fraction of bays with windows ("0" for no windows to "1" for a window in each bay) and if the window is recessed into a wall. Check boxes are provided if partial windows are desired, and for interior and/or exterior shading. Exterior shading consists of window fins and overhangs. Interior shading consists of blinds or shades used to block excessive solar heat gains.

## Systems Tab

The *systems* tab is used to define the number of HVAC systems present in the building. Additional editors are available from this tab to define the HVAC system, water heating system, and the central plant. This tab is shown in Fig. A6. Description of the editors and options available are outside of the scope of this report.

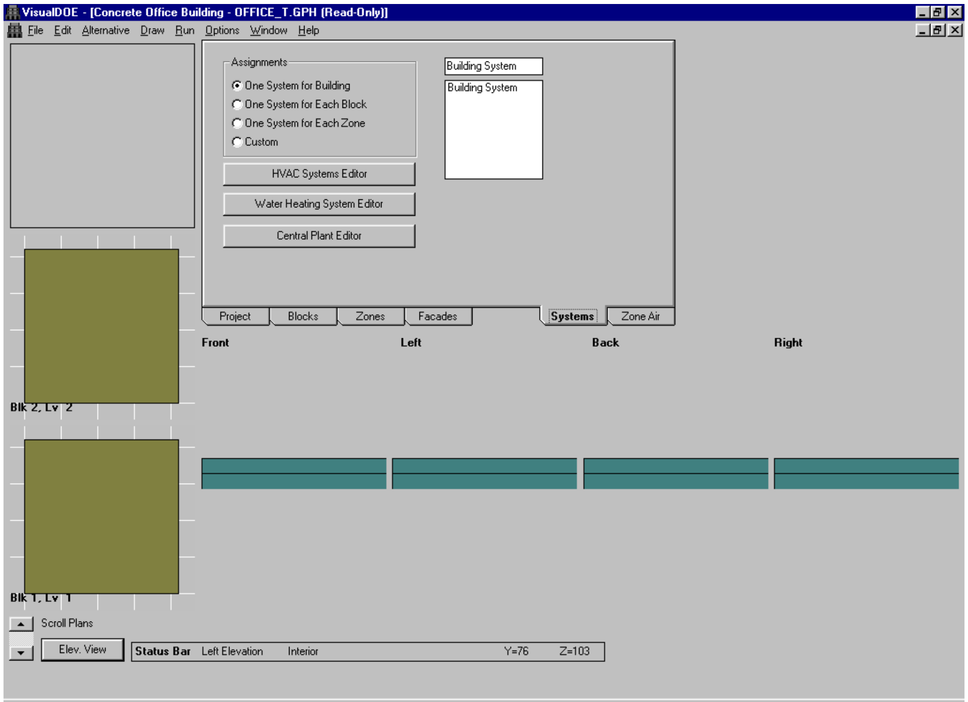


**Figure A6 – The systems tab showing the available options**

### Zone Air Tab

The *zone air* tab is used to define the ventilation of the building and the type of thermostat control. The defaults used in the modeling of the buildings presented in this report are shown in Fig. A7. Again, descriptions of the available options are outside of the scope of this report.

## Construction Editor

The construction editor is used to create or modify wall, floor, and roof assemblies. It is accessed through the "Window" menu item, or by clicking on the fourth icon from the left, shown in Fig. A1. The main screen of the construction editor (the "Constructions" tab) is shown in Fig. A8.

The construction tab allows for the modification of existing assemblies. Using list and data boxes, the assembly can be renamed, its solar absorption and texture characteristics can be modified, and layers can be added, deleted, or changed.

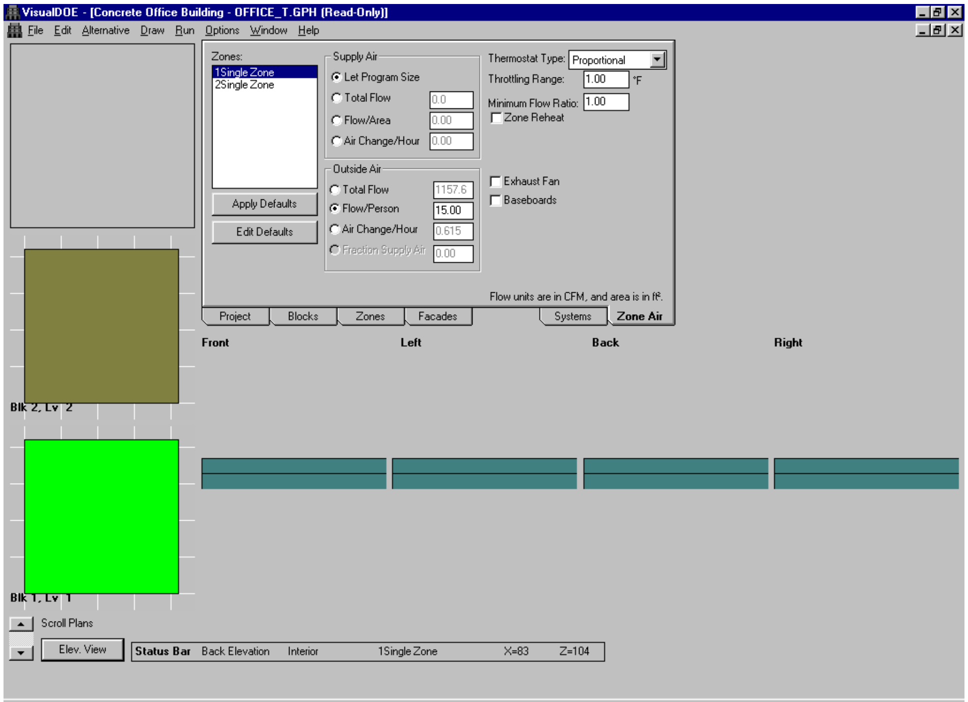


**Figure A7 – The zone air tab showing the available options**

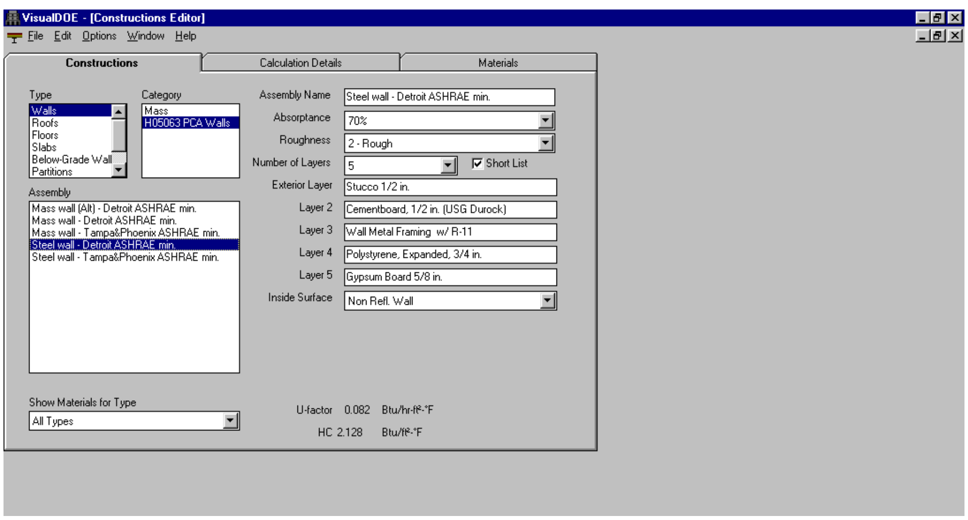


**Figure A8 – The constructions tab of the construction editor showing the construction materials used in the exterior steel framed wall in Detroit**

New assemblies can be added by selecting the type of assembly then selecting the "Add New" menu item in the "Edit" menu. The total assembly U-factor and heat capacity of the assembly are automatically calculated based on the characteristics of the layers. These data along with other pertinent data are presented in the "Calculation Details" tab, shown in Fig. A9.

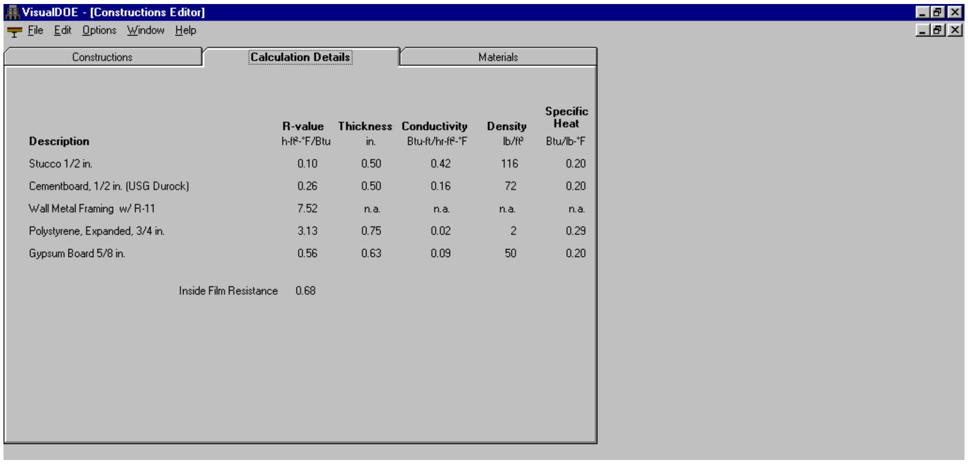


**Figure A9 – The calculation details tab of the construction editor showing the calculated properties of the exterior steel framed wall in Detroit**

Additional material can be added and modified through the "Materials" tab. For all materials, either the R-value or the thickness, thermal conductivity, density, and specific heat must be known. For mass materials such as concrete and block, the thickness, thermal conductivity, density, and specific heat should be entered to get credit for mass effects.

## Other Editors

The software is highly flexible and allows modification of many other items, most of which are outside the scope of this report. These editors are accessed through the "Window" menu item, or by clicking on the icons shown in Fig. A1. Several of the editors were used in the modeling of the buildings described in this report. The "Schedule Maker" allows for the customization of the occupancy of the building. The "Fenestration" editor allows for incorporation and modification of windows. The "Climate" editor allows additional hourly weather data files to be used by the software. The "Utility Rates" editor allows for modification of the fuel and electricity costs and price plans.

## Building Variations

As indicated previously, the software allows for building variations to be compared. Once the building is constructed in the software, variations are added by selecting the "Define Alternatives" menu in the "Edit" menu. As shown in Fig. A10, alternatives can be limited to utility rates, the (HVAC) plant and utility rates, the (HVAC) plant and utility rates, or no limits. Alternatives provide a convenient way to modify a portion of the building without re-entering the building data. Additionally, when the calculations are performed, the alternatives are compared on an energy use and energy cost basis.

Building alternatives are edited by selecting the alternative building through the "Alternative" menu item. Modifications are preformed by changing information in the tabs of the "Graphic Editor", as described above. Changing items in the "Project" tab changes items for the base case and all alternatives.

For the purposes of this report, the effective orientation of the retail building (with all of the windows on the front facade) was averaged by defining four alternatives that oriented the windows on the front, back, left, or right sides. The energy usage from each alternative was averaged to negate the effect of orientation.

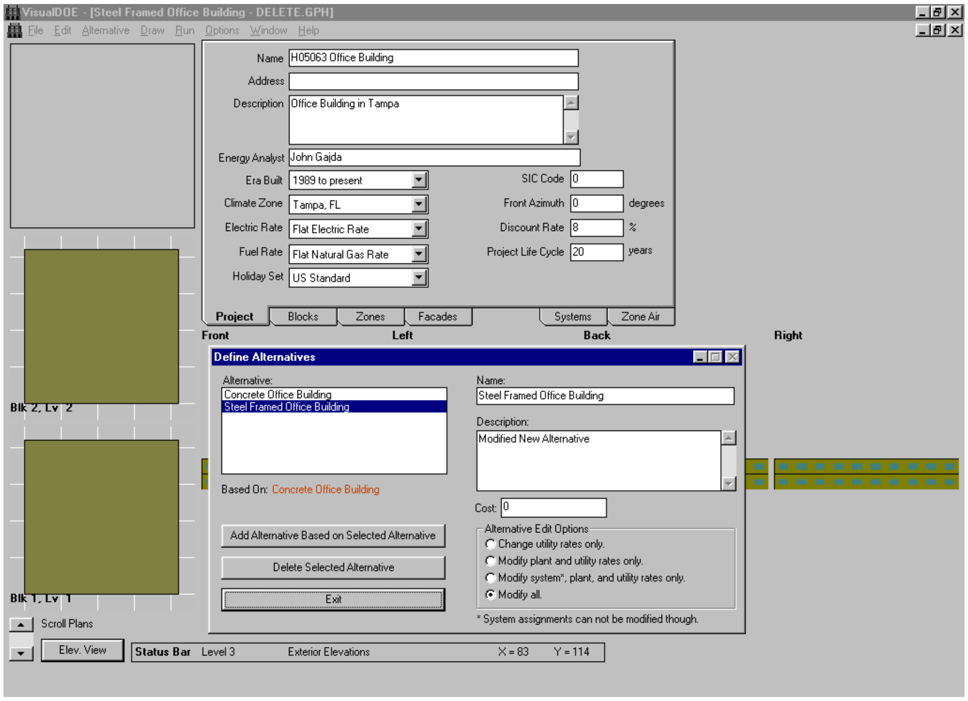


**Figure A10 – Defining the steel framed office building alternative from the concrete office building base case.**

## APPENDIX B - BLCC 4.5

This Appendix guides the user through the use of BLCC software for those who may desire to model other buildings.

A full user's manual for BLCC is available from NIST (NISTR 5185-3). What follows are examples of some typical input screens and a summary of input data required by the program. The program is able to deal with a much wider scope than addressed by this report and reference must be made to the manual before the program is used.

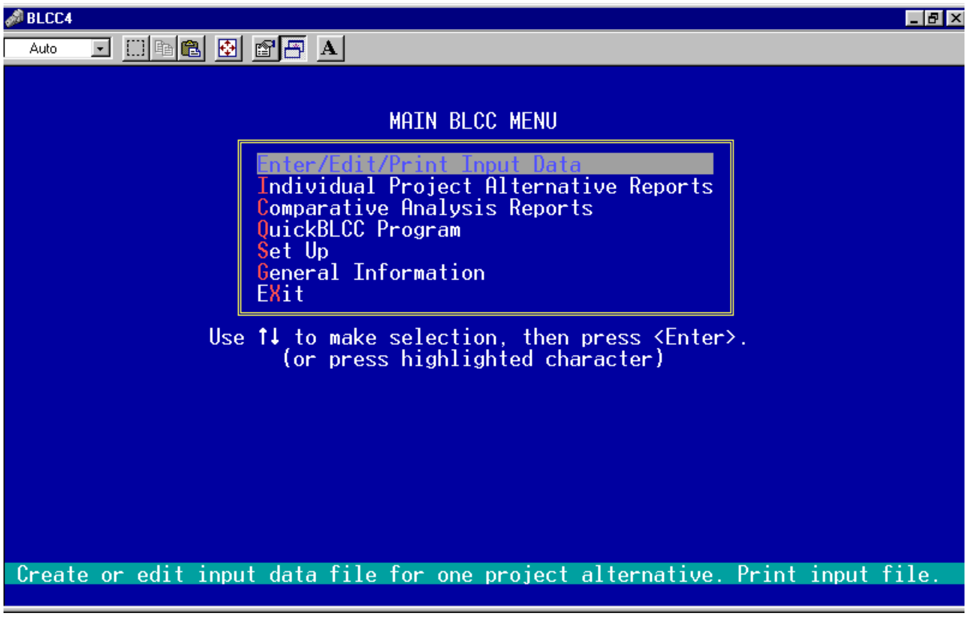


**Figure B1 – BLCC Main Menu**

The main BLCC menu is the first displayed (Fig. B1), providing access to the data input routine, which is started with the following screen (Fig. B2), where data are entered. Successive screens provide access to all the data input fields in the following categories:

1. General
2. Capital assets
3. Capital asset replacement
4. Operating, maintenance and repair
5. Energy

Escalation rates for energy costs can be based on DOE figures already in the program (as a function of a selected interest rate), or based on data input by the user. Energy data are entered as consumption in amount of fuel, and the cost per unit of fuel at the start of the analysis period. The program does not provide assistance in estimating fuel requirement.

For this the purposes of this report, it was assumed that the examples to be studied were non-Federal projects, but without the influence of taxation on the analyses, as shown in Fig. B2. Because the program is DOS based, the file names are limited to eight characters.

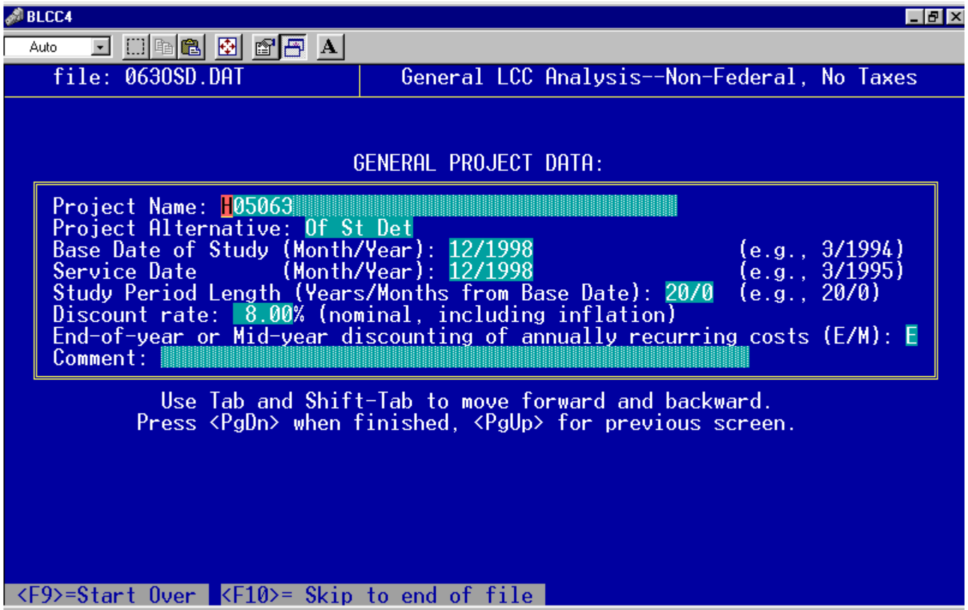


**Figure B2 – General project data input screen**

A full listing of input data can be printed from the program and an example from one of the data sets used in this project is attached at the end of this appendix.

The data set for a single case is then saved and the life cycle costs computed. Reports of calculated life cycle costs are then accessed from the main menu and can either be viewed on screen or saved as text files to be accessed from a word processing package. A typical example of a full report is given at the end of this appendix. A typical abbreviated report with only the final costs is given in Fig. B3.

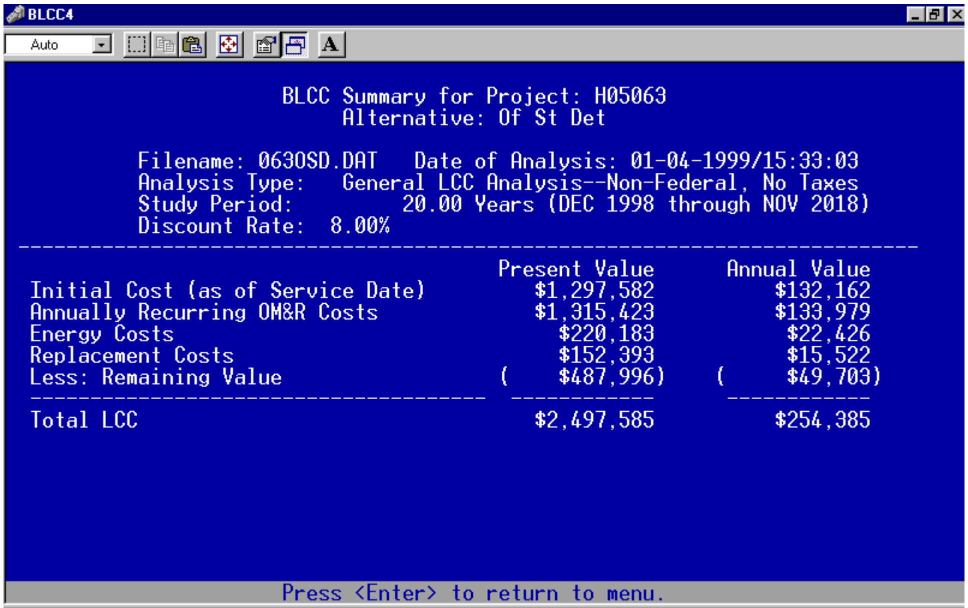


**Figure B3 – Summary data output screen**

It is also possible to compare different sets of data, as shown at the end of this appendix.

## BLCC 4.5 Typical Data Input Set

```
*********************************************************************
N I S T  B L C C:  I N P U T  D A T A  L I S T I N G (ver. 4.51-97)
*********************************************************************
FILE NAME:                0630SD
FILE LAST MODIFIED ON     11-04-1999/09:00:02
PROJECT NAME:             H05063
PROJECT ALTERNATIVE:      Of St Det
COMMENT:                  (NONE)

GENERAL DATA:
-------------
ANALYSIS TYPE:                  General LCC Analysis-Non-Federal, No Taxes
BASE DATE FOR LCC ANALYSIS:     DEC 1998
STUDY PERIOD:                   20 YEARS, 0 MONTHS
SERVICE DATE:                   DEC 1998
DISCOUNT AND INTEREST RATES:    Nominal (including general inflation)
DISCOUNT RATE:                  8.0%
End-of-year discounting convention
Escalation rates include general inflation

CAPITAL ASSET COST DATA:
------------------------
INITIAL COST (BASE YEAR $)            1290653
EXPECTED ASSET LIFE (YRS/MTHS)        20/0
RESALE VALUE FACTOR                   80.00%
AVG PRICE ESC RATE(SERVICE PD.)       4.00%
NUMBER OF REPLACEMENTS                1
```

REPLACEMENTS TO CAPITAL ASSETS:
-------------------------------

| | |
|---|---|
| REPLACEMENT NUMBER | 1 |
| YEARS/MONTHS FROM SERVICE DATE | 10/0 |
| INITIAL COST (BASE YEAR $) | 222264 |
| EXPECTED REPL. LIFE (YRS/MTHS) | 10/0 |
| RESALE VALUE FACTOR | 0.00% |

OPERATING, MAINTENANCE, AND REPAIR COST DATA:
---------------------------------------------

| | |
|---|---|
| ANNUAL RECUR OM&R COST ($): | 95477 |
| ESCALATION RATE FOR OM&R: | 4.00% |

No non-annually-recurring OM&R costs reported.

ENERGY-RELATED DATA:
-----------------

| | |
|---|---|
| NUMBER OF ENERGY TYPES = | 2 |
| DOE energy price escalation rates filename: | ENCOST7A |
| DOE region (state code): | 2 (MI) |
| DOE rate schedule type: Commercial | |
| Underlying gen. inflation rate used with DOE rates: | 4.00% |

| ENERGY TYPE: | Electricity | Natural Gas |
|---|---|---|
| BASE ANNUAL CONSUMPTION: | 241758 | 7423 |
| UNITS: | kWh | Therm |
| PRICE PER UNIT ($): | 0.0800 | 0.5600 |
| ANNUAL DEMAND CHARGE ($): | 0.00 | 0.00 |

| ESCALATION RATE METHOD: | DOE rates | DOE rates |
|---|---|---|
| 1998 | 3.42 | 3.51 |
| 1999 | 3.41 | 3.75 |
| 2000 | 3.36 | 4.25 |
| 2001 | 3.36 | 4.00 |
| 2002 | 3.45 | 4.00 |
| 2003 | 3.00 | 3.50 |
| 2004 | 3.14 | 3.50 |
| 2005 | 3.69 | 3.75 |
| 2006 | 3.80 | 4.00 |
| 2007 | 3.54 | 3.50 |
| 2008 | 3.18 | 3.75 |
| 2009 | 2.19 | 3.75 |
| 2010 | 1.37 | 3.49 |
| 2011 | 2.00 | 4.26 |
| 2012 | 4.28 | 4.25 |
| 2013 | 4.99 | 5.01 |
| 2014 | 3.73 | 4.00 |
| 2015 | 3.24 | 3.75 |
| 2016 | 3.29 | 3.75 |
| 2017 | 3.28 | 4.00 |
| 2018 | 3.28 | 3.75 |

## BLCC 4.5 Typical Data Output Set

```
* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
N I S T  B L C C:  D E T A I L E D  L C C  A N A L Y S I S (ver. 4.51-97)
* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *

PART I - INITIAL ASSUMPTIONS AND COST DATA
-----------------------------------------------------------------------
      Project Name:           H05063
      Project Alternative:    Of St Det
      Run date:               11-04-1999 09:07:14
      Run type:               General LCC Analysis-Non-Federal, No Taxes
      Comment:
      Input data file:  063OSD.DAT, last modified: 11-04-1999/09:00:02
      LCC output file:  063OSD.LCC, created: 11-04-1999/09:00:04
      Base Date of Study:     DEC 1998
      Service Date:           DEC 1998
      Study period            20.00 years (DEC 1998 through NOV 2018)
      Discount rate:          8.0%  Nominal (including gen. inflation)
      End-of-year discounting convention

Initial Capital Asset Costs (not discounted)
-----------------------------------------------------------------------
                                    Total Cost
                                    ------------
      Total Initial Capital Asset Costs   $1,290,653

Energy-Related Costs
-----------------------------------------------------------------------
Energy                Avg Annual Price+ -- Avg Annual Cost+       Total
Type         Units    Usage   ($/Unit)    Energy    Demand      PV Cost
-----------------------------------------------------------------------
Electricity   kWh    241,758  $0.080      $19,341      $0     $250,070
Natural Gas   Therm    7,423  $0.560       $4,157      $0      $56,531


+Energy price as of base date (not adjusted for price escalation)
```

PART II - LIFE-CYCLE COST ANALYSIS

Discount Rate = 8.0% Nominal (including general inflation)

---

Project Alternative: Of St Det      Run Date: 11-04-1999/09:07:15

| | Present Value (1999 Dollars) | Annual Value (1999 Dollars) |
|---|---|---|
| Capital Requirements as of Service Date: | $1,290,653 | $131,456 |
| Operating, Maintenance & Repair Costs: | | |
| Annually recurring Costs (non-energy) | $1,315,423 | $133,979 |
| Subtotal | $1,315,423 | $133,979 |
| Energy Costs | $306,600 | $31,228 |
| Replacements to Capital Components | $152,393 | $15,522 |
| Residual Value of Orig Capital Components | $485,867 | $49,487 |
| Residual Value of Capital Replacements | $0 | $0 |
| Total Life-Cycle Project Cost | $2,579,679 | $262,746 |

* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *

PART III - EMISSIONS SUMMARY*

Region:     Source Documentation:

| Energy Type | Avg Annual Emissions | Life-cycle Emissions |
|---|---|---|
| Electricity: | | |
| $CO_2$ (Kg): | 234,350.0 | 4,687,000 |
| $SO_2$ (Kg): | 788.7 | 15,773 |
| $NO_x$ (Kg): | 706.0 | 14,119 |
| Natural Gas: | | |
| $CO_2$ (Kg): | 39,203.3 | 784,066 |
| $SO_2$ (Kg): | 0.2 | 3 |
| $NO_x$ (Kg): | 30.5 | 611 |
| Total: | | |
| $CO_2$ (Kg): | 273,553.3 | 5,471,067 |
| $SO_2$ (Kg): | 788.8 | 15,776 |
| $NO_x$ (Kg): | 736.5 | 14,730 |

* Based on emission factors from file USAVG.EMI

## BLCC 4.5 Comparative Data Output Set

```
*******************************************************************
N I S T  B L C C:  COMPARATIVE  ECONOMIC  ANALYSIS (ver. 4.51-97)
*******************************************************************
      Project: H05063
      Base Case: Ret St Tam
      Alternative: Ret Co Tam

      Principal Study Parameters:
      ---------------------------------
      Analysis Type:          General LCC Analysis--Non-Federal, No Taxes
      Study Period:           20.00 Years (DEC 1998 through NOV 2018)
      Discount Rate:          8.0% Nominal (including general inflation)
      Base Case LCC File:     063RST.LCC
      Alternative LCC File:   063RCY.LCC
```

Comparison of Present-Value Costs

| | Base Case Ret St Tam | Alternative Ret Co Tam | Savings from Alt. |
|---|---|---|---|
| Initial Investment item(s): | | | |
| Capital Requirements as of Service Date | $505,080 | $511,986 | -$6,906 |
| Subtotal | $505,080 | $511,986 | -$6,906 |
| Future Cost Items: | | | |
| Annual and Non-Annual Recurring Costs | $535,127 | $535,127 | $0 |
| Energy-related Costs | $343,012 | $324,302 | $18,710 |
| Capital Replacements | $63,715 | $63,715 | $0 |
| Residual Value at End of Study | -$189,951 | -$192,548 | $2,597 |
| Subtotal | $751,904 | $730,597 | $14,401 |
| Total P.V. Life-Cycle Cost | $1,256,984 | $1,242,583 | $14,401 |

Net Savings from Alternative 'Ret Co tam' compared to Base Case 'Ret St Tam'

```
Net Savings  =    P.V. of Future Cost Savings   $21,307
                  -  Increased Initial Invest.  $ 9,906
                                             -------------
                              Net savings:      $14,401
```

Note: the SIR and AIRR computations include only differential initial costs as investment costs.

Savings-to-Investment Ratio (SIR)
For Alternative 'Ret Co tam' compared to Base Case 'Ret St Tam'

```
             P.V. of Future Cost Savings
SIR  = --------------------------------------------- =   3.09
             Increased Capital Investment
```

Adjusted Internal Rate of Return (AIRR)
For Alternative 'Ret Co tam' compared to Base Case 'Ret St Tam'
(Reinvestment Rate =  8.00%; Study Period = 20 years)

AIRR =  14.26%

Estimated Years to Payback

Simple Payback occurs in year 6
Discounted Payback occurs in year 8

ENERGY SAVINGS SUMMARY

| Energy type | Unit | --- Average Annual Consumption ---- Base Case | Alternative | Savings | Life-Cycle Savings |
|---|---|---|---|---|---|
| Electricity | kWh | 315,279 | 297,898 | 17,381 | 347,620 |
| Natural Gas | Therm | 1,650 | 1,585 | 65 | 1,300 |

EMISSIONS REDUCTION SUMMARY

| Energy type | ---------- Average Annual Emissions -------- Base Case | Alternative | Reduction | Life-Cycle Reduction |
|---|---|---|---|---|
| Electricity: | | | | |
| CO2 (Mg): | 305.6 | 288.8 | 16.8 | 337.0 |
| SO2 (Kg): | 1,028.5 | 971.8 | 56.7 | 1,134.0 |
| NOx (Kg): | 920.7 | 869.9 | 50.8 | 1,015.1 |
| Natural Gas: | | | | |
| CO2 (Kg): | 8,714.2 | 8,370.9 | 343.3 | 6,865.7 |
| SO2 (Kg): | 0.0 | 0.0 | 0.0 | 0.0 |
| NOx (Kg) | 6.8 | 6.5 | 0.3 | 5.3 |
| Total: | | | | |
| CO2 (Mg): | 314.3 | 297.1 | 17.2 | 343.8 |
| SO2 (Kg): | 1,028.5 | 971.8 | 56.7 | 1,134.0 |
| NOx (Kg): | 927.4 | 876.4 | 51.0 | 1,020.4 |

## APPENDIX C - WINLCCID 98

This Appendix guides the user through the use of WinLCCID 98 for those who may desire to model other buildings.

The data input and output, and processing assumptions for this program are very similar to BLCC. Like BLCC, the energy input is in terms of fuel requirements and unit fuel prices at the beginning of the study period. The program applies standard published escalation rates for fuel prices in the same way as BLCC, except that it does not permit the imposition of a general inflation rate over the given escalation rates.

The greatest difference between the systems is that BLCC is DOS based and runs in a batch form, while WinLCC is Windows based. Data are entered into the latter program by stepping through a menu system in which flags are checked after data are input. The front page of the system is shown in Fig. C1. Alternatives are either selected from preset data within the program, or entered as new data depending on the type of information desired.

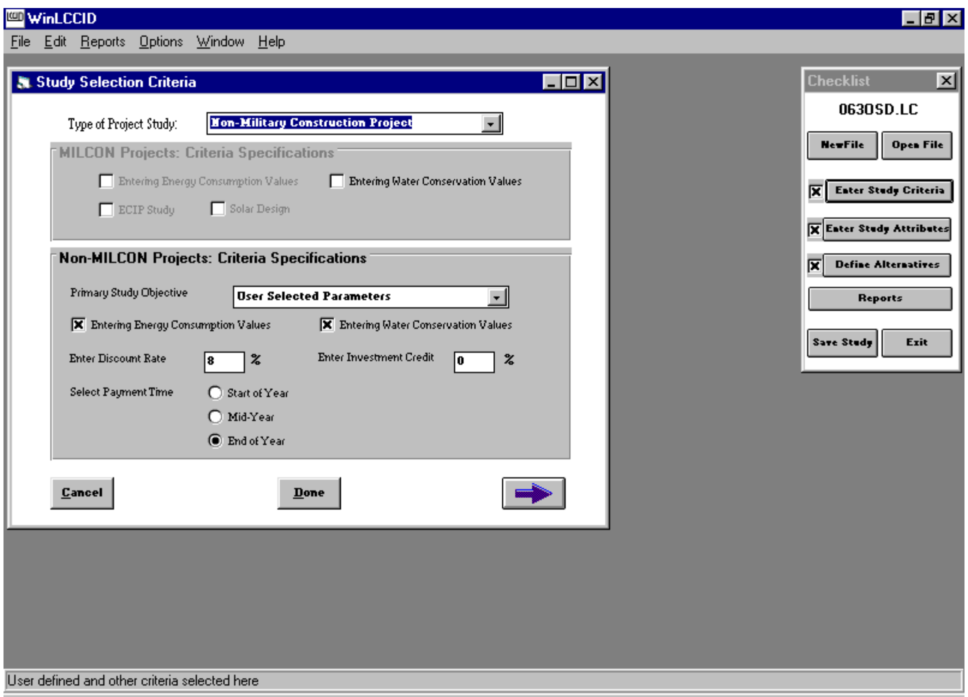


**Figure C1 – WinLLC front screen**

Once all the steps have been completed the program prompts for a file name and calculates the life-cycle output. This is then accessible in a series of reports, either in abbreviated or complete forms selected from buttons on the front screen. A typical report is shown in Fig. C2.

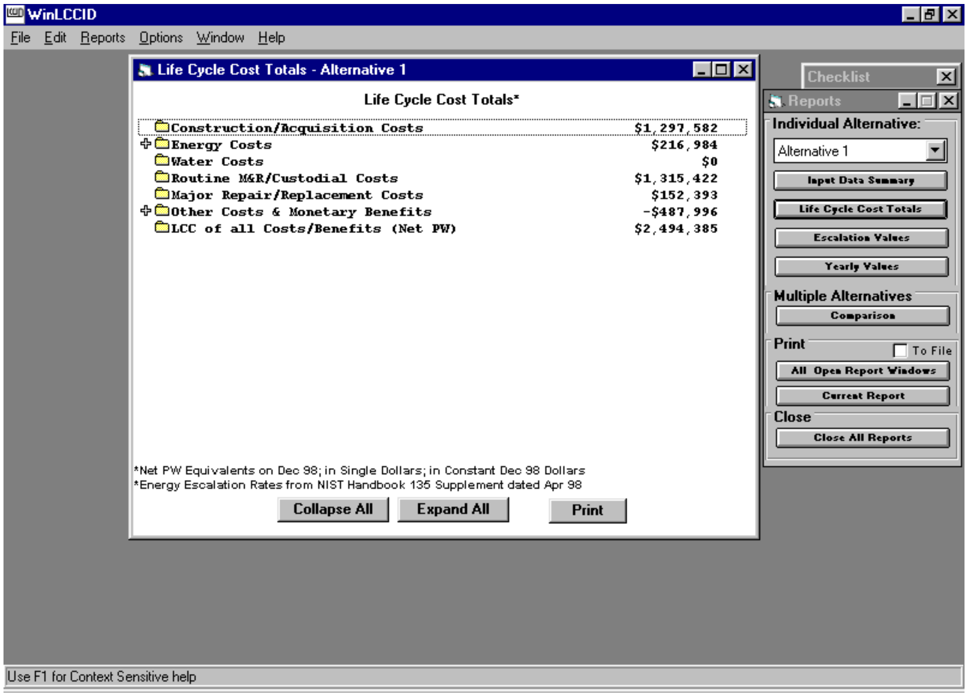


**Figure C2 – Summary data output screen**

## APPENDIX D - BUILDING CONSTRUCTION COSTS DATA SHEETS

For each component, a material or system was selected based on the building description given in the body of the report. The unit price for the material or system was extracted from Reference No. 8 and the source of the data, as referenced in the book, was noted. Total cost of each material or system in the building was calculated, based on the relevant number of units. The total cost for each material or system was then expressed as a cost per square foot of the building.

Correction factors for each city were applied to account for environment and "cost of living" effects. Contractor profit and professional fees were calculated as percentages and added to the totals.

**OFFICE, CONCRETE**

## Building Details

| | |
|---|---|
| Total area | 22,050 |
| Floors | 2 |
| GF | 11,025 |
| Susp floors | 11,025 |
| Roof | 11,025 |
| Story height | 10.25 |
| Wall length | 420 |
| Wall area | 8,610 |
| Windows | 1,760 |

## Component Costs

| Component | Description | Unit | Unit Cost | Source | Quantity | Cost | SF cost |
|---|---|---|---|---|---|---|---|
| Excavation | Exc + backfill 4' | SF | 3.70 | 2.1100.105 | 11025 | 40792.50 | 1.85 |
| Foundations | Strip footings 4' | SF | 4.35 | P87 | 11025 | 47958.75 | 2.18 |
| Slab on grade | R/C 6" | SF | 4.02 | 2.1700.110 | 11025 | 44320.50 | 2.01 |
| Columns | Precast 14" | LF | 78.92 | 3.0110.105 | 185 | 14560.74 | 0.66 |
| Beams & girders | Precast 18 x 24" | LF | 64.7 | 3.0210.110 | 1260 | 81522.00 | 3.70 |
| Structural floors | Precast | SF | 5.55 | 3.0310.115 | 11025 | 61188.75 | 2.78 |
| Roof | Precast | SF | 5.55 | 3.0310.115 | 11025 | 61188.75 | 2.78 |
| Exterior walls | Block 8x16x8 | SF | 9.56 | 4.1120.110 | 6850 | 65486.00 | 2.97 |
| Interior finish | Gypsum on furring | SF | 2.64 | 4.1175.105 | 6850 | 18084.00 | 0.82 |
| Windows | Metal + fixed glass | SF | 19.55 | 4.1200.125 | 1760 | 34408.00 | 1.56 |
| Exterior doors | Al + glass | EA | 1182 | 4.1300.135 | 4 | 4728.00 | 0.21 |
| Roof cover | Asphalt + Board | SQ | 105.73 | 4.2100.200 | 110 | 11656.73 | 0.53 |
| Roof insulation | R15 | SF | 0.59 | 4.3400.125 | 11025 | 6504.75 | 0.30 |
| Ceiling | Spray | SF | 0.76 | 5.1125.405 | 22050 | 16758.00 | 0.76 |
| Floor finish | Average commercial | SF | 0.76 | 5.4300.255 | 22050 | 16831.50 | 0.76 |
| Stairs | Concrete | FL | 6848 | 9.0100.125 | 4 | 27392.00 | 1.24 |
| Elevators | | EA | 47379 | 9.0205.120 | 1 | 47379.00 | 2.15 |
| Plumbing | Washroom | FIX | 2.44 | P87 | 22050 | 53802.00 | 2.44 |
| Fire protection | Sprinkler | SF | 2.24 | P87 | 22050 | 49392.00 | 2.24 |
| HVAC | Complete | SF | 10.08 | P87 | 22050 | 222264.00 | 10.08 |
| Power | | SF | 10.19 | P87 | 22050 | 224689.50 | 10.19 |
| Special systems | Alarms phone | SF | 3.25 | P87 | 22050 | 71662.50 | 3.25 |
| | | | | | | | |
| Total | | | | | | | 55.45 |

**City Correction Factors**

**DETROIT**

| Component | Description | Unit | Unit Cost | Source | Quantity | Cost | SF cost |
|---|---|---|---|---|---|---|---|
| Seismic 1 | -3.88 | SUM | | P87 | | | -3.88 |
| Insulation walls | R11 | SF | 0.46 | 4.3400.105 | 6850 | 3131.00 | 0.14 |
| Windows extra | | SF | 8.46 | 4.1200.180 | 1760 | 14889.60 | 0.68 |
| City cost | 85 | % | | | | | 44.53 |
| Profit | 15 | % | | | | | 6.68 |
| Fees | 7 | % | | | | | 3.58 |
| TOTAL | | | | | | | $54.79 |
| | | | | | | $1,208,102.55 | |

**PHOENIX**

| Component | Description | Unit | Unit Cost | Source | Quantity | Cost | SF cost |
|---|---|---|---|---|---|---|---|
| Seismic 1 | -3.88 | SUM | | P87 | | | -3.88 |
| Insulation walls | | SF | 0 | | 6850 | 0.00 | 0.00 |
| City cost | 82 | % | | | | | 42.28 |
| Profit | 15 | % | | | | | 6.34 |
| Fees | 7 | % | | | | | 3.40 |
| TOTAL | | | | | | | $52.03 |
| | | | | | | $1,147,260.49 | |

**TAMPA**

| Component | Description | Unit | Unit Cost | Source | Quantity | Cost | SF cost |
|---|---|---|---|---|---|---|---|
| Seismic 1 | -3.88 | SUM | | P87 | | | -3.88 |
| Insulation walls | | SF | 0 | | 6850 | 0.00 | 0.00 |
| City cost | 75 | % | | | | | 38.67 |
| Profit | 15 | % | | | | | 5.80 |
| Fees | 7 | % | | | | | 3.11 |
| TOTAL | | | | | | | $47.59 |
| | | | | | | $1,049,323.62 | |

## OFFICE, STEEL

### Building Details

| | |
|---|---|
| Total area | 22,050 |
| Floors | 2 |
| GF | 11,025 |
| Susp floors | 11,025 |
| Roof | 11,025 |
| Story height | 10.25 |
| Wall length | 420 |
| Wall area | 8,610 |
| Windows | 1,760 |

### Component Costs

| Component | Description | Unit | Unit Cost | Source | Quantity | Cost | SF cost |
|---|---|---|---|---|---|---|---|
| Excavation | Exc + backfill 4' | SF | 3.70 | 2.1100.105 | 11025 | 40792.50 | 1.85 |
| Foundations | Strip footings 4' | SF | 4.35 | P87 | 11025 | 47958.75 | 2.18 |
| Slab on grade | R/C 6" | SF | 4.02 | 2.1700.110 | 11025 | 44320.50 | 2.01 |
| Columns | Pipe + R/C | LF | 32.77 | 3.0115.170 | 185 | 6046.07 | 0.27 |
| Beams & girders | W8x24 | LF | 21.12 | 3.0215.105 | 1260 | 26611.20 | 1.21 |
| Structural floors | Steel beam + deck | SF | 12.93 | 3.0315.120 | 11025 | 142553.25 | 6.47 |
| Roof | Metal with joists 30' | SF | 4.14 | 3.0325.105 | 11025 | 45643.50 | 2.07 |
| Exterior walls | Stud & siding | SF | 12.70 | 4.1145.170 | 6850 | 86995.00 | 3.95 |
| Interior finish | Gypsum on furring | SF | 2.64 | 4.1175.105 | 6850 | 18084.00 | 0.82 |
| Windows | Metal + fixed glass | SF | 19.55 | 4.1200.125 | 1760 | 34408.00 | 1.56 |
| Exterior doors | Al + glass | EA | 1182 | 4.1300.135 | 4 | 4728.00 | 0.21 |
| Roof cover | Asphalt + Board | SQ | 105.73 | 4.2100.200 | 110 | 11656.73 | 0.53 |
| Roof insulation | R13 | SF | 0.48 | 4.3400.115 | 11025 | 5292.00 | 0.24 |
| Ceiling | Gypsum board | SF | 3.27 | 5.2100.130 | 22050 | 72103.50 | 3.27 |
| Floor finish | Average commercial | SF | 0.76 | 5.4300.255 | 22050 | 16831.50 | 0.76 |
| Stairs | Concrete | FL | 6848 | 9.0100.125 | 4 | 27392.00 | 1.24 |
| Elevators | | EA | 47379 | 9.0205.120 | 1 | 47379.00 | 2.15 |
| Plumbing | Washroom | FIX | 2.44 | P87 | 22050 | 53802.00 | 2.44 |
| Fire protection | Sprinkler | SF | 2.24 | P87 | 22050 | 49392.00 | 2.24 |
| HVAC | Complete | SF | 10.08 | P87 | 22050 | 222264.00 | 10.08 |
| Power | | SF | 10.19 | P87 | 22050 | 224689.50 | 10.19 |
| Special systems | Alarms phone | SF | 3.25 | P87 | 22050 | 71662.50 | 3.25 |
| | | | | | | | |
| Total | | | | | | | 58.98 |

## City Correction Factors

### DETROIT

| Component | Description | Unit | Unit Cost | Source | Quantity | Cost | SF cost |
|---|---|---|---|---|---|---|---|
| Seismic 1 | -3.88 | SUM | | P87 | | | -3.88 |
| Insulation walls | R15 | SF | 0.59 | 4.3400.125 | 6850 | 4041.50 | 0.18 |
| Windows extra | | SF | 8.46 | 4.1200.180 | 1760 | 14889.60 | 0.68 |
| City cost | 85 | % | | | | | 47.57 |
| Profit | 15 | % | | | | | 7.14 |
| Fees | 7 | % | | | | | 3.83 |
| TOTAL | | | | | | | $58.53 |
| | | | | | | $1,290,653.25 | |

### PHOENIX

| Component | Description | Unit | Unit Cost | Source | Quantity | Cost | SF cost |
|---|---|---|---|---|---|---|---|
| Seismic 1 | -3.88 | SUM | | P87 | | | -3.88 |
| Insulation walls | R11 | SF | 0.46 | 4.3400.110 | 6850 | 3151.00 | 0.14 |
| City cost | 82 | % | | | | | 45.30 |
| Profit | 15 | % | | | | | 6.80 |
| Fees | 7 | % | | | | | 3.65 |
| TOTAL | | | | | | | $55.75 |
| | | | | | | $1,229,178.50 | |

### TAMPA

| Component | Description | Unit | Unit Cost | Source | Quantity | Cost | SF cost |
|---|---|---|---|---|---|---|---|
| Seismic 1 | -3.88 | SUM | | P87 | | | -3.88 |
| Insulation walls | R11 | SF | 0.46 | 4.3400.110 | 6850 | 3151.00 | 0.14 |
| City cost | 75 | % | | | | | 41.44 |
| Profit | 15 | % | | | | | 6.22 |
| Fees | 7 | % | | | | | 3.34 |
| TOTAL | | | | | | | $50.99 |
| | | | | | | $1,124,248.63 | |

## RETAIL, CONCRETE

### Building Details

| | |
|---|---|
| Total area | 12100 |
| Floors | 1 |
| GF | 12100 |
| Susp floors | 0 |
| Roof | 12100 |
| Story height | 10.25 |
| Wall length | 440 |
| Wall area | 4510 |
| Windows | 677 |

### Component Costs

| Component | Description | Unit | Unit Cost | Source | Quantity | Cost | SF cost |
|---|---|---|---|---|---|---|---|
| Excavation | Exc + backfill 4' | SF | 3.7 | 2.1100.105 | 12100 | 44770.00 | 3.70 |
| Foundations | Strip footings 4' | SF | 1.47 | P113 | 12100 | 17787.00 | 1.47 |
| Slab on grade | R/C 6" | SF | 4.02 | 2.1700.110 | 12100 | 48642.00 | 4.02 |
| Columns | Precast 14" | LF | 78.92 | 3.0110.105 | 92 | 7280.37 | 0.60 |
| Beams & girders | Precast 18 x 24" | LF | 64.7 | 3.0210.110 | 660 | 42702.00 | 3.53 |
| Structural floors | Precast | SF | 5.55 | 3.0310.115 | 0 | 0.00 | 0.00 |
| Roof | Precast | SF | 5.55 | 3.0310.115 | 12100 | 67155.00 | 5.55 |
| Exterior walls | Block 8x16x8 | SF | 9.56 | 4.1120.110 | 3834 | 36648.26 | 3.03 |
| Interior finish | Gypsum on furring | SF | 2.64 | 4.1175.105 | 3834 | 10120.44 | 0.84 |
| Windows | Metals + fixed glass | SF | 28.01 | 4.1200.180 | 677 | 18948.77 | 1.57 |
| Exterior doors | Al + glass | EA | 2167 | 4.1300.140 | 4 | 8668.00 | 0.72 |
| Roof cover | Asphalt + Board | SQ | 105.73 | 4.2100.200 | 121 | 12793.33 | 1.06 |
| Roof insulation | R15 | SF | 0.59 | 4.3400.125 | 12100 | 7139.00 | 0.59 |
| Ceiling | Spray | SF | 0.76 | 5.1125.405 | 12100 | 9196.00 | 0.76 |
| Floor finish | Average commercial | SF | 0.76 | 5.4300.255 | 12100 | 9236.33 | 0.76 |
| Stairs | Concrete | FL | 6848 | 9.0100.125 | 0 | 0.00 | 0.00 |
| Elevators | | EA | 47379 | 9.0205.120 | 0 | 0.00 | 0.00 |
| plumbing | Washroom | FIX | 1.7 | P113 | 12100 | 20570.00 | 1.70 |
| Fire protection | Sprinkler | SF | 2.24 | P113 | 12100 | 27104.00 | 2.24 |
| HVAC | Complete | SF | 7.68 | P113 | 12100 | 92928.00 | 7.68 |
| Power | | SF | 8.96 | P113 | 12100 | 108416.00 | 8.96 |
| Special systems | Alarms phone | SF | 0.82 | P113 | 12100 | 9922.00 | 0.82 |
| | | | | | | | |
| Total | | | | | | | 49.59 |

**City Correction Factors**

**DETROIT**

| Component | Description | Unit | Unit Cost | Source | Quantity | Cost | SF cost |
|---|---|---|---|---|---|---|---|
| Seismic 1 | -3.74 | SUM | | P113 | | | -3.74 |
| Insulation walls | R11 | SF | 0.46 | 4.3400.105 | 3834 | 1763.41 | 0.15 |
| Windows extra | | SF | -0.33 | 4.1200.175 | 677 | -223.25 | -0.02 |
| City cost | 85 | % | | | | | 39.08 |
| Profit | 15 | % | | | | | 5.86 |
| Fees | 7 | % | | | | | 3.15 |
| TOTAL | | | | | | | $48.09 |
| | | | | | | $581,861.32 | |

**PHOENIX**

| Component | Description | Unit | Unit Cost | Source | Quantity | Cost | SF cost |
|---|---|---|---|---|---|---|---|
| Seismic 1 | -3.74 | SUM | | | | | -3.74 |
| Insulation walls | | SF | 0 | | 3834 | 0.00 | 0.00 |
| City cost | 82 | % | | | | | 37.60 |
| Profit | 15 | % | | | | | 5.64 |
| Fees | 7 | % | | | | | 3.03 |
| TOTAL | | | | | | | $46.26 |
| | | | | | | $559,771.00 | |

**TAMPA**

| Component | Description | Unit | Unit Cost | Source | Quantity | Cost | SF cost |
|---|---|---|---|---|---|---|---|
| Seismic 1 | -3.74 | SUM | | | | | -3.74 |
| Insulation walls | | SF | 0 | | 3834 | 0.00 | 0.00 |
| City cost | 75 | % | | | | | 34.39 |
| Profit | 15 | % | | | | | 5.16 |
| Fees | 7 | % | | | | | 2.77 |
| TOTAL | | | | | | | $42.31 |
| | | | | | | $511,985.67 | |

**RETAIL, STEEL**

**Building Details**

| | |
|---|---|
| Total area | 12100 |
| Floors | 1 |
| GF | 12100 |
| Susp floors | 0 |
| Roof | 12100 |
| Story height | 10.25 |
| Wall length | 440 |
| Wall area | 4510 |
| Windows | 677 |

**Component Costs**

| Component | Description | Unit | Unit Cost | Source | Quantity | Cost | SF cost |
|---|---|---|---|---|---|---|---|
| Excavation | Exc + backfill 4' | SF | 3.7 | 2.1100.105 | 12100 | 44770.00 | 3.70 |
| Foundations | Strip footings 4' | SF | 1.47 | P113 | 12100 | 17787.00 | 1.47 |
| Slab on grade | R/C 6" | SF | 4.02 | 2.1700.110 | 12100 | 48642.00 | 4.02 |
| Columns | Pipe + R/C | LF | 32.77 | 3.0115.170 | 92 | 3023.03 | 0.25 |
| Beams & girders | W8x24 | LF | 21.12 | 3.0215.105 | 660 | 13939.20 | 1.15 |
| Structural floors | Steel beam + deck | SF | 12.93 | 3.0315.120 | 0 | 0.00 | 0.00 |
| Roof | Metal with joists 30' | SF | 4.14 | 3.0325.105 | 12100 | 50094.00 | 4.14 |
| Exterior walls | Stud & siding | SF | 12.7 | 4.1145.170 | 3834 | 48685.45 | 4.02 |
| Interior finish | Gypsum on furring | SF | 2.64 | 4.1175.105 | 3834 | 10120.44 | 0.84 |
| Windows | Metals + fixed glass | SF | 28.01 | 4.1200.180 | 677 | 18948.77 | 1.57 |
| Exterior doors | Al + glass | EA | 2167 | 4.1300.140 | 4 | 8668.00 | 0.72 |
| Roof cover | Asphalt + Board | SQ | 105.73 | 4.2100.200 | 121 | 12793.33 | 1.06 |
| Roof insulation | R13 | SF | 0.46 | 4.3400.115 | 12100 | 5566.00 | 0.46 |
| Ceiling | Gypsum board | SF | 3.27 | 5.2100.130 | 12100 | 39567.00 | 3.27 |
| Floor finish | Average commercial | SF | 0.76 | 5.4300.255 | 12100 | 9236.33 | 0.76 |
| Stairs | Concrete | FL | 6848 | 9.0100.125 | 0 | 0.00 | 0.00 |
| Elevators | | EA | 47379 | 9.0205.120 | 0 | 0.00 | 0.00 |
| plumbing | Washroom | FIX | 1.7 | P113 | 12100 | 20570.00 | 1.70 |
| Fire protection | Sprinkler | SF | 2.24 | P113 | 12100 | 27104.00 | 2.24 |
| HVAC | Complete | SF | 7.68 | P113 | 12100 | 92928.00 | 7.68 |
| Power | | SF | 8.96 | P113 | 12100 | 108416.00 | 8.96 |
| Special systems | Alarms phone | SF | 0.82 | P113 | 12100 | 9922.00 | 0.82 |
| | | | | | | | |
| Total | | | | | | | 48.82 |

**City Correction Factors**

**DETROIT**

| Component | Description | Unit | Unit Cost | Source | Quantity | Cost | SF cost |
|---|---|---|---|---|---|---|---|
| Seismic 1 | -3.74 | SUM | | P113 | | | -3.74 |
| Insulation walls | R19 | SF | 0.59 | 4.3400.125 | 3834 | 2261.77 | 0.19 |
| Windows extra | | SF | -0.33 | 4.1200.175 | 677 | -223.25 | -0.02 |
| City cost | 85 | % | | | | | 38.47 |
| Profit | 15 | % | | | | | 5.77 |
| Fees | 7 | % | | | | | 3.10 |
| TOTAL | | | | | | | $47.33 |
| | | | | | | $572,712.00 | |

**PHOENIX**

| Component | Description | Unit | Unit Cost | Source | Quantity | Cost | SF cost |
|---|---|---|---|---|---|---|---|
| Seismic 1 | -3.74 | SUM | | P113 | | | -3.74 |
| Insulation walls | R11 | SF | 0.46 | 4.3400.110 | 3834 | 1763.41 | 0.15 |
| City cost | 82 | % | | | | | 37.09 |
| Profit | 15 | % | | | | | 5.56 |
| Fees | 7 | % | | | | | 2.99 |
| TOTAL | | | | | | | $45.64 |
| | | | | | | $552,221.04 | |

**TAMPA**

| Component | Description | Unit | Unit Cost | Source | Quantity | Cost | SF cost |
|---|---|---|---|---|---|---|---|
| Seismic 1 | -3.74 | SUM | | P113 | | | -3.74 |
| Insulation walls | R11 | SF | 0.46 | 4.3400.110 | 3834 | 1763.41 | 0.15 |
| City cost | 75 | % | | | | | 33.92 |
| Profit | 15 | % | | | | | 5.09 |
| Fees | 7 | % | | | | | 2.73 |
| TOTAL | | | | | | | $41.74 |
| | | | | | | $505,080.22 | |

## APPENDIX E – ANNUAL BUILDING MAINTENANCE COSTS DATA

| Location | Reference No. 9 Page No. | Total Operating Expense, $/sq ft | Utilities, $/sq ft | Rate Used, $/sq ft | Total Cost, $ | |
|---|---|---|---|---|---|---|
| | | | | | Office | Retail |
| Detroit | 166 | 6.42 | 2.09 | 4.33 | 95,477 | 52,393 |
| Phoenix | 224 | 5.06 | 1.70 | 3.36 | 74,088 | 40,656 |
| Tampa | 267 | 4.86 | 1.65 | 3.21 | 70,781 | 38,841 |

Notes: Rate used is the total operating expense less the cost of utilities.
Private sector, median values taken for downtown locations.
Office floor area is 22,050 sq ft.
Retail floor area is 12,100 sq ft.