INCREASING ENERGY EFFICIENCY IN BUILDINGS PROJECT, CHINA

LEARNING UNIT 05

BUILDING ECONOMIC ANALYSIS

Building Engineering
Source Document

November 2002
O/Ref.: 680514

INCREASING ENERGY EFFICIENCY IN BUILDINGS PROJECT, CHINA

LEARNING UNIT 05
BUILDING ECONOMIC ANALYSIS

Source Document

DESSAU-SOPRIN
Building Engineering

Prepared by: Marie-Judith Jean-Louis, E.I.T.

Martin Paré, P.Eng.

Laurier Nichols, P.Eng.

Dessau-Soprin Inc.
1441 René-Lévesque Blvd. West, Suite 500
Montreal (Quebec) Canada H3G 1T7
Phone: (514) 281-1010
Fax: (514) 875-2666
Email: allen.zhai@dessausoprin.com
Website: www.dessausoprin.com

July 2002
O/Ref.: 680514

TABLE OF CONTENTS

Page

FORWARD

As the acting Canadian Executing Agency (CaEA) for the Canadian International Development Agency (CIDA), DESSAU-SOPRIN was given the mandate to help China's Ministry of Construction (MOC) promote building energy conservation through the China Energy Efficiency in Buildings (EEB) Project, initiated in 1996. Part of this project involves promoting energy efficient buildings in China through training.

This is one of a series of six Source Documents that will serve as references for the dissemination of information and training material on energy efficient buildings in China. Detailed information on specific components of energy efficient buildings is discussed in other Source Documents.

The titles of the series of Source Documents are as follows:

01 Introduction to Energy Efficient Buildings
02 Energy Efficient Envelope Design
03 Energy Efficient Window Selection
04 Energy Efficient HVAC Systems
05 Energy Efficient Building Economic Analysis
06 Energy Efficient Building Retrofit

1. BUILDING ECONOMIC ANALYSIS

1.1 INTRODUCTION

The present document examines three main aspects of building economic analysis as important decision-making tools in the design of a building: (1) the energy consumption cost (2) the payback period and (3) the life cycle cost analysis. As presented here, building economics are used not only to help in design decisions, but also to establish standards for building codes.

No matter how energy efficient or environmentally friendly a building may be, the final analysis always depends on the expenditures and the savings. Even if price is one of the final determinants in decision-making, there are two different approaches to determine how costs should be considered: the short-term approach and the long-term approach. The following examples demonstrate the limitations and benefits of the two approaches for a building owner:

i. Add caulking to all windows at a cost of 40,000 Yuan in order to reduce the annual energy consumption by 10,000 Yuan per year.

ii. Spend 60,000 Yuan for the retrofit of the existing coal fired boiler in order to save 15,000 Yuan per year in energy consumption.

iii. Replace the old boiler with a new gas fired boiler for 80,000 Yuan and save 20,000 Yuan per year in energy consumption.

The most economical choice would appear to be the first one as it has the lowest initial cost. However, economic analysis will show that this is not necessarily the case, although the results may vary according to the analysis method, since different analytic approaches give different results. The main reason, however, for the difference between these two approaches is in the way the costs of building are taken into account. The short-term approach shows only the initial building costs, the tip of the iceberg, while the long-term approach shows complete building costs, not only the tip of the iceberg but the hidden portion as well (**Figure 1.1.1**).

The main challenge of building economics is to "determine when it is appropriate to spend more money now in order to save more money in the long term" while bearing in mind that long-term savings cannot always justify additional investments (Kenneth Spain, 2000). The long-term approach method requires more effort from the building cost analyst compared to the short-term method, and that extra effort is not always justifiable. In some cases the long-term approach will be inappropriate for a study. Often, in cases where the long-term method is appropriate, it will be discarded because of a lack of time or, ironically, a lack of money. Consequently, real cost saving opportunities are lost.

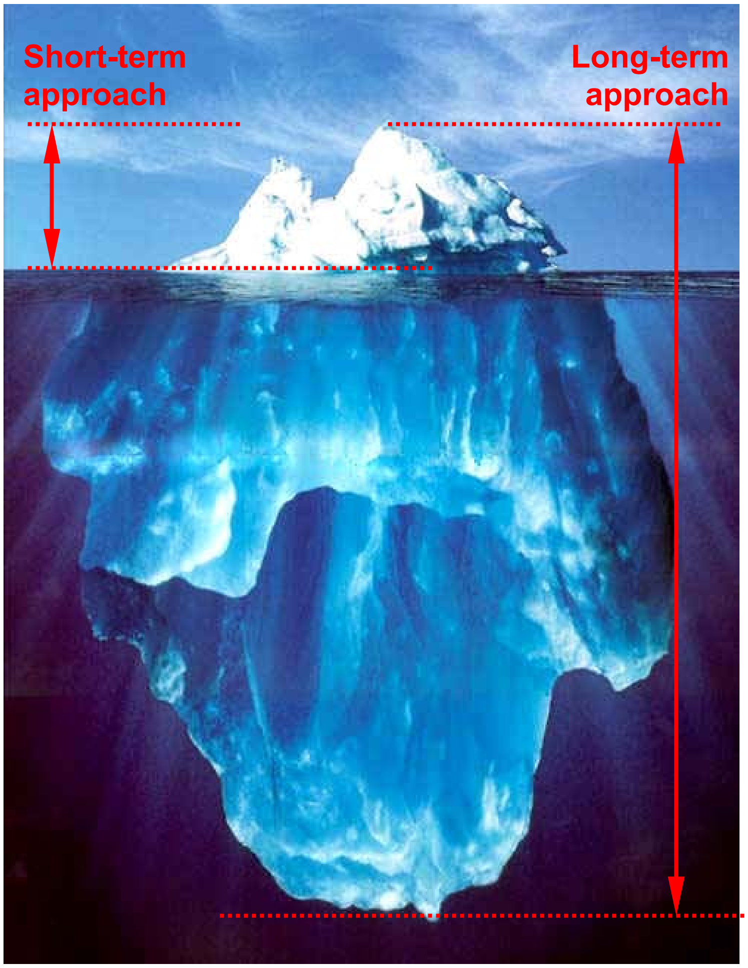

Figure 1.1.1: Two approaches to economic analysis

1.2 BUILDING ENERGY CONSUMPTION COST ANALYSIS

The cost of energy consumption should be the first aspect to be considered during the evaluation of various building designs because it represents the largest portion of the cost of a building over a lifetime. Often, the lower the energy consumption cost, the more money can be saved over the life of the building.

The energy consumption cost of various building design options is evaluated by making several calculations to obtain their annual energy consumption according to the building envelope's characteristics, the internal gains, and the type of heating and/or cooling systems used. This is done using building energy simulation tools to perform all the necessary equations. When using computer software to calculate the energy consumption of a building, it is important to build a reference model to perform the analysis.

When performing an analysis for the retrofit of a building, the reference model is the representation of the behaviour of the existing building. When evaluating the performance of a building to be constructed, the reference model is the representation of the behaviour of the building to be constructed, assuming various influencing factors that correspond to an average existing construction standard. This reference model is then compared to other models with various modifications to several parameters. The use of computer technology in the calculation of building energy consumption enables the evaluator to make as many changes and compare as many building design options as wanted.

1.2.1 Case Study: Tianjin Demonstration Project

In order to select the best design for the construction of a demonstration project in Tianjin, a reference model was built based on the preliminary architectural plans and drawings of the building **(Figure 1.2.1)**. The building is a single-family dwelling. The reference model was built based on the traditional Chinese construction method for a residential building in this area. The reference model, then, for the Tianjin house has single-pane clear glass windows, exterior brick walls, a concrete roof with no insulation, a hot water heating system using a central coal boiler having an overall efficiency of approximately 47% and cast iron radiators. No cooling is included. Based on these parameters, the annual energy consumption obtained from the simulation of the building was 1,585 kWh of electricity at 872 Yuan and 12,042 kg of coal at 7,225 Yuan, which amounts to a total energy consumption cost of 8,097 Yuan per year.

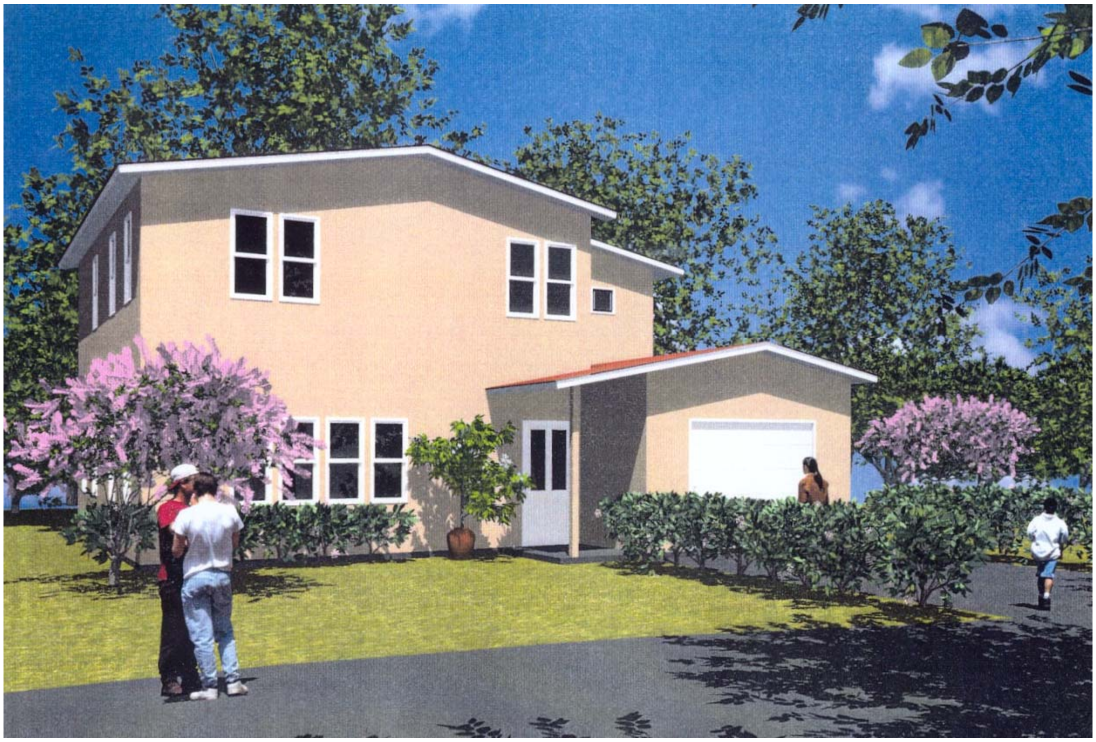

Figure 1.2.1: Design of the demonstration project in Tianjin
Source: Digigraph

The building parameters evaluated in this analysis were the types of **window**, the **infiltration rate**, the composition of the **exterior wall** and **roof**, the **boiler efficiency**, the type of **energy source** used by the boiler and the type of **heating and cooling system**. Each simulation is compared to the reference model's energy consumption cost of 8,097 Yuan per year. The savings they produce is shown in the following Table in order to assess and compare the impact of each parameter change (**Table 1.2.1**).

Table 1.2.1: Energy consumption cost evaluation for the Tianjin demonstration project

Parameters	Electrical cost (Yuan)	Natural gas cost (Yuan)	Coal Cost (Yuan)	Total energy cost (Yuan)	Annual savings (Yuan)
TYPE OF WINDOWS					
Double clear glass windows	872	N/A	6,880	7,752	345
Double clear reflective glass windows	872	N/A	7,542	8,414	-317
AIR CHANGE RATES					
1.50 air change per hour	872	N/A	8,044	8,916	-819
0.75 air change per hour	872	N/A	6,866	7,738	359
0.50 air change per hour	872	N/A	6,703	7,575	522
0.30 air change per hour	872	N/A	6,579	7,451	646
0.30 air change per hour with double clear glass windows	872	N/A	6,447	7,318	779
TYPE OF EXTERIOR WALLS					
25mm polystyrene	872	N/A	5,399	6,271	1,826
50mm polystyrene	872	N/A	4,881	5,753	2,344
75mm polystyrene	872	N/A	4,732	5,604	2,493
TYPE OF ROOF					
75mm polystyrene	872	N/A	5,450	6,322	1,775
100mm polystyrene	872	N/A	5,355	6,227	1,878
125mm polystyrene	872	N/A	5,315	6,187	1,910
150mm polystyrene	872	N/A	5,280	6,152	1,945
150mm polystyrene for roof and 75mm polystyrene for walls	872	N/A	2,854	3,726	4,373
BOILER EFFICIENCY AND HEATING SOURCE					
Coal, 54.0%	872	N/A	6,253	7,125	972
Coal, 58.5%	872	N/A	5,774	6,646	1,451
Coal, 63.0%	872	N/A	5,358	6,230	1,867
Gas, 70.0%	872	9,334	N/A	10,206	-2,109
HEATING AND COOLING SYSTEMS					
Low COP heat pump (coal)	18,270	N/A	1,147	19,417	-5,482
High COP heat pump (coal)	12,320	N/A	923	12,243	1,692
High COP heat pump (water)	3,445	N/A	7,515	10,960	2,975
High COP heat pump (gas)	12,320	1,192	N/A	13,512	423
High COP heat pump (electrical)	15,221	N/A	N/A	15,221	-1,286
Low COP heat pump (electrical)	22,614	N/A	N/A	22,614	-8,679
Low COP electric system	29,221	N/A	N/A	29,221	-15,286
High COP electric system	26,922	N/A	N/A	26,922	-12,987
FINAL DESIGN					
Double clear glass window, 0.30 air charge per hour, 75mm wall insulation, 150mm roof insulation, 70% efficient gas boiler, high COP hot water heat pump	4,005	234	N/A	4,239	3,858

The unit costs of the various energy sources used for the simulations are shown in **Table 1.2.2**.

Table 1.2.2: Energy cost

ENERGY SOURCE	Cost
Coal	600 yuan/ton
Electricity	0.55 yuan/ kWh
Natural gas	1.5 yuan/m^3

The parametrical analysis demonstrated for the evaluators what the best features would be for the house. In this case, energy efficiency came from double-pane clear glass windows, the lowest infiltration rate, insulation in the walls and roof, and a heat pump. Not only were the annual savings compared, but the energy consumption as well. Although the Table shows that savings were low when using natural gas as a heat source, total energy consumption for the Final Design shows the opposite. Using natural gas in this case is the most energy efficient measure, but because of the difference between the price of gas and the price of coal, it cannot be understood only through an analysis of the energy costs.

For this simulation a number of energy efficient design measures were chosen, such as double-pane clear glass, an hourly air change rate of 0.3, 65mm insulation in the walls, 140mm insulation in the roof, a 70% efficient natural gas boiler and a central heating and cooling heat pump system. The combination of these energy efficient parameters gave a total annual savings of 3,858 Yuan compared to the Reference Model built in the traditional manner.

Although this analysis provides information for decision-making, a more detailed analysis concerning the cost of implementing the proposed measures and the life cycle of the building is important to assure that the most economical design is chosen. For this project, only a payback analysis was performed to ensure that the payback period was not too long. Given the budget and the limited access to information on the cost of building materials for the project, using the long-term approach was not pertinent.

1.3 PAYBACK ANALYSIS

Payback analysis is a short-term approach to building economic analysis. The main principle of payback analysis is to ascertain how quickly the initial investment on a project can be recovered.

This kind of analysis ignores all costs, savings and residual value occurring after the payback time. Consequently, it should be used only as a screening method to identify single project alternatives that are clearly economical and for which a full life cycle cost analysis would be a waste of time and money. In no case should the payback method be used as a tool to select between several mutually exclusive project alternatives (Fuller & Petersen, 1996).

1.3.1 Types of Payback Methods

There are two main types of payback method: the simple payback and the discounted payback. Both methods are relative measures, which means that the result can only be compared with the results of one other base case.

SIMPLE PAYBACK METHOD

The payback analysis referred to earlier as the short-term approach, is known as the Simple Payback (SPB) Method. **Table 1.3.1** shows the SPB method, which bases the decisions to be made on the design of a building, on the time it takes to get back in annual savings the amount of money initially invested. The longer it takes to get this money back, the least appealing an option will be. In this case however, the payback period is the same for each option, so whichever option is implemented in the building, the owner will get his money back in four years.

Table 1.3.1: Simple payback calculations approach

Options	Installation cost	Annual savings	Simple payback period
1. Caulking	40,000.00 YUAN	10,000.00 YUAN	4 years
2. Boiler retrofit	60,000.00 YUAN	15,000.00 YUAN	4 years
3. New boiler	80,000.00 YUAN	20,000.00 YUAN	4 years

The SPB method is relatively simple and fast to use, but it is not always effective, as shown here. Based on the results, the owner still does not know which is the most economical option. He can choose based on the least expensive installation cost, which in this case is the installation of caulking around the windows, or based on the largest savings, which would be the installation of a new boiler.

Although extensively used, the SPB method, according to Kenneth Spain, has the following three major limitations:

(1) It does not effectively consider the time-value of money even though most organizations consider the dollar recovered sooner as having a higher value than that received later.

(2) It does not consider how long the different alternatives will last so two options having the same SPB period but that have different useful life periods will be considered as equivalent when they are not. Furthermore, it ignores all the costs and savings after the payback period.

(3) It often uses an arbitrary payback period that is usually short. Consequently, only the projects having a payback below a certain amount of years will be considered and the period of time is directly proportional to their priority.

RETURN ON INVESTMENT METHOD

The Return on Investment (ROI) Method is also known as the simple rate of return or the investor's rate of return. It is essentially the same as the SPB method. Instead of giving the number of years it takes to recover an initial investment, it gives the percentage of the investment that can be recuperated each year (**Table 1.3.2**). This method also has major limitations. The owner is once again faced with the dilemma of not knowing which option is the most economical since each option has a return on investment of 25%.

Table 1.3.2: Return on investment calculations approach

Options	Installation cost	Annual savings	Return on investment
1. Caulking	40,000.00 YUAN	10,000.00 YUAN	25%
2. Boiler retrofit	60,000.00 YUAN	15,000.00 YUAN	25%
3. New boiler	80,000.00 YUAN	20,000.00 YUAN	25%

DISCOUNTED PAYBACK METHOD

The Discounted Payback (DPB) Method is similar to the SPB Method except that it takes the value of money saved over time into consideration on the basis of a discount rate. As the discount rate increases, the DPB period increases because the value of future cash flow is reduced.

1.3.2 Case Study: Simple Payback Analysis

The Harbin-1 Demonstration project (**Figure 1.3.1**) consisted of retrofitting an existing apartment building in order to reduce the energy consumption of the building by 50% as stipulated in the JGJ 26-95 Standard, while ensuring that the cost of the retrofit would be within 10% of the construction cost for a new building of the same type. In order to reach this goal, an economic analysis was required. In this case, the simple payback method was used.

Attention was paid to the composition of the exterior walls, the roof and the windows that were proposed to improve the energy efficiency of the building.

Figure 1.3.1: Harbin-1 Demonstration

For example, two types of wall system were considered for this project: a rain screen system and an EPS wall. Since the demonstration project was jointly conducted by Canadian and Chinese participants, it was important to consider the differences in material and labour costs between China and Canada. At the time of the study, the cost of labour in China was approximately six times lower than in Canada. The following tables (**Table 1.3.3 & 1.3.4**) summarize the analysis carried out on the retrofit of the exterior walls of the apartment.

Table1.3.3: Composition of exterior wall options

	Rain Screen System	EPS wall
Exterior facing:	Fibre cement panel	Mesh and finish (vapour & air barrier)
Air gap:	35 mm	0 mm
Insulation:	70 mm	70 mm expanded polystyrene
Vapour and air barrier:	Elastomeric membrane	From exterior facing
Brick wall:	149 mm (existing brick wall)	149 mm (existing brick wall)
Interior mortar:	10 mm (existing interior mortar)	10 mm (existing interior mortar)

Table1.3.4: Wall construction cost* comparison

	Rain Screen System		EPS wall	
	Canadian	Chinese	Canadian	Chinese
Material	390 YUAN/ m^2	348 YUAN/ m^2	90 YUAN/ m^2	82.2 YUAN/ m^2
Labour	504 YUAN/ m^2	84 YUAN/ m^2	84 YUAN/ m^2	13.8 YUAN/ m^2
Transportation	96 YUAN/ m^2	84 YUAN/ m^2	24 YUAN/ m^2	20.4 YUAN/ m^2

* 1 CAD = 6 CNY (1996)

At the time the calculations were made, the international cost of coal was 1000 Yuan/ton compared to 200 Yuan/ ton in China. The analysis was made according to the coal price in China at the time.

There were two main design propositions for this project. One of them integrated a rain screen system, insulated the roof and replaced the single-pane windows with double-pane windows, which would reduce the infiltration by 25%. The second proposition used EPS walls, insulating the roof and sealing the windows to reduce infiltration by 25%. The total cost of construction was calculated twice for each proposition in order to take into consideration the price difference between Chinese and Canadian products and labor (**Table 1.3.5**).

Table1.3.5: Construction cost of the design propositions for Harbin

	Option-1 (Canadian costs)	Option-1 (Chinese costs)	Option-2 (Canadian costs)	Option-2 (Chinese costs)
Walls (ext.)	990.00 Yuan/ m^2	517.98 Yuan / m^2	196.50 Yuan / m^2	99.60 Yuan / m^2
Stair walls	990.00 Yuan / m^2	517.98 Yuan / m^2	196.50 Yuan / m^2	99.60 Yuan / m^2
Windows	2,880.24 Yuan / m^2	2,125.98 Yuan / m^2	46.50 Yuan / m^2	20.88 Yuan / m^2
Roof	373.50 Yuan / m^2	208.50 Yuan / m^2	293.28 Yuan / m^2	127.44 Yuan / m^2
Total	5,233.74 Yuan / m^2	3,370.44 Yuan / m^2	732.78 Yuan / m^2	347.52 Yuan / m^2

The payback period was then calculated for each case (**Table 1.3.6**). As shown here, the payback period is rather long. This is a function of the extremely low cost of coal in China at the time. If the price of coal in China were similar to the international cost, the payback period would be lower (**Table 1.3.7**).

Table 1.3.6: Savings based on coal at 200 Yuan per ton

Savings (Yuan /yr)		Payback for Option-1 (Canadian costs) (Years)	Payback for Option -1 (Chinese costs) (Years)	Payback for Option -2 (Canadian costs) (Years)	Payback for Option -2 (Chinese costs) (Years)
Walls-exterior	8,443.08	277	145	62	37
Stair walls	1,335.36	342	179	85	50
Windows	2,186.16	589	434	14	8
Roof	2,046.18	84	47	115	58
Total	14,010.78	288	167	64	37

Table 1.3.7: Savings based on coal at 1,000 Yuan per tons

Savings (Yuan /yr)		Payback for Option -1 (Canadian) (Years)	Payback for Option -1 (Chinese) (Years)	Payback for Option -2 (Canadian) (Years)	Payback for Option -2 (Chinese) (Years)
Walls-exterior	26,880.00	55	29	11	7
Stair walls	4,630.00	68	36	14	8
Windows	5,450.00	118	87	2	1
Roof	7,790.00	17	9	13	7
Total	44,750.00	58	33	10	6

It is possible that in some cases the cost effectiveness of a project is so obvious that no further analysis is required. However, it may be important to ensure that all appropriate alternatives are economically viable and that principles of economic choices are applied to select the optimum alternative. In cases where more than one option is viable, their life cycle cost can be compared to differentiate them and to choose the best alternative.

1.4 LIFE-CYCLE COST ANALYSIS

The life cycle cost analysis is a long-term approach. It takes into account the total cost of the building over its lifetime. This approach offers greater advantages than the Simple Payback Method. Using the previous example, it is likely that, based on the long-term approach, installing a new boiler would be a more economical choice for a building owner, even if the initial cost is higher.

Table 1.4.1: Simple payback calculations approach

Options	Installation cost (Yuan)	Life	Gross Savings (Yuan)	Payback loss (8%)	Net Savings (Yuan)	Investment on savings ratio
1. Caulking	40,000	15	150,000	14,419	135,580	29.5 %
2. Boiler retrofit	60,000	20	300,000	21,629	278,370	21.5 %
3. New boiler	80,000	30	600,000	28,839	571,160	14.0 %

Table 1.4.1 demonstrates information using the Long Term Approach Method, helping the building owner to know which option is the most economical. In this case the savings are calculated based on the life of the given option. For example, retrofitting the boiler will save 15,000 Yuan a year for 20 years, which comes to a total savings of 300,000 Yuan over that period. The payback loss is the amount of money lost during the payback period, assuming that the initial investment of 60,000 Yuan had been placed instead in a bank with interest rates at 8% for four years (payback period). The interest generated over that period would have been 21,629 Yuan. As the 60,000 Yuan was spent, this amount of money was lost and is accounted for as the Payback Loss in order to get the net savings. The evaluation of the most economical option is based on the ratio of the investment over the sum of the savings. The smaller the ratio, the more economical an option is. In this case the most economical option is to install a new boiler. For the third option, the investment on savings ratio is calculated as the required investment for the boiler at 80,000 Yuan over the total net savings of 571,160 Yuan, generated by the use of the new boiler, which results in a ratio of 14.0%.

The life cycle cost analysis (LCCA) provides a better assessment of the long-term cost effectiveness of a project compared with other cost analysis methods and is in direct contrast to the payback method described earlier. It is an economic method of project evaluation in which all costs, from owning, operating, maintaining, and disposing of a building are considered (Fuller & Peterson, 1996). It may also take into account the rate of increase of energy costs.

Life-Cycle Cost (LCC) is the basic building block of LCCA. It is the total cost of owning, operating, maintaining, and disposing of a building or a building system over a given study period with all costs adjusted (discounted) to take into consideration the time-value of money (Fuller & Peterson, 1996). The LCC is used to compare two or more mutually exclusive design alternatives that perform the same function in order to choose the single most cost effective option.

According to the NIST (U.S. National Institute of Standards and Technology) Handbook on life cycle costing, the following ten key steps should be applied during the life cycle cost analysis of a project:

1. Define the problem and state the objectives
2. Identify the feasible alternatives
3. Establish common assumptions and parameters
4. Estimate costs and times of occurrence for each alternative
5. Discount future costs to present values
6. Compute and compare LCC for each alternative
7. If required, compute supplementary measures for project prioritization
8. Assess uncertainty of input data
9. Take into account effects for which dollar costs or benefits cannot be estimated
10. Advise on the decision

1.4.1 Life-Cycle Cost (LCC) Method

In order to calculate the life cycle cost of a project, the cost estimated by year for two or more competitive alternatives, the discount rate, as well as the study period are required parameters. In order to calculate the LCC, the present value of each cost that will appear during the study period using the discount rate is required. The present value costs are then summed up to get the LCC of each alternative. The general formula used to calculate the life-cycle cost of a project is:

$$LCC=\sum_{t=0}^{N}\frac{C_t}{(1+d)^t}$$

Where:

LCC is the total LCC in present-value dollars of a given alternative,

C_t is the sum of all relevant costs, including initial and future costs, excluding any positive cash flows occurring in year ***t***,

N is the number of years in the study period, and

d is the discount rate used to adjust cash flow to present value.

Using this equation can become tedious when the study period is more than a few years long and for annually recurring amounts for which future costs must first be calculated to include changes in prices. The NIST Handbook 135 gives the following simplified LCC equation for evaluating energy and water conservation projects in buildings:

$$LCC = I + Repl - Res + E + W + OM\&R$$

Where:

LCC is the total LCC in present-value dollars of a given alternative,

I is the present-value investment cost,

Repl is the present-value capital replacement cost,

Res is the present-value residual value (resale value, scrap value, salvage value) minus the disposal costs,

E is the present-value energy cost,

W is the present-value water cost, and

OM&R is the present-value non-fuel operating, maintenance, and repair costs.

Other important concepts in building economics are the net savings, the adjusted internal rate of return and the savings to investment ratio.

- **Net Savings:** The net savings are a relative measurement of the economic performance for investments, which reduces operational cost. This measure should be calculated with a base case. Whenever the net savings are positive, the investment costs are effective (Fuller & Petersen, 1996).

- **Adjusted Internal Rate of Return:** The adjusted internal rate of return (AIRR) is a relative measure of the annual percentage yield from a project investment over the study period and must be measured with respect to a base case. The AIRR is usually compared to the investor's minimum acceptable rate of return (MARR) (similar to discount rate in LCCA) and is considered economic when its value is larger. If both the AIRR and MARR are of equal value, the AIRR is considered to be economically neutral. The AIRR can be used to help in the decision of accepting or rejecting a single project alternative compared to a base case, or to allocate a given investment budget among a number of independent projects. It should not be used to make a decision based on multiple and mutually exclusive alternatives (Fuller & Petersen, 1996).

- Savings-to-Investment Ratio: The savings-to-investment (SIR) ratio is defined in the NIST Handbook as being a relative measure of economic performance for a project alternative expressing the relationship between its savings and its increased investment present value cost as a ratio. If the SIR is greater than 1 for a given project alternative, it is considered to be justified with reference to a base case. This basically means that the savings due to the implementation of the alternative, having a SIR greater than 1, are greater than its incremental investment costs and that its net savings are greater than zero. The savings-to-investment ratio should not be used to choose between mutually exclusive project alternatives. It should be used to rank projects with other independent projects as a guide to allocate limited investment funding.

1.4.2 Case Study: LCCA Method

LCCA is mainly used to help make informed decisions on the purchase of products or investment on projects. Decisions on things such as the purchase of a central air conditioner for a house may require a life cycle cost analysis, as demonstrated here (**Table 1.4.1**) from the *Mechanical Estimating Guidebook for Building Construction*:

> *Suppose you are selecting a new central air conditioner for installation in a house with a design-cooling load of 38.0 MJ/hr (36,019 Btu/hr) in a region with approximately 1,500 full-load cooling hours per year. The system with the lowest initial cost that meets the Department of Energy's current energy performance standards has a seasonal energy-efficiency ratio (SEER) of approximately 10.55 kJ/Wh (10.0 Btu/Wh). Because the cooling load hours are above average, you will probably also want to consider systems with*

SEERs of 12.66 and 14.77 kJ/Wh (12.0 and 14.0 Btu/Wh), even though their initial costs are higher. The LCC method helps you determine which SEER will result in the lowest LCC over a 15-year study period.

Local electricity rates are currently $0.08/kWh (summer rates), with no demand charge, and are expected to increase at about 3% per year. Let's use an 8% discount rate to convert future cost (including price increases) to present value. All three systems have an expected life of 15 years and approximately the same maintenance costs.

[…] System B has the lowest LCC and is therefore the economic choice, assuming that its reliability, maintenance, and sound characteristics are not worse than those of system A or C.

Note that if the local utility were to offer a cash rebate for selecting a higher efficiency air conditioner, the initial investment cost should be reduced accordingly for systems B and C. Based on the rebates reflected, system C becomes the most economic choice.

(Marshall 1995)

Table 1.4.1 LCC analysis for air conditioners (Source: Marshall 1995)

		System A	**System B**	**System C**
Seasonal energy efficiency ratio (Btuh/W) SEER obtained from product literature		10.0	12.0	14.0
Annual kWh use $kWh=\frac{36{,}000Btuh}{SEER}\times 1{,}500h/year$		5,400	4,500	3,855
Annual kWh cost ($) $Cost=kWh\times\$0.08/kWh$		432	360	308
Present Value kWh Cost ($) $PV=Cost\times 10.48^{*}$		4,527	3,773	3,234
Without utility rebate	**Initial cost ($)**	2,000	2,500	3,100
	Total LCC	6,527	6,273	6,334
With utility rebate	**Initial cost ($)**	2,000	2,200	2,500
	Total LCC	6,527	5,973	5,734

*** 10.48 is the UPV factor for an annually recurring cost increasing at a rate of 3% and discounted at 8% per year**

1.5 LIFE-CYCLE COST FOR BUILDING CODES

Life cycle costing is used not only to make decisions on certain purchases but it is also used to formulate building codes and standards. The Canadian Model National Energy Code for Building, the first draft of the National Energy Code of China for Commercial Buildings, and the Design Standard for Energy Efficiency of Residential Buildings in Hot summer and Cold Winter Zone JGJ 134 were created in this way. The following section describes the Life-Cycle Cost for Buildings (LCCB) software used to develop the codes.

1.5.1 The Canadian Model National Energy Code for Buildings

The Canadian Model National Energy Code for Buildings (MNECB), previously known as the National Energy Code for Building (NECB), was developed with the use of the LCCB software, which calculates the life-cycle cost values of various building models. The code establishes minimum standards of construction for building components and features that affect a building's energy efficiency and is jointly used with the 1995 National Building Code. The MNECB applies to additions larger than 10m^2 and to all new buildings, except single-family dwellings, multiple-unit residential buildings that are three storeys or less in height and have a building area of 600 square meters (m2) or less, buildings having a surface area under 10 m^2, and farm buildings. A separate code, *Model National Energy Code for Houses*, is used for residential buildings.

A life cycle cost analysis was completed for envelope components in order to determine the appropriate minimum prescriptive requirements. During the analysis process, a reference-building model was created from a set of correlations based on over 5,000 building energy simulations on DOE2.1E for 25 Canadian locations. These correlations are used to predict the heating and the cooling energy of a building based on location, building envelope characteristics and internal gains from lights, equipment and occupants. The reference model consists of a building with four exterior zones facing the cardinal orientation; a lightweight exterior wall with a layer of insulation of unit thickness and a variable U-value; a strip of glazing running the entire length of the wall; a medium weight concrete floor and adiabatic interior walls (Cornick & Sander, 1995).

The following assumptions were also made during the simulation (Cornick & Sander, 1995):

- No internal heat transfer
- Fixed 0.25 L/s•m^2 infiltration rate
- Internal load on a six-day office-type schedule
- Heating setback to 15°C and cooling off when unoccupied
- Variable-air-volume (VAVS) system with terminal reheat (**Figure 1.5.1**)
- Supply air temperature of 13°C
- Free-cooling (enthalpy-controlled air-side economizer)
- 9.4 L/s•person (minimum ventilation as prescribed by ANSI/ASHRAE 62-1989

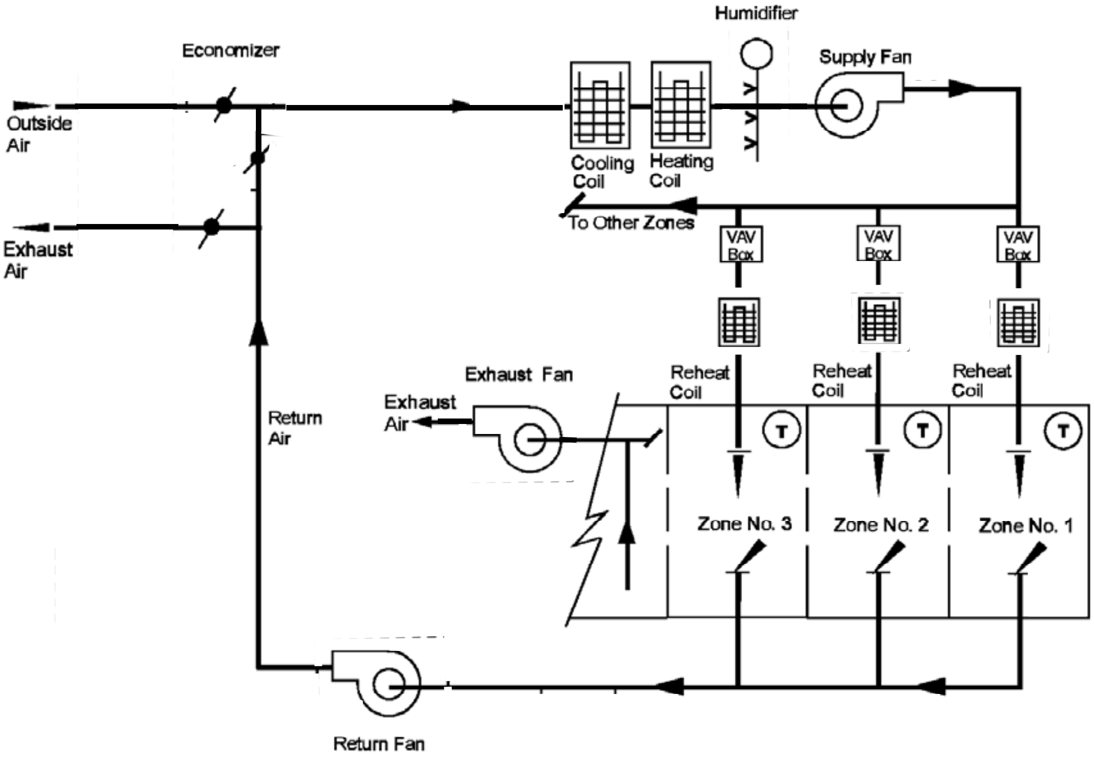

Figure 1.5.1: Variable-volume fan system with optional reheat (VAVS)
Source: Birdsall et al.

The LCCB software is a relatively simple and effective tool used to calculate the changes in heating and cooling energy resulting from the variation of the thermal characteristics of a building envelope, especially the composition of the roof, the exterior walls and the windows. Life-cycle cost analysis of the various options is also performed in order to determine the prescriptive envelope requirements for the code in various regions, taking into consideration the cost and availability of energy and building materials as well as the surrounding weather conditions.

1.5.2 National Energy Code of China for Commercial Buildings

In an effort to build an energy code for commercial buildings in China, both the Chinese and Canadian groups launched a research project in order to develop a National Energy Code of China for Commercial Buildings (NECCB). Part of the project involved adapting the LCCB software to Chinese needs. The following assumptions were made during the building simulations on DOE (Chinese A2000 team, 1999):

- Square building with four identical perimeter zones
- No internal heat transfer between the zones
- Window to wall ratio of 40%
- Six-day office-type schedule
- Internal gains of 25 W/m^2
- Fixed infiltration of 0.25 L/s per m^2
- Minimum ventilation rate of 34 m^3/h per person
- Constant air volume (CAV) system with terminal reheat (**Figure 1.5.2**)
- Supply air temperature automatically controlled with respect to the outdoor temperature
- Free cooling during transitional seasons
- 65% seasonal efficiency for a heating system using coal, and 100% for a system using electricity
- COP (seasonal efficiency for cooling) is 3.0
- Heating setback to 15°C and cooling off during unoccupied periods
- Energy content of 2.2 MJ/ kg for coal

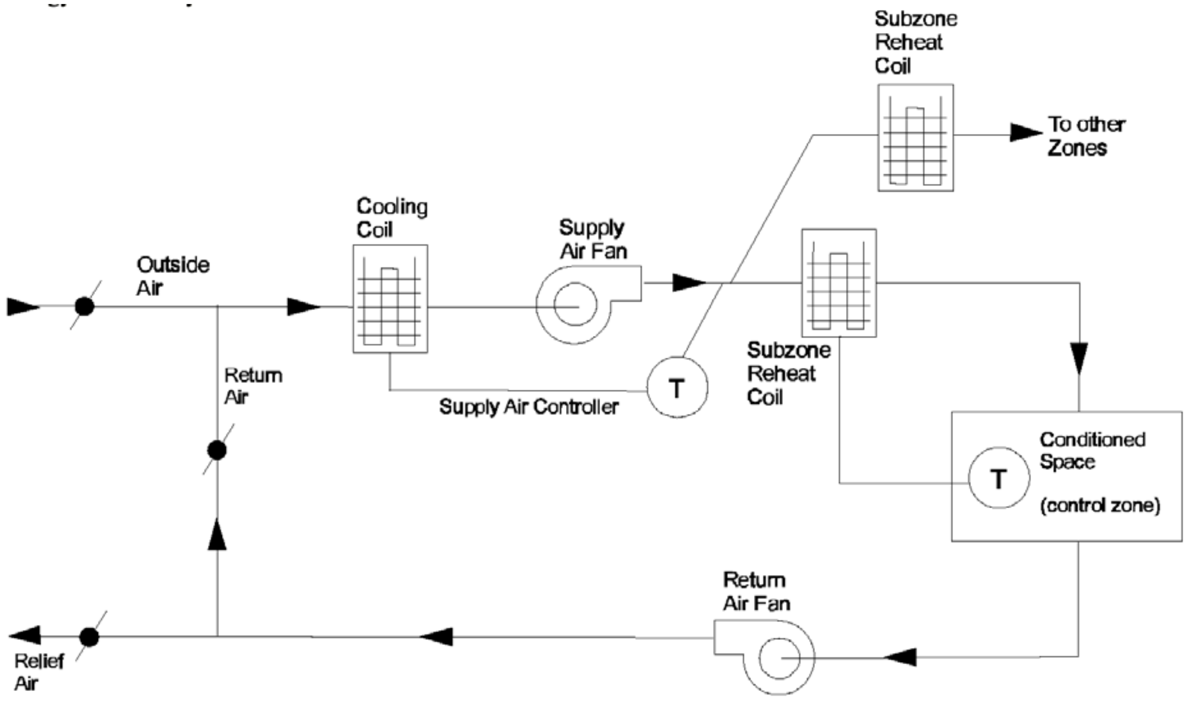

Figure 1.5.2: Constant volume reheat system
Source: Birdsall et al.

1.5.3 LCCB Software Calculations

In the following section we will present detailed explanations of the many LCCB software calculations. The following graph (**Figure 1.5.3**) illustrates the sequence of calculations as well as the required base data for LCC, whereas the tables (**Tables 1.5.1, 1.5.2, and 1.5.3**) enumerate the actual calculations necessary to calculate the Life Cycle Cost of various design options. The first series of tables describe the calculations for the heating load and the second series deal with the cooling load. The final table explains the LCC calculations themselves which is based on the Adjusted Incremental Costs of building materials (AIC), the incremental Costs due to heating (LCC$_{h)}$ as derived from the heating load calculations and the incremental costs due to cooling (LCCc) derived from the cooling load calculations. As will be seen, a number of calculations are required to obtain the life-cycle cost of a building option. For this reason, calculating tools are required[1]. Nevertheless, the calculations themselves are relatively simple and can be performed with the use of spreadsheets.

---

[1] For more details on the calculating tool, refer to *Conversion of the Life Cycle Cost Software – Detailed Analysis Report,* Dessau-Soprin, July 2001

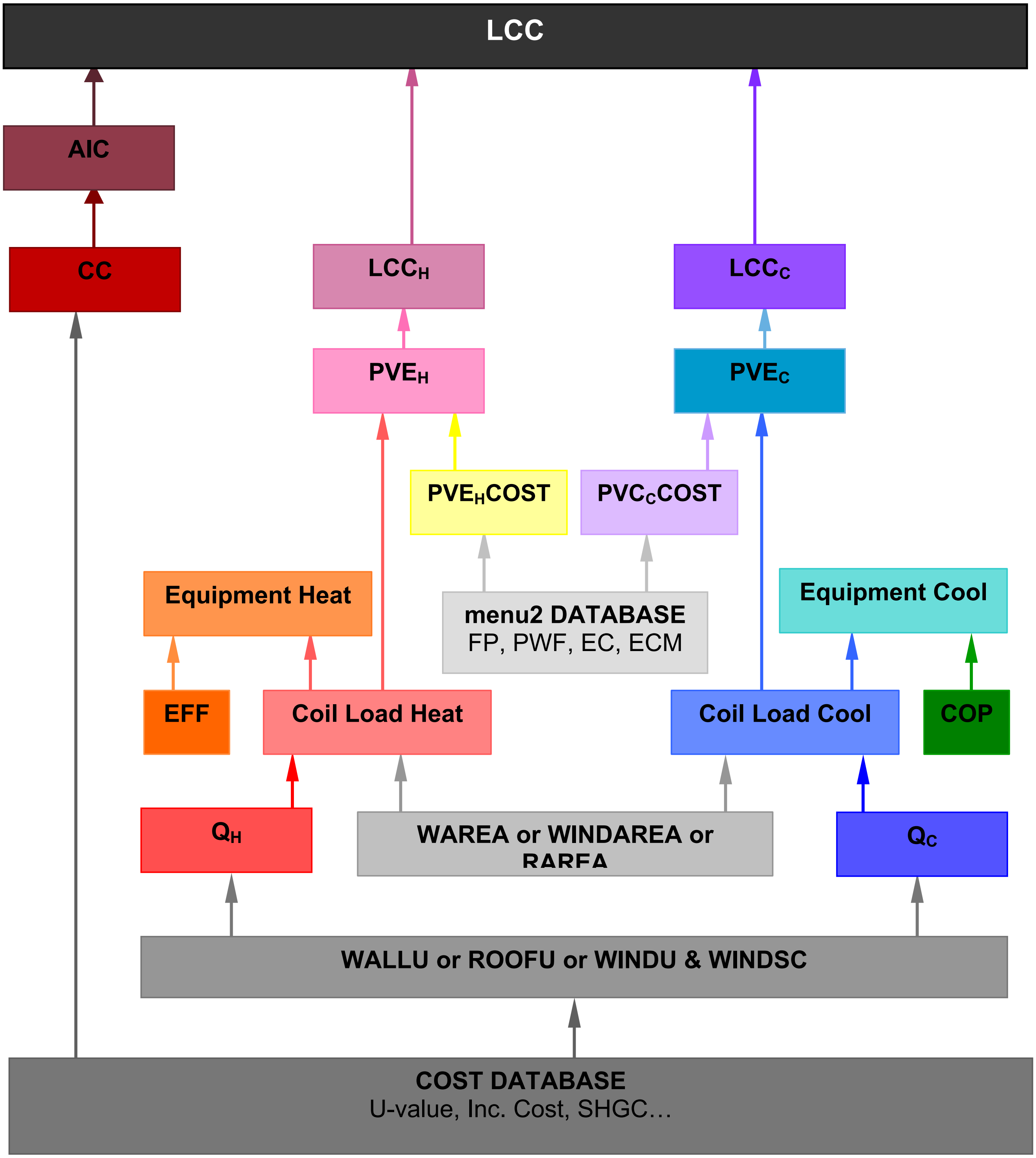

Figure 1.5.3: Simple schematic of the calculations on LCCB software

Table 1.5.1: Calculating the heating loads

Comments	Equations
The **total heating load (Q_H)** is the sum of heating loads for each zone. These heating loads are a function of their respective total gross wall area (A_T), the annual heat loss (H_0), the solar gain reduction factor (f_{SGR}), the internal gain reduction factor (f_{IGR}), the gain interaction factor (f_{GIF}) and the direction of the zone (North, East, West, South).	$Q_H = \sum Q_i$ $Q_i = A_{Ti} + H_{0i} + f_{SGRi} + f_{IGRi} + f_{GIFi}$ * i 5 north, east, west or south
[1] The **annual heat loss (H_0)** is a function of the direction of the zones, a transmission parameter that accounts for heat losses or heat gains through the envelope (U), and two constants: a constant representing the losses due to ventilation and infiltration (b_0), and a constant representing the relationship between the U-factor and the heat losses (b_1)	$H_{0i} = b_{0i} + U \times b_{1i}$
[1.1] The **infiltration and ventilation losses constant (b_0)** is a function of the zone direction, two climate correlation constants for the annual heat losses ($C_{1\text{-}1}$, $C_{1\text{-}2}$), and the heating degree-days at 65F (18.3°C) (HDD65). In some cases the value of the constant b_0 is known, so it is not necessary to calculate it.	$b_{0i} = C_{1-1i} + C_{1-2i} \times HDD65$
[1.2] The **constant for the relationship between the U-factor and the heat loss (b_1)** is also a function of other climate correlation constants for the annual heat loss ($C_{2\text{-}1}$, $C_{2\text{-}2}$) and the heating degree-days at 65F.	$b_{1i} = C_{2-1i} + C_{2-2i} \times HDD65$
[1.3] The **transmission parameter (U)** is a function of the U-values of the walls and the windows, as well as their areas. Where U_{wall} and A_{wall} are the U-value and the area of the exterior walls, U_{window} and A_{window} are the U-value and area of the windows. The total gross area of the wall is represented as A_T.	$U = \frac{(U_{wall} \times A_{wall}) + (U_{window} \times A_{window})}{A_T}$
[2] The **solar heat gain reduction factor (f_{SGR})** accounts for the solar gain through the envelope. It is a function of the direction of the zones (i), three coefficients (α_1,α_2,α_3), a value (X) depending on the ratio of the annual heat loss (H_0) and a parameter (V)	$f_{SGR} = \frac{1}{1 + \alpha_1 X_i + \alpha_2 X_i^2 + \alpha_3 X_i^3}$
[2.1] The **solar gain reduction factor coefficients (α_1,α_2,α_3)** are a function of the climate factor for solar gain reduction (k_1). They	$\alpha_{1i} = C_{3-1} \times k_{1i}$ $\alpha_{2i} = C_{3-2} \times k_{1i}^2$

Comments	Equations
also vary according to the direction of the zones (*i*).	$\alpha_{3i}=C_{3-3}\times k_{1i}^{3}$
[2.1.2] The **climate factor for solar gain reduction (k$_1$)** is a function of the direction of the zones (*i*), certain coefficients, the vertical solar radiation (V), the latitude (LAT), the cooling degree-days (CDD50) and the heating degree-days (HDD50) at 50F (10°C).	$k_1=C_{(4-1)i}+\left(C_{(4-2)i}\times LAT\right)+\left(C_{(4-3)i}\times CDD50\right)$ $+\left(C_{(4-4)i}\times V_i\times CDD50\right)+\left(C_{(4-5)i}\times V_i\right)$ $+\left(C_{(4-6)i}\times CDD50^2\right)+\left(C_{(4-7)i}\times HDD50\right)$
[3] The **internal gain reduction factor (f$_{IGR}$)** is a function of the direction of the zones (*i*), certain coefficients (β_1,β_2,β_3) and the Y factor, which is the ratio of the W factor and the annual heat loss (H$_0$)	$f_{IGR}=e^{\left(\beta_1 Y+\beta_2 Y^2+\beta_3 Y^3\right)}$
[3.1] The **coefficients for the internal gain reduction factor (β_1,β_2,β_3)** are proportional to a climate parameter for the internal gain reduction factor (k$_2$), they also vary according to the direction of the zones (*i*)	$\beta_{1i}=C_{5-1}\times k_{2i}$ $\beta_{2i}=C_{5-2}\times k_{2i}^{2}$ $\beta_{3i}=C_{5-3}\times k_{2i}^{3}$
[3.1.2] The **climate parameter for the internal gain reduction (k$_2$)** is a function of the direction of the zones (*i*), the latitude (LAT), the vertical solar radiation in the east and west direction (V$_{EW}$), the cooling degree-days at 65F (CDD65) and some constants.	$k_2=C_{(6-1)i}+\left(C_{(6-2)i}\times CDD65\right)$ $+\left(C_{(6-3)i}\times V_{EW}\right)+\left(C_{(6-4)i}\times LAT\right)$
[4] The **gain interaction factor (f$_{GIF}$)** is a function of the Z parameter and some constants	$f_{GIF}=e^{\left(C_{7-1}+C_{7-2}Z_i+C_{7-3}Z_i^2+C_{7-4}Z_i^3\right)}$
[4.1] The **Z parameter** values vary according to the value of the product between the solar gain reduction factor and the internal gain reduction factor.	If $f_{SGRi}\times f_{IGRi}=1, Z_i=1$ For $f_{SGRi}\times f_{IGRi}\neq 1, Z_i=\frac{1-f_{SGRi}\times f_{IGRi}}{\left(1-f_{SGRi}\right)+\left(1-f_{IGRi}\right)}$

Table 1.5.2: Calculating the cooling loads

Comments	Equations
The **cooling load (Qc)** is the larger of two equations. The first one is a function of the total gross wall area, the base cooling load (Q_{c0}), and the correction factor for the losses and gains from the envelope (ΔQc). The second one is the product of the total gross wall area and the minimum-cooling load (Q_{Cmin}). All values vary according to the direction of the zone (*i*)	$Qc=MAX\{[A_T i\times(Q_{C0i}+\Delta Q_{Ci})];[A_{Ti}\times Q_{C\min i}]\}$
[1] The **base-cooling load (Q_{C0})** is the larger of two equations. The first equation is proportional to the minimum-cooling load, while the second equation depends on three coefficients (a_0, a_1, a_2), the V and the W parameters. The base-cooling load also varies according to the direction of the zones (*i*).	$Q_{C0}=MAX\{[C_{\min i}];[a_{0i}+a_{1i}\times V+a_{2i}\times W]\}$
[1.1] The **coefficients that intercept for cooling load (a_0)** is proportional to degree-days at 65 (CCD65) and 50 F (CDD50), the vertical solar radiation (V), and the direction of the zones (*i*)	$a_0=C_{8-1i}+(C_{8-2i}\times CDD65)+(C_{8-3i}\times V_i)$ $+(C_{8-4i}\times CDD50)+(C_{8-5i}\times V_i\times CDD50)$ $+C_{8-6i}\times\sqrt{V_i\times CDD\,50}$
[1.2] The **coefficient representing the variation of the cooling with solar parameter (a_1)** is a function of direction of the zones (*i*), the cooling degree-days at 50F, the heating degree-days at 65F, and the vertical solar radiation.	$a_1=C_{9-1i}+(C_{9-2i}\times CDD50)+\left(C_{9-3i}\times\sqrt{CDD50}\right)$ $+(C_{9-4i}\times HDD65)+(C_{9-5i}\times V_i)$ $+(C_{9-6i}\times V_i\times CDD50)$
[1.3] The **coefficient representing the variation of cooling with the internal load parameter (a_2)** is a function of the direction of the zones (*i*), and the cooling degree-days at 65 and 50F.	$a_2=(C_{10-1i}\times CDD50)+(C_{10-2i}\times CDD65)$ $+(C_{10-3i}\times CDD50\times CDD65)$ $+C_{10-4i}\sqrt{CDD50\times CDD65}$
[1.4] The **minimum cooling load (C_{min})** is a function of the cooling degree-days	$C_{\min}=C_{11-1}i\times CDD50+C_{11-2i}\times CDD50^2$ $+C_{11-3i}\times CDD65$ $+C_{11-4}\times CDD50\times CDD65$ $+C_{11-5}\times\sqrt{CDD50\times CDD65}$
[2] The **correction for the envelope losses and gains (ΔQ_C)** is a function of the minimum cooling load and base cooling load and a coefficient representing the variation of cooling with thermal transmittance.	$\Delta Q_C=a_{3i}\times U\times\frac{C_{\min i}}{Q_{C0i}}$

Comments	Equations
[2.1] The **coefficient representing the variation of cooling with thermal transmittance (a$_3$)** is a function of the latitude, the heating degree-days, and the cooling degree-days	$a_3 = C_{12-1i} + \left(C_{12-2i} \times LAT\right) + \left(C_{12-3i} \times LAT^2\right) + \left(C_{12-4i} \times CDD50\right) + \left(C_{12-5i} \times \sqrt{CDD50}\right) + C_{12-6i} \times HDD65$

Table 1.5.3: Calculating the life-cycle cost

Comments	Equations
The **life-cycle cost (LCC)** is a the sum of the adjusted incremental cost (AIC) of building materials, the incremental cost due to heating (LCC$_H$) and the incremental cost due to cooling (LCC$_C$). In order to compare the variation of building characteristic, their incremental life-cycle cost is taken into consideration.	$LCC = AIC + LCC_H + LCC_C$
The **incremental costs due to cooling (LCC$_C$) and heating (LCC$_H$)** depend on the present value of energy for heating (PVE$_H$) and the cooling (PVE$_C$). PVE$_{Cmin}$ and PVE$_{Hmin}$ are the smallest PVE$_H$ and PVE$_C$ values from the list of materials.	$LCC_C = PVE_C - PVE_{C\min}$ $LCC_H = PVE_H - PVE_{H\min}$
The **present values of energy (PCE$_C$ & PVE$_H$)** are functions of the coil load for heating (CL$_H$) and for cooling (CL$_C$) and the present values of energy costs for heating (PVE$_H$Cost) and the present value for cooling (PVE$_C$Cost)	$PVE_H = CL_H \times PVE_H Cost$ $PVE_C = CL_C \times PVE_C Cost$
The **coil loads for heating (CL$_H$) and cooling (CL$_C$)** is calculated for each assembly of each building component analyzed (i.e. window, roof, walls). They are calculated as the ratio of the total heating loads (Q$_H$) or cooling loads (Q$_C$) over the area of the exterior walls, windows or roofs (A$_n$).	$CL_H = \frac{A_n}{Q_H}$ $CL_C = \frac{A_n}{Q_C}$
The **present value of energy cost for both heating and cooling (PVE$_H$Cost & PVE$_C$Cost**) are functions of the present worth factor (PWF), the fuel price (FP), the energy contents (EC), the environmental cost multiplier (ECM), the coefficient of performance for cooling (COP) and the efficiency for heating (EFF). The default value for the ECM is 1. The default values for the EC are given as: 3.6MJ for electricity, 37.88 MJ for gas, 38.68MJ for oil and 22.00MJ for coal.	$PVE_H Cost = \frac{PWF \times FP}{EC \times EFF} \times ECM$ $PVE_C Cost = \frac{PWF \times FP}{EC \times COP} \times ECM$

REFERENCES

BIRDSALL, B.E. et al.; **DOE-2.2 Basics Manual**; '*HVAC Programs*'; Building Technologies Program; Environmental Energies Technology Division; Lawrence Berkeley National Laboratory; University of California; James J. Hirsh & Associates; LBNL and James J. Hirsh, April 1998; 59 pages.

CHINA ACADEMY OF BUILDING RESEARCH (CABR); Report on the Application of LCCB Software in the Development of NECCB of China, Chinese Side Team for A2000; China; April 1999

CORNICK, Steven M. & SANDER, Daniel M.; A Simplified Energy Model for Analysis of Building Envelope Thermal Characteristics; *Thermal Envelopes VI / Building Energy Codes – Principles*; pp. 687-695, 1995

CORNICK, Steven M.; HAYSOM, John C.; SANDER, Daniel M.; SWINTON, Michael C.; Determination of Building Envelope Requirements for the (Canadian) National Energy Code for Buildings; *Thermal Envelopes VI / Building Energy Codes – Principles*; pp. 679-685, 1995

FULLER, Sieglinde K. & PETERSEN, Stephen R.; Life-Cycle Costing Manual for the Federal Energy Management Program; NIST Handbook 135; Building and Fire Research Laboratory; Office of Applied Economics; MD; February 1996

KENNETH SPAIN, T., *PE*, *CEM,* Pay Now or Pay Later: Life-Cycle Cost and Payback Analysis Techniques, Energy User News, Energy Management for the commercial, industrial and institutional markets, November 9, 2000,
http://www.energyusernews.com/CDA/Article_Information/Fundamentals_Item/0,2637,14541,00.html

MARSHALL, M. E.; Mechanical Estimating Guidebook for Building Construction; '*Chapter 27: Life Cycle Costing*'; 6th edition; McGraw-Hill Inc.; 1995, pp 407-417

RAKHRA, A.S., CBD-212. Buildings and Life-Cycle Costing, Canadian Building Digest, IRC, National Research Council Canada (NRC), 1980, http://www.nrc.ca/irc/cbd/cbd212e.ntmh