LOW-INCOME HOUSING REHABILITATION FOR SUSTAINABILITY AND AFFORDABILITY

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EXECUTIVE SUMMARY

Johnson Creek Commons is a 15-unit apartment complex located in the Brentwood-Darlington neighborhood of Outer Southeast Portland and the Johnson Creek watershed. The Johnson Creek Commons apartment complex, built in 1973, was operated until 1998 as market-rate housing. In the Spring of 1998, Sustainable Communities Northwest and ROSE Community Development created a limited liability corporation to purchase, rehabilitate, and manage the property on a 50/50 basis. The Portland Development Commission provided a low-interest loan and grant funds to finance the bulk of the development costs, and Shorebank Pacific provided an additional loan to cover the gap. The Housing Development Center provided technical assistance in the areas of financial packaging and construction management.

Johnson Creek Commons meets objectives for both affordability and ecological sustainability. Physical improvements during the eight-month rehabilitation included replacing rotten siding with durable Hardi-Plank siding; replacing kitchen flooring with extremely durable, nontoxic Marmoleum; replacing drafty windows and patio doors with high-efficiency vinyl windows; dramatically increasing insulation; implementing water-saving measures; and replacing electric baseboard heaters with a more comfortable, energy-efficient heating system.

This study analyzed the effects of the rehabilitation that was initiated in November 1998 and completed in August 1999. The objectives of the study were the following:

- Estimate the energy and utility bill savings resulting from the energy-efficiency retrofits that were conducted on the buildings in the housing complex.
- Determine the economic impacts of the energy-efficiency retrofits.
- Assess the effects of other retrofits that affected the costs of owning and maintaining the buildings and the health and comfort of the occupants.

The approach used to assess the energy-efficiency retrofits was based on applying the WATTSUN computer program to estimate the changes in energy consumption that resulted from the retrofits. The methods of analyzing other retrofits varied depending on the nature of the retrofit. The combined perspective of the property owners and occupants was used to assess the effects of the rehabilitation.

S.1 ENVELOPE ENERGY-EFFICIENCY IMPROVEMENTS

For analysis purposes, we divided the property into five building units comprised of one or more apartments. Project documents provided the costs of individual envelope efficiency measures that were implemented. These measures included:

- Upgrading ceiling insulation from R-11 to R-38 blown-in insulation,

- Upgrading floor insulation from none to R-30 insulation,
- Adding rigid wall insulation (in conjunction with new siding) to walls with R-8 batt insulation, and
- Upgrading single-pane aluminum frame windows and sliding glass doors to vinyl-framed, double-pane, low-emissivity (low-E), argon-filled glazing with a U-value of 0.35.

The total cost of these upgrades was $43,942. A $15,200 rebate from Portland General Electric partially offset the initial costs. The remaining costs were prorated among the loans and grants used to finance the project.

The effects of these upgrades on space heating electricity consumption were estimated by running the WATTSUN program with the original insulation levels and other characteristics of the building compared with the installed insulation levels, windows, and sliding glass doors. Table S-1 shows the estimated space heating electricity use for the initial apartment complex and the same units with the upgrades ("improved"). Our analysis estimated annual electricity savings of about 103,000 kWh, or about a 75 percent reduction.

Table S-1
Space Heating Energy Impacts

Estimated Annual Energy Use, kWh		Estimated Annual Energy Savings, kWh
Initial	Improved	
136,570	33,365	103,205

We used current electricity prices to determine the utility bill impacts of these efficiency improvements. We also estimated the net impacts over two time periods—25 years and 60 years. The 60-year time horizon was used because the property owners guaranteed to the Portland Development Commission that the housing project would be maintained as affordable housing over that time period. In this analysis, we assumed no increase in real electricity prices. Table S-2 shows that the electricity bill for all 15 units combined decreased an average of about $500 per month. Over a 25-year horizon, the electricity savings were estimated to exceed the costs of financing the efficiency improvements by $83,000. Over the 60-year horizon, the savings were estimated to be nearly $145,000.

Table S-2
Economic Impacts

Change in First Year Electricity Bills		Net Change in Life Cycle Costs, Present Discounted Value	
Monthly Average	Annual	25 Year Horizon	60-Year Horizon
-$501	-$6,012	-$83,000	-$144,800

S.2 OTHER IMPROVEMENTS

A number of other enhancements were made or are planned to the apartment complex and its site to improve the overall resource efficiency and sustainability. We discussed the following:

- Installation of Marmoleum brand linoleum flooring in place of standard vinyl,
- Installation of high flow rate bathroom fans to reduce mold problems,
- Repainting with solvent-free paints,
- Use of recycled exterior paint,
- Installation of energy-efficient appliances and equipment, and
- Implementation of a water-efficiency program in conjunction with the Portland Water Bureau.

The linoleum flooring is made from natural materials and is biodegradable. Because it is more durable than vinyl flooring, it also offers direct economic benefits. We analyzed the economic impacts of the flooring and found that, despite the fact that it was about twice as expensive as standard vinyl flooring, over a 25-year period it will reduce ownership and maintenance costs to the property owners by nearly $5,000 and over 60 years it will reduce costs nearly $9,000.

S.3 IMPLICATIONS AND AREAS FOR FOLLOW-UP RESEARCH

Our analysis has shown that this project achieved its objectives of combining affordability with ecological sustainability in a low-income apartment complex rehabilitation. The electric utility bill savings will provide substantial economic benefits to the occupants over the lifetime of the buildings. The efficiency improvements and several of the other green improvements to the building will benefit the occupants through improved living conditions, improved air quality, better comfort, and improved health.

There are a number of areas in which further research should be conducted on this project to verify the effects highlighted by this study and explore other effects.

- *The electricity bills for individual apartments should be analyzed to verify the electricity savings we estimated.*
- *Interviews with tenants should be conducted to assess other effects of the rehabilitation.*
- *The effects of installing high-efficiency refrigerators should be analyzed.*
- *The effects of the water efficiency program should be analyzed.*
- *The transferability of the approaches used in this project to other low-income housing projects should be assessed.*

1 INTRODUCTION

This section describes the objectives of a study that was conducted to assess a recently completed multifamily, low-income housing project rehabilitation. The rehabilitation was conducted to improve the property to meet objectives of affordability and ecological sustainability.

1.1 STUDY OBJECTIVES

This study analyzed the Johnson Creek Commons multifamily, low-income housing complex rehabilitation that began in November 1998 and completed in August 1999. The primary objectives of the study were the following:

- Estimate the energy and utility bill savings resulting from the energy-efficiency retrofits that were conducted on the buildings in the housing complex.
- Determine the economic impacts of the energy-efficiency retrofits.

In addition to the primary objectives, the study also had the following objective:

- Assess the effects of other retrofits that affected the costs of owning and maintaining the buildings and the health and comfort of the occupants.

The approach used to assess the energy-efficiency retrofits was based on applying the WATTSUN computer program to estimate the changes in energy consumption that resulted from the retrofits.[1] The methods of analyzing other retrofits varied depending on the nature of the retrofit.

1.2 JOHNSON CREEK COMMONS REHABILITATION PROJECT

This subsection discusses the Johnson Creek Commons apartment complex and the purposes of the rehabilitation project. It also discusses what steps were taken in the rehabilitation, funding sources, the characteristics of the units, and the retrofits that were performed.

1.2.1 Project Description

Johnson Creek Commons is a 15-unit apartment complex located in the Brentwood-Darlington neighborhood of Outer Southeast Portland and the Johnson Creek watershed. This neighborhood faces a serious lack of affordable housing, leading to its designation by the Portland Development Commission and the City's Bureau of Housing and Community Development as a "target" area for affordable housing development. The Johnson Creek Commons apartment

[1] We used WATTSUN 5.6 for our analysis. WATTSUN was produced by the Washington State University Energy Program.

complex, built in 1973, was operated until 1998 as market-rate housing. It is situated on almost an acre of land and is located in close proximity to schools, shopping, jobs, green space, and public transport. The complex is composed entirely of two-bedroom apartments set around a courtyard planted in grass. Current tenants are mostly low-income Hispanic families with children.

In the Spring of 1998, Sustainable Communities Northwest and ROSE Community Development created a limited-liability corporation to purchase, rehabilitate, and manage the property on a 50%/50% basis. The Portland Development Commission provided a low-interest loan and grant funds to finance the bulk of the development costs, and Shorebank Pacific provided an additional loan to cover the gap. The Housing Development Center, an experienced provider of technical assistance to nonprofit housing groups, provided technical assistance in the areas of financial packaging and construction management.

Johnson Creek Commons meets objectives for both affordability and ecological sustainability. Rents are maintained at rates affordable to very low-income households. Ten of the 15 units rent affordably to households earning 50 percent of median income, and 5 units rent affordably to households earning 30 percent of median income. Physical improvements during the eight-month rehabilitation included replacing rotten siding with durable Hardi-Plank siding; replacing kitchen flooring with extremely durable, non-toxic Marmoleum; replacing drafty windows and patio doors with high-efficiency vinyl windows; dramatically increasing insulation; implementing water-saving measures; and replacing electric baseboard heaters with a more comfortable, energy-efficient heating system.

The land in the interior courtyard and around the perimeter of the apartments has been planted with vegetable beds, fruit trees, and native plants, providing healthy, fresh food to tenants. Many volunteers from the community have helped with the gardening program and other initiatives. Over time, the project sponsors will work with tenants to implement other community-driven initiatives, which may include training in reducing resource consumption, job skills training, transportation alternatives, bartering programs, and even cooperative business ventures.

1.2.2 Property Description

The property is divided into 4 structures that contain 15 apartment units and 1 laundry facility. The total square footage of the property is 11,436 sq. ft. Apartment units 1 through 14 are nearly identical 2-bedroom units of approximately 775 sq. ft. each. Apartment 15 is a 1-bedroom unit of approximately 420 sq. ft.

Apartments 1 through 3 and 4 through 6 are contained in two, single-story buildings oriented on an east/west axis. Apartments 1 though 3 face north, and 4 through 6 face south. Apartments 7 through 10 are in a two-story building with two apartments on each floor. The structure housing apartments 11 through 14 is identical to the unit with apartments 7 through 10, except that a single-story wing, housing unit 15 and the laundry room, is attached to the north side. Units 7 through 15 all face east. The majority of the glazing in each unit is on its front side and is dominated by a large patio sliding door.

1.2.3 Project Expenditures and Funding

Johnson Creek Commons was purchased for $660,000. Subsequent to the purchase, approximately $230,000, including administrative costs, was expended to address numerous deferred maintenance items and make significant energy-efficiency improvements to the property. Based on the cost breakdown for the project, the actual capital improvements cost $168,868, for a total investment of approximately $829,000. The financing for the project came in the form of grants and loans from several different sources, as shown in Table 1-1, and totaled $889,632.

Table 1-1
Sources of Capital Funds

Description	Amount	Source	Interest Rate	Term
"Equity Gap Grant"	$284,622	Portland Development Commission	N/A	N/A
Loan	$350,000	Portland Development Commission	3%	30 years
Loan	$245,010	Shorebank Pacific	8%	20 years
Grant	$10,000	U.S. Bank	N/A	N/A

1.2.4 Renovations

A wide range of renovations was performed on the complex. Most of the renovation funds were dedicated to materials and repairs to improve the condition of the property. In some cases, these materials and repairs applied to only a subset of the units. They included such items as:

- Fence repairs,
- Sidewalk repairs,
- Siding replacement,
- Exterior and interior painting,
- New flooring,
- Repair and replacement of plumbing fixtures,
- New electrical equipment and repairs,
- Replacement of baseboard heaters with radiant systems, and
- New appliances.

Several measures were installed in the building shell specifically to improve the energy efficiency of the property. These measures were installed in all the units. The energy-efficiency measures included the following:

- R-38 ceiling insulation,
- R-30 floor insulation,
- Rigid wall insulation (in conjunction with new siding), and
- High-efficiency windows and sliding glass doors.

Expenditures on building shell energy-efficiency improvements comprised $43, 942 of the total improvements. These costs were offset partially by a rebate from Portland General Electric (PGE) in the amount of $15,200.

Some measures listed earlier and others produced benefits associated with "green" buildings such as water savings, better indoor air quality, and reduced use of nonrenewable resources. Some of the measures were applied to only certain units. These measures included:

- Replacement of vinyl flooring with Marmoleum, a product made with cork, wood, and linseed oil,
- Replacement of carpeting with carpet made from recycled plastic,
- Use of recycled paints on the exterior and paints with no petroleum-based solvents on the interior,
- Replacement of conventional incandescent exterior light bulbs with high-efficiency compact fluorescent bulbs (CFLs), and
- Use of sustainably harvested lumber in a few locations.

In addition to these improvements, a number of others are being conducted in conjunction with the Portland Water Bureau to improve the efficiency of water use at the site. These are not analyzed here, but are an important component of the overall green building enhancements that are being made to the property.

1.3 STUDY CONTENTS

Section 2 focuses on the analysis that was conducted of the building shell energy-efficiency improvements. We used a computer model (WATTSUN) to estimate the energy savings from these improvements and then analyzed the economics of making the improvements.

Section 3 discusses some of the other property improvements that were made that did not involve the building shell and were not aimed primarily at saving energy. These are not analyzed in detail, but their importance and potential benefits are examined.

Section 4 summarizes our overall findings for this project. Because this project is very unique and had the objective of making the property more affordable and ecologically sound, the findings could be very important to future low-income housing rehabilitation efforts in Portland and elsewhere.

2 ENERGY-EFFICIENCY IMPROVEMENTS

This section discusses the energy and cost impacts of the energy-efficiency retrofits that were made to the units in Johnson Creek Commons. The first subsection discusses our analysis approach. The second presents the analysis results.

2.1 ANALYSIS APPROACH

For analysis purposes, we divided the property into five building units comprised of one or more apartments. A typical floorplan of apartments 1 through 14 is shown in the appendix. The five units were the following:

- Apartments 1 through 3 (single story)
- Apartments 4 through 6 (single story)
- Apartments 7 through 10 (two story)
- Apartments 11 through 14 (two story)
- Wing apartment 15 and the laundry room.

2.1.1 Costs

Project documents provided the costs of individual envelope efficiency measures that were implemented.[1] These measures included:

- Upgrading ceiling insulation from R-11 to R-38 blown-in insulation,
- Upgrading floor insulation from none to R-30 insulation,
- Adding rigid wall insulation (in conjunction with new siding) to walls with R-8 batt insulation, and
- Upgrading single-pane aluminum frame windows and sliding glass doors to vinyl-framed, double-pane, low-emissivity (low-E), argon-filled glazing with a U-value of 0.35.

We prorated the initial purchase cost, total energy-efficiency improvement cost, and the PGE rebate over each of the five building units based on the unit's floor area.[2] These data are presented in Table 2-1. We did not include expenditures associated with deferred maintenance

[1] These documents were provided by Rosemarie Cordello, Executive Director, Sustainable Communities Northwest.

[2] Note that was done for convenience and would not be completely accurate because wall and window area would not be directly proportional to floor area. For our purposes, this did not affect the overall results because they were calculated for the project as whole.

or administrative costs in this analysis since these costs were not related directly to the energy-efficiency improvement costs.

Table 2-1
Summary Cost and Rebate Information

Units	Square Footage	Pro Rata Share of Initial Purchase Cost	Pro Rata Share of PGE Rebate:
1,2,3	2,316	$133,662.12	$3,078.28
4,5,6	2,316	$133,662.12	$3,078.28
7,8,9,10	3,192	$184,218.26	$4,242.60
11,12,13,14	3,192	$184,218.26	$4,242.60
15	420	$24,239.24	$558.24
Totals	11,436	$660,000.00	$15,200.00

Table 2-2 shows how the costs were broken down by shell component for each group of apartments. The majority of the costs were for window and sliding door upgrades to high-efficiency vinyl frame units. The wall upgrade costs were for installing ¾-inch, expanded polystyrene (EPS) that was applied in conjunction with the new siding. We did not include the cost of the new siding since the siding material was applied to improve the exterior condition and durability, not as an energy conservation measure.

Table 2-2
Energy-Efficiency Upgrade Cost by Component and Unit

Units	Pro Rata Share for Floor Improvements	Pro Rata Share for Wall Improvements	Pro Rata Share for Ceiling Improvements	Pro Rata Share for Glazing Improvements	Totals for Each Apartment Group
1,2,3	$1,378.75	$1,012.59	$827.29	$5,680.44	$8,899.06
4,5,6	$1,378.75	$1,012.59	$827.29	$5,680.44	$8,899.06
7,8,9,10	$1,900.24	$1,395.59	$1,140.20	$7,829.00	$12,265.03
11,12,13,14	$1,900.24	$1,395.59	$1,140.20	$7,829.00	$12,265.03
15	$250.03	$183.63	$150.03	$1,030.13	$1,613.82
Totals	$6,808.00	$5,000.00	$4,085.00	$28,049.00	$43,942.00

2.1.2 Energy Analysis

To analyze the energy effects of the efficiency retrofits, we had to model each unit before and after the retrofits occurred. The initial characteristics of each unit, such as original insulation levels, were provided by a form from an energy audit conducted by PGE. The building dimensions were available from documentation provided on each unit. The orientation of the units was determined through a site visit. The characteristics of upgrades to each unit were available from the project documentation on the measures that were installed.

We used the WATTSUN computer program to estimate the space heating energy consumption of each building unit. This program uses the building characteristics data and long-term weather data to estimate space heating consumption. We used weather data for Portland, Oregon and modeled each unit before and after retrofit. Because WATTSUN does not permit temperature setbacks in the analysis, the units were modeled with a constant thermostat setpoint of 65 °F to take into account likely setback during the nighttime and a setpoint of 68 °F during the daytime. The infiltration rate was assumed to decrease from 0.6 air changes per hour (ACH) before retrofit to 0.4 ACH after retrofit.[3] This was likely to be a conservative assumption, given comments of the occupants about how drafty the units were before the windows, doors, and sliding doors were replaced.

2.1.3 Life-Cycle Cost Analysis

We conducted a life-cycle cost analysis of the units with and without the energy-efficiency upgrades. The analysis took the perspective of the project developers and the apartment occupants. Thus, the initial and future incremental costs of upgrading the units were included, along with the costs of heating the units. The first set of costs will be paid directly by the project developers, and the heating costs will be paid by the occupants. The costs to the developers were calculated by taking into account the unique mix of financing that was used.

To analyze the impacts of future energy savings, we projected electricity costs for heating the units with and without the efficiency retrofits. The calculations were conducted over several intervals, up to 60 years. The 60-year time span was used because the project developers have committed to maintaining the property as low-income housing for that period.

Future economic costs and benefits are typically adjusted to convert them to their equivalent values from today's perspective, or their present discounted value. This is done by applying a time preference rate or discount rate.[4] The discount rate takes into account the fact that a dollar invested today can earn a rate of return based on the interest rate and be worth $(1+the interest rate) a year from now. Determining the appropriate discount rate in cost-benefit analysis can be complicated by issues such as what alternative investments are available, whether the investment is a private or public one, whether the discount rate should vary from year to year, the inflation rate, risk, and whether a different rate should be applied to different types of costs or benefits. Furthermore, many economists and analysts have argued that future costs that affect subsequent generations should not even be discounted if the intergenerational impacts are to be accounted for equitably.

Discount rates used in economic studies have ranged from 0 to over 20 percent. For this analysis we used a real discount rate of 3 percent, which is comparable to long-run, real discount rates used in most analyses of public investments. Accounting for inflation (see discussion below), the

[3] These values were based on the assumptions used in the 1986 *Northwest Conservation and Electric Power Plan, Volume 2*, from the Northwest Power Planning Council.

[4] Layard, Richard (ed.). 1974. *Cost-Benefit Analysis*, p. 29. Great Britain. Penguin Books.

nominal discount rate would be 5.8 percent. Although an argument could be made that a higher discount rate should be used, in this case selecting a higher rate would actually increase the estimated life-cycle benefits because of the low effective interest rate that applied to project financing (discussed below) and the minimal energy price escalation assumed (also discussed below). Consequently, the discount rate we used provides a conservative estimate of the life-cycle cost impacts of the project.

To account for inflation, we assumed a nominal escalation rate for electricity prices of 2.8 percent. This escalation rate was chosen to be equal to the general inflation rate, which was assumed to be 2.8 percent.[5] This assumption was based on the fact that PGE's projections of real electricity prices provided at the time we conducted this study were relatively constant over the next 10 to 20 years. This assumption is conservative because electricity prices will probably rise faster than general inflation over a time horizon longer than about 10 years.

The second component of future costs taken into account was the cost of financing the energy-efficiency improvements. The postretrofit life-cycle costs were calculated by deducting the PGE rebate from the total investment in the efficiency improvements. The financing costs were calculated by splitting up the retrofit costs according to the funding proportions shown in Table 1-1. The grant funds were treated as a direct reduction in the initial costs (like the rebate). Because the actual loans were for different periods (20 years and 30 years) and different interest rates, we calculated a blended interest rate that would give the same present value of financing costs over a 25-year period. The resulting blended interest rate was 4.85 percent over 25 years.

Another relevant component of future costs was property insurance. The annual insurance rate was calculated to be 0.362 percent, based on a current insurance payment of $3,000 per year on a capital basis of approximately $829,000. We assumed that the insurance expenditures remained constant in future years. This was consistent with an assumption that there would be no appreciation or depreciation in the building value.[6] The estimated insurance costs differed for the pre- and postretrofit buildings based on the difference in their capital value that was attributable to the efficiency improvements.

2.2 RESULTS

This subsection presents the results of our energy and economic analyses.

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[5] National Institute of Standards and Technology (NIST). 2000. *Energy Price Indices and Discount Factors for Life-Cycle Cost Analysis - Annual Supplement to NIST Handbook 135 and NBS Special Publication 709.* Gaithersburg, Maryland.

[6] Strictly speaking, an appreciation or depreciation rate should be applied to the building value, and the insurance cost should be calculated over each period based on the change in value. However, since both the "initial" and "improved" buildings are analyzed in the same way, our analysis is focused on the difference *between* the two buildings and the appreciation or depreciation rates are unknown, this is an uncertain and relatively insignificant effect and it has been ignored in this analysis.

2.2.1 Electricity Consumption

Table 2-3 shows the estimated space heating energy consumption for the units before retrofit (initial) and after (improved). Estimates for the total consumption and consumption per square foot of floor area are shown. The consumption per square foot for apartment number 15 was the highest before retrofit because it had the largest glazing area relative to floor area (25 percent); for the other units, glazing was about 13 percent of the floor area. This unit had the lowest consumption per square foot after the retrofits because the internal loads contributed a higher fraction of the heating load.[7]

Table 2-3
Space Heating Energy Impacts

Units	Estimated Annual Energy Use, kWh		Estimated Annual Energy Savings, kWh	Estimated Annual Energy Use, kWh/sq.ft.	
	Initial	Improved		Initial	Improved
1,2,3	30,400	6,990	23,410	13.1	3.0
4,5,6	29,800	6,580	23,220	12.9	2.8
7,8,9,10	35,600	9,800	25,800	11.2	3.1
11,12,13,14	34,600	9,190	25,410	10.8	2.9
15	6,170	805	5,365	14.7	1.9
Total or average	136,570	33,365	103,205	11.9	2.9

2.2.2 Electricity Expenditures

We estimated the energy cost impacts by converting electricity consumption into electric utility costs. The space heating (electricity) consumption was converted to dollars by using PGE's current residential rate of $0.05825/kWh. The results of this analysis for the first year are summarized in Table 2-4. Note that first year energy savings for the entire project amount to $6,012. Taking the PGE rebate and grants into account, the simple payback would be approximately 2.4 years from the perspective of owners/occupants.

2.2.3 Life -Cycle Costs

The life-cycle cost results are summarized in Table 2-5.[8] The results are presented for two different time horizons—25 years and 60 years. The values shown for the improved property include the initial cost of the property plus the present discounted value of the energy-efficiency retrofit costs based on the future stream of financing costs. As noted before, the retrofits that were undertaken for reasons other than energy-efficiency improvements are not included.

[7] WATTSUN assumes the same internal gains of 1,500 Btu/hour for each apartment. This is probably a reasonable assumption as long as the appliances and number of occupants do not vary significantly.

[8] Detailed results are shown in the appendix.

Table 2-4
First Year Space Heating Electricity Cost Impacts

Units:	Estimated First Year Electricity Cost		First Year Electricity Bill Savings	Estimated First Year Average Monthly Electricity Cost		First Year Monthly Average Electricity Bill Savings
	Initial	Improved		Initial	Improved	
1,2,3	$1,771	$407	$1,364	$148	$34	$114
4,5,6	$1,736	$383	$1,353	$145	$32	$113
7,8,9,10	$2,074	$571	$1,503	$173	$48	$125
11,12,13,14	$2,015	$535	$1,480	$168	$45	$123
15	$359	$47	$313	$30	$4	$26
Total	$7,955	$1,944	$6,012	$663	$162	$501

Table 2-5
Change in Life Cycle Cost

Case	25-Year Life Cycle Period	60-Year Life Cycle Period
Initial Property	$827,100	$917,800
Improved Property	$743,700	$773,000
Difference	*-$83,400*	*-$144,800*

Taking into account the costs and savings over a 25-year period, the efficiency upgrades reduce the life-cycle costs by $83,400. Over a 60-year period, the total life-cycle costs are reduced nearly twice as much, or about $145,000.

In summary, based on energy consumption estimates from WATTSUN, the energy-efficiency improvements that were implemented will reduce utility bills enough to pay back the amount invested many times over. Over the project's 60-year time horizon, the net effect is a reduction in life-cycle cost of $144,800. This is equivalent to a benefit-cost ratio of 6.0 (total benefits/ incremental first cost), or ($144,800+$28,742)/($28,742) over the 60-year time horizon.

The life-cycle cost results show that, from the combined perspective of the complex owners and apartment occupants, the energy-efficiency investments had a significant economic payoff over the life of the project. This was due primarily to the large energy savings attributable to the efficiency improvements. It is important to stress also that the financing terms for this project were very advantageous, and they improved the economics of the efficiency investments substantially over what they would have been if all financing were done at typical market terms.

3 OTHER IMPROVEMENTS

This section discusses other implemented or planned property and site enhancements to improve the overall resource efficiency and sustainability of Johnson Creek Commons. A thorough analysis of these improvements is outside the scope of our study, but this section delineates these improvements and discusses them briefly. These improvements, in conjunction with the energy-efficiency retrofits discussed in Section 2, are key components of green buildings. It is especially important to document them here because the Johnson Creek Commons project is unique in demonstrating their applicability to low-income multifamily housing.

The first subsection presents two flooring measures that we assessed. The second discusses measures related to indoor environmental quality. The third discusses measures involving recycling and better use of resources. The fourth subsection addresses measures that were likely to affect energy consumption, other than those discussed in Section 2. The final subsection summarizes the actions being taken under a water conservation pilot program conducted jointly with the Portland Water Bureau.

3.1 FLOORING MEASURES

Marmoleum was installed in several units to replace worn vinyl flooring. Marmoleum is a linoleum flooring produced by Forbo Industries. It is manufactured from natural raw materials including linseed oil, limestone, pine tree rosin, wood flour, and jute. Linoleum has received favorable ratings for its environmental characteristics during production, use, and disposal. Sheet vinyl flooring, on the other hand, is a petroleum-based material that offgases volatile organic compounds (VOCs). A useful life of about 40 years provides potential economic advantages over vinyl flooring.

We compared the installation and life-cycle cost of Marmoleum with conventional vinyl flooring. According to project documents, 366 sq. yds. of Marmoleum were installed at a total cost of $8,930, or $24.40 per sq. yd. installed. Based on manufacturer's data, vinyl would have cost about $12 per sq. yd. to install. The useful life of vinyl flooring is about 7 years. The results are shown in Table 3-1.

Table 3-1
Economic Comparison of Marmoleum and Vinyl Flooring

Material	First Cost	Present Discounted Cost	
		Over 25 Years	Over 60 Years
Marmoleum	$8,930	$7,330	$10,900
Vinyl	$4,392	$12,300	$19,500
Difference (Marmoleum - Vinyl)	$4,538	-$4,970	-$8,600

The Marmoleum cost about twice as much to install initially as standard vinyl flooring. We calculated the present value of the discounted cost stream for each type of flooring as shown in the table. We used two time horizons to calculate the costs, 25 years and 60 years. For each item horizon, we deducted the present economic value of the remaining life for the flooring from the initial flooring cost since the remaining life has an economic value that should be taken into account. For a 25-year horizon, the Marmoleum would have a net present discounted cost of $7,330 (since about 15 years of lifetime are still left). At 25 years, the vinyl would have required three replacements and have a discounted cost of $12,300. The net economic savings from installing Marmoleum would be nearly $5,000 in present discounted value at 25 years. Over a 60-year time horizon, the net savings would be $8,600.

The carpets in two units were replaced with Envirotech Image Renaissance carpeting. This material is naturally stain-resistant and does not offgas any harmful or irritating chemicals. Most importantly, it is made from recycled plastic bottles (PET). We did not have sufficient data to analyze the economics of this carpet choice compared with other options. Some of the key characteristics of different types of carpeting are summarized in Table 3-2. The Carpet and Rug Institute (CRI) Green Label requirements can be met by available products in all three categories. The recycled PET carpet has an intermediate cost and lifetime.

Table 3-2
Carpeting Characteristics

Carpet Type	Material Cost, per sq. yd.	Installed Cost, per sq. yd.	Life, yrs.	Other Comments
Standard nylon	$10 - $12	$16 - $21	5-8	• Possibly recyclable
Vinyl-backed	$18 - $20	$25 - $28	~15	• Recyclable • Has anti-microbial fibers
Recycled PET	~$14	~$22	~10	• Used in project • Not currently recyclable

3.2 INDOOR ENVIRONMENTAL QUALITY MEASURES

The most significant action that was taken to improve indoor environmental quality (IEQ) was to clean mold off of several bathroom walls and replace the bathroom fans in all apartments with high flow rate, relatively quiet fans. High humidity levels are a major contributor to mold and mildew growth, which can have serious health effects on people who are allergic to these

substances.[1] The fans were intended to be used to reduce the moisture levels in the bathrooms and reduce mold and mildew growth. The cost of procuring and installing these fans in all apartments was $7,010. Slotted vents also were required in new windows installed in the apartments to improve ventilation, especially in conjunction with the fans. No documentation of the use and effects of the bathroom fans has been undertaken yet, but it would be useful to conduct site visits and interview the occupants to determine what effects the fans have had.

The bathroom walls in several apartments were repainted and the specified paint was solvent-free acrylic latex. This type of paint would have had less deleterious IEQ effects than paints with petroleum-based solvents.

Kitchen countertops were replaced-in several units, and the contractor was required to use a formaldehyde-free substrate, if available. No such material was located, however. Bathroom vanities and kitchen cabinets were replaced in several apartments with new units that were specified to be constructed with low-formaldehyde materials in place of standard materials.

Besides its maintenance advantages, the Marmoleum flooring also contributed to IEQ improvements because, unlike standard vinyl flooring, it is made from natural materials and emits no VOCs.

3.3 MATERIAL RECYCLING AND SUSTAINABLE RESOURCES

The contractor was required to "efficiently use resources to the fullest extent possible."[2] Required techniques included minimizing waste generation, salvaging materials for reuse and resale, reusing materials on site, and recycling of generated waste. Because of the nature of the work performed, however, there was very little waste generation through demolition or construction activities.

The contractor was required to use recycled latex paint to paint the exterior. Recycled paint was obtained from the Metro/Regional Government Recycling Center and applied, thus reducing the impacts associated with producing new paint.

The contractor also was required to use salvaged or certified sustainably harvested wood. Very little wood was used in the project, however, but the wood that was used was sustainable harvested.

3.4 OTHER MEASURES RELATED TO ENERGY CONSUMPTION

In addition to the envelope improvements made to all the units, several other measures were applied that directly or indirectly could reduce energy use. In conjunction with the Portland

[1] The American Industrial Hygiene Association is a good source of information. Information is available at url www.aiha.org/pr/iaq.html.

[2] Johnson Creek Commons Construction Specifications. July 20, 1998.

Energy Office, compact fluorescent light bulbs (CFLs) were installed in most of the exterior fixtures. These bulbs use about one-fourth the energy used by standard incandescent bulbs and have a much longer expected lifetime.

In coordination with PGE, new, high-efficiency refrigerators were installed in many of the apartments. These appliances were estimated to use 20 to 25 percent less electricity than standard models. The new refrigerators cost a total of $4,356. The actual performance of the refrigerators has not been analyzed to date.

New radiant heaters were installed in all the apartments to replace the existing baseboard systems at a total cost of $12,375. Although the basic efficiency of such systems does not differ from the efficiency of baseboard heaters, there is evidence that these systems allow occupants to reduce the temperature setpoint. This can reduce space heating energy consumption. We did not attempt to include this effect in our energy analysis.

Five existing water heaters were replaced with new electric water heaters at a total cost of $2,000. Because efficiency standards have improved, these units probably consume less electricity than the original units.

3.5 WATER EFFICIENCY MEASURES

In conjunction with the project developers, the Portland Water Bureau undertook a water efficiency pilot program in this complex. The facility owner pays the water bill and water use in each building is metered, but individual apartment use is not. The program included both indoor and landscaping efficiency measures.

The components of the program include the following:

- Audits of plumbing fixtures in each apartment,
- Provision of water-efficient equipment such as faucet aerators, toilet tank displacement bags, etc.,
- Cold water use submetering using Automated Meter Reading technology for each building, outdoor use, and the laundry facility,
- Installation of front-loading, high-efficiency washing machines and submetering,
- Landscaping to minimize water consumption and design and installation of drip irrigation or another efficient water system,
- Collection of tenant demographics data and unit occupancy data, and
- Education of tenants and the property manager/owner and landscaper on water efficiency.

This program was initiated in mid-1999 and was planned to extend over three years. It would be very beneficial to analyze and report on the water consumption data from this program and changes in water consumption.

4 OVERALL FINDINGS

This section summarizes the key findings from our study. It includes the results of our analyses and suggestions for additional steps that should be taken to follow up the research conducted for this study.

4.1 ENERGY IMPACTS

The primary focus of this study was on the energy-efficiency improvements made to the envelopes of the apartments in this complex. The costs and space heating electricity consumption effects of these improvements were analyzed and presented in terms of payback periods and life-cycle cost impacts. Another set of measures was implemented that did not involve the building envelope, but should affect overall electricity consumption.

4.1.1 Envelope Efficiency Measures

We used the WATTSUN computer model to estimate energy savings from the envelope efficiency measures installed in these apartments. These measures resulted in significant estimated energy savings—approximately 75 percent of the energy used for space heating before the retrofits. Table 4-1 summarizes the key values used in the energy impact analysis and the primary results. Life-cycle results are presented for two time periods—25 years and 60 years. The 60-year time horizon was used because the property owners guaranteed to the Portland Development Commission that the housing project would be maintained as affordable housing over that time period.

Table 4-1
Key Data and Results Related to Envelope Energy-Efficiency Upgrades

Quantity		Value
A	Annual electricity savings	103,205 kWh
B	First year electric bill savings	$6,012
C	Cost of envelope efficiency measures	$43, 942
D	Simple, overall payback period (C/B)	7.3 years
E	Share financed by grants	33%
F	PGE utility rebate	$15,200
E	Simple payback period to owner/occupants ((C*(100% - E) - F)/B)	2.4 years
F	25-year discounted life-cycle electric bill savings	$103,000
G	60-year discounted life-cycle electric bill savings	$165,000
H	25-year net change in life-cycle cost to owner/occupants	-$83,400
I	60-year net change in life-cycle cost to owner/occupants	-$144,800

These results show that the energy-efficiency investments were very favorable for the project developers and occupants. The electricity costs for the 15 apartments were estimated to decrease by over $6,000 in the first year. Over the 60-year life cycle, the life-cycle costs of owning and heating the entire property decreased by a present discounted value of about $145,000.

The estimated energy and utility bill savings, of course, are contingent on the accuracy of the estimates produced by the energy analysis model, WATTSUN. The actual electricity savings will depend on occupant behavior, the assumptions used in the analysis, and the accuracy of the model. We suggest later that this analysis should be supplemented with an analysis of the electric bills.

It is important to point out that, in addition to energy savings, these efficiency measures are likely to increase occupant comfort, reduce drafts, decrease condensation, and provide other difficult-to-quantify benefits. These benefits will improve the living conditions for the occupants, reduce health problems, and reduce maintenance costs for the occupants and owners.

4.1.2 Other Measures Affecting Energy Use

In addition to the envelope improvements made to all the units, several other measures were applied that directly or indirectly could reduce energy use. These included the following:

- Installation of compact fluorescent light bulbs (CFLs),
- Replacement of several refrigerators with new, high-efficiency refrigerators,
- Installation of new washing machines that reduce both energy and water use,
- Replacement of baseboard heaters with radiant heaters, and
- Replacement of five existing water heaters with new units constructed to higher efficiency standards.

The potential electricity savings of these measures have not been estimated. Their electricity consumption effects could be analyzed individually. Although they probably have had less effect on total electricity consumption than the envelope improvements; a complete energy analysis of the complex should take them into account. The high-efficiency refrigerators, in particular, have probably had a significant effect on electricity consumption relative to the refrigerators replaced and relative to new replacement units of standard efficiency that could have been installed instead.

4.2 ADDITIONAL MEASURES

Many of the measures that were implemented in this apartment complex involved deferred maintenance that would have been required to improve the quality of the units regardless of concerns about sustainability or green buildings. Several of the measures that were implemented

reflected decisions on the part of the owners to enhance the sustainability of the complex and site.

Flooring materials that were installed were selected based on sustainability criteria, as well as the need to repair the flooring. The Marmoleum used to replace vinyl flooring in some of the units was selected based on its green characteristics. This material costs more than vinyl flooring, but is manufactured from renewable materials. We analyzed the direct economic effects of this choice by comparing the initial costs and future replacement costs of Marmoleum with conventional vinyl flooring. Table 4-1 shows that the initial cost of the Marmoleum was a little over $4,500 more than vinyl flooring, but over a 25-year time horizon the Marmoleum reduced the present discounted costs by nearly $5,000 and the savings increased to nearly $9,000 over a 60-year horizon.

Table 4-2
Economic Effects of Installing Marmoleum in Place of Vinyl Flooring

Change in First Cost	Change in Present Discounted Cost	
	Over 25 Years	Over 60 Years
$4,538	-$4,970	-$8,600

A number of steps were taken to improve indoor environmental quality. High flow rate bathroom fans were installed to reduce mold growth in the bathrooms and solvent-free paint was applied inside the apartments. The bathroom fans are likely to have a significant beneficial effect on the indoor air quality in the apartments and the resulting health of the occupants. In addition, they are likely to decrease deterioration of the surfaces in the bathrooms, thus reducing maintenance costs. The energy-efficient windows that were installed also had slotted vents that should improve ventilation and help improve indoor air quality.

Pollutant source levels were reduced in a number of ways. Kitchen cabinets and bathroom vanities made with materials with reduced levels of formaldehyde were installed in several of the apartments, thus improving the indoor air quality. The Marmoleum flooring, unlike conventional vinyl flooring, will add no volatile organic compounds to the indoor air.

Finally, several steps are being taken as part of a three-year program to improve the water efficiency of the apartments and the site. In conjunction with the project developers, the Portland Water Bureau is implementing a water efficiency pilot program. These measures constitute an important component of the overall greening of this project.

4.3 OVERALL IMPLICATIONS

Our analysis has shown that this project achieved its objectives of combining affordability with ecological sustainability in a low-income apartment complex rehabilitation. The electric utility

bill savings will provide substantial economic benefits to the occupants over the lifetime of the buildings. The efficiency improvements and several of the other green improvements to the building will benefit the occupants through improved living conditions, improved air quality, better comfort, and improved health.

Several of the measures implemented to improve sustainability will reduce the operating and maintenance costs to the building owners. For example, the ongoing water efficiency program should reduce water bills for the complex, and the improved bathroom fans should reduce the need for painting and repairs.

The measures will have benefits beyond the complex as well. Reduced electricity and water consumption should reduce the impacts of the complex on the costs of supplying electricity and water. Over the 60-year lifetime of the complex, the estimated energy savings could reduce carbon dioxide (CO_2) emissions from electricity generation by as much as 5,000 tons. CO_2 is a major contributor to global warming.

Overall, this project illustrates how low-income rental properties can be rehabilitated successfully to benefit both the occupants and the owners. It should provide an effective model for future projects that aim to improve the sustainability of low-income housing while improving affordability.

4.4 AREAS FOR FOLLOW-UP RESEARCH

We identified a number of areas in which further research should be conducted on this project to verify the effects highlighted by our analysis and explore other effects that we were unable to explore in depth.

- *The electricity bills for individual apartments should be analyzed to verify the electricity savings we estimated.* Our analysis was conducted using a computer model to estimate electricity consumption. Although this provides a reliable estimate of energy savings based on a model widely applied in the Pacific Northwest, the actual savings may be more or less than the model estimated. Factors such as occupant behavior, the effects of efficiency measures (such as more efficient refrigerators) that were not modeled, and assumptions made in the analysis could cause actual electricity consumption to be higher or lower than our estimates. Several apartments were occupied by the same tenants before and after the retrofits so analyzing their electricity bills would provide very useful information about changes in energy consumption that would not be affected by changes in occupancy. Interviews with occupants would provide essential information about possible changes in behavior, perceptions of changes in air leakage, and other factors that could be related to energy use.
- *Interviews with tenants should be conducted to assess other effects of the rehabilitation.* Tenant interviews would provide information about possible changes in indoor air quality, occupant health and comfort, and changes in the presence of mold and mildew in

the bathrooms. Such interviews would help establish what other benefits could be attributed to the retrofits and some measure of their significance.

- *The effects of installing high-efficiency refrigerators should be analyzed.* New, high-efficiency refrigerators were installed in several of the apartments. The change in energy consumption that is attributable to these appliances can be estimated based on refrigerator efficiency data. The effects of these appliances on electricity consumption should be taken into account in the overall analysis of electricity usage.
- *The effects of the water efficiency program should be analyzed.* This program involves a number of steps to improve efficiency including changes in equipment and practices as well as education. The installation of high-efficiency clothes washers should save both electricity and water. The water-efficiency improvements to the plumbing will reduce water consumption and energy used for heating water. Over the course of the three-year program, the effects of the education program on occupant and owner behavior and practices should be analyzed and their long-term effects should be studied.
- *The transferability of the approaches used in this project to other low-income housing projects should be assessed.* As noted earlier, this project provides a model for other such projects. The benefits of this project can be leveraged and expanded by determining what other housing projects would be good candidates for applying similar approaches and the types and magnitudes of expected costs and benefits.

A SUPPLEMENTAL INFORMATION

This appendix presents detailed supporting information for this study. The first subsection presents detailed building dimension and characteristics information. The second presents the complete results of the life-cycle cost analysis. The final subsection presents a typical floorplan for one of the apartments.

A.1 BUILDING CHARACTERISTICS

All but one of the apartments at Johnson Creek Commons are laid out in a "typical" configuration with some minor variation between the apartments in the two-story buildings and the apartments in the one-story buildings. The apartments in the two-story buildings have a slightly larger square footage and small differences in the glazing. The one exception to the typical layout is apartment 15.

The typical layout is based on a drawing received from Rosemarie Cordello of Sustainable Communities Northwest and is titled "Unit #3 -- Typical Layout." Section A.3 shows this typical layout. This apartment is described in the drawing as having 772 sq. ft. of living area, comprised of two bedrooms, one bath, a kitchen, dining room, and a living room. The "exterior" dimensions of the apartment are given to be 24 feet, 0 inches wide and 33 feet, 6 inches deep with a small porch alcove approximately 11 feet, 8 inches by 2 feet, 8 inches deep. Using the "exterior" dimensions, the apartment can be calculated to have a floor area of 773 sq. ft. For purposes of our analysis, the 772 sq. ft. figure was used with the "front" of the unit being the 24-foot side with the entrance door.

According to the "typical" plan, each bedroom has a 6 foot, 0 inch-by-3 foot, 0 inch window facing out the rear of the apartment. The front of the apartment has a 6 foot, 0 inch-by-4 foot, 0 inch window looking out from the dining room and a 6 foot, 0 inch-by-6 foot, 8 inch glass patio slider looking out from the living room onto the patio alcove. There are no windows in either of the side walls of the apartment. (These walls are typically shared walls with adjoining apartments.)

The overall dimensions of the apartment buildings were shown in the drawing titled "Page 1 -- Apartment Complex – Plot plan and lot details." This drawing shows the locations and relative orientation of each structure as well as penciled notes concerning the exterior dimensions of each building. A visit to the complex determined the actual orientation of the property; however, in the absence of specific permission to do so, no new measurements were taken to confirm the building dimensions shown in the drawings.

The complex is divided into four apartment buildings. Discussing each in numerical order, apartments 1, 2, and 3 are in a one-story structure with the front side facing north. The drawing provides overall exterior dimensions of 75 feet, 0 inches by 33 feet, 0 inches. This provides a

figure for gross enclosed square footage of 2,475 sq. ft., or 825 sq. ft. per apartment. Allowing for the exterior patio spaces, this corresponds to a calculated 794 sq. ft. per unit. Since the penciled notes were not consistent with the original specified "typical" layout, a decision was made to take the "typical" layouts as binding. Therefore, the building hereafter referred to as "Unit123" is taken to have a total square footage of 2,316 sq. ft. We note that the penciled figure on the drawing for the square footage of Unit123 is given to be 2,232 sq. ft., which is less than the figure used in the analysis and not consistent with an area calculated with the penciled exterior dimensions. The complex labeled "Unit456" is exactly like Unit123 except that the building faces south rather than north.

The complex labeled "Unit78910" is a two-story structure with two "typical" apartments on each floor. The drawings provide penciled exterior dimensions of 51 feet, 0 inches by 30 feet, 0 inches. Due to the previously described concerns about the accuracy of these figures, we decided to use a set of energy survey documents from PGE's Home Weatherization Program for the building dimensions. The PGE documents provide exterior dimensions of 52 feet, 0 inches by 34 feet, 0 inches. Based on the PGE documents, apartments 7, 8, 9, and 10 are calculated to each have floor areas of 798 sq. ft. "Unit78910" then has a total floor area of 3,192 sq. ft. Apartments 11, 12, 13, and 14 are exactly like 7, 8, 9, and 10 and are enclosed in a complex labeled "Unit11121314". Both Unit78910 and Unit11121314 face to the east. While the apartments are somewhat larger than the "typical" layout, they have the same type and number of rooms. There are, however, minor variations in the glazing of these apartments. These differences will be addressed below.

The final apartment, #15, is part of a one-story wing that is attached to the north side on Unit11121314. This structure, which includes a laundry facility, is treated as a separate unit for purposes of analysis and is labeled "Unit15". This unit provided a number of difficulties in the analysis. No drawings were available to show the layout or the complete interior dimensions. The PGE documents show a space with exterior dimensions of 20 feet, 0 inches by 21 feet, 0 inches, with a resultant estimate for floor area of 420 sq. ft. Information provided by Sustainable Communities Northwest indicate that this is a one-bedroom unit. Exterior observation from the sidewalk suggested the locations and possible dimensions for the glazing. Due to these difficulties, the figures in the analysis should not be taken as anything more than indicative. However, since Unit15 comprises only 3.68 percent of the total square footage of the complex, the possible error for purposes of analysis is considered to be quite small.

The area figures calculated above were used for the floor and ceiling areas in each building with one modification. Since the two-story buildings have only one envelope floor and one envelope ceiling (rather than the physical two floors and two ceilings) the figures for the floor and ceiling areas of Unit78910 and Unit11121314 are one half of the total calculated floor area, or 1,596 sq. ft. The interior volume of all apartments was calculated by assuming a typical ceiling height of 8 ft.

The determination of wall area was somewhat more involved since the buildings are not rectangles. Based on a combination of figures drawn from the "typical" layout and the PGE

documents, we calculated the following wall areas. Unit123 was calculated to have 225.5 linear feet of exposed wall or, using the assumption of 8-foot ceilings, 1,804 sq. ft of wall. Unit456 is taken to be identical to Unit123. The volumes of Unit123, and Unit456 are calculated to be 18,528 cu. ft. Unit78910 is calculated to have a total of 212 linear feet of exposed wall, and, using the assumed 8-foot ceilings times 2 floors (for a total enclosed height of 16 ft.), a total exterior wall area of 3,392 sq. ft. The exposed wall area of Unit11121314 must be adjusted somewhat to account for the wing housing Unit15. An assumption was made that the presence of Unit15 affected only one story of Unit11121314. This was taken over a linear wall distance of 30 feet. This results in an estimate for the exposed wall area of Unit11121314 of 3,152 sq. ft. The volumes of Unit78910 and Unit11121314 are taken to be identical and equal to 25,536 cu. ft. Unit15 is estimated to have 46 linear feet of exposed wall or 368 sq. ft. of exposed wall. The laundry and Unit 11121314 enclose the remaining wall areas. The volume of Unit15 is taken to be 3360 cu. ft. based on a 420 sq. ft. floor and 8ft. ceilings. For all of the units, these figures for wall area must be reduced by an amount equal to the area occupied by the doors and the windows.

The exact glazing in each unit was somewhat difficult to pin down, even given the "typical" layout. Based on contractor documents from All Weather Home Remodeling Company, the following glazing distributions were assumed.[1] All of the apartments except number 15 have patio sliders on the front side with dimensions of 6'-0" x 6'-8". Apartment #15 has a patio slider 8 feet, 0 inches by 6 feet, 8 inches. The bedroom windows in Unit123, and Unit456 are 6 feet, 0 inches by 3 feet, 0 inches. The bedroom windows in Unit78910 and Unit11121314 are taken to be divided such that one bedroom in each unit has a window 6 feet, 0 inches by 3 feet, 0 inches and a window 5 feet, 0 inches by 3 feet, 0 inches in the other bedroom. (This is the most likely distribution of the windows ordered from All Weather.) The dining rooms of Unit123 and Unit456 have windows 6 feet, 0 inches by 4 feet, 0 inches. The dining rooms of Unit78910 and Unit 11121314 have windows 7 feet, 0 inches by 5 feet, 0 inches. (Once again, this is the most likely distribution of windows ordered from All Weather.) Unit15 again presented difficulties. It was assumed (based on a best guess about where remaining windows from All weather were located and a visit to the site) that Unit15 has two 1-foot, 6-inch by 5-foot, 0-inch windows facing north, and one 3-foot, 0-inch by 5-foot, 0-inch window facing east. The remaining two 4-foot, 0-inch by 5-foot, 0-inch windows are assumed to be west facing from the laundry–a space that was not analyzed.
The above glazing distribution can be summarized as follows:

Unit123:	North: 192 sq. ft.	South: 108 sq. ft.	Total: 300 sq. ft.
Unit456:	North: 108 sq. ft.	South: 192 sq. ft.	Total: 300 sq. ft.
Unit78910:	East: 300 sq. ft.	West: 132 sq. ft.	Total: 432 sq. ft.
Unit11121314:	East: 300 sq. ft.	West: 132 sq. ft.	Total: 432 sq. ft.
Unit15:	North: 15 sq. ft.	East: 93.3 sq. ft.	West: 15 sq. ft.
	Total: 123.3 sq. ft.		

[1] Once again, as indicated earlier, no actual measurements of the glazing in each unit were taken. However, the glazing figures from All Weather are usually in close agreement with the figures shown in the "typical" layout.

Areas for the other building elements can be summarized as follows:

	Doors	Floor/Ceiling	Walls
Unit123:	60 sq. ft.	2316 sq. ft.	1444 sq. ft.
Unit456:	60 sq. ft.	2316 sq. ft.	1444 sq. ft.
Unit78910:	80 sq. ft.	3192 sq. ft.*	2880 sq. ft
Unit11121414:	80 sq. ft.	3192 sq. ft.*	2640 sq. ft.
Unit15:	20 sq. ft.	420 sq. ft.	244.7 sq. ft.

*Note: The envelope floor area used for the energy analyses was half the first and second story floor area, or 1596 sq. ft.

According to the PGE energy audit documents, the original buildings had ceiling insulation of R-11, wall insulation of R-8, no floor insulation, single-pane metal frame windows, and "insulated" doors with weatherstripping. According to the 1997 ASHRAE Handbook of Fundamentals, a "fixed" single-pane aluminum window has a U-value of 1.13 and an "operable" version of the same window has a U-value of 1.27. Since there was uncertainty about whether the original windows were operable, fixed, or (most likely) a combination of both, the default U-value of 1.2 (available in WATTSUN5 for aluminum single-pane windows) was used for all of the original building glazing. The doors were assumed to be "Wood 1 3/8", solid flush" for both the original and the improved buildings. In WATTSUN5 this door has a U-value of 0.390. (The assumption is required due to the lack of specific information on the doors. Since only one door in the complex was changed, this assumption should not introduce any meaningful error in the analysis.) An infiltration figure of 0.6 ach was assumed in the original apartments.

The energy-efficiency envelope improvements made to the property were as follows:

- Insulate ceiling to R-38
- Insulate floors to R-30
- Add ¾-inch EPS to all exterior wall surfaces before putting on new siding. Adds approximately R-3 to the walls for a total of R-11.
- Replace windows and patio sliders with double pane, low-e, Argon-filled, high-efficiency glazing with a U-value of 0.35.
- The sum of improvements is assumed to also decrease infiltration to 0.4 air changes per hour.

A.2 DETAILED LIFE CYCLE COST RESULTS

Table A-1
Detailed Life Cycle Costs

INITIAL PROPERTY PROFILE:								
Units	Pro Rata Share of Initial Purchase Cost	Pro Rata Share of Improvement Costs	Pro Rata Share of PGE Rebate	First Year Energy Cost	Present Value of Future Energy Costs Over 20 Years	Present Value of Future Energy Costs Over 30 Years	Present Value of Future Energy Costs Over 60 Years	Present Value of Future Energy Costs Over 25 Years
1,2,3	$133,662.12	N/A	N/A	$1,770.80	$25,822.15	$34,122.52	$48,519.27	$30,270.27
4,5,6	$133,662.12	N/A	N/A	$1,735.85	$25,312.50	$33,449.05	$47,561.65	$29,672.83
7,8,9,10	$184,218.26	N/A	N/A	$2,073.70	$30,239.09	$39,959.27	$56,818.62	$35,448.08
11,12,13,14	$184,218.26	N/A	N/A	$2,015.45	$29,389.68	$38,836.82	$55,222.59	$34,452.35
15	$24,239.24	N/A	N/A	$359.40	$5,240.88	$6,925.52	$9,847.50	$6,143.67
Total	$660,000.00	N/A	N/A	$7,955.20	$116,004.30	$153,293.18	$217,969.63	$135,987.21
Units	PV of Insurance (20 yrs)	PV of Insurance (30 yrs)	PV of Insurance (60 yrs)	PV of Insurance (25 yrs)	**LCC (20 yrs)**	**LCC (30yrs)**	**LCC (60 yrs)**	**LCC (25yrs)**
1,2,3	$5,641.04	$6,805.20	$8,059.12	$6,304.63	**$165,125.31**	**$174,589.84**	**$190,240.51**	**$170,237.02**
4,5,6	$5,641.04	$6,805.20	$8,059.12	$6,304.63	**$164,615.66**	**$173,916.37**	**$189,282.90**	**$169,639.58**
7,8,9,10	$7,774.70	$9,379.19	$11,107.39	$8,689.28	**$222,232.05**	**$233,556.71**	**$252,144.27**	**$228,355.62**
11,12,13,14	$7,774.70	$9,379.19	$11,107.39	$8,689.28	**$221,382.64**	**$232,434.26**	**$250,548.24**	**$227,359.89**
15	$1,022.99	$1,234.10	$1,461.50	$1,143.33	**$30,503.11**	**$32,398.87**	**$35,548.24**	**$31,526.24**
Total	$27,854.48	$33,602.88	$39,794.53	$31,131.14	**$803,858.77**	**$846,896.06**	**$917,764.17**	**$827,118.34**

Table A-1
Detailed Life Cycle Costs (cont.)

IMPROVED PROPERTY PROFILE								
Units	Pro Rata Share of Initial Purchase Cost	Pro Rata Share of Improvement Costs	Pro Rata Share of PGE Rebate	First Year Energy Cost	Present Value of Future Loan and Energy Costs Over 20 Years	Present Value of Future Loan and Energy Costs Over 30 Years	Present Value of Future Loan and Energy Costs Over 60 Years	Present Value of Future Loan and Energy Costs Over 25 Years
1,2,3	$133,662.12	$8,899.06	$3,078.28	$407.17	$9,074.90	$11,352.52	$14,662.83	$10,466.76
4,5,6	$133,662.12	$8,899.06	$3,078.28	$383.29	$8,726.64	$10,892.32	$14,008.46	$10,058.51
7,8,9,10	$184,218.26	$12,265.03	$4,242.60	$570.85	$12,648.48	$15,832.94	$20,474.00	$14,591.10
11,12,13,14	$184,218.26	$12,265.03	$4,242.60	$535.32	$12,130.34	$15,148.24	$19,500.42	$13,983.70
15	$24,239.24	$1,613.82	$558.24	$46.89	$1,252.76	$1,539.48	$1,920.71	$1,437.47
Total	$660,000.00	$43,942.00	$15,200.00	$1,943.51	$43,833.12	$54,765.51	$70,566.41	$50,537.54
Units	PV of Insurance (20 yrs)	PV of Insurance (30 yrs)	PV of Insurance (60 yrs)	PV of Insurance (25 yrs)	**LCC (20 yrs)**	**LCC (30yrs)**	**LCC (60 yrs)**	**LCC (25yrs)**
1,2,3	$6,016.62	$7,258.28	$8,595.69	$6,724.38	**$148,753.64**	**$152,272.93**	**$156,920.64**	**$150,853.26**
4,5,6	$6,016.62	$7,258.28	$8,595.69	$6,724.38	**$148,405.38**	**$151,812.72**	**$156,266.27**	**$150,445.01**
7,8,9,10	$8,292.33	$10,003.64	$11,846.91	$9,267.80	**$205,159.07**	**$210,054.84**	**$216,539.16**	**$208,077.15**
11,12,13,14	$8,292.33	$10,003.64	$11,846.91	$9,267.80	**$204,640.93**	**$209,370.14**	**$215,565.59**	**$207,469.76**
15	$1,091.10	$1,316.27	$1,558.80	$1,219.45	**$26,583.10**	**$27,095.00**	**$27,718.76**	**$26,896.17**
Total	$29,708.99	$35,840.12	$42,444.00	$33,203.81	**$733,542.11**	**$750,605.63**	**$773,010.42**	**$743,741.35**

A.3 TYPICAL FLOORPLAN

Figure A-1 presents a typical floorplan for the apartments.
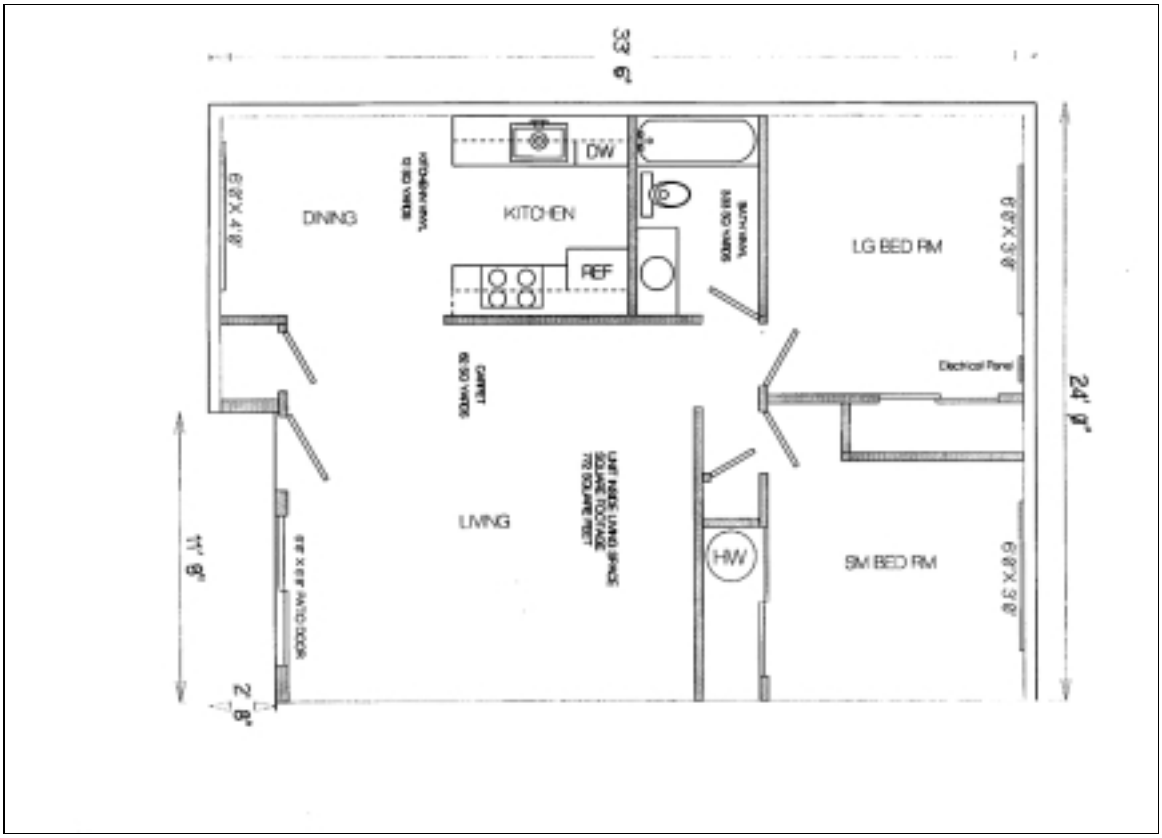
Figure A-1
Typical Apartment Floorplan