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Measured Energy Savings and Economics of Retrofitting Existing Single-Family Homes: An Update of the BECA-B Database

S.D. Cohen, C.A. Goldman, and J.P. Harris

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MEASURED ENERGY SAVINGS AND ECONOMICS OF RETROFITTING EXISTING SINGLE-FAMILY HOMES: AN UPDATE OF THE BECA-B DATABASE

Volume II

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APPENDIX A: SINGLE-FAMILY RETROFIT DATA BASE

The following tables include data on physical characteristics, energy consumption and savings, and retrofit measures installed and their costs for each retrofit project. Each retrofit is uniquely identified by a label. The abbreviations are used in the tables are explained below. Data is sorted by project type (state or city loan program [L], research study or demonstration program [R], utility weatherization [U], and low income weatherization [W]) and then by label. The numbers in these tables typically represent average values for groups of houses.

TABLE A-1:

Label: The first letter in each label stands for the fuel used for the end-use affected by the retrofit. *E* = Electricity, *G* = Natural Gas, *M* = Mixed, *O* = Oil.

Project Type: *L* = State or City Loan Program, *R* = Research Study or Demonstration Program, *U* = Utility Conservation Program, *W* = Low Income Weatherization Program.

Floor Area: Average conditioned floor area per house, in ft^2.

Pre-Retrofit R Ceiling: Pre-retrofit R-value (in ft^2-°F-hour/Btu) of ceiling or attic insulation (excluding structural components).

Post-Retrofit R Ceiling: Post-retrofit R-value (in ft^2-°F-hour/Btu) of ceiling or attic insulation (excluding structural components).

Pre-Retrofit R Wall: Pre-retrofit R-value (in ft^2-°F-hour/Btu) of wall insulation (excluding structural components).

Post-Retrofit R Wall: Post-retrofit R-value (in ft^2-°F-hour/Btu) of wall insulation (excluding structural components).

TABLE A-2:

End Uses: End uses included in consumption data: *C* = Cooling (HVAC System), *D* = Domestic hot water, *F* = All end uses of space heat fuel, *H* = Space heat, *W* = Space heat and hot water.

Energy Use Data: Annual average electricity use per house is reported in kWh, average consumption for fuel-heat projects is expressed in MBtu (1 MBtu=10^6 Btu). Oil converted to MBtus using the following conversion factor: Oil = 0.139 MBtu/gallon.

NAC: Weather-normalized annual consumption, for end uses coded as *C*, *D*, *F*, *H*, and *W*.

Space Heat: Weather-normalized space heat consumption, for end uses coded as *H*, or weather-dependent portion of consumption estimated in PRISM analysis.

Heating Factor: Estimated *space heating* intensity in Btu/ft^2-HDD.

Analysis Method: *E* = Regression of submetered end-use data (e.g., space heat), *F* = Regression with fixed reference temperature (usually 65°F), *O* = Calculation based on measured steady state efficiency (SSE) improvements of HVAC equipment (often done for oil furnaces), *R* = Regression (PRISM) with variable reference temperature, *S* = Scaling of space heat data by annual or monthly HDD.

Confidence Level Energy: *A* = Submetered energy data, *B+* = PRISM analysis (variable reference temperature), *B* = Regression analysis of energy data with fixed reference temperature or accurate baseload determination from summer months' bills, *C* = Annual consumption data that is weather-corrected by scaling space-heat fraction by ratio of actual to normal HDD, *D* = Energy data only available for small part of heating season.

Prediction Method: Description or complexity of audit prediction method: *HOUR* = Building energy simulation program that computes building loads each hour, *MONTH* = Building energy simulation program that computes building loads each hour, *MHDD* = Modified base degree-day engineering calculation, *VHDD* = Variable base degree-day engineering calculation (using measured reference temperature), *EST* = Estimate based on previous results for similar buildings.

HDD: Long-term average heating degree-days for that location (base 65^{O}F).

Heat System Type: *B* = central steam or hydronic boiler, *E* = Individual resistance electric heating unit installed in wall,floor, or baseboards, *F* = Central warm air furnace (forced and gravity; can be gas or electric).

Hot Water Fuel: *E* = Electricity, *G* = Gas, *M* = Mixed, *O* = Oil.

TABLE A-3:

Retrofit Measures: *CR* = Cooling system replacement, *CS* = Cooling system retrofit, *CW* = Caulk + weatherstrip, *DR* = Storm doors, *HR* = Heating system replacement, *HS* = Heating system retr., *IA* = Ceiling/attic insulation, *ID* = Duct insulation, *IF* = Subfloor insulation, *IP* = Foundation insulation (perimeter), *IS* = Sill box insulation, *IW* = Wall insulation, *OM* = Operations & maintenance, *PI* = Pressurization, infil. reduction ('House-Doctor'), *RB* = Radiant barriers, *RD* = Replace Ducts *SD* = Sealing ducts *SK* = Mobile Home Skirting *T* = Clock thermostat, *WH* = Water-heating retr., *WM* = Window management (storm windows, exterior blinds or shutters), *WR* = Replace windows, *WZ* = Warm room zoning.

Heat System Measures: This field provides a more detailed list of heating system retrofit options: *CF* = Install New Condensing Furnace, *FD* = Full furnace derating, *FDF* = Install New Forced Draft Furnace, *HES* = Non-condensing heat extractor, *HEL* = Condensing heat extractor, *HP* = Install New Heat Pump, *IHW* = Insulating water heater blanket, *IID* = Intermittent ignition device, *IPI* = Insulation on hot water pipes, *LFS* = Low-flow showerhead, *PGB* = Power Gas Burner (forced or induced draft), *RHB* = Flame retention head burner, *TU* = Furnace tune-up, *VDE* = Electronic vent dampers, *VDT* = Thermal vent dampers, *VR* = Vent restrictor.

Retrofit Classification: LBL classification of major retrofit strategy used in each project. *BC* = Boiler/Furnace replacement and controls, *BR* = Boiler/furnace replacement, *CI* = Ceiling insulation and infiltration-reduction package, *CB* = Ceiling insulation and foundation insulation package, *HC* = Heating controls (and relatively low-cost heating system retrofits), *HD* = House-doctoring, *IX* = Insulation in various areas (e.g., wall, attic, foundation), *SH* = Shell packages (e.g., insulation, windows, caulking), *SS* = Shell & system packages, *SY* = Heating and hot water system packages, *WI* = Window replacement or modification, *CS* = Cooling system modifications, *CR* = Cooling system replacement,

Simple Payback Time: The period required for the undiscounted cumulative value of future energy savings (based on the energy price at the time of the retrofit) to equal the initial cost of the measure in question.

Net Present Value: The difference between the present value of the benefits resulting from a retrofit's lifetime energy savings and the present value of the lifetime costs of the retrofit. A retrofit is cost-effective if it has a positive NPV. To calculate the NPV we used a 7% real discount rate, economic lifetimes for measures shown in Table C-1, and fuel price escalation rates of 0.001 for electricity and 0.028 for gas and oil (EIA Annual Energy Outlook, 1989).

Cost of Conserved Energy: The ratio of the annualized investment in a retrofit to the annual energy savings caused by it. An efficient investment is one whose CCE is less than the cost of fuel.

Confidence Level Cost: *A* = Well-documented cost data, cost breakdown for individual measures, *B* = Documented cost data, contractor cost of retrofit, estimated O&M costs, *C* = Adequate cost data, aggregate cost data for group of buildings or buildings that have only materials cost plus labor hours, *F* = No retrofit cost data.

Table A-1: Project/Building Description

LABEL	LOCATION		PROJECT TYPE	PROJECT NAME	NO. OF HOUSES	COND. FLOOR AREA (ft^2)	YEAR BUILT	PRE-RETR R CEIL-ING	POST-RETR R CEIL-ING	PRE-RETR R WALL	POST-RETR R WALL	COMMENTS
				State and City Loan Programs								
G051.1	MINNEAPOLIS	MN	L	84 MINN FOUND INSUL	8	1394						INTERIOR FOUNDATION INSULATION
G051.2	MINNEAPOLIS	MN	L	84 MINN FOUND INSUL	5	1009						EXTERIOR FOUNDATION INSULATION
G052.1	MINNEAPOLIS	MN	LR	MEO FURN,INSUL	3	1533						BOILER REPLACEMENT (CONDENSING)
G052.2	MINNEAPOLIS	MN	L	MEO FURN,INSUL	13	1147	1923					80-84% AFUE FURNACE REPLACEMENT
G052.3	MINNEAPOLIS	MN	L	MEO FURN,INSUL	4	1945						80-84% AFUE BOILER REPLACEMENT
G052.4	MINNEAPOLIS	MN	L	MEO FURN,INSUL	8	1313	1923			0	12	WALL INSULATION
G078.1		IN	L	INDIANA ECFAP	234	1300	1947					OVERALL PROGRAM
G078.2		IN	L	INDIANA ECFAP	30	1300	1947					CONDENSING FURNACE
G078.3		IN	L	INDIANA ECFAP	41	1300	1947					REPLACEMENT WINDOWS
M028.1	WINNIPEG	CAN	L	MANITOBA CHEC PROGRAM	265							ENTIRE PROGRAM
M028.2	WINNIPEG	CAN	L	MANITOBA CHEC PROGRAM	130							ENTIRE PROG. EXCEPT DOORS,WINDOWS
M028.3	WINNIPEG	CAN	L	MANITOBA CHEC PROGRAM	47			11	40			ATTIC INSULATION
M028.4	WINNIPEG	CAN	L	MANITOBA CHEC PROGRAM	12					0	11	WALL INSULATION
M028.5	WINNIPEG	CAN	L	MANITOBA CHEC PROGRAM	24							INTERIOR FOUNDATION INSULATION
M028.6	WINNIPEG	CAN	L	MANITOBA CHEC PROGRAM	89							WINDOW REPLACEMENTS
M028.7	WINNIPEG	CAN	L	MANITOBA CHEC PROGRAM	15							DOOR REPLACEMENTS
				Research and Demonstration Projects								
E003.1	DENVER	CO	R	COLORADO AIR INFIL	23	1600						AIR INFIL. REDUCTION STUDY
E003.2A	DENVER	CO	R	COLORADO AIR INFIL	22							ACTIVE CONTROL GROUP
E003.3B	DENVER	CO	R	COLORADO AIR INFIL	30							BLIND CONTROL GROUP
E008.1	MIDWAY	WA	R	BPA/LBL MIDWAY PROJECT	5	1260	1950					EXTENDED INFILTRATION REDN.
E008.2	MIDWAY	WA	R	BPA/LBL MIDWAY PROJECT	5	1253	1950					ATTIC AND CRAWLSPACE INS.
E008.3	MIDWAY	WA	R	BPA/LBL MIDWAY PROJECT	4	1239	1950					INSUL.+ STORM WINDOW & DOOR
E010	WASHINGTON DC	DC	R	NBS BOWMAN HOUSE	1	2054	1950					FIRST EXTENSIVE RES. STUDY
E015.1	SEATTLE	WA	R	SCL ENERGY CHECK PROGRAM	321							AUDIT PGM.-HOT WATER RETR.
E015.2A	SEATTLE	WA	R	SCL ENERGY CHECK PROGRAM	124							AUDIT PGM.-NO HOT WATER ACTION
E031.1	PACIFIC NW		R	PURPA LOAD	7							HEAT PUMP INSTALLATION
E031.2	PACIFIC NW		R	PURPA LOAD	68			16	28	11	11	
E031.3A	PACIFIC NW		R	PURPA LOAD	15							
E031.4A	PACIFIC NW		R	PURPA LOAD	29							LOW POTENTIAL SAVINGS CONTROL
E032.1	HOOD RIVER	OR	R	HOOD RIVER	362	1670						GOODFIT SF HOMES
E032.2	HOOD RIVER	OR	R	HOOD RIVER	13	1010	1975					GOODFIT MOBILE HOMES
E033.1	HOOD RIVER	OR	R	HOOD RIVER H2O	20	1209						WATER HEATER WRAP
E033.2	HOOD RIVER	OR	R	HOOD RIVER H2O	54	1415						WATER HEAT WRAP,LOWFLOW SHOWRHD
E033.3A	HOOD RIVER	OR	R	HOOD RIVER H2O	14	1260						SUBMETERED WATER HEATING
E034	AUSTIN	TX	R	TX A/C REPLACEMENT	12	1503	1971	11	11	10	10	A/C REPLACEMENT (SUBMETERED)
E036.1	TULSA	OK	R	ORNL OK COOLING RETROFIT	22	1244	1949		19			WEATHERIZATION ONLY
E036.2	TULSA	OK	R	ORNL OK COOLING RETROFIT	19	1244	1949		19			WEATHERIZATION + RADIANT BARRIER
E036.3	TULSA	OK	R	ORNL OK COOLING RETROFIT	18	1244	1949		19			WEATHERIZATION+HIGH EFF. WINDOW A/C
E037	PALM BEACH	FL	R	FSEC FL COOLING RETROFIT	25	1891	1973					COOLING RETROFIT PACKAGE
G002	TWIN RIVERS	NJ	R	TWIN RIVERS	1	1500	1972					EXTENSIVE RETR. AT TWIN RIVERS
G003		NJ	R	TWIN RIVERS	1	1200	1957					RES. STUDY ON BYPASS LOSSES
G004		NJ	R	TWIN RIVERS	1	1560	1963					RES. STUDY ON BYPASS LOSSES
G005.1	FREEHOLD	NJ	R	PRINCETON MODULAR RETR	6	2500	1960					HOUSE DOCTOR + CONTRACTOR RETR.
G005.2	FREEHOLD	NJ	R	PRINCETON MODULAR RETR	12	2500	1960					HOUSE DOCTOR RETR. ONLY
G005.3B	FREEHOLD	NJ	R	PRINCETON MODULAR RETR	6	2500	1960					BLIND CONTROL GROUP

Table A-1: Project/Building Description

LABEL	LOCATION		PROJECT TYPE	PROJECT NAME	NO. OF HOUSES	COND. FLOOR AREA (ft^2)	YEAR BUILT	PRE-RETR R CEIL-ING	POST-RETR R CEIL-ING	PRE-RETR R WALL	POST-RETR R WALL	COMMENTS
G005.4B		NJ	R	PRINCETON MODULAR RETR	140000							UTILITY AGGREGATE
G006.1	TOMS RIVER	NJ	R	PRINCETON MODULAR RETR	6	870	1970					HOUSE DOCTOR + CONTRACTOR RETR.
G006.2	TOMS RIVER	NJ	R	PRINCETON MODULAR RETR	12	860	1970					HOUSE DOCTOR RETR. ONLY
G006.3B	TOMS RIVER	NJ	R	PRINCETON MODULAR RETR	6	900	1970					BLIND CONTROL GROUP
G006.4B		NJ	R	PRINCETON MODULAR RETR	140000							UTILITY AGGREGATE
G007.1	OAK VALLEY	NJ	R	PRINCETON MODULAR RETR	6	1400	1950					HOUSE DOCTOR + CONTRACTOR RETR.
G007.2	OAK VALLEY	NJ	R	PRINCETON MODULAR RETR	9	1400	1950					HOUSE DOCTOR RETR. ONLY
G007.3A	OAK VALLEY	NJ	R	PRINCETON MODULAR RETR	6	1400	1950					ACTIVE CONTROL GROUP
G007.4B		NJ	R	PRINCETON MODULAR RETR	75000							UTILITY AGGREGATE
G008.1	WHITMAN SQ	NJ	R	PRINCETON MODULAR RETR	5	2120	1960					HOUSE DOCTOR + CONTRACTOR RETR.
G008.2	WHITMAN SQ	NJ	R	PRINCETON MODULAR RETR	9	1880	1960					HOUSE DOCTOR RETR. ONLY
G008.3A	WHITMAN SQ	NJ	R	PRINCETON MODULAR RETR	4	2000	1960					ACTIVE CONTROL GROUP
G008.4B		NJ	R	PRINCETON MODULAR RETR	75000							UTILITY AGGREGATE
G009.1	SASKATCHEWAN		R	CASWELL HILL STUDY	5	2157	1925					GROUP #1 - INSUL.+ INFIL. REDN.
G009.2	SASKATCHEWAN		R	CASWELL HILL STUDY	5	1752	1925					GROUP #2 - INFIL. REDN. ONLY
G009.3	SASKATCHEWAN		R	CASWELL HILL STUDY	10	1925						GROUP #3 - INSUL. MAINLY
G010	BUTTE	MT	R	NCAT (MT)	1	2300						PASSIVE SOLAR WALL IN 2ND YR
G014.1	OAKLAND	CA	R	CSA/NBS-OAKLAND	8	1300						LIW RESEARCH DEMO. PGM.
G014.2A	OAKLAND	CA	R	CSA/NBS-OAKLAND	4							ACTIVE CONTROL GRP.
G015	ST LOUIS	MO	R	CSA/NBS-ST LOUIS	18	1355						LIW RESEARCH DEMO. PGM.
G016	CHICAGO	I	R	CSA/NBS-CHICAGO	10	1464						LIW RESEARCH DEMO. PGM.
G017.1	COLORADO SPRINGS	CO	R	CSA/NBS-CO SPRINGS	16	998						LIW RESEARCH DEMO. PGM.
G017.2A	COLORADO SPRINGS	CO	R	CSA/NBS-CO SPRINGS	4							ACTIVE CONTROL GROUP
G018.1	ST PAUL	MN	R	CSA/NBS-MN	17	1421						LIW RESEARCH DEMO. PGM.
G018.2A	ST PAUL	MN	R	CSA/NBS-MN	5							ACTIVE CONTROL GROUP
G024.1	EDISON	NJ	R	PRINCETON MODULAR RETR	6	1780	1960					HOUSE DOCTOR + CONTRACTOR RETR
G024.2	EDISON	NJ	R	PRINCETON MODULAR RETR	5	1810	1960					HOUSE DOCTOR RETR. ONLY
G024.3A	EDISON	NJ	R	PRINCETON MODULAR RETR	6	1800	1960					ACTIVE CONTROL GROUP
G024.4B		NJ	R	PRINCETON MODULAR RETR	75000							UTILITY AGGREGATE
G025.1	WOOD RIDGE	NJ	R	PRINCETON MODULAR RETR	6	1345	1920					HOUSE DOCTOR + CONTRACTOR RETR
G025.2	WOOD RIDGE	NJ	R	PRINCETON MODULAR RETR	6	1370	1920					HOUSE DOCTOR RETR. ONLY
G025.3A	WOOD RIDGE	NJ	R	PRINCETON MODULAR RETR	6	1400	1920					ACTIVE CONTROL GROUP
G025.4B		NJ	R	PRINCETON MODULAR RETR	550000							UTILITY AGGREGATE
G026.1	NEW ROCHESTER	NY	R	PRINCETON MODULAR RETR	5	1300	1950					HOUSE DOCTOR + CONTRACTOR RETR
G026.2	NEW ROCHESTER	NY	R	PRINCETON MODULAR RETR	5	1460	1950					HOUSE DOCTOR RETR. ONLY
G026.3A	NEW ROCHESTER	NY	R	PRINCETON MODULAR RETR	6	1400	1950					ACTIVE CONTROL GROUP
G027.1	WALNUT CREEK	CA	R	CA(PG&E) HOUSE DOCT	13	2240	1964					HOUSE DOCTOR ONLY
G027.2A	WALNUT CREEK	CA	R	CA(PG&E) HOUSE DOCT	6	2500	1968					AUDIT ONLY-ACTIVE CONTROL
G027.3B	WALNUT CREEK	CA	R	CA(PG&E) HOUSE DOCT	1800							BLIND CONTROL-UTIL. AGGREGATE
G028	CHAMPAIGN	IL	R	IL WALL,CEIL INS	12	1596						INSUL. INSTALLED BY PRIV. FIRM
G028.1	CHAMPAIGN	IL	R	IL CEILING INSUL	5	1643	1967	14	31	9	9	CEILING INSULATION
G029.1	DENVER	CO	R	COLORADO 50/50	24	2488	1952	21		6		
G029.2A	DENVER	CO	R	COLORADO 50/50	23							NON-PART. CONTROL GROUP
G033.1	PRINCETON	NJ	R	PRINCETON MOD R AGG	40							COMPOSITE - MAJOR RETR. GROUP
G033.2	PRINCETON	NJ	R	PRINCETON MOD R AGG	58							COMPOSITE - HOUSE DOCTOR ONLY
G053.1	KANSAS CITY	MO	R	MO WARM ROOMS	5	1843	1934					WARM ROOMS
G053.2A	KANSAS CITY	MO	R	MO WARM ROOMS	4	2193	1915					WARM ROOM CONTROL
G054.1	LOUISVILLE	KY	R	KY GAS PILOT	43							CONDENSING HEAT EXTRACTOR
G054.2A	LOUISVILLE	KY	R	KY GAS PILOT	43							CONDENSING HEAT EXTRACTOR CONTROL
G054.3	LOUISVILLE	KY	R	KY GAS PILOT	16							POWER BURNER

Table A-1: Project/Building Description

LABEL	LOCATION		PROJECT TYPE	PROJECT NAME	NO. OF HOUSES	COND. FLOOR AREA (ft^2)	YEAR BUILT	PRE-RETR R CEIL-ING	POST-RETR R CEIL-ING	PRE-RETR R WALL	POST-RETR R WALL	COMMENTS
G054.4A	LOUISVILLE	KY	R	KY GAS PILOT	15							POWER BURNER CONTROL
G054.5	LOUISVILLE	KY	R	KY GAS PILOT	42							THERMALLY ACTUATED VENT DAMPERS
G054.6A	LOUISVILLE	KY	R	KY GAS PILOT	39							THERMALLY ACT. VENT DAMPER CONTROL
G055.1		MI	R	MICH GAS PILOT	13	1133	1961					FURNACE TUNE-UP
G055.2		MI	R	MICH GAS PILOT	16	1057						FURNACE TUNE-UP AND WEATHERIZATION
G055.3		MI	R	MICH GAS PILOT	11	1141	1949					THERMAL VENT DAMPER
G055.4		MI	R	MICH GAS PILOT	9	1105	1937					THERMAL VENT DAMP., WEATHERIZATION
G055.5		MI	R	MICH GAS PILOT	7	1224	1940					CONDENSING HEAT EXTRACTOR
G055.6		MI	R	MICH GAS PILOT	13	1629	1939					COND. HEAT EXT. AND WEATHERIZATION
G055.7A		MI	R	MICH GAS PILOT	12	1129	1944					
G058		CO	R	HOUSE NURSE PGM	28							
G059.1		USA	R	SHEIP	131	1600	1965					DERATING AND VENT RESTRICTOR
G059.2		USA	R	SHEIP	105	1600	1965					FULL FURNACE DERATING
G059.3		USA	R	SHEIP	146	1600	1965					VENT DAMPER
G059.4		USA	R	SHEIP	35	1600	1965					VENT RESTRICTOR
G059.5		USA	R	SHEIP	52	1600	1965					NON-CONDENSING HEAT EXTRACTOR
G062		MN	R	M200 HIGH LEVEL WX	128	1346						HIGH LEVEL WEATHERIZATION
G063.1	MINNEAPOLIS	MN	R	MN GAS PILOT	35							CONDENSING HEAT EXTRACTORS
G063.2A	MINNEAPOLIS	MN	R	MN GAS PILOT	34							CONDENSING HEAT EXTRACTOR CONTROL
G063.3	MINNEAPOLIS	MN	R	MN GAS PILOT	14							POWER BURNER
G063.4A	MINNEAPOLIS	MN	R	MN GAS PILOT	20							POWER BURNER CONTROL
G063.5	MINNEAPOLIS	MN	R	MN GAS PILOT	26							ELEC. VENT. DAMP. AND IGN.
G063.6A	MINNEAPOLIS	MN	R	MN GAS PILOT	30							ELEC. VENT. DAMP. AND IGN. CONTROL
G063.7	MINNEAPOLIS	MN	R	MN GAS PILOT	23							THERMALLY ACTUATED VENT DAMPERS
G063.8A	MINNEAPOLIS	MN	R	MN GAS PILOT	20							THERMALLY ACT. VENT DAMPER CONTROL
G064.1	MADISON	WI	R	ORNL/WECC WI AUDIT TEST	3							CONDENSING FURNACE
G064.3	MADISON	WI	R	ORNL/WECC WI AUDIT TEST	7							MINOR RETROFITS
G064.4A	MADISON	WI	R	ORNL/WECC WI AUDIT TEST	28							
G064.5	MADISON	WI	R	ORNL/WECC WI AUDIT TEST	20							RETROFIT SELECTION AUDIT TEST
G067.1	MINNEAPOLIS	MN	R	1989 MN FOUND INSUL	9	1299	1923	35	35	13	13	INTERIOR FOUNDATION INSULATION
G067.2	MINNEAPOLIS	MN	R	1989 MN FOUND INSUL	6	906	1939	32	32	13	13	EXTERIOR FOUNDATION INSULATION
G068		PA	R	NCAT CRITICAL NEEDS	25	1067						WARM ROOMS
G069.1	BUFFALO	NY	R	ORNL NY AUDIT TEST	32	1315	1941	7		2		RETROFIT SELECTION AUDIT TEST
G069.2A	BUFFALO	NY	R	ORNL NY AUDIT TEST	40	1315	1941	7		2		
G070	MINNEAPOLIS	MN	R	MEO NEW PROGRAM	110	1281						OWNER-PERFORMED HOUSE DOCTORING
G075.1		MI	R	MI WEATH. PRIORITY	173	1250	1940					NEW MEASURE PRIORITIZATION
G079	WINNIPEG	CAN	R	E&M WINNIPEG COND FURN	49	2140	1952	30	30	10	10	CONDENSING FURNACES
M001.1	CHARLESTON	SC	R	CSA/NBS-CHARLESTON	13	1111						LIW RESEARCH DEMO. PGM.
M001.2A	CHARLESTON	SC	R	CSA/NBS-CHARLESTON	5							ACTIVE CONTROL GROUP
M002	ATLANTA	GA	R	CSA/NBS-ATLANTA	8	1055						LIW RESEARCH DEMO. PGM.
M003	WASHINGTON D.C.	DC	R	CSA/NBS-WASH DC	4	915						LIW RESEARCH DEMO. PGM.
M004.1	TACOMA	WA	R	CSA/NBS-TACOMA	9	978						LIW RESEARCH DEMO. PGM.
M004.2A	TACOMA	WA	R	CSA/NBS-TACOMA	5							ACTIVE CONTROL GROUP
M005.1	EASTON	PA	R	CSA/NBS-EASTON	13	1334						LIW RESEARCH DEMO. PGM.
M005.2A	EASTON	PA	R	CSA/NBS-EASTON	3							ACTIVE CONTROL GROUP
M006.1	PORTLAND	ME	R	CSA/NBS-PORTLAND	14	1008						LIW RESEARCH DEMO. PGM.
M006.2A	PORTLAND	ME	R	CSA/NBS-PORTLAND	4							ACTIVE CONTROL GROUP
M007.1	FARGO	ND	R	CSA/NBS-FARGO	12	786						LIW RESEARCH DEMO. PGM.
M007.2A	FARGO	ND	R	CSA/NBS-FARGO	5							ACTIVE CONTROL GROUP

Table A-1: Project/Building Description

LABEL	LOCATION		PROJECT TYPE	PROJECT NAME	NO. OF HOUSES	COND. FLOOR AREA (ft^2)	YEAR BUILT	PRE-RETR R CEIL-ING	POST-RETR R CEIL-ING	PRE-RETR R WALL	POST-RETR R WALL	COMMENTS
M008.1	CSA/NBS		R	CSA/NBS AGGREGATE	142	1168						COMPOSITE - CSA/NBS DEMO. PGM.
M008.1A	CSA/NBS		R	CSA/NBS AGGREGATE	41							COMPOSITE - CSA/NBS CONTROL GROUP
M008.2			R	CSA/NBS SHELL,SYSTEM	73	1248						CSA/NBS SHELL & SYSTEM AGGREGATE
M008.3			R	CSA/NBS SHELL	69	1248						CSA/NBS SHELL ONLY AGGREGATE
M013.1	SWEDEN		R	ROYAL INST OF TECH	130	1485						WALL INSUL. - SF AGG. RESULTS
M013.2	SWEDEN		R	ROYAL INST OF TECH	106	1808						ATTIC INSUL. - SF AGG. RESULTS
M013.3	SWEDEN		R	ROYAL INST OF TECH	105	1528						WALL+ATTIC INS.-SF AGG. RESULTS
M013.4	SWEDEN		R	ROYAL INST OF TECH	140	1636						WALL+ATTIC INS.+TRV - AGG.
M013.5	SWEDEN		R	ROYAL INST OF TECH	111	1829						TRIPLE GLAZING - AGG. RESULTS
M013.6	SWEDEN		R	ROYAL INST OF TECH	17	1549						TRIPLE GLAZING+WALL INS.- AGG.
M013.7	SWEDEN		R	ROYAL INST OF TECH	32	1937						TRV VALVE
M014.1	SWEDEN		R	ROYAL INST OF TECH	30	689						WALL INSUL. - MF AGG. RESULTS
M014.2	SWEDEN		R	ROYAL INST OF TECH	25	764						ATTIC INSUL. - MF AGG. RESULTS
M014.7	SWEDEN		R	ROYAL INST OF TECH	63	807						TRV VALVE + VARIATOR EQUIP.
M025.1		MA	R	MASS AUDOBON	11	1339	1920					STORM WINDOWS
M025.2A		MA	R	MASS AUDUBON	6	966	1920					STORM WINDOW CONTROL
M025.3		MA	R	MASS AUDUBON	29	1037	1920					HOUSE DOCTORING
M029.1		VA	R	1989 VA PILOT LIW	43							PILOT SITE-BUILT HOMES
O001		NJ	R	TWIN RIVERS	1	1990						ELIM. BYPASS LOSSES
O007.1	PHILADELPHIA	PA	R	PA OIL FURN RETR	47							OIL FURNACE PILOT RETR. PGM.
O007.2A	PHILADELPHIA	PA	R	PA OIL FURN RETR	45							ACTIVE CONTROL-OIL FURN. RETR.
O010	LONG ISLAND	NY	R	BNL OIL FURN RETR	169	2045						COMPOSITE - OIL-FIRED BOILER RETR.
O010 B	LONG ISLAND	NY	R	BNL OIL FURN RETR	30	1559						CONTROL GROUP
010.0	LONG ISLAND	NY	R	BNL OIL FURN RETR	45	2045						COMPOSITE- OIL-FIRED FURNACE RETR.
O010.1	LONG ISLAND	NY	R	BNL OIL FURN RETR	19	1720						RET. HEAD BURNER (RHB)
O010.2	LONG ISLAND	NY	R	BNL OIL FURN RETR	2	1824						RHB W/ OPT INSTALLATION
O010.3	LONG ISLAND	NY	R	BNL OIL FURN RETR	14	1893						RHB W/ TEMP. PROGRAMMER
O010.4	LONG ISLAND	NY	R	BNL OIL FURN RETR	9	2004						RHB W/ VENT DAMPER
O010.5	LONG ISLAND	NY	R	BNL OIL FURN RETR	17	1886						DAMPER WITH CONV. BURNER
O010.6	LONG ISLAND	NY	R	BNL OIL FURN RETR	21	1814						FLUE HT. EXCH. W/ BURNER
O010.7	LONG ISLAND	NY	R	BNL OIL FURN RETR	14	1910						SETBACK W/ CONV. BURNER
O010.8	LONG ISLAND	NY	R	BNL OIL FURN RETR	14	1858						SETBACK + TEMP. PROG.
O011.1		MN	R	MN OIL FURN RETR	42							GR. I - OIL FURNACE RETROFIT
O011.2		MN	R	MN OIL FURN RETR	29							GR. II - WEATHERIZATION ONLY
O011.3		MN	R	MN OIL FURN RETR	15							GR. III-OIL FURN RETR.+WEATH.
O011.4A		MN	R	MN OIL FURN RETR	32							GR. IV - ACTIVE CONTROL
O025			R	ASE OIL PERSISTENCE	52							PERSISTENCE OF SAVINGS
026	PORTLAND	OR	R	OR OIL BURNER RETR	92	1144	1930					FLAME RETENTION BURNERS
O027.1		MI	R	MI OIL BURNER RETR	76							FLAME RETENTION BURNERS
O027.2		MI	R	MI OIL BURNER RETR	67							OIL FURNACE TUNEUP
O028		VA	R	1989 VA PILOT LIW	12							PILOT MOBILE HOMES
				Utility Weatherization Programs								
E001.1	KNOXVILLE	TN	U	TVA HOME INSUL. R&D	69	1013		0				DEMO PGM. BY PRIVATE CONTRAC.
E001.2	KNOXVILLE	TN	U	TVA HOME INSUL. R&D	105			0				DEMO PGM. BY TVA PERSONNEL
E002		TN	U	TVA HOME INSUL PROG	546	1550	1960	9	26			ELEC. SP. HT. SUB-SAMPLE
E004.1		OR	U	PP&L HEA AND WEATH.	973	1488						GROUP 1 - WEATH. + HTR. WRAP
E004.4B	NORTHWEST STATES		U	PP&L HEA AND WEATH.	69337							CONTROL GR.-ALL SF NON-PARTS
E005.1	SEATTLE	WA	U	SCL INSUL. PROGRAM	133							INSUL. PGM.-EARLY RESULTS

Table A-1: Project/Building Description

LABEL	LOCATION		PROJECT TYPE	PROJECT NAME	NO. OF HOUSES	COND. FLOOR AREA (ft^2)	YEAR BUILT	PRE-RETR R CEIL-ING	POST-RETR R CEIL-ING	PRE-RETR R WALL	POST-RETR R WALL	COMMENTS
E005.2B	SEATTLE	WA	U	SCL INSUL. PROGRAM	551							BLIND CONTROL GROUP
E006.1	WESTERN WASHINGT	WA	U	PP WEATH. PROGRAM	6289	1672						ZERO-INT. LOAN WEATH. PGM.
E007.1	PORTLAND	OR	U	PGE WEATH. PROGRAM	300				30			EARLY PARTS. IN WEATH. PGM.
E007.2B	PORTLAND	OR	U	PGE WEATH. PROGRAM	200							BLIND CONTROL GR.- NON-PART.
E009.1	E. WASH, IDAHO	WA	U	WWP WEATH. PROGRAM	1030	1250						ZERO-INTEREST WEATH. PGM.
E009.2	E. WASH, IDAHO	WA	U	WWP WEATH. PROGRAM	810	1250						ZERO-INTEREST WEATH. PGM.
E009.3B	E. WASH, IDAHO	WA	U	WWP WEATH. PROGRAM	251	1390						CONTROL GROUP
E011.1	OR, WA, MT		U	81 BPA PILOT	179	1760	1960					WEATH. PILOT PGM. - AUDIT+LOAN
E011.2A	OR, WA, MT		U	81 BPA PILOT	38	1320	1960					WEATH. PILOT PGM. - AUDIT ONLY
E011.3B	OR, WA, MT		U	81 BPA PILOT	132		1960					WEATH. PILOT PGM. - NON-PART.
E013.1	SEATTLE	WA	U	81 SCL HELP PROGRAM	132	1589	1954		38			HELP PROGRAM - AUDIT + LOAN
E013.2	SEATTLE	WA	U	82 SCL HELP PROGRAM	116	1702			38			HELP PROGRAM - AUDIT + LOAN
E013.3	SEATTLE	WA	U	83 SCL HELP PROGRAM	111	1530			38			HELP PROGRAM - AUDIT + LOAN
E013.4	SEATTLE	WA	U	84 SCL HELP PROGRAM	108	1645			38			HELP PROGRAM - AUDIT + LOAN
E013.5	SEATTLE	WA	U	85 SCL HELP PROGRAM	285	1867			38			HELP PROGRAM - AUDIT + LOAN
E013.6	SEATTLE	WA	U	86 SCL HELP PROGRAM	278	1808			38			HELP PROGRAM - AUDIT + LOAN
E013.7B	SEATTLE	WA	U	SCL HELP PROGRAM CTL	229	1673			38			
E014.1	SEATTLE	WA	U	SCL LIEP PROGRAM	293	1274						LOW-INC. ELEC. PGM.-AUDIT+LOAN
E014.2B	SEATTLE	WA	U	SCL LIEP PROGRAM	208	1312						LOW-INCOME ELEC. PGM.-CONTROLS
E016.1	PORTLAND	OR	U	PGE WEATH. PROGRAM	208	1577						ZIP WEATH. PGM. - AUDIT+LOAN
E016.2A	PORTLAND	OR	U	PGE WEATH. PROGRAM	105	1565						ZIP WEATH. PGM. - AUDIT ONLY
E016.3B	PORTLAND	OR	U	PGE WEATH. PROGRAM	91	1445						ZIP WEATH. PGM. - NON-PART.
E017.1	BOISE	ID	U	ID ZIP PGM	101	1322						IDAHO ZIP PROGRAM
E017.2B	BOISE	ID	U	ID ZIP PGM	48							IDAHO ZIP PROGRAM
E030.1	PACIFIC NW		U	82 BPA TREATMENT	229	1600	1964					
E030.2	PACIFIC NW		U	83 BPA TREATMENT	248	1660	1965					
E030.3A	PACIFIC NW		U	82-83 BPA CONTROL	114	1720	1963					
E035.1		WI	U	1984 WI LIW	36							
E035.2A		WI	U	1984 WI LIW	37							
E038.1	Pacific NW		U	85 BPA RWP	239	1650						
E038.2B	Pacific NW		U	85 BPA RWP	731	1650						
E039.1	Pacific NW		U	86 BPA RWP	252	1650						
E039.2B	Pacific NW		U	86 BPA RWP	688	1650						
G011	RAMSEY COUNTY	MN	U	NSP WEATH. PGM	84	1900						UTILITY LOW-INCOME WEATH. PGM.
G012.1	BAKERSFIELD	CA	U	CA (PG&E) CEIL INS	33							ATTIC INSUL. PGM.
G012.2	FRESNO	CA	U	CA (PG&E) CEIL INS	16							ATTIC INSUL. PGM.
G013		CO	U	CO CEILING INSUL	33000							ATTIC INSUL. LOW-INT. LOAN PGM
G030	DETROIT	MI	U	MI CEILING INSUL	71							ATTIC INSULATION PROG.
G060	MINNEAPOLIS	MN	U	NSP PUCIP LOAN	162	1610	1928					
G061.1		OH	U	1987 OH LIW	8912	1095	1935					SITE-BUILT HOUSES
G061.2		OH	U	1987 OH LIW	60	620						MOBILE HOME SUBSET
G061.3A		OH	U	1987 OH LIW	1620							CONTROL GROUP
G061.4		OH	U	1987 OH LIW	162	793						CEILING INSULATION
G066.1		WI	U	1984 WI UWAP	483	1274						LIW TREATMENT
G066.2A		WI	U	1984 WI UWAP	265	1274						LIW CONTROL
G066.3		WI	U	1984 WI UWAP	33	1416	1938					FURNACE REPLACEMENTS
G066.4		WI	U	1984 WI UWAP	7	1206	1938					WALL INSULATION
G072.1		CA	U	PG&E DIRECT WEATH.	5920							SITE-BUILT HOUSES
G072.2		CA	U	PG&E DIRECT WEATH.	671							MOBILE HOMES

Table A-1: Project/Building Description

LABEL	LOCATION		PROJECT TYPE	PROJECT NAME	NO. OF HOUSES	COND. FLOOR AREA (ft²)	YEAR BUILT	PRE-RETR R CEIL-ING	POST-RETR R CEIL-ING	PRE-RETR R WALL	POST-RETR R WALL	COMMENTS
G072.3A		CA	U	PG&E DIRECT WEATH.	5020							CONTROL GROUP
G082.1		WI	U	1983 WI UWAP	1357	1274						
Low-Income Weatherization Programs												
G001		WI	W	1981 WI LIW	11	900						LOW-INC. WEATH.- STATE EVAL.
G019	LUZERNE CITY	PA	W	1979 PA LIW	30							LOW-INC. WEATH.- COUNTY EVAL.
G021.1	KANSAS CITY	MO	W	1977 MO LIW	21							LOW-INC. WEATH.- CITY EVAL.
G021.2	KANSAS CITY	MO	W	1977 MO LIW	45							LOW-INC. WEATH.- CITY EVAL.
G021.3	KANSAS CITY	MO	W	1978 MO LIW	44							LOW-INC. WEATH.- CITY EVAL.
G022		KY	W	1979 KY LIW	138							LOW-INC. WEATH.- STATE EVAL.
G023		IN	W	1978 IN LIW	30	1102						LOW-INC. WEATH.- STATE EVAL.
G056.1		OH	W	1985 OH LIW	1083	1222	1926	7				
G056.2A		OH	W	1985 OH LIW	356	1138	1924	7				
G057.1		WI	W	1982 WI LIW	243	1040	1940					
G057.2A		WI	W	1982 WI LIW	46	1030	1944					
G065.1	MINNEAPOLIS	MN	W	1981 MN LIW	239	837						SITE-BUILT AND MOBILE HOMES
G065.2	MINNEAPOLIS	MN	W	1981 MN LIW	35	867						MOBILE HOME SUBSET
G071.1	MINNEAPOLIS	MN	W	MEO PROJECT CHOICE	30	1595						HOUSE DOCTORING
G071.2	MINNEAPOLIS	MN	W	MEO PROJECT CHOICE	13	1600						HOUSE DOCTORING AND WX
G073.1		MN	W	1984 MN LIW	155	917						SITE-BUILT HOUSES
G073.2		MN	W	1984 MN LIW	28	868						MOBILE HOMES
G074.1	DETROIT	MI	W	84 MI REPAIR/WEATH.	41	1602	1935					HIGH USERS, REPAIR/WEATHERIZATION
G074.2	DETROIT	MI	W	85 MI REPAIR/WEATH.	158	1475	1931					HIGH USERS, REPAIR/WEATHERIZATION
G075.2		MI	W	MI WEATH. PRIORITY	65	1250	1946					OLD MEASURE PRIORITIZATION
G076.1		MI	W	1983 MI LIW	364	892	1937		33			REGULAR WEATHERIZATION
G076.2		MI	W	1983 MI LIW	72	877	1946		19			REDUCED COST WEATHERIZATION
G076.3		MI	W	1983 MI LIW	124	812	1940					CONTROL GROUP
G077.1		MI	W	1984 MI LIW	155	942	1934	13	33			SITE-BUILT HOUSES
G077.2		MI	W	1984 MI LIW	47	816	1967					MOBILE HOMES
G077.3A		MI	W	1984 MI LIW	125	844	1936	14	14			CONTROL GROUP
G080		NY	W	1988 NY LIW	683	1277						
G081		IL	W	IHWAP MOBILE HOMES	227							MOBILE HOMES
G083		IL	W	1988 IL LIW	192	1550						
G084		VA	W	1989 VA LIW	91							
G085		IL	W	1984 IL LIW	497							
M009	NW WISCONSIN	WN	W	1976 WI LIW	65	1292						LOW-INC. WEATH.-REGIONAL EVAL.
M010.1		MN	W	1978 MN LIW	59	806						LOW-INC. WEATH.-STATE EVAL.
M010.2B		MN	W	1978 MN LIW	37	1325						BLIND CONTROL GROUP
M010.3		MN	W	1978 MN LIW	19	774						SUB-GROUP W/ 2 POST-RETR. YRS
M011		WN	W	1979 WI LIW	13							LOW-INC. WEATH.- STATE EVAL.
M012	ALLEGAN CITY	MI	W	1974-76 MI LIW	86				38			LOW-INC. WEATH.- COUNTY EVAL.
M026		USA	W	1981 NATIONAL LIW	965							NATIONAL LIW EVALUATION
M027.1		OH	W	COAD MOBILE HOMES	99							MOBILE HOMES
M027.2A		OH	W	COAD MOBILE HOMES	26							MOBILE HOME CONTROL
O006		VT	W	1980 VT LIW	13							LOW INCOME WEATHERIZATION

Table A-2: Project/Building Description

LABEL	END USES	NAC BEFORE (MBtu or kWh)	NAC SAVINGS (MBtu or kWh)	NAC SAVINGS (%)	SPACE HEAT BEFORE (MBtu or kWh)	SPACE HEAT SAVINGS (MBtu or kWh)	SPACE HEAT SAVINGS (Per cent)	HEATING FACTOR BEFORE (Btu/ ft²-HDD)	HEATING FACTOR AFTER (Btu/ ft²-HDD)	ANALYSIS METHOD	CONFI-DENCE LEVEL ENERGY	ENERGY SAVINGS PRED. METHOD	PRED SAVINGS (MBtu or kWh)	HDD (65°F)	HEAT SYST TYPE	DHW FUEL
State and City Loan Programs																
G051.1	F	128.7	19.7	15						R	B+	MHDD	27	8007	FB	G
G051.2	F	109.6	11.0	10						R	B+	MHDD	16	8007	FB	G
G052.1	F	174.9	33.2	19				9.0	7.5	R	B+	MHDD	37	8007	B	G
G052.2	F	145.4	19.3	13				10.3	8.9	R	B+	MHDD	24	8007	F	G
G052.3	F	229.6	30.1	13				9.6	8.3	R	B+	MHDD	37	8007	B	G
G052.4	F	168.0	20.0	12				9.8	8.7	R	B+	MHDD	41	8007	FB	
G078.1	F	127.1	14.6	11						R	B+			5500		
G078.2	F	148.9	29.0	19						R	B+			5500		
G078.3	F	111.9	1.5	1						R	B+			5500		
M028.1	H					18.8				F	B	MONTH	16	10572		
M028.2	H					32.4				F	B	MONTH	28	10572		
M028.3	H					21.3				F	B	MONTH	17	10572		
M028.4	H					44.2				F	B	MONTH	38	10572		
M028.5	H					31.9				F	B	MONTH	26	10572		
M028.6	H					4.9				F	B	MONTH	2	10572		
M028.7	H					0.7				F	B	MONTH	2	10572		
Research and Demonstration Projects																
E003.1	H				17615.0	2836.0	16	6.2	5.2	F	B+			6016		E
E003.2A	H	21803.0	2068.0	9	11890.0	1415.0	12			F	A			6016		
E003.3B	H				23886.0	2852.0	12			F	A			6016		
E008.1	H				19984.0	1846.0	9	11.4	10.3	R	A	MONTH	840	4760		
E008.2	H				19803.0	3235.0	16	11.3	9.5	R	A	MONTH	4460	4760		
E008.3	H				19649.0	8204.0	42	11.4	6.6	R	A	MONTH	6510	4760		
E010	H				20330.0	11906.0	59	7.3	3.0	S	A			4610		
E015.1	B	11249.0	465.0	4						S	C			5121		
E015.2A	B	11894.0	-83.0	-1						S	C			5121		
E031.1	F	25519.0	6683.0	26						E	A				A	
E031.2	F	26818.0	3670.0	14						E	A				E	
E031.3A	F	26717.0	1907.0	7						E	A				E	
E031.4A	F	24137.0	876.0	4						E	A				E	
E032.1	F	24400.0	4000.0	16	10300.0	3300.0	32	3.8	2.6	R	B+			5600	E	E
E032.2	F	20800.0	2000.0	10	9700.0	1600.0	16	5.9	4.9	R	B+			5600	E	E
E033.1	D									E	A	EST	962	5600	E	E
E033.2	D									E	A	EST	1001	5600	E	E
E033.3A	D									E	A			5600	E	E
E034	C	12708.0	1556.0	12		2133.0	42			E	A	HOUR	2068	1760		G
E036.1	C									E	A			3731		
E036.2	C									E	A			3731		
E036.3	C									E	A			3731		
E037	C					5320.0	65			E	A			262		
G002	H				81.0	61.8	76	11.0	2.6	R	A			4911		
G003	H				59.6	23.9	40	10.1	6.1	R	A			4911		
G004	H				114.4	30.3	26	14.9	11.0	R	A			4911		
G005.1	F	179.0	44.0	25	112.0	35.3	32	9.2	6.3	R	A			4872		
G005.2	F	172.0	29.0	17	113.3	14.6	13	9.3	8.1	R	A			4872		
G005.3B	F	185.0	11.0	6	132.8	1.3	1	10.9	10.8	R	A			4872		
G005.4B	F			3						R	A			4872		

Table A-2: Project/Building Description

LABEL	END USES	NAC BEFORE (MBtu or kWh)	NAC SAVINGS (MBtu or kWh)	NAC SAVINGS (%)	SPACE HEAT BEFORE (MBtu or kWh)	SPACE HEAT SAVINGS (MBtu or kWh)	SPACE HEAT SAVINGS (Per cent)	HEATING FACTOR BEFORE (Btu/ft²-HDD)	HEATING FACTOR AFTER (Btu/ft²-HDD)	ANALYSIS METHOD	CONFI-DENCE LEVEL ENERGY	ENERGY SAVINGS PRED. METHOD	PRED SAVINGS (MBtu or kWh)	HDD (65°F)	HEAT SYST TYPE	DHW FUEL
G006.1	F	87.0	17.0	20	60.1	14.5	24	14.2	10.7	R	A			4872		
G006.2	F	99.0	7.0	7	65.8	4.0	6	15.7	14.7	R	A			4872		
G006.3B	F	98.0	0.0	0	69.3	0.0	0	15.8	15.8	R	A			4872		
G006.4B	F			4						R	A			4872		
G007.1	F	116.0	27.0	23	68.2	21.1	31	10.0	6.9	R	A			4872		
G007.2	F	121.0	27.0	22	66.2	16.4	25	9.7	7.3	R	A			4872		
G007.3A	F	128.0	13.0	10	72.3	13.0	18	10.6	8.7	R	A			4872		
G007.4B	F			11						R	A			4872		
G008.1	F	147.0	35.0	24	124.7	33.1	27	12.1	8.9	R	A			4872		
G008.2	F	135.0	26.0	19	101.3	20.4	20	11.1	8.8	R	A			4872		
G008.3A	F	145.0	16.2	11	103.3	23.4	23	10.6	8.2	R	A			4872		
G008.4B	F			12						R	A			4872		
G009.1	H	209.9	53.3	25	177.1	53.3	30	7.5	5.2	S	B			10939		
G009.2	H	198.7	14.6	7	163.5	14.9	9	8.5	7.8	S	B			10939		
G009.3	H	150.8	15.8	10	127.2	15.9	12	9.2	8.1	S	C			10939		
G010	H				262.9	58.5	22	11.8	9.2	R	B			9669		
G014.1	H				76.1	2.2	3	20.1	19.6	R	A			2909		
G014.2A	H				116.9	-11.5	- 10	31.9	35.0	R	A			2909		
G015	H				174.7	17.4	10	27.1	24.4	R	A			4750		
G016	H				264.8	109.7	41	29.5	17.3	R	A			6127		
G017.1	H				132.0	60.4	46	20.4	11.1	R	A			6473		
G017.2A	H				164.8	0.2	0			R	A			6473		
G018.1	H				180.9	39.3	22	15.6	12.2	R	A			8159		
G018.2A	H				286.1	23.4	8			R	A			8159		
G024.1	F	163.0	38.0	23	108.7	35.0	32	12.5	8.5	R	A			4872		
G024.2	F	164.0	24.0	15	105.2	21.9	21	11.9	9.4	R	A			4872		
G024.3A	F	166.0	11.0	7	114.9	23.7	21	13.1	10.4	R	A			4872		
G024.4B	F			10						R	A			4872		
G025.1	F	177.0	26.0	15	128.9	35.5	28	19.7	14.2	R	A			4872		
G025.2	F	159.0	21.0	13	114.6	25.9	23	17.2	13.3	R	A			4872		
G025.3A	F	148.0	17.0	11	109.8	23.2	21	16.1	12.7	R	A			4872		
G025.4B	F			11						R	A			4872		
G026.1	F	155.0	31.0	20	99.6	21.8	22	15.7	12.3	R	A			4872		
G026.2	F	160.0	24.0	15	88.0	13.0	15	12.4	10.5	R	A			4872		
G026.3A	F	159.0	19.0	12	111.9	16.4	15	16.4	14.0	R	A			4872		
G027.1	F	128.2	16.4	13						R	A	MHDD	11	2900		
G027.2A	F	134.6	14.2	11						R	A			2900		
G027.3B	F	87.8	6.2	7						R	A			2900		
G028	F	175.1	41.6	24	133.7	40.2	30	14.5	10.1	S	B	MHDD	20	5773		
G028.1	F	169.2	29.1	17						S	B			5773		
G029.1	F	127.1	26.2	21	95.94	24.9	26	6.4	4.7	R	C	MHDD	26	6014	FB	G
G029.2A	F	116.0	12.0	10						R	B			6014		
G033.1	F	146.0	31.0	21	99.7	29.9	30			R	A			4872		
G033.2	F	140.0	22.0	16	91.6	15.3	17			R	A			4872		
G053.1	F	170.1	48.1	28						F	B			5283	F	G
G053.2A	F	209.6	4.9	2						F	B			5283	F	G
G054.1	F	133.2	18.9	14	98.9	18.7	19			R	B+			4525	F	G
G054.2A	F	143.6	11.0	8	102.7	10.3	10			R	B+			4525	F	G
G054.3	F	161.5	9.5	6	127.0	-5.0	-4			R	B+			4525	F	G
G054.4A	F	160.7	8.8	5	126.2	9.6	8			R	B+			4525	F	G

Table A-2: Project/Building Description

LABEL	END USES	NAC BEFORE (MBtu or kWh)	NAC SAVINGS (MBtu or kWh)	NAC SAVINGS (%)	SPACE HEAT BEFORE (MBtu or kWh)	SPACE HEAT SAVINGS (MBtu or kWh)	SPACE HEAT SAVINGS (Per cent)	HEATING FACTOR BEFORE (Btu/ ft^2-HDD)	HEATING FACTOR AFTER (Btu/ ft^2-HDD)	ANALYSIS METHOD	CONFI-DENCE LEVEL ENERGY	ENERGY SAVINGS PRED. METHOD	PRED SAVINGS (MBtu or kWh)	HDD (65°F)	HEAT SYST TYPE	DHW FUEL
G054.5	F	109.6	7.2	7	77.7	9.2	12			R	B+			4525	F	G
G054.6A	F	106.6	10.7	10	74.0	11.7	16			R	B+			4525	F	G
G055.1	H				115.1	-3.1	-3	15.4	15.8	R	B+			6598	F	G
G055.2	H				115.2	19.9	17	16.6	13.7	R	B+			6573	F	G
G055.3	H				120.1	-0.5	0	16.2	16.3	R	B+			6491	F	G
G055.4	H				126.8	24.1	19	17.4	14.1	R	B+			6583	F	G
G055.5	H				104.8	0.6	1	13.0	12.9	R	B+			6592	F	G
G055.6	H				122.4	10.6	9	11.4	10.4	R	B+			6585	F	G
G055.7A	H				118.1	3.1	3	16.0	15.5	R	B+			6555	F	G
G058	F	132.4	12.6	10						R	B			6000		
G059.1	H						9			E	A				FB	
G059.2	H						6			E	A				FB	
G059.3	H						5			E	A				FB	
G059.4	H						4			E	A				FB	
G059.5	H						3			F	A				FB	
G062	F	141.6	25.0	18	113.3	25.0	22	10.5	8.2	R	B+			8000	FB	
G063.1	F	169.4	6.5	4	153.0	18.5	12			R	B+			8007	F	G
G063.2A	F	178.5	-6.9	-4	154.9	18.3	12			R	B+			8007	F	G
G063.3	F	205.0	11.4	6	178.3	7.4	4			R	B+			8007	F	G
G063.4A	F	228.8	-3.4	-1	200.7	-4.3	-2			R	B+			8007	F	G
G063.5	F	180.0	6.3	4	164.5	5.0	3			R	B+			8007	F	G
G063.6A	F	214.2	-3.9	-2	187.4	-5.6	-3			R	B+			8007	F	G
G063.7	F	178.9	-3.4	-2	145.4	-7.2	-5			R	B+			8007	F	G
G063.8A	F	169.6	-4.2	-2	138.1	0.9	1			R	B+			8007	F	G
G064.1	H				124.3	29.6	24			E	A	VHDD	20	7500	FB	
G064.3	H				85.7	-0.6	-1			E	A	VHDD	4	7500	FB	
G064.4A	H				91.3	-0.5	-1			E	A			7500	FB	
G064.5	H				104.5	16.4	16			E	A	VHDD	20	7500	FB	
G067.1	F	112.3	6.4	6						R	B+	MHDD	32	8007	FB	G
G067.2	F	86.6	2.4	3						R	B+	MHDD	7	8007	F	G
G068	F	137.2	31.1	23	90.3	31.1	34	15.2	10.0	E	C			5550		
G069.1	F	132.8	19.9	15	102.1	18.3	18	11.4	9.4	E	A	VHDD	35	6798	FB	G
G069.2A	F	123.4	-6.4	-5	90.2	-6.1	-7	10.1	10.8	E	A			6798	FB	G
G070	F	173.0	13.6	8	138.4	10.9	8	13.5	12.4	R	B+			8007		
G075.1	H	171.5	31.1	18	137.2	26.6	19	16.3	13.2	S	B			6724	G	
G079	H				115.7	38.6	33	5.1	3.4	S	C			10661	F	G
M001.1	H				62.5	21.1	34	26.2	17.4	E	A			2146		
M001.2A	H				36.3	5.6	15			E	A			2146		
M002	H				108.1	14.0	13	33.1	28.8	E	A			3095		
M003	H				130.5	61.4	47	33.9	17.9	E	A			4211		
M004.1	H				168.8	69.0	41	33.3	19.7	E	A			5185		
M004.2A	H				59.5	9.4	16			E	A			5185		
M005.1	H				121.7	28.6	24	15.7	12.0	E	A			5827		
M005.2A	H				44.0	4.2	9			E	A			5827		
M006.1	H				187.3	81.9	44	24.8	13.9	E	A			7498		
M006.2A	H				232.5	28.7	12			E	A			7498		
M007.1	H				109.5	43.7	40	15.0	9.0	E	A			9271		
M007.2A	H				145.1	13.8	10			E	A			9271		
M008.1	H				146.7	44.8	31	21.7	15.1	E	A		59	5778		
M008.1A	H				145.2	6.5	4			E	A					

Table A-2: Project/Building Description

LABEL	END USES	NAC BEFORE (MBtu or kWh)	NAC SAVINGS (MBtu or kWh)	NAC SAVINGS (%)	SPACE HEAT BEFORE (MBtu or kWh)	SPACE HEAT SAVINGS (MBtu or kWh)	SPACE HEAT SAVINGS (Per cent)	HEATING FACTOR BEFORE (Btu/ ft²-HDD)	HEATING FACTOR AFTER (Btu/ ft²-HDD)	ANALYSIS METHOD	CONFI-DENCE LEVEL ENERGY	ENERGY SAVINGS PRED. METHOD	PRED SAVINGS (MBtu or kWh)	HDD (65°F)	HEAT SYST TYPE	DHW FUEL
M008.2	H				150.0	61.9	41	18.6	10.9	E	A			6468		
M008.3	H				126.6	22.6	18	20.1	16.5	E	A			5048		
M013.1	W	142.4	18.5	13						S	C	MHDD	15	7220		
M013.2	W	157.7	16.2	10						S	C	MHDD	12	7220		
M013.3	W	151.1	17.2	11						S	C	MHDD	24	7220		
M013.4	W	164.9	24.2	15						S	C	MHDD	9	7220		
M013.5	W	155.0	11.5	7						S	C	MHDD	6	7220		
M013.6	W	142.1	14.1	10						S	C	MHDD	16	7220		
M013.7	W	173.3	21.1	12						S	C	MHDD		7220		
M014.1	W	64.5	9.0	14							C	MHDD	10	7220		
M014.2	W	78.7	6.6	8							C	MHDD	3	7220		
M014.7	W	76.7	5.9	8							C			7220		
M025.1	H						10			F	B			5500	FB	
M025.2A	H						2			F	B			5500	FB	
M025.3	H						9			F	B			5500	FB	
M029.1	153.0	24.2	16	107.0	24.2	23	21.0	15.7	E	A			4300			
O001	H				132.0	69.5	53	13.5	6.4	R	A			4911		
O007.1	W	146.5		19	117.2	21.9	19				C			4865		
O007.2A	H					3.9	3				C			4865		
O010	W			16						F	B			5500		
O010B	W	148.3		12	123.1	14.5	12	14.4	12.7	F	B			5500		
O010.0	H						11			F	B			5500		
O010.1	W	152.7		14	126.7	17.8	14	13.4	11.5	F	B			5500		
O010.2	W	166.0		19	137.8	26.7	19	13.7	11.1	F	B			5500		
O010.3	W	159.6		23	132.5	30.1	23	12.7	9.8	F	B			5500		
O010.4	W	175.3		25	145.5	36.2	25	13.2	9.9	F	B			5500		
O010.5	W	170.2		16	141.3	22.8	16	13.6	11.4	F	B			5500		
O010.6	W	167.8		14	139.3	19.7	14	14.0	12.0	F	B			5500		
O010.7	W	170.2		9	141.3	12.7	9	13.4	12.2	F	B			5500		
O010.8	W	175.9		22	146.0	32.2	22	14.3	11.1	F	B			5500		
O011.1	H						22				I			8983		
O011.2	H						12				I			8983		
O011.3	H						29				I			8983		
O011.4A	H						0				I			8983		
O025	H				104.7	24.1	23			O	C					
O026	H				89.7	21.7	24	16.7	12.7	O	C			4691	F	
O027.1	H				130.5	32.4	25			O	C			7000	F	
O027.2	H				130.5	4.7	4			O	C			7000	F	
O028				66.0	10.9	17	22.0	17.6	E	A			4300			
Utility Weatherization Programs																
E001.1	H				11270.0	6122.0	54	8.6	3.9	S	C			3838		
E001.2	H				12383.0	4112.0	33			S	C			3838	E	
E002	H				10148.0	2211.0	22	5.6	4.4	S	B	MHDD	2174	4010	E	E
E004.1	F	25421.0	4461.0	18	12060.0	3980.0	33	5.6	3.8	S	C			4905	E	
E004.4B	F	24386.0	869.0	4						S	C			4905		
E005.1	H	30110.0	4180.0	14	17110.0	4180.0	24			S	C			5185	FE	E
E005.2B	H	29843.0	2209.0	7	16843.0	2209.0	13			S	C			5185		
E006.1	F	32800.0	8575.0	26	19336.0	7903.0	41	7.2	4.2	S	C	MHDD	5454	5500	FE	E
E007.1	F	23638.0	3937.0	17	11900.0	3500.0	29			F	B	MHDD	4082	4792	FE	E

Table A-2: Project/Building Description

LABEL	END USES	NAC BEFORE (MBtu or kWh)	NAC SAVINGS (MBtu or kWh)	NAC SAVINGS (%)	SPACE HEAT BEFORE (MBtu or kWh)	SPACE HEAT SAVINGS (MBtu or kWh)	SPACE HEAT SAVINGS (Per cent)	HEATING FACTOR BEFORE (Btu/ ft^2-HDD)	HEATING FACTOR AFTER (Btu/ ft^2-HDD)	ANALYSIS METHOD	CONFI-DENCE LEVEL ENERGY	ENERGY SAVINGS PRED. METHOD	PREL SAVINGS (MBtu or kWh)	HDD (65°F)	HEAT SYST TYPE	DHW FUEL
E007.2B	F	20177.0	8.0	0						F	B			4792		
E009.1	F	30007.0	4448.0	15						F	B	MHDD	9865	6835	FE	E
E009.2	H	30137.0	4349.0	14	18137.0	4349.0	24	7.2	5.5	F	B			6835		
E009.3B	F	24794.0	1248.0	5						F	B			6835		
E011.1	F	28500.0	6000.0	21	14700.0	6000.0	41	5.4	3.2	F	A	MHDD	12000	5324		
E011.2A	F	20700.0	1800.0	9	11700.0	3800.0	32	5.7	3.8	F	A			5324		
E011.3B	F	24600.0	2800.0	11	11400.0	3100.0	27			F	A			5324		
E013.1	F	25873.0	4341.0	17	13736.0	2919.0	21	5.8	4.5	R	B			5121		
E013.2	F	25948.0	4015.0	15	15706.0	4632.0	29	6.1	4.3	R	B+			5121		
E013.3	F	24399.0	3815.0	16	13092	2913.0	22	5.7	4.4	R	B+			5121		
E013.4	F	24932.0	5047.0	20	14822.0	4081.0	28	6.0	4.4	R	B+			5121		
E013.5	F	25180.0	2004.0	8	13852.0	1316.0	10	4.9	4.5	R	B+			5121		
E013.6	F	22769.0	207.0	1	12444.0	-37	0	4.6	4.6	R	B+			5121		
E0[illegible]7B	F									R	B+			5121		
E014.1	F	21055.0	3039.0	14	10555.0	2555.0	24	5.5	4.1	S	C			5185		
E014.2B	F	21840.0	-299.9	-1						S	C			5185		
E016.1	F	24491.0	4041.0	16	11880.0	3701.0	31	5.4	3.7	F	A	MHDD	4300	4792		
E016.2A	F	23464.0	2329.0	10	11240.0	2127.0	19	5.1	4.1	F	A	MHDD		4792		
E016.3B	F	21045.0	1085.0	5	9340.0	968.0	10	4.6	4.1	F	A	MHDD		4792		
E017.1	F	23080.0	2130.0	9	12080.0	2180.0	18	5.3	4.4	S	C	MHDD	3051	5833		
E017.2B	F	20880.0	550.0	3	9880.0	550.0	6			S	C			5833		
E030.1	F	27600.0	4800.0	17	14200.0	4200.0	30	5.4	3.8	R	B+	MHDD	7600	5600	E	
E030.2	F	25400.0	2900.0	11	13200.0	2800.0	21	4.8	3.8	R	B+	MHDD	5800	5600	E	
E030.3A	F	26400.0	200.0	1	12200.0	0.0	0	4.3	4.3	R	B+			5600	E	
E035.1	F	21942.0	-67.0	0						R	B+			7500		
E035.2A	F	17337.0	-794.0	-5						R	B+			7500		
E038.1	F	23860.0	2100.0	9	12100.0	2600.0	21	4.5	3.5	R	B+	MHDD	5308	5600		E
E038.2B	F	22460.0	-90.0	0	10480.0	100	1	3.9	3.8	R	B+			5600		E
E039.1	F	23400.0	1456.0	6	10383.0	1589.0	15	3.8	3.2	R	B+			5600		E
E039.2B	F	22266.0	-748.0	-3	10144.0	1022.0	10	3.7	3.4	R	B+			5600		E
G011	H	195.8	11.8	6	156.7	11.8	8	10.1	9.3	S	C			8159		
G012.1	H	116.6	14.9	13	83.0	14.9	18	30.1	24.7	S	B			2185		
G012.2	H	95.1	19.6	21	61.5	19.6	32	18.4	12.6	S	B			2650		
G013	H	157.2	19.7	13	119.2	19.6	16	15.7	13.1	S	C			6016		
G030	H	234.7	31.3	13	169.2	29.4	17			S	C			6258		
G060	F	169.0	32.6	19	135.2	32.6	24	10.5	8.0	F	B			8007	F	G
G061.1	F	135.1	11.7	9	101.3	11.7	12	15.4	13.6	S	C			6000		
G061.2	F	66.5	1.8	3	49.9	1.8	4	13.4	12.9	S	C			6000		
G061.3A	F	132.9	-1.6	-1	99.7	-1.6	-2			S	C			6000		
G061.4	F	110.5	12.9	12	82.9	12.9	16	17.4	14.7	S	C			6000		
G066.1	F	139.2	23.3	17	111.4	18.6	17	11.7	9.7	R	B+			7500		
G066.2A	F	137.0	-4.1	-3	109.6	-4.1	-4	11.5	11.9	R	B+			7500		
G066.3	F	120.8	26.3	20	104.6	26.3	25	9.9	7.4	R	B+			7500	F	
G066.4	F	114.9	19.4	17	91.9	19.4	21	10.2	8.0	R	B+			7500		
G072.1	F	69.0	5.3	8						R	B+			2700		
G072.2	F	51.9	0.6	1						F	B+			2700		
G072.3A	F		-1.6							R	B+			2700		
G082.1	F	148.6	28.9	19	118.9	23.1	19	12.4	10.0	R	B+			7500		
G082.2A	F	145.9	1.7	1	116.7	1.4	1			R	B+			7500		

Table A-2: Project/Building Description

LABEL	END USES	NAC BEFORE (MBtu or kWh)	NAC SAVINGS (MBtu or kWh)	NAC SAVINGS (%)	SPACE HEAT BEFORE (MBtu or kWh)	SPACE HEAT SAVINGS (MBtu or kWh)	SPACE HEAT SAVINGS (Per cent)	HEATING FACTOR BEFORE (Btu/ ft^2-HDD)	HEATING FACTOR AFTER (Btu/ ft^2-HDD)	ANALYSIS METHOD	CONFI-DENCE LEVEL ENERGY	ENERGY SAVINGS PRED. METHOD	PRED SAVINGS (MBtu or kWh)	HDD (65°F)	HEAT SYST TYPE	DHW FUEL
Low-Income Weatherization Programs																
G001	H	143.7	20.5	14	120.3	20.8	17	17.6	14.6	S	C			7597		
G019	H	207.0	28.9	14	149.1	28.9	19			S	C			6277		
G021.1	H	175.0	20.0	11	135.0	20.0	15			S	C			5161		
G021.2	H	236.0	44.0	19	196.0	44.0	22			S	C			5161		
G021.3	H	231.0	52.0	23	191.0	52.0	27			S	C			5233		
G022	H	143.0	15.7	11	118.5	15.7	13			S	C			4729		
G023	H	219.8	46.4	21	182.1	46.4	25	29.6	22.1	S	C			5577		
G056.1	F	153.2	16.9	11	114.9	16.9	15	15.7	13.4	R	B+			6000	FR	G
G056.2A	F	155.7	-14.8	-10	116.8	-14.8	-13	17.1	19.3	R	B+			6000	FR	G
G057.1	F	124.2	12.9	10	99.4	10.3	10	12.5	11.2	R	B+			7642	F	G
G057.2A	F	135.6	5.7	4	108.5	5.7	5	13.8	13.1	R	B+			7642	F	G
G065.1	F	160.8	23.2	14	128.6	18.6	14	19.2	16.4	S	C			8007	FB	
G065.2	F	122.0	12.8	10				11.4	10.2	S	C			8007	FB	
G071.1	F	247.0	21.3	9	197.6	17.0	9	15.5	14.1	R	B+			8007		
G071.2	F	229.2	48.0	21	183.4	38.4	21	14.3	11.3	R	B+			8007		
G073.1	F	128.4	11.9	9	102.7	9.5	9	14.0	12.7	R	B+			8000	F	
G073.2	F	116.7	3.4	3	93.4	2.7	3	13.4	13.1	R	B+			8000		
G074.1	F	387.8	95.2	25	322.3	92.5	29	30.7	21.9	S	B			6563		G
G074.2	F	376.1	80.7	21	312.0	72.1	23	32.2	24.8	S	B			6563		G
G075.2	H	171.5	22.5	13	137.2	18.0	13	16.3	14.2	S	B			6724		G
G076.1	H	181.6	21.2	12	145.3	21.2	15	24.2	20.7	S	B			6724		G
G076.2	H	154.0	11.6	8	123.2	11.6	9	20.9	18.9	S	B			6724		G
G076.3A	H	156.8	-7.3	-5	125.4	-7.3	-6	23.0	24.3	S	B			6724		G
G077.1	H	177.0	17.0	10	141.6	17.0	12	22.4	19.7	S	B			6724		G
G077.2	H	98.4	4.0	4	78.7	4.0	5	14.3	13.6	S	B			6724		M
G077.3A	H	147.6	1.0	1	118.1	1.0	1	20.8	20.6	S	B			6724		G
G080	F	155.6	19.2	12	116.7	14.4	12	13.1	11.4	R	B+			7000		
G081	F	86.1	5.5	6						R	B+			6500		
G083	F	177.0	21.7	12	133.1	21.7	16	14.1	11.8	E	B			6092		
G084	F	104.0	6.9	7	72.8	4.8	7	19.6	17.3	R	B+			4500		
G085	H	188.3	14.3	8	141.6	14.3	10			S	B			6100		
M009	H				143.0	27.1	19	13.2	10.7	S	C			8388		
M010.1	H	138.6	14.1	10	110.9	11.3	10	16.6	14.9	S	B			8310		
M010.2B	H	160.6	-4.0	-2	128.5	-3.2	-2	11.7	12.0	S	B			8310		
M010.3	H	129.5	8.6	7	103.6	6.9	7	16.1	15.0	S	B			8310		
M011	H				139.3	23.0	17			S	D			8820		
M012	H				156.0	44.0	28			S	D			6801		
M026	F	132.6	13.8	10	105.5	13.9	13			S	C					
M027.1	F	70.2	2.2	3						R	B+			6000		
M027.2A	F	68.1	-0.5	-1						R	B+			6000		
O006	H				143.5	43.5	30			S	D			7876		

Table A-3: Retrofit Measures and Economics

LABEL	RETROFIT MEASURES	HEATING SYSTEM MEASURES	RETROFIT CLASSI-FICATION	YR OF RETRO. FIT	RETRO. COST (89$)	RETRO. LIFE (yrs)	SIMPLE PAYBACK (yrs)	NPV ($/house)	CCE (¢/kWh or $/MBtu)	LOCAL ENERGY PRICE ($)	CONF. LEVEL COST
State and City Loan Programs											
G051.1	IP		IX	84	1040	20	8.4	523	4.98	5.50	B
G051.2	IP		IX	84	1343	20	19.3	-470	11.53	5.50	B
G052.1	HR		BR	82	4752	25	20.3	-1414	12.28	5.70	B
G052.2	HR	FDF	BR	82	3037	25	22.3	-1097	13.50	5.70	B
G052.3	HR		BR	82	3588	25	16.9	-562	10.23	5.70	B
G052.4	IW		IX	82	1598	25	11.3	412	6.86	5.70	B
G078.1	WR,HR,IA,IW		SS	89	1880	25	26.3	-862	11.05	4.90	C
G078.2	HR	CF	BC	89	2110	25	14.8	-87	6.24	4.90	C
G078.3	WR		SH	89	3350	25	455.8	-3245	191.64	4.90	C
M028.1	WR,IA		SH	84	906	25	12.4	136	44.13	3.39	A
M028.2	IA,IW,IP		SH	84	904	25	7.2	890	2.40	3.39	A
M028.3	IA		SH	84	660	20	8.0	382	2.93	3.39	A
M028.4	IW		SH	84	847	25	4.9	1601	1.64	3.39	A
M028.5	IP		SH	84	1019	20	8.2	541	3.02	3.39	A
M028.6	WR		SH	84	939	25	49.2	-668	16.45	3.39	A
M028.7	RD		SH	84	521	20	191.3	-487	70.28	3.39	A
Research and Demonstration Projects											
E003.1	PI		HD	78	1742	10	10.8	142	8.75	0.06	
E003.2A											
E003.3B											
E008.1	PI		HD	80	731	10	11.4	-280	5.64	0.03	
E008.2	IA,IX,CW		IX	79	2853	20	23.0	-1539	8.33	0.03	
E008.3	IA,IX,WM,DR,CW		SH	79	6171	20	19.6	-2838	7.10	0.03	
E010	IA,IF,IW,WM,CW		SH	75	5893	15	8.0	857	5.43	0.03	
E015.1	WH		SY	79	47	7	3.8	20	1.87	0.02	
E015.2										0.02	A
E031.1	HR	HP	BR	83		18					
E031.2	IA,IX,IF,ID,DR,WM,CW		SH	83		20					
E031.3A											
E031.4A											
E032.1	WM,CW,IA,IF,IW,T	LFS,IHW,IPI	SH	85	6089	20	31.9	-4064	14.37	0.04	A
E032.2	WM,CW,IA,IF,IW,T	LFS,IHW,IPI	SH	85	2300	20	24.1	-1288	10.85	0.04	A
E033.1	WH	IHW	SY	85	22	7	0.5	228	0.42	0.04	A
E033.2	WH	IHW,LFS	SY	85	32	7	0.7	226	0.60	0.04	A
E033.3A										0.04	
E034	CR		CS	88	2757	15	12.9	-809	14.19	0.10	P
E036.1	CW,IA,WM		SH	88	854	15				0.07	A
E036.2	CW,IA,WM,RB		SH	88	1297	15				0.07	A
E036.3	CW,IA,WM		SS	88	1870	15	47.6		38.40	0.07	A
E037	CR,IA,SD,RD		SS	82	7417	15	14.9	-2868	15.30	0.08	A
G002	IX,WM,CW,PI		SH	77	5653	15	16.2	-2002	10.04	3.00	
G003	IA,WM,OM,PI		SH	79	1138	15	7.9	364	5.23	3.70	

Table A-3: Retrofit Measures and Economics

LABEL	RETROFIT MEASURES	HEATING SYSTEM MEASURES	RETROFIT CLASSI-FICATION	YR OF RETRO. FIT	RETRO. COST (89$)	RETRO. LIFE (yrs)	SIMPLE PAYBACK (yrs)	NPV ($/house)	CCE (¢/kWh or $/MBtu)	LOCAL ENERGY PRICE ($)	CONF. LEVEL COST
G004	IA,DR,OM,PI		SH	79	1625	15	8.9	279	5.89	3.70	
G005.1	IX,IA,PI,WH,T		SH	80	3833	20	12.9	-110	8.22	4.50	
G005.2	PI,WH,T		HD	80	486	10	2.5	1029	2.39	4.50	
G005.3B											
G005.4B											
G006.1	IX,IA,PI,WH,T		SH	80	1903	20	16.6	-465	10.57	4.50	
G006.2	PI,WH,T		HD	80	486	10	10.3	-121	9.89	4.50	
G006.3B											
G006.4B											
G007.1	IX,T,PI,WM		SH	80	1363	20	6.2	1378	4.76	5.40	
G007.2	PI,WH,T		HD	80	486	10	2.2	1206	2.56	5.40	
G007.3A											
G007.4B											
G008.1	IX,IA,PI,WH,T		SH	80	993	20	3.5	2560	2.68	5.40	
G008.2	PI,WH,T		HD	80	486	10	2.3	1143	2.66	5.40	
G008.3A											
G008.4B											
G009.1	IA,IF,CW,PI		SH	80	2820	15	17.2	-372	5.81	3.08	
G009.2	CW,PI		HD	80	734	10	16.0	-225	7.01	3.08	
G009.3	IA,IW,WM,DR		SH	80	2058	20	42.0	-1180	12.22	3.08	
G010	IA,IW,CW,SH		SH	80	19859	20	84.9	-15563	32.04	4.00	
G014.1	IA,CW,WR		SH	79	436	15	18.5	-190	21.78	6.72	
G014.2A											
G015	IA,CW,WM,IW,IX		SH	79	2836	15	43.6	-2157	17.90	2.35	
G016	IA,IW,WM,CW,WR,HS,WH,ID,T		SS	79	3738	15	7.3	1630	3.74	2.94	
G017.1	IA,IW,IX,CW,WM,WR,HS,WH,T		SS	79	2811	15	12.0	-369	5.11	2.43	
G017.2A											
G018.1	IA,IW,CW,WR,WM,IX		SH	79	2805	15	15.7	-941	7.84	2.85	
G018.2A											
G024.1	IX,T,PI		SH	80	2049	20	7.2	1522	5.09	5.00	
G024.2	PI,T		HD	80	486	10	2.7	907	2.88	5.00	
G024.3A											
G024.4B											
G025.1	IX,PI		SH	80	1438	20	7.4	1006	5.22	5.00	
G025.2	PI,WH		HD	80	486	10	3.1	733	3.30	5.00	
G025.3A											
G025.4B											
G026.1	IX,T,PI,OM		SH	80	1508	20	6.5	1406	4.59	5.00	
G026.2	PI,WH,OM,T		HD	80	486	10	2.7	907	2.88	5.00	
G026.3A											
G027.1	PI,HS,WH,OM		SS	80	636	10	6.3	143	5.52	4.40	
G027.2A										4.40	
G027.3B										4.40	
G028	IA,IW		IX	78	1556	20	5.7	1855	3.53	3.77	
G028.1	IA		IX	78	971	20	5.1	1415	3.15	3.77	

Table A-3: Retrofit Measures and Economics

LABEL	RETROFIT MEASURES	HEATING SYSTEM MEASURES	RETROFIT CLASSI-FICATION	YR OF RETRO. FIT	RETRO. COST (89$)	RETRO. LIFE (yrs)	SIMPLE PAYBACK (yrs)	NPV ($/house)	CCE (¢/kWh or $/MBtu)	LOCAL ENERGY PRICE ($)	CONF. LEVEL COST
G029.1	OM,ID,WH,CW,T,IA,IX,IP	IHW,IPI,LFS	SS	82	926	10	4.8	573	5.03	5.95	C
G029.2A										4.80	
G033.1			SH	80	1900	20	8.2	1014	5.79	5.00	
G033.2			HD	80	486	10	3.0	791	3.15	5.00	
G053.1	WZ		SS	85	1583	10	10.6	-422	4.69	2.80	B
G053.2A										2.80	
G054.1	HS	HEL	HC	85	722	10	7.0	76	5.44	4.90	B
G054.2A										4.90	
G054.3	HS	PGB	HC	85	556	15	10.7	-15	6.42	4.90	B
G054.4A										4.90	
G054.5	HS	VDT	HC	85	194	10	5.0	110	3.84	4.90	B
G054.6A										4.90	B
G055.1	HS	TU	HC	85	83	5		-175		6.14	B
G055.2	HS,CW,IA,WM,IW	TU	HC	85	959	10	7.1	94	6.86	6.14	B
G055.3	HS	VDT	HC	85	211	12		-241		6.14	B
G055.4	HS,CW,IA,WM,IW	VDT	HC	85	1031	10	6.3	245	6.09	6.14	B
G055.5	HS	HEL	HC	85	796	12	194.4	-759	166.92	6.14	B
G055.6	HS,CW,IA,WM,IW	HEL	HC	85	1170	10	16.2	-609	15.71	6.14	B
G055.7A										6.14	B
G058	PI,T,WH,IA		HD	85	333	10	4.5	242	3.77	5.30	
G059.1	HS	FD,VR	HC	78		15					
G059.2	HS	FD	HC	78		15					
G059.3	HS	VDE	HC	78		15					
G059.4	HS	VR	HC	78		15					
G059.5	HS	HES	SY	78		15					
G062	IA,IW,IS,CW,T,IP		SH	88	1334	15	10.7	-27	5.86	4.90	A
G063.1	HS	HEL	HC	85	722	10	22.7	-475	15.82	4.41	B
G063.2A										4.41	
G063.3	HS	PGB	HC	85	556	15	9.9	28	5.35	4.41	B
G063.4A										4.41	
G063.5	HS	VDE	HC	85	444	10	14.4	-205	10.04	4.41	B
G063.6A										4.41	
G063.7	HS	VDT	HC	85	194		10	-324		4.41	B
G063.8A										4.41	
G064.1	HR,IP	CF	BR	86	1877	25	9.3	1008	5.92	6.80	B
G064.3	HS,CW	VDE,VDT,IID,TU	HC	86	394	10		-429		6.80	B
G064.4A										6.80	
G064.5	CW,HS,HR,IW,IS,IA	TU,VDT,IID	SS	86	1427	20	11.7	108	8.22	6.80	B
G067.1	IP		IX	88	1198	20	33.3	-740	17.66	5.50	A
G067.2	IP		IX	88	1712	20	127.0	-1542	67.30	5.50	A
G068	HR,IA,CW		SS	86	2382	15	12.0	-306	8.41	5.90	D
G069.1	CW,IA,IW,IS	IHW,IPI,TU	SS	88	1484	20	12.6	-5	7.04	5.79	A
G069.2A										5.79	
G070	PI		HD	82	99	10	1.0	645	1.04	5.69	B
G075.1	CW,IW,IA,WH,WM,T	IHW	SS	86	1019	20	6.6	932	3.62	5.39	A

Table A-3: Retrofit Measures and Economics

LABEL	RETROFIT MEASURES	HEATING SYSTEM MEASURES	RETROFIT CLASSI-FICATION	YR OF RETRO. FIT	RETRO. COST (89$)	RETRO. LIFE (yrs)	SIMPLE PAYBACK (yrs)	NPV ($/house)	CCE (¢/kWh or $/MBtu)	LOCAL ENERGY PRICE ($)	CONF. LEVEL COST
G079	HR	CF	BR	86	2169	25	16.2	-261	4.82	3.17	C
M001.1	IA,IX,CW,WR,WH		SH	79	1556	15	6.6	909	8.10	7.02	A
M001.2A											
M002	IA,WM,IX,CW,IW,WR		SH	79	1929	15	18.9	-862	15.13	4.58	A
M003	IA,IW,IX,CW,WM,HS,WH,T		SS	79	4657	15	6.3	3068	8.33	7.56	A
M004.1	IA,IW,IX,WM,CW,WH		SH	79	2878	15	8.4	705	4.58	3.12	A
M004.2A											
M005.1	IA,IW,CW,WR,WH,T,HS		SS	79	1441	15	6.1	1029	5.53	5.19	A
M005.2A											
M006.1	IA,IW,IX,CW,WM,HS,T,WH,WR		SS	79	3528	15	3.8	6178	4.73	7.12	A
M006.2A											
M007.1	IA,IW,IX,CW,WM,WH,HS,T		SS	79	2590	15	5.7	2160	6.51	6.53	A
M007.2A											
M008.1	CW,IW,IA,WM,T		SS	79	2564	15	8.2	701	6.29	4.38	A
M008.1A											
M008.2	IA,IW,CW,WM,HS,WH		SS	79	2922	15	5.8	2301	5.18	5.07	A
M008.3	IA,IW,CW,WM,WH		SH	79	2003	15	10.8	-63	9.74	5.16	A
M013.1	IW		IX	77		20					
M013.2	IA		IX	77		20					
M013.3	IW,IA		IX	77		20					
M013.4	IA,HS		SS	77		20					
M013.5	WM		WI	77		20					
M013.6	WM,IA		SH	77		20					
M013.7	HS		HC	77		20					
M014.1	IW		IX	77		20					
M014.2	IA		IX	77		20					
M014.7	HS		HC	77		20					
M025.1	WM		WI	84	826	10	10.5	-275	12.26	7.12	B
M025.2A										7.12	B
M025.3	PI		HD	84	949	10				7.12	B
M029.1	PI,WH,IA,IW,SD,RD,HS		SH	89	982	15	7.3	421	4.46	5.65	C
O001	IA,WM,OM,PI		SH	79	1950	15	3.1	4719	3.08	5.65	
O007.1	HS,OM,T		HC	80	696	15	2.5	1802	2.79	7.19	
O007.2A											
O010	HS,OM,T		HC	80	614	15				7.91	
O010 B										4.24	
O010.0	HS,OM		HC	80	742	15				7.91	
O010.1	HS		HC	80	464	15	1.9	1746	2.37	7.91	
O010.2	HS,OM		HC	80	585	15	1.6	2725	1.99	7.91	
O010.3	HS,OM,T		HC	80	968	15	2.4	2764	2.93	7.91	
O010.4	HS,OM		HC	80	1003	15	2.0	3479	2.53	7.91	
O010.5	HS		HC	80	421	15	1.4	2406	1.68	7.91	
O010.6	HS		HC	80	742	15	2.8	1694	3.44	7.91	
O010.7	HS,T		HC	80	114	15	0.7	1459	0.82	7.91	
O010.8	HS,T		HC	80	564	15	1.3	3425	1.60	7.91	

Table A-3: Retrofit Measures and Economics

LABEL	RETROFIT MEASURES	HEATING SYSTEM MEASURES	RETROFIT CLASSI-FICATION	YR OF RETRO. FIT	RETRO. COST (89$)	RETRO. LIFE (yrs)	SIMPLE PAYBACK (yrs)	NPV ($/house)	CCE (¢/kWh or $/MBtu)	LOCAL ENERGY PRICE ($)	CONF. LEVEL COST
O011.1	HS		HC	83	684	15				8.63	
O011.2	IA,IW,CW,WM		SH	83	1635	15				8.63	B
O011.3	HS,IA,IW,CW,WM		SS	83	2319	15				8.63	
O011.4A						15				8.63	
O025	HS	RHB	HC	82	620	15	3.6	1198	2.82	5.82	B
O026	HS	RHB	HC	85	556	15	4.5	724	2.81	5.08	B
O027.1	HS	RHB	HC	84	574	15	2.0	2444	1.95	7.77	B
O027.2	GM	TU	HC	84	86	5	2.1	96	4.47	7.77	B
O028	PI,SD,WR,RD,WH,IF		SH	89	615	15	9.2	17.2	6.19	5.65	C
Utility Weatherization Programs											
E001.1	IA,IF,CW		IX	76	853	15	3.6	1310	1.53	0.02	C
E001.2	IX		IX	76	359	20	2.2	1331	0.82	0.02	D
E002	IA		IX	78	537	20	5.0	599	2.29	0.03	B
E004.1	IA,IF,WM,DR,CW,WH		SH	79	2431	20	8.1	742	5.14	0.04	C
E004.4B											
E005.1	IA,IF		IX	79	635	20	5.0	705	1.44	0.02	B
E005.2B											
E006.1	IA,IW,IF,WM,DR,T,WH		SH	80	1749	20	5.0	1965	1.93	0.03	B
E007.1	IA,IF,WM,DR,WH,CW		SH	8	2256	20	12.8	-388	5.41	0.03	B
E007.2B										0.03	
E009.1	IA,IF,DR,WM,WH		SH	79	1907	20	17.5	-750	4.05	0.02	C
E009.2	IA,IF,DR,WM		SH	79	1834	20	17.2	-704	3.98	0.02	
E009.3B											
E011.1	IA,IF,IW,DR,WM,CW		SH	81	2800	20	17.5	-1103	4.40	0.02	
E011.2A						11				0.02	
E011.3B										0.02	
E013.1	IA,WM,IF,WH,IW,ID,CW		SH	81	2018	20	15.5	-636	4.39	0.02	
E013.2	IA,WM,IF,WH,IW,ID,CW		SH	82	2448	20	13.0	-445.6	5.76	0.04	
E013.3	IA,WM,IF,WH,IW,ID,CW		SH	83	2315	20	13.4	-481	5.73	0.04	
E013.4	IA,WM,IF,WH,IW,ID,CW		SH	84	1841	20	6.8	1043.5	3.44	0.05	
E013.5	IA,WM,IF,WH,IW,ID,CW		SH	85	2395	20	22.9	-1286	11.28	0.05	
E013.6	IA,WM,IF,WH,IW,ID,CW		SH	86	2659	20	228.2	-2536	121.29	0.05	
E013.7B											
E014.1	IA,IF,IW,WH,ID,CW		SH	81	1900	20	23.4	-1041	5.90	0.02	
E014.2B											
E016.1	IA,IF,WM,DR,WH,CW		SH	79	2230	20	12.4	-321	5.21	0.03	
E016.2A										0.03	
E016.3B										0.03	
E017.1	IA,IF,IW,WM,ID,CW		SH	81	1327	20	14.4	-353	5.75	0.03	
E017.2B										0.03	
E030.1	IA,IF,WM,T,ID		SH	82	1982	20	12.8	-344	3.90	0.03	B
E030.2	IA,IF,WM		SH	83	2149	20	19.4	-975	7.00	0.03	B
E030.3A											
E035.1	IA,IW,IP,WH,WM,IF,CW	IHW,LFS	SH	84	760	15		-810		0.07	A

Table A-3: Retrofit Measures and Economics

LABEL	RETROFIT MEASURES	HEATING SYSTEM MEASURES	RETROFIT CLASSI-FICATION	YR OF RETRO. FIT	RETRO. COST (85$)	RETRO. LIFE (yrs)	SIMPLE PAYBACK (yrs)	NPV ($/house)	CCE (¢/kWh or $/MBtu)	LOCAL ENERGY PRICE ($)	CONF. LEVEL COST
E035.2A										0.07	A
E038.1	IA,IF,WR,CW,WM,ID,IW		SH	85	2089	20	24.9	-1198.9	9.39	.036	B
E038.2B										.036	
E039.1	IA,IF,WR,CW,WM,ID,IW		SH	86	2361	20	41.6	-1760.6	15.31	.036	B
E039.2B										.036	
G011	IA,CW		CI	79	453	20	8.4	228	3.62	2.94	
G012.1	IA		IX	79	694	20	5.7	826	4.40	5.00	
G012.2	IA		IX	79	678	20	4.3	1322	3.26	5.00	
G013	IA		IX	77	504	20	6.2	1400	2.43	4.17	
G030	IA		IX	74	631	20	4.7	1054	2.03	2.06	
G060	CW,HR,IA,T,DR,IW,WM,WH		SS	81	3774	20	15.6	-725	10.93	5.70	C
G061.1	CW,WM,IA	TU	SH	87	536	15	9.7	43	5.03	4.50	A
G061.2	CW,WM	TU	SH	87	343	15	40.2	-254	20.94	4.50	A
G061.3A										4.50	
G061.4	IA		SH	87		20				4.50	
G066.1	IA,IW,IP,HR,WH,WM,IF,CW	IHW,LFS	SH	84	1830	15	10.6	-24	8.62	6.46	A
G066.2A										6.46	
G066.3	HR		BC	84	1864	25	9.6	912	6.08	6.46	A
G066.4	IW		IX	84	806	25	5.6	1242	3.56	6.46	A
G072.1	IA,CW,ID	LFS,IHW	SH	86	571	15	21.0	-287	11.83	4.70	A
G072.2	IA,CW,ID	LFS,IHW	SH	86	446	15	144.7	413	81.53	4.70	A
G072.3A										4.70	
G082.1	CW,IA,HS,IW,HR,IS		SS	83	2567	15	11.4	-220	9.75	6.46	A
G082.2A										6.46	
Low-Income Weatherization Programs											
G001	CW,IA,WH,IS		SH	81	2215	15	15.8	-753	11.69	5.04	
G019	IA,CW,WM		SH	79	1257	15	7.5	487	4.78	3.63	
G021.1	IX,CW		SH	77	755	15	13.0	-147	4.14	1.57	
G021.2	IX,CW		SH	77	945	15	7.6	352	2.36	1.57	
G021.3	IX,CW		SH	78	2533	15	15.5	-827	5.35	1.85	
G022	IA,WM,DR,CW		SH	79	405	15	4.7	504	2.83	3.48	
G023	IA,IF,CW,HS,WH		SS	78	2380	15	14.1	-612	5.63	2.11	
G056.1	WH,CW,IS,ID,IA	TU,IHW,LFS	SH	85	2000	15	17.5	-809	12.99	6.07	B
G056.2A										6.07	
G057.1	CW,IA,WM,IS,DR,IP,ID	IHW	SH	82	1561	15	17.5	-629	13.29	5.58	B
G057.2A										5.58	
G065.1	CW,IA,WH,DR,WM,IP,IW	IHW,TU	SH	81	1110	15	7.2	511	5.25	5.12	D
G065.2	HS,IA,IF	TU	SH	81	914	15	10.7	-20	7.84	5.12	D
G071.1	PI		HD	85	669	10	5.3	312	4.47	5.34	B
G071.2	PI,IA,IW		SH	85	2510	15	8.8	466	5.74	5.34	B
G073.1	CW,IA,WM,IW,IP	IHW	SH	84	1247	20	16.9	-321	9.89	5.39	A
G073.2	CW,IA,WM	IHW	SH	84	946	15	45.0	-726	30.55	5.39	A
G074.1	CW,WH,IW,IA,HR,HS	IHW,VDT	SS	84	4038	20	6.3	4037	4.00	5.88	A
G074.2	CW,WH,IW,HS,IA,HR	IHW,VDT	SS	85	3846	20	7.1	3001	4.50	6.08	A

Table A-3: Retrofit Measures and Economics

LABEL	RETROFIT MEASURES	HEATING SYSTEM MEASURES	RETROFIT CLASSI-FICATION	YR OF RETRO. FIT	RETRO. COST (89$)	RETRO. LIFE (yrs)	SIMPLE PAYBACK (yrs)	NPV ($/house)	CCE (¢/kWh or $/MBtu)	LOCAL ENERGY PRICE ($)	CONF. LEVEL COST
G075.2	CW,WH,WM,IA,IS	IHW	SH	86	1068	15	10.1	39	6.51	5.39	A
G076.1	CW,IA,WM		SH	83	1090	15	7.3	465	5.65	5.88	A
G076.2	IA,CW	IHW	IX	83	813	15	10.0	38	7.70	5.88	A
G076.3A										5.88	
G077.1	CW,WM,IA		SH	84	1063	15	9.3	136	6.87	5.88	A
G077.2	CW,WM		SH	84	405	10	15.0	-196	14.42	5.88	A
G077.3A										5.88	
G080	PI,WH,IA,IW	IHW		88	985	15	9.3	122	5.63	5.40	A
G081	WR,IF,T		SH	86	1161	20	36.2	-758	19.93	5.39	A
G083				88	1034	15	9.3	124	5.23	5.00	B
G084	CW,IA,WM		SH	88	1014	15	25.5	-598	16.13	5.65	C
G085	CW,IA,WM,T,IW,IP		SH	84	878	15	9.7	65.2	6.74	5.50	B
M009	IA,WM,DR,CW		SH	76	430	15	2.4	1443	1.74	3.37	
M010.1	IA,CW,DR,WR,WM,IW		SH	78	1568	15	13.4	-342	15.24	6.00	
M010.2B											
M010.3	IA,CW,DR,WR,WM,IW		SH	78	1470	15	20.5	-721	23.39	6.00	
M011			SH	79	1733	15	11.1	-102	8.27	4.26	
M012	IA,WM,CW		SH	75	2179	15	3.9	3660	5.44	6.12	
M026	IA,IW,IP,WM,CW,DR		SH	81	1384	15	12.8	-254	11.01	6.00	D
M027.1	CW,SK,RD,WH,HS,WM	IHW,TU	SS	87	872	10	40.5	-705	56.44	9.14	B
M027.2A										9.14	
O006	IA,WM,DR		SH	80	2199	15	4.1	3383	5.55	8.41	

Appendix B

Summary of Retrofit Projects in the BECA-B (Existing Single Family Residential Building) Data Base

Appendix B contains a brief description of each retrofit project in the data base. Program summaries are arranged in order of the project label. The label consists of a letter that indicates the fuel used for space heating (e.g., gas (G), oil (O), mixed (M), and electricity (E)) and a number unique to that project. Each summary includes a description of the retrofit measures that were installed, a discussion of energy savings and cost-effectiveness, and notes key adjustments to the data. Retrofit costs in this appendix are given in nominal dollars.

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E001, E002: Tennessee - 1976-78 Tennessee Valley Authority Insulation Program[1]

Buildings/Retrofit Description: The pilot phase of TVA's Home Insulation Program targeted low-income families with high electric heating bills. Participating households initially had little or no attic insulation, used electricity for space heating, and had an annual income under $6000. The evaluation examined changes in consumption for two groups of homes that were retrofitted in 1976: 81 homes that received attic and floor insulation, caulking, and weatherstripping from private contractors and 138 homes that had attic insulation installed by TVA personnel. Only 69 of the 81 homes and 105 of the 138 homes were included in a data summary sheet provided by TVA (label E001). A study of the 1978 part of TVA's Home Insulation Program was made by ICF, Inc (label E002). In the ICF study, the principal retrofit measure in the sample of 546 homes was attic insulation.

Data Analysis: In both groups, the savings were adjusted to correspond to a normal winter (using the 30-year average for heating degree-days). Cost data were unavailable for the households that were retrofitted by TVA personnel and hence were estimated using cost/ft^2 data from the first group. The ICF study separated out the baseload usage and made a weather adjustment for a normal winter season. Savings of 2170 kWh/yr for E002 were predicted using HLC.

Results: Space heat energy savings were 54% and 33% respectively with payback times of 3.5 and 2.2 years. In the ICF study, the principal retrofit measure was attic insulation. ICF did a careful study of 546 homes and found an average 22% savings for space heat (also a 15% savings for summer air conditioning).

E003: Denver, Colorado - 1978 Johns-Manville Company Air Leakage[2]

Buildings/Retrofit Description: In 1978, Johns-Manville did a research type study of 90 homes in the Denver area to determine the effect of air leakage on heating energy usage. For one-third of the homes, the leakage was measured and the homes were retrofitted. For the next one-third, the leakage was measured but no action was taken (these homes served as an active control group). The last group of homes served as a blind control. A blower door was used to pressurize the houses. In the retrofit group caulking and sealing (a glass mat was used for a complete wall covering) were done and the infiltration rate was reduced by 30%.

Data Analysis: The individual house savings did not correlate with reduced air leakage as measured by the fan method. This is not surprising given the number of significant actions reported in each homeowner's log that affected consumption (i.e. in the retrofit group, 17 homes lowered their thermostat settings and 5 homes added storm windows). During the post-retrofit period, the homes were sub-metered to record electric energy for heating only. Princeton's Center of Energy and Environmental Studies analyzed the data using the PRISM scorekeeping method.

Results: Johns-Manville reported results space heat savings of 2836 kWh (16%) in the retrofit group at a cost of $1050, 1415 kWh (12%) savings for the active control group, and 2852 kWh (12%) savings in the blind control group. The payback time for the retrofit group was 11 years.

E004: Pacific Northwest - 1979 Pacific Power & Light Weatherization[3]

Building/Retrofit Description: Over 14,000 customers have participated in Pacific Power & Light's Weatherization Program through 1982. A study of early participants (1,896 homes) found space heat savings of 20 percent (reported in BECA-B, LBL-13385). PP&L recently completed a more extensive evaluation of their Home Energy Analysis (HEA) and Weatherization Program. During the audit, cost-effective weatherization measures are recommended and, if desired, a water heater blanket is installed free of charge. Principal measures financed under the weatherization program include: R-38 ceiling insulation, R-19 floor insulation, storm windows and doors, caulking and weatherstripping, wrapping of ducts and pipes, and timed thermostats.

Data Analysis: The utility analyzed pre-and-post program consumption data for customers who had an HEA and/or been weatherized during 1979 throughout their service territory (parts of six Pacific Northwest states). In addition, energy savings were estimated for a control group that consisted of all single-family electric space heat customers (69,000 homes) who had not been involved in any company-sponsored program from 1978-80. Actual savings were weather adjusted for four basic customer groups home energy analysis and weatherization customers with and without water heater wrap.

Results: Weatherized homes decreased consumption by 4461 kWh (18%) at a cost $1,557 per house, corresponding to a 8 year payback. Control group consumption decreased 869 kWh (4%).

E005: Seattle, Washington - 1979 Seattle City Light Insulation Program[4]

Buildings/Retrofit Description: From November 1978 to December 1980, Seattle City Light offered 6% interest loans as part of a pilot Residential Insulation Program. Program evaluation focussed on the energy savings observed in 133 electrically heated homes that installed attic and floor insulation.

Data Analysis: Using utility survey data, LBL researchers made a baseload correction and adjusted actual savings based on six months billing data for both the pre and post retrofit period to a normal heating season.

Results: Total consumption decreased 4180 kWh (14%) at a cost of $400, corresponding to a payback time of 5 years. A blind control group of 551 full electric customers showed a 13% drop in space heat consumption. Significant differences were observed in the initial consumption levels of the weatherized and nonparticipant group and thus the control group was weighted to approximate the same customer usage distribution as the weatherized group.

E006: Western Washington - 1980 Puget Power Weatherization[5]

Buildings/Retrofit Description: Since December of 1978, Puget Sound Power & Light Company has offered a zero interest loan weatherization program to single-family electric-heat customers. Effective January 1982, customers could alternatively receive a grant outright from the utility in an amount equal to 71.8% of the loan amount. Puget Power monitored the actual energy savings from all weatherized homes and reported results from 6,289 homes. They have updated and revised the preliminary program results presented in LBL #13385. The principal retrofit measures included insulation of attic, floor and wall, storm windows and doors, free water heater wrap and clock thermostat.

Data Analysis: Each home was individually adjusted and had at least one year of billing history after retrofit but no attempt was made to delete non-weather sensitive kWh consumption. Savings of 5,450 kWh/yr were predicted using HLC.

Results: Total consumption per home decreased by roughly 8600 kWh after retrofit, a 26% reduction. With a retrofit cost of $1200 per house this corresponds to a 5 year payback. Actual savings exceeded the utility's predicted estimates by 30%, attributed to increased use of wood stoves or fireplace inserts and dramatic rate hikes in the last three years.

E007: Portland, Oregon - 1978 Portland General Electric Zero Interest Weatherization[6]

Buildings/Retrofit Description: In July 1978, Portland General Electric implemented a zero-interest weatherization program to encourage better insulation in existing single-family residences that used electricity as their space heating fuel. Upon customer request, an audit was conducted to determine which covered actions were needed. If cost-effective, PGE would finance the following retrofit measures: attic insulation to R-30, floor insulation up to R-19, storm windows and doors, and caulking and weatherstripping. In 1980-81, PGE analyzed pre-and post retrofit consumption data from the first 300 customers along with a control group of 200 ZIP-eligible but non-participating households.

Data Analysis: The utility developed a sophisticated weather-adjustment model that incorporated heating degree days and wind speed and that matched billing consumption data with weather happening specifically during the billing periods. Actual usage was then normalized to a typical heating season. Savings of 4,080 kWh/yr were predicted using HLC.

Results: The treatment group consumption declined by 3,937 kWh (17%) while the control group's usage remained virtually unchanged. At a cost of $1360 per unit, the simple payback period is 13 years. Estimated savings were derived from engineering estimates of the first 818 customers, a larger sample than included in this evaluation study.

E008: Midway, Washington - 1979 BPA/LBL Weatherization[7]

Buildings/Retrofit Description: The Bonneville Power Administration (BPA) retrofitted 18 houses over a three-year period (only 14 are included in the final analysis). Evaluation of energy savings and cost effectiveness of different conservation retrofits were the principal study objectives. Houses were divided into three different groups. Cell 1 homes received an extensive infiltration-reducing weatherization using a blower door to find air leaks. Cell 2 houses received attic insulation, foundation sill caulking, and increased attic ventilation, and Cell 3 received these retrofits plus storm windows and doors. This project had several unique characteristics which affected the results. First, Midway residents pay a *flat* monthly fee for electricity regardless of their energy usage, and thus the normal market signals (i.e., changing prices affecting demand) were not operative. Second, all 18 houses were owned by BPA, thus making it easier to ensure that the retrofit work was identical.

Data Analysis: Before and after each set of retrofits, infiltration rates were determined by calculating leakage area using blower door fan pressurization techniques. LBL entered the data as three groups: 5 houses with extensive infiltration reduction, 5 houses with attic and crawlspace insulation, and 4 houses with insulation and storm doors and windows. Using CIRA, annual space heat savings of 840 kWh, 4460 kWh, and 6510 kWh were predicted for the three groups of houses.

Results: Storm windows and infiltration reduction decreased effective leakage area by 14% and 27% respectively. Energy savings ranged between 9% (payback period = 11 years) for infiltration reduction to 42% from installation of storm windows and insulation (payback period = 20 years).

E009: Eastern Washington/Idaho - 1979 Washington Water Power Weatherization[8]

Buildings/Retrofit Description: Starting in 1978, Washington Water Power (WWP) sponsored an extensive zero-interest loan program for its single-family electric heat residential customers. Possible retrofit measures for which loans were available included ceiling and floor insulation, storm windows and doors, and insulation of the hot water tank.

Data Analysis: The company analyzed the fuel bills of 1,030 participants and 251 customers selected at random (control group) to determine energy savings and to evaluate the accuracy of their energy prediction methods. The data has been disaggregated by retrofit measure and we calculated the space heat savings for 810 homes that installed measures designed to reduce space heat usage only (no water heater wrap). LBL researchers used WWP's baseload estimate of 1,000 kWh/month in determining the space heating fraction of total electric consumption.

Results: The entire participant group (1030 homes) obtained annual weather- adjusted savings of 4448 kWh, only 51 percent of estimated savings (using ASHRAE steady state heat loss calculation). At a cost of $1,243 per house the simple payback period was 18 years. A revised method, using the ratio of a home's pre-retrofit actual heating load to the load estimated using steady state heat loss calculation to adjust the new savings estimate, proved to be far more accurate in predicting actual energy savings.

E010: Bowman House, Maryland - National Bureau of Standards[9]

Buildings/Retrofit Description: This was the first extensively monitored residential retrofit on record. The National Bureau of Standards retrofitted a wood-frame structure in three stages: reduction of air leaks, addition of storm windows, and installation of floor, ceiling, and wall insulation. Bowman House was unoccupied but occupant behavior (i.e. lighting, appliance usage) was simulated.

Data Analysis: Pre- and post-retrofit annual heating loads (e.g. delivered heat to the house) were calculated from a least-squares regression of daily average heating loads correlated with outside average temperature. LBL calculated annual space heat fuel consumption based on the efficiency rating (92%) given for the house's electric resistance heater.

Results: The retrofits resulted in significant reductions in space heat usage (59%) but did not reduce the house's cooling energy requirement. NBS researchers concluded that installation of storm windows was the most cost-effective measures at that site. The retrofit cost $2,840 and had an 8 year payback.

E011: Oregon, Washington, Montana - 1981 BPA Weatherization Pilot Program[10]

Buildings/Retrofit Description: The Bonneville Power Administration (BPA) operated a pilot program with eleven small public utilities in the Pacific Northwest for almost three years that provided residential energy audits to 6,000 electrically-heated homes and financed weatherization of roughly half those homes with a zero-interest loan program. Oak Ridge National Laboratory conducted an extensive evaluation of the program that encompassed estimation of energy savings attributable to the program, comparison of key characteristics among three groups of households (audit plus weatherization, audit only, eligible non-participants), and a cost/benefit analysis. Retrofit measures financed included attic, wall and floor insulation, storm windows and doors, caulking and weatherstripping, the insulation of heating ducts and hot water heaters. The average retrofit cost was $2,098.

Data Analysis: LBL researchers used results obtained from a 3 parameter (reference temperature, weather-sensitive slope coefficient, nonweather-sensitive intercept) regression model of monthly electricity consumption developed for each household (Model 3) in our analysis. LBL calculated the space heat fraction by subtracting the baseload usage estimated by the regression model from total electricity consumption. The authors assumed a constant 60°F reference temperature for each of 449 households (total of the three different groups). Savings of 12,000 kWh/yr were predicted using the revised BPA version of SSHL.

Results: Major findings that emerge from the evaluation study are: 1) electricity savings of roughly 3,500 kWh per weatherized home attributable to the BPA program 2) total annual savings of 4,500 kWh/home 3) actual savings were much less than predicted levels, resulting in significant changes in estimation methods 4) households receiving an audit only showed no reduction in electricity use relative to nonparticipants and 5) homes in the audit plus loan group consumed substantially more electricity prior to the program than the other two groups. Study authors developed several approaches to the problem of estimating program energy savings. The simple payback period was 18 years.

E013: Seattle, Washington - 1981-86 Seattle City Light HELP Program[11]

Building/Retrofit Description: The Home Energy Loan Program (HELP) program provided weatherization loans for residential customers in Seattle who installed measures between 1981 and 1986. The loans were ten year, zero-interest loans with payments deferred for the first five years and ranged from $250 to $5500. In order to participate in the program, certain measures are mandatory. Over the life of the program, the mandatory measures have consistently included ceiling insulation to R-38, crawl space insulation to R-19, and R-10 water heater tank wraps. Optional measures have included wall insulation to R-11, windows, minor repairs, caulking and weatherstripping, and clock thermostats.

Data Analysis: Data was collected from 1980 to 1987, providing up to six years of post-retrofit data. All homes analyzed were single-family, electrically heated homes constructed prior to 1981 that had no ownership changes. The non-participant sample was designed to match the treatment group in terms of house age size, and electric heating system type. Energy consumption was weather normalized using a heating degree day method and PRISM. LBL entered the PRISM-normalized data.

Results: The results for the program are given below. The simple payback period is based on the first year savings. NAC_{post2} and NAC_{post3} refer to the post-retrofit consumption two and three years after the retrofit.

Year	# of Units	Cost ($)	NAC_{pre} (kWh)	NAC_{sav} (kWh)	SPT (yrs)	NAC_{post2} (kWh)	NAC_{post3} (kWh)
81	132	1545	25873	4341	16	21453	19957
82	116	1976	25948	4020	13	20255	19906
83	111	1939	24399	3815	13	20295	21357
84	108	1604	24932	5050	7	21429	22813
85	285	2155	25180	2004	23	23723	
86	278	2456	22769	207	230		

E014: Seattle, Washington - 1981 Seattle City Light LIEP Program[12]

Buildings/Retrofit Description: The Seattle City Light Conservation and Solar Division conducted an evaluation of their Low-Income Electric Program (LIEP). The program provides free home weatherization grants to qualified low-income customers. The retrofit package includes similar mandatory measures as the HELP program (see E013) along with such optional features as R-11 wall insulation, caulking and weatherstripping, smoke detectors, and up to

$250 of weatherization-related home repairs. The average cost per house was $1,424.

Data Analysis: Complete electricity billing data were obtained for 377 of 557 homes weatherized in 1981 in addition to a control group of 208 non-participants, drawn from customers who received LIEP weatherization the following year. LBL did a somewhat crude weather-adjustment on bi-monthly electricity consumption data, estimated the space heating fraction of total usage using SCL's estimate of the baseload (50% of total annual consumption or 10,500 kWh/yr) and normalized the data to a typical heating season.

Results: Weather normalized consumption declined by 3,000 kWh (14%) in the participant group and increased by 300 kWh (1%) in the control group. The simple payback period was 23 years.

E015: Seattle, Washington - 1979 Seattle City Light Energy Check Program[13]

Building/Retrofit Description: The Evaluation Unit of the Seattle City Light Conservation and Solar Division published an evaluation of their Home Energy Check Program. They compared program performance data (number of audits/yr, conservation actions taken, and energy savings in audited homes relative to a control group) against program objectives. From 1978 through 1980, the Utility completed 11,000 audits, performed 4,800 hot water tank wraps and 6,600 thermostat setbacks on water heaters. SCL looked closely at two sub-groups of audited homes: those that had a hot water tank wrap and/or thermostat setback and those audited homes that did not take either of these actions. LBL used these results in the analysis.

Data Analysis: Electricity consumption before and after the audit was examined for a sample of 518 audited homes (66 with electric space heat and 452 non-electric space heat). LBL assumed a contractor cost of $30/home for audited homes that had only a hot water tank wrap and/or thermostat setback.

Results: The electric space heat homes showed average net savings (test minus control group) of 1,534 kWh per year while usage in the non-electric space heat residences declined by 516 kWh. Annual electricity consumption declined by 465 kWh in those homes that reported taking actions to reduce hot water energy consumption. In these homes (with an assumed contractor cost of $30/home for these measures,) yielded a 3.8 year simple payback time.

E016: Portland, Oregon - 1980 Portland General Electric Zero-Interest Loan Weatherization[14]

Buildings/Retrofit Description: In September of 1982, Portland General Electric (PGE) released a more extensive evaluation of their zero-interest weatherization audit and financing program. A principal focus of this later study was analysis of the portion of weather-adjusted gross savings that could be assigned to either weatherization, a change in the use of wood for space heat, appliance replacements, or other factors. Conservation measures eligible for financing include: insulation of attics, floors, walls, and heating ducts; addition of storm windows and doors, caulking and weatherstripping, and wrapping of hot water tanks (free of charge at time of audit) and pipes. PGE's evaluation drew heavily on an in-depth survey of 758 homes that sought information on actions that potentially could lead to changes in consumption from mid-1978 to early 1981. The study defined four participant-level categories: non-electric space heat customers (ineligible for participation) and groups of electric space heat non-participants, audit only customers and ZIP audit and finance households. The average retrofit cost was $1,400.

Data Analysis: Each individual household's consumption data was weather-adjusted with separate adjustments made in the before and after period. The utility also collected two years of post-retrofit data in order to examine the persistence of savings and customer behavior patterns. The reported cost data for the weatherized homes is an overall program average for that time period.

Results: Using several multiple regression models, PGE apportioned the first year's annual weather-adjusted savings of 4,000 kWh (16%) for the audit and finance homes as follows: weatherization, 2,627 kWh; use of wood heat, 782 kWh; appliance replacements, -191 kWh; and other factors, 823 kWh. The reduction in consumption due to increased use of wood heat was in the 700-800 kWh range for all three groups of electric space heat customers. The study found that expected savings from performed actions exceeded actual savings attributable to weatherization (3,475 kWh versus 2,627 kWh). Possible explanatory factors cited include: audit overestimation of expected savings (calculated for a typical house), lifestyle factors that the audit did not incorporate (zoning), and customer relaxation of various conservation practices in the initial period after weatherization. The simple payback period averaged 12 years.

E017: Idaho - 1981 Idaho Power Company ZIP Program[15]

Buildings/Retrofit Description: Idaho Power Co. conducted an evaluation of their Zero Interest Loan Program with the primary objective of comparing actual energy savings with engineering estimates obtained from audits. The conservation program finances the installation of attic, wall and floor insulation, storm windows, caulking and weatherstripping, and clock thermostats. The average retrofit cost was $1,040.

Data Analysis: Their study analyzed pre- and post-retrofit consumption data for 101 single-family electric space heat customers who participated in the program along with a matched sample of 48 control homes. LBL normalized the actual consumption data to a typical heating season and made a annual baseload subtraction of 11,000/kWh (using the utility's estimate) to estimate the space heating portion of total consumption.

Results: Actual savings in the test group fell substantially short of predicted savings based on the audit. Possible explanations include shortcomings in the audit program (double-counting of savings from measures) and problems in the evaluation design (in some homes, installation of retrofits occurred during the time period defined as pre-retrofit, thus yielding lower savings because the before period includes a portion of the retrofit savings impact). The average payback period was 14 years.

E030: Pacific Northwest - 1982-83 BPA Residential Weatherization Program[16]

Building/Retrofit Description: During 1982 and 1983, the Bonneville Power Administration (BPA) conducted the Residential Weatherization Program in the Pacific Northwest. BPA spent $157.3 million on the project and weatherized 25,200 homes in 1982 and another 78,400 in 1983. BPA calculated that it was cost-effective to pay for retrofit measures that cost up to $0.292 per annual kWh saved. For negotiating the contracts, kilowatt hours saved were estimated by engineering calculations. Utility auditors surveyed the houses to determine the necessary parameters for the engineering calculations. Homeowners were expected to pay the balance of the retrofit cost so that the utility would pay no more for the retrofit than was cost-effective ($0.292 per annual kWh saved). BPA spent an average of $1,600 per house in 1982 and $1,800 per house in 1983, an average of 85% of the total retrofit costs. The saturation and cost of measures is given below.

Measure	% Saturation (cost) 1982	1983
Ceiling insulation	90($530)	81($560)
Floor insulation	71(790)	74(810)
Storm windows	34(1140)	45(1390)
Clock thermostat	26(170)	14(170)
Heating duct insulation	21(240)	15(240)
Caulking and weatherstripping	18(90)	18(50)
Unfinished exterior wall insulation	13(380)	10(450)
Storm doors	12(200)	8(230)

Data Analysis: Oak Ridge National Laboratory (ORNL) used PRISM to weather normalize utility billing data and chose a subset with $R^2 > 0.75$, heating slope and baseload coefficients significant at the 10% level or better, and a reference temperature less than 75°F. Such a definition should select homes that use very little supplemental heat (from wood). ORNL collected four years of data. Thus, the 1982 group has three years of post-retrofit data and the 1983 group has two years of post-retrofit data. Using SSHL, savings of 7,600 kWh/yr were predicted for the 1982 program and 5800 kWh/yr savings were predicted for the 1983 program. LBL entered the data as three aggregate points: the control group data for both years (114 houses), the 1982 treatment group (229 houses), and the 1983 treatment group (248 houses). LBL assumed an average retrofit lifetime of twenty years for the package of measures.

Results: Weather normalized annual electricity consumption decreased from 27,600 kWh to 22,800 kWh (17%) in the treatment group in the first year of the program, corresponding to a 13 year simple payback period. In the second year of the program, NAC values in the new treatment group decreased from 25,400 kWh to 22,500 kWh (11%), corresponding to a 19 year simple payback period. Savings in the control group were 0.8% in the first year of the program and 2.7% in the second year. One factor that may help to explain the lower savings in the second year of the program is the slowing in the rise of electricity prices. Real (corrected for inflation) electricity prices increased 29% in the first year of the study and another 12% the next year.

E031: Pacific Northwest - 1981-84 BPA Load Profiles[17]

Building/Retrofit Description: From 1981 to 1984, Bonneville Power Administration (BPA) submetered homes for the Public Utility Regulatory Policy Act (PURPA) load research data. From this set of metered houses, four categories were analyzed: heat pump retrofits, shell measure packages, a control group, and a low potential savings group. The PURPA load research, and thus these subsets, were biased toward high energy users.

Data Analysis: If an audit indicated potential savings of 1500 kWh or more and had electric space and water heating, the house was included in the weatherization group. Homes that audits determined to be well weatherized formed the low potential savings group. The control group was randomly selected. Submetered hourly data was collected for two years before the retrofits and for one year afterwards. LBL entered the data as four aggregate groups: heat pumps (7), shell measure packages (68), control group (15), and low potential savers (29). LBL assumed an eighteen year lifetime for the heat pumps (California Collaborative Process) and twenty years for the shell measure package. The winter peak day was created by averaging the hourly demands for the day of system peak for the months of December, January, and February.

Results: Consumption for the heat pump group decreased 6683 kWh (26%) and peak load decreased 1.72 kW (20%). Consumption for the shell measure sites decreased 3670 kWh (14%) and peak load decreased 0.64 kW (7%). No cost data was given.

E032: Hood River, Oregon - 1985 BPA Hood River Conservation Project[18]

Building/Retrofit Description: The Hood River Conservation Project (HRCP) was a $19.2 million, five year test of the upper limits of residential energy conservation. The project was proposed by the National Resource Defense Council (NRDC), funded by the Bonneville Power Administration, and carried out by Pacific Power and Light in Hood River, Oregon. Monitoring was done from 1982 to 1986 with most of the retrofits being installed in 1985. The goal was 100% participation of electrically heated homes and consequently an extensive package of measures was installed, generally at no charge. BPA paid for measures up to a limit of $1.15 per first year kWh saved, nearly four times that which the BPA RWP program paid. 91% of the eligible homes received audits and 85% had major weatherization measures installed. BPA spent an average of $5480 on site-built homes and $2070 on mobile homes. The saturation and predicted energy savings of retrofit measures are listed below.

Measure	Saturation (%)	Cost ($)
Insulation		
Ceiling	67	960
Floor	63	1350
Wall	39	720
Duct	12	270
Windows and Doors		
Storm windows	89	1730
Sliding glass doors	29	720
Insulated doors	3	430
Infiltration		
Caulking	78	110
Door weatherstrip	69	80
Outlet gaskets	85	10
Clock thermostats	26	150
Water heater		
Insulation	51	20
Pipe insulation	63	10
Low-flow showerheads	62	10

Data Analysis: ORNL used PRISM to weather normalize fuel consumption for houses with utility billing data (some houses were submetered). The "Goodfit" sample that LBL analyzed contained 362 site-built homes and 138 mobile homes. The screening criteria for this sample were $R^2 > 0.75$, a and b coefficients statistically significant at the 10% level or better, T_{ref} less than the maximum daily outside temperature for the year, and T_{ref} standard error of less than

20°F for each year of data. As a result of these criteria, the homes do not use wood for a significant portion of their space heating. Oak Ridge adjusted PRISM space heating results since it generally underestimates base use by about ten percent. LBL entered the data as two aggregate groups: the site-built homes (362) and the mobile homes (138). The site-built and mobile homes had R^2 values of 0.94 and 0.96 respectively. LBL assumed a lifetime of twenty years for the retrofit packages.

Approximately two thirds of the Hood River Residences are served by Pacific Power and Light (PP&L) and the rest are served by the Hood River Electric Cooperative (HREC). PP&L rates are roughly double those of HREC. LBL took a weighted average of electricity prices according to the number of houses in the region served by each utility. Without knowing what fraction of houses in each data group were served by each utility, this is the best estimate LBL can make. However, price will effect the household energy use.

Results: For site-built homes, the NAC decreased 16% and for mobile homes the NAC decreased 10%. The simple payback periods for the site-built and mobile homes were 24 and 32 years respectively. Single family homes decreased peak demand by 0.48 kW per household while mobile homes reduced the demand by only 0.26 kW household. The time of the peak advanced 15 to 30 minutes. Space heat savings account for the peak demand reduction. The cost of avoided peak power (CAPP) is $11,400/kW for site-built and $7961/kW for mobile homes. These numbers are higher than the cost to produce and transmit power. However, selecting the most cost effective retrofits would decrease the CAPP.

Averaged over all the homes in the Hood River Project (including multi-family homes), actual savings were 43% of the predicted savings (6,100 kWh). Low pre-program energy use may be one cause of the smaller than predicted savings. Pre-HRCP energy use was much lower in the Hood River area than in comparable areas in the Pacific Northwest.

End Use	Hood River	Pacific NW
NAC Pre (kWh)	20,000	25,000
Space Heat Pre (kWh)	8,000	12,000

Several factors account for low pre-program energy use. In the two years preceding HRCP, real (corrected for inflation) electricity prices rose 40%. Additionally, many households had participated in earlier conservation programs. Single-family homes that had not participated in prior conservation programs saved 4,500 kWh, while those that had saved only 2,200 kWh. These factors account for the low pre-program energy use and consequently make it harder to save large amounts of energy. Another factor that contributed to small savings is that the HRCP was trying for 100% participation. New homes that were retrofit had small savings due to better construction practices. Also, some of the savings were taken in the form of increased comfort and convenience. For homes retrofit in 1985, households raised their indoor temperature by an average of 0.6 F which corresponds to an increased electricity use of 300 kWh. Post-HRCP electricity use for the primary-electric, single-family homes was lower than typical new-home levels.

E033: Hood River, Oregon - 1985 BPA Hood River Water Heating Retrofits[19]

Building/Retrofit Description: Savings from water heating retrofits were measured in Hood River end-use monitored (EUM) houses equipped with a water heater channel. Retrofits included water heater wraps ($20) and low-flow showerheads ($9). If houses contained a dishwasher (75% of homes), the temperature was reduced to 140 F, if not the temperature was lowered to 120 F. Thermostat setbacks were performed in 30% of the homes.

Data Analysis: LBL entered the data as three aggregate groups. Group one contained 20 households that had water heater wraps installed. The second group (54 homes) received both water heater wraps and low flow showerheads. Group three (14 households) was a control group. LBL assumed a seven year lifetime for all the water heating measures.

Results: Data from the Hood River Project indicate that water heating retrofits are highly cost-effective, though savings seem somewhat uncertain. A sample of 20 homes with submetered water heating were found to save 972 kWh per year (22% of water heating electricity use) from water heater tank wraps, yielding a 0.5 year payback. A group of 54 homes that had both water heater wraps and low flow showerheads installed saved 1,001 kWh per year (17% of water heating electricity use), resulting in a 0.7 year payback. An unknown percentage of the homes in each group also reduced the water temperature to reduce standby losses. Peak savings for all homes with submetered water heating (more than these 74 homes) were estimated to be 0.088 kW on peak (per house), corresponding to a cost of avoided peak power (CAPP) of $228/kW.

E034: Austin, Texas - 1988 Central Air Conditioner Replacement[20]

Building/Retrofit Description: The City of Austin (Texas) Resource Management Department is attempting to defer the building of an additional power plant by using demand side management. One of the measures is a Residential Appliance Rebate Program which offers rebates to consumers that replace low-efficiency appliances (air conditioners in particular) with high-efficiency units. This study included twelve homes that replaced low efficiency central air conditioning units (EER = 6.8) with high efficiency units (EER = 11.4) in early 1988. The new units were also smaller capacity, 2.8 versus 2.4 tons. The average installed cost based on information from the six available low-interest loan applications, was $2640 per unit.

Data Analysis: Pre-retrofit performance was monitored in September and October of 1987 and post-retrofit performance was monitored between May and October of 1988. Air conditioner energy use, ambient and indoor temperatures, and indoor relative humidity were recorded at fifteen minute intervals. Electric billing data was also run through PRISM. The peak load savings are for 100°F conditions and are predicted using a least squares regression of kW use versus outdoor temperature squared. The median R^2 is 0.82 for the pre-retrofit data and 0.89 for the post-retrofit data. Peak power savings were predicted to be 2.48 kW per house. Peak power use per house decreased from 4.18 kW before the retrofit to 2.59 kW afterwards, a difference of 1.59 kW. A linear regression of yearly air conditioning consumption per square foot of floor space versus outdoor temperature was found to have R^2 values of 0.87 to 0.92 for the twelve houses. Using a "bin method" to group days according to their average temperature gave pre- and post-retrofit weather normalized cooling values of 5,110 kWh and 2977 kWh. For comparison, PRISM predicted weather normalized cooling to be 5,220 kWh before the retrofit and 3,451 kWh after. PRISM showed a reduction in total household electricity use from 12,708 kWh before the retrofit to 11,152 afterwards. LBL assumed a fifteen year lifetime for the new central air conditioning units based on estimates from the LBL Residential Energy model.

Results: The cost of avoided peak power is $1660/kW. Normalized annual cooling consumption decreased from 5,110 kWh before the retrofit to 2,977 after the retrofit. In Austin, Texas where electricity costs $.0964/kWh during the summer, the simple payback period is about 13 years.

E035: Wisconsin - 1984 LIW[21]

Building/Retrofit Description: The Utility Weatherization Assistance Program (UWAP) involves all Class A gas and electric utilities in Wisconsin and provides free weatherization services to qualified low-income households. This evaluation analyzed both electrical and gas heated homes (G066). The final sample for the evaluation of the 1984 program contained 36 treatment houses and 37 control houses. Measures offered included: water heating retrofits (tank wraps and water flow restrictors), insulation for all areas of the house, furnace replacements and retrofits (electronic ignition, setback thermostat, and vent dampers), storm windows and doors, blower door sealing and caulking and weatherstripping, and attic ventilation. An average of $1594 was spent on each house.

Data Analysis: Utility billing data was weather normalized using PRISM. Homes included in the sample had no occupancy changes, at least six consecutive billing dates, $R^2 > 0.75$, and positive baseloads and heating slopes. LBL entered the treatment and control groups as two aggregate data points and assumed a fifteen year lifetime for the package of measures.

Results: The consumption of the treatment group increased 67 kWh per year (0.3%). The control group consumption increased 794 kWh (4.5%).

E036: Oklahoma - 1988 ORNL Cooling Retrofit[22]

Buildings/Retrofit Description: Oak Ridge National Laboratory ran an experiment in 1988 to test the effect of cooling retrofits on air conditioning use in low income weatherization programs. Three categories of homes in the Oklahoma weatherization program were analyzed: 22 homes that received only weatherization ($836/house), 19 homes with weatherization and a radiant barrier ($1,270), and 18 homes with weatherization and a replacement high-efficiency air conditioner ($1831). All homes were weatherized with attic insulation, caulking and weatherstripping, storm windows. Weatherization expenditures were approximately $860 in all three groups.

Data Analysis: Air conditioning electricity use was submetered and weather normalized using regression analyses based on the outdoor-indoor temperature difference. Homes included in the sample had no occupancy changes. LBL entered the data as the three aggregate groups described above and and assumed a fifteen year lifetime for the package of measures.

Results: The cooling energy consumption of the weatherization-only group increased by 2% (31 kWh/yr) and by 4% (52 kWh/yr) for the weatherization and radiant barrier group. For the weatherization and replacement window air conditioning group, average cooling energy savings were 28% (535 kWh/yr) resulting in a simple payback of 47 years.

E037: Florida - 1982 FSEC Cooling Retrofit[23]

Buildings/Retrofit Description: The Florida Solar Energy Center (FSEC) analyzed cooling energy savings from 25 homes in Palm Beach County, Florida that were retrofitted in 1982. Expenses averaged $5,927 per house. The saturation of measures is given below.

Measure	Saturation (%)
Replacement Central A/C	80
Attic insulation	80
Ceiling Fans	40
Duct Sealing	32
Duct Replacement	20
Window Tinting	16

Data Analysis: Air conditioning electricity use was submetered. Since the correlation between cooling energy savings and cooling degree days was poor, data was not normalized by cooling degree days. Normalizing by square footage produced data that varied by two orders of magnitude. Therefore, cooling consumption was reported in unadjusted form. LBL entered all 25 homes as one data point and assumed a lifetime of 15 years for the retrofit package.

Results: This study points out the difficulty of normalizing cooling energy data. Indoor-outdoor temperature difference, humidity, landscaping, house design, and occupant behavior all effect cooling energy consumption. (See the section on research studies in the first volume of this report for more detail). Cooling energy savings of 5,320 kWh (65%) resulted in a 15 year payback period. Regression analyses indicated that air conditioning replacement saved 3,600 kWh/yr, duct replacement saved 2,900 kWh/yr, and ceiling insulation saved 1,900 kWh/yr (all at greater than 90% confidence levels). Ceiling fans saved 890 kWh/yr (confidence level 87%).

E038: Pacific Northwest - 1985 Regionwide Weatherization Program[24]

Buildings/Retrofit Description: In 1985, the Bonneville Power Administration began operation of the Long-Term Regionwide Weatherization Program (RWP). In 1985, 21,982 non low-income, single-family homes were weatherized. A sample of 239 retrofitted homes and 731 non-participants were analyzed. Three years of post-retrofit consumption metering was done. The average retrofit cost was $1,880 per house, of which $1371 (73%) was paid by BPA with the balance being paid by the customer. Retrofit measures installed in large saturations included attic insulation, floor insulation, window replacements, caulking and weatherstripping, storm windows, duct insulation, and wall insulation.

Data Analysis: Utility billing data was weather normalized using PRISM. Screening criteria included continuous billing histories, no occupancy changes and an $R^2 > 0.25$. LBL assumed a 20 year lifetime for the retrofit measures and entered the treatment and nonparticipant houses in two aggregate groups.

Results: Using a 31 year financing term and a discount rate of 3%, the CCE for Bonneville was 2.96¢/kWh. In the first year after retrofit, total consumption decreased 2,100 kWh (9%), resulting in 25 year payback. Control group consumption increased 90 kWh in the first year after retrofit. NAC usage for three post-retrofit years are shown below.

Treatment	NAC (kWh/yr)	23860	21760	21670	21335
Nonparticipants	NAC	22460	22550	22430	22300

E039: Pacific Northwest - 1986 Regionwide Weatherization Program[25]

Buildings/Retrofit Description: In 1985, the Bonneville Power Administration began operation of the Long-Term Regionwide Weatherization Program (RWP). A sample of 252 retrofitted homes and 688 non-participants were analyzed. Three years of post-retrofit consumption metering was done. The saturation of retrofit measures is given below.

Measure	Saturation (%)
Ceiling insulation	77
Floor insulation	61
Replacement windows	48
Weatherstripping	44
Caulking	38
Storm windows	32
Duct insulation	27
Wall insulation	23
Clock thermostat	14

Retrofit costs averaged $2,181 per house. 63% was paid by Bonneville and the balance was paid by the customer.

Data Analysis: Utility billing data was weather normalized using PRISM. Screening criteria included continuous billing histories, no occupancy changes and an $R^2 > 0.25$. The average R^2 was 0.90. LBL assumed a 20 year lifetime for the retrofit measures and entered the treatment and nonparticipant houses in two aggregate groups.

Results: In the first year after retrofit, total consumption decreased 1,460 kWh (6%), resulting in 42 year payback. Control group consumption increased 750 kWh in the first year after retrofit. NAC usage for three post-retrofit years are shown below.

Treatment	NAC (kWh/yr)	24300	21944	22342	22939
Nonparticipants	NAC	22226	23014	22704	23040

G001: Wisconsin - 1981 LIW[26]

Buildings/Retrofit Description: The Wisconsin Department of Health and Social Services did a small sample (17 homes) evaluation study of their state's low-income weatherization program in an effort to gain insight into service provider effectiveness (i.e. the local community action agencies). Typical retrofit measures installed included attic insulation (bringing existing levels to R-38), caulking and weatherstripping, wrapping of hot water heaters, and storm windows and floor insulation (in a several of the homes). Retrofit costs averaged $1,660.

Data Analysis: In most cases, degree day data and fuel use data were obtained for two years prior to the weatherization activity and averaged along with one year of post-retrofit data. The study authors reported annual energy consumption of the space heating fuel and material costs for each home's conservation measures. LBL researchers used 11 of the 17 homes, those that utilized natural gas for space heating and for which a baseload subtraction (using an average summer months fuel usage as the non- space heating portion of total consumption) could be accurately made. Cost data was multiplied by 1.85 in order to estimate the contractor cost of the retrofit (the factor used by Wisconsin personnel).

Results: Average annual space heat consumption was reduced by 21 MBtu (17%) after the retrofit and the simple payback period was 16 years.

G002: Twin Rivers, New Jersey - 1977 Princeton University[27]

Buildings/Retrofit Description: In 1977, the Princeton Center for Energy and Environmental Studies (CEES) retrofitted a town house in stages. In the first stage, conventional retrofits such as additional attic insulation and moderate sealing of attic air leaks reduced heating fuel usage by 25% in a townhouse. Second stage "super-retrofits" included insulating shutters for south windows, basement insulation, and sealing additional air leaks. Subsequent to these retrofits, another attic bypass heat loss was discovered, by a convective loop within the masonry party walls. This heat loss was partially corrected by blowing cellulose into the walls at the attic floor level. The importance of sealing attic bypass losses and the usefulness of a blower door in house diagnostics were the two major outcomes of this Princeton retrofit experiment. Many of the window and door retrofits were custom-made, resulting in high retrofit costs (average of $3,000).

Results: Net savings in heating fuel increased to 62 MBtu (76%) following completion of all retrofits including the sealing of attic bypasses. The simple payback period was 16 years.

G003 and G004: New Jersey - 1979 Princeton University/HS 11 & 22[28]

Buildings/Retrofit Description: In 1979, two occupied houses were retrofitted by Princeton University's CEES Group and local contractors. Additional attic insulation, furnace tuneups, and sealing air leak convective loops, diagnosed using a blower door and infrared viewer, were the main retrofit measures. The retrofits costs were $700 (for G003) and $1,000 for G004.

Results: The results for the two houses are shown below.

Label	Space Heat Savings (MBtu)	(%)	Payback (yrs)
G003	24	40	8
G004	30	26	9

G005-8, G024-6: New Jersey and New York - 1980 Modular Retrofit Experiment[29]

Buildings/Retrofit Description: In 1980, groups of homes at seven different sites, called "modules," were retrofitted in a collaborative study between Princeton University, four gas utilities in the State of New Jersey, and Consolidated Edison. The principal aim of the study was to make a quantitative evaluation of the "house doctor" concept. Each module consisted of three groups of houses at the same site: "no treatment" houses used as a control group, "house doctor only" homes, and "house doctor plus contractor retrofit" homes. The house doctor treatment included the plugging of air leaks and convective loops diagnosed using a blower door and an infrared scanner, the installation of clock thermostats, the wrapping of water heaters with insulation, and sometimes the installation of low-flow shower heads and lowering of water heater temperature settings. A list of possible contractor retrofits was prepared for each house following the house doctor visit and in one group in each module these improvements were carried out. These included such measures as installation of insulation in attics, walls, and basements, and storm windows.

Results: In all seven modules the "house doctor only" group yielded the lowest cost of conserved energy (CCE) for the module, indicating that some of the most cost effective retrofit measures were included in the typical house doctor visit. The "house doctor plus contractor retrofit" had considerably higher CCEs than the "house doctor only" group because the additional contractor work was relatively expensive and saved less energy per dollar spent. In six of the seven modules the control group decreased its energy usage as well, a trend also seen for the aggregate of New Jersey's gas heating customers. The results of this study are discussed in detail in volume I of this report.

G009: Saskatoon, Saskatchewan - 1980 Energy Conservation Info. Center Caswell Hill Study[30]

Buildings/Retrofit Description: The Caswell Hill Infiltration Project attempted to determine the relative cost-effectiveness of sealing air leaks by caulking and weatherstripping throughout the thermal envelope. Ten houses were sealed and thereafter five of them received attic and basement insulation. The National Research Council (NRC) of Canada used pressure tests to measure air leakage rates before and after retrofitting. The NRC found significant variations in the quality of workmanship and materials used in the retrofit work.

Data Analysis: It should be noted that retrofit costs have been converted from Canadian to U.S. dollars.

Results: Results from these two groups were compared to another group of ten houses that had mainly added insulation and storm windows. The five homes that had been sealed and insulated achieved energy savings of 53 MBtu (30%) at a an average cost of $1,940 per house. The simple payback period was 17 years for this group.

G010: Butte, Montana - 1980-81 NCAT Halfway House[31]

Buildings/Retrofit Description: In 1980 and 1981, the National Center for Appropriate Technology retrofitted a 2,300 square foot halfway house in Butte, Montana. This retrofit occurred in two steps: attic insulation only was added to a halfway house before the first winter with wall insulation, caulking and weatherstripping, and a south-facing passive wall installed before the second winter. $4000 was spent on weatherization materials. The solar retrofit cost approximately $6,000 (materials only).

Data Analysis The basic data (consumption, weather, costs) were provided by NCAT and LBL did the calculations.

Results: NCAT concluded that the money spent on the solar retrofit would have been better spent on weatherization. The payback period for the weatherization and solar retrofit was 85 years.

G011: Ramsey County, Minnesota - 1979 Northern States Power Weatherization[32]

Buildings/Retrofit Description: In 1979, the City of St. Paul, Ramsey County, and Northern States Power Company (NSP) combined to institute a test program of weatherizing homes for low income people in St. Paul. The principal weatherization measures were the addition of attic insulation, caulking, and weatherstripping at an average cost of $290 per house. The test program was funded by an NSP grant and NSP conducted an evaluation study.

Data Analysis: After the 1980 winter the gas consumption records of 84 participating customers were analyzed. Baseload corrections and weather adjustments were made.

Results: Post-retrofit space heat energy consumption decreased by 12 MBtu (8%) and the payback period was 8 years. A 1981 follow-up study on 25 customers in the program (the initial group was reduced by changes in occupancy) found that annual consumption declined further in 16 households and increased slightly in nine households.

G012: San Joaquin Valley, California - 1979 Pacific Gas & Electric Ceiling Insulation[33]

Buildings/Retrofit Description: This study analyzed pre- and post-retrofit consumption of a small sample of the 7,629 customers who financed ceiling insulation through Pacific Gas & Electric Company's low interest loan program in 1979. The study focussed on 49 customers who initially had no ceiling insulation and installed R-19 and lived in the San Joaquin Valley of California (33 in Bakersfield and 16 in Fresno). The average cost was approximately $425 per house.

Data Analysis: P.G. & E. made a baseload correction on the consumption data and calculated the savings for a 5-month heating season. The results were scaled up to reflect a normal winter season.

Results: Savings averaged 15 MBtu (12%) in Bakersfield and 20 MBtu (13%) in Fresno. The respective payback periods were 6 and 4 years.

G013: Colorado - 1977 Public Service Company Ceiling Insulation[34]

Buildings/Retrofit Description: Public Service Company (PSC) provided a low-interest loan program for its customers over a 40-month period from September 1975 to the end of 1978. Over 33,000 gas users, mainly in the Denver metropolitan area, increased their attic insulation, usually from R-11 to R-30.

Data Analysis: The PSC provided weather-adjusted total gas usage numbers for before and after retrofit periods and we subtracted a baseload use estimate to derive the space heating component.

Results: Approximately 20 MBtu per customer were saved with an original investment of less than $300. The investment had a average payback time of 5 years.

G014-18: 1979 CSA/NBS Optimal Weatherization Demonstration Program[35]

Buildings/Retrofit Description: The Community Services Administration and the National Bureau of Standards designed and completed an optimal weatherization research project involving low-income houses throughout the United States. Retrofits were performed in 1979. Energy savings and retrofit costs were carefully compiled for twelve different sites. Even though the study concentrated on low-income households, the results have applicability to most middle-income homes since many of the houses were occupied by people whose retirement from work dropped them into the low-income category. More than half of the 142 retrofitted homes used in the final study received optimal weatherization, including both shell measures and mechanical options. The remainder of the retrofitted homes received shell measures only. The final control group consisted of 41 homes.

Retrofit options included all improvements to the thermal envelope such as insulation, caulking and weatherstripping, and storm windows and doors as well as space heating system or domestic hot water system measures - such things as flue dampers, furnace tuneups, electronic ignition, thermostats, duct and pipe insulation, and flow restrictors. Submetering of all space heating systems and of many hot water systems was done in this project.

Data Analysis: The CSA/NBS study listed individual consumption and cost data for each house. Only space heating data were presented even though in many cases water heater data had been collected. All consumption data had been weather-adjusted.

Results: The sites with both envelope and heating system retrofits appear to be more cost-effective than those sites for which only shell retrofits were done. Absolute savings per house were 45 MBtu with 31 percent savings in space heating energy for the composite of 12 cities (label M008). Retrofit costs averaged $1,610 per house and the payback period was 8 years. The control group space heating consumption decreased by 4 percent. As expected, the results vary from site to site because of such factors as: differences in the original thermal integrities of the houses, selection of retrofit options implemented, and the different fuel types.

G019: Luzerne County, Pennsylvania - 1979 LIW[36]

Buildings/Retrofit Descriptions: This was a local study of the DOE Weatherization Program for low-income homes. The retrofit measures included attic insulation, caulking and weatherstripping, and energy efficient windows. Retrofit costs averaged $790 per home.

Data Analysis: Gas consumption data for 30 homes during both December through March periods of '78-'79 and '79-'80 were included in the study. LBL made a baseload correction and adjusted the data to a normal winter season.

Results: Post-retrofit consumption declined by 29 MBtu (14%), yielding a payback time of 9 years.

G021: Kansas City, Missouri 1977-78 LIW[37]

Buildings/Retrofit Description: Kansas City, Missouri conducted several evaluations of the Home Weatherization Program. The programs were implemented with DOE Low-Income Weatherization funds dispensed through the Missouri Department of Natural Resources. Results are reported for three sample groups that received insulation, caulking and weatherstripping during 1977 and 1978.

Data Analysis: LBL used the consumption data in the report (3 months winter billing data representing approximately 60% of the HDD in the heating season), and made a baseload correction and weather adjustment to a normal Kansas City winter.

Results: Percent savings of space heating energy use for the three groups ranged between 15-27% with a simple payback time of 7 to 15 years.

G022: Kentucky - 1979 LIW[38]

Buildings/Retrofit Description: The Kentucky report on the DOE Low-Income Weatherization Program was very extensive and detailed. It contained a large sample of homes heated with a mixture of fuel sources. Many of the homes had several fuel sources including some with wood heating. In order to avoid possibly inaccurate fuel consumption records, only the homes heated by natural gas were included. The principal retrofit options implemented were caulking and weatherstripping, storm windows and doors, and ceiling insulation. Retrofit costs averaged $250 per house. There was a control group in the study but no results are shown due to insufficient consumption data.

Data Analysis: LBL made a baseload correction and adjusted usage to a normal heating season.

Results: Average savings were 16 MBtu per year (11%) yielding a 5 year payback.

G023: Indiana - 1978 LIW[39]

Buildings/Retrofit Description: Results from the DOE Low-Income Weatherization Program in Indiana are presented. The principal retrofit options were insulation, caulking and weatherstripping, and adjustments of the heating system. Retrofit costs averaged $1,375 per house.

Data Analysis: Consumption data was provided by U.S.R.&E. LBL made a baseload correction and adjusted for a normal winter of heating degree-days.

Results: Total consumption decreased by 46 MBtu (21%) after the retrofit, yielding a payback time of 14 years.

G027: Walnut Creek, California - 1981 LBL/PG&E House Doctoring[40]

Buildings/Retrofit Description; In cooperation with Pacific Gas & Electric Co., Lawrence Berkeley Laboratory conducted a demonstration project to measure the incremental savings that result from adding house doctoring to an energy audit. The experiment analyzed the pre-and post retrofit energy consumption of 19 homes divided into 4 groups: a "full retrofit" group (A) that received an audit, house doctoring and conventional contractor retrofits, a group (B) that received the audit and house doctoring, a group (C) that had the audit only, and a blind control (D) which received no treatment. The house doctor treatment emphasized the installation of an intermittent ignition device (IID), infiltration-reduction measures using diagnostic equipment, low-flow showerheads, insulating the water heater, and sealing furnace ducts.

Data Analysis: At this stage of the experiment, usage data from Group A includes the results from house doctoring only (the conventional retrofits were done in June 1981) and thus the data from Groups A and B together were combined.

Results: Though the "house-doctored" group had a larger average value of savings than either the audit only or blind control (11.4% compared to 9.4 and 7.0%), the differences were not statistically significant (at the 95% confidence level) due to the small sample size.

G028: Champaign, Illinois - 1978 University of Illinois Insulation[41]

Buildings/Retrofit Definition: Energy consumption data were studied by University of Illinois researchers for 12 households that received insulation retrofits in 1978. Five homes received ceiling insulation only, one received wall insulation only. Retrofit costs averaged $900 for the group of all 12 homes and $560 for the group of five homes that received only attic insulation.

Data Analysis: Researchers analyzed several years of utility bills for each home before and after retrofit. LBL calculated annual space heat energy savings using their data on "heating factors" and baseload correction (summer usage in the pre-and post retrofit years defined as baseload). LBL entered the data in two groups: the entire group of 12 and the 5 homes that received only attic insulation.

Results: The entire group had average savings of 42 MBtu per year (24%) and the ceiling insulation only saved 29 MBtu per year (17%). The respective paybacks were 6 and 5 years.

G029: Denver, Colorado - 1982 DOE/SERI 50/50 Program[42]

Buildings/Retrofit Description: This study analyzed the energy savings from 25 households that participated in a DOE/SERI demonstration project of the 50/50 program. Working with local contractors, SERI adapted the retrofit package to gas-heated homes in Colorado (i.e. included attic insulation and eliminated cooling system and 7 sealing/heating system improvements that were not applicable to gas systems). Thirty low-cost measures could potentially be installed by contractors with estimated savings up to 40%. Retrofit costs averaged $750 per house.

Data Analysis: Saving estimates are based on extrapolations from 6 months of post-retrofit data.

Results: From 12 to 21 retrofit measures were actually installed in each house. The retrofits resulted in average annual energy savings of 26 MBtu (21%). The package of conservation measures had an average payback time of 5 years. A "non-participant" control group of 25 households also reduced their consumption by 14% attributed to rising gas prices and "independent" retrofit action taken by at least 7 of the 25 "non-participants."

G030: Detroit, Michigan - 1973-76 Consolidated Gas Company Ceiling Insulation[43]

Buildings/Retrofit Description This study conducted by staff of the Michigan Public Service Commission analyzed energy savings from 71 homes that participated in a Michigan Consolidated Gas Company loan program to finance the installation of attic insulation [up to R-19]. The retrofits occurred between 1973-76 and were installed by contractors at an average cost $285 per house.

Data Analysis: PSC staff made a baseload correction of annual energy consumption data and used cost data estimates from local contractors.

Results: Consumption decreased by 21 MBtu per year (13%) after the retrofit with a payback time of 4 years.

G051: Minneapolis, Minnesota - 1983-85 MEO Foundation Insulation (Unconditioned Basements)[44]

Building/Retrofit Description: Minnegasco and the Minneapolis Energy Office (MEO) conducted a study of fifteen houses whose foundations were insulated between 1983 and 1985. These basements were *unconditioned* spaces. All of these houses already had insulated walls and attics. Eight houses received interior foundation insulation, five houses received exterior foundation insulation, while two received a combination. For interior insulation (average cost of $1820), a 2 x 4 wall was erected against the foundation wall and R-11 fiberglass batts were sandwiched between two polyethylene vapor barriers. The average cost was $1820 including sheetrock and $906 excluding sheetrock installation. As LBL is interested in the costs related to the energy savings, we used the figure of $906. However, sheetrock is mandated by most fire codes. For exterior insulation (average cost of $1170), R-10 polystyrene rigid foam was attached at the first-floor bottom plate and ran four feet below that level. The polystyrene was coated with a cement-based finish.

Data/Analysis: None of the houses in the sample had other retrofits done during the analysis period or significant changes in occupant lifestyle. Utility billing data was weather normalized using PRISM. Houses were included in the study only if they had an $R^2 > 0.95$ and a coefficient of variance of the NAC of less than five percent. To calculate the end use fractions of the NAC, LBL assumed that 80% of the pre-retrofit NAC was used for space heating (EIA 1989). LBL reported aggregate results for the two groups of houses: those that received interior insulation (eight) and those that received exterior insulation (five). There is a large uncertainty in the lifetime of the foundation insulation. LBL assumed twenty year lifetimes for both interior and exterior insulation. However, if interior (fiberglass) insulation is exposed to water, it will be ruined and there will be little or no subsequent energy savings.

Results: Before the retrofit, the interior insulation group used an average of 129 MBtu annually, while the exterior group used 110 MBtu. This is less than the 145 MBtu average for single family homes in Minneapolis. The savings from interior insulation were 15±5% resulting in a 8 year payback period (excluding sheetrock costs). The savings from exterior insulation were 10±3% resulting in a 21 year payback. After the retrofit, ten percent of the study sample reported moisture problems in the basement which were not due to improper backfilling. In these cases, insulation was apparently trapping water that previously evaporated into the basement. Two thirds of the houses with exterior insulation reported that the cement finish on the insulation had cracked. This is a problem with the material selected, not the retrofit.

G052: Minneapolis, Minnesota - 1982 MEO Heating System Replacements and Wall Insulation[45]

Building/Retrofit Description: The Minneapolis Energy Office (MEO) conducted a pilot study of houses that were retrofitted in 1982 with furnace or boiler replacements or wall insulation. The retrofits were financed through a city/utility loan program called the Energy Bank. Twenty homes installed new furnaces or boilers. Three installed condensing boilers (AFUE = 90.4%), thirteen installed forced draft furnaces or vent damper and electronic ignition (AFUE = 80-84%) furnaces, and four installed forced draft or vent damper and electronic ignition (AFUE = 80-84%) boilers. Eight homes received blown-in wall insulation. The retrofit cost averaged $1290 for the wall insulation, and $2990 for the furnace replacement.

Data Analysis: Fuel consumption was weather normalized using PRISM. Houses were dropped from the sample that had changes in occupancy, less than eight gas bill readings over a one year period, installed other energy saving measures, or changed the heated volume of the house. Additional criteria were an $R^2 > 0.90$ and a coefficient of variation not greater than 0.10. Using the Minnesota RCS audit, predicted energy savings were 37 MBtu/yr for condensing furnaces, 24 MBtu/yr for forced draft furnaces, 37 MBtu/yr for forced draft boilers, and 41 MBtu/yr for wall insulation. LBL separated the heating system replacement data into three groups, condensing boilers (three), AFUE 80-84% furnaces (thirteen), and AFUE = 80-84% boilers (four). LBL entered the furnace and wall insulation retrofits as four aggregate data points. LBL assumed a twenty-five year lifetime for both the furnace/boiler replacements and the wall insulation.

Results: The percent NAC savings and payback periods are shown below.

Measure	Retrofit Cost ($)	% Savings	Payback Period (yrs)
Wall Insulation	1290	11.9	12
Condensing furnace	3835	16.5	24
Forced draft furnace	2451	12.3	22
Forced draft boiler	2896	13.1	17

Retrofit costs were high for many of these measures and thus the economics are less favorable than might be seen currently.

G053: Kansas City, Missouri - 1985 Urban Consortium Warm Rooms Project[46]

Building/Retrofit Description: In 1985 and 1986, the Urban Consortium carried out a **warm room** program in Kansas City for low income, elderly residents. The warm zone included the kitchen, bathroom, and one or two additional rooms. Other areas of the house were allowed to float at 50°F to 60°F. Zoning was accomplished by closing off selected furnace ducts and adding insulation to the warm zone of the house. There were five treatment houses and four control houses. The average cost of the retrofits was $1425 per house.

Data Analysis: Warm room and cool room temperatures were measured with thermographs. Utility billing data was collected on a weekly basis for five months after the retrofit and was weather normalized by doing a linear regression of fuel use versus degree days. To test the validity of this method, a pre-retrofit five month period was analyzed using the linear regression technique and a one year pre-retrofit period was analyzed using PRISM. The NAC values were essentially the same for the two methods. LBL entered the treatment and control groups as two aggregate data points. In some of the houses, electricity use went up after the warm room retrofit due to the use of electric space heaters to maintain minimum temperatures in selected cold zones. LBL converted the difference in electricity use to site energy (3412 BTU = 1 kWh) and added it to the NAC gas consumption in order to calculate energy savings. The economics take into account the different prices for gas and electricity. LBL assumed a lifetime of ten years for the zoning measures. Though only three of the five houses used zoning techniques properly, LBL entered the average results for all five homes because presumably it will be difficult to get all the recipients in such a program to use it effectively.

Results: Average savings for the control houses were 2%. In the three houses where warm rooms were used effectively, total gas savings ranged from 21% to 47%, with the average being 32%. In another treatment house, zoning was not well maintained, but overall house temperature was lowered and 31% savings were obtained. Average savings for the five treatment houses were 26%. Using 1983 national energy prices of $0.60/therm, the simple payback times were 2.4 to 4.6 years for the four treatment houses that achieved substantial savings. Including the two houses that did not use the zoning system properly, the simple payback period was still 5.0 years (at national energy prices). At the Kansas City price of $0.28/therm the simple payback period was 10.8 for the entire group. In the treatment house that did not achieve substantial savings, the residents nullified the zoning effects by opening furnace vents and doors and curtains between rooms. These residents were unhappy that energy was not still saved. Residents in the other four treatment houses were satisfied with the results of the program.

G054: Kentucky - 1985 ASE/ORNL Gas Pilot[47]

Building/Retrofit Description: In 1985, the Alliance to Save Energy and the Department of Energy's Weatherization Assistance Program (WAP) sponsored a gas heating system retrofit pilot program in Kentucky for single-family, low income homes. Furnaces were retrofitted with one of three options (average costs given in parentheses): condensing heat extractors ($650), power burners ($500), or thermally actuated vent dampers ($175). There were 101 treatment houses and 97 control houses.

Data Analysis: ORNL used PRISM to weather-normalize fuel billing data. There was a treatment and a control group for each retrofit measure. Houses were dropped from the study that did not have at least one year of preprogram fuel consumption, used supplemental heating fuels, installed additional weatherization measures, or had occupancy changes. LBL entered the data as six aggregate points which consisted of all the treatment or control houses for an individual retrofit measure.

Results: The treatment group, control group, and net savings are shown below for each of the three retrofits.

Retrofit Measure	Treatment Group Savings	Control Group Savings	Net Savings
Heat Extractors	14%	7%	7%
Power Burners	6%	5%	1%
Thermally Actuated Vent Dampers	7%	9%	-2%

The condensing heat extractors provided significant gas savings, but the energy savings do not include the extra electricity required for pumps to circulate the cooling water and drain the condensate. The heat extractors used oversized 0.25 horsepower motors, which may have used one third of the primary energy that the heat extractor saved (Mark Hopkins [ASE], personal communication, 1989). Additionally, the heat extractors had serious reliability problems.

The simple payback periods (based on gross savings) were seven years for heat extractors, eleven years for power burners, and five years for the thermally actuated vent dampers. The cause of the large savings for the control groups is unknown.

G055: Michigan - 1985 PSC Gas Furnace Pilot[48]

Building/Retrofit Description: In 1985 and 1986, the Michigan Public Service Commission (PSC) sponsored a gas heating pilot retrofit project. The furnace retrofits were: 1. tune-up and minor repairs ($75), 2. thermal vent damper and tune-up ($175), and 3. heat extractor and tune-up ($700). Each retrofit was performed individually and with additional weatherization work. On retrofits numbers 1,2, and 3, $475, $435, and $200 were spent respectively on the additional weatherization. Eighty one houses were in the study, twelve of which were a control group.

Data Analysis: Utility billing data was collected from December 1984 through July 1986, though often not over the entire period for a given house. The data was weather normalized using PRISM. Only homes with at least three months of winter fuel consumption data and no supplemental fuel use were included in the analysis. The length of the pre and post-retrofit monitoring period depended on when in the twenty month monitoring period that the retrofit was done. The baseload was calculated by averaging the fuel consumption for the month with the least heating degree days and the utility's estimate of baseload provided on the fuel consumption record. Space heating energy use was calculated by subtracting off the baseload from the total fuel consumption. LBL entered data from the study as seven aggregate points. One is the control group and the other six are the three furnace retrofits with and without weatherization. Base 65°F heating and cooling degree days were calculated by taking a weighted average of the regions in the sample.

Tune-ups were assumed to have a five year lifetime. Hardware furnace modifications were assigned a twelve year lifetime, roughly half the lifetime of an average furnace. Furnace hardware modifications combined with weatherization were given a ten year lifetime. The combination was assumed to have the lifetime of weatherization measures since the only statistically significant savings were from weatherization. LBL used a lifetime of ten years rather than fifteen years because the low cost of weatherization implies short term measures like caulking and weatherstripping.

Results: None of the furnace retrofits showed statistically significant savings by themselves. However, all of the furnace retrofits showed significant savings when combined with additional weatherization measures. With the additional weatherization measures, the gross percentage fuel savings were 17% for tune-ups (SPT = 7 years), 19% for vent dampers (SPT = 6 years) and 9% for heat extractors (SPT = 16 years). For a larger data set that did not screen for supplemental heating fuels or a minimum of three winter heating fuel bills, the savings were much larger for heat extractors (18.2%), but not radically different for other measures. Heat extractors were subject to frequent operational problems and have additional electricity costs from pumps that circulate water and drain the condensate. The authors of the study do not recommend heat extractors due to their reliability problems.

G056: Ohio - 1985 LIW[49]

Building/Retrofit Description: In 1985, 13,427 low income homes were weatherized by the state of Ohio. General heat waste (GHW) measures were assigned the first priority for all houses. GHW measures include: heating unit tune-up, water heater tank wrap, infiltration reduction, sealing of thermal bypasses. Floor, attic, and sidewall insulation and storm windows were done with the money left over after GHW measures were installed. (Wall insulation was generally loose cellulose fill - not high density blown cellulose). Sufficient data was collected to analyze 1083 treatment homes and 356 control homes. The control homes were selected from a group eligible for the program but which had not received prior weatherization work. An average of $1800 per house was spent on weatherization.

Data Analysis: Utility billing data was weather normalized using PRISM. Homes were excluded that had auxiliary heat or did not have at least nine readings in both the pre- and post-weatherization years. LBL assumed a fifteen year lifetime for the retrofit packages and entered the data as two aggregate points: the treatment and the control homes. Based on data in the Residential Energy Consumption Survey for houses in this degree day range, LBL assumed that 75% of the pre-retrofit NAC was used for space heating (EIA 1989).

Results: Retrofit packages that emphasized insulation measures were found to be the most cost-effective. Units with a large percentage of the money spent on general heat waste measures had low or negative savings. Consumption in the treatment group decreased from 153 MBtu before the retrofit to 136 MBtu after the retrofit (11 percent savings). The simple payback period is 18 years. The control group consumption increased 10 percent in the second year of monitoring, but no explanation is provided for this dramatic increase.

G057: Wisconsin - 1982 LIW[50]

Building/Retrofit Description: An evaluation of Wisconsin's 1982 low income weatherization program analyzed a treatment group consisting of 243 houses and a control group of 46 homes weatherized in the next year (1983) of the program. (The control houses were not weatherized during the study period). Weatherization measures and saturations are shown below.

Measure	Saturation (%)
Caulking and weatherstripping	100
Water heater wraps	83
Attic insulation and ventilation	68
Storm windows	65
Sill insulation	50
Storm doors	35
Foundation insulation	27
Duct insulation	20

The materials cost per house average $572. Assuming a 60/40 labor material split, the average cost for materials and labor is $1260 per house.

Data Analysis: Utility billing data was weather-normalized using PRISM. LBL entered the treatment and control groups as two aggregate data points. For any house with less than nine readings in the pre- or post-weatherization period, the balance temperature was set equal to 62°F. Houses were excluded that had a change of resident. LBL assumed a lifetime of fifteen years for the retrofit package. Based on data in the Residential Energy Consumption Survey for houses in this degree day range, LBL assumed that 80% of the pre-retrofit NAC was used for space heating (EIA 1989).

Results: The work crews had "Minimum Production Standards" of $1200 per crew person per month. This resulted in money being spent preferentially on material intensive measures rather labor intensive measures. Field visits rated each weatherization job in terms of completeness of application, quality of workmanship, and materials degradation. Thirty percent of the occupants that responded to mailed questionnaires did not feel that a thorough job had been done. No effort was made to implement the retrofit measures in order of cost-effectiveness.

Consumption in the treatment group decreased from 124 MBtu before the retrofit to 111 MBtu after the retrofit (10%). The simple payback period is 18 years. Control group consumption decreased by 6%.

G058: Colorado - 1985 Sun Power House Nursing Program[51]

Building/Retrofit Description: Sun Power has carried out House Nurse work on over 1,500 low-income, gas-heated homes. The House Nurse program uses trained individuals to systematically address the heat loss problems of a house, rather than the conventional caulking, weatherstripping, and storm window approach. In 1985, the Colorado Office of Energy Conservation (O.E.C.) funded Sun Power to conduct an analysis of its "House Nursing" program. Twenty eight homes were analyzed. The technicians address the following issues in each house:

1. Thermostat setback
2. Low domestic hot water temperature
3. Insulate the hot water tank and the first three feet of hot and cold water pipes
4. Reduce shower flow - If flow exceeds 3.75 gpm, replace with low flow head.
5. Check the safety and cycle efficiency of the heating system.
6. Insulate uninsulated horizontal surfaces to R-19.
7. Eliminate major air leaks.
8. Reduce or eliminate convective loops
9. Reduce or eliminate wind washes.

Technicians carry out client education, which is essential for longterm savings, especially for the first two measures. Checking the efficiency and safety of the heating system provides another important client benefit and helps identify homes that should be targeted in furnace programs. In order for the crew to know whether they have succeeded in sealing the major sources of heat leaks, the house is pressurized before and after the work with a window fan or blower door. Technicians identify and record the suspected leakage areas, noting the ones that they have been able to seal. The pressurization readings and the technicians commentary are then passed on to the manager.

Another essential component of the House Nurse Program is management. Savings dropped from an average of 9.5% to 2.4% when the management system was not followed. The management system evaluates the work done on every house and provides prompt feedback to the technician. Additionally, the management inspects about thirty percent of the houses to establish the accuracy of information provided by the technicians.

Data Analysis: Sun Power obtained the utility bills of the first 100 houses in the program. The final study sample contained twenty eight houses; seventy two houses were dropped from the analytical part of the study because of other weatherization work, changes in occupancy, shutoffs, or lack of utility data. Sun Power weather normalized data using a procedure similar to PRISM, except the base use was determined from the measured summer fuel use. LBL entered the twenty eight homes as one aggregate data point.

Results: Energy use was reduced by 9.5% at an average per-house cost of $300 (including materials, labor, and overhead). For six of the houses examined in an accelerated monitoring program, the cost breakdown was as follows: materials 26%, labor 39%, and administration and overhead 35%. Twelve person hours of labor were typically required per house. With the cost breakdown above, this assumes an average labor cost of $9.75 per hour. Labor costs appear lower than for most other low income programs and thus contribute to a low program cost. The average payback time for the House Nurse Program is 4.5 years. Savings vary dramatically from one unit to the next. Therefore, the program keeps the per house investment low and continually tries to improve the program to increase the percentage of large-saving houses.

G059: USA - 1976-79 AGA Space Heating Efficiency Improvement Program (SHEIP)[52]

Building/Retrofit Description: The SHEIP study analyzed 2,650 homes that received gas furnace retrofits between 1976 and 1979. The study was carried out by the Institute for Gas Technology and was sponsored by American Gas Association. The sample was national (but not statistically representative) and only percentage savings were given. Retrofits that reduce off cycle losses will produce different savings in climates of different severity and therefore these results should be interpreted with caution. Retrofits that LBL examined included derating and fixed vent restrictor (131 homes), full furnace derating (105 homes), vent damper (146 homes), vent restrictor (35 homes), and noncondensing heat extractor (52 homes). The distribution of heating systems in the study homes was 88% central, gas-fired, forced-air furnaces and 12% central hot-water boilers. The average pre-retrofit steady-state furnace efficiency was 77.2%.

Data Analysis: LBL entered each of the five retrofits as one aggregate data point. For all the measures LBL assumed a lifetime of fifteen years. The SHEIP report gives net savings (gross minus control). Two types of control measures were used: reference homes and flip-flop retrofits. Reference homes were monitored for two years with no retrofits. In the flip-flop method, retrofits were turned on and off at one to two week intervals so that the furnace ran half the season with the retrofit and half the season without it. Seventy five percent of the furnaces were equipped with submetering at least for the post-retrofit period.

Results: The percentage savings for the different retrofits are given below.

Measure	% Savings
Derating and vent restrictor	9.1
Full furnace derating	6.2
Vent damper	5.1
Vent restrictor	3.7
Non condensing heat extractor	3.0

No cost data was given.

G060: Minnesota - 1981 Northern States Power Weatherization[53]

Building/Retrofit Description: In 1981 and 1982, Northern States Power (NSP) administered two energy audit and low interest loan programs for residential customers. The state program, the Minnesota Energy Conservation Service (MECS), provided residential energy conservation audits. The Public Utility Conservation Investment Program (PUCIP) provided loans for the measures recommended by a MECS audit. The final sample included 162 single-family, owner-occupied homes in St. Paul, Minnesota and expenditures average $2890 per house. The saturation of retrofit measures is given below.

Measure	Saturation (%)
Caulking/weatherstripping	89
New Heating System	61
Ceiling insulation	57
Clock thermostat	46
Storm doors	40
Wall insulation	34
Storm windows	32
Water heater tank insulation	31

Data Analysis: Monthly utility billing data was weather normalized using a linear regression with a fixed reference temperature. LBL assumed that 80% of the pre-retrofit NAC was used for space heating (EIA 1989). The 162 PUCIP loan homes were entered as one aggregate point, LBL took the post-retrofit NAC value to be the year three data because many audits were done late in year two. LBL assumed a twenty year lifetime for the retrofit measures because of the high saturation of furnace replacements and insulation.

Results: The PUCIP loan recipients achieved 19 percent savings which corresponded to a 15.6 year simple payback period. Gas prices increased from $3.70/MBtu in the spring of 1981 to $5.70/MBtu in the spring of 1983 (54% increase). Simple payback times were calculated using the price at the end of the program ($5.70/MBtu).

G061: Ohio - 1987 Utility LIW[54]

Building/Retrofit Description: In 1986 and 1987, the major gas utilities in Ohio weatherized 15,000 low-income homes based on a PUC order. Sufficient data was collected to analyze a group of 8,912 treatment homes and 1,620 control homes. The saturation of retrofit measures in site-built and mobile homes is given below.

Measure	Saturation (%) Site-built	Mobile Home
Storm Windows	53	92
Caulking	52	88
Weatherstripping	48	58
Furnace Tune-up/Repair	38	72
Ceiling Insulation	27	0
Door/Window Repair	3	12
Duct Insulation	0	18

Data Analysis: Utility billing data was weather normalized by scaling the space heat data to daily outside temperatures. Since homes were weatherized over a two year period, homes weatherized late in the program were used as control homes for homes weatherized early in the program and vice versa. LBL entered the data as four aggregate points: a group of all the treatment homes, the mobile home subset, the control homes, and ceiling insulation retrofits. LBL assumed a fifteen year lifetime for the packages of measures and twenty for the ceiling insulation. Based on data in the Residential Energy Consumption Survey for houses in this degree day range, LBL assumed that 75% of the pre-retrofit NAC was used for space heating (EIA 1989).

Results: The treatment homes achieved 9% savings at a cost of $509 per home (materials and labor) which corresponded to a 10 year simple payback period. The mobile home subset had 3% savings at cost of $326 which corresponded to a 40 year payback period. Consumption in the control group homes increased one percent. Note, however that retrofits costs are low as some of the work was done by community volunteer organizations. A group of 162 homes that received only attic insulation decreased their consumption from 110.5 MBtu to 97.6 MBtu (12% savings). LBL did not calculate the economics for this group of homes since the cost of $163 per home relied on extensive volunteer work.

G062: Minnesota - 1988 University of Minnesota M200 High Level Weatherization[55]

Building/Retrofit Description: The M200 program was designed by the Underground Space Center at the University of Minnesota to increase the cost-effectiveness of weatherization programs in Minnesota. Two hundred low income homes were weatherized in 1988. 128 homes were included in the final analysis (see screening criteria below). The cost per house averaged $1306 ($822 for labor and $484 for materials). Ninety seven percent of the homes were gas heated and the remaining three percent were electrically heated.

The procedure starts with a visit by the energy advisor, who conducts client education, inspects the heating unit and heat distribution system, determines how much insulation and what repair materials the weatherization crew will need, and conducts a blower door test. The energy advisor then recommends whether or not weatherization crews or heating contractors are needed.

If specified by the energy advisor, the heating contractor is called in to deal with safety problems or furnace efficiency improvements. The weatherization crew installs materials and conducts repairs (if called for) in the following order. Uninsulated walls are brought up to R-11. High density (3.5-4.0 lb/ft^3) cellulose wall insulation is installed by removing the siding and using a tube feed method. The high density cellulose reduces infiltration while insulating the wall. Next, attic bypasses are sealed and attic insulation is installed. Houses with less than R-11 ceiling insulation were brought up to R-44. Large duct leaks are then sealed. A blower door reading is taken to determine whether further air sealing is cost-effective and safe. The minimum air exchange is 1,200 cfm at 50 Pascals. The cost-effectiveness criteria requires that each 100 cfm air reduction cost less than $40. Next, houses with forced air distribution systems are pressure balanced. Additional measures recommended by the energy advisor are then installed. For houses with gas heating or hot water, a backdrafting test is done for safety reasons. Finally, a blower door test and, if possible an IR scan, are done to check the success of the retrofitting.

The saturation of measures is given below.

Measure	Saturation (%)
Attic insulation and bypass sealing	70
Heating system repairs/adjustments	66
Wall insulation	51
Rim joist insulation	47
Caulking/weatherstripping	32
Clock thermostats	20
Exterior foundation insulation	8

Data Analysis: Homes were randomly selected for inclusion in the M200 program and then screened to assure no auxiliary heat, no occupancy changes, and at least seven utility bill readings in both the pre- and post-weatherization years. Utility billing data was weather normalized using PRISM. Additionally, homes had to have an $R^2 > 0.95$ and less than a five percent standard error. Based on data in the Residential Energy Consumption Survey for houses in this degree day range, LBL assumed that 80% of the pre-retrofit NAC was used for space heating (EIA 1989). LBL entered the 128 treatment homes as one aggregate point, and assumed a fifteen year lifetime for the measures.

Results: Gas consumption dropped from 142 MBtu before the retrofit to 117 MBtu after the retrofit (18% savings). With a retrofit cost of $1306 and a fuel cost of $4.85/MBtu, the simple payback period is 11 years.

G063: Minnesota - 1985 ASE/ORNL Gas Pilot[56]

Building/Retrofit Description: In 1985, the Alliance to Save Energy and the Department of Energy's Weatherization Assistance Program (WAP) sponsored a gas heating system retrofit pilot program in Minnesota single-family, low income homes. Furnaces were retrofitted with one of four options (average costs given in parentheses): condensing heat extractors ($650), power burners ($500), electric vent dampers and electronic ignition ($400), or thermally actuated vent dampers ($175). There were 98 treatment houses and 104 control houses.

Data Analysis: ORNL used PRISM to weather-normalize utility billing data. There was a treatment and a control group for each retrofit measure. Houses were dropped from the study that did not have at least one year of preprogram fuel consumption, used supplemental heating fuels, installed additional weatherization measures or had occupancy changes. LBL entered the data as eight aggregate points which consisted of all the treatment or control houses for an individual retrofit measure in one state.

Results: The treatment group, control group, and net savings are shown below for each of the four retrofits.

Measure	Treatment Group Savings	Control Group Savings	Net Savings
Heat Extractors	4%	-4%	8%
Power Burners	5%	-1%	6%
Thermally Actuated Vent Dampers	-2%	-3%	-1%
Electric Vent Dampers and Electronic Ignition	3%	-2%	5%

The energy savings from heat extractors do not include the extra electricity required for pumps to circulate the cooling water and drain the condensate. Heat extractors used oversized 0.25 horsepower motors, which may have used one third of the primary energy that the heat extractor saved (Hopkins, Mark [ASE], personal communication, 1989). Additionally, the heat extractors had serious reliability problems. They are no longer available for the residential market.

G064: Wisconsin - 1985 ORNL/WECC/ASE Audit Field Test[57]

Building/Retrofit Description: In 1985 and 1986, ORNL, ASE, and Wisconsin Energy Conservation Corporation (WECC) conducted an audit-directed retrofit program designed to optimize the benefit-to-cost ratio of energy efficiency retrofits. The first step in the process is for an auditor to collect the relevant information on the treatment houses to allow prediction of the expected savings from different measures. Savings and costs are estimated and then the benefit to cost (B/C) ratio of each retrofit is calculated. The retrofits are ordered by the B/C ratio and then the B/C ratios are revised due to interactions. Retrofits with the highest B/C ratios are selected first. Thus, more money is spent on some houses than others. Houses with the largest initial consumptions generally received the most retrofit dollars.

There were twenty treatment and twenty eight control homes. Retrofit measures included condensing furnace installations, wall insulation, vent dampers, intermittent ignition devices, infiltration reduction, and exterior foundation insulation. All furnaces that were not replaced were cleaned and tuned at a cost of $70.

The saturation of retrofit measures is given below.

Measure	Saturation (%)
Caulking/weatherstripping	50
Intermittent ignition device	40
Condensing furnace installation	35
Wall insulation	30
Vent damper	30
Sill box insulation	25
Attic insulation	20
Furnace cleaning and tuneup	15
Exterior foundation insulation	10

Data Analysis: Shell measures savings were predicted by using a steady state heat loss calculation with degree days corresponding to the house's estimated balance temperature. Savings from retrofitting the heating system were predicted based on estimated heating system efficiency changes. Predicted savings were 20 MBtu/yr for both the condensing furnace subgroup and the entire sample. Space heat was submetered. Metering ran from late October, 1985 to early May, 1986. Most of the retrofits were performed at the end of January. Heating fuel consumption was calculated by multiplying the run-time meter reading by the consumption rate of the heating system. The consumption rate of the heating system was found by turning off all the other appliances and timing one revolution of the utility meter. Miscellaneous pilots were not turned off leading to a 1-5% overestimation of the furnace firing rate.

LBL entered the data as four aggregate points: condensing furnace installations (three), minor retrofits (seven), an overall treatment group (twenty) and a control group (twenty eight). Two of the three houses with condensing furnace installations also had sill box insulation added. As the cost and energy savings attributable to this measure are small compared to those for the condensing furnace, LBL opted to include all three houses in the furnace replacement group.

Households were excluded that used significant auxiliary heat. Thirty eight of the forty eight homes had $R^2 > 0.90$. LBL assumed twenty five year lifetimes for the new condensing furnaces and a ten year lifetime for the minor retrofits. For the group that included all the treatment homes, LBL assumed a twenty year average lifetime for the packages of measures.

Results: There was a wide scatter on the savings from condensing furnace replacements (42, 9, and 31 MBtu). Given the wide scatter and small sample size, the data is not conclusive. The savings for all the measures are given below.

Measure (# of Units)	Predicted Savings (MBtu)	Measured Savings (MBtu)	Measured/ Predicted Savings (%)	Payback Time (yrs)
Condensing furnaces (2)	20.3	27.2	134	9.3
Minor Retrofits (7)	3.5	-0.6	-	-
Overall Group (20)	19.7	16.4	83	11.7

Control group consumption increased by 0.5 MBtu per year.

G065: Minnesota - 1981 LIW[58]

Building/Retrofit Description: The study took a representative sample of 274 site-built and mobile homes weatherized in 1981 under Minnesota's low income weatherization program. Weatherization measures and saturations for the site-built homes are listed below.

Measure	Saturation (%)
Weatherstripping and caulking	96
Glass repair	63
Attic insulation	62
Water heater wrap	56
Storm doors	39
Storm windows	35
Basement insulation	31
Wall insulation	29
Floor insulation	17
Furnace work	10
Clock thermostats	8

For the mobile homes, insulation retrofits had different saturations than for the site-built homes. Attic insulation was installed half as often as in site-built homes, wall insulation one third as often, and floor insulation more often. Furnace retrofits were done in approximately 40% of the mobile homes.

Data Analysis: To obtain the retrofit cost, LBL multiplied the materials cost by 2.2 (based on 60/40 labor/materials split). The corresponding combined labor and materials costs were $850 for site-built homes and $700 for mobile homes. Homes with occupancy changes were excluded from the sample. Weather normalization was done by scaling estimated space heat fuel usage to the ratio of longterm actual-year HDDs. LBL assumed that 80% of the pre-retrofit NAC was used for space heating (EIA 1989). LBL entered the data in two aggregate groups: the 239 site-built homes and the 35 mobile homes and assumed a fifteen year lifetime for the retrofit package.

Results: Site-built homes achieved 14 percent savings, corresponding to a 7 year simple payback period. Mobile homes had 11 percent savings for a 11 year simple payback period.

G066: Wisconsin - 1984 Utility LIW[59]

Building/Retrofit Description: The Utility Weatherization Assistance Program (UWAP) involves all Class A gas and electric utilities in Wisconsin and provides free weatherization services to qualified low-income households. The analytical sample for the evaluation of the 1984 program contained 483 treatment houses and 265 control houses. The sample was designed to be representative of the state low income housing stock, but due to data quality screening criteria, the final sample was less representative. Measures offered included: water heating retrofits (tank wraps and water flow restrictors), insulation for all areas of the house, furnace replacements and retrofits (electronic ignition, setback thermostat, and vent dampers), storm windows and doors, blower door sealing and caulking and weatherstripping, and attic ventilation. An average of $1594 was spent on each house.

Data Analysis: Utility billing data was weather normalized using PRISM. Homes included in the sample had no occupancy changes, at least six consecutive billing dates, $R^2 > 0.75$, and positive baseloads and heating slopes. LBL received all the data on disk and extracted records for houses with individual retrofit measures. LBL looked for expensive individual retrofits where less than $100 was spent on other measures and also screened for inexpensive water heating measures which might have provided substantial savings at low cost. Thirty-three homes had furnace replacements and less than $100 worth of other work done (average cost of $1624 including $35 of additional work). The installed cost of the furnaces ranged from $700 to $2500. Neither the efficiencies or capacities of the new furnaces were recorded. Seven homes had wall insulation and less than $100 of additional work (average cost of $702 including $27 of additional work). LBL entered the data in four aggregated groups: the treatment group of weatherized homes (483), the control group (265), and subsets of **furnace replacements** (33), and **wall insulation** (7). LBL assumed a fifteen year lifetime for the general treatment group and twenty-five years each for the furnace replacements and wall insulation. Based on data in the Residential Energy Consumption Survey for houses in this degree day range, LBL assumed that 80% of the pre-retrofit NAC was used for space heating (EIA 1989).

Results: The weatherization treatment group averaged 23 MBtu savings (17%). At $6.46/MBtu, the simple payback period was 11 years. The control group consumption increased 4 MBtu (3%). The furnace replacement subset averaged 26 MBtu savings (20%) and had a payback period of 10 years. Since the efficiency and capacity of the new furnaces were not recorded, LBL can not correlate the savings to either likely factor. The wall insulation subset averaged 19 MBtu savings (17%) and had a 6 year payback. The insulation costs ranged from $125 to $1170, indicating that some houses were partially insulated.

G067: Minneapolis, Minnesota - 1988 Robinson Foundation Insulation (Unconditioned Basements)[60]

Building/Retrofit Description: In 1988, twenty well-insulated homes in Minneapolis received wall insulation. After screening the data, fifteen homes remained. Nine of these were retrofitted with interior foundation insulation and the other six received exterior foundation insulation. The interior foundation insulation retrofits was either fiberglass batts or polystyrene sheets, while all the exterior insulation was polystyrene sheets. The interior insulation cost averaged $2130 including the sheet rock and $1173 without sheetrock. Since LBL is interested in the savings due to energy-related costs, we used the $1173 cost figure. The exterior foundation insulation cost averaged $1676.

Data Analysis: Utility billing data was weather normalized using PRISM. Using the Minnesota RCS audit, energy savings of 32 and 17 MBtu/yr were predicted for interior foundation and exterior foundation insulation. LBL entered the interior and exterior foundation insulation as two aggregate groups and assumed a twenty year lifetime for each.

Results: The interior insulation saved 6 MBtu (6%) and had a payback period of 33 years. The exterior insulation saved 2 MBtu (3%) and had a payback period of 127 years. Energy savings were significantly higher in the group of houses that participated in the Minneapolis Energy Office (MEO) foundation insulation study [G051] (10 to 15% for interior and exterior insulation respectively) compared to the homes that were monitored by Robinson Technical Services (3-6%). The apparent discrepancy in performance may be due to the fact that the Robinson study sought to study conductive losses only. They therefore performed infiltration reduction in the basement at the beginning of the pre-retrofit heating season. Thus, the MEO study was recording savings from both air sealing and reduced conduction losses, while the Robinson study recorded lesser savings from reduced conduction losses only.

G068: Pennsylvania - 1986 NCAT Critical Needs Project (Warm Rooms)[61]

Building/Retrofit Description: In 1986, the National Center for Appropriate Technology (NCAT) carried out "warm room" retrofits on twenty-five houses in Pennsylvania. A 37 kBtu gas zone heater was installed in each house and used in place of the central heating system. The houses also received zoning and infiltration reduction measures as well as ceiling insulation and client education was stressed. Costs were not well documented but were estimated to be $2,200 per house.

Data Analysis: Post-retrofit monitoring was done for four to six months during the heating season. Energy consumption data was given only for the monitoring period, not for an annual period. In order to calculate annual space heating values, LBL scaled up the pre-retrofit space heating consumption for the monitoring period by multiplying the it by the ratio of the HDDs in a year to the number in the monitoring period. For the post-retrofit space-heating, LBL assumed that the retrofit was only used during the deep heating season (corresponding to the monitoring period) and did not scale up the savings.

LBL assumed a fifteen year lifetime for the retrofit. LBL assigned this zoning retrofit a longer lifetime than the Kansas City project (G053), which was assigned a ten year lifetime, because both the zone heater and the insulation have long lifetimes. The Kansas City project used curtains and infiltration reduction measures that have shorter lifetimes.

Results: The retrofit produced 35 percent space heat savings, which corresponds to 23% of total gas consumption. The payback period is 12 years. Ten of the participants preferred the zone heater to the central furnace, eight accepted the central heater because it saved them money, and seven preferred the central furnace. Central heating systems result in more uniform temperatures throughout the house and two participants had problems with exposed pipes freezing when they used the zone heater. Note, since a space heater has no distribution system, it will thus work better in a more open floor plan.

G069: Buffalo, New York - 1988 Oak Ridge Audit Field Test[62]

Building/Retrofit Description: The purpose of this study was to test a new audit procedure developed by Oak Ridge National Laboratory for selecting the most cost-effective retrofit options. The 32 treatment and 40 control homes were all located in Buffalo, New York. The retrofits were done in 1988. The treatment and control houses were poorly insulated, 62% had no wall insulation and 17% had no envelope insulation at all.

For this audit procedure, options are ranked by benefit-to-cost ratio (B/C). The highest B/C ratio options for a group of houses are selected first and consequently some houses will receive more work than others. After an option is selected, the remaining options are adjusted to account for their interaction with previously selected measures. Options are chosen until the retrofit funds are spent or a minimum B/C ratio is reached. The overall B/C ratio for the treatment houses was 1.25 using local fuel prices and a five percent discount rate. An average of $1453 was spent per house, but less than $500 was spent in five houses and more than $2000 was spent in eleven houses.

Infiltration reduction measures were done first and a B/C ratio of 2.0 was used for the cutoff, since savings from infiltration reduction are difficult to predict. Furnace tune-ups were often done for safety and liability reasons, not for predicted cost-effectiveness. Attics with less than R-10 insulation were insulated. Of the thirty six treatment homes, five were completely insulated prior to the start of the program. Twenty three of the remaining thirty one had wall insulation installed in all uninsulated areas. Of the other eight, two had brick or stone siding, three had B/C ratios greater than 1.0, and for three others the measure was determined to be not applicable. Heating system replacement was cost-effective in six homes before considering the interaction with higher B/C ratio options. Then heating system replacement was cost effective in only one house.

Measure	Saturation (%)
Water Heater Pipe Insulation	97
Furnace Tune-up	89
Infiltration Reduction	86
Attic Insulation	81
Water Heater Tank Wrap	72
Hot Water Temp. Reduction	69
Wall Insulation	64
Sill Box Insulation	47
Floor Insulation	11
Interior Foundation Insulation	6
Condensing Furnace	3
Water Heater Replacement	3

Data Analysis: Shell measures savings were predicted by using a steady state heat loss calculation with degree days corresponding to the house's estimated balance temperature. Savings from retrofitting the heating system were predicted based on estimated heating system efficiency changes. Savings of 35 MBtu/yr were predicted for the treatment group. Houses with occupancy changes or substantial use of a secondary heating fuel were not included in the study. ORNL split houses into four categories: high and low consumption furnaces and boilers. Half of the houses in each group were randomly assigned to the treatment or control groups. Heating and hot water use were submetered. Indoor temperatures were monitored and found to increase 0.5°F in the post-retrofit period. LBL assumed a twenty year lifetime for the retrofits because the measures that save most of the energy (insulation) have long lifetimes.

Results: Treatment homes experienced 15% savings and a 13 year simple payback period. Energy use for both the control and treatment groups are shown below.

End Use	Treatment Group NAC		Control Group NAC	
	Pre-retrofit	Post-retrofit	Pre-retrofit	Post-retrofit
Space Heating	102.1	83.8	90.2	96.3
Water Heating	27.2	25.6	29.0	29.5
Baseload other than hot water	3.5	3.5	4.2	4.0
Total Consumption (MBtu)	132.8	112.9	123.4	129.8

G070: Minneapolis, Minnesota - 1982 MEO NEW Program (House Doctoring)[63]

Building/Retrofit Description: The Minneapolis Energy Office (MEO) and Minnegasco began co-sponsorship of the Neighborhood Energy Workshop (NEW) program in 1981. The program is owner-performed house-doctoring coupled with extensive training and energy education sessions. Expenses are kept low (average = $80) and simple measures, such as sealing attic bypasses, caulking and weatherstripping, and water heating measures are emphasized. 110 houses that were retrofitted in 1982 were analyzed.

Data Analysis: Billing data was weather normalized using PRISM. LBL entered the entire sample of 110 houses as one data point and assumed a lifetime of ten years for the house doctoring measures. Based on data in the Residential Energy Consumption Survey for houses in this degree day range, LBL assumed that 80% of the pre-retrofit NAC was used for space heating (EIA 1989).

Results: Initial consumption was high (173 MBtu/yr) and the savings averaged 14 MBtu/yr (8%). The simple payback time was one year.

G071: Minneapolis, Minnesota - 1985 MEO Project Choice (High Users)[64]

Building/Retrofit Description: In 1985, six Minneapolis government and non-profit agencies formed Coordinated Energy Services (later renamed Project Choice) to reduce gas bills and payment arrearages in low income homes. A group of high energy users was targeted for this study. Thirty homes received house doctoring and thirteen received house doctoring and weatherization. Client education was a part of all the retrofits. An average of $602 was spent on the house-doctoring homes and $2,259 was spent on the homes that received house-doctoring and weatherization. The additional weatherization was mainly in the form of attic and wall insulation.

Data Analysis: Billing data was weather normalized using PRISM. LBL entered the homes as two data points: house-doctoring only and house-doctoring with weatherization. LBL assumed a lifetime of ten years for the house doctoring measures and fifteen years for the combined house-doctoring and insulation. Based on data in the Residential Energy Consumption Survey for houses in this degree day range, LBL assumed that 80% of the pre-retrofit NAC was used for space heating (EIA 1989).

Results: Initial consumption was extremely high (average of 242 MBtu/yr for all 43 homes). The savings averaged 21 MBtu/yr (9%) for the house-doctoring only sample and 48 MBtu/yr (21%) for the house-doctoring and weatherization group. The simple payback time was 5 years for weatherization and 9 years for the house-doctoring and weatherization. Post-retrofit consumption was still relatively high (181 MBtu/yr), even in the homes that received house-doctoring and weatherization, compared to typical existing single-family homes in Minnesota.

G072: California - 1986 Pacific Gas and Electric Weatherization[65]

Building/Retrofit Description: Initiated in 1983, Pacific Gas and Electric's Direct Weatherization Program weatherized 252,000 homes by the end of 1987. The program provides no cost retrofits to households earning less than 150% of the poverty guideline or senior citizens with incomes less than 200% of the poverty level. Retrofit measures include ceiling insulation, caulking and weatherstripping, low flow showerheads, water heater tank wraps, and duct wrapping. The homes that were analyzed were retrofitted between January and May, 1986. An average of $523 was spent on site-built homes and $408 was spent on mobile homes.

Data Analysis: Data was weather normalized using a variable reference temperature method similar to PRISM. LBL entered the data in three groups: site-built homes (5,920), mobile homes (671), and the control group (5,020) and assumed a fifteen year lifetime for the retrofit package.

Results: Site-built homes saved 5 MBtu per year (8%) and had a simple payback of 21 years. Mobile homes had considerably poorer performance: savings of less than 1 MBtu per year, corresponding to a payback of more than 100 years.

G073: Minnesota - 1984 LIW[66]

Building/Retrofit Description: The University of Minnesota Underground Space Center conducted an evaluation of the 1984 Minnesota low income weatherization program by selecting a random sample of 1,200 houses weatherized that year. The saturation of measures is given below.

Measure	Saturation (%)
Caulk/weatherstrip	99
Water heater tank wrap	73
Attic insulation	66
Glass repair	53
Storm windows	34
Wall insulation	25
Exterior foundation insulation	23
Heating System Repairs/Retrofits	13
Interior foundation insulation	12
Rim joist insulation	12
Floor insulation	11
Storm doors	9
Clock thermostat	2

An average of $1086 was spent on site-built homes ($496 for materials) and mobile home expenditures averaged $824 ($397 for materials).

Data Analysis: Utility billing data was weather normalized using PRISM. Screening criteria for the final sample included: no occupancy changes, minimum of four meter readings during the pre- or post-retrofit period, $R^2 > 0.90$, standard error of the NAC less than ten percent of the pre- or post-retrofit value, and reference temperature between 40°F and 80°F. LBL entered the data in two aggregate groups: site-built homes (155) and mobile homes (28). In general, DOE low income weatherization programs are assigned a fifteen year lifetime. However, due to the high saturations of insulation retrofits, we assigned a twenty year lifetime to the package of measures used in site-built homes. LBL assumed a fifteen year lifetime for the measures installed in mobile homes. The difference in assumed lifetimes is due to the fact that the mobile homes had ceiling insulation installed much less frequently. Based on data in the Residential Energy Consumption Survey for houses in this degree day range, LBL assumed that 80% of the pre-retrofit NAC was used for space heating (EIA 1989).

Results: The site-built homes saved 12 MBtu per year (9%) which resulted in a seventeen year payback. Less money was spent on mobile homes, but they had dramatically lower savings. Mobile homes averaged savings of 3 MBtu per year (3%) which corresponded to a simple payback period of forty-five years.

G074: Michigan - 1984-85 PSC Home Repair and Weatherization Program[67]

Building/Retrofit Description: The Public Service Commission (PSC) conducted an evaluation of the 1984-85 Michigan Home Repair and Weatherization Program. The program targets households receiving public assistance for heating bills, with high users getting first priority. Repairs are designed for energy conservation or to protect newly installed measures. The program has a per house limit of $5000. For the 1984 group of 41 homes, an average of $2029 was spent on repairs in addition to $1,489 for weatherization for a total average retrofit cost of $3518. Administrative costs were $923 per house. For the 158 homes weatherized in 1985, an average of $2039 was spent on repairs, and $1422 for weatherization for a total cost $3461. The saturation of retrofits and repairs is shown below.

Measure	Saturation (%) 1984	1985
Caulking	100	92
Door/Window Repair	95	98
Water Heater Tank Wrap	90	89
Wall Insulation	73	79
Ceiling Insulation	61	68
Weatherstripping	54	48
New Furnace	41	21
Roof Repair/Replacement	41	43
Vent Damper	39	71
Clean/Adjust Furnace	12	5
Rewiring	10	30
Storm Windows	7	15
Floor Insulation	5	11
Plumbing	2	44

Data Analysis: Baseload gas use was estimated from summer energy use. Space heating energy use was then calculated by subtracting the baseload from total consumption. Space heating fuel use was weather normalized by scaling the consumption by heating degree days. Houses with supplemental heating fuels or occupancy changes were dropped from the sample. LBL assumed a lifetime of twenty years for the retrofit measures due to the the high incidence of wall and ceiling insulation and furnace replacements.

Results: Initial consumption levels were extremely high, over 375 MBtu per year. The 1984 repair/weatherization program saved 25 percent (95 MBtu) and had a simple payback period of 6 years. The 1985 program saved 21 percent (81 MBtu) and the payback period was 7 years.

G075: Michigan - 1986 PSC Weatherization Measures Priority System[68]

Building/Retrofit Description: In 1986, the Michigan Public Service Commission experimented with a new weatherization priorities list to increase the cost-effectiveness of the standard weatherization measure priority list that was then in use in the Michigan low income weatherization program. The saturation of measures for the houses retrofit under the old and new system is given below.

Measure	Saturation (%) New Program	Old Program
Infiltration Reduction	85	97
Wall Insulation	60	2
Ceiling Insulation	59	69
Water Heater Tank Wraps	30	75
Storm Windows	27	75
Clock Thermostat	23	0
Infiltration Repairs	18	36
Low Flow Showerhead	15	0
Band Joist Insulation	13	23
Pipe Insulation	7	13

The new program emphasizes wall insulation, low flow showerheads, and clock thermostats more than the old program, while the use of storm windows and water heater tank wraps has decreased. The decrease of water heater wraps is coincidental as it is assigned a high priority under the new system. Also, infiltration was separated into two categories under the new system. Major infiltration is a high priority and minor infiltration is not. Additionally, the new program decreased the required ceiling insulation level from R-38 to R-19. Average expenditures were comparable at $978 per house for the old program and $941 for the new program.

Data Analysis: The Michigan PSC estimated baseload gas use from summer energy use. Space heating energy use was estimated by subtracting this baseload from total consumption. Space heating fuel use was then weather normalized by scaling the consumption by heating degree days. In order to calculate the NAC, LBL used an estimate by the Michigan PSC (Personal communication Patti Witte, December 1990) that space heating was 80% of the NAC. Additionally, based on a subsample of 31 homes, the PSC estimated baseload water heating savings to be 13% of the baseload. These assumptions were used to calculate the pre-retrofit NAC and the baseload from the reported space heating values. Screening criteria for the analytical sample included no supplemental fuels and no occupancy changes for at least one year prior to the retrofit. LBL assumed a lifetime of twenty years for the new retrofit package due to the high incidence of both wall and ceiling insulation. For the old package LBL assumed a lifetime of fifteen years. LBL entered the data as two aggregate points: the old (65 houses) and the new (173 houses) weatherization priority systems.

Results: The new approach saved an average of 27 MBtu (19%) of the space heating energy end use while the old system produced savings of 18 MBtu (13%). The new measure prioritization approach had a simple payback period of 7 years versus 10 for the old system.

G076: Michigan - 1983 LIW[69]

Building/Retrofit Description: The Michigan Public Service Commission conducted a study of the state's 1983 low income weatherization program. Standard and reduced-cost weatherization techniques were compared. The reduced cost weatherization program installs R-19 instead of R-33 ceiling insulation, installs a high saturation of water heater tank wraps, and does not install storm windows. Neither program installs wall insulation. The saturation of retrofits and repairs for the two different programs is shown below.

Measure	**Saturation (%)**	
	Regular	Reduced-Cost
Caulking	99	100
Weatherstripping	97	96
Ceiling Insulation	95 (R-33)	100 (R-19)
Door/Window Repair	94	94
Storm Windows	87	0
Basement Infiltration Reduction	59	100
Floor Insulation	14	0
Water Heater Tank Wrap	4	83

For the group of 364 homes that received standard weatherization, an average of $494 was spent on materials and $419 for labor for a total average retrofit cost of $913 per house. For the 72 homes weatherized under the reduced-cost program, materials averaged $305 per house and labor was $376 for an average retrofit cost of $681 per house.

Data Analysis: Control houses were randomly selected from the waiting lists of weatherization agencies participating in this study. Baseload gas use was estimated from summer energy use. Space heating energy use was then calculated by subtracting the baseload from total consumption. Space heating fuel use was weather normalized by scaling the consumption by heating degree days. Only space heating energy use was reported, but based on a PSC estimate (personal communication Patti Witte, December 1990) LBL assumed that space heating was 80% of the NAC. This assumption was used to calculate the pre-retrofit NAC and the baseload. Post-retrofit NAC was calculated by adding the post-retrofit space heating and the pre-retrofit baseload. Since baseload consumption was not reported, it was assumed to be unchanged by the retrofit. However, due to the high saturation of water heating retrofits in the reduced-cost group, actual NAC savings are somewhat higher than reported. Houses with supplemental heating fuels or occupancy changes were dropped from the sample. LBL entered the data in two groups, regular and reduced-cost weatherization and assumed a lifetime of fifteen years for the packages of retrofit measures used in both programs.

Results: The regular weatherization program saved 15 percent (21 MBtu) and had a simple payback period of 7 years. The reduced-cost program saved 9 percent (12 MBtu) and the payback period was 10 years.

G077: Michigan - 1984 LIW[70]

Building/Retrofit Description: The Michigan Public Service Commission conducted a study of the state's 1984 low income weatherization program. Both site-built and mobile homes were analyzed. The saturation of retrofits and repairs for the two different samples is shown below.

Measure	Saturation (%) Single-Family	Saturation (%) Mobile Homes
Caulking	99	85
Weatherstripping	97	92
Door/Window Repair	94	87
Storm Windows	79	66
Ceiling Insulation (R-33)	73	0
Basement Infiltration Reduction	44	n.a.
Floor Insulation	16	7
Water Heater Tank Wrap	3	17

For the group of 155 site-built homes that were weatherized, an average of $441 was spent on materials and $485 for labor for a total average retrofit cost of $926 per house. For the 47 mobile homes, materials averaged $198 per house and labor was $155 for an average retrofit cost of $353.

Data Analysis: Baseload gas use was estimated from summer energy use. Space heating energy use was then calculated by subtracting the baseload from total consumption. Space heating fuel use was weather normalized by scaling the consumption by heating degree days. Only space heating energy use was reported, but based on a PSC estimate (personal communication Patti Witte, December 1990) LBL assumed that space heating was 80% of the NAC. This assumption was used to calculate the pre-retrofit NAC and the baseload. Post-retrofit NAC was calculated by adding the post-retrofit space heating and the pre-retrofit baseload. Since baseload consumption was not reported, it was assumed to be unchanged by the retrofit. As few water heaters were wrapped, this is a reasonable assumption. Houses with supplemental heating fuels or occupancy changes were dropped from the sample. LBL entered the data in three groups: the 155 site-built homes, the 47 mobile homes, and 125 control houses. For the site-built homes, we assumed a lifetime of fifteen years for the package of retrofit measures. Since the mobile homes received mainly caulking and weatherstripping, LBL assumed a ten year lifetime for those retrofits.

Results: The site-built houses saved an average of 12 percent (17 MBtu) and had a simple payback period of 9 years. The mobile home group averaged 5 percent savings (4 MBtu) and the payback period was 15 years.

G078: 1989 Indiana ECFAP Weatherization[71]

Buildings/Retrofit Description: From 1984 to 1989, the Indiana Energy Conservation Financial Assistance Program (ECFAP) provided partial subsidies for low and moderate income households that installed energy conservation measures. Common measures installed under the program were replacement furnaces and windows, and attic and wall insulation. In recent years, the majority of funds allotted have been for furnace replacements and window replacements. Eligibility for the program required a maximum income of 150% of the median area income. Subsidies ranged from 20-50% with lower income participants receiving the larger subsidies.

Data Analysis: Houses were excluded that had occupancy changes or changes in the conditioned space. Data were further screened using a minimum $R^2 = 0.90$ and a coefficient of variance of the NAC of less than 0.06. Cost data includes only the reported costs funded by the program. Some households may have installed other measures at the same time and not received any money from the program. In this case, these costs would not be included. LBL entered the data in three groups: overall program (234 houses), condensing furnace installations (30 houses), and window replacements (41 houses). LBL assumed a twenty-five year lifetime for all the sets of measures.

Results: Overall, the expenditures averaged $1,880 per house and the program saved 15 MBtu/year (11%). The simple payback period was twenty-six years (at $4.90/MBtu). Condensing furnace replacements cost $2,110 and saved 29 MBtu/year (19%), corresponding to a fifteen year payback. Window replacements were extremely costly ($3,350/house) and saved only 1% of total household energy use. The payback is essentially infinite given these results. A control group of 383 neighboring houses increased by 1.3%.

G079: 1985 Manitoba Energy and Mines Condensing Furnace Replacements[72]

Buildings/Retrofit Description: Manitoba Energy and Mines sponsored a study to document the performance of of furnace replacements done between September 1985 and August 1986 in Winnipeg, Manitoba. Questionnaires were mailed to almost one thousand homes that installed new furnaces of various efficiency. After data screening, forty-nine homes with **condensing furnace replacements** remained. The condensing furnaces replaced existing gas and oil furnaces and almost all the replacements were downsized. The retrofit cost was approximately $2,750 1986 Canadian dollars. Using an exchange rate of 1.39:1, the cost in U.S. dollars was $1980.

Data Analysis: For the initial analysis, space heat data was scaled to heating degree days. Since the actual consumption numbers were difficult to obtain, Manitoba Energy and Mines estimated them for us off bar graphs in the report. Screening criteria included no occupancy changes, no supplemental heat, a steady pattern of hot water usage and electricity consumption, and no other significant retrofits.

Results: All houses experienced large savings. Space heat savings ranged from 19% to 50% (average = 33%) for all forty-nine houses with an average of 39 MBtu per year. The simple payback period was 16 years using the local gas price of $3.17/MBtu, but the CCE is favorable at $4.82/MBtu considering current gas prices.

G080: New York - 1988 LIW[73]

Buildings/Retrofit Description: In 1988, the New York low income weatherization program weatherized 20,675 homes. Based on data from those homes, Synertech Systems Corporation conducted the first thorough examination of the the state's low income weatherization program. For the sample of 683 gas-heated home sample the average cost was $964. Retrofit measures included general heat waste reduction using blower doors, hot water water retrofits, attic insulation, and wall insulation.

Data Analysis: Synertech used a modified version of PRISM to weather normalize utility billing data. They assumed that the reference temperature before and after the retrofit was the same. However, if significant shell retrofits are done, this will not be true. LBL entered all the gas heated homes as one data point and assumed a fifteen year lifetime for the package of retrofit measures. Based on data in the Residential Energy Consumption Survey for houses in this degree day range, LBL assumed that 75% of the pre-retrofit NAC was used for space heating (EIA 1989).

Results: The savings averaged 19 MBtu/year (12%). At a cost of $964 per house, the simple payback period is 9 years. Houses with significant expenditures on window replacements were found to have a statistically significant greater likelihood of no or negative savings.

G081: Illinois - 1986 Mobile Home Weatherization[74]

Buildings/Retrofit Description: The Energy Resources Center at the University of Illinois - Chicago evaluated energy savings of mobile homes weatherized in 1986 using Illinois Heating Weatherization Assistance Program (IHWAP) funds. The final sample contained 227 treatment homes and 73 control homes. The average cost was $1,072 per home. The saturation and cost of measures is given below.

Measure	Saturation (%)
Window, door replacement	96
Clock thermostat	52
Insulated skirting	21
Floor insulation	17
Insulate existing skirting	12
Storm windows	7

Data Analysis: Utility billing data was weather normalized using PRISM. Houses with $R^2 < 0.8$ in either the pre- or post-retrofit period were dropped from the study. LBL entered all the homes as one data point. LBL assumed a twenty year lifetime for the package of retrofit measures since the main measures, window replacements and floor insulation have long lifetimes.

Results: The treatment group savings averaged 5.5 MBtu/year (6%). At a cost of $1,072 per house, the simple payback period is 36 years. The control group experienced no change in consumption.

G082: Wisconsin - 1983 Utility LIW[75]

Building/Retrofit Description: The Utility Weatherization Assistance Program (UWAP) involves all Class A gas and electric utilities in Wisconsin and provides free weatherization services to qualified low-income households. The 1983 utility low-income weatherization program weatherized 2,090 houses. For comparison, the state program weatherized 4,000 houses in the same period.

Measure	Saturation (%)
Caulking/weatherstripping	95
Attic insulation	77
Furnace retrofits	58
Wall insulation	40
Furnace replacements	29
Sillbox insulation	28
Water heater tank wrap	17
Storm windows	16
Setback thermostat	14
Foundation insulation	14
Floor insulation	9
Low flow showerhead	8

An average of $2,134 was spent on each house.

Data Analysis: Utility billing data was weather normalized using PRISM. Homes included in the sample had at least ten consecutive billing dates and $R^2 > 0.90$ for both the pre- and post-retrofit periods. LBL assumed a fifteen year lifetime for the package of measures and entered the data in two aggregate groups: 606 treatment houses and 366 control houses. Control group houses were eligible homes that had not yet been weatherized, but they were not screened to assure that no retrofits were done by the homeowners. Based on data in the Residential Energy Consumption Survey for houses in this degree day range, LBL assumed that 80% of the pre-retrofit NAC was used for space heating (EIA 1989). Based on a breakdown by the author, average baseload savings in the treatment group were 5.8 MBtu/yr and the rest of the savings were assigned to the space heating end use.

Results: The weatherized houses averaged 29 MBtu savings (19%). The simple payback period was 11 years. Control group consumption decreased by 1.2%.

G083: Illinois - 1988 LIW[76]

Building/Retrofit Description: An evaluation of the 1988 Illinois weatherization program analyzed 157 homes, 24 of which were mobile homes and 3 of which were multifamily units. The saturation of measures is given below.

Measure	Saturation (%)
Caulking/weatherstripping	97
Door replacement	61
Attic insulation	45
Window replacement	45
Wall insulation	42
Floor insulation	39
Storm windows	30
Sill box insulation	20
Foundation insulation	17

Caulking and weatherstripping was done using a blower door. An average of $2,134 was spent on each house.

Data Analysis: Furnace run time meters were used to determine energy savings. LBL assumed a fifteen year lifetime for the package of measures and entered the treatment group as one aggregate data point. Control group houses were eligible homes that had not yet been Based on data in the Residential Energy Consumption Survey for houses in this degree day range, LBL estimated the NAC from space heating values by assuming that 75% of the NAC was used for space heating (EIA 1989).

Results: The weatherized houses averaged 21 MBtu savings, corresponding to 15% space heat savings (approximately 12% NAC savings). The simple payback period was 10 years.

G084: Virginia - 1988 LIW[77]

Building/Retrofit Description: The Virginia Center for Coal and Energy Research conducted the first evaluation of Virginia's low income weatherization program using data from the 1988 program. The saturation of weatherization measures in the sample of 91 homes is given below.

Measure	Saturation (%)
Caulking/weatherstripping	100
Attic insulation	56
Storm windows	44
Door replacements	41
Water heater wrap	21
Window replacements	25

More than 20 tubes per house of caulking were installed in 75% of the sample. Total costs averaged $1,489 per house, including materials, labor, and overhead. Labor costs are not explicitly accounted for, but rather are assumed to be a given percentage of material costs.

Data Analysis: Utility billing data was weather normalized using PRISM. Local weatherization agencies are reimbursed 229% of material costs (average of $1,489 per house). LBL assumed that 1/3 of the cost was overhead and thus assumed a retrofit cost of $993. (For comparison, the 1989 Virginia pilot program had 32% overhead). To calculate the end use fractions of the NAC, LBL assumed that 70% of the pre-retrofit NAC was used for space heating (EIA 1989). LBL entered the data as one aggregate group and assumed a fifteen year lifetime for the package of measures.

Results: Gas consumption decreased 7 MBtu (7%) after the retrofit, corresponding to a 26 year payback period.

G085: Illinois - 1984 LIW[78]

Building/Retrofit Description: A sample of 497 homes were analyzed in an evaluation of the 1984 Illinois low-income weatherization program. 387 were single-family detached houses, 60 were multifamily, and 46 were mobile homes. The saturation of measures is given below.

Measure	Saturation (%)
Ceiling insulation	72
Storm windows	52
Clock thermostat	47
Wall Insulation	37
Foundation insulation	34
Storm doors	30
Floor insulation	11

An average of $765 was spent on each house.

Data Analysis: Utility billing data was weather normalized by subtracting off the baseload and scaling by heating degree days. LBL assumed a fifteen year lifetime for the package of measures and entered the treatment group as one aggregate data point. LBL estimated the NAC from space heating values by assuming that 75% of the NAC was used for space heating (EIA 1989).

Results: Space heat savings were 14 MBtu/yr (10%) and the simple payback period was 10 years.

M001 through M008: 1979 CSA/NBS Optimal Weatherization Demonstration Program[79]

Buildings/Retrofit Description: The CSA/NBS Program was discussed earlier (see Label G014-G018) and overall results are listed there. The mixed fuels for M001 through M008 include natural gas, heating oil, propane, and electricity. There were few electrically heated homes in the sample (small numbers in Atlanta, Charleston, Easton) except in Tacoma where 25% of the homes used electric heat. Natural gas was the main fuel in the Atlanta and Tacoma groups, whereas homes in Charleston used mainly propane. Gas and oil usage were almost equal in Easton and Fargo homes. Oil was the dominant fuel in the Portland, Maine, and Washington, D.C. groups.

Results: Wide variance in energy savings and economic indicators was observed for individual houses in these sites. Aggregate results are presented below.

Category of Retrofit	**Space Heat Savings** (MBtu)	%	**Simple Payback** (yrs)
All Houses	45	31	8
Shell and System Retrofits	62	41	6
Shell Retrofits	23	18	11

M009: Northwest Wisconsin - 1976 CSA Demonstration Program[80]

Buildings/Retrofit Description: An evaluation of the 1976 CSA (Community Services Administration) Weatherization Program in the northwest quarter of Wisconsin was conducted by University of Wisconsin researchers. Of the 65 homes analyzed, 50% used fuel oil, 33% used propane, and 17% used natural gas for their space heating fuel. Retrofit costs averaged $220 per house.

Data Analysis: The study sampled 240 homes out of 4,344 weatherization jobs and obtained reliable fuel records and retrofit cost data for 75 homes (including 10 homes which relied primarily on wood-burning stoves for space heating which we have excluded in our analysis). LBL aggregated the consumption data for the various types of fuel and adjusted to a normal heating season.

Results: Space heat energy savings of 27 MBtu per year (19%) were obtained with a payback time of 2.4 years.

M010: Minnesota - 1978 LIW[81]

Buildings/Retrofit Description: Mid-America Solar Energy Center analyzed changes in consumption in low-income households participating in the DOE Weatherization Program in Minnesota. Over 2600 homes were weatherized in FY'77 and FY'78 in the state. The first study involved 59 weatherized and 37 control houses. Roughly 2/3 of the sample used natural gas and the other 1/3 used oil as the heating fuel. The principal weatherization actions were ceiling insulation, caulking and weatherstripping installed at an average cost of $910 per house.

Data Analysis: Care was given to checking fuel use data and homes with wood heating were eliminated. The study author made a baseload correction and also adjusted for a normal heating season.

Results: The treatment group had average savings of 14 MBtu per year (10%) and a payback period of 13 years. The control group showed a 2% increase in fuel consumption during the same time period. The second study followed 19 homes from the original sample group through a second post-retrofit winter. Their savings during the second year were not as large as the first year, with a 2-year average of 6.9 percent.

M011: Wisconsin - 1979 LIW[82]

Buildings/Retrofit Description: Results are reported from an 1979 evaluation study of the DOE Low-Income Weatherization Program in Wisconsin. The 13 home sample group mainly used natural gas for space heating but several homes were heated with propane or fuel oil. Retrofit costs averaged $1,090 per house.

Data Analysis: Total consumption data was provided by Cooper and LBL staff made a baseload correction to determine space heating consumption. Retrofit measures were not specified and the consumption data were suspect and thus a "D" confidence level rating was assigned to the results.

Results: Average space heat savings were 23 MBtu per year (17%) and the payback period was 11 years.

M012: Allegan County, Michigan - 1974-76 LIW[83]

Buildings/Retrofit Description: This study of the DOE Weatherization Program for low-income persons in Michigan involved the analysis of consumption data for 86 single-family homes. The primary data were provided courtesy of Mark Cooper of CECA but no information about the actual retrofit options was received. Based on a later report by Martin Kushler, retrofits measures for Michigan's weatherization program in this period would have included R-38 ceiling insulation, storm windows, and caulking and weatherstripping. Two-thirds of the sample group used oil as the heating fuel with the other one-third mainly natural gas with a sprinkling of liquid propane users. Retrofit costs averaged $1,050 per house.

Data Analysis: A baseload correction was made for the gas users and all consumption data was adjusted for a normal heating season (based on the 30-year average for heating degree-days). Significant missing elements in the data led us to assign a "D" confidence ranking to the results.

Results: The 44 MBtu (28%) annual space heating savings resulted in a payback time of 4 years.

M013: Sweden - Royal Institute of Building Technology[84]

Buildings/Retrofit Description: The Swedish government has sponsored an extensive program of home loans and grants for the installation of various conservation measures in existing residential buildings. These measures included attic and wall insulation, upgrading to triple glazed windows, and the installation of radiator thermostatic valves and motorshunts. The Royal Institute of Technology performed an in-depth analysis of several hundred single family houses which were heated by oil, electricity, wood or district heating. Sample homes were drawn from throughout the country to reflect different climate zones. A principal objective of the study was to compare actual and theoretical savings for different measures and combinations of measures.

Data Analysis: Houses included in the final analysis met the following criteria: no change in occupancy during the study period, no other conservation measures were performed by the residents, and no other structural changes to the building. Fuel bills for a period of at least one year before and after the retrofit were analyzed for each house and actual consumption was normalized to the long-term average value for heating degree days.

The data is presented by grouping the regional data (from the 5 counties) by measure or combination of measures. In calculating average values for heated dwelling area, energy consumption, and predicted theoretical savings, we weighted the above values by the number of houses from each region to estimate the mean.

Results: Regional average energy savings ranged from 12 - 24 MBtu per year. Unfortunately, cost data were not collected for the project and thus it is not possible to assess cost-effectiveness of the program and/or specific measures.

M025: Massachusetts - 1985 Audubon Society Weatherization[85]

Building/Retrofit Description: The Massachusetts Audubon Society (MAS) conducted fuel savings studies of the low income weatherization program administered by the Massachusetts Executive Office of Communities and Development (EOCD) during the winter of 1985-1986. The study looked at savings from **house-doctoring** and **storm windows**. Sixty three percent of the homes used oil for space heating, the rest used gas. Of the heating distribution systems, fifty two percent used hot air, twenty percent used hot water, seventeen percent used steam, and eleven percent did not respond. Twenty nine homes received house-doctoring by three contractors. There was no control group. House-doctoring cost $\$0.45/ft^2$ when performed by in-state contractors and the out-of-state contractor charged $900 for single family homes and $1,600 for two family homes. Eleven homes received storm windows and six were in a control group. An average of 16 windows per home were fitted with storm windows at an average cost of $720 per house.

Data Analysis: MAS excluded homes from the study which had changes in occupancy or an inadequate number of fuel bills. Fuel usage was calculated from weekly burner run-time meter readings taken by the tenants. The oil flow rate was determined by backing out the burner and noting the nozzle size. MAS assumed that the oil flow would be the rated flow for a given nozzle size. (If the pressure varies from the set point, this will not hold). Gas burners were assumed to consume fuel at the manufacturer's rated rate. Space heating fuel consumption was weather normalized by scaling it to the number of heating degree days. A temperature difference accumulator measured degree hour differences between indoor and outdoor temperatures. The balance point was taken to be 60°F (based on research by Fels, 1985). The indoor temperature was assumed to be 68°F, which was corroborated by averages of client thermostat settings. The pre-retrofit monitoring period was from mid-December to the end of January and the post-retrofit period was from mid-February to the end of March.

LBL entered the data as three aggregate data points: house-doctoring treatment group and window treatment and control groups. The authors of the study used the mean ratio method to estimate fuel savings: The mean ratio method compares the mean ratio of fuel consumption per degree hour during the pre-weatherization period to that during the post-weatherization period.

Results: Fuel savings had large uncertainties. The mean fuel savings for house-doctoring were 8.9 ± 7.6%. The median savings was 6.0%. Savings ranged from -0.4% to 25.6%. The simple payback period was approximately 8 years. Savings from house doctoring have a wide range. Fuel savings in the storm windows treatment group ranged from -0.5% to 20.6%. The mean fuel savings were 9.6 ± 9.6% and the median was 10.8%. In the control group, savings ranged from -9.1% to 9.4% with a mean of 2.0 ± 8.7%. The simple payback period was 6.1 years. House doctoring and storm windows are cost effective, but once again, other measures should be done first before installing storm windows.

M026: Energy Information Administration 1981 National LIW Study[86]

Building/Retrofit Description: The Energy Information Administration (EIA) conducted a national evaluation of DOE's 1981 LIW program. 965 homes weatherized in 1981 were randomly selected. The main heating fuel was natural gas for 66%, fuel oil/kerosene for 21%, LPG for 8%, and electricity for 5%. The saturation of weatherization measures is given below.

Measure	Saturation (%)
Weatherstripping or caulking	91
Attic, wall or floor insulation	81
Storm windows or doors	53
Other services	69

Data Analysis: The report did not indicate how the fuel consumption was weather normalized or how the percentage of the main fuel used for space heating was calculated. Homes were only included if the same family occupied the house both before and after the retrofit and if they did not fuel switch. However, some houses had changes in the number of occupants. Houses with large amounts of supplemental heating sources were dropped from the study. There was no control group for the experiment. Savings were found by subtracting the actual consumption from the predicted consumption if no work had been done. Electricity consumption was converted to site energy (3412 Btu/kWh). LBL assumed a fifteen year effective lifetime. Since most other low-income weatherization evaluations measure only the main space heating fuel, LBL used these numbers in our analysis, rather than total house energy consumption. To estimate the total contractor cost of the retrofit, LBL multiplied the materials cost ($393 per house) by 2.7 and came up with $1060.

Results: Before the retrofit, sample homes used 133 MBtu annually. After the retrofit, this number dropped to 119 MBtu which corresponds to 10 percent NAC savings. The simple payback period was 15 years. Other measures should be done first before installing storm windows.

M027: Ohio - 1986 COAD Mobile Home Weatherization[87]

Buildings/Retrofit Description: The Corporation for Ohio Appalachian Development (COAD) evaluated energy savings in mobile homes weatherized in its district in 1986 and 1987. The final sample contained 99 treatment and 26 control homes. Retrofit costs averaged $815 per house. The saturation of retrofit measures is given below.

Measure	Saturation (%)
Caulking/weatherstripping	100
Skirting	71
Replacement of doors and sashes	70
Water heater tank wrap	65
Heating unit service	38
Storm windows	36
Ceiling insulation	7

Data Analysis: Utility billing data was weather normalized using PRISM. Screening criteria included no occupancy changes and no supplemental fuels. LBL assumed a ten year lifetime for the retrofits and entered the data as two aggregate groups: treatment and control homes.

Results: The treatment group consumption decreased 2.2 MBtu/yr (3%) and the control group consumption increased 0.5 MBtu/yr (1%). At a mixed fuel cost of $9.14/MBtu, the payback period is 41 years.

M028: Winnipeg - 1977-84 Manitoba E&M CHEC Program[88]

Buildings/Retrofit Description: Manitoba Energy and Mines evaluated energy savings from the 1977 to 1984 period of the Cut Home Energy Costs (CHEC) loan program. The CHEC program provided loans of up to $1,000 at 9.5% interest for homeowners to retrofit their homes. A sample of 265 homes were analyzed extensively. Retrofit costs for these homes averaged $789 per house (in 1984 U.S. $). (Costs for foundation insulation do not include the cost of sheetrock) to finish the basement). The saturation of retrofit measures is given below.

Measure	Saturation (%)
Window replacements	44
Ceiling insulation	38
Wall insulation	16
Door replacements	15
Interior foundation insulation	14
Infiltration reduction	4

On average, wall and foundation insulation increased the insulation level from R-0 to R-11. Ceiling insulation R-values were increased from R-11 to R-40. Walls were insulated with high density blown cellulose. Foundations were usually insulated with batts and attics received a mixture of fiberglass batts and cellulose fill.

Data Analysis: The sample was composed of 77% gas-heated homes with the balance being heated with propane and wood. Utility billing data was weather normalized and then HOTCAN was used to correct for internal gains and add the energy content of fuels other than gas. LBL entered the data in seven groups: the entire program (265 houses), the entire program except for those who installed door and window retrofits (130) and five categories of individual retrofits. The five individual retrofits measure included attic insulation retrofits (47), wall insulation (12), interior foundation insulation in heated basements (24), window replacements (89), and door replacements (15). LBL assumed a 25 year lifetime for the retrofit packages as well as for the high density cellulose wall insulation and window replacements. The other other retrofit measures were assigned twenty year lifetimes. The study authors provided retrofit costs in adjusted 1984 Canadian dollars. LBL used an exchange rate of 1.3 Canadian dollars per U.S. dollar to convert to 1984 U.S. dollars. Payback periods were calculated using the natural gas price of $3.39/MBtu (local price converted to 1984 U.S. dollars).

Results: The study did not report initial consumption levels. Savings and simple payback periods are provided below.

Retrofit Category	Retrofit Cost (1984 $)	Savings (MBtu)	Payback (yrs)
Entire program	789	19	12
" " w/o door,window retrofits	788	32	7
Attic insulation	575	21	8
Wall insulation	738	44	5
Interior foundation insulation	888	32	8
Window replacements	818	5	49
Door replacements	454	0.7	191

Door and window retrofits are much less cost-effective than the other options. Wall insulation appears to be the most cost-effective measure as well as savings the most energy.

M029: Virginia - 1989 LIW Pilot[89]

Building/Retrofit Description: The Virginia Center for Coal and Energy Research received a contract from the Virginia Association of Community Action Agencies to develop a new priority system of energy conservation measures and to recommend improvements in administrative procedures. The pilot emphasized four new weatherization techniques (high-density blown wall insulation, advanced airsealing techniques, heating system inspections, and furnace cleaning as well as ceiling insulation which was a part of the traditional Virginia program. Four local weatherization agencies were trained in implementing the new measures. The final sample for evaluating the pilot program included 43 site-built homes (60% gas and 40% oil-heated, label M029.1) and 12 oil-heated mobile homes (label O028). The saturation of weatherization measures is given below.

Measure	Saturation (%)	
	Site-built	Mobile
Blower door guided sealing	100	100
Heating inspections	95	19
Duct sealing	37	81
Water heater wrap	79	50
Attic insulation	65	
High-density cellulose wall insulation	40	
Cleaning/tuning of furnace	23	
Replacement window	<20	81
Door replacements	28	75
Floor insulation		25

The protocol was adhered to fairly well for the site-built homes, but in the mobile home sample, more floor insulation was recommended than installed and window and door retrofits, which were specifically deemphasized in the protocol, were installed in high saturations. In both the site-built and mobile homes, too much traditional caulking and weatherstripping and not as much wall insulation as recommended was done. The average weatherization costs were $626 for mobile homes and $1,000 for site-built homes (materials and labor).

Data Analysis: Space heating energy use was monitored using run time meters on the furnaces for several weeks before and after weatherization. Weekly readings that deviated more than 50% from the mean were discarded. LBL assumed that 70% of the pre-retrofit NAC was used for space heating (EIA 1989) in order to estimate the NAC from monitored space heating for the site-built homes. No such estimate was made for mobile homes. LBL entered the site-built and mobile homes as two aggregate data points and assumed a fifteen year lifetime for both packages of measures.

Results: Space heating energy consumption decreased 24 MBtu/yr in the site-built homes, corresponding to a 7 year payback. The savings were 11 MBtu/yr in mobile homes (10 year payback).

OIL HEAT

O001: New Jersey - 1979 Princeton/HS 21[90]

Buildings/Retrofit Description: A 2-story single-family dwelling (vintage 1974) was retrofitted by the Princeton CEES Group and local contractors. Retrofit options implemented include attic and basement insulation, shell tightening with the use of a blower door, and a furnace tuneup. The retrofit cost $1,200.

Results: The space heat savings were 70 MBtu per year (53%) yielding a 3 year payback time.

O006: Vermont - 1980 LIW[91]

Buildings/Retrofit Description: Data from the DOE Low-Income Weatherization Program in Vermont were provided by Mark Cooper of CECA. The 23 dwelling sample included trailers, apartments and single family homes, but only the single family houses were included in this study. The principal retrofit options implemented were insulation, storm windows, and storm doors. Retrofit costs averaged $1,500 per house.

Data Analysis: LBL adjusted the space heat savings to the 30-year average for heating degree-days.

Results: The retrofit program achieved 44 MBtu per year (30%) and the payback period was 4 years.

O007: Philadelphia, Pennsylvania - Oil Furnace Retrofit Program[92]

Buildings/Retrofit Description: A 200-home pilot program was conducted by the Alliance to Save Energy, the Institute for Human Development, and the Department of Energy during the winter of 1980-81 to demonstrate the feasibility and cost-effectiveness of oil furnace retrofits in low-income homes. The retrofit measures included a new flame retention head burner, a furnace tune-up that had to achieve a minimum steady state efficiency of 80%, an automatic setback thermostat, and new combustion chamber if necessary. Private fuel oil dealers performed all the work, guaranteed its quality for one year and received $500/home.

Data Analysis: Energy savings were determined using two methods: 1) fuel consumption was measured for six consecutive winter weeks after retrofit and a k factor (degree days/actual consumption) was calculated and percent savings was determined through a comparison to the pre-retrofit value and 2) changes in pre-and-post retrofit steady state efficiency was measured and percent fuel savings were estimated through multiplying by a factor of 1.4 (based on experimental results from Brookhaven National Laboratory).

Results: Using the first method, energy savings of 22 MBtu per year (19%) were obtained for a 47 home sample while a 45-home control group reduced their consumption during the same period by 2.6 percent. The retrofits appear to be very cost-effective with a 2.4 year payback time.

O010: Long Island, New York - 1980 Brookhaven National Lab/DOE[93]

Buildings/Retrofit Description: Brookhaven National Laboratory (BNL) conducted field tests in 250 homes that installed various retrofit measures designed to improve residential oil burner efficiency. The principal objectives of the study were: to measure the fuel savings of several retrofit options and combinations of options, to examine the variation in savings of a given type of measure(s) over a number of similar houses, and to identify service problems associated with these retrofits. The homes were divided into 10 groups: group 1 had a retention head burner (RHB) installed in a boiler while group 2 measured the same conversion with an optimized installation; groups 3 and 4 added a boiler temperature programmer and a vent damper respectively to the optimized RHB retrofit; groups 5 through 8 compared the savings obtained when refitting a conventional burner with a stack heat exchanger, double setback thermostat and boiler temperature programmer; and groups 9 and 10 examined the impact on oil furnaces of the optimized RHB alone and with a vent damper.

Data Analysis: Fuel oil delivery data were analyzed for two heating seasons prior to retrofit and for one year afterwards with consumption corrected for seasonal weather differences and normalized to a standard year.

Results. Major findings from the project were: 1) the median savings for the optimal retention head burner retrofit in boilers and furnaces were 18% and 11% respectively, 2) the optimized installation procedure increased fuel savings by 6% (Group 2 vs 1); in terms of simple payback time alone, 3) the double setback thermostat had the quickest return on initial investment (Group 7); and 4) while the flue gas heat exchangers installed in conventional burners achieved 10% median savings, it had the longest payback time with additional maintenance requirements (soot buildup) and thus the retrofit did not compare favorably with the retention head burner.

O011: Minnesota - 1981 LIEAP Oil Furnace Retrofits[94]

Buildings/Retrofit Description: The Institute for Human Development provided technical assistance to the state of Minnesota's Low Income Energy Assistance Program by instituting an oil furnace retrofit program that was complementary to existing weatherization efforts. The experimental design consisted of four groups: Group 1, households whose heating systems were retrofitted with flame retention burners and tuned up to achieve at least 80% steady state efficiency; Group 2, homes that were weatherized (e.g. infiltration reduction measures, attic and some wall insulation, storm windows and energy-related minor repairs); Group 3 that received weatherization plus heating system retrofit, and a control group in which no retrofits were installed. Major objectives of the project included: assessment of the additivity of savings between weatherization and oil furnace retrofit, the relative cost-effectiveness of the different treatments, and analysis of the correlation between changes in fuel use and changes in steady state efficiency.

Data Analysis: After the measures were installed, fuel use for each house was determined from 8 weekly oil tank dipstick measurements taken during mid-winter from which a regression equation was estimated. Results were compared to a schedule of oil deliveries from the previous year (Sept. 1981 - Sept. 1982). For almost one-half of the houses only total annual usage was available for the pre-retrofit period.

Results: The authors concluded that average usage decreased by 22.3% in Group 1, consumption declined by 12.4% in Group 2, Group 3 showed a 29.2% reduction and the control group's usage remained virtually unchanged.

O025: Wisconsin, Maine - ASE Persistence of Savings for Flame Retention Head Burners[95]

Building/Retrofit Description: In 1987, the Alliance to Save Energy (ASE) looked at the persistence of savings from retrofits of flame retention head burners for oil furnaces. The retrofits were performed in 1982 for low income households in Wisconsin and Maine. The contractors were paid a flat fee of $500 to install the retrofit.

Data Analysis: LBL entered the fifty two furnaces as one aggregate data point and assumed a fifteen year lifetime for flame retention head burners. Fuel savings were calculated based on measured steady state efficiency (SSE) improvements. Based on work done by Brookhaven National Laboratory (Batey, et al., 1978), LBL multiplied overall savings from burner efficiency improvements by 1.4 to include savings from reduced off-cycle losses. (Flame retention burners reduce the off-cycle air flow through the burner and consequently reduce off-cycle losses).

Results: The steady state efficiency and associated heating energy savings are shown below.

Time period	SSE (%)	Fuel Savings (%)
Pre-retrofit	67.8	0
Post-retrofit year 1	81.1	23.0
Post-retrofit year 5	76.9	16.5

Based on the assumption of constant post-retrofit SSE, the simple payback period is 3.6 years. Assuming a linear decay in efficiency, the simple payback period is 4.1 years. In either case, the payback period is shorter than most other measures used in weatherization programs.

Many furnaces were not serviced in the five years following the retrofit. Filters were often dirty or missing. Without tuning, many heat exchangers became covered with soot and therefore transferred heat less efficiently. ASE recommends that some of the money for such a program go into yearly maintenance of the furnaces to maintain the high efficiency gains.

O026: Portland, Oregon - 1985 Oil Burner Retrofit Pilot Program[96]

Building/Retrofit Description: In 1985 and 1986, the state of Oregon funded a pilot program that installed flame retention head burners for low income households. Portland Energy Conservation, Inc. conducted an evaluation of the program. Only furnaces with steady state efficiencies less than 70% were retrofitted. Outside contractors were hired and had a $500 limit (per household). The contractors were responsible for installing and tuning up the new burner and achieving a minimum efficiency of eighty percent. The final sample included ninety-two homes.

Data Analysis: Fuel savings were calculated both from steady state efficiency improvements and from dipstick readings. The measured fuel savings based on dipstick readings (22.8%) were calculated by looking only at the coldest part of the year. Thus, the measured savings do not reflect all of the savings from reduced standby (off-cycle) losses. Standby losses occur primarily during the warmer part of the year when the furnace is used only occasionally. Off-cycle (or standby) losses occur when the warm chimney is cooled by natural convection after the furnace cycles off. Flame retention burners reduce off-cycle losses because the furnace is checked and sealed against outside air leakage into the furnace, draft regulators in the vent pipe were repaired or installed, and the flame retention burner reduces air movement in the combustion chamber.

The second method for calculating fuel efficiency is based on steady state furnace efficiency improvements. Based on work done by Brookhaven National Laboratory (Batey, et al., 1978), PECI multiplied overall savings from burner efficiency improvements by 1.4 to include savings from reduced off-cycle losses. Annual fuel savings are then 28.7% which is significantly higher than the calculations based only on dipstick measurements from the cold part of the year. LBL entered the conservative 22.8% savings figure and assumed a fifteen year lifetime for the flame retention head burner retrofit.

Results: The retrofit resulted in 23 percent fuel savings. Based on a 1986 fuel price of $5.08/MBtu (Energy Information Administration, State Energy Price and Expenditure Price Report, 1986) and a conversion factor of 0.139 MBtu/gallon, the price of heating oil in Oregon in 1986 was $0.706/gallon. The corresponding simple payback period is 5 years.

O027: Michigan - 1984 PSC Oil Furnace Fuel Efficiency and Retrofit (OFFER) Program[97]

Building/Retrofit Description: The Michigan PSC evaluated the OFFER program which inspected 1,014 oil furnaces. Both low income and general clients participated. Furnaces with efficiencies less than seventy one percent received retrofits and furnaces with efficiencies between seventy one and eighty percent received tuneups. 517 had **furnace tuneups** ($75), 385 had **flame retention burners ($500)** installed and 112 were ineligible because the furnace had an expected lifetime of less than five years or a pre-retrofit efficiency higher than eighty percent. A random sample containing 208 homes with furnace work done in 1984 was chosen for analysis. The final analysis was of seventy six retrofits and sixty seven tuneups.

Data Analysis: Homes were not included that used auxiliary heat. LBL entered the data in two aggregate groups: flame retention burner retrofits and furnace tuneups. Based on work done by Brookhaven National Laboratory (Batey, et al., 1978), the Michigan PSC multiplied savings from steady state burner efficiency improvements by 1.4 to include savings from reduced off-cycle losses. LBL assumed a fifteen year lifetime for the retrofit and five years for the tuneup.

Results: The flame retention burner retrofit averaged 25% fuel savings and the tuneups averaged 4% savings. Both had a 2 year payback period.

O028: Virginia - 1989 LIW Pilot Mobile Homes[98]

See description under label M029.

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Appendix C -
Estimating End Use Breakdowns

Since retrofit projects in this study encompass a range of climates and house sizes, we normalized space heating use by these two variables in order to make comparisons. In many cases, program evaluations reported the normalized annual consumption (NAC) and not the estimated space heating end use (either given by PRISM or a baseload subtraction). In those cases, we used the enduse breakdowns given below in Table D-1 to calculate pre-retrofit space heating energy use from the NAC. (Space heating data from other regions were extremely limited and enduse breakdowns were not calculated).

Table C-1. Estimated space heat fraction.

Climate	Pre-Retrofit Space Heat Fraction of NAC
Gas Heat	
>7000 HDD	80%
5500-7000 HDD	75%
4000-5500 HDD	70%
Electric Heat	
Pacific NW	50%

If less than 50% of the sample installed water heating (baseload) retrofits, we set the post-retrofit baseload equal to the pre-retrofit baseload. (Post-retrofit space heating equals post-retrofit NAC minus pre-retrofit baseload). If more than 50% of the sample installed water heating retrofits, we used the same enduse breakdown percentages pre- and post-retrofit. This procedure is intended to avoid crediting baseload savings to shell and heating system measures.

The gas end use breakdowns are based on the Residential Energy Consumption Survey (EIA 1989). RECS gives values of 81% and 76% for the two climate regions, but their figures are based on *all* households that use natural gas and our data points are for houses that use natural gas as the main space heat fuel. However, most homes in climates with more than 5,000 HDD use natural gas for space heating if they are hooked up to it at all. The RECS numbers agree with studies in our database where complete end use breakdowns were given, further validating these assumptions.

We were unable to use the same RECS tables for end use breakdowns of electrically heated homes because end use breakdowns are not reported separately for electric-heat homes. For the Pacific Northwest, many retrofit program evaluations did provide enduse breakdowns. For all these studies, space heating accounted for 48-52% of the NAC and thus we estimated 50% for studies that did not report the enduse breakdown.

Appendix D -

Material, Labor and Administrative Costs for Low-income Weatherization Programs

The intent of the BECA database is to evaluate the energy savings and economics of retrofit measures themselves, rather than programs. Therefore, the program costs used in the BECA-B database include labor and materials, but not program overhead. For those evaluations that do break out labor, material, and administrative costs, we have listed all three of those costs below.

Table D-1. Cost Breakdown for Weatherization Programs.

Label	Program	# of Units	Materials Cost	Labor Cost	Admin. Cost	Contractor Installed Cost	Total Pgm. Cost	Ratio of Mat./Prog. Cost	% Admin. Overhead
Site-built Homes									
G056.1	1985 OH LIW	1083	527	1273		1800		3.42	
G062	1986 MN M200	128	822	484	265	1306	1571	1.59	17
M029.1	1989 VA LIW Pilot	43	553	447	466	1000	1466	1.81	32
G076.1	1983 MI LIW	364	494	419	580	913	1493	1.85	39
G077.1	1984 MI LIW	155	441	485	580	926	1506	1.32	39
G074.1	1984 MI HRW	41			923	3518	4441		21
G074.2	1985 MI HRW	158			923	3461	4384		21
G075.1	1986 MI LIW	173	392	549		941		2.40	
G075.2	1986 MI LIW Demo	65	414	564		978		2.36	
Mobile Homes									
G076.2	1983 MI LIW	72	305	376	580	681	1261	2.23	46
G077.2	1984 MI LIW	47	198	155	580	353	933	4.71	62
M029.2	1989 VA LIW Pilot	12	442	184	466	626	1092	1.42	43

Administrative costs include all expenses not incurred at the house sites. The contractor installed cost includes labor and materials. The total program cost is the contractor cost plus administrative costs. (All costs in Table D-1 are given in nominal dollars.)

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